Prediction of alpha factor values for fine pore aeration systems

S. Gillot and A. Héduit

ABSTRACT

The objective of this work was to analyse the impact of different geometric and operating parameters on the alpha factor value for fine bubble aeration systems equipped with EPDM membrane diffusers. Measurements have been performed on nitrifying plants operating under extended aeration and treating mainly domestic wastewater. Measurements performed on 14 nitrifying plants showed that, for domestic wastewater treatment under very low F/M ratios, the alpha factor is comprised between 0.44 and 0.98. A new composite variable (the Equivalent Contact Time, ECT) has been defined and makes it possible for a given aeration tank, knowing the MCRT, the clean water oxygen transfer coefficient and the supplied air flow rate, to predict the alpha factor value. ECT combines the effect on mass transfer of all generally accepted factors affecting oxygen transfer performances (air flow rate, diffuser submergence, horizontal flow).

Key words | activated sludge, aeration, alpha factor, bubble residence time, EPDM diffuser, wastewater

S. Gillot
A. Héduit
Hydrosystems and Bioprocesses Research Unit,
Cemagref, Parc de Tourvoie, BP 44,
F-92163 Antony Cedex,
France
E-mail: *sylvie.gillot@cemagref.fr*;
alain.heduit@cemagref.fr

INTRODUCTION

Oxygen transfer efficiency under process conditions for systems equipped with fine pore EPDM membranes depends on the same factors as in clean water, i.e.: (i) geometric ones such as the diffuser submergence (Capela *et al.* 2002), surface area, diffuser layout and placement (Gillot *et al.* 2005*a*) and (ii) operating ones: mainly the air flow rate (Bischof *et al.* 1993; Gillot & Héduit 2000; Gillot *et al.* 2005*b*; Rosso *et al.* 2005) and the circulation velocity in horizontal flow systems (Gillot *et al.* 1999). In comparison to clean water, the impact of these variables is modified by two groups of factors (Mueller *et al.* 2002; Gillot *et al.* 2005*a*): the dissolved contaminants in the process water (surfactants, inorganics) (Capela *et al.* 2002; Rosso & Stenstrom 2006) and the diffuser aging process (fouling and clogging) (Wagner & Von Hoessle 2003). The process variables influencing the concentration and distribution of contaminants have thus a potential effect on the mass transfer coefficient: wastewater characteristics, process loading, flow regime.

doi: 10.2166/wst.2008.222

Among the factors cited, the mean cell retention time (MCRT) or sludge age (or the load received by the plant Food/micro-organism ratio) seems to be the main parameter affecting the value of the alpha factor (ratio of the oxygen transfer coefficients under process conditions and in clean water). This factor indeed determines the degree of degradation of the substances responsible for oxygen transfer depletion, mainly surfactants.

Figure 1 shows the evolution of the alpha factor as a function of the MCRT for several published data.

The alpha factor is an increasing function of the MCRT. Rather large discrepancies between alpha values are still observed for plants working under equivalent MCRT conditions (Groves *et al.* 1992; Wagner 1999; Rosso *et al.* 2001). Recently, Rosso *et al.* (2005) proposed a parameter to take into account the combined effect of MCRT and air flow rate on oxygenation performances under process conditions. This parameter (ratio between MCRT and the normalized air flux) is interesting, but part of the alpha

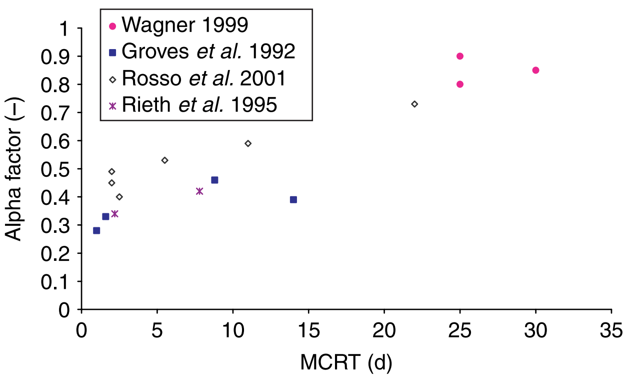

Figure 1 | Alpha factor versus MCRT.

factor variability (up to 30%) can not be explained by these variables (Mueller *et al.* 2002). Moreover, the impact of certain factors such as the diffuser submergence is still not fully understood.

