Designed to Characterise Activated Sludge Biokinetics

Filip Coen & Peter Vanrolleghem
Department of Applied Mathematics, Biometrics and Process Control (BIOMATH)
University of Gent, Coupure 653, B-9000 Gent, Belgium

Introduction

Aim = Study of the Dynamic Responses of a Biological System

Biological System = Activated Sludge in Batch Respirometer
Biological process = Aerobic respiration

Method = Relaxation Times Concept

Influence of one or more physical or biological mechanisms
⇓
Characteristic : Relaxation Time of the mechanism (Fig. 1)
⇓
Insight in complexity of biosystem

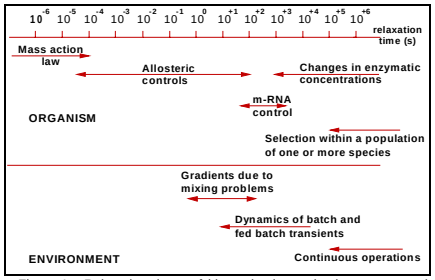

Figure 1. Relaxation times of biosynthesis mechanisms compared to relaxation times of the environment (Roels, 1983)

The phenomena that were observed, can be classified into **3 main categories** characterised by their time constants :

1) Time constant less than one minute
2) Time constant in the order of minutes
3) Time constant of a few hours

Time constant < 1 minute

Experiment

Pulse of Acetate dosed to batch respirometer RODTOX (Kelma bvba, Niel, Belgium). DO and OUR are recorded (Fig 2). Only after several minutes a maximum OUR is reached. Three hypotheses were evaluated to explain this 'start-up' phenomenon : DO probe response, inadequate mixing and substrate diffusion.

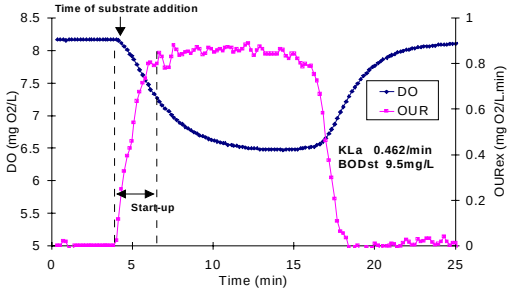

Figure 2. DO and OUR-profile recorded by the RODTOX.

Mechanisms

1. Probe response

Endress and Hauser Conducta 905 : Time constant of 55 seconds (Fig. 3). Assumption of a first order electrode model and knowledge of the model parameters allows to calculate the actual dissolved oxygen concentration S_{O2} from the electrode output E.

$$S_{O2} = \tau \frac{dE}{dt} + E$$

2. Mixing

The OUR 'start-up' phenomenon may also be caused by inadequate mixing in the respirometer vessel. This may result in different respiration rates depending on the local substrate concentration. Figure 3 shows the mixing properties of the respirometer measured with the colouring method. One can see that mixing in the batch reactor occurs significantly faster than the observed transient behaviour.

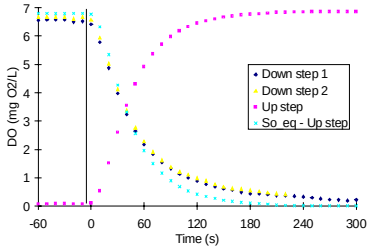

Figure 3. Response of DO-probe

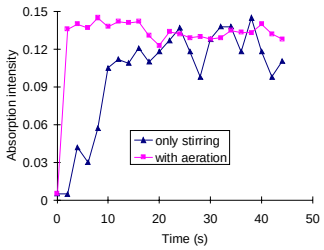

Figure 4. Mixing characteristics in the respirometer

3. Diffusion in the sludge floc

Theoretic estimation of diffusion limitations for oxygen and acetate :

$$\tau_D = \frac{\delta^2}{D_b} \quad \textit{with} \ \delta = \textbf{biofilm thickness (mm)}$$

D_b = **diffusion constant (mm² / s)**
τ_D = **diffusion time constant (s)**

	Diffusion constant (μm²/s)	Diffusion time (s)
Oxygen	2500	16
Acetate	1240	40

- No reaction is assumed => calculated time constants are maximum values.
- Diffusion : possible explanation for the observed 'start-up' phenomenon.

