

# Effect of Salinity Variation on the Autotrophic Kinetics of the Start-up of Membrane Bioreactor and Hybrid Moving Bed Biofilm Reactor-Membrane Bioreactor at Low Hydraulic Retention Time

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**Abstract.** A membrane bioreactor (MBR) and a hybrid moving bed biofilm reactor-membrane bioreactor (hybrid MBBR-MBR) for municipal wastewater treatment were studied to determine the effect of salinity on the nitrogen removal and autotrophic kinetics. The biological systems were analyzed during the start-up phase under regular and variable salinities, with a hydraulic retention time (HRT) of 6 h. The variable salinity affected the autotrophic biomass, which caused a reduction of the nitrogen degradation rate and an increase of time to remove ammonium from municipal wastewater.

**Keywords:** Moving bed biofilm reactor · Autotrophic kinetics · Salinity

## 1 Introduction

The growing awareness of environmental protection has led to more stringent legislation regarding the treatment of saline wastewater before discharge. This aspect is especially important for activities such as the fish canning, petroleum, petrochemical and tannery industries, as well as the wastewater produced during shipboard activities that is characterized by high saline concentrations (Sun et al. 2010; Abdollahzadeh Sharghi et al. 2014).

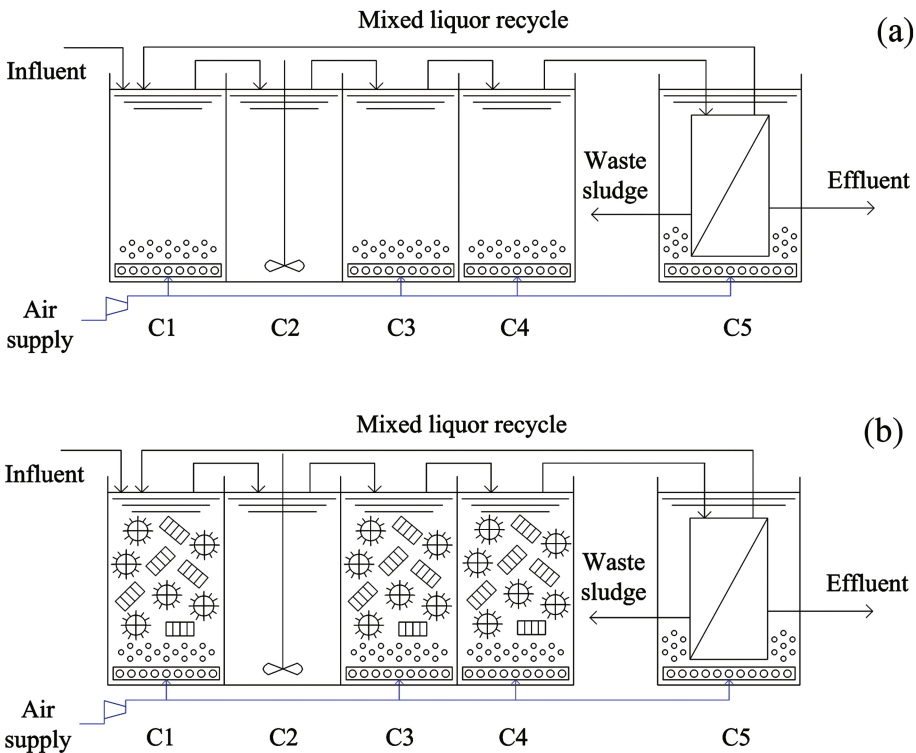
In recent years, membrane bioreactor (MBR) systems have been applied to treat saline wastewater (Di Bella et al. 2013). To improve the performance of MBR regarding the pollutant removal and membrane filtration, the hybrid moving bed biofilm reactor-membrane bioreactor (hybrid MBBR-MBR) systems have been developed during the last years (Leyva-Díaz et al. 2014).

