

Designing biological filters to eliminate odors in septic tank based on the amount of hydrogen sulfide

Mansooreh Dehghani¹, Mohamad Mehdi Taghizadeh^{2*}

1- Department of Environmental Health Engineering, Shiraz University of Medical Sciences, Shiraz, Iran.

2-Islamic Azad University, Estahban Branch, Iran.

Abstract

Introduction: Odor emission is a common environmental problem in septic tank. The feasibility of using trickling filter to eliminate the malodorous gases from the septic tank was studied.

Methods and Material: A trickling filter is set up at the outlet of the waste gases of the septic tank, which was attached to the university's cafeteria. In this investigation, the trickling filter system was used, measuring the hydrogen sulfide and ammonia concentration to control the odor and to determine the elimination capacity (EC) of filtration.

Results: The obtained results showed insignificant amount of ammonia, while the concentration of H₂S was recorded at 90 ppm. Empty Bed Residence Time (EBRT) in the filter represented a significant relevance with the inlet concentration and the elimination rate of H₂S. There is a significant linear relationship between the mass flow rate of H₂S and the amount of cooked food as well as temperature. Also a significant relationship between EC and inlet concentration of H₂S was observed. The trickling filter in an optimum condition with an EBRT of 200 seconds was able to remove H₂S up to 99.9%. An empirical equation is developed to design a trickling filter.

Conclusions: Trickling filter is an affordable and cost-effective method to remove hydrogen sulfide from the septic tank.

Keywords: Irritating odors; Hydrogen sulfide; Trickling filter; Ammonia

*Corresponding author:
Mohamad Mehdi Taghizadeh;
Islamic Azad University Estahban Branch, Iran
Tel: +989173135359
Email: m-taghizadeh@iauest.ac.ir

► Please cite this paper as:

Dehghani M, Taghizadeh MM. Designing biological filters to eliminate odors in septic tank based on the amount of hydrogen sulfide. *Jundishapur J Health Sci* 2013;5(2):79-87

Received: 19.2.2013

Revised: 15.4.2013

Accepted: 19.6.2013

Introduction

Despite the existence of the state-of-the-art systems for sewage filtrations, the septic tanks are of much use nowadays due to inexpensive construction and simple exploitation [1]. They are the most moderate pre-filtering means to eliminate suspended particles as well as greasy substances [2, 3]. Anaerobic wastewater treatment is an affordable and low cost system. Using up-flow anaerobic sludge blanket (UASB) reactor followed by a trickling filter costs 30–60% lower than the systems, mainly due to low energy [4]. The effect of different operational parameters in anaerobic processes such as septic tank and UASB are studied [5]. In an anaerobic process, the decomposition of suspended and/or deposited particles and the yielding of fetid gases in the septic tanks are unavoidable. Odor emission is a common environmental problem [6] and it causes serious annoyance in the neighborhood of the sources, especially in dense residential areas. Among other things, hydrogen sulfide and ammonia are main gases produced from the anaerobic decomposition. The limit for distinguishing the odor of hydrogen sulfide is 8 ppb [7], hence its elimination in the systems could be instances when reference will make to other odors [8].

Though hydrogen sulfide is the main odorous gas, other compounds such as indole, skatole, and mercaptan could cause more detrimental odors during the anaerobic process [9, 10]. Various physical, chemical and biological odor abatement technologies have been developed and applied [7]. Among these methods, biological methods have gained much attention [11] due to their characteristics of simplicity, high efficiency, cost-effectiveness, reliability, minimal energy consumption, and less secondary waste production [12, 13]. The biological method of eliminating air pollutants is a more appropriate technology to control air

