**Desalination and Water Treatment** 9 (2009) 126–130
www.deswater.com
1944-3994/1944-3986 © 2009 Desalination Publications. All rights reserved

# Optimization of the operations conditions in membrane bioreactors through the use of ASM3 model simulations

J. Lobos[a,b,*], M. Heran[b], A. Grasmick[b]

[a]*Chemical Engineering Department, Universidad de Santiago de Chile, Av. Lib. Bernardo O'Higgins 3363, Casilla 10233, Santiago, Chile*
[b]*Laboratoire Génie des Procédés, Eau et Bioproduits, UMR-CIRAD 016, Université Montpellier II- CC005, 34095, Montpellier Cedex 05, France*
*email: jlobos@usach.cl, heran@univ-montp2.fr, grasmick@univ-montp2.fr*

Received 15 September 2008; Accepted 5 November 2008

## ABSTRACT

The aim of this work was the application of the ASM3 models simulations to obtain most favorable operations conditions in membrane bioreactors for efficient organic matter removal, sludge production reduction and oxygen transfer costs.

Simulations were realized used the ASM3 model (Activated Sludge Model)(Henze *et al.*, 2000) for three theoretical influents. The organic load rate (OLR) and the hydraulic retention time (HRT) were fixed at 1 kg COD $m^{-3}$ $d^{-1}$ and 0.4 $d^{-1}$ respectively and the sludge retention time (SRT) was varied from 2.5 d to 67 d. The steady state values of the active biomass concentration ($X_{BH}$), the total biomass concentration ($X_{SS}$) (active biomass + inert suspended solid), and the oxygen uptake rate (OUR) were obtained for each condition. Thus the observed conversion yield was evaluated ($Y_{OBS}$). The results show that, if the SRT increases, the $X_{BH}$ increases until a maximal value. In the other hand, a constant increase evolution of the $X_{SS}$ is observed, without reach a saturation value. Therefore, the suspended solids accumulation after this maximal value are due to a dilution of the active biomass by inert compounds coming from endogenous respiration and also, inert influent.

If the OLR restricted the amount of active biomass, on the contrary, high SRT induced high $X_{SS}$ concentration, thus generating rheological sludge properties that penalize the phenomena of mixing, oxygenation and membrane separation

***Keywords:*** Wastewater treatment; MBR control; ASM; Active biomass

## 1. Introduction

The biological models endogenous respiration or Activated Sludge Model (ASM1 and ASM3, Henze *et al.*, 2000) are usually used for biological behavior modeling in aerobic wastewater treatment reactors. Both models have showed good results to describe the evolutions of the principal's biological system variables. Compared to ASM1, the ASM3 model has a more realistic description of the biological processes involved, that is, endogenous respiration process and storage composes synthesis. These models are described in figures 1, 2 and 3. These biological models allow the mass balance calculation of each consider variable during the wastewater treatment plant. The variables are usually express as Chemical Oxygen Demand COD as g $O_2$ $L^{-1}$.

### 1.1. The endogenous respiration

The Substrate is used for the biomass growth according to the conversion Yield $Y_{H.}$ This coefficient (g Biomass

---

*Corresponding author.

*Presented at the Conference on Membranes in Drinking and Industrial Water Production, 20–24 October 2008, Toulouse, France.*

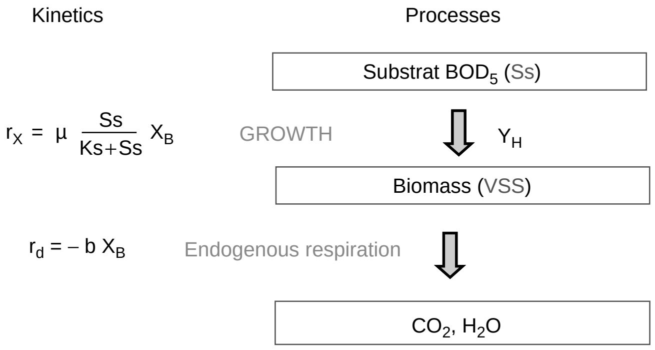

Fig. 1. Endogenous model (Pirt 1965).

formed/g substrate removed) will reduced the part a biomass production in relation to the micro-organisms metabolism. The associated kinetics rate comes from Monod equation. Then the biomass will decay according to the endogenous respiration. This decay leads to gas production which is an open window in the carbon mass balance. In fact, it is very difficult to measure the carbon contains in the gas.

*Remarks:* The endogenous respiration leads to minimize the sludge production due to the transformation of volatile suspended solid (VSS) to gas.

