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Acetic Acid and Pentane Treatment by a Biofiltration System Based on Organic Beds Under Transient Conditions

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Assessment of biofiltration systems under transient conditions is necessary when determining industrial operating conditions of biofiltration beds. The key system variables such as filter bed moisture content, the pollutant type and its concentration, must be evaluated in order to accurately calculate scaling of biofiltration beds. The removal efficiency of two organic volatile compounds (VOCs) was evaluated: acetic acid (hydrophilic) and pentane (hydrophobic). Two independent biofiltration systems were operated (A and B), in each system the fluidized bed was the same. The filtration beds were made from compost, with the following mixtures: rice husk-chicken manure (CAS) and pruning waste-chicken manure (POD), each in a ratio of 1:1 (v:v). As part of this study, in system A, the effect of moisture on acetic acid removal efficiency was analyzed, finding that in a moisture range of 50-15% and of 50-25%, efficiencies above 90% are reached for CAS and for POD respectively. On the other hand, in system B, the performance of the biofilters was evaluated against different concentrations of pentane, resulting in removal efficiencies of 25% and 43% for POD and CAS, respectively. In general, these results indicate that there is a significant dependence between the performance of the system and the moisture content of the filter bed and the lower limit in which the bed would operate under industrial conditions is defined. The pollutant water solubility was also considered in order to define the maximum concentrations that the bed would support under transient conditions.

1. Introduction

In the last decades, there has been evidence of a rise in atmospheric pollutants, out of which 7% are VOCs. VOCs concentrations above acceptable levels can produce health issues such as: eye irritation, respiratory tract irritation, headaches, skin rashes, nausea, fatigue and vertigo. The main sources of VOCs emissions include: industrial processes, vehicle emissions, and solvent use. VOCs produced from human activities are hundreds of chemical compounds and are distinguishable by their water solubility, difference in concentrations or abundance and their reactivity levels (Guo et al., 2017)

Acetic acid is a hydrophilic substance and an important chemical used in vinyl acetate production, acetic anhydride synthesis and as an industrial solvent in terephthalic acid production, vinegar, adhesives, textile and photographic products (Ni et al., 2015). There is evidence of acetic acid emissions in poultry industry (Trabue et al., 2010), where concentrations as high as 783.06 ppm are found in farms. On the other hand, pentane is derived from its fabrication and use in other domestic products. Emissions of pentane and other VOCs such as acetic acid take place in poultry farming; in the organic composting of poultry manure coupled with inadequate ventilation, lack of hygiene such as decomposing food, animal corpses among others (Forero, et al., 2018). Mean concentrations of 12.4 ppm of pentane are found in poultry farms. Lastly, pentane in water solubility is very low therefore it is a hydrophobic substance.

Technologies made to reduce atmospheric pollutants such as VOCs can be classified as physical, microbiological, physiological, biochemical, and chemical (Almarcha et al., 2014). Amongst microbiological techniques are biofiltration systems. Physicochemical and operational parameters must be taken into account during the biofiltration process such as: humidity, pollutant concentration, residence time, pollutants water

solubility, and culture medium nutrients. Finally, biofilters, have better efficiencies when the substances to remove are water soluble and biodegradable, this is because pollutant degradation takes place in liquid phase or biofilm and low water solubility causes problems in pollutant removal (Cheng et al., 2016).
The biofiltration system efficiency for the removal of acetic acid (hydrophilic substance) and pentane (hydrophobic substance) was evaluated. The filter bed used is based on a mature compost of a mixture of chicken manure, pruning waste and rice husk. Studied variables were: moisture for removal of acetic acid and concentration for the case of removal of pentane, the filter bed adaptation capacity to the pollutants was also evaluated. The present study, ads an analysis of hydrophobic VOCs treatments and the limitations in biofiltration systems for these substances.

