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RAPID COMMUNICATION

Hydrogen sulfide (H_2S) removal using schist packings in industrial biofilter applications

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Abstract−Expanded schist can be a promising biofilter media for Hydrogen Sulfide (H_2S) removal in industrial applications. In this work, H_2S removal performance of a biofilter packed with expanded schist is compared with a patented (EU Patent No. 0 497 214 B1) media which has been commercialized and used in many industrial applications for odor and VOC control from contaminated airstreams. Hydrogen sulfide (H_2S) removal performance data from two different schist packing media combinations were used in the analysis (BF1: inoculated with activated sludge, BF3: inoculated with activated sludge and 12% synthetic nutrient-UP20). Different mathematical models that describe H_2S removal performance of a patented and schist packing media, respectively, were used to determine the limitations, similarities and differences of both media. The results show that both model predictions are in close agreement with the experimental data of schist packing that is inoculated with activated sludge (BF1). Thus, patented media removal performance of H_2S is closely equivalent to expanded schist media inoculated with activated sludge (BF1). When model comparisons are made on a similar basis with schist media inoculated with activated sludge and 12% UP20 nutrient (BF3), the removal performance of schist media is found to be superior to that of patented biofilter media, especially for loading rate greater than 7 g/m^3 media/hr. Since the patented biofilter media (EU Patent No. 0 497 214 B1) is commercially used by many industries, the results presented in this work will be valuable for practicing engineers and consultants who work in full-scale design and operation of biofilters.

Keywords: Biofilter, Patented Media, Schist Packing, Mathematical Model, H_2S Removal

INTRODUCTION

Hydrogen sulfide (H_2S) is one of the odorous and harmful pollutants emitted in various industrial facilities, including municipal waste processing plants, wastewater treatment facilities, pet food manufacturing plants, gasification processes and pulp and paper industries. Over 10 ppm of H_2S exposure can cause health problems and fatality occurs when concentration exceeds 600 ppm [1]; H_2S also causes symptoms such as mental stress, hysteria,and headache [2].

Classical methods for removal of odor and toxic air pollutants such as H_2S are activated carbon, catalytic decomposition, adsorption, and chemical scrubbing [2]. However, in the last few decades some of the traditional methods have been replaced by biofilter technology and commercial biofilters have been successfully employed for H_2S removal by many industries.

A bioreactor where biofiltration process takes place is known as a biofilter or vapor phase biological reactor. Schematic diagram of a typical biofilter unit is shown in Fig. 1. A biofilter system consists of a humidifier and a bioreactor which is packed with media particles consisting of micro-organisms capable of degrading pollutants such as H_2S, ammonia, and volatile organic compounds (VOCs). Contaminated air is first humidified and passed through a bioreactor where mass transfer and biological oxidations take place. Humidification step is necessary to keep the micro-organisms active on bioreactor media, which plays a major role in the biofiltration process. Traditionally, different types of organic (i.e., wood, peat, soil, compost mixture etc.) and manufactured media have been used as biofilter packing.

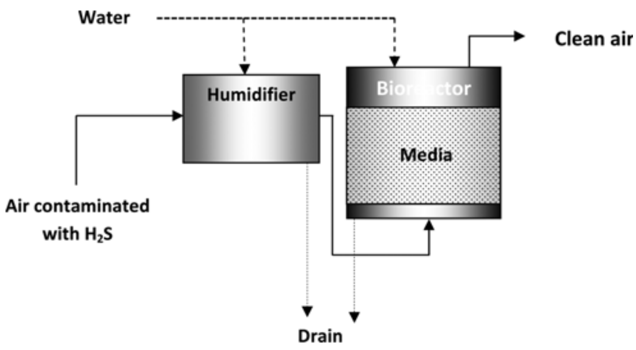

Fig. 1. Schematic diagram of a typical biofilter unit.

Although biofiltration technology has been well established, research projects are underway in identifying new biofilter media products, process and equipment improvements. Shareefdeen et al. [3] have used a patented media (EU Patent No. 0 497 214 B1) and obtained H_2S removal performance data from a pilot scale biofilter unit under different empty bed residence times (EBRTs) and H_2S inlet concentrations. Empty bed residence time (EBRT) is de-

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fined as the ratio of media volume (V) to the volumetric flow rate of air (Q). A typical EBRT value for commercial biofilter applications is about 30 seconds; however, higher EBRTs values may be needed when inlet concentrations become very high. When EBRT becomes large (>60 seconds), biofilter technology is no longer economically attractive. The patented bioreactor media (EU Patent No. 0 497 214 B1) is made of expanded porous aggregate particles, organic carbon source such as peat, adsorptive coatings, bonding agents, nutrients and phosphoric acid. This biofilter media is synthetically manufactured and has good structural and biological properties. It has been commercialized and used in a number of field scale biofilter installations across North America by several industries, including wastewater treatment facilities, pet food industries, and solid waste management facilities.

