IFAS intermittent aeration membrane bioreactor system: the influence of sludge retention time

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Abstract: This study presents a comparative evaluation of a Membrane BioReactor – Integrated Fixed Film Activated Sludge – Intermittent Aeration (MBR-IFAS-IA) pilot plant operated under two different (Period I and Period II) sludge retention time (SRT) conditions. Specifically, the SRT was set to 7 and 3.5 days during Period I and II, respectively. The study has the main scope of investigating how lowering the SRT of the biofilm contributes to pollutant removal. During both experimental periods, total chemical oxygen demand (TCOD) removal was very high (97.8% on average). An improvement in orthophosphate (PO_4-P) removal efficiency occurred during Period II (43.8%) compared to Period I (27.7%). However, a slight worsening in the removal efficiency performances was obtained during Period II, mainly for ammonia oxidation, total nitrogen (TN) and soluble (sCOD) removal. The reduction of SRT from Period I to Period II showed a substantial reduction of nitrous oxide emission (N_2O) from 0.42% to 0.23% of the influent total nitrogen.

Keywords: wastewater; nutrient removal; membrane fouling; biofilm, sewage sludge production

1. INTRODUCTION

Membrane Bioreactor (MBR) represents one of the most promising technologies for increasing biological nutrient removal and minimising excess sludge production in wastewater treatment plants (WWTPs) (Mannina et al., 2017). MBRs can achieve high effluent quality even in terms of pathogenic bacteria and lower ecological impact compared to conventional activated sludge (CAS) systems (Bertanza et al., 2018). This aspect has relevant interest since MBRs also guarantee the production of reused water (Mannina et al., 2022; Cosenza et al., 2022). However, MBRs have the disadvantage of having higher energy consumption compared to CAS. Therefore, during the last decade, several attempts to improve MBRs by combining this technology with others have been made in the literature (Neoh et al., 2016). For example, Mannina et al. (2020) have investigated an Integrated Fixed Film Activated Sludge (IFAS) MBR combining the membrane and the moving bed biofilm technologies, investigating the role of SRT, hydraulic retention time and influent carbon to nitrogen ratio on the system performance. Mannina et al. (2020) found that lowering the SRT from indefinite to 15 days did not entail the worsening of the system performance thanks to the biofilm role. However, as the authors are aware, the influence on the system performance of SRT is lower than that investigated by Mannina et al. (2020) has never been investigated in the literature for an IFAS-MBR system.

Moreover, adopting operating strategies aimed at reducing the carbon footprint (direct, indirect and derived emissions) of the IFAS system has yet to be investigated in literature and only for CAS systems. The intermittent aeration (IA) strategy could be an option for lowering the energy required. For example, Singh et al. (2018) investigated the influence of IA operation on the production and sludge characteristics of extracellular polymeric substances (EPS) in a field-scale IFAS reactor applied in a CAS WWTP. Singh et al. (2018) operated the IFAS reactor under three IA cycles (150 min aeration on and 30 min off; 120 min aeration on and 60 min off; 90 min aeration on and 60 min off); they found an increase in EPS concentration with the increase of non-aeration to aeration time ratio despite the 27.1% of energy saving. The findings obtained by Singh et al. (2018) could be relevant in an IFAS-MBR where the EPS and soluble microbial product (SMP) concentrations strongly affect the membrane fouling, causing further energy consumption.

This study aims to explore the influence of low SRT values on the performance of an IFAS-MBR pilot plant operated under IA conditions. With this scope, the IFAS-MBR-IA pilot plant was operated under two different SRTs (7 days and 3.5 days during Period I and II, respectively). Throughout the study, carbon and nutrient removal, process kinetics, EPS production, sludge production, nitrous oxide (N_2O) emissions, and carbon footprint were monitored and quantified.

2. MATERIALS AND METHODS

An MBR-IFAS-IA pilot plant (Figure 1) was built at the Water Resource Recovery Facility (WRRF) of Palermo University (Mannina et al., 2021a;b) treating real wastewater. The pilot plant was monitored during the experimental campaign. The pilot plant consisted of one intermittent aeration reactor (225 L) with the working mode of 40 minutes of aeration on and 20 minutes of aeration off, followed by a membrane bioreactor (MBR) (48 L). The MBR was equipped with a hollow fibers ultrafiltration membrane module. The membrane was operated under filtration cycles (9 min filtration and 1 min backwashing) using peristaltic pumps (Watson Marlow Qdos 30 Universal pumps, 30 L h^{-1}). The membrane reactor had a clean-in-place (CIP) tank for ordinary backwashing. An oxygen depletion reactor (ODR, 53 L) was inserted in the internal recycling line between the MBR and IA reactor, depleting the dissolved oxygen concentration before entering the IA reactor. Moreover, 40 litres of carriers (0.95 g/cm3 density and 500 m2/m3 specific) were inserted inside the IA reactor.
The pilot plant was operated under two different average SRT values. Specifically, the SRT was maintained for 7 days during Period I and 3.5 days during Period II. The SRT was controlled by manipulating the daily sewage sludge withdrawing flow rate.

