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Removal of toluene from Air- scream using semi industrial two-phase bioscrubber with cutting oil: an intervention study

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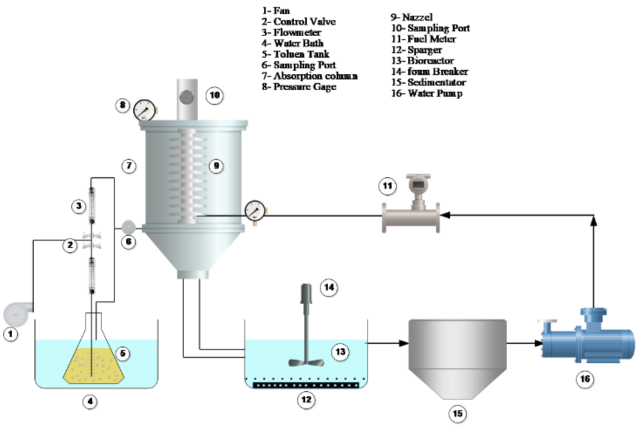
Graphical abstract



Abstract

Toluene is a monocyclic aromatic compound that finds widespread use in various industrial processes. Due to its harmful effects on human health and environment, this study aimed to remove toluene from the air stream using a two-phase bioscrubber. The bioscrubber design consisted of an absorption column that separated contaminants from the gaseous phase to the aqueous phase and a bioreactor for the biodegradation of toluene by microorganisms. Organic phases of cutting oil were added at concentrations of 5%, 7.5%, and 10%. The biodegradability test results revealed that 98% of the toluene concentration was further biodegraded after 72 hours compared to the control sample. The results showed that the use of 5% concentration of cutting oil increased the efficiency from 22% to 55%, At a concentration of 7.5%, the lowest efficiency was 38% and the highest was 63%. Also, the minimum and maximum removal capacity are 17 and 269 $g/m^3.h$, respectively. Efficiency at a concentration level of 5% of cutting oil as an organic phase is better than a concentration of 7.5%. These findings indicate that the efficacy of the bioscrubber is better when using a 5% concentration of cutting oil as an organic phase. Moreover, this study is the first to use cutting oil as an organic phase in Iran, which showed that using cutting oil in concentrations less than 10% had no adverse effects on microorganisms' growth.

Keywords: Biodegradation, toluene, bioscrubber, cutting oil, organic phase

1. Introduction

Volatile organic compounds (VOCs) are one of the most important sources of air pollution that have effects on the human health and environment (Tsai, 2019; Chen *et al*. 2015). Environmental aspects of these contaminants, such as stratospheric ozone depletion, the production of ozone around the earth and global warming (Ghirardo *et al*. 2020; Wang *et al*. 2013). Toluene is a single-ring aromatic VOC, which is widely used in various industrial processes. This compound is produced in large quantities by consuming fossil fuels. It is also used in industries as a solvent in the preparation of paints, adhesives, rubbers, plastics, and the production of various chemical compounds. Though toluene is less toxic than benzene and is not considered a carcinogen, its combination with other compounds increases its carcinogenic effect (Görgülü *et al*. 2019; Kuranchie *et al*. 2019).

Therefore, removing toluene from the air stream is of great importance for preserving human health and the environment. Two groups of methods, including common (physical-chemical) and biological methods, have been employed in removing VOCs from the air stream (Guieysse *et al*. 2008). Disadvantages of common methods for removing these compounds from the air stream include the high cost, use of chemicals that are mostly expensive, and the production of waste materials (chemical solvents and activated carbon). Also, the disposal of these materials requires safe operating methods (Guieysse *et al*. 2008). On the contrary, biological methods such as biodegradation are more economically and environmentally sound as they do not produce secondary contamination. Flow treatment methods based on the ability of some microorganisms (mainly bacteria) to decompose a vast range of organic and inorganic compounds have a low environmental impact and low operating costs compared to physico-chemical methods, making it a suitable choice for environmental controls (Nourmohammadi *et al*. 2021). The earliest known instances of biological decomposition can be traced back to the 1950s, approximately sixty years ago, when this technique was first utilized to counteract odors, particularly those generated from wastewater disposal and treatment facilities (Mehrizi *et al*. 2020). Carlson *et al*. initially introduced soil-based biofilters in 1966 as an advanced method of odor control. Following the increase in utilization of biodegradation, several types of equipment were built based on this principle. Among the air purification equipment based on microorganisms, biofilters and bioreactors are notable (Nourmohammadi *et al*. 2021). A fundamental bioreactor for air purification, the bioscrubber, consists of two parts: the absorption section and the bioreactor. In the absorption unit, gaseous pollutants are transferred to the liquid phase. In this segment, the gas and liquid phases traverse an absorption column in reverse flow. The liquid phase holding the target pollutant is then conveyed to the bioreactor. The bioreactor unit comprises a suspension of an appropriate microbial species and nutritional elements supporting the growth of microorganisms (Nourmohammadi *et al*. 2018). For eliminating the unwanted volatile organic compounds (VOCs) with a bioscrubber, water is typically utilized as the liquid phase. However, recent investigations have found that the organic phase is equally effective in increasing the removal efficiency. Fouhy demonstrated that a two-phase bioscrubber using water/silicone oil enhances the absorption of hydrophobic molecules by 10 to 30% (Fouhy, 1992). Similarly, Darracq *et al*. asserted that silicone oil having a concentration of 20 to 30% optimally eliminates hydrophobic compounds such as toluene. Thus, studies have revealed that bioscrubbers having operating costs of 1.2 to 1.4 times those of chemical scrubbers and superior efficacy than drip filters provide a suitable alternative to biofiltration (Darracq *et al*. 2011). According to a study conducted by Esmaeili-Faraj *et al*., the study of water-based nanofluids in bioscrubbers to enhance sulfur dioxide removal was investigated. The findings of the study demonstrated a notable increase in sulfur dioxide absorption in bioscrubbers upon the incorporation of these compounds. This highlights the potential effectiveness of water-based nanofluids in improving the removal of sulfur dioxide in bioscrubbing processes. (Esmaeili-Faraj *et al*. 2019)