Hernandez et al. [4] demonstrated that expanded schist, fine-grained sedimentary rock, can be successfully used as a biofilter media. In their study, the laboratory biofilter system used consisted of three columns constructed with plastic cylinders (1.5 m in height and 0.1 m in diameter). Two columns (biofilters BF1 and BF2) were filled with 3.97 kg of expanded schist (0.87 m in height) while biofilter BF3 was filled with 3.57 kg of expanded schist (0.77 m height) and 0.48 kg of UP20 (0.1 m height). Tap water was sprayed onto the top of the biofilters for 5 min each hour (80 mL each time) to maintain the humidity. The polluted air entered the column in an up flow mode and the H_2S stream was controlled by mass flow controllers; the temperature within the biofilters ranged between 14 °C and 22 °C during the whole experiments. Under different empty bed residence times (EBRTs), H_2S removal performance of expanded schist is investigated for the three different packing media combinations: BF1 (inoculated with activated sludge), BF2 (without inoculation) and BF3 (inoculated with activated sludge and 12% by volume of synthetic nutrient UP20). UP20 is made from carbamoyloxonium (CH_4NO_2), phosphoric acid (H_3PO_4), calcium carbonate ($CaCO_3$,) and an organic binder [4].

The objective of this work was to compare and evaluate expanded schist media against patented (EU Patent No. 0 497 214 B1) media and to use respective mathematical models to identify limitations, similarities and differences of both biofilter media with respect to H_2S removal performance.

THEORY

In this section, the mathematical models that describe experimental data of patented media and expanded schist media, respectively are described.

1. Model (Patented Media)

Deshusses and Shareefdeen [5] reviewed bio-trickling and biofilter mathematical models, respectively, and in their work, Shareefdeen presented a validated biofilter model which was based on the assumptions presented in the reference of Ottengraf et al. [6]. The validation of the model was accomplished using H_2S removal data obtained from a lab as well as pilot-scale biofilters which were packed with patented media. The performance data were obtained under different experimental conditions by varying flow rates and inlet H_2S concentrations. The model includes a lump parameter (α_{lump}) for the patented media (EU Patent No. 0 497 214 B1) and the value of α_{lump} was found to be 0.18. The model is given by Eq. (1), in which H_2S concentration is expressed in ppm_v units and EBRT is expressed in seconds.

$$\sqrt{\frac{C_{out}}{C_{in}}} = \left\{ 1 - \alpha_{lump} \mathrm{EBRT} \sqrt{\frac{1}{C_{in}}} \right\} \tag{1}$$

The parameters used for evaluation and comparison are loading rate (LR; g/m^3/hr), elimination capacity (EC; g/m^3/hr), and percent removal efficiency (RE %). There are defined as follows:

$$\mathrm{LR} = \frac{Q}{V} C_{in} \tag{2}$$

$$\mathrm{EC} = \frac{Q}{V}(C_{in} - C_{out}) \tag{3}$$

$$\mathrm{RE}\ \% = 100\frac{(C_{in} - C_{out})}{C_{in}} \tag{4}$$

2. Model (Hernandez et al.)

Hernandez et al. [4] used forms of both Michaelis-Menten and Haldane kinetics to describe performance of expanded schist media. Their model equations are presented as follows:

Michaelis-Menten model

$$\mathrm{EC} = \frac{\mathrm{EC}_{max} C_{lin}}{K_s + C_{lin}} \tag{5}$$

where C_{lin} is defined as,

$$C_{lin} = \frac{(C_{in} - C_{out})}{\ln\left(\frac{C_{in}}{C_{out}}\right)} \tag{6}$$

Haldane model

$$\mathrm{EC} = \frac{\mathrm{EC}' C_{lin}}{K'_s + C_{lin} + \frac{C_{lin}^2}{K_I}} \tag{7}$$

$$\mathrm{EC}'_{max} = \frac{\mathrm{EC}'}{1 + 2\sqrt{\frac{K'_S}{K_I}}} \tag{8}$$