The analysis of available scientific literature shows a lack of knowledge in terms of autotrophic biomass respiratory activity in MBR and hybrid MBBR-MBR used to treat municipal wastewater under salinity variation. In light of this, kinetic modeling can be an important tool for design and operation of MBR and hybrid MBBR-MBR plants (Leyva-Díaz et al. 2014).

The aim of this study was to assess the effect of salinity on the autotrophic bacteria kinetics during the start-up of MBR and hybrid MBBR-MBR working at low hydraulic retention time (HRT) (6 h).

## 2 Materials and Methods

An MBR (Fig. 1a) and a hybrid MBBR-MBR (Fig. 1b), working in parallel, were fed with municipal wastewater containing regular ( $1.05 \text{ mS cm}^{-1}$ ) and variable salinity ( $1.2\text{--}6.5 \text{ mS cm}^{-1}$ ). These systems included a bioreactor divided into four zones: one anoxic zone and three aerobic ones, as well as a membrane tank. There was a biomass recycling from the membrane tank to the bioreactor to get the working mixed liquor concentration and the nitrogen removal. The total biomass concentration for the steady state was  $2,500 \text{ mg L}^{-1}$ . Wastewater treatment plants (WWTPs) operated at HRT of 6 h. The working volumes of the bioreactor and the membrane tank were 24 L and 4.32 L, respectively, and the anoxic zone of the bioreactor had a volume of 6 L. Regarding the hybrid MBBR-MBR, the K1 media filling-fraction had a value of 35% in the aerobic zone and the anoxic zone did not



**Fig. 1.** Diagram of the experimental plants used in the study. (a) Membrane bioreactor (MBR). (b) Hybrid moving bed biofilm reactor-membrane bioreactor (hybrid MBBR-MBR).

contain carriers. Furthermore, the dissolved oxygen (DO) in the aerobic zone varied between 2.0 and 2.5 mg O<sub>2</sub> L<sup>-1</sup> and DO in the anoxic zone fluctuated between 0.2 and 0.4 mg O<sub>2</sub> L<sup>-1</sup>.

Respirometric tests were carried out on suspended biomass for the MBR. In order to evaluate the effect of biomass adhered to carriers, respirometric assays were performed on total biomass, suspended and attached, for the hybrid MBBR-MBR. Kinetic parameters for autotrophic bacteria and the total nitrogen (TN) degradation rate ( $r_{su,A}$ ) were evaluated through respirometric techniques according to Leyva-Díaz et al. (2013). The evolution of the dynamic oxygen uptake rate ( $R_s$ ) was registered from the respirograms obtained (Leyva-Díaz et al. 2013).

The concentrations of MLSS and mixed liquor volatile suspended solids (MLVSS) were calculated from standard methods (APHA 2012). The concentrations of autotrophic biomass ( $X_A$ ) were determined by supposing the percentages of autotrophic bacteria that were obtained by Leyva-Díaz et al. (2015) for the same MBR and hybrid MBBR-MBR under similar operation conditions.

Thus, respirometric tests allowed for assessing the maximum specific growth rate ( $\mu_{m,A}$ ), substrate half-saturation coefficient ( $K_{M,A}$ ) and yield coefficient ( $Y_A$ ) for autotrophic biomass. The assessment of these parameters was carried out in six steps:

- (1) Determination of the oxygen consumption (OC) through the integration of  $R_s$ , as shown in Eq. (1):

$$OC = \int_{t_0}^t R_s dt \quad (\text{mgO}_2 \text{ L}^{-1}) \quad (1)$$

- (2) Estimation of  $Y_A$  according to Eq. (2) described by Helle (1999):

$$Y_A = \frac{S - OC}{S_{NH} \cdot f_{cv}} \quad (\text{mgVSS mgTN}^{-1}) \quad (2)$$

where  $S$  is the ammonium concentration expressed as oxygen (mgO<sub>2</sub> L<sup>-1</sup>),  $S_{NH}$  is the ammonium concentration expressed as total nitrogen (mgTN L<sup>-1</sup>) and  $f_{cv}$  is a conversion factor (1.42 mgO<sub>2</sub> mgVSS<sup>-1</sup>).