The outcomes of Oliver *et al*.'s research indicated that the bioscrubber displayed a higher removal capacity for toluene, which is more biodegradable than monochlorobenzene, compared to the drip filter (Oliver and Bothen, 1982). Additionally, Muldiar *et al*. found that bioscrubners are more effective than other methodologies in removing organic compounds at higher concentrations. Moreover, the organic phase used in a bioscrubber also plays a crucial role. As mentioned in studies, silicone oil is the organic phase typically employed (Mudliar *et al*. 2010).

Concerning the reduction of emissions and the elimination of toluene compounds, biological removal of this substance is primarily accomplished utilizing cutting oil as the organic phase that is extensively utilized across a diverse range of industries due to its affordability and widespread accessibility. studies have been conducted to assess the impact of cutting oil on the growth of microorganisms in biological removal methods. The findings consistently indicate that the utilization of cutting oil does not exert any discernible effect on microorganism proliferation. (Nourmohammadi *et al*. 2021) To the best knowledge of the authors of this study, only a few endeavors have been pursued to evaluate the efficacy of two-phase bioscrubbers on an industrial scale using cutting oil as the organic phase to remove toluene. Therefore, the present study aims to remove toluene from the airflow utilizing industrial-scale low-pressure two-phase bioscrubbers with cutting oil.

2. Methods

The interventional study was designed and performed with the objective of removing toluene from the air stream using an industrial scale two-phase bioscrubber. The bioscrubber was designed with two distinct components: an absorption column and a bioreactor. The absorption column is responsible for separating toluene from the gaseous phase and transferring it to the aqueous phase. Meanwhile, the bioreactor facilitates the biodegradation of toluene by incorporating microorganisms, ultimately converting it to carbon dioxide and water.

2.1. Absorption column

In order to build an industrial-scale absorption column according to the scrubber design standards, a stainless-steel scrubber with a height of 1.2 meters and a diameter of 30 cm was selected. The body of the scrubber was made of two parts connected by installing a flange at the end of each part. In the first part with a height of 60 cm and a diameter of 30 cm, the air outlet was installed. The second part is the air inlet and the liquid phase inl*et al*ong with the scrubber cone, which has a diameter of 30 cm at the beginning of the cone and a diameter of 3 cm at the end. Also, the size of the scrubber inlet was 4 cm. in the present study the retention time was considered 5 seconds. Also, another important parameter in the design of the bioscrubber is the volumetric flow rate of the air, which was calculated 60 m^3/h. for the purpose of increase the solubility of toluene and its greater absorption in the liquid phase, we used the cutting oil (density of 0.86, pH of 9.5) as the organic phase. As a result, the liquid phase of the bioscrubber consisted of three parts: water, organic phase, and nutrients needed for the growth of microorganisms.

This research was spurred by the fact that cutting oil manufacturers promote the presence of bactericidal agents as a distinguishing characteristic of their products. so that conduct the study, a sludge sample containing microorganisms was inoculated into three different concentrations of cutting oil (10%, 20%, and 30%) along with broth nutrient. After a 24-hour incubation period, the mixture was cultured using agar nutrient. The results showed that cutting oil at concentrations below 10% had no effect on the growth of microorganisms. Therefore, the study was performed on concentrations of 5, 7.5 and 10%.