Model Eqs. (1)-(8) along with the model parameters given in Table 1 were solved using software POLYMATH 5.1. Both model predictions were then compared with the experimental data of H_2S removal [4]. For comparison study, only BF1 and BF3 parameter values from Table 1 were used. BF2 parameters are not applicable

Table 1. Model parameter values [4]

EBRT=24 s	BF1	BF2	BF3
Michaelis-Menten			
EC_{max} (gm^{-3} h^{-1})	30.6	10.5	46
K_s (gm^{-3})	0.069	0.102	0.068
Haldane			
EC' (gm^{-3} h^{-1})	35	-	174.2
K'_s (gm^{-3})	0.088	-	0.324
K_I (gm^{-3})	2.65	-	0.052
EC'_{max} (gm^{-3} h^{-1})	25.6	-	29

for comparison with the patented media because BF2 is filled with expanded schist media without inoculation and nutrients.

RESULTS AND DISCUSSION

From the solution of the model Eqs. (1)-(8), biofilter outlet concentration (C_{out}), removal efficiency (RE %), loading rate (LR), elimination capacity (EC), and log mean average concentration C_{lin} are calculated. The model predicted values are then compared in Figs. 2 to 5 with the experimental values of Hernandez et al. [4]. Experimental data from BF1 are for expanded schist media inoculated with activated sludge only and experimental data from BF3 are for expanded schist media with nutrients UP20 in addition to inoculated activated sludge.

In Fig. 2, elimination capacity (EC) values calculated by the models described by Eqs. (1)-(8) versus C_{lin} are compared with the experimental data. C_{lin} is the average log mean concentration as defined by Eq. (6). Fig. 2 shows that all the model (Shareefdeen model, Hernandez Michaelis-Menten, and Haldane models) predicted values are in good agreement with the experimental data of Hernandez et al. [4] for schist media inoculated with activated sludge (BF1). In Fig. 3, elimination capacity (EC) values calculated by the same three models versus the loading rates (LR) are compared with the experimental date of BF1. This figure also shows that there is a good agreement between the model predictions and the experimental data. Thus, from Figs. 2 and 3 one can conclude that H_2S removal performance by the patented commercial media (EU Patent No. 0 497 214 B1) is similar to that of expanded schist media when inoculated with activated sludge. Furthermore, for the experimental data range considered predicted curves by Hernandez's Michaelis-Menten and Haldane models overlap; this means that the inhibition effects for this experimental range is not significant and, thus, there is no need for the Hernandez Haldane model to be employed for this range of experimental conditions.

Fig. 4 shows elimination capacity (EC) versus loading rate (LR) data for the three models (Shareefdeen model, Hernandez Michaelis-

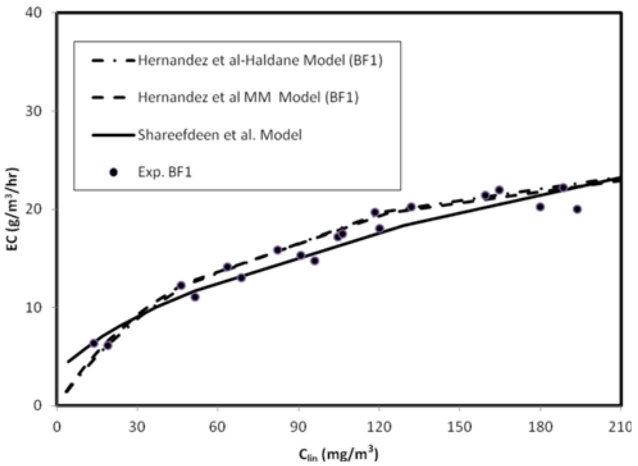

Fig. 2. Comparison of elimination capacity (EC) versus C_{lin} (data: BF1-inoculated with activated sludge).

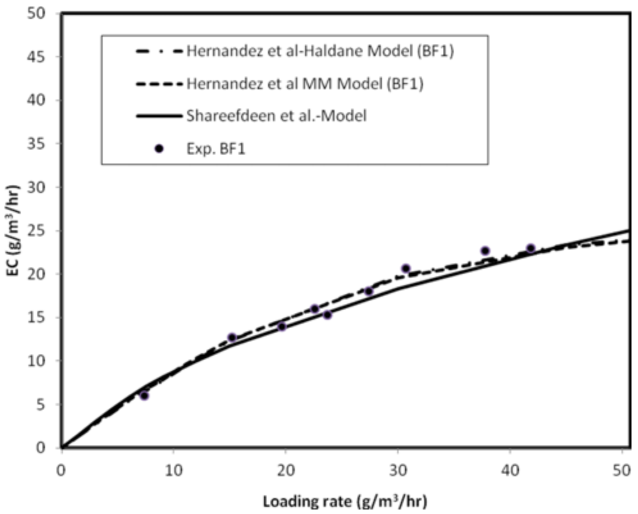

Fig. 3. Comparison of elimination capacity (EC) versus loading rate (LR) (data: BF1-inoculated with activated sludge).

