CHEMICAL ENGINEERING TRANSACTIONS Volume 17, 2009
Editor Sauro Pierucci

DOI: 10.3303/CET0917091

Oxygen Transfer In A Counter-Current Fibrous Bed Bioreactor: Case Of Liquid Recycle

Martin Martinov[1] , Dimiter Hadjiev[1*] , Serafim D. Vlaev[2]
[1]LBCM, UEB-UBS, Research Centre, rue Saint Maudé, 56321, Lorient, France,
*hadjiev@univ-ubs.fr
[2]Institut of Chemical Engineering, Bulgarian Academy of Sciences, Acad.G. Bontchev str. Bl.103, 1113, Sofia, Bulgaria

In this work, the gas-liquid mass transfer in a lab-scale fibrous bed reactor with liquid recycle has been studied. The volumetric gas-liquid mass transfer coefficient k_La is determined over a range of superficial liquid velocity (0.0042- 0.0126 m/s), gas velocity (0,006 m/s to 0.021 m/s), surface tension (35-72 mN/m) and viscosity (1-6 mPa.s). The effects of superficial gas and liquid velocities, surface tension and viscosity are examined. Increasing fluid velocities and viscosity, and decreasing interfacial tension, the volumetric oxygen transfer coefficient increased. In contrast to the case of co-current flow, the effect of gas superficial velocity was found to be more significant than the liquid one. This behaviour is explained by variation of the coalescing gas fraction and reduction of bubble size.

Key words: three-phase fixed bed, gas-liquid mass transfer, physicochemical properties

Introduction

Three-phase fixed bed reactors (TFBR) are often used in aerobic treatment of urban wastewaters for carbon, nitrogen and suspended particle elimination. Compared to activated sludge systems, using fixed bed biofilm higher biomass concentration can be obtained and higher volumetric loading rate can be ensured at the required removal efficiency. Referring to microorganisms showing low growth rates and/or yields it can be demonstrated that the use of biofilm reactors offers several advantages. Generally, the liquid and the gas are injected at co-current flow in the lower part of the column but down-flow TFBRs are also in use. The up-flow systems are claimed to have a more uniform water and air distribution, thus, making the treatment more efficient through better use of the reactor volume. The superficial gas and liquid velocities commonly used in the bioreactors are relatively low. At such conditions, biofilm thickness and structure control is hard because of the low liquid and particle shear on the biofilm, particle elutriation as a result of biofilm growth becoming a major problem. Indeed, supported biofilm systems often suffer from poor long-term stability which can be ascribed to reactor bed clogging, flow channelling, cell degeneration and gradual pressure drop rise. One possibility to overcome these problems is the use of highly porous fibrous packing. Recently Shim et al. (2001) and other researcher have shown that some fibrous materials might be suitable for aerobic fixed bed reactor (AFBR) packing, especially in so far as they provide high specific surface for microbial

Please cite this article as: Martinov M., Hadjiev D. and Vlaev S., (2009), Oxygen transfer in a counter-current fibrous bed bioreactor: case of liquid recycle, Chemical Engineering Transactions, 17, 543-548 DOI: 10.3303/CET0917091

attachment, high porosity and relatively low pressure drop. The cells are immobilised on an inert fibrous matrix loosely convoluted in a column. The structured bed allows uniform multiphase flow and provides renewable surface for cell immobilisation. On the other hand, liquid recycling in the fibrous structure may be employed to control cell detachment and biofilm depth. Such approach should be beneficial to clogging problems. In this study, the gas-liquid mass transfer capacity of a lab-scale TFBR reactor and the effect of physicochemical properties on it have been targeted. The volumetric mass transfer coefficient is measured at various fluid velocity, viscosity and surface tension. Based on these data, the mass transfer characteristics of the reactor are analysed. A correlation is proposed allowing estimation of the volumetric gas-liquid mass transfer coefficient with good agreement to experimental results.