The objective of this paper is therefore to analyse the impact of different geometric and operating parameters on the alpha factor value for fine bubble aeration systems equipped with EPDM membranes. Measurements have been performed on nitrifying plants operating under extended aeration and treating mainly domestic wastewater. 27 full scale tests (performed on 14 plants, in clean water and, a few months later, under process conditions) have been scrutinized, and a new flow chart to obtain an adequate alpha factor value on the basis of the aeration system characteristics is proposed.

DATABASE

The database gathers the results of tests performed in full scale tanks equipped with fine bubble aeration systems. The aim of these tests was to determine the standard oxygenation capacities of the aeration systems in clean water and under process conditions. Clean water tests have been performed according to the standardized non steady state method (ASCE 1992; NFEN 12255-15 2004). Dirty water tests were performed using either the off-gas method or the hydrogen peroxide method (ASCE 1996; Capela *et al.* 2004). Alpha values have been deduced from oxygen transfer coefficients in clean water (k_La) and in dirty water (k_La_f), obtained under the same setting conditions:

$$a = \frac{k_La_f}{k_La}$$

27 measurements performed on 14 plants initially designed to treat domestic wastewater under low F/M ratios (sludge ages around 15 d) are used in the analysis. The main ranges of the tested aeration system characteristics are presented on Table 1.

The surface air flow rate (Q_A/S_A) is defined as the air flow rate (Q_A) divided by the total area covered by the grids of diffusers (S_A = aerated area). This parameter has been proved to be more relevant than the specific air flow rate (air flow rate divided by the active diffuser surface area), to represent the variation of the oxygen transfer efficiency in clean water (Gillot *et al.* 2005*a*).

RESULTS AND DISCUSSION

Alpha factor values for two ranges of MCRT

Among the 14 plants, one was not nitrifying despite a high MCRT (αSSOTE = 1.5%/m) and another was obviously functioning under unstable conditions (unusual high load received the day before the test under process conditions). Results obtained on these 2 plants have been excluded. Figure 2 presents αSSOTE and alpha factor values obtained for 2 subsets of data, corresponding to two MCRT ranges (larger than 25 d and around 15 d). Unfortunately, too few

Table 1 | Measurement conditions

Parameter	Aeration tank volume (m^3)	Diffuser submergence (m)	Specific airflow rate* Q_A/S_P ($m_N^3\ h^{-1}\ m^{-2}$)	Surface airflow rate† Q_A/S_A ($m_N^3\ h^{-1}\ m^{-2}$)	MLSS ($g\ L^{-1}$)
Range	250–10,200	2.5–7.7	30–110	4–50	2.2–6.5

*Airflow rate per unit of active diffuser surface area.
†Airflow rate per total area covered by diffuser grids.

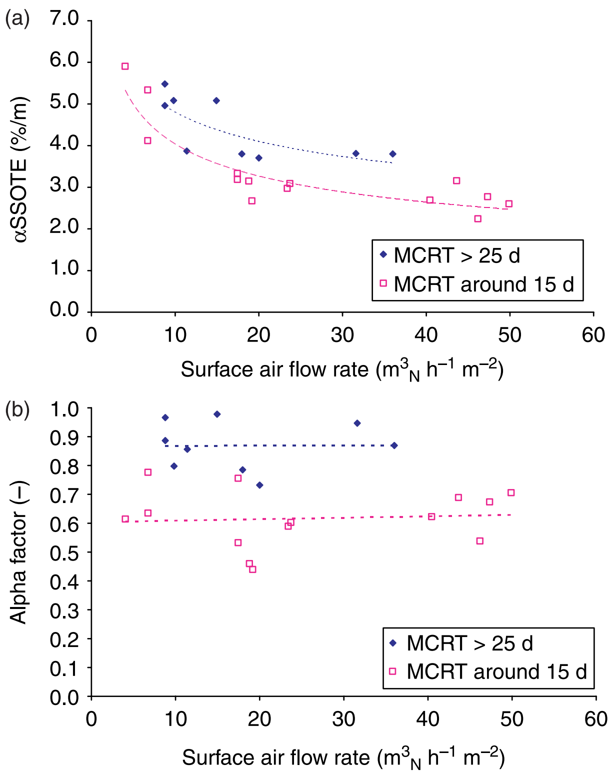

Figure 2 | αSSOTE (2a) and alpha factor (2b) versus surface air flow rate.

data were available to precisely calculate MCRT for all plants.

