

Investigation the impact of using the recess air bio-filter (TBAB) with integrated system of a cyclic 2-recess adsorption/desorption unit for treatment of squander gas streams

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ABSTRACT

In the chemical industry, changes in influent fixations and shifts in the composition of squander air make bio-filtration a challenging technique. As a possible solution to the constraints of bio-filtration technology, this research designs and implements a coordinated framework that includes a cyclic 2-recess (adsorption/desorption) unit and a trickling recess air bio-filter (TBAB). The study's major goal was to keep the TBAB volatile organic compound (VOC) degradation performance stable and consistent over time. The studies were conducted on different TBABs with a single VOC exchange and a biomass control of periodic discharging. Solvents that are routinely used in paint booths were examined as VOCs. Two aromatic chemicals (styrene and toluene) were investigated, as well as two aliphatic chemicals (methyl ethyl ketone (MEK) and methyl isobutyl ketone) (MIBK). While the production process rotated, our study duplicated VOC emission rotation in certain chemical sectors. When VOCs were switched to aromatics, the bio-filter required an apparent re-acclimation period, according to the results. The second phase looked at two different combinations of these VOCs in two separate TBAB trains with a step change in influent focus. In the third phase, the buffering performance of a cyclic 2-recess adsorption unit was tested for a taking care of creation based on an EPA modern emanation report under a square wave of fluctuating conditions. The VOC combination was treated in the fourth step with a coordinated framework that includes two cyclic adsorption/desorption recess as well as TBAB. When compared to the control unit, the incorporated framework had the option to accomplish high steady performance, according to the studies' findings. Lastly, researchers looked at the microbial communities of the bio-filters employed in the VOC interchange and VOC mixing studies. The interchange of VOCs demonstrated a steady transition in microbial diversity. The community structure of VOC mixes demonstrated a significant degree of independence from the component content.

Keywords: Bio-filtration technology, volatile organic compounds, Squander Gas Streams, TBAB

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1. Introduction

Volatile organic compounds (VOCs) are an important class of air pollutants, commonly found in the atmosphere at ground level in all urban and industrial centers [1]. The VOCs play important roles in a wide range of environmental problems of concern. They can cause the stratospheric ozone depletion, and can arise to the ground level photochemical smog formation [2].

VOC biotreatment is a more cost-effective option than more traditional approaches. Bio-filtration has been shown to be a reliable and cost-effective way to reduce VOC emissions. The bio-filtration process uses a

biological microbial film that is attached to a support medium and absorbs impurities from squander gas before biologically converting them to innocuous components like water and carbon dioxide [3]. Bio-filter packing materials have a substantial impact on their ability to decrease VOCs. Peat, compost, leaves, wood bark and/or soil, as well as inert synthetic media, are the two most common bio-filter media [4]. Moisture levels can be kept up with by the flow of feed and buffer liquids, which are usually sufficient. It is known as a trickle-recess air bio-filter (TBAB). TBABs are more reliable than normal media bio-filters because they have more control over total pressure drop, nutrient focus, and pH. Furthermore, unlike natural media, they are immune to the effects of aging. The ideal attachment medium has a large explicit surface region, low back pressure, and a surface that is suited for microbe adhesion. The number of studies on the use of TBABs to treat contaminated gas streams has increased in the previous decade [5].

The primary goal of this proposed research is to use a novel method to remove VOCs from a contaminated gas stream with a high removal efficiency (>99%) that is stable and steady. This was accomplished using a two-recess cyclic adsorption/desorption machine in conjunction with TBAB. Based on previous studies on single solute [6], VOCs interchange and combination were studied in order to mimic operations in chemical industries. The 2-recess adsorption unit would serve as a buffer for fluctuating contaminant focus to the TBAB system and obtain stable, the bio-filtration system's overall efficiency is stable. VOCs that are commonly found in paint booths are chosen as target VOCs. The study's particular objectives were stated in several stages: Phase I: Characterization of TBAB for VOC exchange under step-change loadings up to Kim's (2006) critical loadings: Determine the effect of interchanged VOC on TBAB performance when contaminant focus change in a step-like manner[7]. Phase II: Discharging and starving were used to characterize TBAB for VOCs combinations. The impact of step-change contaminant focus and starvation periods on TBAB performance has been investigated. Phase III: Testing a 2-recess adsorption unit for attenuating variations in influent focus into the TBAB system and ensuring that the system's effective removal capacity is not exceeded. The adsorption and desorption cycles of the 2-recess adsorption unit were simulated. In Phase IV, a ground-breaking integrated method to removing harmful VOCs will be implemented. Long-term performance was evaluated using a combination arrangement of a 2-break adsorption unit and a TBAB unit. Microbial diversity in TBAB for VOC mixing and exchange in Phase V.

2. TBAB study under Interchanging VOCs

TBABs were tested in the presence of an exchange of the feed unstable natural combinations (VOCs). Toluene and styrene were substituted for two aromatic molecules what's more two oxygenated ones, respectively (methyl ethyl ketone and methyl isobutyl ketone). The results demonstrated that, within the critical loading, the bio-filter exhibited a high removal efficiency, as determined previously in non-interchanging VOC-fed bio-filters. The bio-filter quickly adapted to the oxygenated compounds (MEK and MIBK), while the aromatic compounds took longer to re-acclimate (toluene and styrene). The molar mass of CO₂ created per molar mass of VOC removed ratios were studied. The aromatic compound ratios were found to be quite similar to the theoretical total chemical oxidation-based ratios, however the oxygenated compound ratios had significant deviations. Oxygenated compounds had higher removal rates along the bio-filter media depth than the aromatic. The nitrogen utilization difference between oxygenated compounds and aromatic compounds was reduced significantly under the interchanging conditions as compared to the difference under long term operation of single solute system.

2.1. TBAB performance overview

The performance of bio-filters "A," "B," and "C" in removing VOCs is shown in Figures 1-3. During the trial, both bio-filters were able to remove the VOCs within the critical loading capacity, indicating that they performed well.

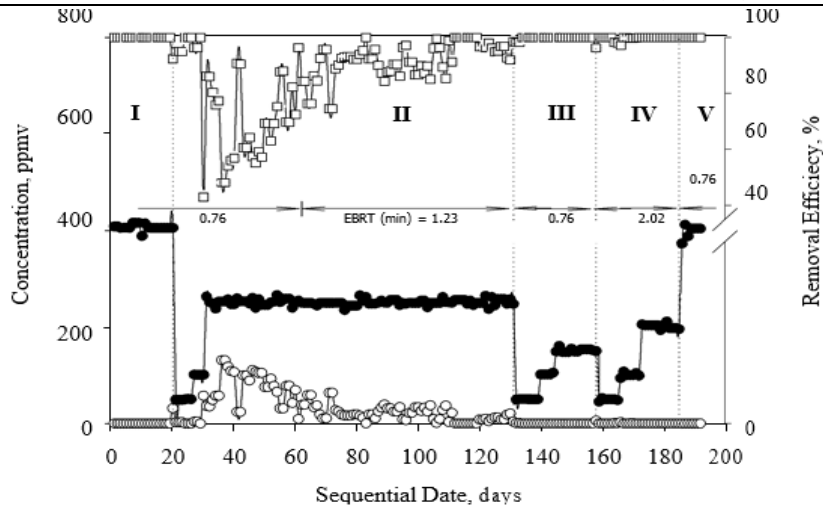


Figure 1. Bio-filter A performance as a component of feed VOCs: (I) MEK, (II) Toluene, (III) MIBK, (IV) Styrene, (V) MEK. (□ Evacuation proficiency, %; ● Bay fixation, ppmv; ○ Outlet focus, ppmv)