2. Materials and Methods

2.1 Biofiltration system assembly

Two biofiltration systems (A and B) with the same structural characteristics and operating conditions were used. Each biofiltration system (Figure 1) consists of two cylindrical PVC biofilters 100 cm high and 10.16 cm in internal diameter, with 95 cm of filling material. The air is supplied through the compressor at a flow rate of 110 cm^3/s. The air current passes through a humidifier, to regulate the moisture. Subsequently, the sparger is found, through which the concentration of the pollutant is controlled. The system operates at room temperature. The residence time of 66 s was set to ensure pollutant degradation (Cabeza et al., 2013).

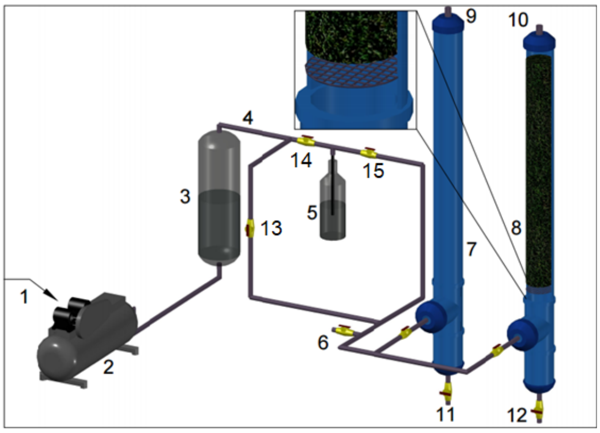

Figure 1: Biofiltration system at laboratory scale.

The Figure 1: Biofiltration system: (1) Air intake; (2) Compressor; (3) Humidifier; (4) Humid air outlet; (5) Sparger / Pollutant Volatilization; (6) Pollutant entry concentration control point; (7) Biofilter / Husk filter bed; (8) Biofilter / Pruning waste Filter bed; (9 and 10) Gas outlet / Sampling point; (11 and 12) Extraction of leachates; (13, 14 and 15). Inlet pollutant concentration control valve.

2.2 Packing Materials

The filling material was previously composted where the chicken manure was mixed with two different residues: pruning waste for the POD biofilter and rice husks for the CAS biofilter. The process is further detailed in Forero et al., 2018, the mixture is in a ratio of 1:1 (v/v). Two mature compost filter beds are then obtained (Table 1). Rice husk was obtained from rice farming in Huila department, while the pruning waste was obtained from local park maintenance in the north of Bogotá. Mature compost particle size was selected between 5-25 mm to prevent airflow obstructions in the biofilter bed (López et al., 2011).

2.3 Operation of the Biofiltration Systems

System A evaluates the influence of moisture variation on removal efficiency for acetic acid. The purpose of this study is to determine the optimum value or range of moisture for biofilter systems to remove the highest percentage of acetic acid, and therefore establish operating conditions for process scaling. According to this, a 10% moisture reduction is made every three days, starting from 50% moisture and a constant concentration of acetic acid (10,860 ppm). To reduce filter bed moisture, the humidifier was removed from the system and the airflow was maintained in order to dry the medium. The bed moisture content was determined by gravimetric analysis. Samples were oven dried at 105°C for 24 hours. During the experiment, the moisture content was calculated by measuring the difference in weight between the initial weight of beds and the weight of biofilter in the specific day (Cabeza et al., 2013).

As for system B, the study concentrations were based on pentane concentrations reported in poultry facilities. In this case, concentrations were set starting from 250 ppm. The moisture content of the biofilter was set at a constant throughout the process between 40% and 50%. This moisture level limits obstructions for this type of filter bed; frequent obstructions are reported at moisture content above 50% (Forero et al. 2018).

Table 1: Characterization of the packing materials.

Characteristics	Units	POD Compost	CAS Compost
pH	-	7.98	8.08
Organic matter	g/kg	74.01	55.42
Volatile solids[1]	mg/kg	838.8±21	710.7±7.1
Biodegradibility coeficient		0.782	0.218
Temperature	°C	20	19
Moisture content a	%	50	50
PS[2] 20-25	mm	50 %(Forero et al., 2018)	-
PS[2] 5-10	mm	-	50 %(Forero et al., 2018)
PO[3] 64.8	%	-	50 %
PO[3] 97	%	50 %	-

[a] Samples over wet basis (w.b); [1] Average ± standard desviation on three for volalie solids; [2] PS: Particle size; [3] PO: Porosity.