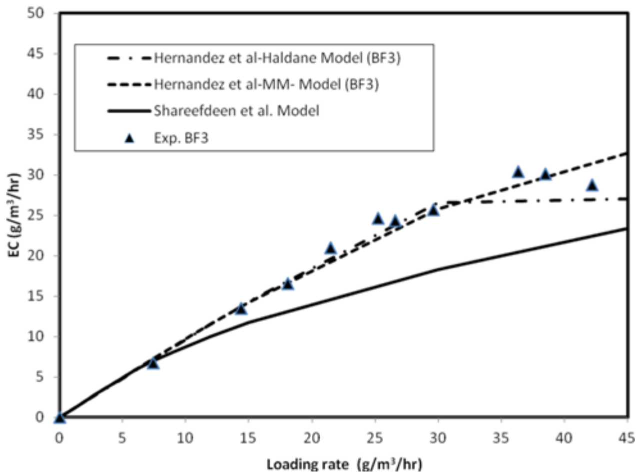

Fig. 4. Comparison of elimination capacity (EC) versus loading rate (LR) (data: BF3-inoculated with activated sludge 12% by vol. of UP 20 nutrient).

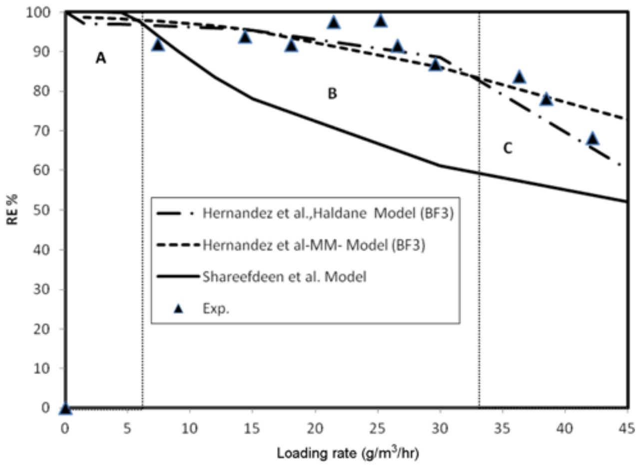

Fig. 5. Model predictions of removal efficiency versus loading rate (LR).

Menten, and Haldane models) and model predictions are compared with the experimental data of BF3, which contains expanded schist media inoculated with activated sludge and UP20 nutrients [4]. The main difference between BF3 and BF1 is the addition of UP 20 nutrients. From Fig. 4, one can conclude that H_2S removal performance by schist media inoculated with activated sludge and UP20 nutrients is better than the patented synthetic media (EU Patent No. 0 497 214 B1). However, for loading rate (LR) less than 7 g/m^3/hr, the mathematical model for the patented media predicts slightly better H_2S removal performance than Hernandez models as well as experimental data, and this is also evident in Fig. 5 which gives prediction of RE% versus loading rate. Thus, patented media will give better performance as long as loading rate does not exceed 7 g/m^3/hr. Loading rate of 7 g/m^3/hr corresponds to biofilter inlet H_2S concentration of 0.058 g/m^3 (38.4 ppm$_v$) and EBRT value of 30 seconds. Many industrial applications such as a wastewater treatment plant or landfill operation facility may emit H_2S concentrations at much lower levels than 38.4 ppm$_v$. For such applications, patented media will give better removal. Furthermore, up to loading rate (LR) of about 35 g/m^3/hr, both Hernandez's Michaelis-Menten and Haldane models predict experimental data more closely. Loading rate of 35 g/m^3/hr corresponds to biofilter inlet H_2S concentration of 0.29 g/m^3 (192 ppm$_v$) and EBRT value of 30 seconds. Fig. 4 also shows that when LR exceeds 35 g/m^3/hr, inhibition prevails; thus predictions by Haldane model are closer to the experimental data of Hernandez et al. [4].