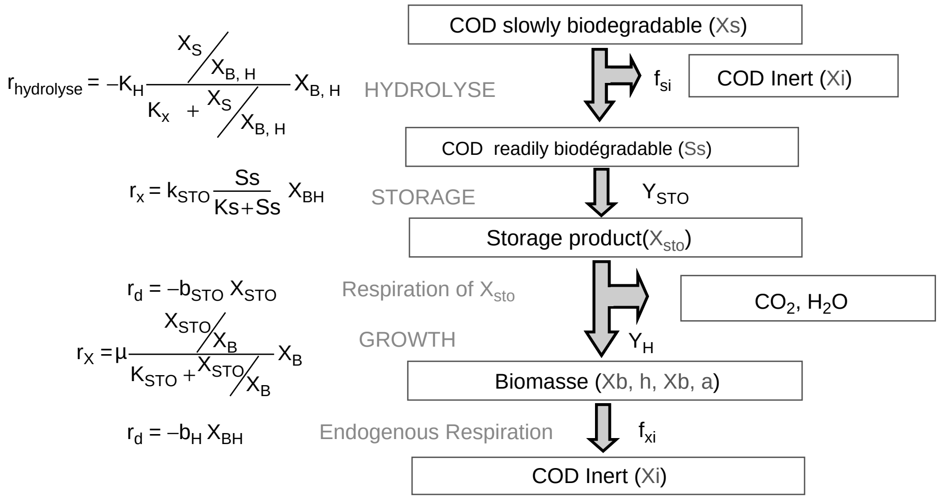

Fig. 2. ASM3 model.

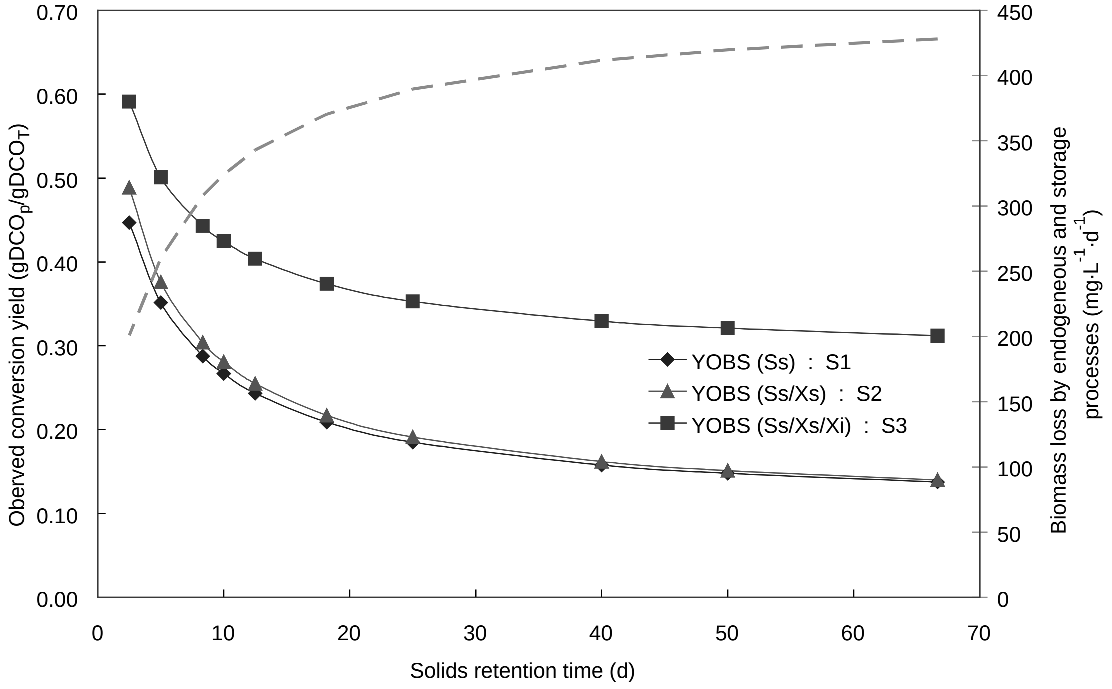

Fig. 3. Influence of Solids retention time and influent cut off on the observed conversion yield.

### 1.2. ASM

Biological activity was also analyzed using the ASM model. Consistent with this model, the COD in the wastewater is split into 2 fractions: Soluble COD ($S_{COD}$) and Particular COD ($X_{COD}$). This COD is thus divided between inert Substrate ($S_i$ or $X_i$) or biodegradable Substrate ($S_s$ or $X_s$). In this model, a slowly biodegradable substrate $X_S$ was added. This (particular: X) substrate ($X_S$) must be hydrolyzed ($X_S \rightarrow S_S$) in order to take part of the microorganisms growth.