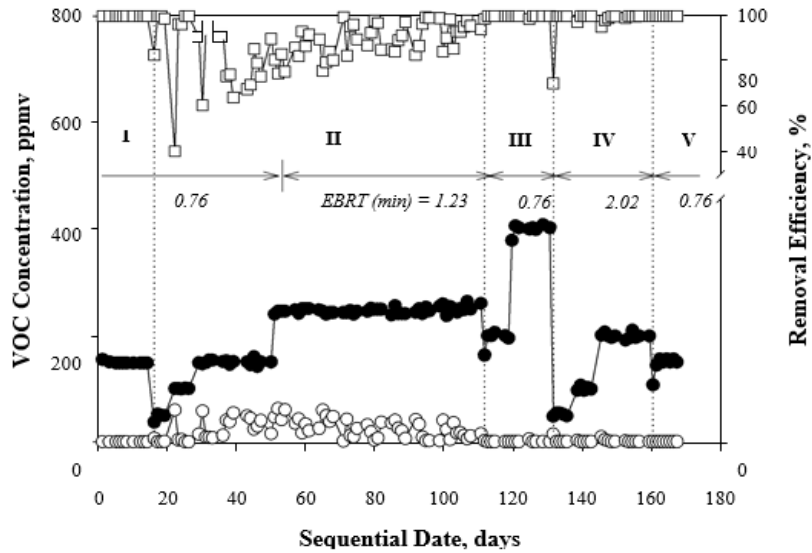


Figure 2. Bio-filter B execution as a component of feed VOCs: (I) MIBK, (II) Toluene, (III) MEK, (IV) Styrene, (V) MIBK. (□ Evacuation proficiency, %; ● Channel focus, ppmv; ○ Outlet fixation, ppmv)

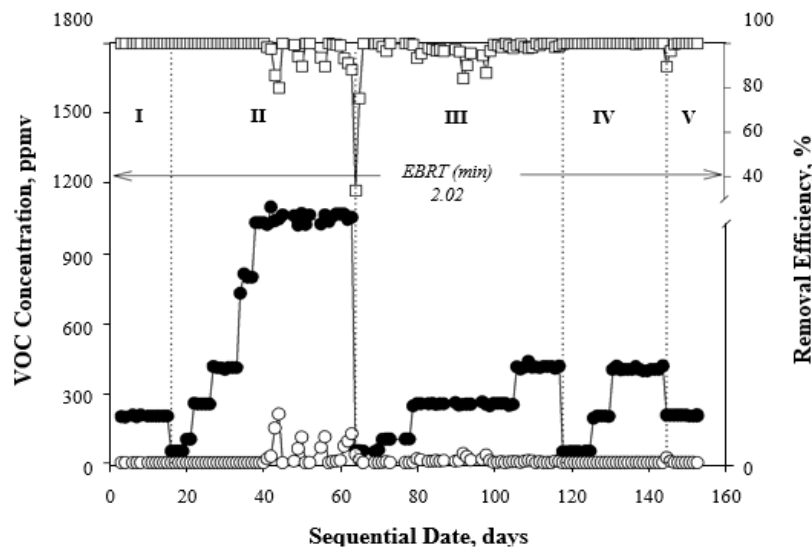


Figure 3. Bio-filter C performance as an element of feed VOCs: (I) Styrene, (II) MEK, (III) Toluene, (IV) MIBK, (V) Styrene. (□ Expulsion proficiency, %; ● Channel focus, ppmv; ○ Outlet fixation, ppmv)

2.2. Response of the bio-filter to a change in feed VOCs

After a feed VOC exchange, emanating tests were taken at predetermined spans to test the bio-filter reactivity of each individual bio-filter. Re-acclimation was considered complete when the bio-filter's performance was 99 percent of its initial value. In comparison to the other two VOCs, the bio-filter recovery of MEK and MIBK was much better after switching VOCs (styrene and toluene). After 30 and 300 minutes of switching to MEK and MIBK, the bio-filter recovered to 99 percent VOC removal. For the elimination of toluene and styrene, however, the re-acclimation durations were lengthened to four and two days. Microbes typically require some acclimation time before they can initiate critical degradation on a new substrate. Furthermore, the chemical structure of a new substrate influences a microbial community's adaptation to it (Alexander 1999). It's worth mentioning that a microbial population's toxicity to a substrate is proportional to the focus of the substrate. Materials that hurt one species' metabolism may help another species' metabolism or have no impact at all [8]. According to this study, aromatic chemicals such as toluene and styrene require a lengthy reclamation period before they can be employed as a fresh substrate without decreasing removal efficiency.

2.3. Profiles of focus in bio-filters

Samples of gas were taken one day after discharging in order to evaluate and compute the removal rate steady for each feed VOC at the critical loading capacity of the bio-filter medium depth. The results are provided as total EBRT (inside the media recess) and displayed on a semi-logarithmic scale for the lingering fixation to evaluate on the off chance that the principal request evacuation rates are great approximations to the bio-kinetics and to decide the appropriate rate steady. The first order removal rate steady were calculated using linear regression analysis. In comparison to bio-filters "A" and "B," bio-filter "C" has a significantly lower MEK removal rate steady and R square value. To achieve a basic stacking of 5.63 kg COD/m³ day for bio-filter "C" at 2.02 min EBRT, a MEK input focus of 1075 ppmv was employed. It may be more accurate to use zero-order kinetics to depict substrate degradation at large focus. A rate steady of 0.027 g/m³sec is really created by bio-filter "C" using 0.96 R2 to obtain the zero-order rate steady for MEK. This proves unequivocally that the increased inflow focus was responsible for the decreased clearance rate [9]. Bio-filters "A" and "B" have higher removal rate steady than bio-filter "C" for all VOCs examined, except for styrene. Low EBRT has a detrimental impact on bio-filter performance because of a lack of contact time between the substrate and the biofilm [10]. VOC influent focus in this investigation were adjusted to ensure that each bio-filter accumulated at the same rate based on the EBRT used [10]. The influent fixation in bio-filter "C" was higher than that in bio-filters "A" and "B" aside from styrene at the critical loading for each VOC examined. In both bio-filters, the depth of the media was the same regardless of the EBRT utilized.

2.4. Production of CO₂ in the bio-filters with change of contaminants

The degradation of VOCs by microbes results in variations in CO₂ generation. Bio-filter "A," "B," and "C" are shown in Figures 4-6, where CO₂ production rate is plotted against the bio-filter VOC elimination rate for each bio-filter.

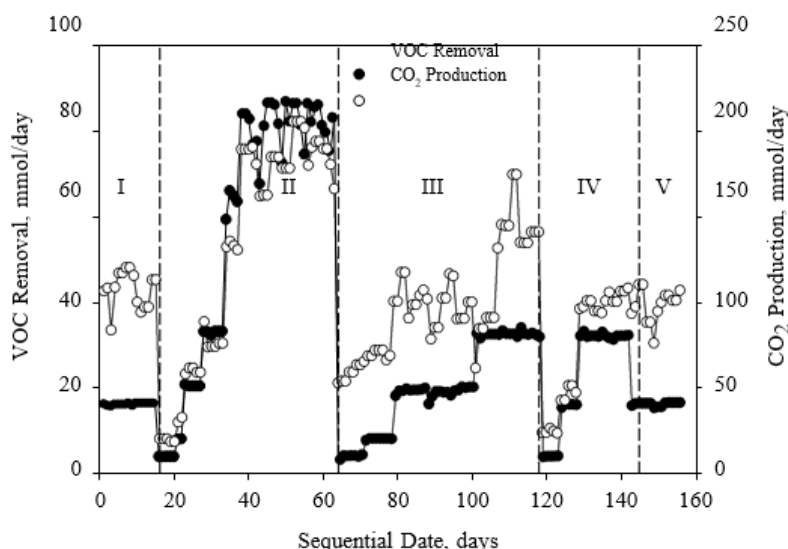


Figure 4. Bio-filter "A" VOC removal and CO₂ production with time (I- MEK, II- Toluol, III- MIBK, IV- Styrene, and V- MEK).