Model predicted removal efficiency (RE %) versus loading rate (LR) data are plotted in Fig. 5. As discussed, this figure illustrates that for loading rate values up to 7 g/m^3/hr, both patented media and expanded schist media (inoculated with activated sludge and UP20 media) remove H_2S with high removal efficiency of greater than 95%. This is illustrated by the region A. However, when loading rate (LR) exceeds 7 g/m^3/hr, model predictions by Hernandez's Michaelis-Menten model and experimental data show superior performance for schist media than the patented media. This is illustrated in the regions B and C of Figure 5. However, in these regions (B to C) removal efficiency (RE %) drops from about 97% to 72%. RE% of 72% corresponds to outlet concentration of 53 ppm$_v$ for biofilter inlet concentration of 192 ppm$_v$ at 30 second EBRT value. Exposure to high value of 53 ppm$_v$ (>10 ppm$_v$) causes serious health issues and also infringes environmental regulations. Thus, EBRT should be substantially increased even if schist media BF3 (inoculated with activated sludge and UP20 nutrient) is used as a biofilter media. High values of EBRT refer to larger biofilter size. Thus, when EBRT exceeds 60 seconds or more, the application of biofilter technology is no longer economically attractive. Note that for loading rate <30 g/m^3/hr, Dumont et al. [7] report experimental removal of 100% removal in 16 second empty bed residence time (EBRT). However, the predictions by the model (see region B) show less than the reported value of 100% at this EBRT. Predictions by the Hernandez's Haldane model (region C) show less H_2S removal due to inhibition effects and RE% drops to 60% at a loading rate of 45 g/m^3/hr. When experimental data of Hernandez et al. [4] are compared with the model predictions, there is a close agreement in the region B for both Hernandez Michaelis-Menten and Haldane kinetic models, but for the region C the experimental data tend to be closer to Haldane model predictions, and due to inhibition the removal efficiency drops.

CONCLUSION

H_2S removal performance of biofilters packed with expanded schist packing materials [4] was evaluated and compared with the performance of commercial patented biofilter media (EU Patent No. 0 497 214 B1). Experimental data [4] from two different schist packing combinations (BF1: inoculated with activated sludge, BF3: inoculated with activated sludge and 12% by vol. of UP 20 nutrient) were used in the analysis. The model that describes patented media and two models of Hernandez et al. [4] (Michaelis-Menten and Haldane) were used to identify limitations and the regions of operations with respect to H_2S removal. When experimental data of Hernandez et al. [4] from a biofilter BF1 which is packed with inoculated expanded schist media and the predictions from the three mathematical models (Shareefdeen model, Hernandez Michaelis-Menten, and Haldane models) were compared, a close agreement was found. Thus, H_2S removal performance of the patented media is very much similar to the inoculated expanded schist media without the UP 20 nutrient.

When evaluations were made on a similar basis, H_2S removal of a biofilter packed with inoculated schist media with UP20 nutrients (BF3) showed better performance than the patented media (EU Patent No. 0 497 214 B1) as well as the expanded schist media without the UP 20 nutrient. For loading rate values of 0-7 g/m^3/hr, H_2S removal efficiency was greater than 95% for both patented as well as expanded schist media; however, when loading rate exceeded 7 g/m^3/hr, H_2S removal became superior for schist media with UP 20 nutrient and when loading rate exceeded 35 g/m^3/hr, inhibitory effects prevailed.

The loading rates can be easily correlated to identify EBRT or biofilter size as well as inlet biofilter concentration levels depending on the type of biofilter media used. Thus, the results of this study will be valuable for practicing engineers, biofilter consultants and operators in selecting either patented or expanded schist media for field scale applications. The patented media has been successfully applied for over a decade in many industrial projects. As recommended by Dumont et al. [7], the long-term use and consistency in delivering H_2S removal performance still need to be investigated for the expanded schist media.

SYMBOLS

C_{in} : concentration of H_2S in the air [inlet to the biofilter, g/m^3]
C_{out} : concentration of H_2S in the air [outlet from the biofilter, g/m^3]
EBRT : empty bed residence time [Q/V, h]
EC' : maximum elimination capacity in the absence of inhibition [g m^{-3} h^{-1}]
EC_{max} : maximum elimination capacity [g m^{-3} h^{-1}]
K_S : saturation constant [g m^{-3}]
K'_S : saturation constant in the Haldane model [g m^{-3}]
K_I : inhibition constant in the Haldane model [g m^{-3}]
Q : gas flow rate [m^{3}h^{-1}]

V : bed volume [m^3]

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