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Biological Elimination Of Volatile Hydrogen Sulphide Compounds In Biofilters

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Abstract: Biofiltration of Hydrogen sulphide from waste gas using compost and wood chips as filter bed material was studied. The biofilter used in this investigation was of 110 cm height and 5 cm in diameter. The inlet H_2S concentration was varied from 5 to 15 ppm with the flow rates ranging from 0.0333 to 0.1000 m^3/s. The equivalent empty bed residence time (EBRT) range was 9 to 30 s, 12 to 33 s and 15 to 48 s for the bed height of 50 cm, 65 cm and 80 cm respectively. The compost to wood chips ratios of 1:2, 1:1 and 2:1 were employed in this investigation. The effect of inlet air- H_2S vapour flow rate, inlet concentration, empty bed residence time, bed height and ratio of compost to wood chips on removal efficiency was studied and found to be significant. The maximum removal efficiency was found to be 99 percent and also found to be strongly depending on the bed height and ratio of compost to wood chips. The percentage removal efficiency was compared with earlier investigations and found to be effective. The biofilter removed as high as 936 g m^{-3} h^{-1} at the empty bed residence time of 16 s and the compost to wood chips ratio of 2:1.
Keywords: Volatile Organic Compound, H_2S, Compost, Wood Chips, Biofiltration, Removal Efficiency.

INTRODUCTION

Volatile Organic Compounds (VOCs) are widely used in many industries such as printing, petrochemicals, plastics, refrigerant, electronics, and paint manufacturing. However, large quantities of VOCs are released into the air, soil and groundwater because of occasional accidents and the absence of proper treatment technologies. Most VOCs are toxic and carcinogenic substances. Loss of these substances to the ambient air may have an adverse impact on air quality and thus endanger public health [1].

Hydrogen sulphide is a highly odorous, toxic and corrosive air contaminant that can cause adverse health effects. The emission of hydrogen sulphide is found in many industrial activities such as petroleum refining, pulp and paper manufacturing and food processing. Hydrogen sulphide is a toxic, colourless, flammable gas that is heavier than air [2, 3]. The maximum safe exposure limit to H_2S gas is approximately 10 ppm; however, the gas detection threshold is approximately 0.47 ppb. Given the exposure limit and the fact that even small quantities can be detected, there are strict regulations in effect for controlling the emission of H_2S in many regions of the world [4].

Biofiltration is an emerging technology to control odor and volatile organic compound (VOC) emissions from contaminated air streams [1, 5-8]. Biofilters are those bioreactors in which a mixed culture is attached to a stationary support material such as compost, soil, peat, granular activated carbon or other porous media capable of adsorbing gaseous compounds and support biological growth. Contaminants pass into a wet biofilm layer surrounding the support particles and are aerobically degraded to carbon dioxide and water. The bed's moisture is maintained at constant level by introducing humid air to maintain a biologically active layer surrounding the media which is known as "biofilm" [9].

However, as more research was conducted on this simple process, it became clear that the biodegradation rates were low and hence the size of the biofilter bed required to achieve high destruction efficiencies was very large. Since, compost had a higher concentration of microorganisms; compost became the media of choice for biofilters.

Although biofiltration has now been used for several years, both at laboratory scale and at industrial scale for the removal of VOCs, sometimes very different results reported in the literature for similar air pollution problems show the need for further investigation, in order to improve and optimize this technology[10].

Laboratory and field studies have shown that biofiltration of H_2S is feasible, however there have been few problems reported due to the formation of acidic intermediate products[11], sulphur deposits on the media[12, 13], and slow rates of H_2S degradation [14] which results in large media volume requirements for full-scale systems.

The objective of this work is to develop a biofiltration system using the Biofilter consisted of mixture of compost and woodchips that support the microbial population for the feasibility of degrading of H_2S vapour. The effects of compost to woodchips ratio, inlet air- H_2S vapour flow rate, inlet concentration, empty bed residence time (EBRT) and bed height on biofiltration of hydrogen sulphide are studied.