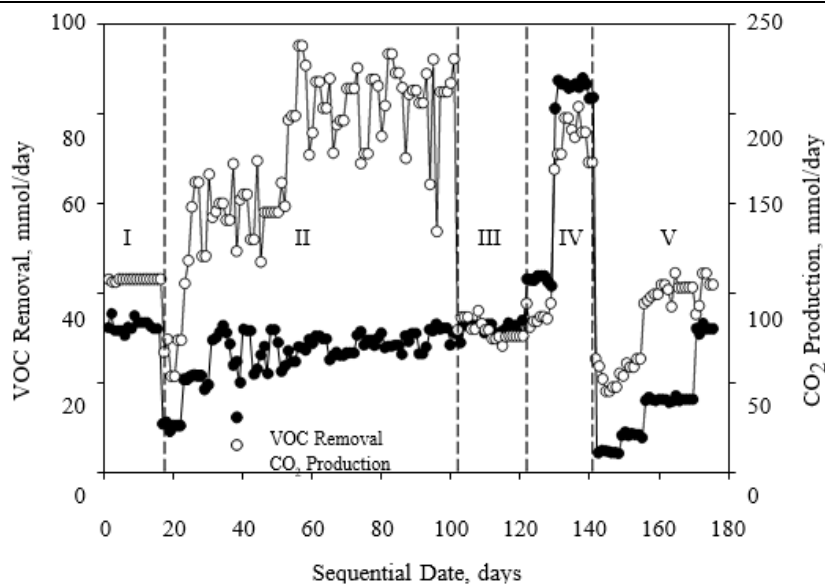


Figure 5. Bio-filter “B” VOC removal and CO₂ production with time (I- MIBK, II- Toluol , III- MEK, IV- Styrene, and V- MIBK).

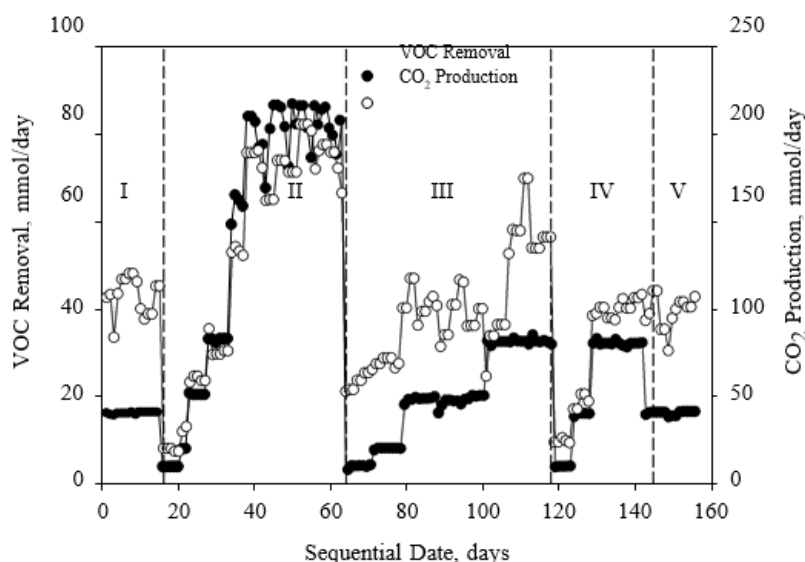


Figure 6. Bio-filter “C” VOC removal and CO₂ production with time (I- Styrene, II- MEK, III- Toluol, IV- MIBK, and V- Styrene).

2.5. Nitrogen utilization and VOC removal

NO₃—N focuss in the influent and effluent were measured on a daily basis. The quantity of NO₃—N species in the effluent water can be estimated by deducting how much NO₃—N species in the nutrient feed from the amount of NO₃—N species in the effluent water. The net nitrogen usage was calculated. The difference between the COD of the feed and the COD of the effluent gas and liquid stream was used to compute COD removal. The ratios do not indicate any dependence on the loading rate in use. However, soon after exchanging VOCs, COD/N ratios were lower, indicating that more NO₃—N was used during the initial periods after exchanging VOCs. Since discharging was conducted before the VOCs were interchanged, most of the biomass in the bio-filters has been washed out. Hence, more NO₃⁻ as the only nitrogen source was consumed to synthesize biomass to biodegrade the contaminants. During the re-acclimation period, aerobic heterotrophs breakdown most VOCs by utilizing VOC carbon as a source of growth. After early re-acclimation, microbial viability stabilizes with increased biomass, and stable nitrogen consumption occurs. Heterotrophs breakdown most VOCs, which use the VOC carbon source as an energy source to keep the bacteria alive. Furthermore, when comparing long-term single-solute circumstances to interchanging VOC conditions, the nitrogen utilization disparity between aromatic chemicals (toluol and styrene) and oxygenated compounds (MEK and MIBK) was drastically reduced (Cai et al. 2004; Kim et al. 2005b; Kim et al. 2005a). It is speculated

that microbial diversity increased and more microorganisms species were sustained for each interchanged VOC compared with the microbial diversity and microorganisms species in the single solute, which could result in the close nitrogen utilization among the interchanged VOCs. Meanwhile, it is interesting to notice that the initial VOC (long term single solute running) and prolonged EBRT (bio-filter "C") did not have apparent effect on the nitrogen utilization under VOC interchanging conditions.

2.6. Carbon balance

Throughout all of the experiments, the total CO₂ equivalent of VOC consumed was looked at to the total CO₂ created by the bio-filter. The total CO₂ created was calculated using the difference between the total CO₂ in the effluent and the total CO₂ in the influent fluid and vaporous streams, in addition to the total CO₂ equivalent of the VSS lost from the framework. The two total values are said to be reasonably close together. For bio-filters "A," "B," and "C," the overall carbon recovery of the ingested VOCs was 91.0 percent, 88.6 percent, and 90.6 percent, respectively. However, the divided VOC carbon recovery in the three figures demonstrates that for hydrophobic VOCs (toluol and styrene), there is a decent conclusion between the two all out qualities, however it is not excellent for hydrophilic VOCs (MIBK and MEK). This could be due to excess biomass accumulating in the bio-filter recess that is not rinsed away during discharging and remains firmly adhered to the media surface for hydrophilic VOCs.

3. Conclusions

In this study, the impact of changing the feed VOCs on the bio-filter's activity was proven. The following are some of the specific conclusions that can be derived from this research:

1. Once the bio-filters were re-acclimated to the new pollutant, high removal performance could be kept up with in the interchanging VOCs-fed bio-filters.
2. Long-term EBRT considerably improved bio-filter performance on aromatic chemicals, but had little influence on bio-filter performance on oxygenated compounds.
3. The bio-filter easily acclimated to oxygenated compounds (MEK and MIBK), notwithstanding the past compound. For the aromatic chemicals, the bio-filter re-acclimation was delayed for more than two days (styrene and toluol).
4. Oxygenated compounds had higher removal rate along the bio-filter media than the aromatic compounds.
5. Aerobic biodegradation was used to destroy the destructed aromatic compounds (toluol and styrene); however, aerobic biodegradation was used to eradicate the destructed oxygenated compounds (MEK and MIBK).
6. Due to biomass synthesis, low COD/N ratios were first found after altering the feed VOCs. When compared to long-term single-solute circumstances, the nitrogen utilization disparity between oxygenated and aromatic molecules was dramatically reduced under interchanging settings.
7. For hydrophobic VOCs (toluene and styrene), there is a good CO₂ conclusion between the two total values, but not for hydrophilic VOCs (MIBK and MEK).