pollution, since it is not only a gas-to-liquid transition, but is also occasion to the demolition of the pollutants [14]. Biofiltration is the most common biological odor treatment process [6], in which waste gases are passed through a biologically active porous filter medium and odorous contaminants are biodegraded by indigenous microbes [15, 12, 13]. Among the various biofiltration methods, the use of biological trickling filter is less expensive and needs no powerful compressors to fulfill the compression [16]. H_2S is emitted from many industrial processes (such as petroleum refineries, paper and pulp manufacturing, food processing) and wastewater treatment plants (anaerobic digestion processes). The lava rock biofilter system is used for removing H_2S and volatile fatty acids (VFA) in a gaseous stream from an anaerobic digester while maintaining methane for using as a biogas. The 99% H_2S removal and complete biodegradation of (VFA) was observed [17]. The simultaneous removal of H_2S and methylmercaptan (CH_3SH) from biogas was determined under aerobic and anoxic conditions in two biotrickling filters. Maximum elimination capacities of H_2S found for both reactors were between 100 and $140 \text{ gSH}_2\text{m}^{-3}\text{h}^{-1}$. The removal of CH_3SH in the presence of high concentration of H_2S was significantly decreased in both biotrickling filters [18]. Simultaneous removal of methanol and H_2S from pulp and paper industry off-gas can be achieved by trickling filter [19]. Using a trickling filter with different media was developed for water and wastewater treatment [20]. A biotrickling filter using iron (III) foam media has the capability to remove 98% H_2S at EBRT ranging from 20 to 60 seconds over a period of 80 days [21].

The convenience in measurement and also high sensibility in odor-making, hydrogen sulfide measured in this study to control the

annoying odor of septic tanks. Therefore, the main objectives of this study are to: (1) investigate the feasibility of using the trickling filter to remove malodorous gases mainly H_2S and to control the nuisance odor from the septic tank which is used for the treatment of the university cafeteria sewage, (2) study the effect of operating parameters on the treatment performance under real case operational conditions, including gas flow rate, inlet concentration and volumetric mass loading, (3) optimize the design of the bioreactor for odor treatment and (4) develop an empirical equation to design a bioreactors based on the elimination capacity of H_2S .

Methods and Materials

The septic tank at the university cafeteria was used in this study. The net volume of the septic tank is $250m^3$. The number of people using the cafeteria was varied. The number of food orders per day was recorded as (NFO) during the study time, which was 60 days.

To extract the odorous gas, a pipe with a diameter of 110 cm was set up at the end of the septic tank and the hydrogen sulfide gas was measured. To filter the gas, a trickling filter was set in place, as shown in Fig. 1. The plant contained a plastic receptacle with 150 liters in volume, of which 120 liters were filled with rubble-stones ranging from 5-18 centimeters. A 4cm thick layer of dung was used on top of the surface media to grow bacteria as well as to provide the

nitrogen and phosphorus needed. The outlet pipe from the septic tank was attached to the bottom of the receptacle, and another PVC pipe was set at the top of the receptacle. The end part of the pipe was connected to a vacuum pump and a valve to control the velocity of the air current. On operation the fan gave rise to air flow from the septic tank into the reactor. There was a sampling point at the inlet pipe. Water was continuously circulated by a small water pump around the surface media trickling into it. In this method, the air current passes through a fixed microorganism media. Continuous circulation of water provides the required moisture for the growth of microorganisms. The odor-making materials are dissolved in the liquid phase and decomposed by the biofilter.

Hydrogen sulfide and ammonia gas were measured by detection tubes (Gas detector tube, Gastec, Japan) in the inlet/outlet of the trickling filter at different air flow velocities. Fig. 2 depicts gas detector tube the sampling pump. The detection limits of the sampling tubes for hydrogen sulfide and ammonia are 0.25 and 5 ppm, respectively. The air flow velocity was controlled by a valve giving the velocities of 0.2 ms^{-1} , 0.4 ms^{-1} , 0.5 ms^{-1} , 0.6 ms^{-1} , 0.7 ms^{-1} , 0.8 ms^{-1} , 0.9 ms^{-1} and 1.2 ms^{-1} in the outlet opening, which had a 3 cm diameter. These velocities were measured by an anemometer. The pH of circulating water was controlled daily by standard paper kits and the temperature of the vacuumed air was measured daily.