EXPERIMENTAL SETUP

The experimental set-up and its ancillary connections are shown schematically in Fig. 1. The biofilter is made-up of acrylic column with the height and diameter of 110 cm and 5 cm respectively. The column has three sections. The first section is 10cm in height and that of second and third sections are 90 cm and 10 cm respectively. The first section is at the bottom; the second section is in middle and the third section is at the top. The filter bed material is kept at the middle section and its height is varied as 50, 65 and 80 cm respectively. A packing support is provided in between the sections 1 and 2. This is a perforated sheet made up of acrylic having the diameter of 0.4 cm. It is also used to distribute the vapour uniformly throughout the bed material. The H_2S vapour is fed to the column at the bottom through rotameter. The initial vapour concentration is varied by mixing the vapour with air and fed to the rotameter in compressed form through the mixer. Before mixing with vapour the air is passed through the surge tank to become saturated. The gas sampling probes 1 and 2 provided at the sections 1 and 2 are used to collect the vapour samples. The initial and final concentrations of the vapour are analyzed using the gas chromatography equipment. The initial concentration of the vapour is varied from 5 to 15 ppm. The bed temperature is noted by the thermocouple provided at the middle of the column (section 2). The composition of the nutrient solution is given in Table1. This nutrient solution is used to maintain the growth of micro organisms in the bed material. It also maintains the moisture content and the pH value of the bed material. The moisture content of the bed material is measured periodically by using moisture meter and maintained constantly. The pH is also monitored continuously using pH meter. Void volume of the packed bed is calculated by using the void volume and total volume.

MATERIALS AND METHODS

Filter bed material

The filter media is a mixture of compost and wood chips. The proportion of compost to wood chips is varied at the ratios of 1:2, 1:1 and 2:1 by volume. A pH buffer solution is added periodically to the filter media to maintain the pH. Table 2 represents the filter media and biofilter operating conditions.

Analytical methods

H_2S is used as volatile organic compound (VOC) with 99.8%. Concentrations of H_2S vapour is analyzed using gas chromatograph (Model 5765, Nucon Gas Chromatography, Nucon Eng,. India) equipped with Poropak-Q column (1/80" ID, liquid-10% FFAP, solid-Ch-WIHP, 80/100 mesh). The injector, oven and detector temperature are maintained at 210, 180, and 230°C, respectively. The hydrogen gas is used as the fuel and nitrogen is used as the carrier gas at a flow rate of 20 mL min^{-1}. The calibration curve is prepared by injecting known amounts of the H_2S into a sealed bottle equipped with a Teflon septum according to the standard procedure. The injected amount of H_2S is allowed to evapourate in the air space within the bottle at experimental temperature (30°C). The air samples are drawn from the top and bottom section sampling ports by using a gas tight syringe and analyzed.

The column is initially charged with filter bed material with desired height (50 cm). The filter bed media is a mixture of compost and woodchips in the proportion of 1:1 ratio by volume. The air H_2S vapour mixture is fed to the column through mixer and rotameter. Inlet flow rate is adjusted to the desired level and noted (0.0333 m^3/s). The inlet and outlet concentration of vapour air mixture is measured by collecting the vapour samples from the probes provided in the sections1 and 2. The same procedure is repeated for another two different air-vapour mixer flow rates namely (0.0666 and 0.1000 m^3/s). Similarly the experiment is conducted for the ratio of compost to wood chips of 2:1 and 1:2 for three different heights such as 50 cm 65 cm and 80 cm.

Operating conditions

To describe the mechanisms of Biofiltration clearly, the general terminology pertinent to the field should be well defined. The studies are performed on the level of the volatile organic compound inlet load (IL) and empty bed residence time (EBRT) while the pollutant degradation performance of the biofilter can be expressed in terms of the pollutant removal efficiency (RE) and the elimination capacity (EC). The definitions of these four parameters are given in Table 3.

