Removal of isopropyl alcohol from air stream using biofiltration

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Abstract

Isopropyl Alcohal (IPA) is flammable, clear, colorless liquid and is slightly odorous. IPA has wide applications in various industries such as paint, pharmaceutical, lithography, rubber manufacture, semiconductor, and printing industries. It is one of the components of many antiseptic and cosmetic products. The exposure of high concentrations of IPA can cause depression in central nervous system, unconsciousness and possibly death. Due to its adverse effects on human being and the environment, there is a dire need for cost effective and innovative treatment technique that can be used for the removal of IPA from industrial effluent streams. Out of various physical and chemical methods (adsorption, absorption, condensation, incineration, etc.) available, biological methods such as biofiltration plays a major role in treatment of IPA. Biofiltration is cost effective method and create negligible secondary pollutants. Biofiltration is an aerobic degradation of organic compounds onto supporting media which include the utilization of VOCs as a carbon source (food) by variety of microorganism's community.

The present study deals with the biofiltration of IPA. The biofiltration study is carried out on a lab scale for 40 days using acclimated mixed culture. The duration of acclimation phase is obtained as 10 days. The removal efficiency obtained after the acclimation phase is 91.25% which indicates the sufficient growth of microbial culture in the biofilter column. The performance of the biofilter column is evaluated in next 30 days by keeping different inlet loads of IPA (0.101 – 0.365 g m^{-3}) at different air flow rates ranging from 0.18 to 0.3 $m^3 h^{-1}$. To check the stability of biofilter column, the biofilter is operated under shock loading conditions for 10 days by varying inlet IPA load and air flow rate after every 3 days.

Keywords: Biofiltration; Isopropyl alcohol; Acclimated mixed culture; Shock loading.

Introduction

Volatile Organic Compounds (VOCs) are the large group of organic compounds emitted into the atmosphere by a wide range of industries and are one of the major pollutants released by the industries which contaminate the atmospheric air and the fresh water resources [1, 2, 3, 4, 5,6] . Isopropyl Alcohal (IPA) is one such VOCs which is flammable, clear, colorless liquid and is slightly odorous. IPA has wide applications as a solvent in paint, pharmaceutical, lithography, and rubber manufacture industries; and as a cleaning agent in semiconductor and printing industries. It also used for sterilizing and disinfecting surfaces in hospitals, dairy farms, food processing plants, household dwellings, veterinary institutions, farm structures, and poultry areas. It is one of the components of many antiseptic and cosmetic products. Prolonged skin contact with isopropyl alcohol caused eczema and sensitivity. Chronic exposure of IPA may cause skin effects. Those who have pre-existing skin disorders or impaired liver, kidney, or pulmonary function may be more susceptible to the exposure of IPA. The exposure of high concentrations of IPA can cause depression in central nervous system, unconsciousness and possibly death [7].

Due to its adverse effects, it needs to be removed from the waste gaseous streams. Out of various techniques such as incineration, ozonation, combustion, adsorption, biofiltration has emerged to be cost effective technology for eliminating odorous and toxic volatile organic compounds (VOCs) from waste gas streams in recent years. Biofiltration takes place by combination of basic processes such as absorption, adsorption and degradation [8]. In this process, microorganisms degrade the contaminants by consuming it as carbon source for their growth and thus releasing end products such as carbon dioxide, water and biomass. The biomass can be reused by sending it back to the environment.

The performance of biofiltration system mainly depends on the selection of microbial culture and packing material. There is a need to use a combination of packing materials which has the advantages over the above mentioned shortcomings. One of the suitable combinations of packing materials could be coal and compost (hybrid bed system) which is used in the present study. Hence, the present work deals with the removal of IPA from waste air streams using biofiltration. A mixture of matured compost and coal which is cheap and is readily available is used as a packing material for the biofilter column. The seeding of the column is carried out with the acclimated mixed culture for IPA obtained from the shake flask studies. The performance of the biofiltration experiment is evaluated for the period of 60 days by changing the inlet concentration of IPA and air flow rates. The performance of biofilter is gauged in terms of removal efficiency and elimination capacity.