2.2. Bioreactor design

The bioreactor consisted of three parts: tank, pump and stirrer. The bioreactor was made of 6 mm thick glass in the shape of a rectangular cube. Also, the required air was supplied by the fan model (Air Flow) with variable speed. The supplied air was absorbed into the column by the transmission system and the flow rate was measured and adjusted by TES-1340 thermal anemometer and Pitot tube. In order to recirculate the liquid phase of the bioreactor, the Pumptax model CM100/01 with a flow rate of 20 to 90 liters per minute, 1 horsepower was utilized (Figure. 1).

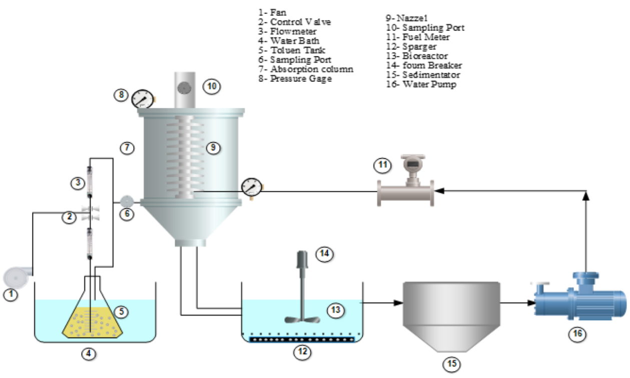


Figure 1. The schematic diagram of the bioscrubber

2.3. Biodegradability test

One of the primary objectives of this study was to ascertain the concentration of cutting oil that would not adversely affect microorganisms. In this study, the Tehran treatment plant of refinery was the source of toluene degrading microorganisms. the bottle culture method was implemented to cultivate toluene-degrading strains of microorganisms. The culture medium was designed to contain all necessary nutrients except for the carbon source, which was supplied by the addition of toluene. The nutrient salt solution utilized was comprised of key micronutrients, all of which were procured from the company Merck (Germany). To confirm the biodegradability of the microorganisms sampled from the sludge, and to enrich the microbial population, a 3:1 ratio of sludge and nutrient solution mix was poured into three 500 mL bottles. one bottle was prepared as a control, while the other two were spiked with toluene and were incubated on a shaker at 90 RPM in complete darkness at 28°C. KCN was added to one of the spiked bottles to kill the microorganisms. Then, 10 µl of toluene was injected into the bottles and incubated on a shaker at 90 rpm in a dark environment at 28°C. This experiment was performed once by adding a certain concentration of cutting oil to the nutrient liquid mixture and sludge sample. After 72 hours, the samples were taken from the top of the sample and control bottles using a gasified Hamilton syringe, and the samples were analyzed using gas chromatography to determine the concentration of toluene. After the assessment of the capability of microorganisms in the biodegradation process of toluene, they were cultivated for implementation in bioreactors.

For the measurement of toluene phase concentration, we utilized a gas chromatograph with a flame ionization detector (GC-FID) (CP-3800, Varian). The GC was programmed with a column temperature of 130°C, split ratio of 5, and injector and detector temperatures of 240°C. The carrier gas flow rate was 1.8 ml/min. The samples were collected from the two sampling ports that placed in the inlet and outlet of absorption column and then directly injected into GC by gas tight syringe (Hamilton US). Finally, the resulting area was compared with a calibration curve of gaseous toluene to determine the concentration of toluene in the samples (Nourmohammadi *et al*. 2019).

Significant operating parameters pertaining to the efficiency of an absorption column are the inlet concentration (mg/m^3) and outlet concentration (mg/m^3), along with the removal efficiency (%) and elimination capacity (g/m^3.h). In order to measure the concentration of toluene, a common contaminant, at the inlet and outlet of the bioscrubber sampling was performed through a Hamilton syringe and subsequently analyzed via gas chromatography.

Removal efficiency (RE): Determination of removal efficiency by inlet and outlet concentration was calculated by the following formula

Equation 1

$$RE(\%) = \frac{\text{Cin} - \text{Cout}}{\text{Cin}} \times 100$$

RE: Removal efficiency (%) C_{in}: Inlet contaminant concentration mg/m^3

C_{out}: Outlet contaminant concentration mg/m^3

Elimination Capacity: The elimination capacity was calculated according to the following formula, which indicates the consumption capacity of the contaminant entering the bioreactor per unit volume of the bioreactor in a specified period of time

Equation 2

$$EC = \frac{Q(\text{Cin} - C_{out})}{V}$$

Where, EC is elimination capacity (g/m^3.h), Q is the inlet gas flow rate, C_{in} is the contaminant concentration at the bioscrubber inlet, C_{out} is the contaminant concentration at the bioscrubber outlet (mg/m^3), and V is the bioscrubber volume (m^3).

