

Kinetics and Modeling of H₂S Removal in a Novel Biofilter

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Abstract

Biofiltration has become a widely accepted technology for the removal of hydrogen sulfide (H₂S) which is one of the major odor causing gases present in the air streams of municipal wastewater treatment facilities. In addition to odorous nature, H₂S is toxic and corrosive. In this study, a biofilter which uses a novel media was employed in a pumping station which is closely located at the University City, Sharjah, UAE. The H₂S removal performance data were collected and subsequently used in the determination of kinetics and modeling of H₂S. The data were best represented by a first order biofilter model. Based on the first order kinetic constant, a correlation is developed to predict concentrations at the biofilter outlet. Based on the predicted outlet concentrations and dispersion (gaussian and US-EPA AERMOD) models, a study on H₂S dispersion is conducted. The dispersion study confirmed a biofilter installation at the pumping station site would significantly reduce H₂S levels in the University community and would provide cleaner air.

Keywords: Biofilter Media, Hydrogen Sulphide, Kinetics, Modeling

1. Introduction

Hydrogen sulfide (H₂S) is one of the major compounds that are emitted from municipal industries [1]. Hydrogen sulfide is odorous and highly toxic. It is heavier than air so it tends to accumulate in poorly ventilated spaces. Exposure to lower level concentrations of this gas can result in eye irritation, sore throat and cough, shortness of breath, and fluid in the lungs. Long-term low-level exposure may result in fatigue, loss of appetite, headaches, irritability, poor memory, and dizziness. Between 150 - 250 ppm levels, the olfactory nerve is paralyzed after a few inhalations, and the sense of smell disappears. Concentrations over 1000 ppm cause immediate collapse with loss of breathing.

Biofiltration has become a widely accepted technology for treating air streams containing odorous compounds. There are three main variations of this technology: biofilters, bio-scrubbers, and biotrickling filters [2]. Of these technologies, biofilter technology is the most popular and widely used at municipal industries. In the case of biofilters and bio-trickling filters, microorganisms are immobilized on support materials or media. Thus, biofilter packing media plays a major role for many reasons such as: providing a higher surface area for biofilm growth, low pressure drop, long term physical stability, and good moisture retention.

Most biofiltration processes are aerobic, employing heterotrophic microbes which are effective in removing H₂S for a wide range of potential applications with respect to pH 4.0 - 8.0 [3]. The pH in a biofilter may also change during operation. In some cases, the pH has to be regulated using buffer substances mixed with the packing media or using alkaline or acid solutions. Temperature control is also very essential. The temperature range for biofilter performance is about 15°C - 40°C. Recent literature [4-6] on biofiltration of H₂S emphasizes that there is a growing need for development of this technology.

This work briefly reviews methods of a novel biofilter media preparation, pilot biofilter column set-up and H₂S removal performance data collection at a pumping station located in the University City, Sharjah, UAE. The main objectives of this work are to determine the kinetics of H₂S removal using the performance data [7], modeling of a biofilter which is packed with the novel media and to study the dispersion effects of H₂S in the vicinity of the University community.

2. Experiments: Media Preparation, Pilot Biofilter and Performance Data

In our recent work [7], we described in details the experi-

mental procedure used in the development of a novel biofilter media, the pilot biofilter unit set-up and H₂S performance data collection. Since the experimental data are used in the determination of kinetics and modeling, a brief description on the novel media preparation and experimental set-up is given below.

Using a specific material that is used in building construction, hollow cylindrical particles were made as media base materials and subsequently coated with nutrients and microbes. Several sets of media samples with different compositions were prepared and analyzed. The mixing ratios of the nutrients were adjusted accordingly so that the desired amount of nutrients was coated. A mobile pilot biofilter unit (as shown in **Figure 1**) was constructed, packed with the novel media and installed at a pumping station for field data collection. The unit consisted of the followings: (a) biofilter column, (b) humidifier, (c) diaphragm pump, (d) gas compressor, (e) rotameter, (f) OdaLog (App-Tek International Pty Ltd, Australia), OdaLog instrument is specifically designed for the wastewater industry to measure H₂S from pumping stations and other operations (g) trolley and (h) manometers.