2.4 Analytical Methods

Pollutant removal efficiency in biofiltration systems for acetic acid and pentane was estimated using Equation 1. The outlet pollutant concentration is calculated daily as the mean of all measurements during that day. There are 6 measurements of the outlet concentration, 1 every 4 hours. This is how the system dynamics are monitored during the day.

$$RE = \frac{(C_i - C_S)\times 100}{C_i} \quad (1)$$

Where, RE: Removal efficiency (%); Ci: pollutant inlet concentration (ppm); Cs: pollutant outlet concentration (ppm) (Cabeza et al., 2013).
Pollutant concentration is determined with a VOC analyzer, a portable device equipped with a 10.6 eV lamp for photoionization. The device measures equivalent isobutylene units; therefore a correction factor must be used to determine concentrations for other substances. The correction factor for acetic acid and pentane is 36.2 and 8.4 respectively. The values are given by the device's makers (RAE Systems, Inc., 2016). MultiRAE detection device was used for pentane measurements and RKI GX-6000 for acetic acid measurements.

3. Results and Discussion

3.1 Biofiltration system for acetic acid

Bellow, the results of the correlation between humidity content and acetic acid removal efficiency in both biofilters, CAS and POD are shown. For the CAS biofilter, the effect of humidity variations (between 50% and 10%) on pollutant removal is evident (Figure 2). At first, the removal efficiency is below 90%, possibly due to obstructions or flow paths from the high-water content in the air stream (Cabeza et al., 2013). An excessive increase of water content in the filter bed can cause it to compact and create obstructions in the filter, which inhibits oxigen and VOCs transfer in the biofilm, thus creating anaerobic zones (Cheng et al., 2016). The presence of anaerobic zones can lead to bad odors. Later on, the acetic acid removal efficiency gradually rose with humidity values below 50%. This can be associated with the hydrophilic nature of the substance. Thus, bacteria have better access to the acetic acid dissolved in the water and can metabolize it to obtain carbon and energy and facilitate the degradation process.

From the 13th to the 18th day, with humidity content between 30-25%, the highest removal efficiency of the biofilter was 100% (Figure 2a). After that, when the humidity content in the biofilter reached 15%, efficiencies above 90% were found despite loss of system efficiency. Unlike other reported studies, this could indicate that this filter bed has a high removal capacity for low humidities (Akdeniz et al., 2011). However, when the filter bed moisture content lowers to 10%, there is a considerable decrease in the biofilter removal efficiency, and efficiencies are registered below 90%. This is due to inhibition of microbiological activity and filter bed cracking because of the lack of water availability which in turn reduces the filter's biodegradability (Taylor et al., 2012).

Figure 2b shows the behavior of removal efficiency in regard to the humidity of the POD biofilter. During the first reported days, different spikes in efficiency can be observed for humidity between 50% and 35%. Such changes can be associated with short conditioning periods between each period of change in humidity in the biofilter. This system dynamic alters in turn the transfer gradient of the pollutant to the biofilm. In the steps with moisture adjustments, there are brief periods of non-operation where pollutant flow to the filter is interrupted, which lowers system efficiency (Cabeza et al., 2013). Results indicated that the optimum POD biofilter water content was within 50% and 25%, range in which the removal efficiencies were above 90%. It is important to remark that when moisture content fell between 30% and 25%, the removal efficiencies reached 100%. Finally, a fall in efficiency is encountered when the filling material moisture content is between 20% and 10%.

When comparing removal efficiencies between both biofilters (CAS and POD) depending on the filter bed moisture content, the CAS biofilter has a stable efficiency while the filter bed gradually dries, whereas the POD biofilter has important changes in efficiency when moisture is reduced. This behavior is caused by the important relation of filter bed moisture content and removal efficiency. An optimum water content is necessary to ensure efficiency in VOC removal. These results are important to the scale up of the process and to establish the control of the parameters strategy in industrial applications. Principally, in areas where the water is not abundant.