Contaminant load (L): (g/m^3.h): The specified amount of pollutants introduced into the bio-scrubber are measured in terms of volume and time. The calculation of this specified amount is determined through the utilization of the equation 3.

Equation 3

$$L = \frac{C \times Q}{V}$$

3. Results

3.1. Degradability of microorganisms for toluene

The study aimed to investigate the degradability of microbial strains in sludge samples, with or without organic phase, at varying concentrations of 10%, 20%, and 30% (samples 1, 2 and 3). The results showed that after 72 hours, an increase in organic phase concentration led to further decomposition of toluene compared to the control sample (Figure 2). As depicted in the graph, the concentration of toluene was 1300 ppm in the control sample, where the bacterial population was killed by kcn. Conversely, in the main samples, it was 34, 40, and 44 ppm, respectively. Furthermore, the observed dissolved oxygen levels indicated the consumption of oxygen by microorganisms, as the control sample showed 9.8 mg/l, whereas the values for main samples were 2.1 mg/l.

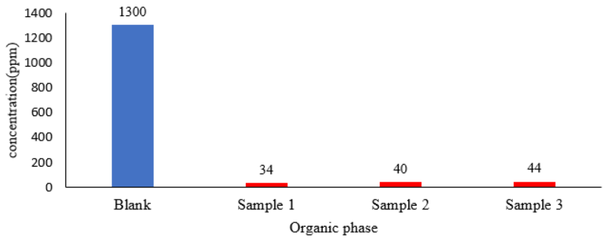


Figure 2. Toluene concentration and samples containing microorganisms in the absence of organic phase and organic phase with concentrations of 10%, 20% and 30%

Table 1. Bioscrubber performance in removing toluene at different concentrations of cutting oil (5%, 7.5% and 10%)

Operational parameters	Different concentrations of organic phase								
	5 %			7.5 %			10 %		
	Minimum	Maximum	Mean (SD)	Minimum	Maximum	Mean (SD)	Minimum	Maximum	Mean (SD)
Inlet concentration mg/m3	178	1507	729 (400)	130	1350	646 (407)	331	776	562 (190)
Outlet concentration mg/m3	62	930	4440 (238)	47	820	235 (105)	138	540	253 (96)
Contaminant load g/m3.h	63	533	330 (180)	6.2	103	45 (32)	117	247	210 (85)
Removal efficiency (%)	35	65	55 (8.8)	38	63	53 (9.5)	30	58	45.8 (7.3)
Elimination capacity g/m3.h	30	227	110 (62)	17	291	129 (91)	38.9	163	99 (40)
Percentage of carbon mineralization	18	42	33 (6)	12	53	38 (15)	21	34	28 (5.8)
The amount of biomass g/lm	0.8	23	13 (4)	1	19	15 (5.4)	1.5	32	19 (8)

3.2. Operational parameters

The present article discusses the findings of a bioscrubber performance evaluation, specifically focusing on the impact of varying concentrations of cutting oil. Data obtained from the study, which is illustrated in Table 1, indicate that the utilization of 5%, 7.5%, and 10% concentrations led to differential outcomes in terms of efficacy. Notably, the outcomes revealed that a lower concentration of 5% cutting oil was associated with a greater level of efficiency, as evidenced by a substantial increase from 22% without any organic phase to 55% with 5% cutting oil. These results suggest the potential of using lower concentrations of cutting oil in bioscrubber systems to achieve optimal performance.

Figure 3 depicts the changes in the functional parameters of the bioscrubber in response to different concentrations of cutting oil. The figure illustrates that removal efficiency rates demonstrated an upward trend over time across all three concentrations, with the slope of the chart being higher in the concentration of 10%. Moreover, at a concentration of 5%, removal efficiency ranged from a minimum of 35% to a maximum of 65% at input concentrations between 178 and 1507 mg/m^3, with minimum and maximum removal capacities of 30 and 227 g/m^3.h, respectively. Notably, the efficiency did not increase at concentrations beyond 1507 mg/m^3, which could indicate microorganism poisoning. Importantly, the addition of cutting oil as an organic phase resulted in increased removal efficiency and removal capacity of toluene. Specifically, at the concentration level of 7.5%, the efficiency rates ranged from a minimum of 38% to a maximum of 63%, with the minimum and maximum removal capacities being 17 and 269 g/m^3.h, respectively. While the efficiency at a concentration level of 5% of cutting oil as an organic phase was better than at a concentration of 7.5%, the removal capacity was higher at

7.5%, likely due to a change in the input concentration of toluene.