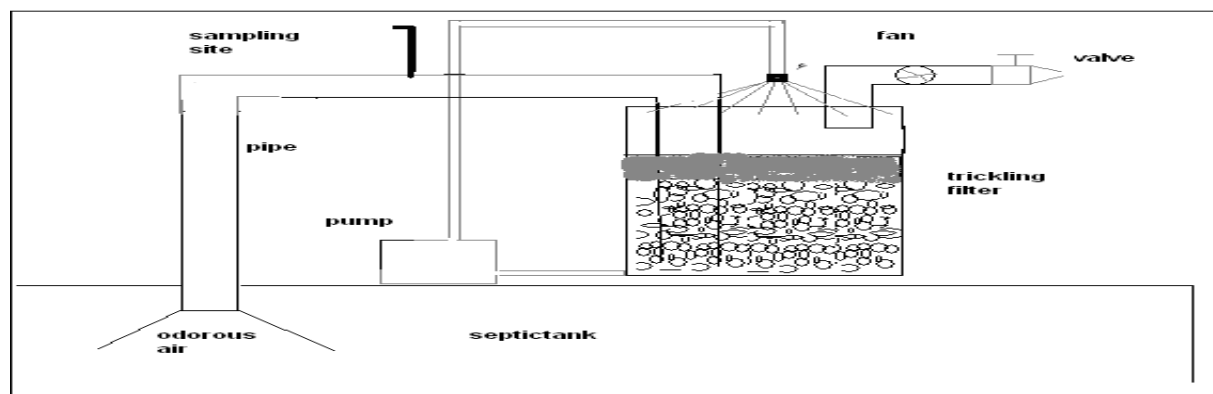


Fig 1: The schematic of experimental set-up for treating the odorous gas by trickling filter



Fig 2: Gas detector tubes and hand pumps

Results

on the amount of H₂S gas produced in septic tank.

$$C_{H_2S} = f(P, T) \quad (1)$$

Where,

P, population in terms of the number of food orders per day (NFO)

T, temperature, °C

Since food decomposition and gas production is done by mesophilic bacteria, the effective temperature is above 25°C (T-25°C).

With the fan and air suction in working order, the concentration of gas decreased proportionately. Its concentration off-gas

The number of meals ordered, the concentration of hydrogen sulfide and ammonia in the inlet and the outlet of the reactor as well as the velocity of the air flow in the outlet pipe were recorded as shown in Table 1.

Important parameters in designing a trickling filter to remove hydrogen sulfide off-gas of the septic tank include vacuum pump flow rate and the volume. The amount of gas produced or its concentration affects the volume of the bioreactor. The temperature and the population using the university cafeteria meals have a direct effect

$$Q_C = 0.1492(T - 25^\circ\text{C}) \times P \quad (4)$$

Where:

Q_C , mass flow rate of gas, $\text{gh}^{-1}\text{m}^{-3}$

P , population

T , temperature, $^\circ\text{C}$

The rate of elimination of hydrogen sulfide per volume of the reactor depends also on the ratio of inlet weight load per volume, as noticed in Fig. 4.

There is a linear relationship between the rate of gas production in the septic tank and the population using the cafeteria (Fig. 3) and also a linear relationship between H_2S removal rate in trickling filter and the rate of gas production in the septic tank (Fig. 4). Therefore, the linear relationship between the elimination capacity of gas per volume and population using the cafeteria-temperature per volume was expected (Fig. 5). According to Fig. 5, we can develop the equation (5) by an empirical regression.

$$EC = 0.0061(P \times (T - 25^\circ\text{C})) \div V \quad (5)$$

where:

EC , elimination capacity of H_2S per volume, $\text{gm}^{-3}\text{h}^{-1}$

P , population

T , temperature, $^\circ\text{C}$

V , volume of reactor, m^3

It can also design the volume of the reactor and the ventilator's fan flow rate according to the amount necessary to reduce the off-gas concentration (Equation 5).

was in reverse proportion to the fan velocity and the flow of the vacuumed air.

The mass flow rate (Q_m) is used which equals the mass of dumped hydrogen sulfide into the bioreactor instead of inlet concentration to the trickling filter. Here we have:

$$Q_m = C_w \times Q_v \quad (2)$$

$$C_w = (C \times M \div 24.5) \times 1000 \quad (3)$$

$$Q_v = V \times A \quad (4)$$

Where,

C_w , the mass concentration of hydrogen sulfide at 25°C , μgm^{-3}

A , the pipe cross sectional area, m^2

V , the velocity of air flow, ms^{-1}

Q_v , the air volume flow, $\text{m}^3 \text{s}^{-1}$

C , the volume concentration, Litem^{-3}

M , the molecular weight of gas, gmole^{-1}

Q_m , mass flow rate, mgm^{-3}

Population and temperature both have a positive impact on the amount of off-gas produced. Fig. 3 shows the relation between population-temperature, and the mass flow of hydrogen sulfide. Linear regression shows the correlation between the production of H_2S mass flow rate and the population - temperature ($R = 0.87$).