Materials and Methods

Development of IPA utilizing acclimated culture

The development of IPA enriched culture was carried out in MSM with IPA as a sole carbon source. The source for the activated sludge was the secondary clarifier of Sewage Treatment Plant of Birla Institute of Technology & Science (BITS) Pilani, India. The activated sludge obtained was allowed to settle for 4 hours away from sunlight. 10 gm of settled sludge was taken and thoroughly mixed with 100 ml of distilled water in a beaker. The shaking was carried out gently and then sludge was allowed to settle in order to subsequently screen out the solid particles. Fifty milliliters of supernatant was then taken in a 50 ml centrifuge tube. The centrifugation was carried out for 2 minutes at 10,000 rpm at 4^0 C in a Centrifuge (Remi Cooling Centrifuge, India). The portion of the upper liquid was removed carefully from the top of the centrifuge tube without disturbing the pellet. The shake flask study was carried out by taking out the pellet with the help of a loop and transferred into a 250 ml flask containing 100 ml MSM in an aseptic environment along with IPA and glucose. Thus the acclimated culture was obtained from 15 days cycle by increasing the amount of IPA from 160 to 480 mg L^{-1} and decreasing the amount of glucose from 1000 to 0 mg L^{-1}. The final acclimated culture was obtained containing only MEK as a sole carbon source which was used as a seeding culture for the biofiltration study. It is observed from several studies that the acclimated mixed culture is much better choice over pure culture as in both the cases better or almost comparable removal efficiencies are obtained [3].

Packing materials (Coal and Compost)

The column was packed with matured mixture of compost and coal in the ratio of 2:1 (V/V). The matured compost was obtained from The JRD Tata Foundation for Research in Yoga, Naturopathy & Ayurvedic Sciences, Chitrakut, UP (India). The matured compost was derived from cow dung and subjected to anaerobic digestion. The coal was obtained from the local market.

Biofilter operation

The biofilter column was packed with the prepared packing material of coal and compost which was mixed with 200 mL of acclimated culture. 300 mL of acclimated culture was again transferred on to the packed column thrice in order to thoroughly mix the packing with the acclimated culture. The entire amount of 500 mL of the total acclimated culture was used in the present study. The leachate which was collected at the bottom of the column was also transferred to the packed column for one week. The packing height was 70 cm. It can be seen from Fig. 1 that the set-up comprised of air sampling bottle, IPA sampling bottle and mixture sampling bottle. The air was passed into the IPA bottle to generate IPA saturated vapor. The IPA saturated vapor and the air stream from the air sampling bottle was then passed separately into the mixing bottle. Finally, IPA enriched stream was then passed into the biofilter column from the mixing bottle in an up flow mode of operation. The packing material was supported on a stainless steel mesh installed at the bottom of the column to maintain a homogeneous radial distribution of the IPA vapors. The moisture content in the bed was maintained periodically by sprinkling fresh MSM from the top of the biofilter column as shown in Fig 1. The MSM provided the necessary nutrient apart from carbon for the development of the biofilm. The column had 6 sampling ports after every 10 cm from the bottom in the 70 cm packed column height. The inlet port for the inlet of IPA vapors was at 10 cm from bottom of the column and the outlet sampling port was at the 20cm from top of the column as can be seen from Fig. 1. The continuous experiments were carried out by varying the flow rates of air and IPA to get different initial concentration of IPA and residence time.