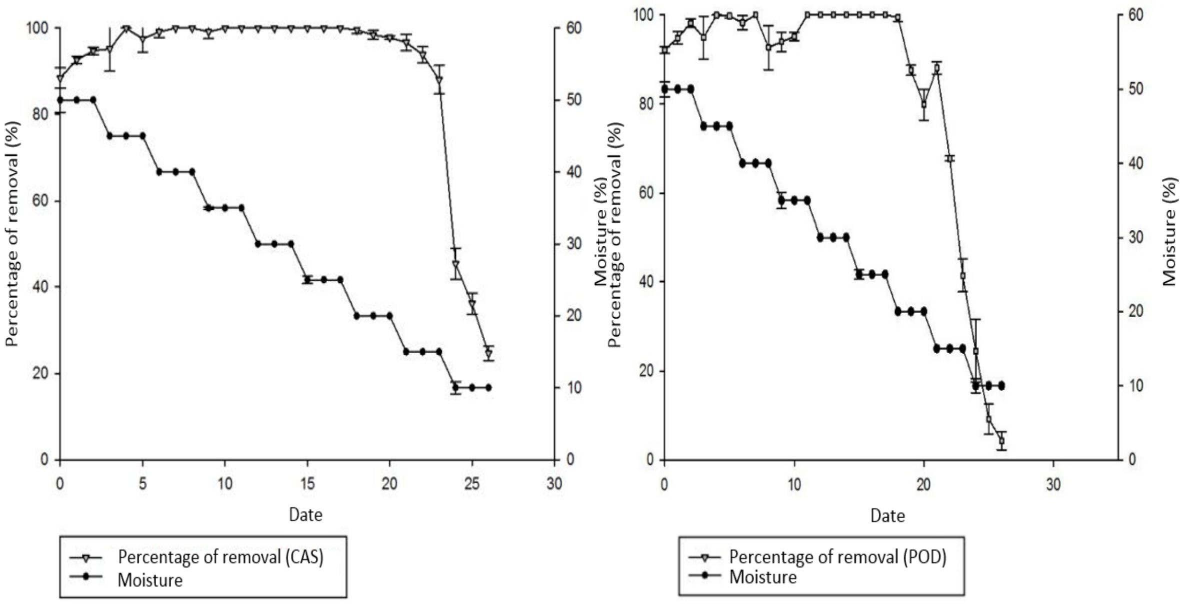

Figure 2a: Acetic acid removal efficiency and rice husk-compost biofilter moisture content (CAS). Figure 2b: Acetic acid removal efficiency and compost-pruning waste biofilter moisture content (POD)

According to the above, another important characteristic of the filling material is the porosity. Water moisture content is directly affected by porosity, aeration and air filtration through the filling material. Therefore, loss of POD biofilter efficiency when the moisture content is below 25% is due to high porosity, this being up to 97% in comparison with rice husk porosity of 64.8%. With such a high porosity, it is to be expected that a reduction in moisture will also reduce the removal efficiency for acetic acid, because the filter bed will require more water to fill unprotected zones to have a mass transfer that entails pollutant degradation. In this sense, when filter material is more porous, water retention in the filter bed is lower, which is unfavorable for microorganism development.

3.2 Biofiltration system for pentane

Pentane removal efficiency in both biofilters varies between 3% and 10% during the first 16 days; the variation is mainly due to the initial conditioning period (Figure 3). During this phase, microorganisms adapt to filter medium conditions such as: pH, temperature, and biological nutrients; in other words, in this phase the microorganisms are growing and adapting and are later able to degrade the pollutant (Miller and Allen, 2005). It has been reported that this phase can last from 5 to 20 days (Pandey et al., 2010). However, once the conditioning phase is over, between 20 and 27 days after, maximum removal efficiency for pentane of 25% was achieved with the POD biofilter (Figure 3). Finally, the removal efficiency for pentane decreased until it reached 0% between 28 and 40 days. The low efficiency is due to low adaptability of the biofiltration system with the pentane caused by its low water solubility (Cheng et al., 2016).