Such as in clean water, αSSOTE is a decreasing function of the surface air flow rate. For MCRT larger than 25 d, corresponding to very low F/M ratios, αSSOTE values are comprised between 3.7 and 5.5%/m and from 2.2 and 5.9%/m at MCRT around 15 d.

For MCRT larger than 25 d, alpha factor values range between 0.73 and 0.98. At a given airflow rate, lower values are obtained when the plant receives its design load (MCRT around 15 d), α factor values ranging from 0.44 to 0.78. The surface airflow rate (between 4 and 50 m^3_N h^{-1} m^{-2}) does not explain the variability of the alpha factor values within the 2 MCRT ranges.

Alpha factor values are presented in a different way in Figure 3, taking into account 2 ranges of diffuser submergence (Z), lower or larger than 5.5 m.

For very low F/M ratios, alpha factor values are found between 0.73 and 0.98. When the design MCRT is around 15 d, the alpha factor value is on average 0.67 when the

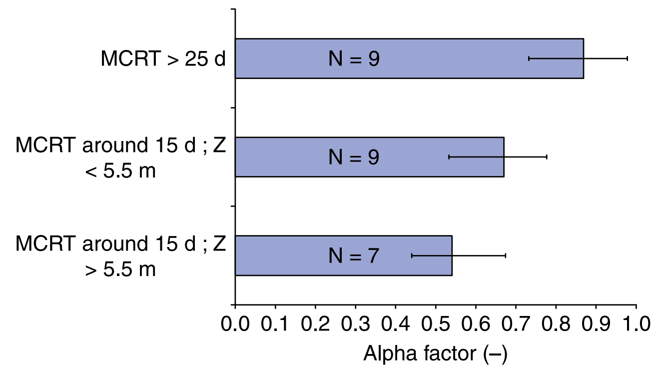

Figure 3 | Alpha factor for different MCRT and diffuser submergences (I – I extreme values).

diffuser submergence is lower than 5.5 m, and 0.54 for higher submergence (the air flow rate lying in the same range).

In addition to MCRT, which governs the quality of the process water, and to the air flow rate, the impact on oxygen transfer of the diffuser submergence seems to be significant. The contact time between bubbles and the liquid phase (bubble age) has therefore to be taken into account. The higher this contact time, the lower the oxygen transfer coefficient and the alpha value, as the surfactants have more time to be absorbed to the interfacial area (Capela *et al.* 2002; Mueller *et al.* 2002; Rosso & Stenstrom 2006).

Impact of the equivalent contact time on alpha factor

In order to take into account the impact of the mean bubble residence time on the alpha factor value, an equivalent contact time (ECT) has been calculated from clean water performances. The ECT corresponds to the time a bubble of 4.5 mm (at atmospheric pressure) will take to pass through the diffuser submergence and gives the measured clean water oxygen transfer coefficient (liquid-side mass transfer coefficient (k_L) assumed to be 3.8×10^{-4} m s^{-1}). The ECT is therefore deduced from the clean water oxygen transfer coefficient (k_La_{20}) and the air flow rate, considering the typical relationships between k_La_{20} and the parameters characterising the gas-liquid interface (bubble diameter, gas hold-up). The derivation of ECT is described in Figure 4.

The oxygen transfer coefficient at 20°C (k_La_{20}) is either measured or deduced from the aeration system/basin characteristics (Gillot *et al.* 2005*b*). The liquid-side mass