### 1.3. ASM3

The concept of storage was introduced, where the substrate must be converted into storage polymer (Xsto) before being transform into active biomass. These equations could explain the quick consumption of soluble substrate (storage) with low oxygen up take rate where the oxygen consumption drag is due to the "slowly" synthesis of active biomass from storage compounds. Then a new open window was introduced in the mass balance: The respiration of storage product (maintenance). On the other hand, the endogenous respiration leads to a fraction $f_{xi}$ of particular inert compounds.

*Remarks*: The respiration of storage product and the endogenous respiration ($1 - f_{XI}$) will reduce the sludge production.

## 2. Materials and methods

The typical values of the stoichiometric and kinetics parameters of the ASM model were used to the simulations (Henze *et al.*, 2000). Several mathematical equations are used to describe the biological process yield in an activated sludge tank. Most of the kinetics rate is based on Michaelis-Menten (Monod) equation. Assuming the concentrations of Oxygen and Nitrogen to be non limiting, the Michaelis functions used for reaction rate (type So/(Koh + So),…,) were taken as equal to the unit. In addition, only the presence of heterotrophic population is interpreted.

Then the concentrations were adjusted in order to reach the steady state where all the accumulation terms (differential term) are equal to zero.

Thus, the ASM3 model was selected to describe the biological behavior of an MBR reactor, working with an organic substrate and with different sludge ages. Three different substrates repartitions were used (Table 1).

The principal variables of the system were simulated used the model equations: total biomass concentration ($X_{SS}$)(active biomass + inert biomass), active biomass concentration ($X_{BH}$) and the oxygen uptake rate (OUR).

Table 1
Substrate cut off: soluble (S1), soluble and particular (S2), soluble, particular and inert compounds (S3).

| | Substrate 1 | Substrate 2 | Substrate 3 |
|---|---|---|---|
| $S_{S0}$ [mg.L$^{-1}$] | 400 | 200 | 200 |
| $X_{S0}$ [mg.L$^{-1}$] | 0 | 200 | 200 |
| $X_{I0}$ [mg.L$^{-1}$] | 0 | 0 | 100 |

## 3. Results and discussion

### 3.1. Sludge production

The sludge production could be calculated with the Observed conversion yield.

This coefficient is egal to the ratio of Effluent COD versus Influent COD. In order to simplify the equation a Inert conversion yield must be introduced. This coefficient, $Y_{inert}$, is the fraction of inert compound in the influent:

$$Y_{inert} = \frac{X_{I0}}{X_{I0} + X_{S0} + S_{S0}} \tag{1}$$

Endogenous respiration:

$$Y_{obs.} = Y_{inert} + (1 - Y_{inert}) \frac{Y_H}{1 + SRT\, b_h} \tag{2}$$

ASM3:

$$Y_{obs.} = Y_{inert} + (1 - Y_{inert}) \left[ \frac{Y_H\, Y_{STO}\, SRT}{5.16\,SRT - 4} + \frac{1}{0.8\,SRT - 3.9} + \frac{1}{0.8\,SRT + 3.9} \right] \tag{3}$$

Due to the size of the ASM3 conversion yield, only its numerical expression is written.

The conversion yield (the sludge production) is first a function of particular inert compound, then a function of the biological process used.

For example, with high Sludge Retention Time, the endogenous respiration concept leads to a complete disappearance of the organics compounds (i.e.: $Y_{obs.} = Y_{inert}$) due to the transformation of volatile suspended solid (VSS) to gas during the endogenous respiration.

On the other hand, for ASM3 under high sludge age, the main parameters which translate the sludge production are:

$$SRT \rightarrow \infty$$

$$Y_{obs.} = Y_{inert} + (1 - Y_{inert}) \frac{f_{XI}\, Y_H\, Y_{STO}}{\frac{Y_H\, b_{STO}\, K_{STO}}{\mu - b_h} + 1} \tag{4}$$

$Y_H$, $Y_{STO}$: the metabolic conversion yield
$b_{STO}$, $K_{STO}$: the storage coefficient

Once, the dependency between the sludge retention time and the conversion yield were link, their evolution versus time were drawn (Fig. 1).

The results show that there is no substrate conversion limitation due to hydrolysis or storage processes. In fact, the conversion yield for S1 (soluble substrate) is very close to the one for S2 (soluble and particular substrate). Then the difference between S1, S2 and S3 is due to the fraction of inert compound in the influent ($Y_{inert} = 0.2$) (Eq. (2)).