An increase of temperature more than 25°C brings about an increase in the velocity of decomposition by the mesophile bacteria ($t = T - 25$). One can develop the following equation (4), using linear regressions between population's using the university cafeteria meals - temperature to predict the amount of produced mass flow rate of gas (Q_C) as follows:

Table 1: Operating parameters for the trickling filter (Number of Food Orders per day (NFO), Operating Time (OT), Velocity of Air Flow rate (VAF), Temperature (T)), inlet and outlet concentration of NH3 (NH_{3In}), (NH_{3Ou}) and inlet and outlet concentration of H₂S (H₂S_{In}), (H₂S_{Ou})

OT (Days)	NFO	VAF (m/s)	T (°C)	NH _{3In} (ppm)	NH _{3Ou} (ppm)	H ₂ S _{In} (ppm)	H ₂ S _{Ou} (ppm)
1	570	0	37	<0.5	<0.5	90	<0.25
20	NAD	0.5	41	<0.5	<0.5	4.3	20
44	904	0.5	34	<0.5	<0.5	<0.25	<0.25
47	455	0.5	39	<0.5	<0.5	8.3	25
48	546	0.5	38	5	0.65	<0.25	<0.25
50	619	0.5	40	3.5	1.35	1.5	32
52	120	0.7	36	1	0.1	0	10
54	310	0.7	32	2.3	0.2	0	7.3
57	340	0.7	38	3.75	0.37	0	10
60	29	0.9	34	1	0.25	0	5
64	533	0.9	33	0	0	0	2.5
66	126	0.6	39	1.66	0	0	3
68	616	0.2	40	0	0	1	45
69	609	0.4	36	0	0	0.3	25
70	620	0.2	37	1.66	0	0.3	60
71	609	0.5	39	0	0	0.1	21
72	591	0.8	40	0	0	0	14
73	63	1.2	37	0	0	0.75	17

