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INFLUENCE OF DISSOLVED OXYGEN ON NITRIFICATION KINETICS IN A CIRCULATING BED REACTOR

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ABSTRACT

The influence of dissolved oxygen concentration in nitrification kinetics was studied in a new biofilm reactor, the circulating bed reactor (CBR). The study was carried out partly at laboratory scale with synthetic water containing inorganic carbon and nitrogen compounds, and partly at pilot scale for secondary and tertiary nitrification of municipal wastewater.

The experimental results showed that either the ammonia or the oxygen concentration could be limiting for the nitrification rate. The transition from ammonia to oxygen limiting conditions occurred for an oxygen to ammonia concentration ratio of about 1.5 - 2 $gO_2/gN\text{-}NH_4^+$ for both laboratory- and pilot-scale reactors. The nitrification kinetics of the laboratory-scale reactor was close to a half order function of the oxygen concentration, when oxygen was the rate limiting substrate. © 1998 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Nitrification; biofilm; kinetics; oxygen; circulating bed reactor; biological oxygen monitor.

INTRODUCTION

In general, ammonia removal from wastewater is problematic because of the low growth rate and growth yield of the bacteria involved. Immobilization of biomass in the form of biofilms is an efficient method to retain slow growing microorganisms in continuous flow reactors. One of the main problems in aerobic biofilm operations is the transport of oxygen to the fixed microorganisms. Generally the oxygen penetration depth in biofilms ranges from 100 to 200 µm (van Loosdrecht *et al.*, 1993). Thus, in some cases, oxygen mass transfer may be the limiting step controlling the nitrification rate.

This study is aimed at investigating the influence of dissolved oxygen in the kinetics of ammonia removal in a circulating bed reactor at laboratory and pilot scales.

MATERIALS AND METHODS

The circulating bed reactor (CBR), as shown in Fig. 1, is a three-phase bioreactor. It has a rectangular geometry and is divided into two sections: an upflow aerated section (the riser) and a downflow non-aerated section (the downcomer). The support for the biomass (24% v/v) is an irregular plastic granular product with a diameter between 0.5 mm and 3 mm and an average density of 0.9 g/m^3. A homogeneous three-phase circulation (liquid-gas-solid) is induced by the injection of air in the riser.

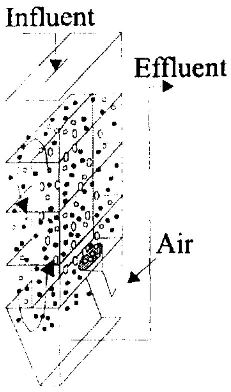

Figure 1. The CBR configuration.

The study was carried out either at laboratory scale with synthetic water containing inorganic carbon and nitrogen compounds, or at pilot scale for secondary and tertiary nitrification of municipal wastewater. The experimental procedure is summarized in the diagram shown in Fig. 2.

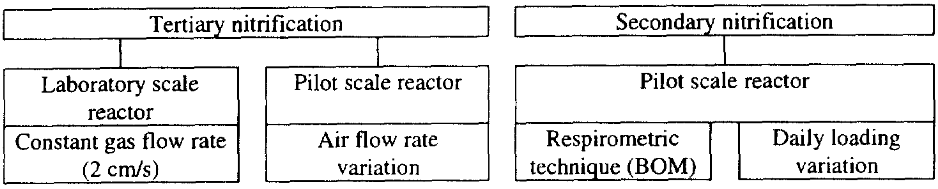

Figure 2. Diagram of the experimental procedure.

Laboratory-scale reactor

The effect of dissolved oxygen on nitrification kinetics was studied by manipulating the oxygen partial pressure in the incoming gas and thereby the dissolved oxygen in the reactor.

Pilot-scale reactor

A biological oxygen monitor (BOM) was used for the measurement of the nitrification rates of biofilm particles taken from the reactor. The respirometric method used was based on that described by Cech *et al.* (1984), adapted for the case of biofilm particles. Nitrification rates were measured at different initial dissolved oxygen and ammonia concentrations.