3.1. TBAB study on VOC combinations

Tests were conducted on two TBABs (A and B) with two distinct VOC combinations. There was toluene, styrene, MEK, and methyl isobutyl ketone (MIB) in the mixes (MIBK). However, bio-filter "B" contained a mix of VOCs based on EPA emission data from 2003 in comparison to bio-filter "A." In addition to discharging and substrate starving, there were biomass management solutions. "A" and "B" were able to remove 99 percent of the influent focus of 500 ppmv and 300 ppmv respectively, when backwashed under these conditions. Influx focus of up to 250 ppmv for bio-filter "A" and 300 ppmv for bio-filter "B" were shown to be effective biomass management in a Hunger study. It took longer for both bio-filters to re-acclimate to higher influent focus. Tolerating large amounts of radiation Because bio-filter "B" has more toluol than bio-filter "A," it has been postponed for re-accreditation. The pseudo first-order removal rate steady for both bio-filters decreased as the volumetric loading rate rose. MEK and MIBK were not permitted in the top three-eighths of media depth. Toluol and styrene removal increased as influent focuss in both bio-filters grew. "B," on the other hand, needs a deeper bio-filter for the removal of toluol, whereas "A" does not.

3.2. Bio-filter performance

Bio-filters "A" and "B" used inlet combination focuss of 50 ppmv, 2.02 min EBRT, and 17.1 mmol NO₃—N/day. Re-acclimation of bio-filter "A" during backwash operations resulted in an overall removal efficiency of 99 percent at focuss of 500ppmv and an overall loading rate of 3.94 kg COD.m-3.day-1 (5.73.4 g/hr-1). Increasing the total focus to 1000 ppmv with a loading rate of 7.88 kg COD.m-3.day-1 (114.67 g.m-3.hr-1) could not restore bio-filter performance to its previous level, and the overall removal efficiency was only about 80%. Toluene removal effectiveness declined to around 50%, while styrene evacuation effectiveness dropped to around 82% in the combination components. MEK and MIBK removal efficiencies kept up with above 99 percent for all influent focuss evaluated. When the inlet combination focus was raised to 500 ppmv and 1000 ppmv, the execution of bio-filter "A" was lowered by 95% and 70%, respectively, under starved operation. When the applied stacking surpassed 3.94 kg COD.m-3.day-1, the bio-filter's execution deteriorated due to starvation (57.34 g.m-3.hr-1). It was found that bio-filter "B" functioned better than bio-filter "A" by a wide margin. At loading rates of 2.41 kg COD.m-3.day-1 (33.9 g.hr-1 (300 ppmv inlet combination focus)), the bio-filter kept up with 99 percent removal efficiency for both operations (discharging and starvation). After increasing the inflow combination focus to 350 ppmv and 500 ppmv, the discharging process reduced the overall removal efficacy to 95% and 90%, respectively. Under starved conditions, execution was reduced to 80% at 500 ppmv inlet combination focus. In bio-filter "B," 99 percent of styrene, MEK, and MIBK were removed at all loading rates utilized in the discharging procedure. While it took Styrene longer than normal to get back in sync with the starving approach, she was able to achieve a 99.999% elimination rate. When the inlet combination focus was increased to 500 ppmv, the removal efficacy for toluene was reduced to 85 percent for discharging and 60-80 percent for starvation techniques. Toluene's bio-filter removal execution is comparable to that of the combination when discharging is performed (Kim et al. 2005a). In order to achieve better than 99 percent overall efficiency, the combination needed a loading of 3.94 COD.m-3.day-1 (57.34 g. m-3.hr-1). As expected, discharging resulted in the same styrene critical loading as the single solute research (1.90 kg COD.m-3.day-1 (25.77 g m-3 hr-1) in bio-filter "A" (Kim et al. 2005b). Because of this, introducing more VOCs had no effect on the ability of bio-filter "A" to extract styrene when it was backwashed. In contrast, the removal of toluene was severely hindered. When stacking surpassed 3.94 kg COD.m-3.day-1, the bio-filter's removal capacity decreased (57.34 g. m-3.hr-1). Toluol and styrene basic loadings in bio-filter "A" were 0.94 kg COD.m-3.day-1 and 1.20 kg COD.m-3.day-1, respectively, using the starved technique (12.53 and 16.27 g. m-3.hr-1, separately).

3.3. After discharging and starvation, the bio-filter's response

The behavior of a bio-filter following discharging and starvation was examined using effluent samples obtained at regular spans. Re-acclimation was judged complete when 99 percent of the original performance was achieved. As seen in Tables 1 and 2, increasing the loading rate delayed bio-filter performance recovery in all combinations. Both bio-filters recovered to 99 percent removal efficiency following discharging with total influent focuss of 500 ppmv (bio-filter "A") and 300 ppmv (bio-filter "B") (bio-filter "B"). Only when the overall influent focus was increased to 250 ppmv for bio-filter "A" and 300 ppmv for bio-filter "B" could the bio-filters return to 99 percent efficiency utilizing a starvation technique.

Table 1. After discharging and starvation, the bio-filter "A" response

Removal efficiency, %									
Discharging									
Time/min	30	60	90	120	180	300	360	1200	2880
50 ppmv	86.8	95.3	97.7	98.8	99.9	99.9	99.9	99.9	99.9
100 ppmv	84.5	89.2	89.2	92.6	96.9	99.9	99.9	99.9	99.9
250 ppmv	88.8	86.6	82.8	87.5	96.1	99.9	99.9	99.9	99.9
500 ppmv	80.6	84.0	79.0	81.7	93.3	98.6	99.9	99.9	99.9
1000 ppmv	79.0	80.3	73.0	72.5	79.4	80.6	81.3	81.7	80.5

Starvation									
Time/min	30	60	90	120	180	300	360	1200	2880
50 ppmv	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
100 ppmv	98.7	92.5	96.4	99.3	99.9	99.9	99.9	99.9	99.9
250 ppmv	96.0	92.8	98.5	96.9	99.9	99.9	99.9	99.9	99.9
500 ppmv	98.8	95.9	93.7	88.0	90.0	92.5	92.4	94.7	95.2
1000 ppmv	92.9	94.2	94.7	78.6	65.3	83.3	73.5	70.4	70.9

Table 2. After discharging and starvation, the bio-filter "B" response

Removal efficiency, %									
Discharging									
Time/min	30	60	90	120	180	300	360	1200	2880
50 ppmv	82.7	93.6	94.3	95.6	96.4	97.5	99.8	99.9	99.9
100 ppmv	77.7	88.4	87.9	90.4	92.7	95.2	99.9	99.9	99.9
250 ppmv	75.9	82.2	84.6	87.2	87.7	93.1	98.5	99.9	99.9
300 ppmv	74.9	80.2	82.2	85.7	88.1	91.9	95.0	99.8	99.9
350 ppmv	72.1	68.8	81.4	83.7	86.1	89.2	94.2	95.4	96.1
500 ppmv	71.4	74.9	79.4	81.0	83.4	86.7	90.0	87.8	91.3
Starvation									
Time/min	30	60	90	120	180	300	360	1200	2880
50 ppmv	82.8	62.1	75.7	99.9	99.9	99.9	99.9	99.9	99.9
100 ppmv	86.5	83.2	70.0	82.1	99.9	99.9	99.9	99.9	99.9
250 ppmv	98.0	89.2	72.9	64.3	85.2	91.4	99.9	99.9	99.9
300 ppmv	97.7	86.9	77.4	68.4	83.4	99.1	99.9	99.9	99.9
500 ppmv	94.4	90.7	83.2	63.3	77.4	79.8	83.2	80.3	81.6

