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Biofiltration of H_2S in air—Experimental comparisons of original packing materials and modeling

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ABSTRACT

The treatment of hydrogen sulfide using a biofilter packed with expanded schist and topped with a layer of a synthetic nutritional material (UP20) was examined at a constant H_2S concentration (100 ppmv). The impact of the empty bed residence time (EBRT) on process performances was clearly underlined by varying the polluted air flow from 4 to 20 $m^3\ h^{-1}$ corresponding to a variation in the EBRT from 63 to 13 s. Complete H_2S degradation was observed when the EBRT was higher than 51 s. Experimental data collected at various EBRTs (13–63 s) were fitted using the Ottengraf model equations. The α_{lump} parameter value was found to be 26.4 $g^{1/2}\ m^{-3/2}\ h^{-1}$. This single parameter, which enables the performance of the biofilter as a whole to be characterized whatever its composition (mixture or layers of different packing materials) and whatever the EBRT, is a powerful tool to compare packing materials and to design such bioreactors. The α_{lump} value characterizing the performances of expanded schist coupled with a thin layer of UP20 was higher than the α_{lump} values obtained for other packing materials (natural or synthetic) reported in previous studies.

1. Introduction

Hydrogen sulfide (H_2S) is a hazardous, toxic air pollutant. It is a colorless, corrosive and flammable gas. H_2S can be problematic due to its unpleasant smell and low odor threshold. It is emitted from many industrial activities such as petroleum refining, leather, waste or wastewater treatments, food processing, anaerobic treatment of paper and pulp manufacturing. Conventionally, different processes have been used to remove H_2S from waste gas streams involving chemical and physical methods. For some years, the focus has shifted toward using biofiltration. This process presents an attractive technology for treating pollutants from air due to its effectiveness, low energy consumption and minimal by-product generation. The gas stream flows through the filter bed. Pollutants are then transferred from the gas phase to the biofilm, where they are metabolized by microorganisms. The by-products of the complete biodegradation of air pollutants are CO_2, water, and microbial biomass. In the case of H_2S biodegradation, sulfur oxidizing bacteria (SOB) are responsible for removing H_2S in aerobic conditions. For their maintenance and growth, SOB use H_2S as a source of energy and CO_2 as the main source of carbon [1,2]. Bacteria from the genus *Thiobacillus* are responsible for the oxidation of H_2S to sulfate and/or elemental sulfur according to the operating conditions [3,4].

The biofiltration of H_2S is well documented (Table 1). As this table shows, a variety of packing materials are used and biofiltration performances are disparate. These packing materials include: (i) organic materials such as soil, peat, compost and pine bark [3,5–10] and different forms of activated carbons [11,12]; (ii) inorganic materials like pozzolan, expanded schist and lava rock [13–15]; (iii) synthetic media such as a patented biofilter medium (Biosorbens™) developed by Shareefdeen [16,17]. Nonetheless, recent studies highlighted that biofilters filled with expanded schist topped with a layer of synthetic nutritional material (UP20) were very efficient for removing high loading rates of H_2S [15,18,19]. The good mechanical behavior of the expanded schist (low pressure drop) and the ability of biofilters to oxidize H_2S under extreme acidic conditions for a long period confirmed the advantage of using expanded schist coupled with UP20 for industrial applications [14,15,18,20]. In biofiltration, the empty bed residence time

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Nomenclature

A	Specific area ($m^2_{biofilm}\ m^{-3}_{packinmaterial}$)
C	Gas concentration ($g\,m^{-3}_{gas}$)
C_L	Pollutant concentration in the biofilm ($g\,m^{-3}_{biofilm}$)
d	Diameter (m)
D	Diffusion coefficient ($m^2_{biofilm}\ s^{-1}$)
EBRT	Empty bed residence time (s); $EBRT = V/Q_v$
EC	Elimination capacity ($g_{H2S}\ m^{-3}_{packinmaterial}\ s^{-1}$); $EC = (Q_v/V)(C_{in} - C_{out})$
H	Height (m)
k	Zero order reaction rate constant ($g\,m^{-3}_{biofilm}\ s^{-1}$)
LR	Loading rate ($gH2S\,m^{-3}_{packin\ material}\ s^{-1}$); $LR = (Q_v C_{in}/V)$
m	Partition coefficient (–)
Q_v	Gas flow rate ($m^3_{gas}\ s^{-1}$)
R	Reaction rate constant ($g\,m^{-3}_{packinmaterial}\ s^{-1}$); $R = k\,a\,\delta$
RE	Removal efficiency (%); $RE = 100\,(C_{in} - C_{out})/C_{in}$
U	Superficial gas velocity ($m_{gas}\ s^{-1}$)
V	Bed volume of packing material ($m^3_{packingmaterial}$)
x	Length coordinate (m)

