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# A new interpretation of endogenous respiration profiles for the evaluation of the endogenous decay rate of heterotrophic biomass in activated sludge

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ABSTRACT

In current activated sludge models aerobic degradation, resulting in loss of activity and mass of activated sludge is expressed with only one process called decay. The kinetics of this process is regarded to be first order and constant with respect to the loading conditions. In this work twelve aerobic digestion batch experiments were conducted for the activated sludge of seven different water resource recovery facilities (WRRFs). An analysis of the obtained respirograms shows three clearly distinguishable phases. The first phase is assumed to be due to the degradation of stored material ($X_{STOR}$) and active biomass simultaneously. The second phase is exclusively due to the degradation of active biomass that is regarded to consist mainly of ordinary heterotrophic biomass ($X_{OHO}$). The first order decay rate is slower than the degradation rate in phase 1 and varies between samples. The decay rate correlates with the activity of the activated sludge expressed as the ratio of initial heterotrophic OUR and the initial organic fraction $X_{ORG}$ of the activated sludge. This second phase was detectable until day 5 of most of the experiments. After that time within phase 3 the OUR decrease slows down and the OUR even increased for short intervals. This behaviour is thought to be due to the activity of higher organisms and the adaptation of microorganisms to starvation.



## 1. Introduction

One of the main objectives of activated sludge modelling is the prediction of sludge production in WRRFs. On the one hand, sludge production is the result of biomass growth and unbiodegradable material accumulation. On the other hand, particularly in systems with a longer solid retention time (SRT), growth antagonistic processes play an important role. These processes are generally described as lysis or decay of active biomass and slow degradation of other organic material (Henze et al., 2000).

Experimentally it is common practise to use aerobic batch digestion experiments to gain information about the processes that are involved in degradation of activated sludge (Spanjers and Vanrolleghem, 1995, 1996). The assumption is that this information is representative to describe decay in an environment where decay and growth takes place simultaneously. The metabolic explanation of these processes is expressed in concepts like endogenous respiration (Gujer et al., 1999), death-regeneration (Dold et al., 1980), maintenance (Loosdrecht van and Henze, 1999) or predation (Moussa et al., 2005). All these concepts are based on the assumption

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that organic material ($X_{ORG}$) in activated sludge consists of a biodegradable fraction ($X_{ORG,DEG}$) and an unbiodegradable fraction ($X_{ORG,U}$).

$$XORG = XORG,DEG + XORG,U \ (mg\ COD/l) \quad (1)$$

To convert organic material that is measured as volatile suspended solids (VSS) into chemical oxygen demand (COD) units typically a constant factor $f_{CV} = 1.42$ g COD/g VSS is used (Henze et al., 2000).

The biodegradable fraction ($f_{DEG}$) of $X_{ORG}$ in long SRT systems consists overwhelmingly of ordinary heterotrophic organisms ($X_{OHO}$), whereby for reasons of simplicity the very small fraction of autotrophic active biomass is included in $X_{OHO}$. However, $X_{OHO}$ has an unbiodegradable fraction $f_U$ that is called endogenous residue ($f_U{}^*X_{OHO}$) and is a left over from the degradation of active biomass $X_{OHO}$.

$$X_{ORG,DEG} = X_{ORG} \cdot f_{DEG} = (1 - f_U) \cdot X_{OHO} \ (mg\ COD/l) \quad (2)$$

The pool of unbiodegradable organic material ($X_{ORG,U}$) is fed by unbiodegradable organic compounds from the influent ($X_{ORG,U,inf}$) and by $X_{OHO}$ in terms of endogenous residue.

$$X_{ORG,U} = X_{ORG,U,inf} + f_U \cdot X_{OHO} X_{ORG,DEG} = X_{ORG} \cdot f_{DEG} = (1 - f_U) \cdot X_{OHO} \ (mg\ COD/l) \quad (3)$$

In the endogenous respiration concept the biodegradable fraction of $X_{OHO}$ is regarded as a homogenous substrate that undergoes self-destruction in the absence of external substrate. The degradation process of $X_{OHO}$ is modelled with Eq. (4) and Eq. (5), where the rate constant of degradation is generally called the decay rate parameter (b). In activated sludge models, the decay rate parameter is assumed to be constant.