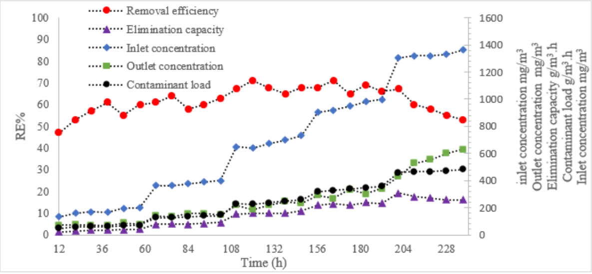


Figure 3a. Bioscrubber performance in toluene biodegradation at 5% of cutting oil as organic phase

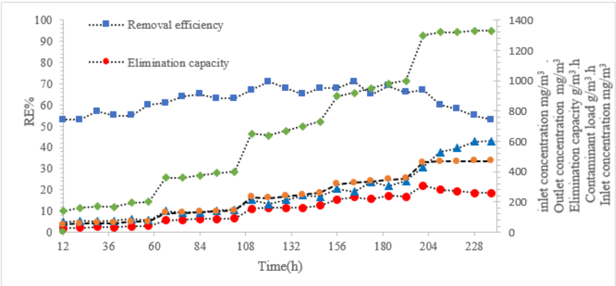


Figure 3b. Performance of bioscrubber in toluene biodegradation at 7.5% of cutting oil as organic phase

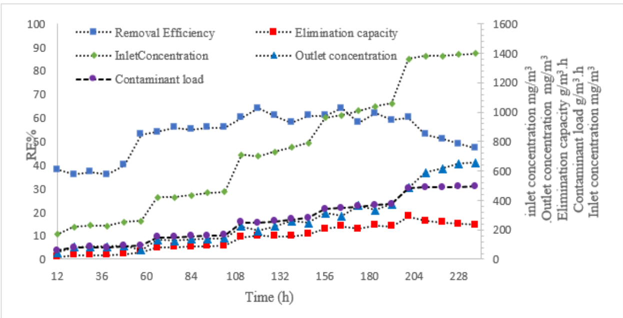


Figure 3c. Bioscrubber performance in toluene biodegradation at 10% of cutting oil as organic phase

The findings of this study indicate a positive correlation between the concentration of organic phase and the efficiency of bioscrubber removal. Specifically, the results demonstrate that an increase in organic phase concentration from 0 to 10% enhances the removal efficacy of the bioscrubber. However, the removal effectiveness seems to be intensified when the concentration of organic phase is increased from 0 to only 5%. Subsequent elevation in concentration from 5% to 7.5% elicits a gradual increment in the removal efficiency. Nevertheless, the removal efficiency decreases with further increases in organic phase concentration to 10% (as depicted in Figure 4). Notably, it is important to acknowledge that these findings deviate slightly from the observed removal capacity.

4. Discussion

The primary objective of this study was to toluene biodegradation by using two-phase bioscrubber. The bioscrubber used in this study consisted of two part. scrubber sections to absorb toluene from the gas phase and transfer it to the aqueous phase, and a microorganism section that bioderadate toluene. In order to confirm the presence of decomposer microorganisms in the analyzed sludge sample, a bottle cultivation test was performed. The findings indicate that the concentration of toluene in the control group, wherein the bacterial population was rendered inactive by kcn, was 60-fold higher in comparison to the bacterial consortium-containing samples.

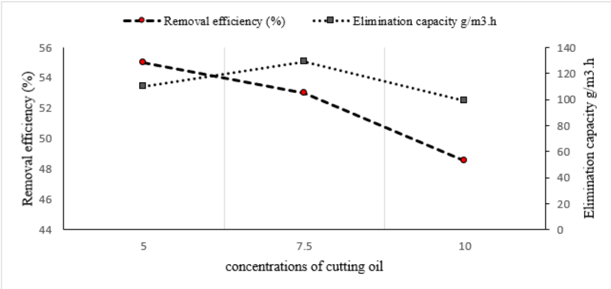


Figure 4. Comparison of removal efficiency and elimination capacity by three concentrations of cutting oil

the growth microorganism in the presence of organic phase with a concentration of less than 10% had the highest efficiency and also the efficiency and removal capacity of bioscrubber in the presence of organic phase with a concentration of 10% were higher.

