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INFLUENCE OF SLUDGE RECIRCULATION ON NUTRIENT REMOVAL IN SUBMERGED MEMBRANE BIOREACTORS

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ABSTRACT

Membrane bioreactors (MBR) technology is a well-developed wastewater treatment process; however, the integrated operation between biological reactions and physical filtration has been poorly studied. Among other operational parameters, optimal control of sludge recirculation can enhance nitrogen and phosphorous removal processes, but the effects on sludge filterability is not clear. In this paper, different recirculation flow rates were tested to evaluate consequences on sludge filterability and nutrient removal in a MBR-UCT pilot plant treating real municipal wastewater. Three distinct sludge recirculation flows were studied during 10 weeks [external recirculation (from the membrane tank to the anoxic reactor), anoxic recirculation (from the aerobic to the anoxic reactor) and anaerobic recirculation (from the anoxic to the anaerobic reactor)]. The obtained results have shown that anaerobic recirculation affected nutrient removal in an inversely proportional way, whereas anoxic recirculation had a directly proportional effect. Referring sludge characteristics, filterability and capillarity suction time (CST) remained independent of sludge recirculation, whereas CST is proportional to transmembrane pressure (TMP), which seems to depend on external and anoxic sludge recirculation.

KEYWORDS: Wastewater; Membrane Bioreactor; Sludge Recirculation; Nutrient removal; Integrated operation; Filterability.

INFLUENCIA DE LA RECIRCULACIÓN DE LODOS EN LA REMOCIÓN DE NUTRIENTES EN LOS BIORREACTORES DE MEMBRANA SUMERGIDA

RESUMEN

La tecnología de Biorreactores de Membrana (MBR) es un proceso de tratamiento de aguas residuales muy bien desarrollado; sin embargo, la operación integrada entre las reacciones biológicas y de filtración física ha sido poco

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estudiada. Entre otros parámetros de funcionamiento, el control óptimo de recirculación de lodos puede mejorar los procesos de eliminación de nitrógeno y fósforo, pero los efectos sobre la filtrabilidad de lodos no son claros. En este artículose ensayaron diferentes caudales de recirculación para evaluar las consecuencias de la filtrabilidad de lodos y la eliminación de nutrientes en una planta piloto real de tratamiento de aguas residuales municipales, MBR-UCT. Se estudiaron tres distintos flujos de recirculación de lodos durante 10 semanas [recirculación externa (desde el tanque de membrana al reactor anóxico), recirculación anóxica (desde el aeróbico al reactor anóxico) y de recirculación anaeróbica (del anóxico al reactor anaeróbico)]. Los resultados obtenidos han demostrado que la recirculación anaeróbica afectó la eliminación de nutrientes de una manera inversamente proporcional, mientras que la recirculación anóxica tuvo un efecto directamente proporcional. Haciendo referencia a las características del lodo, el tiempo de filtrabilidad y capilaridad de aspiración (CST) permanecieron independientes a la recirculación de lodos, mientras que el CST es proporcional a la presión transmembrana (TMP), que parece depender de la recirculación externa y anóxica de lodos.

PALABRAS CLAVE: aguas residuales; biorreactor de membrana; recirculación de lodo; eliminación de nutrientes; funcionamiento integrado; filtrabilidad.