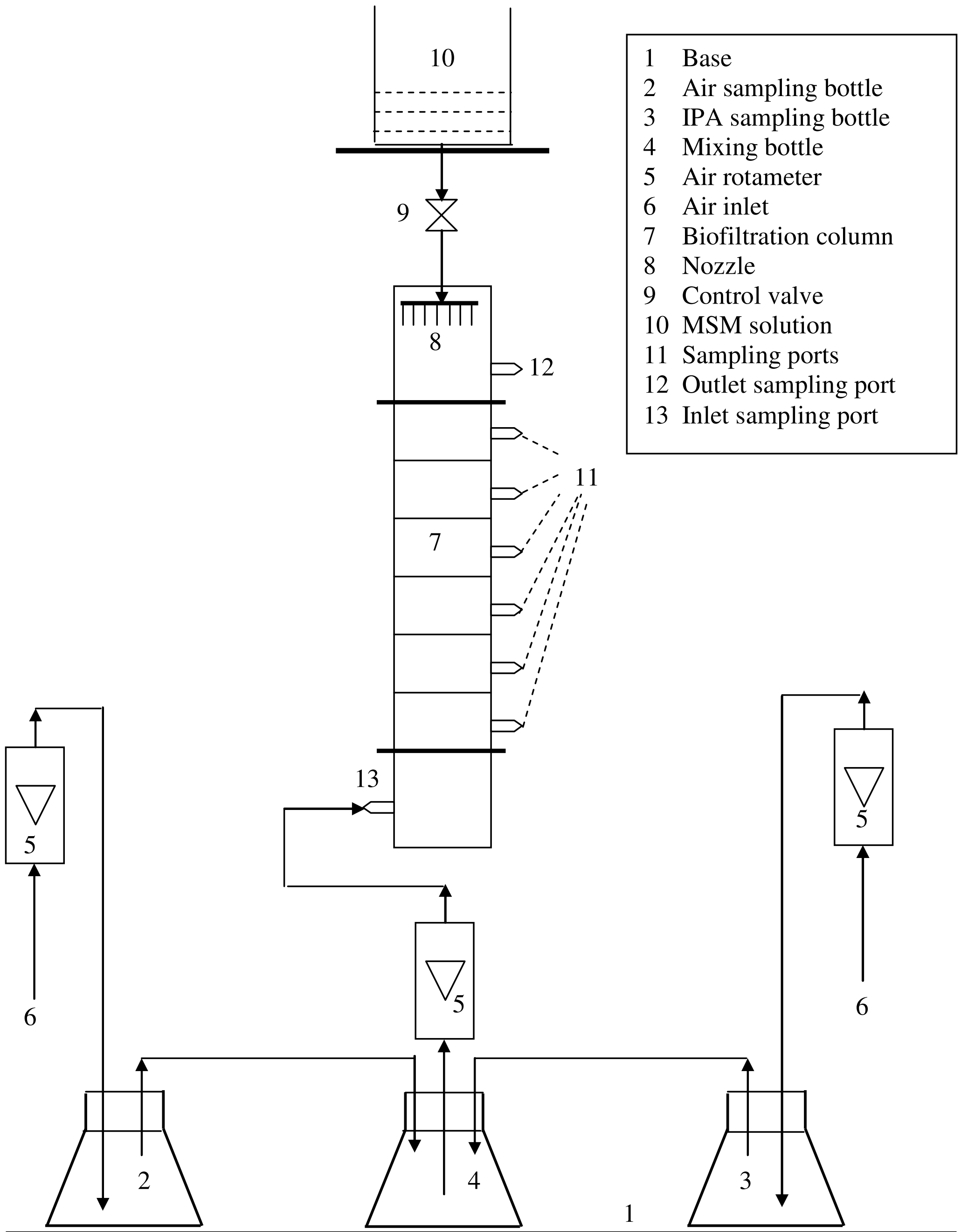

Fig. 1 Biofilter set up

Analytical methods

The optical density (OD) of the microbial culture was obtained at 540 nm with respect to blank MSM solution using UV-VIS Spectrophotometer (Model 119- Systronics, India). The path length for the optical density measurements is 10 mm. These samples were then centrifuged at 10000 rpm for 2 minutes in order to separate biomass and supernatant (aqueous solution obtained after biodegradation) [9]. A known volume of microbial culture was used to calculate the dry weight of biomass per volume of solution. The calibration curve was prepared in between optical density value and biomass concentration. The IPA concentrations in aqueous samples (supernatant) were analyzed using a gas chromatograph (Model 5700 series, Nucon Engineers, India). Nitrogen was used as the carrier gas and the temperatures of injection port, detector and oven were maintained at 1500 ^{0}C, 1500 ^{0}C and 2000 ^{0}C, respectively. All the experiments and measurements were conducted twice and the arithmetic averages of the values obtained were taken for calculations and data analysis.

Results and Discussion

Biofilter performance for IPA removal

The effect of operating time on outlet concentration and removal efficiency of IPA at various air flow rates is studied during 40 days of biofilter operation and is shown in Fig. 2. The total operating time is divided into 4 phases which include the acclimation phase of 10 days (phase I). The operating conditions for the 40 days of biofilter operation are given in Table 3.6. In phase I, the inlet concentration is maintained in the range of 0.04 – 0.051 g m^{-3} and air flow rate is kept constant at 0.18 m^3 h^{-1} for the initial 10 days of biofilter operation. The removal efficiency increases from 40.23% to 91.25% with an increase in the operation time of biofilter column from 2 to 10 days respectively (Fig. 2). The obtained maximum removal efficiency is 91.25% after 10 days of biofilter operation which indicates that there is sufficient microbial growth inside the biofilter column. This fact can also be justified with the obtained large value of microbial concentration as 8.6X10^5 CFU g^{-1}. Hence, the acclimation phase is kept as 10 days for the IPA removal.