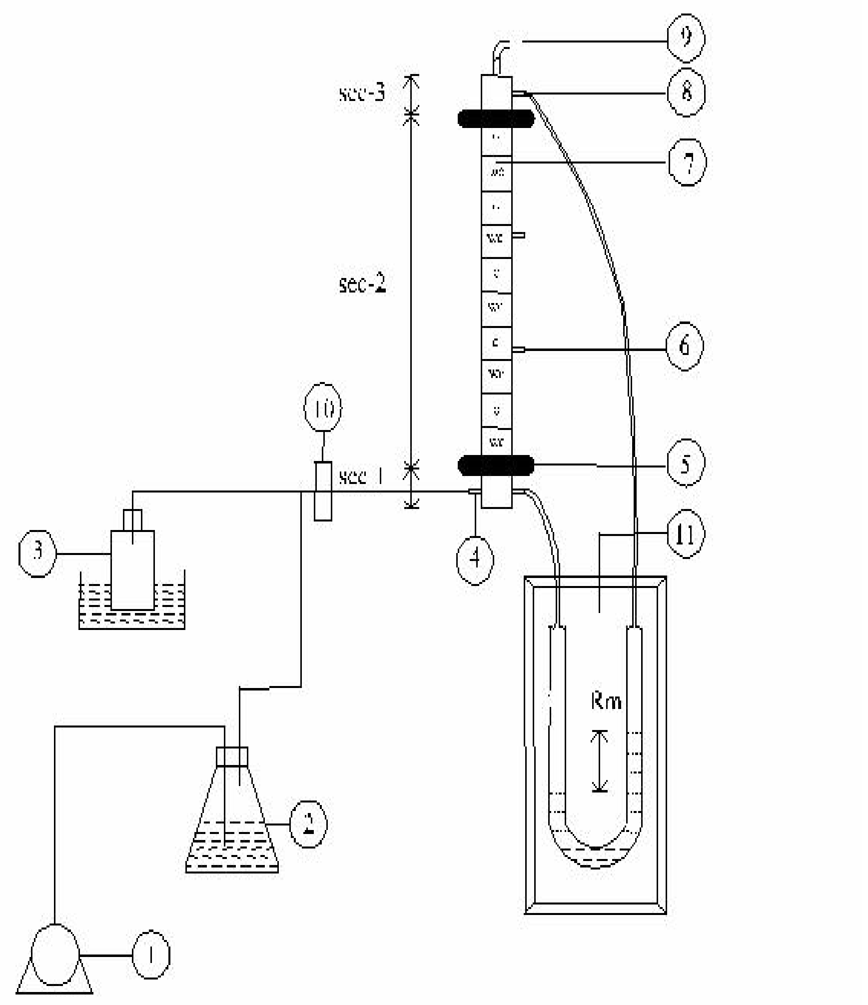

Fig. 1: Experimental setup of biofilter

1 air compressor, 2 surge tank, 3 methanol vapour, 4 air-methanol vapour inlet, 5 packing support, 6 gas sampling probe 1, 7 bed material, 8 gas sampling probe 2, 9 vapour outlet, 10 rotameter, 11 Simple U tube manometer.

Table 1: Composition of one litre of the nutrient solution

Composition	Amount
KH_2PO_4	0.91 g
Na_2HPO_4 $12H_2O$	2.39 g
KNO_3	2.96 g
$(NH_4)_2$ SO_4	1.97 g
$NaHCO_3$	1.50 g
$FeSO_4$ $7H_2O$	0.20 mg
$MgSO_4$ $7H_2O$	2.00 mg
$MnSO_4$ H_2O	0.88 mg
Na_2MoO_4 $2H_2O$	1.00 mg
$CaCl_2$	3.00 mg

Table 2: Biofilter operating conditions

Filter media	Compost and woodchips
Pollutant	H_2S
Micro organism	Indigenous to filter media
Bed height	50, 65 and 80 cm
Column diameter	5 cm
Inlet concentration	5, 10 and 15 PPM
Air flow rate	2, 4 and 6 LPM
EBRT	9 – 48 s

