Experimental determination of the heterotroph anoxic yield in anoxic-aerobic activated sludge systems treating municipal wastewater

AW Muller[1], MC Wentzel[1]* and GA Ekama[1]

[1]*Water Research Group, Department of Civil Engineering, University of Cape Town, Rondebosch 7701, South Africa*

Abstract

This paper describes experimental research to directly quantify the ordinary heterotrophic organism (OHO) cell yield coefficient under anoxic and aerobic conditions with real wastewater as substrate. Until recently these two values were assumed equal in activated sludge models, despite theoretical predictions that the anoxic yield should be reduced relative to its aerobic value. In this study, parallel aerobic and anoxic batch tests were conducted on the same mixtures of wastewater and mixed liquor drawn from anoxic-aerobic activated sludge systems. By equating the readily biodegradable (RB)COD concentrations in the aerobic and anoxic batch tests, the anoxic yield was determined in terms of the respective measured oxygen and nitrate utilisations and the aerobic yield. Additionally, the aerobic and anoxic yield coefficients were directly determined by using defined quantities of the artificial RBCOD acetate. The wastewater batch tests demonstrated that the OHO anoxic yield is reduced to approximately 81% (0.54) of the aerobic value (0.67 mgCOD/mgCOD). The anoxic:aerobic yield ratio (0.81) was confirmed independently in the acetate batch tests at 0.84, and closely equals that predicted theoretically from thermodynamic and bioenergetic principles (0.83). From these investigations, it is recommended that the OHO anoxic yield be decreased to 0.54 for an aerobic yield value of 0.67 mgCOD/mgCOD.

Introduction

Integral to the biological nutrient removal (BNR) activated sludge system is the biologically mediated process of denitrification. Accordingly, biological denitrification has been explicitly incorporated into the steady-state design (e.g. WRC, 1984; Wentzel et al., 1990) and kinetic simulation (e.g. Van Haandel et al., 1981; Henze et al., 1987; Dold et al., 1980, 1991; Gujer et al., 1999) models developed as aids to the design and operation of BNR activated sludge systems. In both sets of models, critical as input to quantify the denitrification is the value for the ordinary heterotrophic organism (OHO) cell yield coefficient under anoxic conditions ($Y_{H,NO}$). In terms of the models, the heterotrophic cell yield coefficient, Y_H, (designated here $Y_{H,NO}$ for anoxic conditions and $Y_{H,AE}$ for aerobic) determines both the mass of electron acceptor utilised and the new cell biomass produced. In activated sludge systems treating municipal wastewaters, the effect of $Y_{H,NO}$ on sludge production typically is small, since the mass of sludge produced under anoxic conditions is small compared with that produced under aerobic conditions, due to the relatively low influent TKN/COD ratios (Barker and Dold, 1997). In contrast, the effect of $Y_{H,NO}$ on the amount of denitrification achievable (and hence, on system design and operation) is quite significant.

In the IWA Task Group models for activated sludge systems, ASM1 (Henze et al., 1987), ASM2 (Henze et al., 1995) and ASM2d (Henze et al., 1999), and similar (e.g. Dold et al., 1991; Wentzel et al., 1992), Y_H is assumed to have the same value under anoxic as under aerobic conditions. However, when nitrate serves as terminal electron acceptor, *ideally* only 2 ATP are formed per pair of electrons (e^-) transferred to nitrate compared with 3 ATP when the transfer is to oxygen (Payne, 1981; WRC, 1984; Kuba et al., 1993; Casey et al., 1999; Wentzel et al., 2003). This difference reduces the energy captured by the organism when nitrate serves as electron acceptor (versus oxygen) in biological oxidation of organic substrate. Correspondingly, therefore, the cell yield under anoxic conditions ($Y_{H,NO}$) should be reduced relative to its aerobic value ($Y_{H,AE}$).

Based on bioenergetic principles set out by McCarty (1971, 1972, 1975), Orhon et al. (1996) theoretically quantified the anoxic to aerobic yield ratio for four organic substrates, municipal wastewater, protein, lactate and carbohydrate, and obtained respective anoxic:aerobic yield ratios of: 0.79, 0.80, 0.80, and 0.85. Accepting the standard aerobic heterotrophic yield value of 0.67 mgCOD/mgCOD used in ASM1 and similar models, this gives an anoxic yield of 0.53 mgCOD/mgCOD for municipal-type wastewaters as substrate. Similarly, based on thermodynamic and bioenergetic principles, Muller et al. (2003a) showed that theoretically the anoxic cell yield coefficient ($Y_{H,NO}$) is about 83% of its aerobic value ($Y_{H,AE}$).

Although limited, several studies reported in the literature (reviewed by Muller et al., 2003a) provide direct and indirect experimental evidence supporting the theoretical assessment that the anoxic cell yield should be reduced relative to its aerobic counterpart. For these studies an average anoxic:aerobic cell yield ratio was calculated as 0.81 ± 0.035, or about 0.54 mgCOD/mgCOD (range 0.52 – 0.57) with respect to the standard aerobic yield of 0.67 mgCOD/mgCOD (Muller et al., 2003a) (The ± symbol denotes standard deviation throughout the paper except where indicated otherwise). This substantiates the theoretical evaluations above that the anoxic yield should be reduced relative to its aerobic value.

While a reduced heterotrophic yield under anoxic conditions is apparent from bioenergetic theory and supported by experimental

This paper was originally presented at the 2004 Water Institute of South Africa (WISA) Biennial Conference, Cape Town, South Africa, 2-6 May 2004.

* To whom all correspondence should be addressed.
☎+2721 6502583; fax:+2721 6897471; e-mail: markw@eng.uct.ac.za