The change of the conversion yield versus SRT is major due to the biomass loss by endogenous respiration and storage processes: $(1 - f_{XI})\ b_H\ X_{BH} + b_{STO}\ X_{STO}$ (Fig. 2).

### 3.2. Sludge composition

For a given organic load, $X_{BH}$ concentration increases with SRT. This evolution is rapid for weak SRT, followed by a « critical » SRT after which $X_{BH}$ increases far more slowly or does not change at all for high biomass retention times. The « critical » SRT value was chosen as equal to that when $X_{BH}$ attains 90 % of the stabilized value after 100 days of operation.

Thus it is interesting to note that, for all influent tested, the « critical » SRT value was close to 30 days. Therefore, **working with sludge ages over 30 days, offers no significant saving in terms of stabilized active biomass in the reactor**. On the contrary, this may be unfavorable in terms of total $X_{SS}$ concentration (Fig. 4) which proves to be far higher than $X_{BH}$ thus generating rheological sludge properties that penalize the phenomena of mixing, oxygenation (Fig. 5) and membrane separation.

At a SRT of 30 days, the active biomass represents less than 18% of the TSS (Fig. 4). In fact, the active biomass is diluted into the total suspended solids due to the concentration factor ($C_F$ = SRT/HRT) and the endogenous respiration which increase the inert suspended solid concentration in the tank. According to ASM3 concept,

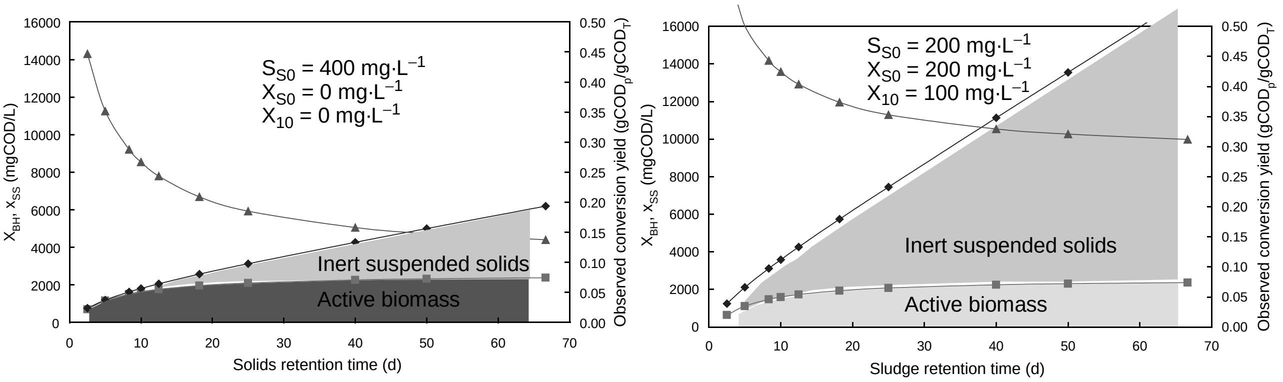

Fig. 4. Influence of Solids retention time and influent cut off on suspended solids concentration.

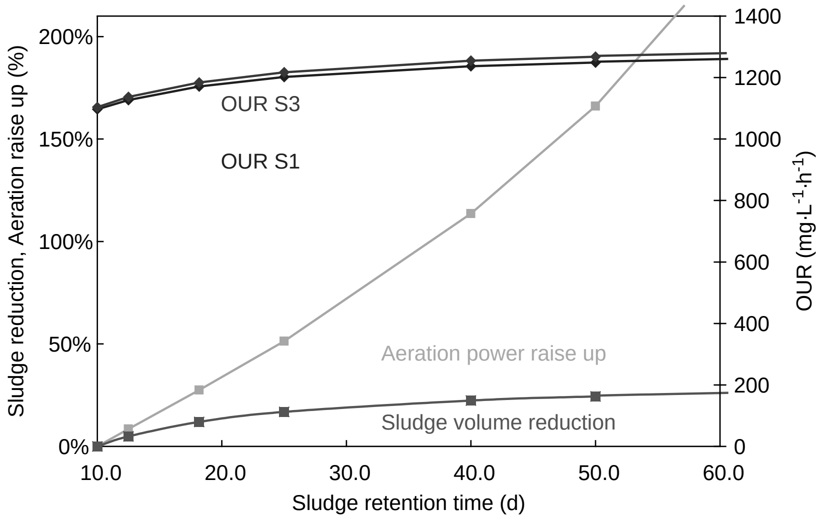

Fig. 5. Influence of Solids retention time on sludge reduction and energy consumption.

the steady state inert compounds are due to the influent and to the endogenous respiration (Eq. (5)):

$$X_I = C_F\, X_{I0} + SRT\, f_{XI}\, b_H\, X_{BH} \qquad (5)$$

At a SRT of 30 days, the concentration factor is egal to 75 ($C_F$= 30/0.4) and raises the inert suspended solids due to the initial influent concentration (0.15 g $L^{-1}$) to 7.5 g $L^{-1}$ inside the reactor.