3.4. Nitrogen utilization and VOCs removal

Daily NO₃—N values in the influent and effluent were determined. The net nitrogen usage was assessed by taking away the NO₃—N species present in profluent water from the NO₃—N species present in the supplement feed. COD disposal was measured by comparing the COD of the feed gas and liquid streams to the COD of the profluent gas and fluid streams. When the discharging procedure is used, the ratios appear to be depending on the stacking rate and time. As the stacking rate was expanded, the COD/N ratio increased to 1.98 kg COD.m⁻³.day⁻¹ (28.67 g m⁻³.hr⁻¹) (stage III). After the bio-filter was acclimated, the COD/N ratios remained steady at around 55 g COD/g N as the loading rate approached 1.98 kg COD.m⁻³.day⁻¹. When the loading rate is increased to 1.98 kg COD.m⁻³.day⁻¹, the nitrogen consumption decreases. This could be due to microbial viability (28.67 g.m⁻³.hr⁻¹). Microbial viability was stabilized when the loading rate was increased after the bio-filter had adapted to the new stacking rate. Besides, as the loading rate was raised, keeping a steady COD/N ratio took longer, similar to the previously observed VOC elimination. Nevertheless, a COD/N ratio for the starving approach did not appear to be altered by loading, showing that microbial viability was sustained during the famine due to the bio-filter's preserved biomass. Each hunger cycle, on the other hand, revealed a dependency on the passage of time. After returning from a starving period, COD/N ratios were initially high, but quickly reduced to a more stable proportion (about 45 g COD/g N). The process of restoring stable microbial viability following each starvation episode could be linked to the time it takes for COD/N ratios to move from high to stable values. After stabilization, the COD/N ratios for discharging and starving operations were 40 and 45 g COD/g N, respectively. After stabilization, bio-filter "B" used the same amount of nitrogen as bio-filter "A" for discharging and starvation operations, with COD/N ratios of 40 and 45 g COD/g N, respectively.

3.5. Bio-filter execution kinetics analysis

One day after discharging, gaseous samples were collected along the media profundity of the bio-filter to decide the evacuation energy of both blends. The kinetic experiment used the pseudo first-order expulsion rate as a capacity of bio-filter depth. The pseudo first order removal rate steady states were decided by graphing the natural logarithmic scale of each component's residual focus against its input focus as a function of depth within the bio-filter (denoted by the total EBRT), i.e. $(\ln(C/C_0) \text{ vs. time})$. According to the findings, the removal rate steady states for toluol and styrene diminished as the stacking rates expanded in both bio-filters. The effect of starved operation appears to shift from positive to negative for both bio-filters, which is consistent with bio-filter execution. At comparable loading rates, the corresponding rate steady states for toluol and styrene in bio-filter "A" appear to be greater than those in bio-filter "B." The lower values of the toluene rate steady state in bio-filter "B" could be explained by the combination's significantly greater toluene focus. Because the two bio-filters had different styrene rate steady states, it is hypothesized that the relative amounts of other components in the combinations would affect styrene. Because both bio-filters effectively removed styrene, the difference in removal rates indicated that bio-filter "A" employed a deeper bio-filter than bio-filter "B." When the results of our previous single-solute studies [11] are compared to the current combination study, it is obvious that the addition of additional components has a significant effect on toluol. The rate of styrene elimination, on the other hand, did not differ significantly between the two combinations investigated and the single solute.

3.6. CO₂ closure (carbon mass balance)

Throughout all experimental runs, the total CO₂ equivalent of VOCs consumed in the mixes was compared to the total CO₂ created within the bio-filter. The total CO₂ focus in the influent (or emanating) fluid and vaporous streams was utilized to calculate the total CO₂ focus in the input (or output) stream. Discharging and starvation procedures yielded around 98.4% and 84.7 percent of the CO₂ input, respectively. Discharging and starvation provided 96.5 percent and 83.2 percent of total CO₂ intake, respectively. Total CO₂ offered a highly successful closure for discharging operations in both combinations, according to the findings. Unwashed biomass within the bio-filter that was not accounted for, as well as indigenous respiration during starvation periods, could explain the substantial discrepancies in total CO₂ input and production during famine operations.

3.7. Conclusions

This review analyzed the exhibition of two equal streaming bio-channels with two unmistakable VOC blends. Step expansions in VOC focus uncovered that for bio-channels "A" and "B," over close to 100% expulsion proficiency could be kept up with at input blend focus of 500 ppmv (stacking rate 3.94 kg COD.m⁻³.day⁻¹) and 300 ppmv, separately (stacking rate 2.40 kg COD.m⁻³.day⁻¹). The focal point of toluene in the blends significantly affected the bio-channel's presentation. Furthermore, assuming that the channel blend center didn't surpass 250 ppmv (2.01 kg COD.m⁻³.day⁻¹) for bio-channel "A" and 300 ppmv (2.40 kg COD.m⁻³.day⁻¹) for bio-channel "B," starved activity helped with keeping up with undeniable degrees of execution and can be used as a measurement of biomass control. According to one study, raising the focus of the inflow combination lowered bio-filter re-acclimation. According to the nitrogen usage study, bio-filters required a change period to re-acclimate to new working circumstances, furthermore nitrogen use fluctuated correspondingly. In terms of nitrogen utilization, there is no discernible difference between the two bio-filters. According to a kinetic analysis of VOC removal, bio-filter depth usage increased for both bio-filters as incoming combination focus increased. MEK and MIBK were extracted from the combinations using a deeper bio-filter depth, whereas styrene and toluol were extracted using a shallower bio-filter depth. When compared with bio-filter "A," bio-filter "B" removed more toluene and styrene, but bio-filter "A" did not remove any. They found a substantial difference in the elimination rate steady states for the two combinations investigated compared to the single solutes.

4. Cyclic 2-recess adsorption unit

Volatile organic compound combination dampening load fluctuations were studied using a cyclic two-recess adsorption/desorption system (VOCs). Behavior of the 2-recess system was compared to that of the system without cyclic operation. The plug flow surface diffusion model (PSDM) forecast of the experimental adsorption data revealed that the cyclic 2-recess unit outperformed the non-cyclic 2-recess unit in terms of attenuating pollutants load fluctuation.

4.1. Recess adsorption unit without cyclic operation

In order to compare the behavior of the buffering capacity with non-cyclic operation, the solenoid valve that operates the cyclic operation was shut off and the two recess will act in behavior as one recess. The

experimentally measured and the model simulation of the VOC combination effluent profiles are presented in Figure 7.