INFLUÊNCIA DA RECIRCULAÇÃO DE LAMAS NA REMOÇÃO DE NUTRIENTES EM BIOREATORES DE MEMBRANA SUBMERGIDA

RESUMO

A tecnologia de bio-reatores de membrana (MBR) é um processo de tratamento de águas residuais muito bem desenvolvido; no entanto, a operação integrada entre as reações biológicas e filtração física tem sido pouco estudada. Entre outros parâmetros operacionais, o controle ótimo de recirculação de lamas pode melhorar os processos remoção de nitrogênio e de fósforo, mas os efeitos sobre a capacidade de filtração das lamas não são claras. Neste artigo foram testados diferentes fluxos de recirculação para avaliar as consequências da filtração de lamas e da remoção de nutrientes em uma usina piloto real de tratamento de águas residuais municipais, MBR-UCT. Foram estudados três fluxos diferentes de recirculação de lamas durante 10 semanas [recirculação exterior (a partir do tanque de membrana ao reator anóxico) recirculação anóxica (a partir de aeróbico ao reator anóxico) e de recirculação anaeróbica (do anóxico ao reator anaeróbico)]. Os resultados obtidos mostraram que a recirculação anaeróbica afetou a remoção de nutrientes de uma forma inversamente proporcional, enquanto que a recirculação anóxica teve um efeito diretamente proporcional. Fazendo referência as características das lamas, e o tempo de filtração e capilaridade de aspiração (CST) manteve-se independentes da recirculação das lamas, enquanto o CST é proporcional à pressão transmembranar (TMP), que parece depender de recirculação externa e anóxica das lamas.

PALAVRAS-CHAVE: Águas residuais; Biorreator de membrana; recirculação de lamas; remoção de nutrientes; Operação integrada filtrabilidade.

1. INTRODUCTION

Membrane bioreactor (MBR) technology is a high quality wastewater treatment that involves biological degradation processes with activated sludge followed by a micro- or ultrafiltration membrane separation (Le-Clech, *et al.,* 2003).

To achieve a good biological nutrient removal it is required consecutive tanks with different conditions (anaerobic, anoxic and aerobic tank) and different sludge recirculation between them. The integrated operation of physical filtration and biological processes makes MBRs a complex operational system.

The relation between recirculation and air scour in a MBR system was studied by Tan and Ng (2008), who stated that there is a conflicting influence on sludge recirculation and oxygen demand (OD) on total nitrogen (TN) removal and membrane fouling.

Ersu, *et al.* (2008) studied MBR sludge recirculation and recommended sludge recirculation to the anaerobic tank and permeate recirculation to the anoxic tank which gave the highest percentage removal with an average 92% soluble chemical oxygen demand (COD), 75% TN.

Sludge recirculation between MBR and the anoxic reactor (E-R) has been studied recently by Sridang, *et al.* (2012) obtaining satisfactory COD reduction and nitrogen (N) removal with global efficiencies between 95 +3% and 98+2%. Dilution effect on high recirculation rates allowed low concentrations of NO_3-N at the effluent, even when the denitrification efficiency decreased at the anoxic reactor.

The anaerobic recirculation flow (ANA-R) (from anoxic to anaerobic tank), which is important to remove directly the phosphorous in the effluents has not been studied in detail. According to the simulation study and expert knowledge of Dalmau, *et al.* (2013), an increase on this recirculation affects directly the nitrate recirculation on the anaerobic tank. Simulation studies are important to evaluate nutrient removal but at the same time are not able to simulate filterability effects.

In addition, it is important to evaluate which are the limits of the recirculation flows that allow an efficient