In various studies, to enrich the microbial population in order to biodegrade volatile organic compounds, they have used the soils around the tanks of oil refineries and gas stations (Shahna *et al*. 2010), sewage or sludge of municipal and industrial wastewater treatment plants (Yeom et al. 2010). In this study, the source of microorganisms was the return part of the refineries of Tehran refinery. Due to the hydrophobic nature of toluene, enhancing its absorption in the liquid phase requires the use of compounds with specific properties, including non-interference with microorganisms. One such compound examined in this study is cutting oil, a widely used and readily available industrial solvent. Notably, the study findings indicate that the addition of cutting oil in concentrations less than 10% did not exhibit any significant impact on inhibiting the growth of microorganisms. However, at concentrations of 20 and 30%, the growth of microorganisms is significantly reduced compared to the control sample, which can be due to the use of side bacteria in the composition of this oil, which at concentrations of 20 and 30% causes an effect on microorganisms. Lalanne *et al*. also showed that cutting oil had no effect on the population of microorganisms (Malhautier et al. 2009). also Fabian *et al.* investigate the growth of bacteria in oil-soluble emulsions found that the use of cutting oil had no effect on the growth of microbial populations in the emulsion. According to their findings, it can be observed that the microbial population in the logarithmic phase decreases as the concentration of organic phase increases. (Fabian and Pivnick, 1953). In a study by Bennett *et al*, 30 different species of bacteria survived at 9 concentrations of cutting oil. Gram-negative bacteria were able to survive for a considerable time, while gram-positive bacteria died very quickly. Darracq *et al*. also examined the biodegradation of silicone oil and concluded that silicon oil was not degraded by microorganisms and did not observe toxicity on the microorganisms (Darracq et al. 2011).

In recent years, the use of two-phase systems to remove VOCs has been developed. In gas-liquid-liquid processes, mass transfer rate is a key parameter for estimating the bioreactor performance (Balseiro-Romero et al., 2018; Xu et al., 2019; Karimi et al. 2013). The findings from this study indicate that the introduction of cutting oil to the liquid phase resulted in a significant reduction in the concentration of toluene present in the gas phase. Such observations may suggest that the contaminant becomes absorbed and retained within the liquid phase. Furthermore, the results also indicate that the addition of cutting oil led to a decrease in the mass transfer coefficient (kla), which subsequently contributed to an increase in the concentration of toluene within the liquid phase. In the study conducted by Esmaeili-Faraj *et al*. to use water-based nanofluids in bioscrubbers to increase the removal of sulfur dioxide, the results showed that the use of these compounds significantly increases the absorption of sulfur dioxide in bioscrubbers.

Montes *et al*. also showed a tendency to absorb silicon oil for oxygen 10 times more than water (Montes *et al*., 2012). Karimi *et al*.'s study showed that the use of 10% by the volume of silicone oil significantly reduced energy consumption compared to concentrations of 20% and 30% in two-phase bioreactors. They also found that the optimum organic phase concentration of silicon oil in terms of oxygen transfer was 10%. They also observed that the use of silicone oil at a concentration of 10% reduced the oxygen transfer coefficient. Jean *et al*. reported that silicon oil at a concentration of 10% had no effect on the mass transfer coefficient (Nourmohammadi *et al*. 2019) According to the findings, the biodegradation of toluene by the bioscrubber exhibited consistent efficiency and removal capacity even in the absence of organic phase. The removal efficiency without organic phase was 20%, which is higher than the study of Lalanne *et al*, who reported the removal efficiency of toluene without the presence of organic phase at 11% (Lalanne *et al*. 2008), and this could be because of the L/G (3.6) ratio that much greater than the study of Lalanne. Malhautier *et al*. also used an industrial-scale scrubber to remove a mixture of VOCs including chlorinated, aromatic, and oxygenated compounds. In water, the removal efficiency was between 80% and 85% and for hydrophobic compounds such as toluene, the removal efficiency was reported to be 35%. Compared to the results of this study, removal efficiency was on average 17% lower (Malhautier *et al*. 2009).

Limited research has been conducted employing cutting oil as an organic phase. Of considerable significance, cutting oil possesses notable attributes that render it suitable for industrial use, namely its affordable price point and widespread accessibility. In the initial phase of the investigation, findings indicated that concentrations of cutting oil surpassing 10% facilitated a reduction in microbial populations.

The bioscrubber's efficacy and removal capacity in the absence of an organic phase were found to be relatively insufficient for toluene, likely attributable to its hydrophobic nature.

Cutting oil increases the removal efficiency from 22% without the use of organic phase to 55% in the presence of 5% cutting oil. Lalanne *et al*. conducted research on the removal efficiency of aromatic compounds in a bioscrubber, observing that the utilization of cutting oil led to an increase in removal efficiency from 12% to 36%. (Lalanne *et al*. 2008). In a conducted study aimed at mitigating the presence of vinyl carbide in the atmospheric air through petrochemical acidification, a removal efficiency rate of 36% was observed for this compound. (Esmaeili Faraj *et al*. 2012)

The removal efficiency in the absence of organic phase and using the organic phase was lower than that of this study, which may be due to the fact that the L/G ratio in this study was higher than the study of Lalanne *et al*. In Kan *et al*.'s investigation on the bioremediation of toluene and trichloroethylene using an emulsion-based bioreactor, the findings revealed that an oleyl alcohol concentration range of 3-5% as the phase was optimal for achieving the highest removal efficiencies. Furthermore, it was also observed that beyond this range, an increase in the organic phase concentration did not lead to any significant enhancement in the removal capacity (Kan E. and Deshusses, 2003).