Figure 3 shows pentane removal efficiency for the CAS biofilter where there are peaks and falls in efficiency during the conditioning period in the first 18 days. These efficiencies range from 6 to 26%. However, between the 19th and 25th day, there is an increase up to 43% removal. This is the highest registered efficiency for the POD biofilter. After that, pentane removal efficiency starts to decrease until the 40th day, and 0% efficiencies are reached. Difference in biofilter efficiency (CAS and POD) are due to the nature of filling material. Pruning waste has higher porosity than rice husk, and therefore water retention is higher in the POD biofilter than in the CAS. Having in mind that moisture content in both biofilters was a constant. It is expected that the lower porosity of CAS will hinder pollutant flow through the filter bed due to pentane hydrophobic property (Govind and Narayan, 2005). This condition limits pentane mobility that would favor microorganism activity for its degradation. In general, low efficiency in both systems is the result of poor mass transfer of pentane from gas form to the biofilm, reducing available substrate concentration for the microorganisms. This is known as bioavailability, which is defined as the accessibility to a chemical compound for its contact and absorption (Alexander, 2000). Therefore, the hydrophobic property of pentane affects bioavailability and degradability which in turn hinders its removal (Cheng et. al. 2016).

In general terms, the efficiencies obtained are acceptable for this kind of compounds, having in mind the high concentrations of work presented in this article (250 ppm). Then, it is necessary to evaluate the concentrations and type of COVs to treat in the industrial application, in order to establish the kind of packing material to use and the useful life of the biofiltration system, as well as the operational parameters.

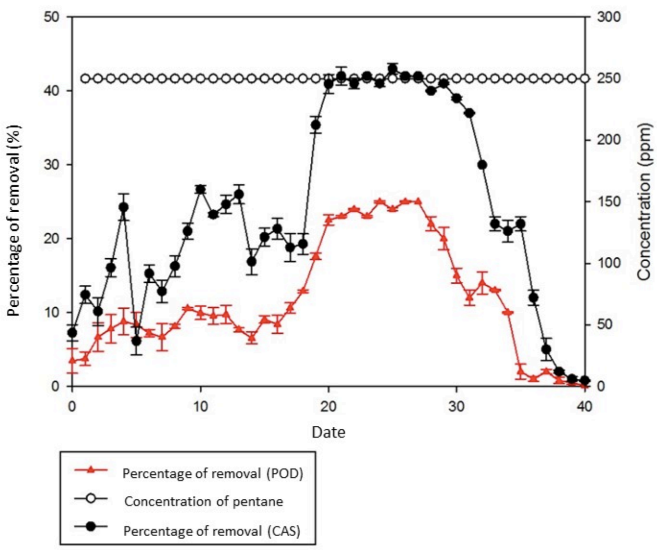

Figure 3: Pentane removal efficiency vs inlet concentration of the compost - rice husk biofilter (CAS) - pruning waste biofilter (POD)

4. Conclusions

There is a link between the moisture content and the filling material, which affects the acetic acid removal efficiency. In the POD biofilter, there was more variation in acetic acid removal efficiency in comparison to the CAS biofilter. For the latter, high efficiency of acetic acid removal was maintained, even in low humidity conditions. Due to high material porosity for the POD biofilter, the system is affected by water loss. The optimum humidity range for the CAS biofilter was determined to be 50-25%, where the removal efficiency for

acetic acid was above 90% range. Both biofiltration systems ensure acetic acid removal efficiency under optimum moisture content conditions. From these results it can be inferred that on an industrial level this technique level can be used to reduce operational costs and energetic costs by avoiding pressure drop due to lack of moisture. Additionally, moisture conditions can be optimized for places where water access is difficult.
As for the pentane, its hydrophobic nature affects system efficiency, thus pentane removal efficiencies are under 50% in both biofilters. Therefore, biofilter material and pollutant affinity is key to obtain these types of efficiencies. Under transient conditions, for industrial application of this technique, it is necessary to determine optimum moisture content in order to ensure a high removal efficiency for pentane and offer viable options to transfer this technology. In biofiltration systems each individual pollutant should be analyzed in order to set concrete operational parameters.

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