### 3.3. Aeration power and sludge reduction

It is possible to calculate the energy consumption in order to supply the oxygen required for the micro-organisms. As indicated by Drews et Kraume, 2005, who considered that the oxygen transfer coefficient ($K_La$) decreases with rising biomass concentration, the oxygen supply was calculated according to Eq. (6):

$$\Phi_{O_2} = \alpha\, K_{la}\, (C^* - C) \quad \text{where} \quad \alpha = e^{-0.08788 \cdot TSS} \qquad (6)$$

If the oxygen required for the micro-organisms slowly increase with SRT, the aeration cost increases so hard that the profit of the SRT on the sludge reduction is quickly counterbalanced by the aeration cost (Fig. 5).

These results highlight several major points:

- For a constant OLR and once the solids retention time is set up, the $X_{BH}$, $X_S$, and $X_I$ and the OUR requirements reach constant values (steady state conditions).
- $Y_{OBS}$ decreases when the solids retention time increases due to the open window in the mass balance (Biomass loss by Endogenous respiration and storage product consumption).
- No significant decrease in the $Y_{OBS}$ is observed after a SRT equal to 30 d.
- $X_{BH}$ increases shortly when the solids retention reaches a certain value whereas the Total Suspended Solids increases steadily with SRT.
- Consequently, a strong influence of the inert influent concentration is observed on the TSS. This values is linked to the Concentration factor: SRT/HRT.
- Then, if a nearly constant value of the oxygen requirements is reached, the aeration power increases strongly due to the bad oxygen transfer efficiency under high concentration.

## 4. Conclusion

If the organic loads directly impact the active biomass, an adapted retention time allows the reduction of Total suspended solid while optimizing the active biomass concentration. These simulations highlight the operating conditions that favor the control of the process in action. It can be observed that a SRT value of the 30 d, the $X_{BH}$ reach a value equal to 90 % of its maximal and simultaneously the $Y_{OBS}$ is close to the minimal value. The same observation was done for the three influents. If considered that the oxygen transfer coefficient ($K_La$) decreases with rising biomass concentration, in order to achieve a feasible $K_La$ and simultaneously an efficient organic matter removal, a SRT value of the 30 days seems very appropriated. In order to take advantage of the membranes, a total suspended concentration higher than 9 g $L^{-1}$ is expected. Therefore, in this case to an efficient MBR operation an OLR equal to 3 g COD $L^{-1}d^{-1}$ should be imposed to reach an acceptable active biomass concentration.

## Acknowledgements

This work is financed by the European Community in the scope of “Euromembra Program”.

## References

[1] A. Drews and M. Kraume, Process improvement by application of membrane bioreactors. *Chem. Eng. Res. Des.*, **83**(A3) (2005), 276–284.

[2] M. Henze, W. Gujer, T. Mino and V. Loosdrecht, Activated sludge models ASM1, ASM2, ASM2d and ASM3. *Scientific and technical report No. 9.* International Water Association, London, UK, 2000.

[3] M. Heran, C. Wisniewski, J. Orantes, A. Grasmick, Measurement of kinetic parameters in a submerged aerobic membrane bioreactor fed on acetate and operated without biomass discharge. *Biochem. Eng.*, 38–1 (2008) 70–77.

[4] S. Rosenberger, U. Krüger, R. Witzig, W. Manz, U. Szewzyk, M. Kraume, Performance of a bioreactor with submerged membranes for aerobic treatment of municipal waste water, *Water Research*, 36 (2002) 413–420.

[5] D.D. Sun, S.L. Khor, C. Teck Hay, J.O. Leckie, Impact of prolonged sludge retention time on the performance of a submerged membrane bioreactor, *Desalination*, 208 (2007) 101–112.

[6] S.J. Pirt, The maintenance energy of bacteria in growing cultures, *Proc R Soc London*, 163B (1965) 224–231.

[7] A. Pollice, G. Laera, D. Saturno, C. Giordano, Effects of sludge retention time on the performance of a membrane bioreactor treating municipal sewage, *J. Membrane Sci.*, 317 (2008) 65–70.