Figure 1. UCT- MBR pilot plant distribution

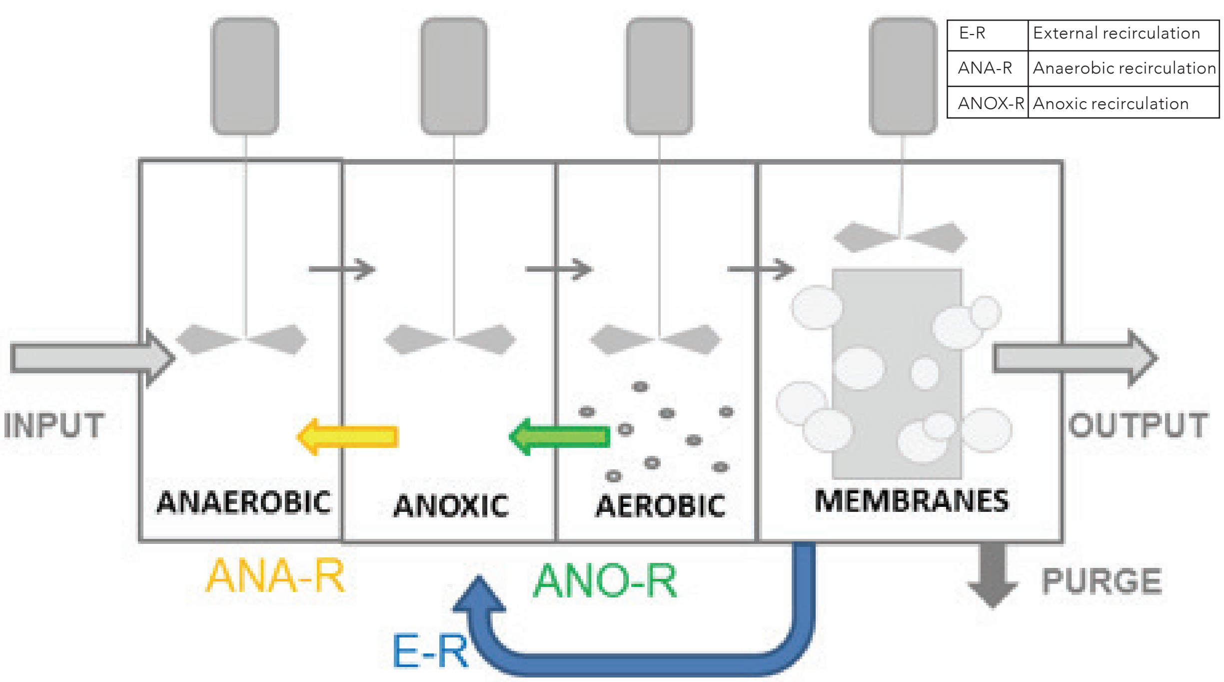
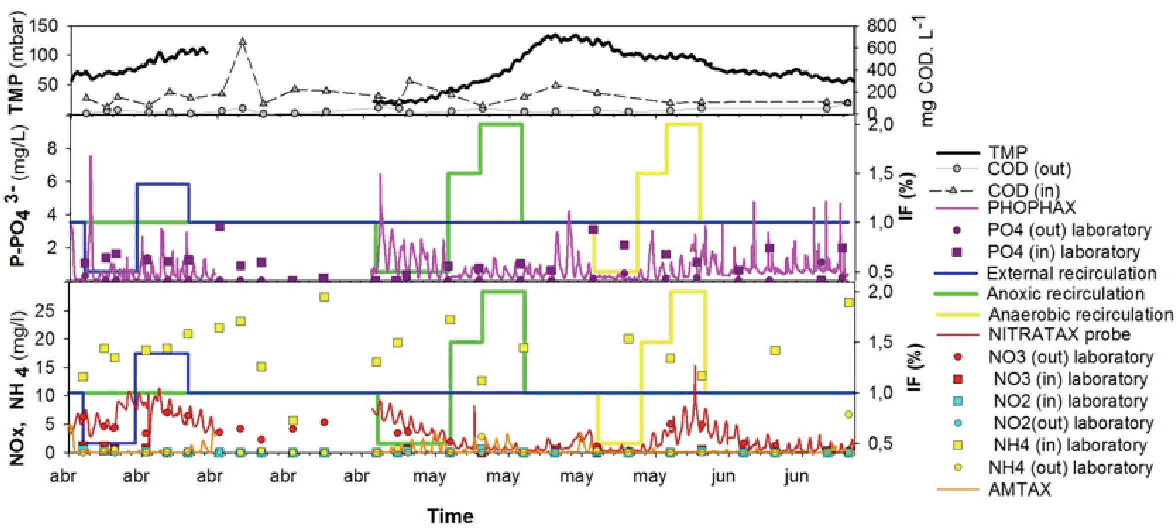


Figure 2. Graph of nutrient removal, transmembrane pressure (TMP) and chemical demand oxygen (COD)



integrated operation of both filtration and biological processes in a MBR plant in order to guarantee nutrient removal.