- (3) Evaluation of the substrate degradation rate ( $r_{su}$ ) from  $R_s$ :

$$r_{su} = \frac{R_s}{1 - \frac{Y_A \cdot S_{NH} \cdot f_{cv}}{S}} \quad (\text{mgO}_2 \text{ L}^{-1} \text{ h}^{-1}) \quad (3)$$

- (4) Assessment of the empirical specific growth rate ( $\mu_{emp}$ ) from the relation between the cell growth rate and  $r_{su}$ :

$$\mu_{emp} = \frac{\frac{1}{f_{cv}} \cdot R_s}{\left(1 - \frac{Y_A \cdot S_{NH} \cdot f_{cv}}{S}\right) \cdot X_A} \quad (\text{h}^{-1}) \quad (4)$$

where  $X_A$  is the concentration of autotrophic biomass (mgVSS L<sup>-1</sup>)

- (5) Estimation of  $\mu_{m,A}$  and  $K_{M,A}$  through the linearization of the Monod model (Monod 1949):

$$\frac{1}{\mu_{emp}} = \frac{1}{\mu_{m,A}} + \frac{K_{M,A}}{\mu_{m,A}} \cdot \frac{1}{S_{NH}} \quad (h) \quad (5)$$

Therefore, the  $r_{su,A}$  can be expressed as a function of the autotrophic kinetic parameters, as well as the substrate and biomass concentrations, as indicated in Eq. (6):

$$r_{su,A} = \frac{\mu_{m,A} \cdot S_{NH} \cdot X_A}{Y_A \cdot (K_{M,A} + S_{NH})} \quad (6)$$

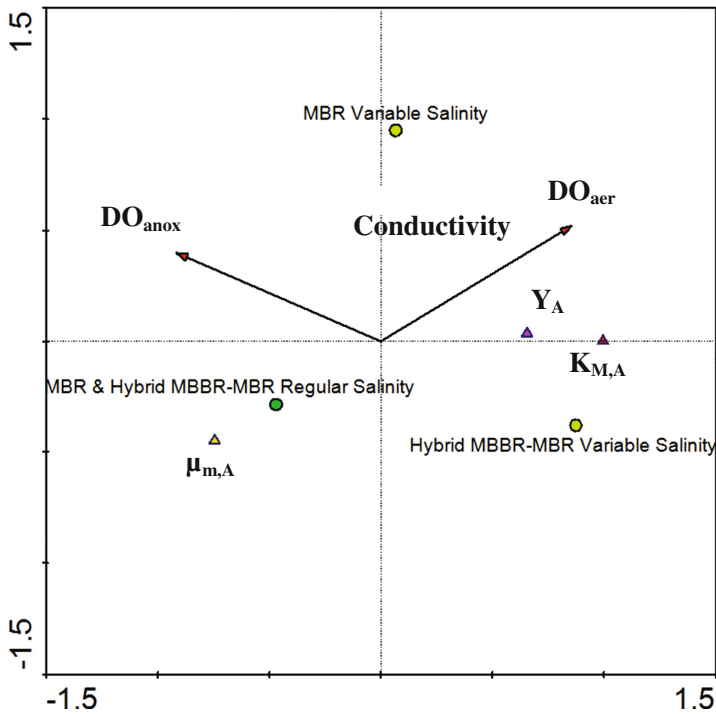
### 3 Results and Discussion

Table 1 shows the autotrophic kinetic parameters for MBR and hybrid MBBR-MBR working at regular and variable salinities. It should be noted that the values of  $\mu_{m,A}$  were higher for the systems operating under regular salinity than those obtained for the technologies working under variable salinity, which favored the substrate degradation rate. Moreover, the values of  $K_{M,A}$  were higher for the systems working under variable salinity, which could be due to the inability of autotrophic biomass to use the whole substrate.

