

20th International Congress of Chemical and Process Engineering CHISA 2012
25 – 29 August 2012, Prague, Czech Republic

Study of mass oxygen transfer in a biotrickling filter for air pollution control

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Abstract

Biotrickling filtration is a potential and cost effective alternative for the treatment of volatile organic compound (VOC) emissions in air, so it is necessary to deepen into the key aspects of design and operation for the optimization of this technology. One of these factors is the oxygen mass transfer of the process. This study would facilitate the selection of the packing material and the mathematical modelling and simulation of bioreactors. Four plastic packing materials with a different specific surface area have been evaluated in terms of oxygen mass transfer. For the tested range of superficial liquid velocities, data show a relationship between the $k_L a$ and the superficial liquid velocity in all packing materials used, except for the biggest plastic rings. No significant differences in mass transfer coefficients at low liquid velocities were observed, however dependency between oxygen transfer and specific surface area increased considerably for high liquid velocities. No significant influences of the superficial air velocity were observed.

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Keywords: Mass transfer; biotrickling filter; oxygen; volatile organic compounds

1. Introduction

The abatement of volatile organic compound (VOC) emissions is a factor of protection of the environment and public health in Europe [1]. As a consequence of these increasingly restrictive environmental regulations, treatment technologies for VOC removal are required. Since late 1990s there

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has been an emergent interest of research towards the biotrickling filter (BTF), which allows better control of the pH and offers smaller footprint compared to conventional biofilters. BTF uses an inert packing material and involves continuous or intermittent trickling of water. In this configuration, the biomass attaches to the media and develops a biofilm, thus, the pollutant and the oxygen will be transferred from the gas phase to the trickling liquid and then to the biofilm, where the biodegradation takes place. As it was pointed out [2,3] the mass transfer could be limiting the performance of the process, so the choice of a suitable packing is very important. In the same way, oxygen limitation could be occur [3,4]. This limitation could be especially vital for the treatment of high loads of VOCs hydrophilic compounds due to their higher partition coefficient than partition coefficient of the oxygen. In order to optimize the cost and efficiency of the BTF at industrial scale, a good gas-liquid contact is necessary. Determining the mass transfer coefficient would facilitate the selection of the packing material and the modelling of bioreactors used for air pollution control. Correlations commonly used for chemical absorption processes do not represent correctly the phenomenon occurred in BTFs due to the different hydrodynamic conditions of chemical absorption [5,6].

2. Materials and methods

In this study, a dynamic method was used for the determination of k_{La} . This method consists of measuring the evolution of the concentration of dissolved oxygen in the recirculation tank in which the oxygen has been previously displaced by bubbling nitrogen gas. The system consisted of a column of methacrylate (14.4 cm internal diameter, 80 cm height) and a recirculation tank. The column was filled with different propylene packing materials to be tested. In this case one structured and three random packing materials with different size and superficial area have been used as can be seen in Table 1.

Table 1. Characteristics of the packing materials used*

			Size (mm)	Superficial area ($m^2 m^{-3}$)
Packing 1		Structured	----	410
Packing 2	Plastic Rings	Random	15	348
Packing 3	Plastic Rings	Random	25	207
Packing 4	Plastic Rings	Random	50	110

* All packing materials were supplied by Pure Air Solutions, The Netherlands.

As shown in Figure 1, the air stream was introduced through the bottom of the column. The flow rate was adjusted using a mass flow controller (Bronkhorst Hi-Tec, The Netherlands). The experiments were carried out for two air superficial velocities of $104 m h^{-1}$ and $312 m h^{-1}$ to evaluate the influence of air flow rate. The trickling water was recirculated in counter current mode, with a water superficial velocity between 3 and $33 m h^{-1}$. The oxygen concentration in the liquid was determined using a dissolved oxygen probe (Cellox® 325i, WTW, Germany), for which the response time was considered.

The value of k_{La} was calculated adjusting experimental data of dissolved oxygen concentration in the recirculation tank with theoretical values obtained from the oxygen mass balance in the tank, using the following equations:

$$dC/dt = 1/\theta (C^* - (C^*-C)/\exp(L/v*k_{La})-C) \quad (1)$$

$$dC_{med}/dt = (C-C_m)/\tau \quad (2)$$

where C is the real dissolved oxygen concentration in the recirculation tank, C_m is the measured dissolved oxygen concentration in the recirculation tank, C^* is the oxygen solubility experimentally determined, θ is the hydraulic residence time in the tank, τ is the response time constant of the probe (time that the probe achieves the 63.2% of the final value) and L and v are the height of the column and the velocity of the trickling water, respectively.

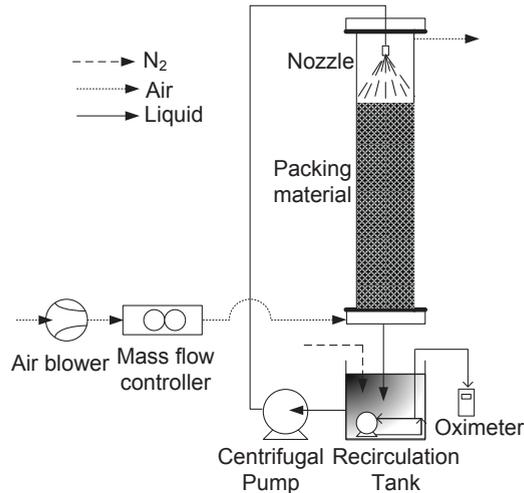


Fig. 1. Experimental setup

3. Results and discussion

The determination of oxygen mass transfer coefficients was carried out for each packing material at several liquid velocities, where $k_L a$ coefficients were obtained using least squares method to minimize the differences between the experimental data and the concentration of oxygen provided by the simple mathematical model established by the equations (1) and (2). Previously, the response time of the probe (τ) was determined by means of a step input assay, resulting in a value of 19.4 ± 1.5 s.