5. Conclusion

According to studies, bioremediation methods like bio filters, bio trickling filters, membrane bioreactors, and bioscrubbers show potential for the removal of volatile organic compounds (VOCs) compared to conventional methods. However, there are challenges associated with the use of biological systems to remove these compounds. For instance, in biofilters, increasing the flow rate and concentration of contamination can lead to a reduction in the microbial population. Similarly, in bio trickling filters, microbial growth can lead to blockages and increased pressure drop. However, the bioscrubber method can overcome these limitations and provide better control over its performance parameters. Based on the results of the present study, it can be inferred that bioscrubber exhibits considerable potential as a viable solution for mitigating volatile organic compounds found in industrial settings. Notably, in this study, cutting oil was utilized as the organic phase for the first time in Iran. It was found that the application of cutting oil at concentrations below 10% posed no adverse effect on the growth of microorganisms. An industrial-scale scrubber was employed to eliminate toluene from an airstream via the implementation of organic phase and absence thereof. The results of the study demonstrated that the usage of shear oil and silicone oil amplified the absorption of volatile organic compounds in the bioscrubber. It was also observed that the liquid phase, along with the mass transfer coefficient, played a crucial role in enhancing the bioremediation of these compounds. The findings of the investigation on the role of this compound in bioscrubber demonstrate a significant enhancement in the efficiency and extraction potential of toluene from the air stream upon its incorporation in the process. While diverse factors, namely temperature, oxygen concentration, pH, and nutrient levels, were considered in the analysis, further exploration of microbial determinants is warranted to ascertain the optimal conditions.

Ethical Approval

Tehran University of Medical Sciences Research Project (Ethic cod: No. 96-01-27-33740)

Consent to Participate

The authors of the article have consented to do this manuscript and submit it to the journal.

Consent to Publish

The authors agree to publish the article

Authors Contributions

(**FG**: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **AK, SR, MN:** Investigation, Methodology, Writing – review& editing.

MN: Methodology, Writing – review & editing, Supervision. **All authors** read and approved the final manuscript)

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Competing Interest

The authors of this article declare that they have no conflict of interests

Availability of data and materials

The datasets generated and analyzed during the current study available from the corresponding author on reasonable request

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Reference

Balseiro-Romero M., Monterroso C. and Casares J.J. (2018). Environmental fate of petroleum hydrocarbons in soil: review of multiphase transport, mass transfer, and natural attenuation processes. *Pedosphere*, **28**(6):833–47.

Chen X., Qian W., Kong L., Xiong Y. and Tian S. (2015). Performance of a suspended biofilter as a new bioreactor for removal of toluene. *Biochemical Engineering Journal*, **98**, 56–62.

Darracq G., Couvert A., Couriol C., Amrane A., Thomas D., Dumont E. *et al*. (2011). Erratum: Silicone oil: an effective absorbent for the removal of hydrophobic volatile organic compounds. *Journal of Chemical Technology and Biotechnology* **86**(2), 324.

Esmaeili Faraj S.H., Esfahany M.N., Kadivar M. and Zilouei H. (2012). Vinyl chloride removal from an air stream by biotrickling filter. *Journal of Environmental Science and Health, Part A*. **47**(14):2263–9.

Esmaeili-Faraj S.H., Esfahany M.N. and Darvanjooghi M.H.K. (2019). Application of water based nanofluids in bioscrubber for improvement of biogas sweetening in a pilot scale. *Chemistry Engineering Process–Process Intensif*, **143**(February):107603.

Fabian F.W. and Pivnick H. (1953). Growth of bacteria in soluble oil emulsions. *Applied Microbiology*, **1**(4):199.

Fouhy K. (1992). Cleaning waste gas, naturally. *Chemical Engineering*, **99**:41–46.

Ghirardo A., Lindstein F., Koch K., Buegger F., Schloter M., Albert A.. *et al*. (2020). Origin of volatile organic compound emissions from subarctic tundra under global warming. *Global Change Biology*, **26**(3):1908–25.

Görgülü A., Yağli H., Koç Y., Koç A. and Baltacioğlu E. (2019). Activated carbon absorption behaviour of toluene at various temperatures and relative humidity. *Environmental Protection Engineering*, **45**(1).