Hydrogen sulphide (H₂S) performance data were collected at different empty bed residence time (EBRT), which is defined as the ratio of the volume of media to the volumetric air flow rate. A detailed H₂S performance data for all EBRTs tested were presented in our previous work [7]. **Figure 2** shows a sample data of H₂S performance data at 30 second EBRT.

3. Theory: Biofilter Models

In a biofilter, the pollutant in the gas phase is first transferred to the biofilm by diffusion and then biodegraded along the depth of the biofilm which is formed on the media particles. Hence, two processes affect the removal of pollutants: diffusion and reaction. For a zero order reaction assumption, one of these processes limits the overall removal. If the rate of diffusion is slower than the rate of reaction, the removal process will be limited by diffusion. Similarly, if the rate of reaction is slower than the rate of diffusion, the process would be reaction limited. The three biofilter models based on these concepts are known as "Ottengraf and van den Oever" models which are widely used by researchers, engineers and environmental professionals in describing performance data and designing biofilter systems [8].

Case 1. Zero Order: Reaction Limited

$$C_{out} = C_{in} - k_0(EBRT) \quad (1)$$

Where, C_{in} : inlet concentration of pollutant in air ($\text{kg} \cdot \text{m}^{-3}$), C_{out} : outlet concentration of pollutant in air



Figure 1. Mobile pilot-biofilter unit.

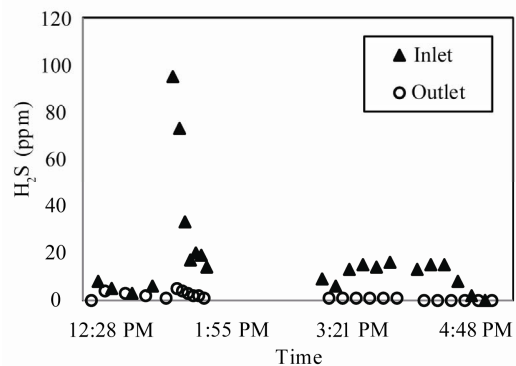


Figure 2. H₂S data at 30 second-EBRT.

($\text{kg} \cdot \text{m}^{-3}$), k_0 = zero order reaction rate constant ($\text{kg} \cdot \text{m}^{-3} \cdot \text{s}^{-1}$) defined as $\mu^* X_V A_S \delta / Y$; μ^* : specific growth rate (s^{-1}), X_V : biofilm density ($\text{kg} \cdot \text{m}^{-3}$), A_S : biofilm surface area per unit volume of biofilter (m^{-1}), δ : biofilm depth (m), Y : yield coefficient which is equal to the amount of biomass produced/substrate consumed, $EBRT = H/u_g$; H : height of biofilter column (m) and u_g : velocity of air (ms^{-1}).

Case 2. Zero order: Diffusion limited

In this case, it is assumed that the diffusion limits the overall removal in the biofilm. The diffusion limited model is based on the idea that the pollutant reaches its maximum biodegradation in the biofilm at a depth that is less than the actual biofilm thickness, implying that the biofilm is not fully active [8]. The equation for the gas phase concentration for this case is given by:

$$C_{out} = C_{in} \left(1 - \beta_1 \frac{EBRT}{\sqrt{C_{in}}} \right)^2 \quad (2)$$

Where, $\beta_1 = A_s \sqrt{\frac{k_0 f(X_V) \cdot D_{H_2S,W}}{2m}}$; $f(X_V)$: ratio of diffusivity of a compound in the biofilm to that in water, $D_{H_2S,W}$: diffusivity of H_2S in water ($m^2 \cdot s^{-1}$), and m : dimensionless Henry's constant of the pollutant.