The biofilm mass was estimated by means of total protein (TP) measurements according to the method of Lowry (SIGMA Diagnostics, Protein Kit Assay no. P5656) adapted by Lazarova *et al.* (1994) for biofilms. Ammonia, nitrite and nitrate were measured according to *Standard Methods.*

RESULTS AND DISCUSSION

Nitrification kinetics

The biofilm development on the support particles began with cell attachment and biofilm formation on the surface macroporosities. Afterwards, the biofilm spread from the macropores until the support surface was completely covered by the biofilm (Fig. 3).

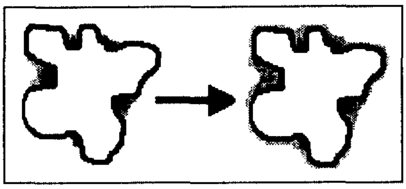

Figure 3. Steps of colonization of the CBR media.

The influence of oxygen concentration on specific nitrification rates is different for these two steps of the biofilm development (Fig. 4, laboratory-scale reactor, tertiary nitrification). The maximum removal rate measured for the completely developed biofilm is almost twice that of those in the partially developed biofim, 1.4 and 0.8 kgN-NH_4^+ kgTP^{-1} d^{-1} respectively. However, the transition value of the bulk oxygen concentration for which diffusion limitation appears is also higher.

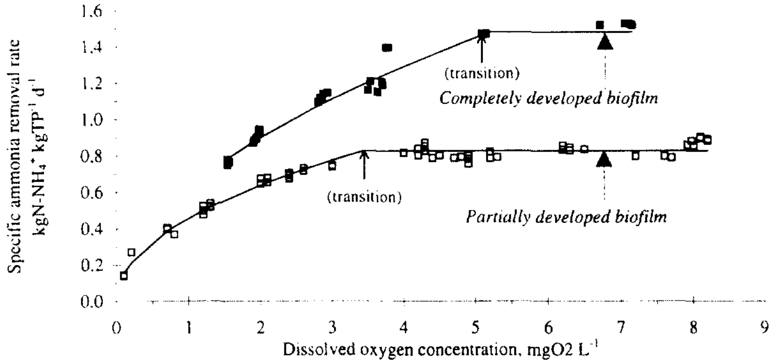

Figure 4. Influence of dissolved oxygen on the specific ammonia removal rate in the laboratory-scale reactor for two types of biofilm development (TP, total protein in the biofilm).

The experimental results fit well in diffusion reaction models of zero order (higher oxygen concentrations) and half order (lower oxygen concentrations). The oxygen diffusion coefficient, 1.75 x 10^{-9} m^2 s^{-1}, estimated by fitting the diffusion-reaction models of zero order and half order to the experimental results (Harremöes, 1978), was around 66% of the respective value in water. The dissolved oxygen concentration for which a change in the order of reaction was observed, i.e. half order to zero order reaction, depends on the fraction of coverage of the support media by the biofilm. The transition values are 3.4 and 5.2 mgO_2 l^{-1}, respectively, for the cases of the partially covered and completely covered by the biofilm support. The increase in the transition value could be related to the higher amount of biomass on the support, increasing the resistance of oxygen transfer into the biofilm.

In order to illustrate the nitrification kinetics in the pilot-scale reactor with secondary effluent as feed water (secondary nitrification), the specific biofilm activity determined using the respirometric technique was plotted as a function of oxygen for different ammonia concentrations (Fig. 5). These data indicate a gradual transition from the first order reaction, observed at lower oxygen concentrations, to a half order reaction and to a zero order reaction at higher oxygen concentrations. The transition value from the first order reaction to the half order reaction is 4.5 $mgO_2\ l^{-1}$ for the bulk oxygen concentration. The maximum specific biofilm activity (zero order reaction) depends on bulk ammonia concentration.

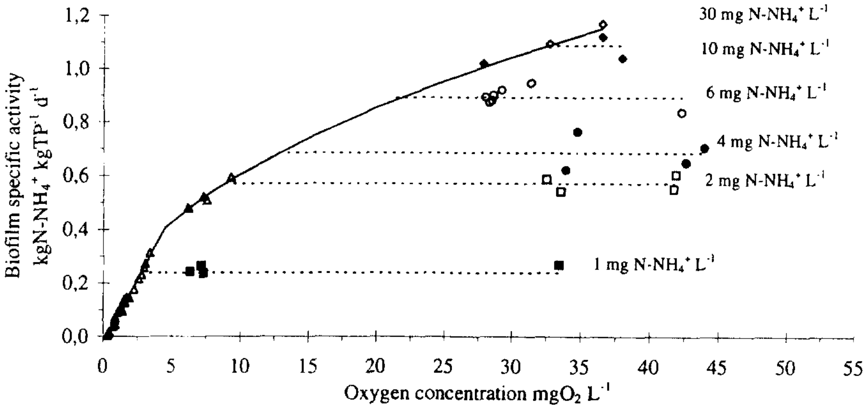

Figure 5. Influence of dissolved oxygen on biofilm specific activity for different bulk concentrations of ammonia nitrogen.