Materials And Method

Experiments were carried out in a laboratory scale fixed bed reactor given in the Fig. 1. The reactor (1) consisted of a glass column of 0.1 m internal diameter filled with a PEVA fibrous packing (0.26 m in height). The height of the section between the air injection point and the liquid level was 0.8 m thus the active volume was about 6 L. The gas distributor, a porous disc diffuser with diameter of 0.09 m was mounted in the bottom lid. It was designed to assure bubble size up to 1mm and uniform spreading in the column. An ALBORG, USA gas flow controller (4) was used to control the gas flow rate. The reactor was continuously fed using a *Masterflex L/S* pump (6) which ensured liquid flow rate was varied using a Sigma/2Ba (ProMinent) recycling pump(5). The data acquisition system (CONSORT) (7) was able to store 1000 experimental values for each parameter measured. In the experiments, superficial gas velocity was varied up to 0.021 m/s and superficial liquid velocity was varied up to 0.0126 m/s. The studies being focused on the effect of gas velocity, liquid recycle, and physical properties, most of the

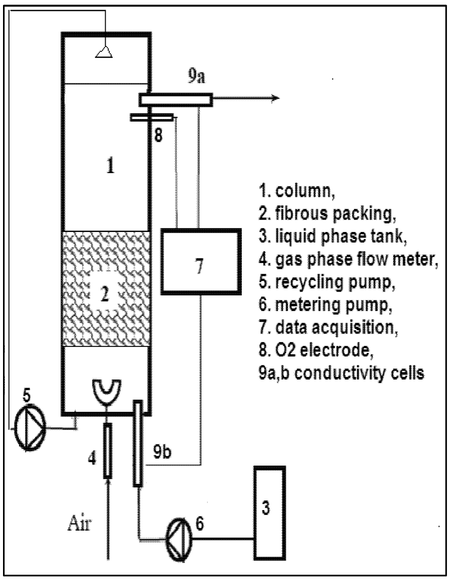

Fig. **1**: *Experimental set up*

Table 1: Physicochemical properties of the solutions

Concentration	Surface tension – σ, mN/m	Viscosity-μ, mPa.s	Density – ρ, kg.m^{-3}
0 (Water)	71.40	1.	998
20 % saccharose	73.00	1.97	1104
40 % saccharose	74.10	6.22	1176
1 g/l methanol	61.02	1.	998
2 g/l methanol	54.11	1.	997
5 g/l methanol	42.74	1.	996
10 g/l methanol	34.87	1.	993

runs were carried out at zero or very low liquid feed. Various media have been used and the solutions' properties are given in Table 1. Pure water with surface tension $\sigma = 71.4$ mN/m and density ρ = 998 kg.m^{-3} was used as a reference.

The volumetric oxygen transfer coefficient k_La was estimated from the dynamic response of dissolved oxygen concentration after a step change of oxygen concentration at the gas inlet. The liquid phase mixing regime was checked by preliminary tracer experiments. Measurement of residence time distribution (RTD) curve moments' ratio at various liquid and gas flow rates showed that typically the result deviated only slightly from unity, as illustrated in Table 2.

Consequently, complete mixing was assumed. The increase in the dissolved oxygen concentration in the liquid was measured using a *Bioblock* oxygen probe, and the data were recorded at time intervals of 10 s using a data acquisition card. In particular, the original procedure described in detail by Dang et al. (1977) was followed. The mass transfer coefficients were obtained by plotting the concentration vs. time relationship and using a linear regression analysis. Each mass transfer coefficient result represents the mean value of 5 runs. The linear regression coefficients for all plots exceeded 0.98.

Results And Discussion

The variation of the volumetric mass transfer coefficient k_La with gas superficial velocity U_G and liquid superficial velocity U_L is illustrated in Fig. 3. The k_La- values increased in parallel to both gas and liquid superficial velocity rise. However, the effect of the gas velocity is registered to be more significant than the liquid one. A triple increase of U_G lead to almost 2 fold k_La rise, while a similar increase of U_L caused k_La to rise by only 10%. Bhatia et al.(2004) measuring k_La in up-flow co-current reactors have shown the opposite effect, i.e. the influence of liquid velocity was prevailing:

Table 2. Moments' ratio in the fibrous bed bioreactor

U_L, m/s	t^2/σ^2	
	U_G= 0.0036m/s	U_G= 0.0054m/s
0.0036	1.11	1.04
0.0045	1.26	1.15
0.0054	1.34	1.25
0.0063	1.63	1.41