Case 3. First order Reaction

For a steady state operation and first order reaction assumption, the model equation is given as follows;

$$C_{out} = C_{in} \exp(-k_1 EBRT) \tag{3}$$

Where, k_1 = first order reaction rate constant (s^{-1}) defined as

$$\frac{A_s}{m} \sqrt{\frac{X_V \cdot \mu^* \cdot f(X_V) D_{H_2S,W}}{KY}} \tanh(\beta_2),$$

$$\beta_2 = \delta \sqrt{\frac{X_{V\mu^*}}{KYf(X_V) D_{H_2S,W}}}; \text{ and } K: \text{ Monod kinetics constant}(\text{kg} \cdot \text{m}^{-3}) \text{ [2].}$$

4. Results and Discussion

To determine the kinetics and the best theoretical model that fits the experimental data, concentrations were averaged at each of the four EBRTs tested (Table 1). The average concentrations (C_{in} and C_{out}) and EBRT data were used to find the kinetics of H_2S removal in the bio-filter.

Equations (1), (2) and (3) were first re-arranged to obtain linear plots. A best fit line was drawn through the points for each case. Figures 3(a)-3(c) show the plots for all the three cases. From the correlation coefficients and Figure 3(c), it is clear that the data of novel biofilter media follows a first order kinetics. Thus, Equation (3) based on the fitted parameter now can be written as:

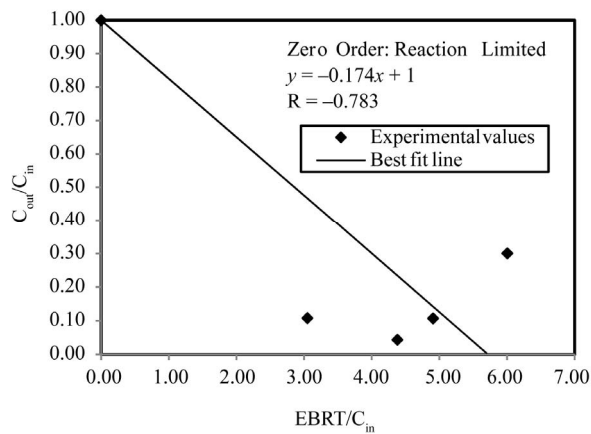
$$C_{out} = C_{in} \exp(-0.055 \cdot EBRT) \tag{4}$$

The removal efficiencies that were determined from the model Equation (4) were compared with the removal efficiencies calculated from the experimental data, as shown in Figure 4. It can be seen that the values of removal efficiency predicted by the model are in good agreement with the experimental data.

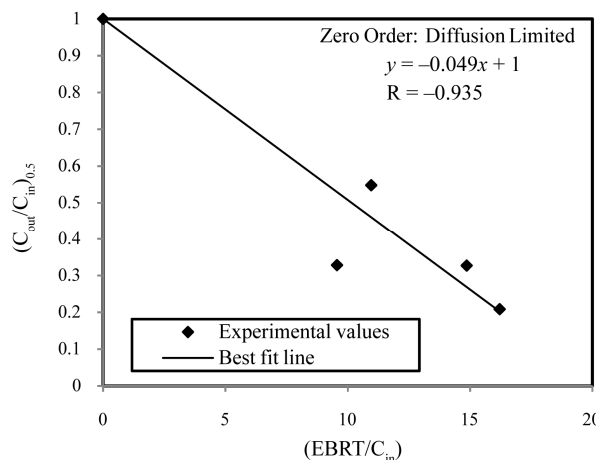
In most industrial countries, air pollution control laws require the prediction of pollutant dispersion in ambient

Table 1. Average concentrations at each EBRT.

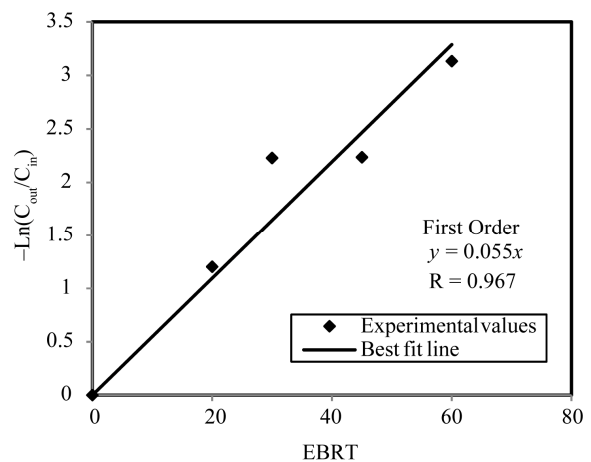
EBRT (s)	C_{in} (ppm)	C_{out} (ppm)
20	3.33	1.00
30	9.84	1.06
45	9.17	0.981
60	13.7	0.597