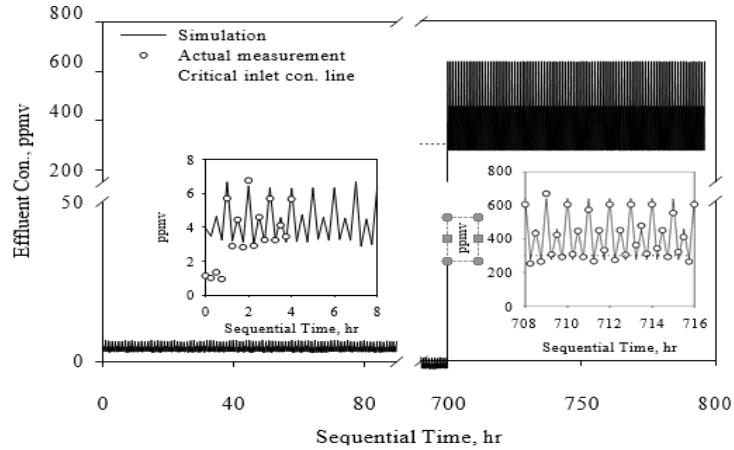


Figure 7. The VOC combination was measured experimentally and modeled without cyclic operation

Figure 7 shows that the overall focuss of effluent VOCs from the non-cyclic 2-recess adsorption unit were below 10 ppmv until roughly 700 hours before breakthrough. Once it broke through, the total focuss of the effluent VOCs fluctuated between 250 to 650 ppmv, which was over the critical focus for a followed bio-filter, i.e. above the critical focus of 300 ppmv. Such a low VOCs focus from the adsorption unit prior to breakthrough will cause the followed bio-filter to be operated under starvation condition, which will delay the acclimation of the bio-filter to the employed contaminants. The sudden breakthrough after 700 hrs will introduce a shock loading to the followed bio-filter. Furthermore, The wide fluctuation (250-650 ppmv) in the effluent from the adsorption unit after breakthrough may cause the bio-filter to work in an unstable manner, potentially resulting in VOC removal failure.

4.2. Recess adsorption unit with cyclic operation

Figure 8. shows an effluent profile generated by the 2-recess adsorption unit.

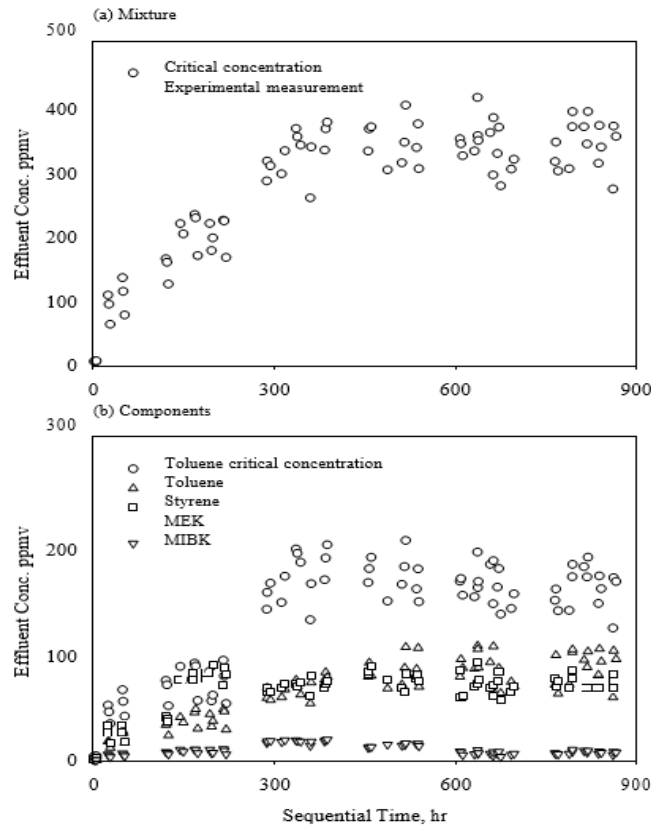


Figure 8. (a) Measurement of the VOC combination in an experimental setting; b) measurement of the components in the combination in an experimental setting using a cyclic operation

4.3. Conclusions

Buffering ability from a two-recess cyclic adsorption system was investigated in this work. To imitate fluctuations in input focus, a square wave feeding condition was used. In both non-cyclic and cyclic operation, The following is the behavior of the 2-recess adsorption unit:

- (1) During the first acclimation phase, a single adsorption recess failed to operate as a buffering unit for the followe bio-filter, and it also failed to attenuate oscillations in inflow focuss after breakthrough.
- (2) The 2-recess adsorption unit's cyclic operation created low effluent, which will promote bio-filter acclimation while also limiting inflow focus variations after stability.
- (3) Serious adsorption happened in the adsorption recess for the various components in the combination due to differences in physicochemical qualities.

5. VOC combination treatment in a trickling-recess air bio-filter with cyclic adsorption/desorption recesss

The removal of a combination of volatile organic pollutants was investigated using an integrated technique that combined cyclic adsorption/desorption recesss with a trickling-recess air bio-filter (TBAB) (VOCs). VOCs investigated included toluol, styrene, methyl ethyl ketone (MEK), and methyl isobutyl ketone (MIBK). The air stream was divided evenly into two sub-air streams to compare the execution of the integrated system. One stream was directed to a 2-recess cyclic adsorption/desorption unit, followed by a bio-filter (Bio-filter "A"), while the other was sent to the control system, followed by another Bio trickling-recess air bio-filter (Bio-filter "B"). To model changing conditions on the integrated and control systems, foursquare waves of influent focuss were used. Discharging for one hour once a week was used to control biomass in all systems. The cyclic adsorption/desorption recess served as a good buffer against the fluctuating input loadings. During the system's famine periods, the cyclic recess may also act as a food source, greatly improving bio-filter re-acclimation. The computed pseudo first order removal rates for toluol and styrene differ dramatically between low and high peak intake focuss, with rates at low peak inlet focuss appearing to be larger than rates at high peak input focuss. The removal rates in Bio-filter "A" were extremely close between peak inflow focuss that are both low and high, which could be owing to the cyclic 2-recess adsorption unit's better inlet focus swing damping.

5.1. Comparison of the bio-filters executions

The bio-filter "A" received the inlet VOC combination focus from the effluent of the 2-recess adsorption unit. The input focus to Bio-filter "A" ranged from 180 ppmv to 280 ppmv once the effluent focus from the adsorption unit stabilized. Because changes in intake focus were less than the threshold focus, Bio-filter "A" maintained a clearance level of greater than 99 percent after a relatively short initial acclimation period (300 ppmv). After only a short period of acclimation to both components, Bio-filter "A" was able to achieve a consistent removal rate of over 99 percent for both toluol and styrene. MEK and MIBK, the remaining two components, did not require acclimation and were regularly removed by the bio-filter at a rate of 99 percent. The execution of Bio-filter "B" on the other hand, ranged from 85 to 99 percent elimination. Bio-filter "B" required a much longer initial acclimation period to reach stability.

5.2. The impact of hunger on integrated and control systems

Following the fourth discharge cycle during the fourth square wave taking care of condition, the needle siphons providing the VOCs to the framework were switched off for two days of the week to decide what starving both bio-channels meant for them. By desorbing the adsorrecess VOCs during the needle siphons' vacation, the two-recess adsorption framework in Bio-channel "A" went about as a taking care of hotspot for the bio-channel. The outcomes demonstrate that the cyclic 2-recess unit worked agreeably as a taking care of hotspot for the ensuing bio-channel all through lacking running occasions, with no conspicuous re-acclimation times needed to recapture past execution. During starvation periods, the desorption of VOCs by the two-recess adsorption framework brought down how much VOCs put away in the adsorption recess, permitting the unit to keep up with its cushion limit with regards to a drawn-out time span.