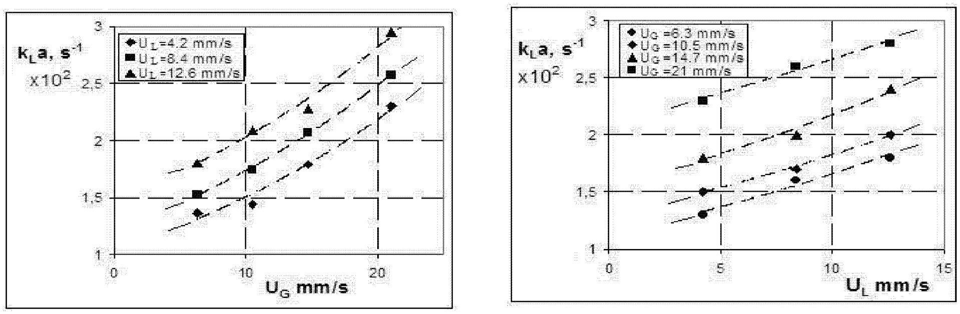

Fig. 3 *Effect of gas and liquid velocities on k_La*

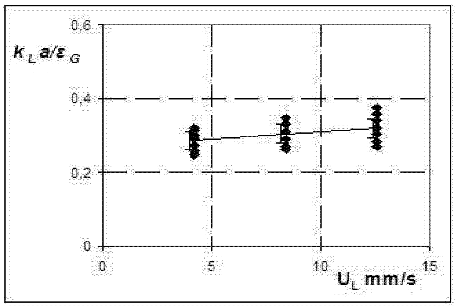

Fig. 4 *Mass transfer ratio k_La / ε_G versus liquid velocity (The experimental error limits are indicated)*

By taking the relationship of the ratio k_La/ε_G vs. U_L at various U_G, the effect of liquid and gas velocity on k_La can be revealed. In Fig. 4, one can observe almost constant behaviour of the ratio versus U_L that shows negligible effect of U_L. In contrast, the ratio variation due to U_G exceeds the limits of the experimental error and may be considered significant, thus, U_G affects also the diffusion component k_L of the volumetric mass transfer coefficient. Evidently, an increase in the gas flow rate favours turbulence and increases both the interfacial area and the rate of diffusion in the liquid film. The solid line in the figure corresponds to the equation (1) that can be used for an approximate calculation of k_La in water:

$$k_La / \varepsilon_G = 0.27 + 4.15\ U_L \qquad (1)$$

Referring to the overall performance of a fibrous fixed bed with liquid recycle aimed at control of the biofilm, one could conclude that an increase of liquid recycle would not affect strongly the mass transfer and that the basic operational variable for the mass transfer remains the rate of aeration. Consequently, the recycle liquid velocity can be varied in wide margins to gain control over the biofilm thickness.A background analysis referring to such flow procedure has been published recently by Sharma et al. (2005).

Fig.5 presents the results for the influence of the surface tension and the viscosity on the mass transfer coefficient. It is seen that k_La depends significantly on both parameters The values of k_La increased when σ decreased. We believe that higher σ inhibited mass transfer because of surface gradients developing around the bubbles and increasing coalescence. Consequently, the variation of k_La due σ has been attributed to variable gas-liquid contact area. Because the increase deviated from similar effects reported by Kastanec (1993), one could expect some additional effect of the contact area 'fluid/

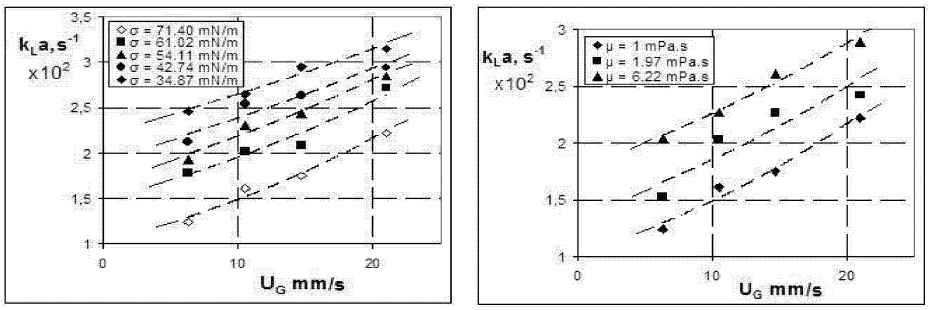

Fig. 5 *Effect of surface tension and viscosity on k_La (U_L=0.0084m/s)*

solid'. Bhatia et al. (2004) reported an increase of interfacial area following a decrease of surface tension forces due to packing presence. What is similar to our case, this would mean an enhanced effect of σ upon k_La in the high porosity fibrous fixed bed. As viscosity is concerned, once a viscous solution other than water was used, k_La increased significantly. The increase was larger at lower viscosity, e.g. k_La increased 1.2 fold at double viscosity rise, while further variation of triple viscosity rise caused equal increase. The explanation of this observation could be assigned to coalescence inhibition at higher viscosity that leads to smaller bubbles and larger interfacial area. Similar effect has been registered in the lower viscosity range at μ<100 mPa.s by Schugerl (1981).