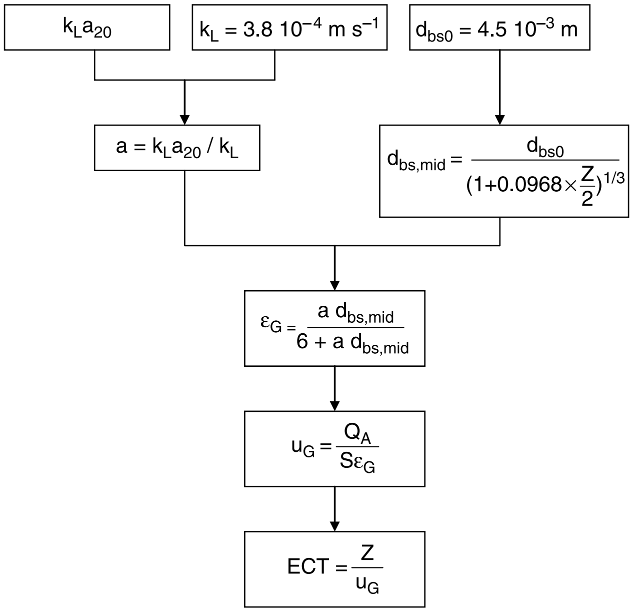

Figure 4 | Derivation of the ECT.

transfer coefficient (k_L) is assumed to be 3.8×10^{-4} m.s^{-1}. It has been verified that calculating k_L using the penetration theory (Higbie 1935) does not modified the results obtained. The Sauter diameter at atmospheric pressure (d_{bs0}; Pöpel & Wagner 1994) is assumed to be 4.5 mm (Fayolle *et al.* 2006). The mid-depth Sauter diameter ($d_{bs,mid}$) is calculated considering the water pressure at mid submergence, and is used to estimate the gas hold-up (ϵ_G). The gas velocity (u_G) is deduced from this value and the air flow rate, to finally give the equivalent contact time considering the diffuser submergence (Z).

Alpha factor values versus ECT are shown in Figure 5.

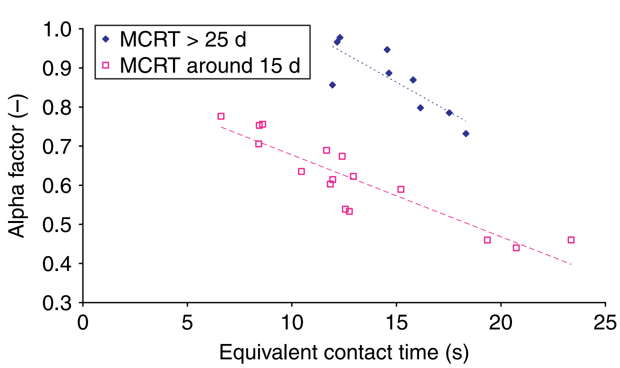

Figure 5 | Alpha factor versus equivalent contact time.

At a given MCRT, the alpha factor is a decreasing function of the equivalent contact time. ECT is a composite variable that takes into account geometrical variables as well hydrodynamic ones. This variable combines the effect on mass transfer of all generally accepted factors affecting oxygen transfer performances (air flow rate, diffuser submergence, horizontal flow…). Combined with the MCRT value, it can be used to better estimate the alpha factor value for a given aeration system with known or estimated clean water transfer efficiencies.

CONCLUSIONS

Measurements performed on 14 nitrifying plants showed that, for domestic wastewater treatment under very low F/M ratios, the alpha factor is comprised between 0.44 and 0.98. Individual variables affecting the oxygen transfer efficiency (MCRT and air flow rates) were not able to explain the discrepancy obtained in the alpha factor values.

A new composite variable (the Equivalent Contact Time) has been defined and makes it possible for a given aeration tank, knowing the MCRT, the clean water oxygen transfer coefficient and the supplied air flow rate, to predict the alpha factor value. ECT combines the effect on mass transfer of all generally accepted factors affecting oxygen transfer performances (air flow rate, diffuser submergence, horizontal flow).

ACKNOWLEDGEMENTS

The authors acknowledge the FNDAE (Fonds National pour le Développement des Adductions d'eau), for financial support (Action 05-119).

REFERENCES

ASCE 1992 *ASCE Standard Measurement of Oxygen Transfer in Clean Water*. American Society of Civil Engineers, New York.

ASCE 1996 *Standard Guidelines for In-Process Oxygen Transfer Testing*. American Society of Civil Engineers, New York.

Bischof, F., Sommerfeld, M. & Durst, F. 1993 Behaviour of fine dispersed bubbles in solutions with surfactants. *Gas-Liquid Flows* **165**, 131–136.