(a)



(b)



(c)

Figure 3. (a) zero-order reaction limited (b) zero-order diffusion limited and (c) first order kinetics.

air resulting from industrial emissions [9]. There are several atmospheric dispersion models (i.e. AERMOD, ISC-PRIME, ISCST3) that are used in the prediction of

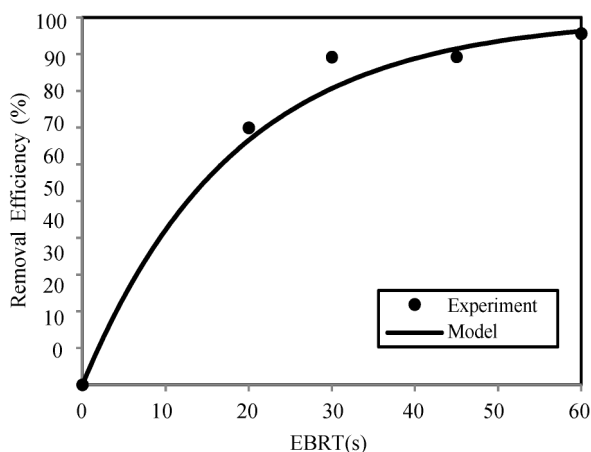


Figure 4. Comparison between the model and the experimental data.

pollutants in the ambient atmosphere [10]. In this work, downwind concentration calculations were made to observe the effect of H₂S dispersion from the pumping station located near the University City. First, a simple Gaussian model [9] was used for two conditions: (a) the dispersion of H₂S from the stack without the use of a biofilter and (b) the dispersion of H₂S with the use of a biofilter. For both cases, it was assumed that the average wind speed of 3 m/s and the stability class of moderate atmosphere. For case A, it was assumed that the stack gas (without biofilter) emits H₂S concentration at 100 ppm. In case B, it was assumed that the biofilter outlet emits H₂S concentration at 1.5 ppm (with 98.5% removal efficiency). Based on the experimental data and the correlation (4), it is clear that a biofilter packed with the novel media can remove 98.5% H₂S. **Table 2** shows the measured and assumed parameters for the stack. The coordinates (x , y , z) were obtained by selecting seven specific locations around the university and finding their approximate distances from the stack using a GPS. The point source (stack) was used as the reference point. **Table 3** shows the coordinates for each location and the corresponding dispersion coefficients.

Downwind concentrations for each case were calculated from the Gaussian plume equation, using the values presented in **Tables 2** and **3**. **Figure 5** shows the comparison of downwind concentrations at each location between case A and case B. Comparing the results, it can be seen that the predicted downwind H₂S concentrations are substantially lower in all 7 locations. The highest possible downwind concentration would be 0.0023 ppb with the use of a biofilter. Using the AERMOD model and with the available meteorological data base, the calculations were repeated for the same point source and the results are presented in the **Figures 6(a)-6(b)**.

Table 2. Stack specifications.

Diameter	0.13 m
Height	3.24 m
Average plume velocity	3.56 ms ⁻¹
Wind speed	3 ms ⁻¹
H ₂ S concentration (case A)	100 ppm
H ₂ S concentration (case B)	1.5 ppm

Table 3. Coordinates and dispersion coefficients (σ_y and σ_z) for each location.