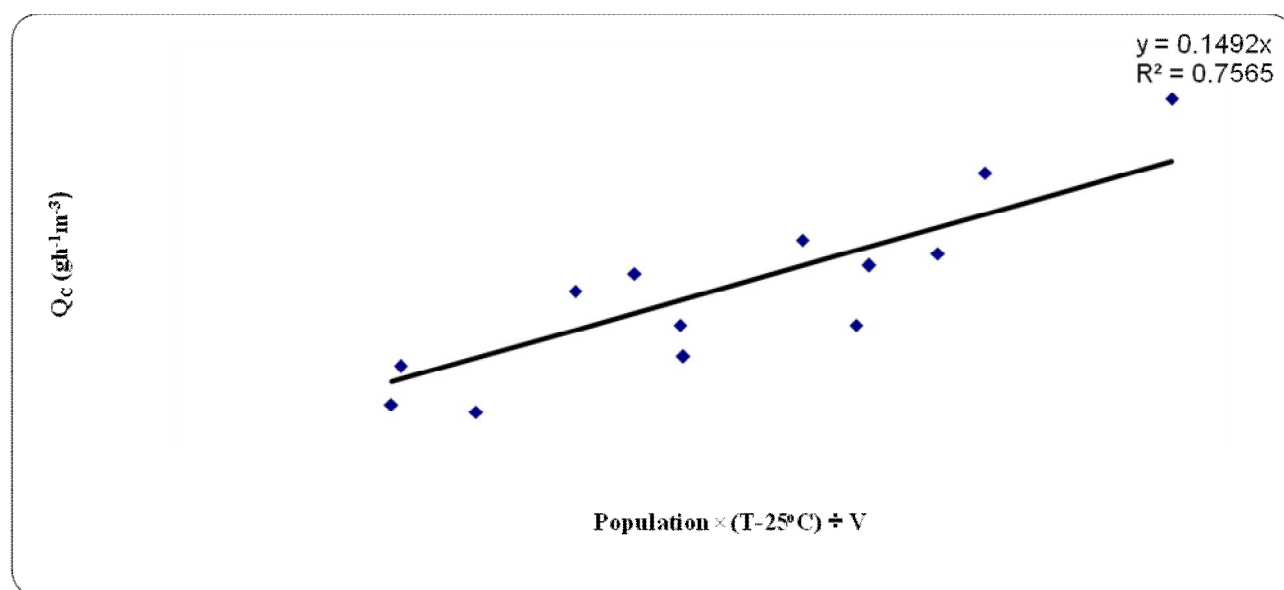


Fig 3: The relation between population-temperature and mass flow rate of hydrogen sulfide (Q_c)

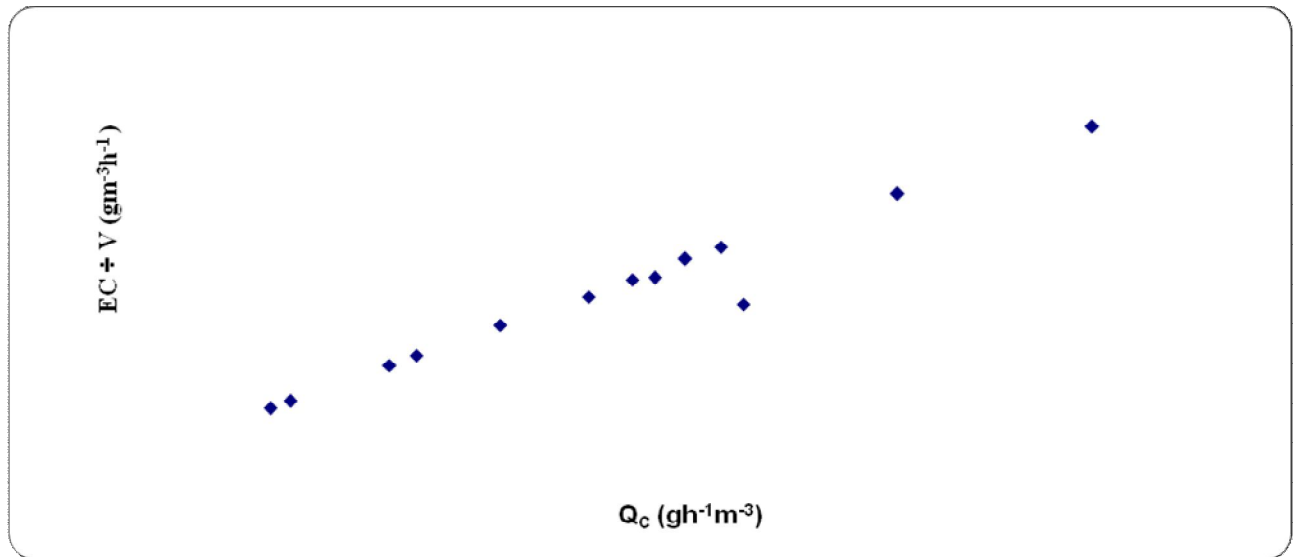


Fig 4: The relation between the Elimination Capacity (EC) of H₂S per volume of the reactor and the ratio of inlet mass load (Q_c) per volume