Capela, S., Héduit, A. & Roustan, M. 2002 Influence of the Water Depth on Fine Bubble Aeration fficiency in the Presence of Surfactants. In: *Preprints of the 3rd IWA World Water Congress*, Melbourne, Australian, 7–12 April 2002.

Capela, S., Gillot, S. & Héduit, A. 2004 Oxygen transfer under process conditions: comparison of measurements methods. *Water Environ. Res.* **76**, 183–188.

Fayolle, Y., Gillot, S., Cockx, A., Roustan, M. & Héduit, A. 2006 In situ local parameter measurements for CFD modelling to optimize aeration. In: *Proceedings of the 79th Annual Water Environment Federation Technical Exposition and Conference*, Dallas, USA, October 21–25.

Gillot, S., Capela, S. & Héduit, A. 1999 Effect of horizontal flow on oxygen transfer in clean water and in clean water with surfactants. *Water Res.* **34**(2), 678–683.

Gillot, S. & Héduit, A. 2000 Effect of air flow rate on oxygen transfer in activated sludge in an oxidation ditch equipped with fine bubble diffusers and slow speed mixers. *Water Res.* **34**, 1756–1762.

Gillot, S., Capela-Marsal, S., Carrand, G., Wouters-Wasiak, K., Baptiste, P. & Héduit, A. 2005*a* Fine bubble aeration with EPDM membranes: conclusions from 15 years of practice. In: *Proceedings of the IWA Specialized Conference, Nutrient Management in Wastewater Treatment Processes and Recycle Streams*, Krakow, 18–21 September 2005.

Gillot, S., Capela-Marsal, S., Roustan, M. & Heduit, A. 2005 Predicting oxygen transfer of fine bubble diffused aeration systems – model issued from dimensional analysis. *Water Res.* **39**(7), 1379–1387.

Groves, K. P., Daigger, G. T., Simpkin, T. J., Redmon, D. T. & Ewing, L. 1992 Evaluation of oxygen transfer efficiency and alpha-factor on a variety of diffused aeration systems. *Water Environ. Res.* **64**(5), 691–698.

Higbie, R. 1935 The rate of absorption of a pure gas into a still liquid during a short time of exposure. *Trans. Am. Inst. Chem. Eng.* **31**, 365–389.

Mueller, J. A., Boyle, W. C. & Pöpel, H. J. 2002 *Aeration: Principles and Practice*. Water Quality Management Library, Boca Raton.

NFEN-12255-15 2004 *European Standard: Wastewater treatment plants - Part 15: Measurement of the oxygen transfer in clean water in aeration tanks of activated sludge plants*. 17 p.

Pöpel, H. J. & Wagner, M. 1994 Modelling of oxygen transfer in deep diffused-aeration tanks and comparison with full-scale plant data. *Water Sci. Technol.* **30**(4), 71–80.

Rieth, M. G., Chiesa, S. C. & Polta, R. C. 1995 Effects of operational variables on the oxygen transfer performance of ceramic diffusers. *Water Environ. Res.* **67**(5), 781–787.

Rosso, D., Iranpour, R. & Stenstrom, M. K. 2001 Fine pore aeration – Fifteen years of off-gas transfer. In: *Proceedings of the 74th Annual Water Environment Federation Technical Exposition and Conference*, Atlanta, Georgia, USA.

Rosso, D., Iranpour, R. & Stenstrom, M. K. 2005 Fifteen years of off-gas transfer efficiency measurements on fine pore aerators: key role of sludge age and normalized air flux. *Water Environ. Res.* **77**(3), 266–273.

Rosso, D. & Stenstrom, M. K. 2006 Surfactant effects on γ-factors in aeration systems. *Water Res.* **40**, 1397–1404.

Wagner, M. 1999 Factor influencing the magnitude of alpha-values of fine bubble aeration systems. In: *Proceedings of the 72nd Annual Water Environment Federation Technical Exposition and Conference*, New Orleans, Louisiana, USA.

Wagner, M. & Von Hoessle, R. 2003 Biological coating of fine bubble diffusers with EPDM-membranes. In: *Proceedings of the 76th Annual Water Environment Federation Technical Exposition and Conference*, Los Angeles, California, USA.