Greek letters

α_{lump}	Lump parameter ($g^{1/2}\,m^{-3/2}_{packinmaterial}\,s^{-1}$) (Ottengraf's equations)
δ	Total biofilm thickness (m)
ε	Porosity of the packing material (–)
φ	Thiele modulus (–)
λ	Effective biofilm thickness (m)
σ	Dimensionless length coordinate in the biofilm ($=x/\delta$)

Subscripts

Crit	Critical
in	Inlet
out	Outlet

(EBRT) is the key parameter influencing biofilter performances. Usually, EBRTs from 20 to 60 s are applied to remove H_2S from air [6,16,21] but higher and lower values are reported in the literature. As illustrated in Table 1, the EBRT may be significantly different from one study to another (from 2 to 120 s, i.e. almost two orders of magnitude). Consequently, it is very difficult to compare the performance of different packing materials on the basis of the Elimination Capacity (EC in $g\,m^{-3}\,h^{-1}$) measured at different EBRTs and the Removal Efficiency (RE), which can be other than 100%. The literature results presented in Table 1 clearly illustrate that the comparison of biofilter performances is difficult. For instance, is it possible to compare the performance of peat reported by Oyarzun et al. [3] ($EC = 14.8\,g\,m^{-3}\,h^{-1}$ at $EBRT = 120$ s and $RE = 100\%$) with that of the biofilter medium Biosorbens™ reported by Shareefdeen [16] ($EC = 6\,g\,m^{-3}\,h^{-1}$ at $EBRT = 30$ s and $RE = 99\%$)? To overcome this problem, it would be better to base the comparison of the performances of packing materials on mathematical models. Several models have been proposed to predict the performances of biofilters and to improve biofilter design [22,23]. One of the earliest steady-state biofiltration models was developed by Ottengraf and Van den Oever [24]. Because of its mathematical simplicity, this model has been widely used for biofiltration [3,25,26]. Therefore, the objective of this work was to show that a single parameter (called α_{lump}) derived from the Ottengraf model equations can be used as a simple tool to compare the performances of different carrier materials used in H_2S biofiltration whatever the configuration

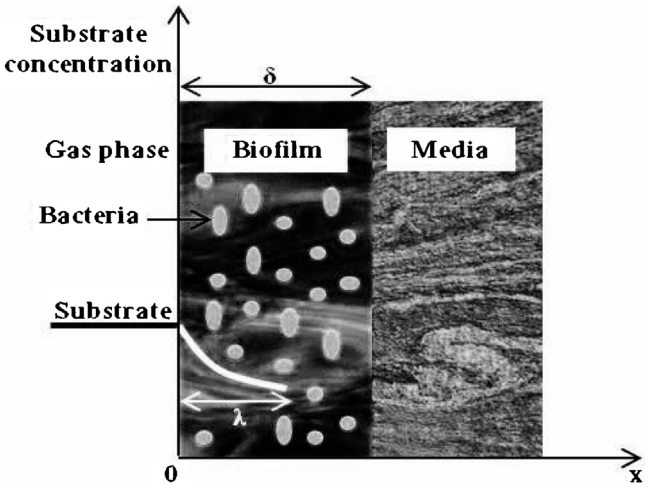

Fig. 1. Substrate concentration profile in the biofilm: diffusional regime.

of the biofilter and whatever the EBRT. The Ottengraf model was therefore applied (i) to determine the α_{lump} parameter experimentally in order to evaluate the performance of a biofilter filled with expanded schist topped with a layer of synthetic nutritional material (UP20) and (ii) to compare this latter with the performance of packing materials reported in the literature. To achieve these objectives, the ability of the biofilter to oxidize H_2S at different EBRTs should be determined beforehand. Therefore, this paper presents a brief description of the mathematical model used and details the experimental study carried out.

2. Ottengraf model equations

In order to describe the mechanisms of transfer and biodegradation in the biofilter (Fig. 1), Ottengraf and Van den Oever [24] proposed a simple model based on the theoretical model built by Jennings et al. [41]. The hypotheses are as follows:

- Biodegradation occurs in a biofilm considered to be water.
- Biofilm thickness is small compared to the packing material diameter.
- Biomass concentration is homogeneous in the reactor.
- Gas phase is ideal.
- Gas phase is a plug flow.
- Mass transfer resistance in the gas phase is negligible.
- Regime is at steady-state.
- Equilibrium occurs at the gas-biofilm interface.

Moreover, Ottengraf and Van den Oever considered that the reaction rate constant of the substrate elimination in the biofilm is of zero-order in the pollutant concentration, which assumes a very low value of the Michaelis-Menten constant in the Monod equation [24]. Zero-order kinetics are encountered at high concentrations of H_2S, which is generally the case in laboratory experiments. With these assumptions, the concentration of a nutrient component inside the biofilm (C_L) is described using the differential equation:

$$D\frac{d^2C_L}{dx^2} - k = 0 \quad (1)$$

with the boundary conditions:

$$x = 0;\ C_L = \frac{C}{m} \quad (2)$$

$$x = \delta;\ \frac{dC_L}{dx} = 0 \quad (3)$$

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