The inlet IPA concentration is increased from 0.051 to 0.101 g m^{-3} and air flow rate is increased from 0.18 to 0.24 m^3 h^{-1} in phase II of biofilter operation. A sudden decrease in removal efficiency from 91.25% (phase I) to 70.32% (phase II) is observed with sudden change in operating conditions from phase I to phase II. The increase in operating time further increases the removal efficiency and reaches to 93.22% after 20 days of biofilter operation [2]. Though the inlet IPA concentration and air flow rate are higher in phase II as compared to phase I, maximum removal efficiency during the phase II is more than that in phase I. This may be due to the increase in microbial concentration.

The phase III lasted for 10 days from 21 to 30 days. In this phase, inlet IPA concentration is increased from 0.115 to 0.352 g m^{-3} and air flow rate is decreased from 0.24 to 0.21 m^3 h^{-1}. The removal efficiency is decreased from 93.22% (phase II) to 65.4% (phase III) and further increases with an increase in operating time and reaches a steady state value of 85.22%. The maximum removal efficiency obtained in phase III is less than that in phase I and phase II. Though the EBRT is increased from 20.6 to 23.6 s, the removal efficiency is decreased in phase III. This may be due to the high inlet IPA concentration which leads to the predominant self inhibition effect.

The performance of biofilter is investigated by decreasing the inlet IPA concentration in the range of 0.162 – 0.173 g m^{-3} and air flow rate is increased to 0.3 m^3 h^{-1}. The removal efficiency decreased from 85.22% (maximum in phase III) to 74.33% (initial value in phase IV) as shown in Fig. 2. The removal efficiency further increased with an increase in operating time and reaches to a maximum value of 90% after 40 days of biofilter operation. The maximum value of removal efficiency in phase IV is higher than that in phase III but less than that in phase II and phase I. This may be due to the fact that the initial MEK concentration in phase IV is more than the phase II and less than that in phase III. The decrease in the removal efficiency as compared to phase II can also be justified by the fact that the EBRT for this phase is 16.5 s which is lesser than the all other phases. So there is no sufficient contact time between microbial culture and IPA for the biodegradation.

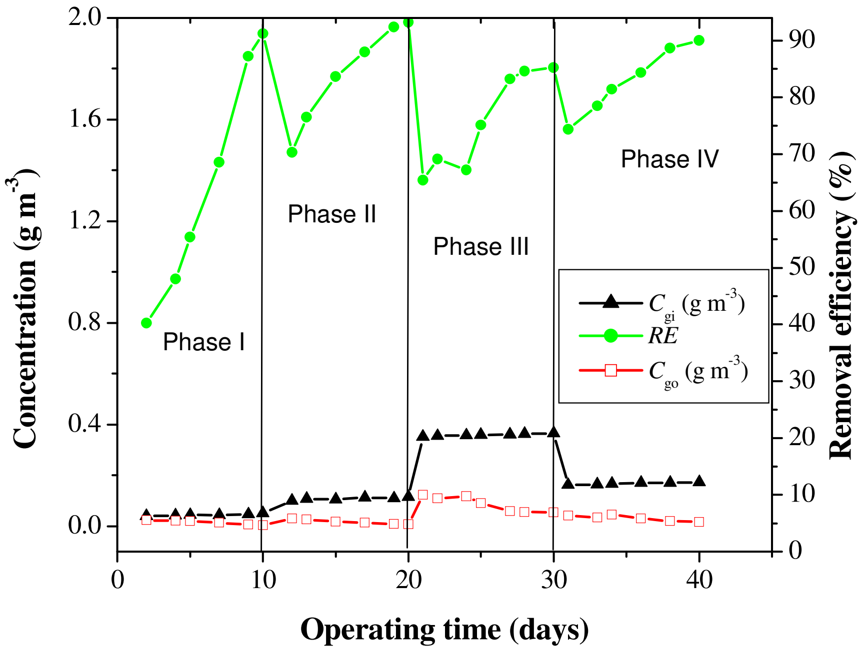

Fig. 2 Performance of biofilter with change in air flow rate and inlet MIBK concentrations

Response to shock loads on the biofilter column for IPA removal

In the present study, the maximum removal efficiency is obtained as 93.22% after 20th day of biofilter operation. The microbial concentration is estimated after 40 days of biofilter operation and is increased from 8.6X10^5 CFU g^{-1} to 9.54X10^7 CFU g^{-1} of packing material with an increase in operation time from 10th day to 40th day of biofilter operation. Hence the biofilter column showed a sufficient increase in the microbial concentration which is required for the degradation of IPA.