**Table 1.** Autotrophic kinetic parameters,  $\mu_{m,A}$ ,  $K_{M,A}$ ,  $Y_A$ , for the start-up of MBR and hybrid MBBR-MBR working under regular and variable salinity.  $Y_A$  (yield coefficient for autotrophic biomass),  $\mu_{m,A}$  (maximum specific growth rate for autotrophic biomass),  $K_{M,A}$  (half-saturation coefficient for ammonium nitrogen).

Salinity condition	Wastewater treatment plant	$Y_A$ (mgVSS mgTN <sup>-1</sup> )	$\mu_{m,A}$ (h <sup>-1</sup> )	$K_{M,A}$ (mgTN L <sup>-1</sup> )
Regular (1.05 mS cm <sup>-1</sup> )	MBR	1.2684 ± 0.1522	0.1607 ± 0.0144	0.3887 ± 0.0390
	Hybrid MBBR-MBR	1.5681 ± 0.1725	0.3579 ± 0.0376	3.9188 ± 0.4311
Variable (1.2–6.5 mS cm <sup>-1</sup> )	MBR	1.5193 ± 0.2279	0.0145 ± 0.0017	15.5913 ± 1.8710
	Hybrid MBBR-MBR	1.6424 ± 0.2628	0.0128 ± 0.0013	35.7900 ± 3.7580

The multivariate analysis linking the operational conditions of the MBR and hybrid MBBR-MBR systems working with municipal wastewater under regular and variable salinity with the Monod growth model parameters clearly showed the influence of salinity and dissolved oxygen concentration in the autotrophic kinetics of the systems (Fig. 2). The yield coefficient for autotrophic biomass ( $Y_A$ ) (purple triangle) and the half-saturation coefficient for ammonium nitrogen ( $K_{M,A}$ ) (red triangle) had a positive correlation with conductivity and dissolved oxygen concentration in the aerobic zone.

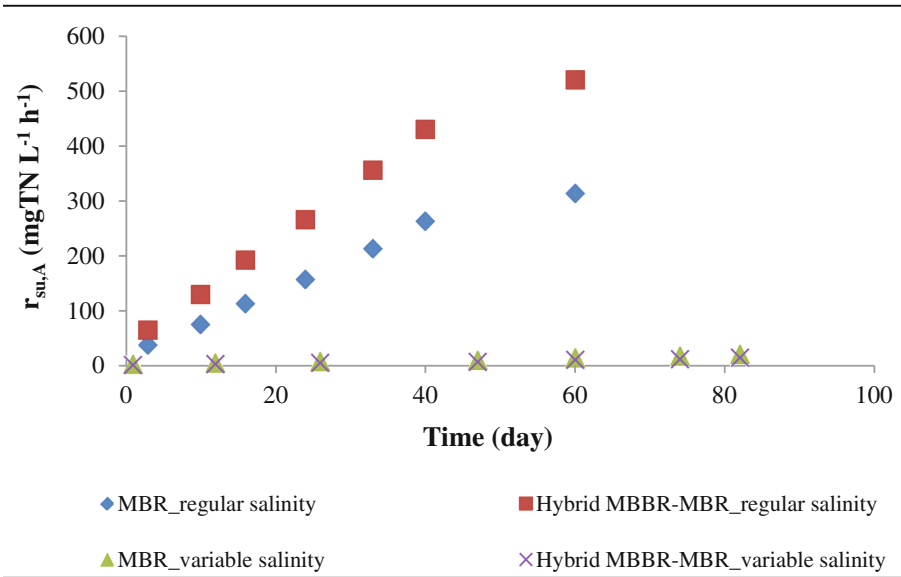


**Fig. 2.** Multivariate redundancy analysis triplot linking the autotrophic kinetics of MBR and hybrid MBBR-MBR systems working under regular and variable salinity wastewater with the conductivity and dissolved oxygen in the anoxic and aerobic chambers,  $DO_{anox}$  and  $DO_{aer}$ , respectively, of the bioreactors. (Color figure online)

On the other hand, the maximum specific growth rate for autotrophic biomass ( $\mu_{m,A}$ ) (yellow triangle) was negatively correlated with electric conductivity and dissolved oxygen concentration in the aerobic zone.