The main aim of this study is to evaluate efficiency of different recirculation rates based on experimental data obtained from a municipal UCT-MBR pilot plant. The studied recirculation flows are: external recirculation (E-R) (from membranes tank to anoxic tank), anoxic recirculation (ANO-R) (from aerobic tank to anoxic tank) and anaerobic recirculation (ANA-R) (from anoxic tank to anaerobic tank) (**Figure 1**).

2. MATERIALS AND METHODS

2.1. Pilot plant

The pilot plant is located at the Castell-Platja d'Aro municipal WWTP (Catalonia, Spain), presenting an average conventional urban ratio between nutrients (C:N:P) of 100:11:0.9. The pilot plant has a University Cape Town (UCT) configuration (**Figure 1**), that is able to biologically remove organic matter, nitrogen and phosphorous (P) (Monclús, *et al.,* 2010). Specifically, the UCT-MBR pilot plant is equipped with a primary settler and a screening system to prevent the entrance of large particles. The bioreactor has a total volume of 2.26 m^3. It consists of an anaerobic (14% of the total volume), an anoxic (14%) and an aerobic compartment (23%), that is ultimately followed by a compartment (49%) with submerged microfiltration flat sheet membranes. The membranes used have a total membrane area of 8 m^2 (LF, Kubota, Japan), with a nominal pore size of 0.4 µm.

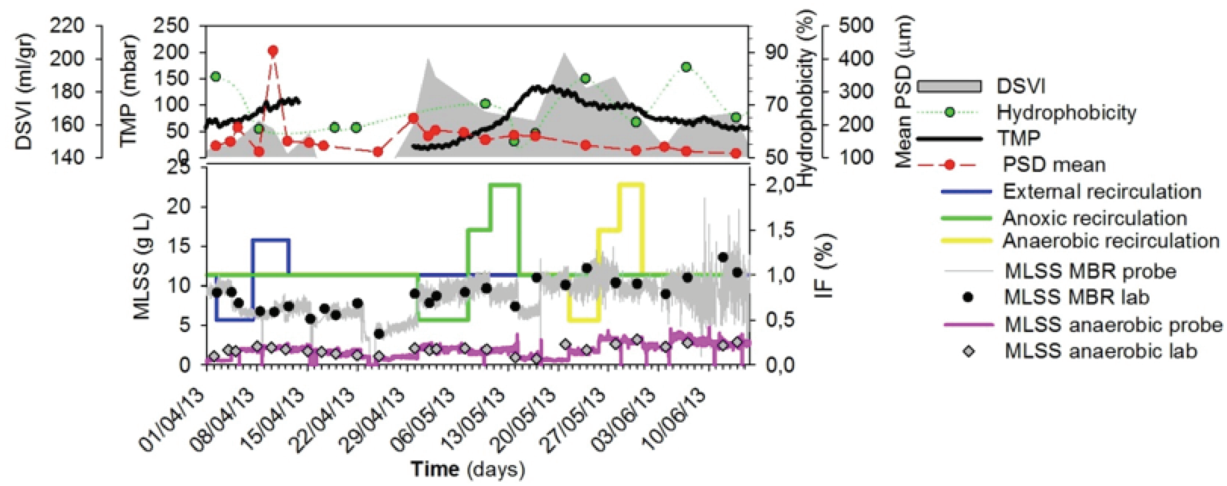
According to Monclús, *et al.* (2010) results, obtained via simulation at the same MBR pilot plant, the optimum E-R rate was 1.36 times the inflow (IF), and ANO-R optimum ratio was 0.92 times the IF and ANA-R ratio was 1.3 times the IF.

2.2. Experimental procedure

The experiment lasted from April to June (10 weeks). The recirculation rates were modified every four days according to the following strategy: 0.5 IF, IF, 1.5 IF and 2 IF, per each recirculation studied (**Figure 1**), being E-R (blue), ANO-R (green) and ANA-R (yellow). During the first two weeks, E-R was studied and after two weeks of operational maintenance, ANO-R and ANA-R were studied.

The variations were carried out individually maintaining the other recirculation rates at IF (4300 l/day), to evaluate the effects separately. The maximum flow of the pumps anoxic and anaerobic was 400l/h, allowing 2 IF experiments, but due to the reduced E-R pump power, in this case it was only able to increase the recirculation up to 1.5 IF.