In the first three days of biofilter operation for IPA removal under shock loading conditions, the inlet IPA concentration is maintained in the range of 0.3 – 0.36 g m^{-3} which corresponds to the inlet load of 45.83 – 55 g m^{-3} h^{-1} at air flow of 0.21 m^3 h^{-1} (Fig. 3). The removal efficiency is obtained in the range of 82.11 – 87.01% and corresponding elimination capacity is 37.64 – 47.86 g m^{-3} h^{-1}. These high values of removal efficiency and obtained values of elimination capacity indicate the high stability of biofilter column. For the 4th to 6th day of biofilter operation, the inlet concentration is increased in the range of 0.41 – 0.43 g m^{-3} and air flow rate is maintained at 0.24 m^3 h^{-1}. The inlet IPA load is in the range of 69.85 – 75.08 g m^{-3} h^{-1} for which the elimination capacity is obtained in the range of 53.95 – 60.15 g m^{-3}. The removal efficiency is found in the range of 77.23 – 80.11% which showed good efficiency under high inlet load. For the next four days of biofilter operation, the inlet concentration is suddenly decreased in the range of 0.2 – 0.23 g m^{-3} to check the stability of biofilter column by maintaining the air flow rate of 0.18 m^3 h^{-1}. The removal efficiency is found to be maximum in the range of 90.01 – 93% which indicates that the microbial culture present inside the biofilter column is well acclimatized with IPA and could be used for the IPA removal at different inlet loads.

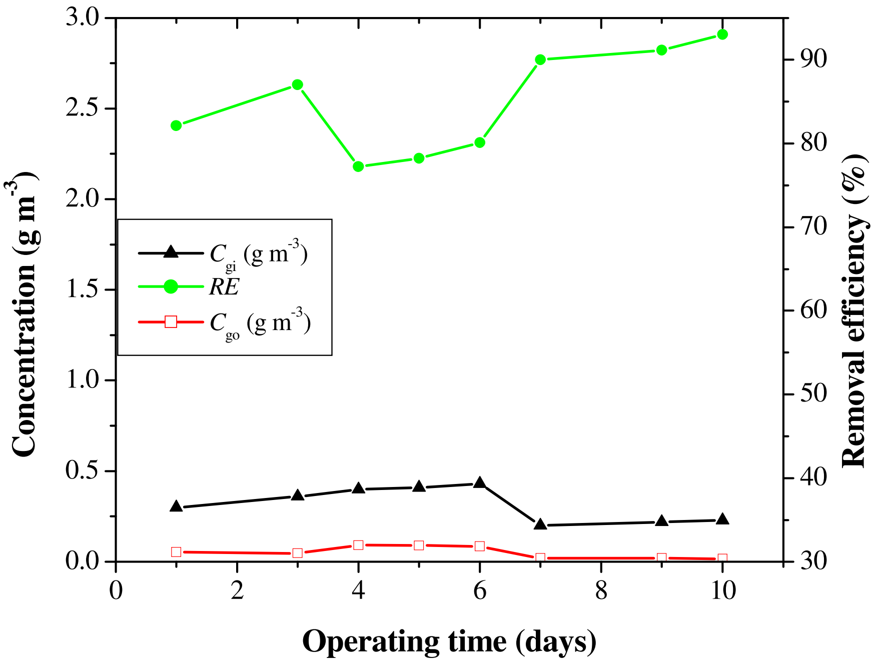

Fig. 3 Performance of biofilter with change in air flow rate and inlet IPA concentrations for shock loading conditions

Conclusions

The performance of a biofilter column packed with coal and matured compost was evaluated for a period of 60 days followed by shock loads for a period of 10 days using acclimated mixed culture. The biofilter column showed removal efficiency as high as 93.22 %, when inlet concentration was maintained in the range of 0.051 to 0.101 g m^{-3} during the 2^{nd} phase of biofilter operation. The microbial concentration is estimated after 40 days of biofilter operation and is increased from $8.6X10^5$ CFU g^{-1} to $9.54X10^7$ CFU g^{-1} of packing material with an increase in operation time from 10^{th} day to 40^{th} day of biofilter operation. The removal efficiency is obtained in the range of 82.11 – 87.01% and corresponding elimination capacity is 37.64 – 47.86 g m^{-3} h^{-1}. These high values of removal efficiency and obtained values of elimination capacity indicate the high stability of biofilter column.

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