Experimental approach : Comparison of pure culture response with activated sludge response (Fig. 5)
⇓ no diffusion limitations
⇓ diffusion limitations ?

'Start up' phenomenon also in pure culture => NO DIFFUSION LIMITATION IN THE SLUDGE FLOC

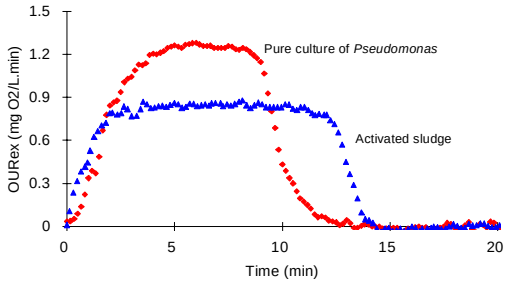

Figure 5. OUR profile for addition of acetate to a *Pseudomonas aeruginosa* culture and an activated sludge mixture

Time constant in the order of 10 minutes

Method : Addition of three pulses of acetate to sludge in starvation regime (Fig. 6)

Observation :

- **First and second OUR profile** : gradual speed-up of respiration rate (max. OUR after 12 min.)
- **Third profile** : Max. OUR reached after 3 min.

First and second respirogram show a dynamic response with a time constant in the range of 10 minutes.

Explanation :

- History of the sludge has impact on the OUR-profiles
- Availability of substrate induces a response at the level of enzymatic breakdown of the substrate
  Possible mechanisms :
  m-RNA control of enzyme synthesis
  Regulation and activation at the level of the enzymes (e.g. allosteric control)

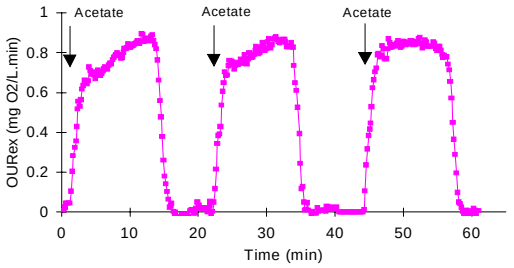

Figure 6. OUR-profiles obtained by addition of acetate to an activated sludge sample

Time constant in the order of hours

Changing loading rate in the respirometer (Fig. 7) => Adaptation response (population shift) with time constants in the range of hours to days (depending on sludge growth rate)

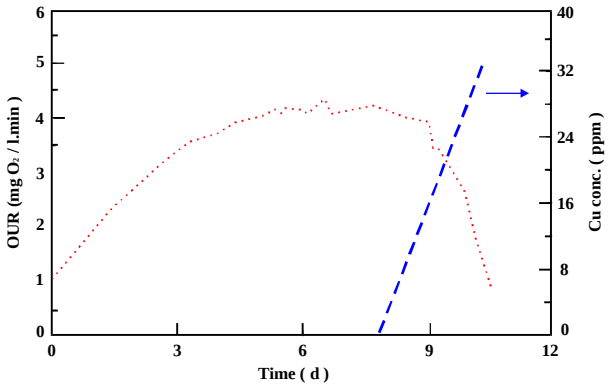

Figure 7. Evolution of maximum OUR of a sludge sample adapting to changed loading rate conditions

Concluding remarks

'Start-up' phenomenon :

Relevant mechanisms	Irrelevant mechanisms
Delay in DO-electrode response	Mixing characteristics of the respirometer
Hypothesis : transport and metabolic reactions inside the cell	Diffusion in the sludge floc

Modelling of the 'start-up' phenomenon :
- probe response : first order model
- Lump model for the intracellular processes : first order model

Enzyme regulation phenomenon :

Time constant of the regulation process was in the order of ten minutes.

Adaptation response

Population shift in respirometer => Representative sludge behaviour of WWTP ?