Table 3: Operating parameters and descriptions

Parameter	Description/Comment	Notation	Units
Inlet Load (IL)	Vapour loading rate per unit bed volume	$\frac{Q \times C_i}{V}$	$\frac{g}{m^3h}$
Empty bed residence time (EBRT)	Measure of time duration of pollutant within the column	$EBRT = \frac{V}{Q}$	s
Removal efficiency (RE)	Performance measure	$\left(1 - \frac{C_o}{C_i}\right) \times 100$	%
Elimination Capacity (EC)	Vapour removal rate per unit bed volume	$EC = \frac{Q \times (C_i - C_o)}{V}$	$\frac{g}{m^3h}$

RESULTS AND DISCUSSION

Effect of air-H_2S vapour mixture flow rate on Removal of H_2S

Fig. 2 shows the effect of air- H_2S vapour mixture flow rate on hydrogen sulphide removal efficiency. Removal efficiency is decreased with increasing flow rate. When air flow rate is increased the concentration of hydrogen is increased in the air-H_2S vapour mixture, due to this increasing hydrogen sulphide concentration in inlet air- H_2S vapour flow, the removal efficiency is decreased. This is due to incompetence of microorganisms or elevated reaction of chemical might lead to decrease of removal efficiency. For the air- H_2S vapour mixture flow rate 0.0333 to 0.1 m^3/s, the removal efficiency is found to the range of 92 to 98 percent for compost to wood chips ratio of 1:1. The removal efficiency is found in the range of 94 to 98 for compost to wood chips ratio of 2:1 and the removal efficiency is found in the range of 91 to 95 for compost to wood chips ratio of 1:2.

Effect of Inlet concentration of H_2S on Removal Efficiency

Fig. 3 shows the effect of inlet concentration on removal efficiency. It is observed that the removal efficiency is a decreasing function of the inlet concentration. For the inlet concentration of 5.5 to 15 ppm of H_2S vapour, the removal efficiency is in the range of 94 to 98 percent for the compost to wood chips ratio of 2:1, 92 to 98 percent for the compost to wood chips ratio of 1:1. The removal efficiency is 91 to 95 percent for the compost to wood chips ratio of 1:2. In all these three ratios the removal efficiency is decrease when inlet concentration is increased. Similar results were reported by the earlier studies. The author [15] reported that for low concentrations, in both reactors, removal efficiency was higher than 90% (below 90 ppm).

Effect of Empty Bed Residence Time (EBRT) on Removal Efficiency

Fig. 4 shows the effect of empty bed residence time on removal efficiency. It is found that the removal efficiency is the strong function of EBRT. While the inlet air-methanol vapour flow is increased, the EBRT is decreased. The decreasing EBRT value decreases the removal efficiency. For the EBRT range of 10 to 49 s, the removal efficiency is found to be in the range of 94 to 99 percent at a compost to wood chips ratio of 2:1. The EBRT range of 9 to 48 s, the removal efficiency is found to be the range of 92 to 98 percent at a compost to wood chips ratio of 1:1 and 91 to 95 percent for 1:2 ratios**.** It [16] was reported that at EBRT of 30 sec, 86% of elimination occurred in 71% of bed height, but when EBRT was decreased to 9 sec, 67% of elimination occurred in the same height of the bed. An increase in the residence time increases the investment cost in the design estimation of the biofilter[17].

Effect of Bed Height on Removal Efficiency

Fig. 5 represents the effect of bed height on removal efficiency. From the graph it is observed that the bed height is the strong function of removal efficiency. The removal efficiency is increased with increasing bed height. At a bed height of 50 cm, the removal efficiency is in the range of 91 to 95 percent for the compost to wood chips ratios 1:1, 2:1 and 1: 2. At the same time, while increasing the bed height to 65 cm, the removal efficiency is increased to the range of 92 to 97 percent for the compost to wood chips ratios 1:1, 2:1 and 1: 2 and increased to the range of 92 to 99 percent for the compost to wood chips ratios 1:1, 2:1 and 1: 2 for the bed height of 80 cm. The authour[18] was reported that it could be seen that increasing of height (H) increases the Removal efficiency. In this manner, H provide more mass transfer area so the contact time between H_2S in gas stream and Fe (III) EDTA solution is increased and reduce the outlet concentration of H_2S.