The k_La values obtained in this study are compared with reference data in Fig. 6. There are only limited results for the volumetric mass transfer coefficient in fibrous bed bioreactors, so prevailingly data obtained for granular beds by Deront et al. (1998) for a 4,6m fixed bed with *ID* 0,52m and by Maldonado et al. (2008) for a co-current gas-liquid up-flow in 4 m high fixed bed in a 0.15m diameter column were used. In so far as a result reported by Bhatia et al. (2004) coincided with the upper range of gas velocity values of this study, it is shown in the figure. One can see that the k_La values in fibrous bed with counter-current recycle (H_B = 0.26 m, *ID* 0.1m) obtained in this study are comparable with the data reported by other authors. Fig. 6 shows that the k_La values in the granular bed 4 m of height relevant to U_G<10 mm/s are slightly higher than those

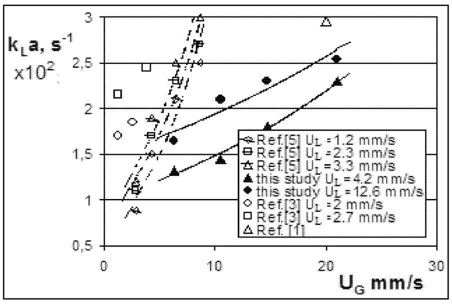

Fig. 6 *Comparison between k_La values obtained in this study with reference values obtained by : a) ref. [5] – Maldonado et al.(2008); b) ref. [3] – Deront et al.(1998); c) ref. [1] - Bhatia et al.(2004)*

obtained in the present smaller fibrous bed. In order to clear the effect of bed height, some experiments in this study were carried out with a fixed bed of different height. A data processing over the experimental values showed a weak effect of bed height (exponent 0.1) quantified by the relationship:

$$(K_L a) \sim (H_B / H_{Bo})^{0.1} \quad (2)$$

Conclusions

Gas-liquid mass transfer in a fibrous bed with counter-current liquid recycle has been studied and the volumetric gas-liquid mass transfer coefficient $k_L a$ has been determined over an extended range of operating conditions. The increase of superficial gas and liquid velocity and viscosity and the decrease in surface tension are found to affect the oxygen transfer positively. The effect of gas velocity was found to be more significant than the liquid velocity one. Explanation is sought in the variation of turbulence and interfacial area due to the counter-current mode of recycle operation.

References

1. Bhatia B., Nigam K.D.P., Auban D. and Hebrard G., 2004, Effect of a new high porosity packing on hydrodynamics and mass transfer in bubble columns, Chem. Eng. Process 43, 1371-1380.
2. Dang N.D.P., Karrer D.A. and Dunn I.J., 1977, Oxygen transfer coefficients by dynamic model moment analysis, *Biotechnol. Bioeng*. 19, 853-865.
3. Deront M., Samb F.M., Adler N. and Peringer P.. 1998, Volumetric oxygen mass transfer coefficient in an upflow cocurrent packed-bed bioreactor. Chem. Eng. Sci. 53, 1321-1330.
4. Kastanek, G., Zahradnik, J., Kratochvil, J. And Cermak, 1993, Chemical Reactors for Gas-Liquid Systems, Ellis Horwwod, New York.
5. Maldonado J.G., Bastoul D., Baid S., Roustan M.. and Hebrard G.. 2008, Effect of solid characteristics on hydrodynamic and mass transfer in a fixed bed reactor operating in co-current gas-liquid up flow. Chem. Eng. Process. 47, 1190-1200.
6. Schugerl, K., 1981, Oxygen transfer into highly viscous media, in: (Fiechter, Ed.) Adv. Biochem. Eng. 19, 71-174.
7. Sharma P.K, Gibcus M.J., van der Mei H.C. and Busscher H.J., 2005, Influence of fluid dynamics and microbubbles on bacterial detachment from a surface, Appl. Environ. Microbiol. 71, 3668-3673.
8. Shim E.B., Shin S.T. and Yang S.,2001, A continuous fibrous-bed reactor for BTEX biodegradation by a co-culture of *Pseudomonas putida* and *Pseudomonas fluoresnens, Adv. Env. Res*. 7, 203-216.