Guieysse B., Hort C., Platel V., Munoz R., Ondarts M. and Revah S. (2008). Biological treatment of indoor air for VOC removal: Potential and challenges. *Biotechnology Advances*, **26**(5):398–410.

Kan E. and Deshusses M.A. (2003). Development of foamed emulsion bioreactor for air pollution control. *Biotechnology and Bioengineering*, **84**(2):240–4.

Karimi A., Golbabaei F., Neghab M., Pourmand M.R., Nikpey A., Mohammad K. *et al*. (2013). Biodegradation of high concentrations of benzene vapors in a two phase partition stirred tank bioreactor. Iranian Journal of Environmental Health Science & Engineering, **10**(1):10.

Kuranchie F.A., Angnunavuri P.N., Attiogbe F. and Nerquaye-Tetteh E.N. (2019). Occupational exposure of benzene, toluene, ethylbenzene and xylene (BTEX) to pump attendants in Ghana: Implications for policy guidance. *Cogent Environmental Science*, **5**(1):1603418.

Lalanne F., Malhautier L., Roux J.C., Fanlo J.L. (2008). Absorption of a mixture of volatile organic compounds (VOCs) in aqueous solutions of soluble cutting oil. *Bioresource Technology*. **99**(6):1699–707.

Malhautier L., Lalanne F. and Fanlo J-L. (2009). Bioscrubbing as a treatment for a complex mixture of volatile organic compounds: influence of the absorption column characteristics on performance. *Canadian Journal of Civil Engineering*. **36**(12):1926–34.

Montes M., Veiga M.C. and Kennes C. (2012). Effect of oil concentration and residence time on the biodegradation of α-pinene vapours in two-liquid phase suspended-growth bioreactors. *Journal of Biotechnology*. **157**(4), 554–63.

Mortazavi Mehrizi M., Yousefinejad S., Jafari S., Baghapour M.A., Karimi A., Mahvi A.H. *et al*. (2020). Bioremediation and microbial degradation of benzo [a] pyrene in aquatic environments: a systematic review. *International Journal of Environmental Analytical Chemistry*, 1–16.

Mudliar S., Giri B., Padoley K., Satpute D., Dixit R., Bhatt P. *et al*. (2010). Bioreactors for treatment of VOCs and odours -

A review. *Journal of Environmental Management*, **91**(5):1039–54.

Nourmohammadi M., Golbabaei F., Karimi A., Pourmand M.R., Noor Poor A., Rahimi Foroushani A. *et al*. (2019). Absorption and Biodegradation of Toluene in a Two-Phase Low-Pressure Bioscrubber Using Cutting Oil as the Organic Phase. *Heal Scope*, **8**(1).

Nourmohammadi M., Golbabaei F., Karimi A., Pourmand M.R., Poor A.N., Foroushani A.R. *et al*. (2018). Absorption and biodegradation of toluene in a two-phase low-pressure bioscrubber using cutting oil as the organic phase. *Heal Scope*, **8**(1).

Nourmohammadi M., Karimi A., Golbabaei F., Pourmand M.R., Rahimi Foroushanid A. and Nourmohammadi E. (2021). Biodegradation of toluene in a two-phase low-pressure bioscrubber with using silicon oil as organic phase. *International Journal of Environmental Analytical Chemistry*, May **14,** 1–13.

Oliver B.G. and Bothen K.D. (1982). Extraction and clean-up procedures for measuring chlorobenzenes in sediments and fish by capillary gas chromatography. *International Journal of Environmental Analytical Chemistry*, **12**(2):131–9.

Shahna F..G, Golbabaei F., Hamedi J., Mahjub H., Darabi H.R., Shahtaheri S.J. (2010). Treatment of Benzene, Toluene and Xylene Contaminated Air in a Bioactive Foam Emulsion Reactor. Chinese *Journal of Chemical & Engineering*, **18**(1):113–21.

Tsai W-T. (2019). An overview of health hazards of volatile organic compounds regulated as indoor air pollutants. *Reviews on Environmental Health*, **34**(1):81–9.

Wang Z., Xiu G., Wu X., Wang L., Cai J. and Zhang D. (2013). Biodegradation of xylene mixture from artificial simulated waste gases by capillary membrane bioreactors. *Chemical Engineering*, **229**, 508–14.

Xu X., Zhou H., Chen X., Wang B., Jin Z. and Ji F. (2019). Biodegradation potential of polycyclic aromatic hydrocarbons by immobilized Klebsiella sp. in soil washing effluent. *Chemosphere*. **223,** 140–7.

Yeom S.H., Daugulis A.J. and Nielsen D.R. (2010). A strategic approach for the design and operation of two-phase partitioning bioscrubbers for the treatment of volatile organic compounds. *Biotechnology Progress*. **26**(6):1777–86.