Figure 3. Sludge quality characterization: PSD; hydrophobicity, DSVI, MLSS



Two-times per week grab samples were gathered from the influent, effluent and MBR tank and analyzed at laboratory as specified on the following section.

2.3. Analytical measurements

Influent and effluent samples were tested and its COD and nutrients [phosphates (PO_4^{3-}), nitrates (NO_3^-), nitrites (NO_2^-), ammonia (NH_4^+) and total nitrogen (TKN)] were measured. COD was measured according to Standard Methods for the Examination of Water and Wastewater (APHA, 2005), nutrients were measured using ion chromatography (APHA, 2005), and TKN by means of consecutive digestion and distillation processes. Samples for COD, NH_4+, NO_2^- and NO_3^-characterization were filtered using 0.45 mm cellulose acetate filters. All samples were measured on the day of collection.

Sludge samples (MBR tank) were analyzed according to APHA (2005) methodologies to determine its diluted sludge volume index (DSVI), sludge suspended solids (MLSS) and sludge volatile suspended solids (MLVSS). Sludge characterization was done based on extra polymeric substances analysis (EPS), analyzing its proteins and the polysaccharides. Sludge volumetric index (SVI), particle size distribution (PSD) and relative hydrophobicity were carried out. Capillarity suction time (CST) and filterability tests were also monitored two times per week.

In addition, on-line measurements during the whole experiment were recorded every 10 seconds, from: the effluent: NH_4^+(AMTAX, Hach Lange), NO_2^- and NO_3^- (Nitratax, Hach Lange) and PO_4^{3-} (Phophax, Hach Lange). Furthermore, from MBR and anaerobic tank: to record MLSS (SOLITAX, Hach Lange). The filtration monitoring, every 10 seconds, was measured with a transmembrane pressure (TMP) sensor (Monclús, *et al.,* 2010).

3. RESULTS AND DISCUSSION

The operational conditions were determined at each recirculation condition, analyzing the biological nutrient removal performance, sludge quality, and filtration behavior.

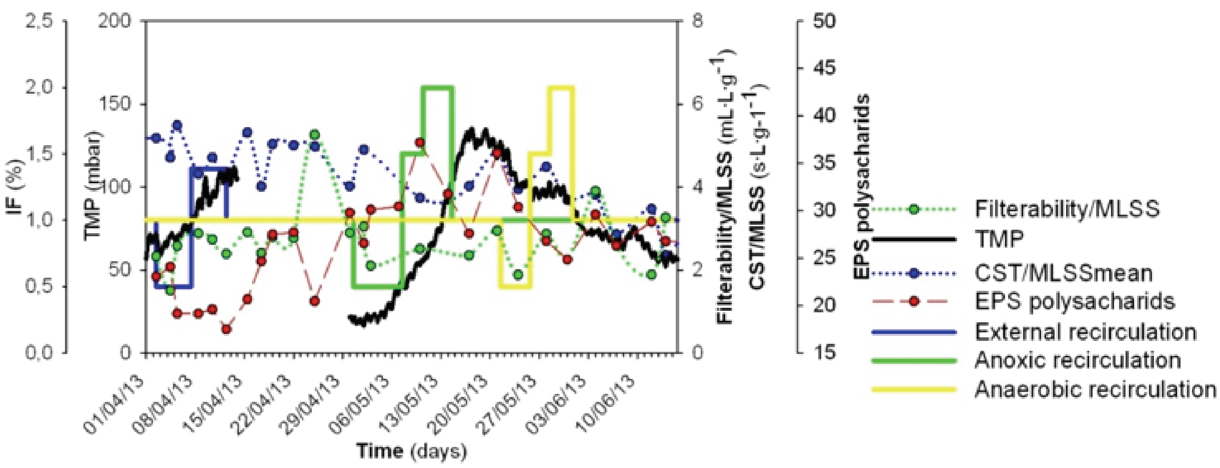
3.1. Nutrient removal

In general, sludge recirculation affects nutrient removal as it could be expected (**Figure 2**)