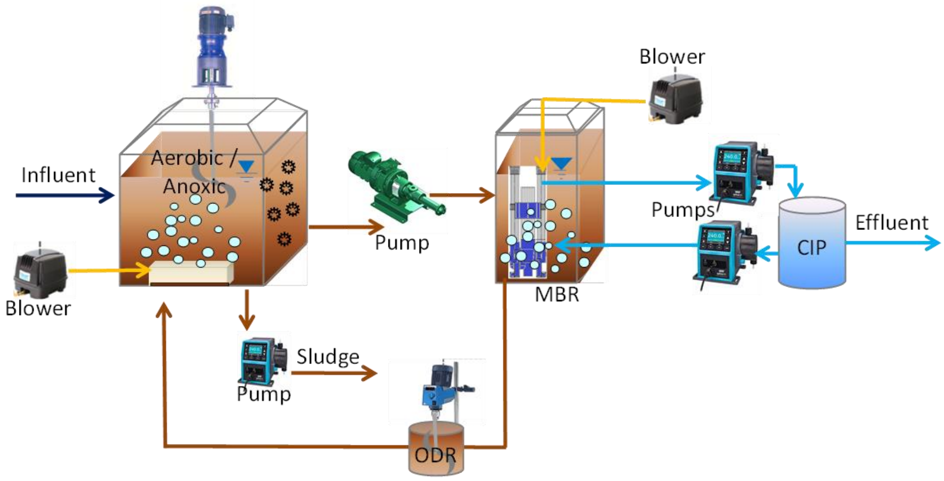

Figure 1. Schematic layout of the UNIPA Pilot Plant

During the two experimental periods, influent and effluent samples were withdrawn two times per week in view of analysing total COD -TCOD, soluble COD - sCOD, ammonia - NH_4-N, total nitrogen - TN and orthophosphate - PO_4-. The analysis was performed according to Standard Methods (APHA, 2012). Further, membrane fouling, sewage sludge production, and biomass kinetics were also analysed, coupled with total suspended solids (TSS) and attached biofilm (AB) concentration inside the IA reactor. EPS and SMP, in terms of carbohydrates and proteins (namely, EPSp, EPSc, SMPp, SMPc), were analysed once per week in the IA reactor's mixed liquor and MBR tank. Dissolved and gaseous N_2O concentrations were evaluated using a gas chromatograph (GC) (Agilent 8860) with an electron capture detector (ECD).

3. RESULTS AND DISCUSSION

Table 1 summarizes the average features and standard deviation (SD) of influent and treated (effluent) wastewater for each period.

Table 1. Average features and standard deviation (SD) of influent and treated (effluent) wastewater for each period.

			Period I				Period II			
			Influent		Effluent		Influent		Effluent	
Parameter	Symbol	Unit	Average	SD	Average	SD	Average	SD	Average	SD
Total COD	TCOD	mg L^{-1}	1621.12	427.15	-	-	1262.08	558.03	-	-
Soluble COD	sCOD	mg L^{-1}	273.96	101.43	46.63	15.04	233.76	136.79	39.14	6.63
Ammonium	NH_4-N	mg L^{-1}	46.37	10.46	7.93	4.37	60.69	9.94	16.80	5.12
Nitrate	NO_3-N	mg L^{-1}	-	-	0.99	1.22	-	-	0.23	0.39
Phosphate	PO_4-P	mg L^{-1}	8.39	3.19	5.97	2.02	9.84	2.37	5.33	0.84
Biochemical oxygen demand BOD	BOD_5	mg L^{-1}	407.00	114.38	23.26	11.41	289.20	156.44	26.94	9.21
Total nitrogen	TN	mg L^{-1}	53.20	11.23	15.73	5.29	76.95	7.79	25.07	7.67
Total suspended solids	TSS	mg L^{-1}	861.35	275.06	0.00	0.00	709.63	383.66	0.00	0.00

For conciseness, only some results will be presented and discussed here. Specifically, Figure 2a shows the average removal efficiencies obtained during the two experimental periods. While, Figure 2b shows the N_2O emission factors. As depicted in Figure 2a, the SRT reduction did not influence the TCOD removal. Indeed, the average TCOD removal was maintained constant during the two periods (97% in both periods). Data from Figure 2a show a slight worsening of sCOD, NH4-N and TN with a decrease of SRT from 7 to 3.5 days. On average, a reduction of around 10% of NH_4-N and TN removal occurred from Period I to Period II. According to the literature, this latter result is likely because the suspended flocs in an IFAS system have the highest ammonia oxidation compared to the biofilm (Huang et al., 2017).
Consequently, under low SRT, where the amount of suspended biomass decreases, the capability of ammonia oxidation and nitrogen removal is reduced. Data from Figure 2a show that an improvement in PO_4-P removal efficiency occurred from Period I (27.7%) to Period II (43.8%) (Figure 2a). The increase in PO_4-P removal efficiency is likely due to the increased contribution of attached biomass due to the anaerobic zone formation within the biofilm. Data from Figure 2b show that the average N_2O emission factor obtained with the IA operation of IFAS-MBR is substantially lower than that obtained in literature with continuous aeration. Indeed, Mannina et al. (2018) obtained an N_2O emission factor close to around 2% of influent nitrogen. The N_2O emission factor obtained here is always lower than 0.42%. This result could have relevant implications regarding carbon footprint quantification that will be discussed in the extended version of the abstract. Data from Figure 2b also show a substantial reduction of the N_2O emission factor with the decrease of SRT from Period I to Period II. Indeed, the average N_2O emission factor during Period I was equal to 0.23% of the influent TN. While, during Period II the average N_2O emission factor reduced till to 0.15% suggesting an improvement of the biological nitrogen transformation processes.