$$\frac{dX_{OHO}}{dt} = -b_{OHO} \cdot X_{OHO} \quad (4)$$

$$X_{OHO(t)} = X_{OHO(0)} \cdot e^{-b_{OHO} \cdot t} \ (mg\ COD/l) \quad (5)$$

The concentration of $X_{ORG}$ at any time within a degradation experiment can be expressed with Eq. (6) and is referred as the VSS based method to determine the decay rate $b_{OHO}$ (Ramdani et al., 2010):

$$X_{ORG(t)} = X_{ORG,U,inf} + f_U \cdot X_{OHO} + (1 - f_U) \cdot X_{OHO(0)} \cdot e^{-b_{OHO} \cdot t} X_{OHO(t)} = X_{OHO(0)} \cdot e^{-b_{OHO} \cdot t} \ (mg\ COD/l) \quad (6)$$

The endogenous respiration is limited by the internal carbon source that is $(1 - f_U)^*X_{OHO}$. The endogenous respiration rate $OUR_{OHO}(t)$ during the aerobic degradation experiment is modelled with Eq. (7) and Eq. (8) and refers to the OUR based method to determine the decay rate $b_{OHO}$ (van Haandel et al., 1998; Ramdani et al., 2010):

$$OUR_{OHO}(t) = (1 - f_U) \cdot \frac{X_{OHO}}{dt} \quad (7)$$

$$OUR_{OHO}(t) = (1 - f_U) \cdot X_{OHO}(0) \cdot b_{OHO} \cdot e^{-b_{OHO} \cdot t} \ (mg\ O_2/(l * h)) \quad (8)$$

Solving Eq. (8) for t = 0 yields:

$$OUR_{OHO}(0) = (1 - f_U) \cdot X_{OHO}(0) \cdot b_{OHO} \ (mg\ O_2/(l * h)) \quad (9)$$

Rearranging Eq. (9) for $b_{OHO}$ shows, that a constant decay rate implies a constant ratio of $OUR_{OHO}(0)$ to $X_{OHO}(0)$.

$$\frac{OUR_{OHO}(0)}{(1 - f_U) \cdot X_{OHO}(0)} = b_{OHO}(h^{-1}) \quad (10)$$

It is important to note that in this model the degradation characteristics of $X_{OHO}$ are independent of the loading of external substrate in the WRRF. Therefore the endogenous decay rate parameter is independent of the F/M ratio and independent of the SRT.

Experimental evidence for the validity of the endogenous respiration model comes from Marais and Ekama (1976). Using the OUR method, the value of $b_{OHO}$ was found to be 0.24 $d^{-1}$ and independent from SRT in the range of 2.5–30 days. Similar results were obtained by van Haandel et al. (1998), who extended the measured parameters by the degradable VSS, the formed nitrate and the loss of alkalinity. In a more recent work of Ramdani et al. (2010), activated sludge was fed with acetate and produced a decay rate of 0.23 $d^{-1}$ for a SRT of 5 and 10 days for both the VSS and the OUR method.

However, from the literature review that is summarized in Table 1 it can be stated that:

The reported **endogenous decay rates** $b_{OHO}$ vary significantly between values of 0.059 $d^{-1}$ and 0.500 $d^{-1}$.

Data for heterotrophic decay rates were reported for four **methods**. The largest number of reported decay rates are based on the above described OUR and VSS based method. There are a few references that show decay rates which were determined with the $OUR_{max}$ method, where not the endogenous respiration but the respiration at substrate saturation was measured and linearized over the time of an aerobic digestion batch experiment. Two references used the DNA concentration instead of respiration as a parameter to correlate the active biomass concentration in the liquid. The method used in the respective experiment appears to have an influence on the decay rate. In general the OUR and the VSS based methods yield higher decay rates than using the DNA concentration or the $OUR_{max}$ at substrate saturation to describe the decay process. This observation indicates that there might be a difference in endogenous degradation of VSS and in the reduction of activity or viability of active biomass.

The **quality** of the degradation experiments are mostly expressed in terms of $R^2$ with respect to the linearized data. Thereby it is common practice to regard a reaction with data of $R^2 > 0.95$ as a first order reaction and the substrate that is used up as homogenous. In reality the data can reveal even at higher $R^2$ a series of different degradation characteristics. However, crucially only a small number of references published the results of the COD balance over the experiment although this is a very important method to show the reliability of the data. Especially the use of open respirometers results in the intrusion of oxygen via the open liquid surface and will affect the COD balance and the decay rate parameter.

There is very little information in the literature about the **initial characteristics of** the used **activated sludge**. From Eq. (10) it is evident that OUR(0) and VSS(0) associated with the degradable fraction of VSS is a very important additional information to explain the measured decay rate.