Effect of Compost to Wood Chips Ratio on Removal Efficiency

Fig. 6 represents the effect of compost to wood chips ratio on removal efficiency. Three ratios of compost to wood chips viz., 1:2, 1:1 and 2:1 are employed in this investigation. It is found that the ratio of compost to wood chips play the predominate role on removal efficiency. At a bed height of 80 cm, the range of removal efficiency is found to be 92 to 95 percent for the ratio of 1:2. For the same height, the range of removal efficiency is found to be 97 to 98 percent for the ratio of 1:1 and 98 to 99 percent for the ratio of 2:1. It is observed that the increase in composition of compost in the filter bed material, increase the removal efficiency. The same phenomenon is observed while increasing the bed height from 65 cm to 80 cm.

Overall performance and comparison with earlier investigation

Removal efficiency is decreased with increasing flow rate. For the flow rate of 0.0333 m^3/s, the maximum removal efficiency is 99 percent for the bed height of 80 cm, compost to wood chips ratio of 2:1, inlet H_2S concentration of 5.5 ppm and the corresponding, EBRT is 47.2 s, elimination capacity is 116 g $h^{-1}m^{-3}$ and the inlet load is 117 g $h^{-1}m^{-3}$ respectively. The same trend is reported that for degradation of H_2S using peat as filter bed material [19]. The biofilter reached an efficiency of 100% when fed with 355 ppm of H_2S and air flow at 0.030 m^3 h^{-1}. When the inlet concentration of H_2S was increased, the removal efficiencies of H_2S decreased, reaching 90 and 60%, at 0.070 and 0.030 m^3 h^{-1}, respectively. While compared to the present investigation, these authors reported a lower value. This might be due to high range of inlet H_2S concentration and flow rates. Another author [20] also reported that the H_2S removal efficiency approached 100% and decreased to 90% over 206 days of operation.

In this present investigation, it is observed that the removal efficiencies as a function of the H_2S concentration and of the volumetric flow of the gas stream. The maximum removal efficiency obtained is 93.33 percent at the corresponding inlet concentration of 0.0333 ppm. The respective compost to wood chips ratio is 2:1 and bed height is 80 cm. For the same operating condition, the removal efficiency is decreased to 98 percent for the increase in inlet concentration to 15 ppm. That increasing the inlet concentration of Hydrogen sulfide, decreases the elimination capacity [21]. The author [22] also reported that the removal efficiency decreased from 94 to 90 percent for the range of inlet concentration of methanol is 6.33 ppm to 6.57 ppm and the corresponding methanol elimination is in the range of 112.8 g $h^{-1}m^{-3}$ to 65.1 g $h^{-1}m^{-3}$. The same trend is reported by some authors [23-25]**.**

While the inlet air- H_2S vapour flow is increased, the EBRT is decreased. The decreasing EBRT value decreased the removal efficiency in this present investigation. The maximum removal efficiency is 99 percent at the EBRT of 47.2 s and it decreased to 98 percent at 15.7 s. The respective compost to wood chips ratio is 2:1with a bed height of 80 cm. The author [26] reported that the H_2S elimination capacity increased as EBRT had a greater value (practically 100% for 40 s). It is found that he present investigation, match with earlier studies.

In this investigation, it is observed that the bed height is the strong function of removal efficiency. The removal efficiency increased with increasing bed height. The maximum removal efficiency is 99 percent at a bed height of 80 cm. The same is reported by author [25] the outlet concentration of methanol decreased with increasing bed height.

In this investigation, it is observed that the increase in composition of compost in the filter bed material increased the removal efficiency. The maximum removal efficiency is 99 percent at the compost to wood chips ratio of 2:1.