5.3. Closure with CO₂ (carbon mass balance)

The absolute CO₂ likeness VOCs devoured was contrasted with the all-out CO₂ delivered by Bio-channels "A" and "B" during the testing. The delta (or outpouring) absolute CO₂ was decided by increasing the all-out all-out CO₂ in the influent (or gushing) watery and vaporous streams by the complete all out CO₂ in the influent (or profluent) fluid and vaporous streams. The leave complete CO₂ for Bio-channel "A" was around 96.6 percent of the info all out CO₂ during the principal square wave taking care of situation. At end from the

preliminary, an absolute CO₂ yield was around 96.4 percent of the complete CO₂ input. It's actually quite significant that Bio-channel "A" was answerable for 69.9% of Bio-channel "Btotal"'s CO₂ admission. Adsorption in the 2-recess adsorption unit created the variety. Toward the finish of the preliminary, the outpouring absolute CO₂ was generally 95.7 percent and 97.5 percent of the information complete CO₂. Bio-channel "A" had a complete CO₂ delta of 71.7 percent, Bio-channel "A" had an all-out CO₂ bay of 65.2 percent, while Bio-channel "B" had an all-out CO₂ contribution of 65.2%. The normal inflow focal point of 198 ppmv in Bio-channel "A" was 66 percent more prominent than in Bio-channel "B," demonstrating that the adsorbent in the two-recess adsorption unit ingested around 34% of the VOCs in the blend. The normal gulf center for Bio-channel "A" was 230 ppmv, which was 65.7 percent higher than the normal bay concentration for Bio-channel "B," proposing that 34.3 percent of the VOCs in the mix were consumed by the adsorbent in the two-recess adsorption unit.

5.4. Removal kinetic analysis

To explore the energy of VOC evacuation at low and high pinnacle input focuss, vaporous examples were required one day subsequent to releasing along the medium profundity of the bio-channel. We did a motor investigation of the pseudo first-request expulsion rate as a component of bio-channel profundity. The pseudo first request evacuation rate steadys were dictated by outlining the proportion of leftover to bay concentration as a component of profundity inside the bio-channel (as addressed by the absolute EBRT), for example $\ln(C/C_0)$ versus time on a characteristic logarithmic scale.

5.5. Conclusions

The adequacy of a streaming recess air bio-channel matched with a 2-recess cyclic adsorption/desorption unit for the evacuation of a blend of VOCs was researched utilizing four square wave taking care of settings. At the point when the control unit's presentation and the coordinated framework's end energy are thought about, the accompanying ends can be drawn:

- 1.The cyclic 2-recess adsorption/desorption unit settled the taking care of climate for the bio-filtration framework by lessening varieties in VOC blend bay focuss.
- 2.During occasions of appetite, as a wellspring of sustenance, the cyclic 2-recess adsorption/desorption unit was utilized. Since the VOCs gathered in the adsorption recess were less focused, it worked better under discontinuous activity.
- 3.Over time, it has been shown that the coordinated framework dependably eliminates a blend of VOCs at undeniable levels.
- 4.In the control framework, the pseudo first request expulsion rate steadys shifted with taking care of conditions; in any case, no noticeable distinction was seen in the coordinated framework due to the successful damping of the cyclic 2-recess adsorption/desorption unit to the feed channel center.

6. Microbial study for TBABs treating interchanged VOCs and their combinations

The microbial populations in trickle recess air bio-filters (TBABs) were studied while the feed volatile organic compounds (VOCs) and VOC mixes were swapped. Three TBABs (Bio-filter "A," "B," and "C") were tested with various starting VOCs and VOC conditions. Two aromatic chemicals (toluol and styrene) were swapped as single solutes, as were two oxygenated molecules (methyl ethyl ketone (MEK) and methyl isobutyl ketone (MIBK). MEK, toluol, MIBK, styrene, and then back to MEK were the interchanging VOCs for Bio-filter "A." MIBK, toluol, MEK, styrene, MI Styrene, MIBK, and finally back to styrene were the interchanging VOCs in Bio-filter "C." In addition, two further TBABs for two VOC blends were performed. The first VOC combination contained the same molar ratios of the four components as the second, which was based on EPA emission data from 2003. The microbial diversity in TBABs for treating VOC combinations, as well as the impact of interchanging VOCs on the bacterial community structure in the bio-filters, were investigated using denaturing gradient gel electrophoresis (DGGE) analysis of 16S rRNA genes. After each VOC exchange, the DGGE data revealed that the microbial population in the bio-filter changed its organization. The bands of certain microbial species faded, while others got stronger. The microbial species did not differ considerably between the two TBABs treating VOC combinations, although their richness varied.

6.1. Polymerase chain reaction (PCR)

PCR amplification of 16S rDNA was used to duplicate the target characteristic DNA sequence. An agarose gel was used to verify the PCR results. Figure 9 shows the agarose gel electrophoresis of PCR results for Bio-filter "B" samples.

The PCR results in samples in Figure 9 were roughly 230 bp when compared to the 100 bp DNA ladder in lane 1, indicating that the DNA sequences-16S rDNA in all samples were successfully amplified. The Bio-filter "A" and "C" samples from interchanging VOC reported in Chapter 2 were PCR amplification in the same way as the Bio-filter "B."

Lane 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

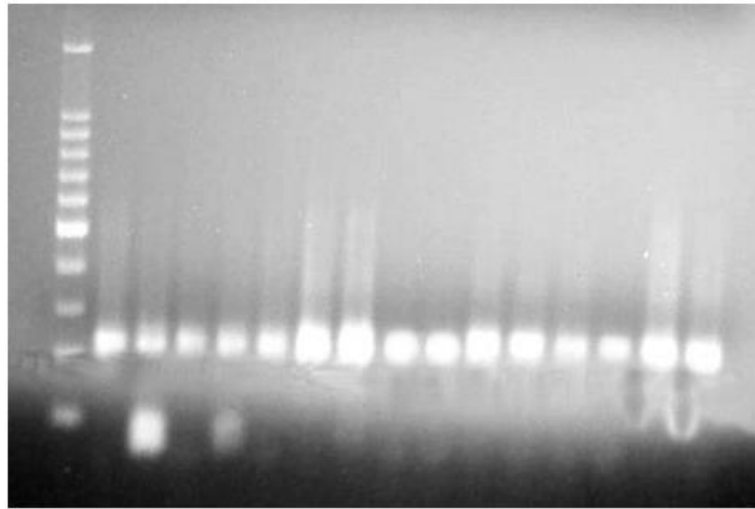


Figure 9. PCR amplification of 16S rDNA for samples from Bio-filter "B" and combinations bio-filters (Lane 1 was the standard 100 base pair (bp) ladder (TaKaRa, Santa Ana, CA, USA) (the difference in base pairs between two bands next to each other is 100 bp). Lanes 2-14 are samples for Bio-filter "B" in VOC interchanging experiments descrirecs in Chapter 2 in detail. Lanes 15-16 are samples from Bio-filter "A" and "B", respectively, descrirecs in Chapter 3 in detail. Lanes 2-14 were samples of MIBK, toluol , toluol , toluol , toluol , MEK, MEK, MEK, styrene, styrene, styrene, styrene, and then back to MIBK, respectively, in sequential discharging dates).

6.2. Biodiversity analysis

Culture-dependent methods are unable to cultivate the bulk of the microorganisms present [12]. Due to recent advancements in 16S rRNA-based genetic fingerprinting techniques, it is now possible to assess biodiversity in activated sludge. ARDRA [13], DGGE [14], thermal gradient gel electrophoresis (TGGE) [15], length heterogeneity PCR (LH-PCR) [16], ARISA [17], and T-RF are just a few of the molecular fingerprinting techniques currently used to assess biodiversity in engineered [18]. T-RFLP and DGEE are the two most often used assays [19]. In this study, DGGE was utilized to assess biodiversity in trickling recess systems as a fingerprinting technique. A preliminary analysis of DGGE banding patterns after VOC exchange revealed considerable alterations in the bacterial community's organization. Furthermore, some bands that are brilliant in one treatment turn dull in another, showing that the relative abundance of separate species has altered as a result of the VOC shift.