For the tested range of superficial liquid velocities, data show a clear dependence of the $k_L a$ with the superficial liquid velocity for all tested packing material, except for the biggest plastic rings. As an example, besides, the influence of superficial liquid velocity versus the mass transfer coefficient for the two gas velocity tested in packing material 3 is shown in Figure 2. As can be observed, by tripling the gas velocity were not observed significant differences between the data obtained. Thus, as was pointed by other authors [5,7] the oxygen mass transfer depends primarily on the superficial liquid velocity for each packing material. This implies that VOC treatment with biotrickling filtration was not affected by the gas velocity from the point of view of the oxygen transfer when the other conditions were kept constant.

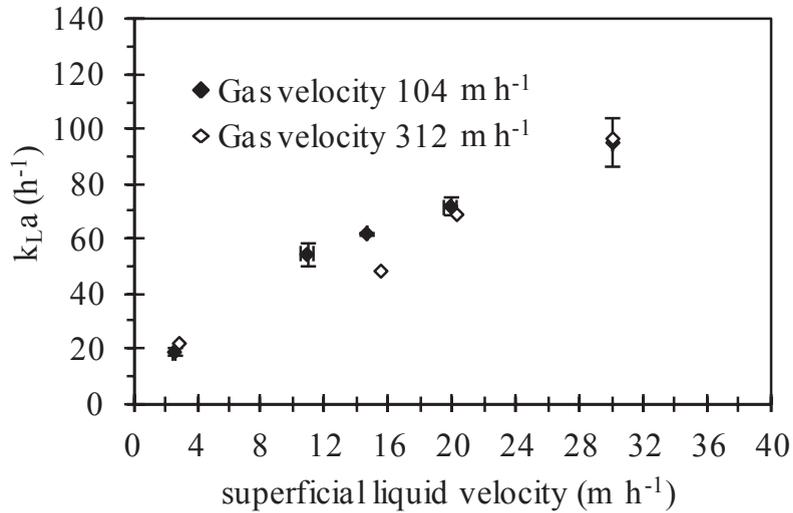


Fig. 2. Influence of superficial liquid velocity and superficial air velocity on the oxygen mass transfer coefficient for the packing material number 3.

The behavior of each packing material on the oxygen mass transfer for the superficial liquid velocities was compared. The oxygen mass transfer coefficient obtained for low and high liquid velocities (3 and 30 m h⁻¹) for each packing material tested are shown in Figure 3 (6 and 30 m h⁻¹ for packing material number 2).

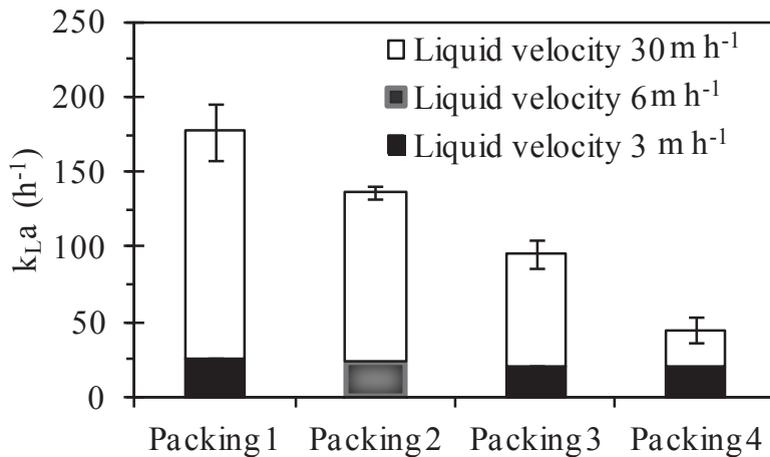


Fig. 3. Influence of the liquid velocity on the oxygen mass transfer coefficient for each packing materials for high and low liquid velocities.

For the low liquid velocities, similar values of k_{La} were obtained. Thus, the influence of the specific surface area seems negligible under the tested conditions. However, for the liquid velocity of 30 m h^{-1} , large differences on the oxygen mass transfer coefficient were obtained for each packing material. This suggests that, at high liquid velocities, by increasing the specific surface area of the packing material is possible to enhance the oxygen mass transfer. So, the superficial liquid velocity is a key parameter in the operation of biotrickling filtration and oxygen mass transfer should be known for each packing material in order to optimize the performance of the process.

4. Conclusion

Results showed that oxygen mass transfer was strongly affected by superficial liquid velocities. No influence of gas velocity on the oxygen mass transfer was obtained. At low liquid velocities, no differences between packings were observed. At high liquid velocities, data show that higher values of specific surface area provide greater mass transfer coefficients for the tested range. Consequently, the study of oxygen mass transfer is a crucial factor in order to improve the biological performance of biotreatments for VOC elimination.

Acknowledgements

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under REA grant agreement n° 284949. Financial support from Ministerio de Ciencia e Innovación (Project CTM2010-15031/TECNO) and Generalitat Valenciana (ACOMP/2012/209), Spain, is also acknowledged. Pau San Valero acknowledges the Generalitat Valenciana, Spain (ACIF2011/067 contract).

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