In light of this, it was clearly shown that high variations of electric conductivity led to the lowest  $r_{su,A}$  values concerning total nitrogen removal during the start-up of MBR and hybrid MBBR-MBR under variable salinity (Fig. 3). Therefore, the autotrophic kinetics was slower for the systems working under variable salinity. Johir et al. (2013) demonstrated an inhibitory effect of salinity on ammonium removal efficiency for an MBR system.

In this regard, it should be highlighted that autotrophic biomass required less time for ammonium oxidation during the start-up of MBR and hybrid MBBR-MBR working under regular salinity due to their higher  $r_{su,A}$  (Fig. 3). Thus, a longer time would be required to accomplish the steady state for the systems working under variable salinity (Fig. 3).



**Fig. 3.** Evolution of total nitrogen degradation rate ( $r_{su,A}$ ) obtained in the autotrophic kinetic study for the MBR and hybrid MBBR-MBR under regular and variable salinity.

## 4 Conclusions

Variable salinity slowed down the total nitrogen degradation rate as a consequence of the reduction of the maximum specific growth rate for autotrophic biomass and the increase of the half-saturation coefficient for ammonium nitrogen. Thus, the autotrophic biomass could be inhibited by salinity, implying the inability of this kind of biomass to degrade ammonium substrate.

The MBR and hybrid MBBR-MBR systems that operated at regular salinity showed the highest values for total nitrogen degradation rate, which involved less time to oxidize ammonium during the start-up phase.

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## References

Abdollahzadeh Sharghi E, Bonakdarpour B, Pakzadeh M (2014) Treatment of hypersaline produced water employing a moderately halophilic bacterial consortium in a membrane bioreactor: effect of salt concentration on organic removal performance, mixed liquor characteristics and membrane fouling. *Bioresour Technol* 164:203–213

- APHA (2012) Standard methods for the examination of water and wastewater, 22nd edn. American Public Health Association, Washington DC
- Di Bella G, Di Trapani D, Torregrossa M, Viviani G (2013) Performance of a MBR pilot plant treating high strength wastewater subject to salinity increase: analysis of biomass activity and fouling behaviour. *Bioresour Technol* 147:614–618
- Helle S (1999) A respirometric investigation of the activated sludge treatment of BKME during steady state and transient operating conditions. Thesis, University of British Columbia
- Johir MAH, Vigneswaran S, Kandasamy J, BenAim R, Grasmick A (2013) Effect of salt concentration on membrane bioreactor (MBR) performances: detailed organic characterization. *Desalination* 322:13–20
- Leyva-Díaz JC, Calderón K, Rodríguez FA, González-López J, Hontoria E, Poyatos JM (2013) Comparative kinetic study between moving bed biofilm reactor-membrane bioreactor and membrane bioreactor systems and their influence on organic matter and nutrients removal. *Biochem Eng J* 77:28–40
- Leyva-Díaz JC, Martín-Pascual J, Muñío MM, González-López J, Hontoria E, Poyatos JM (2014) Comparative kinetics of hybrid and pure moving bed reactor-membrane bioreactors. *Ecol Eng* 70:227–234
- Leyva-Díaz JC, González-Martínez A, González-López J, Muñío MM, Poyatos JM (2015) Kinetic modeling and microbiological study of two-step nitrification in a membrane bioreactor and hybrid moving bed biofilm reactor-membrane bioreactor for wastewater treatment. *Chem Eng J* 259:692–702
- Monod J (1949) The growth of bacterial cultures. *Annu Rev Microbiol* 3:371–394
- Sun C, Leiknes T, Weitzenbock J, Thorstensen B (2010) Development of a biofilm-MBR for shipboard wastewater treatment: the effect of process configuration. *Desalination* 250:745–750