	#1	#2	#3	#4	#5	#6	#7
x(m)	462	467	395	397	245	614	950
y(m)	140	23	32	34	247	519	42
z(m)	3	3	10	10	0	0	0
σ_y (m)	78	79	67	68	44	101	149
σ_z (m)	47	48	40	40	24	64	104

5. Conclusion

In conclusion, a kinetic study of H₂S removal for a novel biofilter media was performed. The data were best represented by a first order model. The kinetic constant was then used in developing a correlation $C_{out} = C_{in} \exp(-0.055 * EBRT)$. This correlation can be used to predict outlet concentration and sizing a biofilter which is packed with the novel media. When compared with the predicted concentration using the correlation, experimental data were in good agreement with the model. A basic gaussian dispersion and US-EPA AER-MOD models were subsequently used “with” and “without biofilters” to determine the effect of dispersion in the University City. The H₂S dispersion data shows a biofilter installation at the pumping station would significantly reduce H₂S levels and would give cleaner air

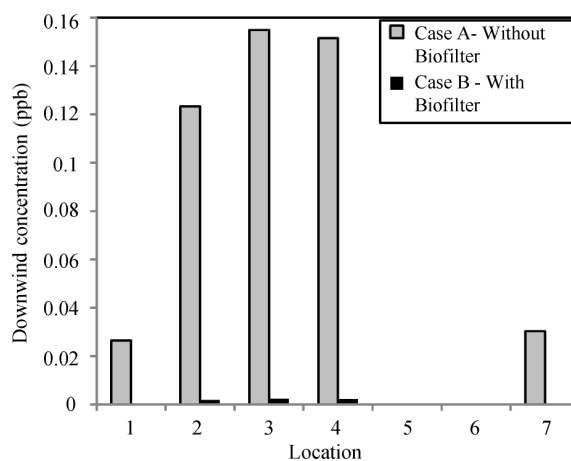
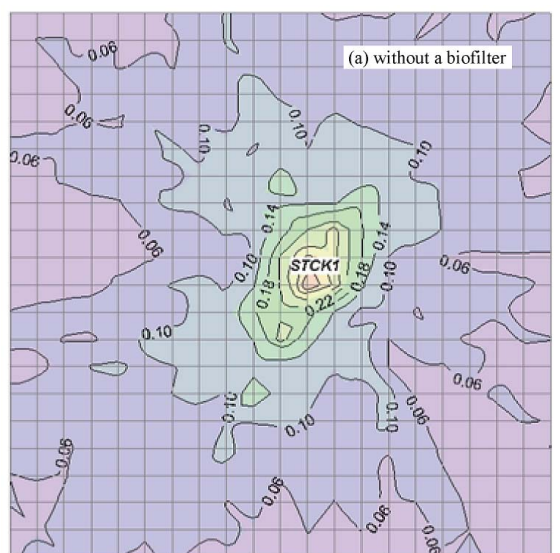
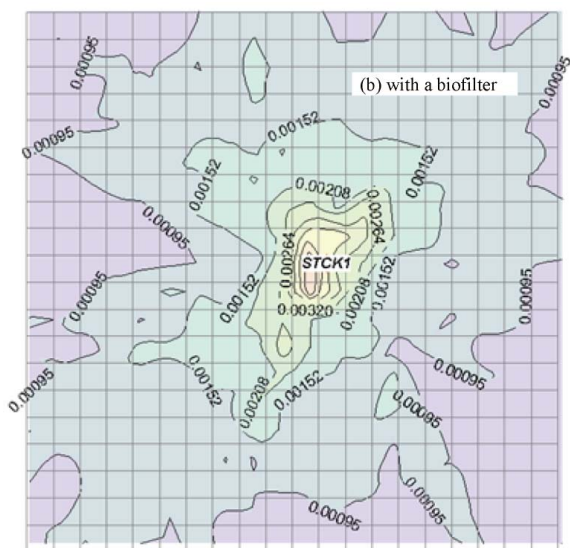


Figure 5. Comparison of downwind concentrations.



UCART 1

(a)



UCART 1

(b)

Figure 6. AERMOD model predicted H₂S concentration profiles in (µg/m³) (a) without a biofilter (top) and (b) with a biofilter (bottom).

to the University community. Based on this study, a local environmental company in UAE has funded a research project for an industrial application. The results of such study will be our future contribution.

6. Acknowledgment

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