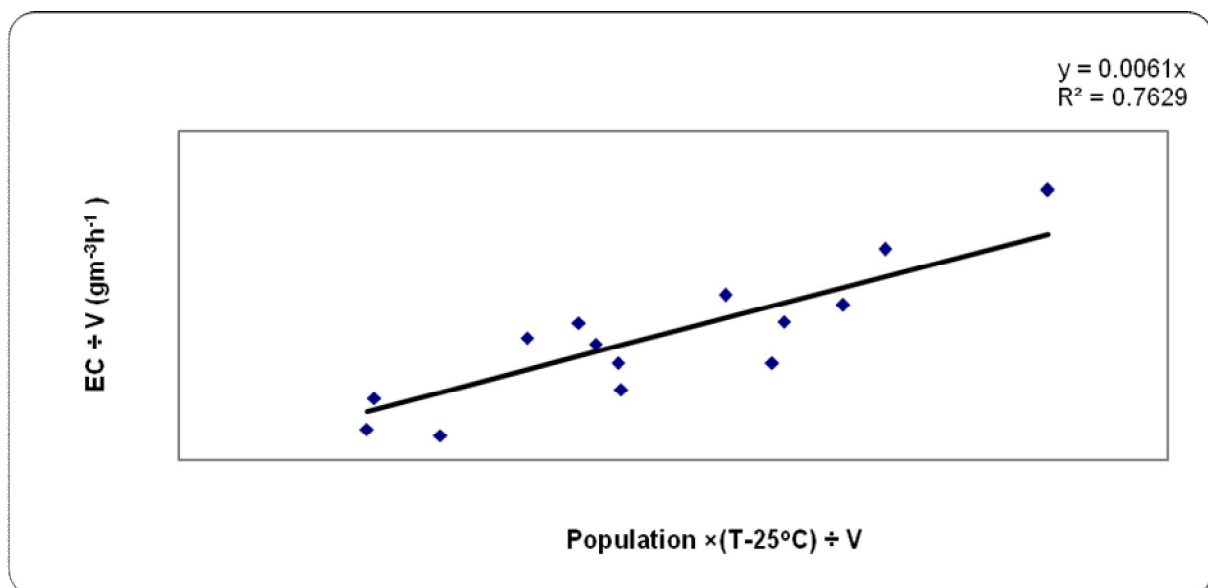


Fig 5: The relation between the elimination capacities (EC) of H₂S per volume and population-temperature per volume

Discussion

While in this research, the mass flow rate of H₂S was between 0.6-1 gm⁻³h⁻¹ with ventilation fan, most of previous studies have worked at a bench scale with higher

mass flow rate of H₂S which was between 20-6500 gm⁻³h⁻¹[22, 23, 24]. These studies have shown that improving the elimination capacities were in lower concentrations of

H₂S and longer operation time. However, in the present study as seen in Table 1 a longer operation time than previous research is required for a better result.

The results revealed an insignificant amount of ammonia in the inlet which was due to the acidity of the septic tank. At a pH of less than 7, ammonia is in a soluble form. Initially, the concentration of ammonia in the outlet increased due to the supplied dung, but after 60 days decreased to less than 0.5 ppm (Table 1).

When the ventilation fan was off, and the airflow velocity was zero, the concentration of hydrogen sulfide reached 90 ppm, being very irritating and intolerable.

The adaptation phase of bacteria in the trickling filter reactor was usually short and about 3 days [25]. In contrast, this study showed a first sign of decrease in H₂S concentration 20 days after the reactor was activated. Using dung to provide a biological film needs more time for adaptation. Another reason is that the concentration of the inlet gas in the trickling filter was low.

The concentration of H₂S in the septic tank significantly decreased with the ventilator in function.

The device used in our study to measure H₂S had an accuracy of 0.25 ppm, so we weren't able to measure concentrations less than 0.25 ppm. Therefore, measuring the gas by the device is only reliable in higher concentrations.

Conclusions

One of the limitations of using the septic tank, especially in dense residential areas is the irritating odors. The trickling filter system was used in this study. Hydrogen sulfide and ammonia concentration were measured to control the odor and to determine the elimination capacity of filtration. Although the concentration of hydrogen sulfide was high in the septic tank (reached to 90 ppm), ammonia concentration

was very low. There was a significant correlation between the population using the cafeteria (the number of order meal) and the amount of H₂S in the septic tank. The gas concentration decreased significantly using ventilation fan, causing a longer EBRT for elimination. The EBRT in low concentrations of the gas should be as high as 200 seconds in order to reach the elimination capacity of over 99%. Based on the results of the present study, an empirical equation was developed for the design of biofilter to reduce malodors in the septic tanks. We can conclude that trickling filter is an affordable and cost-effective method to remove hydrogen sulfide from the septic tank.

Acknowledgement

The authors would like to thank Azad University at Esteban for financial support. We wish to acknowledge Shiraz University of Medical Sciences for supporting the laboratory analysis.

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