6.3. Conclusions

The findings of this investigation backed up the following conclusions:

- (1) For the interchanged VOC, the microbial diversity showed a steady transformation.
- (2) The community structure of VOC mixes shows a high degree of independence from the component content.
- (3) Unlike the behavior of the other three VOCs tested, toluol 's microbial diversity showed no significant connection with the other VOCs.
- (4) There was no evident relationship between the bio-filter community structure and bio-filter execution.

7. Conclusions and summary for this study

In industry, fluctuating focuss and variations in squander air composition are widespread, posing a challenge to the use of bio-filtration technology. A cyclic 2-recess adsorption/desorption unit and a trickling recess air bio-filter are combined in this system (TBAB) presented in this research as a potential solution to overcome the limits of bio-filtration technology is presented and used in this study. Five phases in this study conducted to approach the objectives proposed included: characterization of TBAB for VOC interchange under step-change loadings up to critical loadings, characterization of TBAB for VOCs combination under two operating

conditions: discharging and starvation, evaluation of a cyclic 2-recess adsorption unit for attenuating fluctuation in the influent focus into the followed TBAB system, Application of integrated technology for removal of the VOC combination in question, as well as microbial diversity research for VOC mixing and interchanging in TBAB. The conclusions based on a experiments can be summarized as following:

Phase I: *Trickle recess air bio-filters (TBABs) were evaluated in the presence of an exchange of the feed volatile organic compounds (VOCs). The following are some of the study's findings:*

1. Once the bio-filters were re-acclimated to the new pollutant, high removal execution could be kept up with in the interchanging VOCs-fed bio-filters.
2. Prolonged EBRT improved the bio-filter efficacy greatly for aromatic chemicals but had little effect on oxygenated compounds.
3. Regardless of the prior molecule, the bio-filter quickly adapted to oxygenated compounds (MEK and MIBK). For the aromatic chemicals, however, the bio-filter re-acclimation was delayed for more than two days (styrene and toluol).
4. Oxygenated compounds were removed at a faster rate than aromatic compounds through the bio-filter media.
5. Initially, low COD/N ratios were reported after exchanging the feed VOCs due to biomass synthesis. The difference in nitrogen utilization between oxygenated compounds and aromatic compounds was greatly reduced under interchanging settings when compared to the difference under single solute conditions.
6. While hydrophobic VOCs (toluol and styrene) had a good CO₂ closure, hydrophilic VOCs had a poor carbon closure (MIBK and MEK).

Phase II: With two different VOC combinations, two streaming recess air bio-filters (TBABs) ("A" and "B") were tested in parallel. In an equal molar ratio, toluol, styrene, MEK, and MIBK were introduced to Bio-filter "A." According to an EPA emission report from 2003, bio-filter "B" was fed a combination with a mole ratio of 0.448: 0.260: 0.234: 0.058 for toluol: styrene: MEK: MIBK.

1. Step increases in VOC focus shown that for bio-filters "A" and "B," above 99 percent expulsion effectiveness could be kept up with at input combination focus of 500 ppmv (loading rate 3.94 kg COD.m⁻³.day⁻¹) and 300 ppmv, respectively (loading rate 2.40 kg COD.m⁻³.day⁻¹). The focus of toluol in the combinations had a significant effect on the bio-filter's execution. Additionally, when the inlet combination focus was less than 250 ppmv (2.01 kg COD.m⁻³.day⁻¹) for bio-filter "A" and 300 ppmv (2.40 kg COD.m⁻³.day⁻¹) for bio-filter "B," starved operation assisted in sustaining high execution levels.
2. A study on bio-filter re-acclimation found that increasing the inlet combination focus slowed re-acclimation of both bio-filters. Due to the higher toluol focus, bio-filter "B" execution took longer to recover than bio-filter "A."
3. According to the nitrogen consumption analysis, bio-filters required a progress period to re-acclimate to their new operating conditions. Additionally, there is no discernible difference in the amount of nitrogen used by the two bio-filters.
4. A kinetic analysis of VOC removal revealed that as combination focus in both bio-filters grew, bio-filter depth usage increased as well. MEK and MIBK were extracted from combinations with a deeper bio-filter depth, whereas styrene and toluol were extracted with a shallower bio-filter depth. While bio-filter "B" was more effective at removing toluol and styrene than bio-filter "A," bio-filter "A" was not. Toluol's elimination rate steady in the two combinations considered were essentially unique in relation to those for single solutes.

Phase III: The buffering capacity of a two-recess adsorption system was decided. To simulate inlet focus changes, square wave feeding conditions were adopted.

1. According to the performance of the two-recess adsorption unit during non-cyclic and cyclic operation, a single adsorption recess failed to function as a buffering unit for the following bio-filter during the first acclimation period and failed to attenuate fluctuation in inlet focus after breakthrough.
2. The 2-recess adsorption unit's cyclic operation created low effluent, which will benefit in the initial acclimation of a subsequent bio-filter while also decreasing inlet focus variations after stability.

3. Due to the differences in physicochemical properties of the various components in the combination, competitive adsorption occurred in the adsorption recess.

Phase IV: A coordinated framework comprised of a trickling-recess air bio-filter and a two-recess cyclic adsorption/desorption unit was employed to remove a combination of VOCs under square wave taking care of conditions.

1. The cyclic two-recess adsorption/desorption unit reduced VOC combination inlet focus changes and provided a generally steady feeding environment for the subsequent bio-filtration system.
2. The cyclic two-recess adsorption/desorption device supplied nutrients during times of hunger. It functioned well because VOCs collected in the adsorption recess were reduced during intermittent operation.
3. The integrated system has been shown to remove a wide variety of VOCs at high levels over time.
4. While the pseudo first order removal rate steady changed with the variance of taking care of conditions in the control system, no discernible difference was observed in the integrated system due to the effective dampening of the cyclic 2-recess adsorption/desorption unit to the feed inlet focus.

Phase V: Following the exchange of feed unstable natural mixtures (VOCs) and VOC combinations, microbial populations in trickle recess air bio-filters (TBABs) were examined. The findings substantiated the following assertions:

1. In response to the exchanged VOC, the microbial diversity underwent a consistent transformation.
2. The community structure of VOC mixes is highly independent of the component content.
3. In contrast to the other three VOCs examined, toluol 's microbial diversity exhibited no significant relationship with the other VOCs.
4. There was no evident association between bio-filter community structure and bio-filter execution.

Based on the research conducted in this study, further studies listed below will be very interesting for further revealing the importance of the integrated system.

1. Expanded studies applied to alkanes with much lower solubility such as methane and hexane and chlorinated benzene chemicals with much higher toxicity such as mono-chlorinated benzene and PCBs. As far as we know from this study, either VOCs mass transfer and/or oxygen transfer from gas phase to liquid phase control the VOCs biodegradation in bio-filters. For the VOCs with low solubility, VOCs mass transfer will be the controlling step for the biodegradation in bio-filters. Methods for improving their mass transfer will be very interesting and valuable study. A possible way to improve the mass transfer is to add surfactants into the nutrient solution.
2. VOCs toxicity has inhibition on the microbial viability; investigation on the effect of VOCs toxicity on bio-filter execution will be also valuable.
3. Further investigation in the microbiology in the bio-filters is also needed. In order to determine the dominant species for single VOC solute or VOC combinations in a future study, DNA sequencing and fluorescence in situ hybridization (FISH) can be employed. Microbial distribution along the media recess can also be determined by employing single strand conformation polymorphism (SSCP). Response of microbial communities and richness to the operating conditions with time will also be very valuable to understand the ecology in the bio-filters. It can be determined by community level physiological profiling (CLPP).

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