The first order reaction could be the result of two phenomena:

(i) The biological reaction rate constants obtained from the respirometric tests may be distorted by oxygen transfer limitation in the respirometer. According to Young and Baumann (1976), mixing intensity and reactor geometry are the two major factors affecting oxygen uptake measurements in a respirometer.

(ii) The higher organic loads in conditions of secondary nitrification promote the growth of heterotrophs in the biofilm (forming a double layer of microorganisms together with the autotrophic population), possibly increasing the oxygen limitation in the inner layers (nitrifying microorganisms).

Nitrification rate limiting phenomena

Figure 6 presents the ammonia removal efficiency as a function of bulk oxygen to ammonia concentration ratio for the laboratory- and pilot-scale reactors.

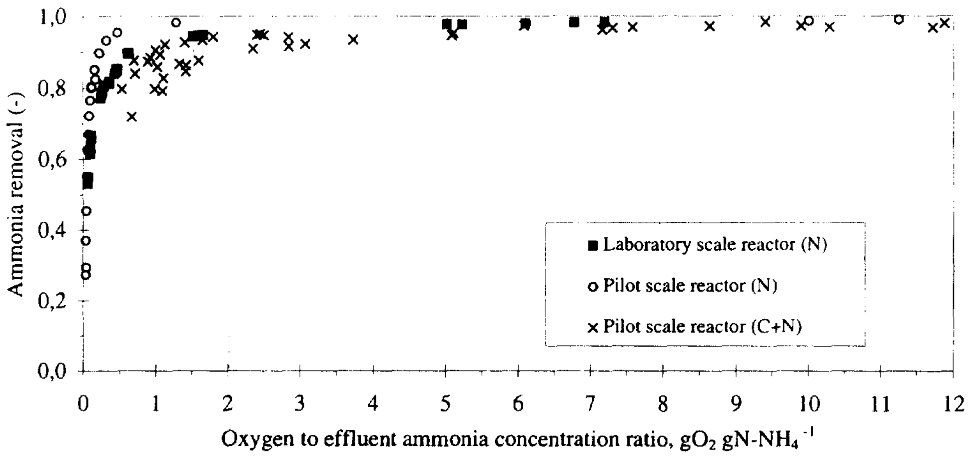

Figure 6. Influence of bulk oxygen to ammonia concentration ratio on nitrification efficiency in three different CBR reactors.

The transition from ammonia to oxygen limiting conditions occurs for an oxygen to ammonia concentration ratio of about 1.2-2 gO_2 $gN\text{-}NH_4^{-1}$ for both laboratory- and pilot-scale CBRs. This value is lower than those reported in the literature, 2.5-4 gO_2 $gN\text{-}NH_4^{-1}$ (Hem *et al.*, 1994). This discrepancy could be due to the high turbulence in the CBR which results in thinner biofilm, thus minimizing the external and internal resistances to oxygen mass transfer.

CONCLUSIONS

The main conclusions to be drawn from the present work are:

- The good hydrodynamic performances of the CFBR (high turbulence and mixing) contribute to the formation of thin and highly active biofilms with high specific nitrification rates up to 1.4 $kgN\text{-}NH_4^+$ $kgTP^{-1}$ d^{-1}.
- Diffusion reaction models of zero order (higher oxygen concentrations) and half order (lower oxygen concentrations) fit the experimental results well. The oxygen diffusion coefficient estimated by fitting the models of zero order and half order to the experimental results was around 66% of the respective value in water.
- For oxygen to ammonia concentration ratios below 1.5-2 gO_2 $gN\text{-}NH_4^{-1}$, the nitrification rate is oxygen limited. Above this value, ammonia is the rate limiting substrate.

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