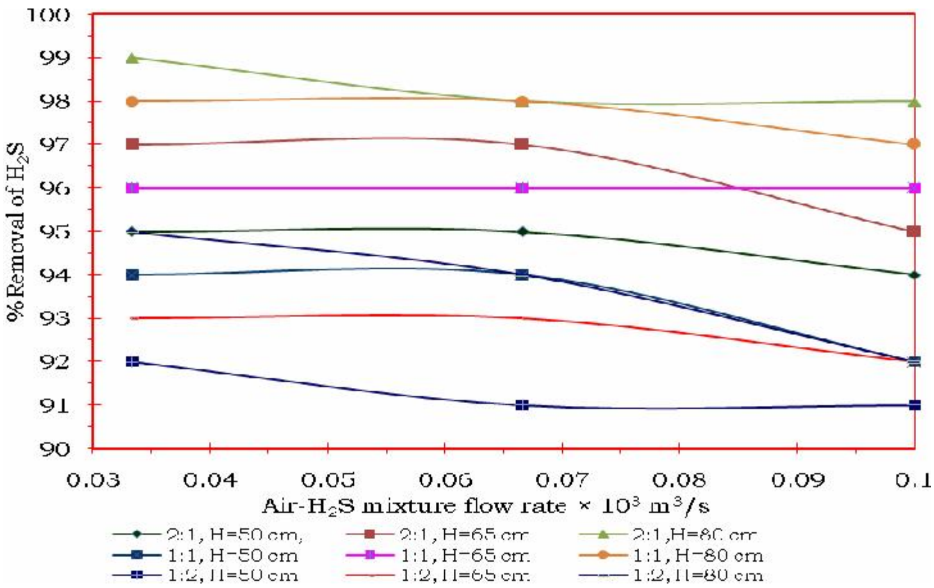

Fig. 2: Effect of Air-H_2S vapour mixture flow rate on % removal efficiency

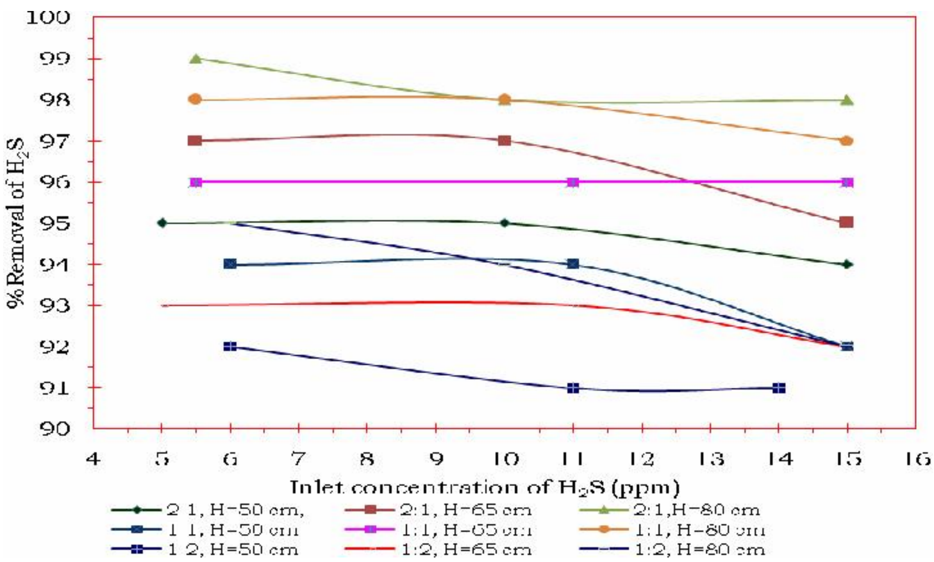

Fig. 3: Effect of inlet concentration of H_2S on % removal efficiency

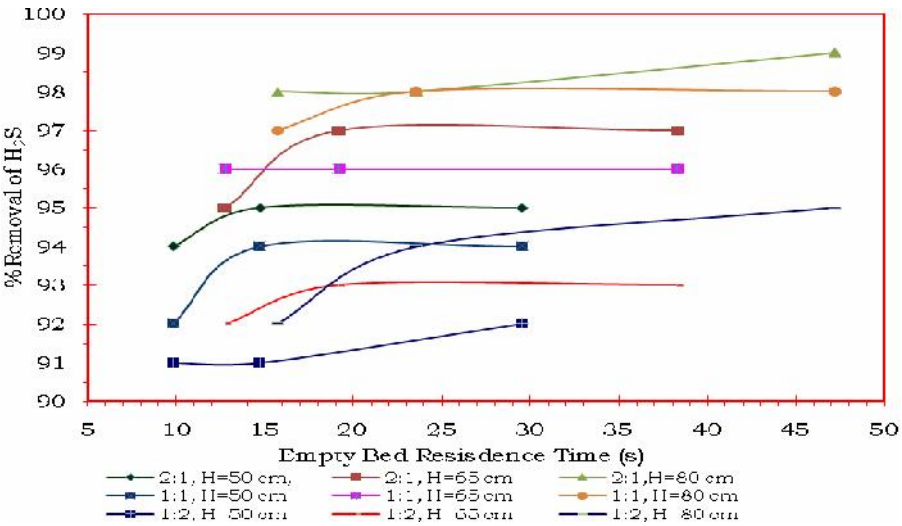