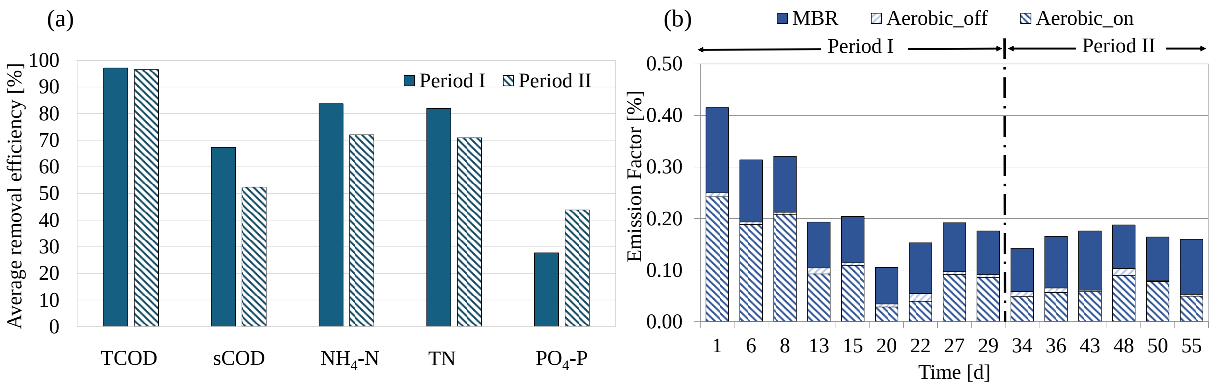

Figure 2. a) Average removal efficiency of TCOD, sCOD, NH_4-N, TN and PO_4-P and b) Cumulative sludge production in Periods I and II

The average TSS concentration inside the IA reactor was equal to 2.92 (± 0.27) g/L during Period I and 1.71 (± 0.39) g/L during Period II. While, the average attached biomass concentration was equal to 1.7 g/L and 1.4 g/L during Periods I and II, respectively.
Table 1 shows the average concentration of SMP and EPS inside the IA reactor and MBR during each experimental period. Data in Table 1 show that with the reduction of SRT (from Period I to Period II), the SMP concentration (both carbohydrates and proteins) increased in the IA reactor and MBR. EPS decreased from Period I to Period II, except for EPS proteins in the IA reactor. This latter result is likely due to the suspended biomass deflocculating due to the low SRT value. The increase in SMP during Period II caused an increase in membrane fouling. Indeed, Period II frequent chemical cleanings (4 Period II and one during Period I) were performed to maintain the transmembrane pressure (TMP) lower than that suggested by the manufacturer (0.8 bar). This result indicates the membrane fouling was irreversible concerning the ordinary backwashing caused by the high SMP concentration.

Table 1. SMP and EPS (in terms of proteins and carbohydrates) concentration in Periods I and II

Average Concentrations	Period I		Period II	
	[mg L^{-1}]			
Reactor	IA	MBR	IA	MBR
SMP proteins	52.32	86.63	66.46	121.51
SMP carbohydrates	3.70	11.09	22.13	18.59
EPS proteins	896.07	1104.45	626.82	674.01
EPS carbohydrates	74.47	101.90	33.95	36.44
Total	**1026.56**	**1304.07**	**749.36**	**850.55**

CONCLUSIONS

Two SRT values (7 and 3.5 days) were tested for an IFAS-MBR pilot plant fed with real wastewater and operated under an intermittent aeration model. Data showed that the TCOD removal was not affected by the SRT. While, the removal performance of sCOD, NH_4-N and TN slightly decreased with the SRT reduction. However, under the lowest investigated SRT, an improvement in PO4-P removal efficiency occurred (from 27.7% to 43.8%) thanks to the improvement of the attached biofilm role. Results also showed a substantial reduction of the N_2O emission factor, with the decrease of SRT from Period I to Period II likely attributed to a more complete biological nitrogen process. Such a fact reveals that the IFAS-MBR operated under intermittent aeration mode with low SRT could represent a sustainable solution in terms of carbon footprint.

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