3.1.1. External recirculation (E-R)

According to the calibrated MLSS probes by means of analyzed data at laboratory (Fig. 3), E-R (from membranes to anoxic tank) affects the amount of membrane MLSS as it could be expected, in an inversely proportional way to the recirculation rate (**Figure 3**). In reference to the nutrient removal, after a decrease of this recirculation nitrates

Figure 4. Filterability correlated with recirculation, TMP and EPS



has followed a rising trend (**Figure 2**). This tendency can be explained because sludge recirculated to the anoxic tank decreases, and that involves lower denitrification on this tank, and consequently, an increase of NO_3^-. After an increase of this recirculation the process is reverted, as conditions are the opposite. NH_4^+ is not affected by recirculation rates and PO_4^{3-} increases with an increase of E-R.

3.1.2. Anoxic recirculation (ANO-R)

The increase of ANO-R (from aerobic to anoxic tank) implies a decrease in aerobic sludge concentration, and consequently a decrease in nitrification rates: NH_4^+ to NO_2^- and NO_3^-. Additionally, this recirculation increase implies an increase in solid concentration at the anoxic tank, involving higher denitrification and consequently a reduction of NO_3^-. These results are coincident with **Figure 2**, where ANO-R is inversely proportional to the presence of nitrates.

PO_4^{3-} is accumulated by means of dPAOs (denitrifying polyphosphate accumulating organisms) at the anoxic phase, and then an increase of the recirculation rate implies a decrease of PO_4^{3-}, as shown in **Figure 2**.

3.1.3. Anaerobic recirculation (ANA-R)

An increase of ANA-R causes a decrease in the sludge concentration at the anoxic tank, and consequently, a decrease in the denitrification process and therefore, an increase of NO_3^-, as shown in **Figure 2**. Concerning to phosphates, an increase in the concentration at the anaerobic tank implies a higher concentration of PO_4^{3-} due to an increase in PAOs (polyphosphate accumulating organisms) which release P, as indicate the obtained results.

3.2. Sludge quality and filterability

Considering DSVI at the MBR reactor as an indicator of sludge sedimentation and, therefore, sludge quality, DSVI was seen to range from 140 to 190 ml/g. Regarding to ANA-R and ANO-R changes it could be seen a decrease in DSVI, which is inversely proportional to the increase of those recirculation flow rates. An increase in DSVI could be related to elevated levels of filamentous microorganisms, causing hindered settling velocity, and an increase of DSVI values (Lee, *et al.,* 1983).

A lower PSD mean, implies an increase in TMP (Meng, *et al.,* 2006) as shown in **Figure 3**; TMP increased, but there is no correlation between ANO-R, ANA-R and PSD.

Regarding to hydrophobicity, a big difference with hydrophobicity values was not observed during the experiment (70-80%).

Drews, *et al.* (2010) observed a decrease in hydrophobicity with a DO increase, which demonstrates minor hydrophobicity values when ANO-R is higher.

TMP rose following an increase in E-R and ANO-R (**Figure 4**), whereas ANA-R do not entail TMP variations. Soluble EPS is directly related to TMP, but in this case, this trend was not observed.

Filterability and CST remained independent of the different recirculation flow rates, whereas CST is proportional to TMP.

4. CONCLUSIONS

The influence of sludge recirculation on nutrient removal was studied in a municipal MBR-UCT pilot plant for 10 weeks. It can be concluded that recirculation rates affect nutrient removal, being ANA-R between the anoxic and the anaerobic reactor inversely proportional to the nutrient removal. On the other hand, ANO-R (from the aerobic reactor to the anoxic reactor) is directly proportional to nutrient removal and E-R (from the membrane tank to the anoxic reactor) affects phosphates directly and nitrates indirectly.

In all recirculation rates, satisfactory nutrient removal was achieved below the established limits for discharge (N total=15, P total =2).

Taking into account sludge characterization, filterability and CST are independent of recirculation rates, while TMP seems to depend on E-R and ANO-R rates.

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