Fig. 4: Effect of empty bed residence time on removal efficiency

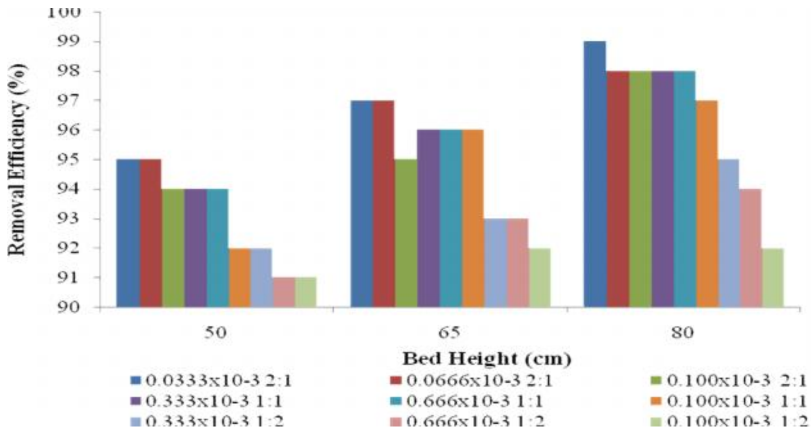

Fig. 5: Effect of Bed Height on Removal Efficiency

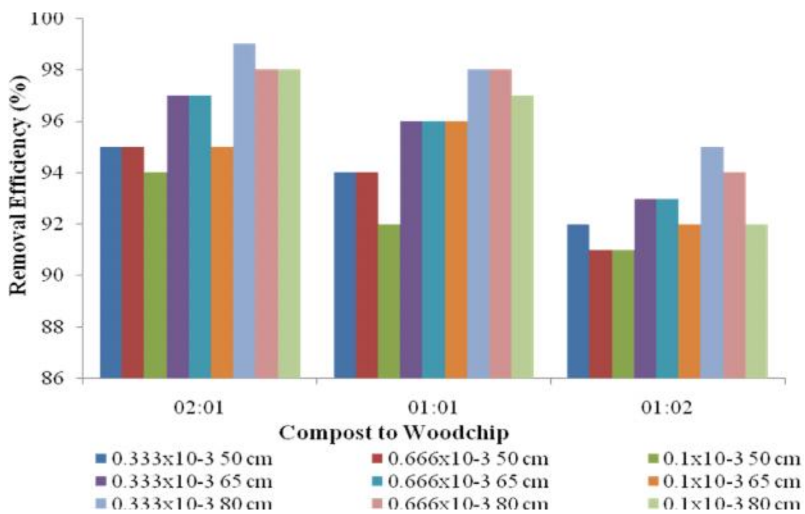

Fig. 6: Effect of Compost to Wood Chips Ratio on Removal Efficiency

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