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Oxic-Settling-Anaerobic under intermittent aeration: effect on system performance, sludge minimization and greenhouse gas emissions

Dı Trapanı D.[1], Cosenza A.[1], Bosco Mofatto P.[1,*], Mannına G.[1]

[1] Department of Engineering, Palermo University, Viale delle Scienze, Bldg. 8, 90128 Palermo, Italy.

*corresponding author:
e-mail: giorgio.mannina@unipa.it

Abstract. The paper presents the results of an experimental study carried out on a pilot scale activated sludge system operated under intermittent aeration and fed with real wastewater at the Water Resource Recovery Facility of Palermo University (Italy). The experimental campaign was divided into two periods: in Period I, the pilot plant was operated as a conventional activated sludge system under intermittent aeration with fixed duration of aerated and non-aerated phases. In Period II, the plant layout was modified according to the Oxic-Settling-Anaerobic (OSA) configuration, by adding one anaerobic reactor in the recycling line from the final settler to the biological reactor. The final aim was to assess the reduction of excess sludge production while monitoring both system performance and N_2O emissions. The results highlighted that the implementation of OSA configuration lead to a decrease of the sludge yield from 0.45 to 0.35 mgVSS/mgCOD. The COD efficiency remained quite stable and close to 90%. Conversely, OSA configuration negatively affected the pilot plant nitrification, with a significant decrease of NH_4-N removal from 91% to 79%. Such reduction was also confirmed by respirometric analysis which showed a change in kinetic behavior from Period I to Period II.

Keywords: sludge minimization; resource recovery from wastewater; advanced wastewater treatment; intermittent aeration; GHG

1. Introduction

Conventional Activated Sludge (CAS) plants represent the most common system adopted in wastewater treatment plants (WWTPs) for biological treatment of wastewater, involving microbial-mediated conversion of biodegradable organic and nutrient pollutants into gaseous and solids with a residual pollution in the effluent suitable with the environmental requirements for discharge into the receiving water bodies. However, CAS systems imply several limitations related to high production of excess sludge, large surface area demand, high energy consumption and low flexibility. Their upgrading generally involves the use of multiple tanks (anoxic and aerobic) in order to obtain a complete nutrient removal. In this context, the upgrading of CAS processes requires additional space that may not be available near the existing treatment plants and, assuming the space availability, large capital investments are needed in highly urbanized areas (Wang et al., 2004). In addition, the operational expenses of a traditional WWTP can be attributed to energy consumption to the extent of around 25–40%, according to the literature and management experience (Descoins et al., 2012; Campo et al., 2023). In this scenario, it is of paramopunt importance the introduction of measures that might optimize processes in WWTPs in terms of energy efficiency as a key issue. This aspect of of particular relevance considering the EU energy dependency and the need to minimize greenhouse gas (GHG) emissions (Elías-Maxil et al., 2014). In this light, a possible solution could be represented by the introduction of new strategies and/or advanced wastewater treatment technologies. Among the new strategies, the intermittent aeration can be an optimal solution (Di Bella and Mannina, 2020). More specifically, the intermittent aeration is the reduction of the aeration time of the biological reactor by introducing periods without oxygen supply to enhance the denitrification process, while reducing energy consumption. On the other hand, nowadays there is a huge concern regarding the production of excess sewage sludge in WWTPs. Indeed, it was estimated that in 2020 in Europe about 13 million tons of dry matter of biological sewage sludge were produced by urban WWTPs (Collivignarelli et al., 2021). Since the management and disposal of excess sludge can account up to 40-60% of the total plant operational costs, several technologies have been proposed to minimize the production of excess sludge, based on chemical, physical, thermal as well as biological processes (Zhang et al., 2021). Among the biological alternatives, the oxic-settling-anaerobic (OSA) process represents one of the most potentially cost-effective and low impact solution for excess sludge minimization (Foladori et al., 2010). Indeed, OSA process can reduce the sludge production up to 60%, depending on its hydraulic retention time (HRT). The OSA process consists in the installation of an anaerobic reactor along the sludge recirculation streamline of a CAS system (Morello et al., 2021). In this process, the total sludge production will reduce due to the alternation of aerobic and anaerobic conditions and the absence of exogenous organic sources inside the anaerobic side stream reactor (ASSR) and stimulates the catabolic activity of the microorganisms (Sodhi et al., 2020). Moreover, since this process does not require any additional physical or chemical treatment, it has the advantage of producing sludge that can be further reused (Chen et al., 2003). However, long-term exposures under anaerobic conditions could result in the worsening of the sludge settling properties. In addition, high HRT under low oxygen availability could affect nitrification, thus altering the fundamental mechanisms of biological nitrogen removal, promoting the production/emission of N_2O, which is recognized as a major greenhouse gas (GHG), due to its high global warming potential (GWP) (Mannina et al., 2018).

In this light, the aim of the present study was to evaluate the sludge minimization in a CAS plant operated under intermittent aeration, by adding an anaerobic sludge retention reactor (ASRR) in the sludge return line, thus realizing an Oxic Settling Anaerobic (OSA) configuration using real wastewater at the Water Resource Recovery Facility of Palermo University (Italy). A comprensive analysis was carried out which included among others: sludge minimization, nitrogen and carbon removal, membrane fouling tendency and biokinetic parameters.

2. Materials and methods

2.1. Description of the pilot plant layout

The pilot scale plant was realized at the Water Resource Recovery Facility of Palermo University (Mannina et al., 2021). The pilot plant was realized as a CAS process designed for carbon and nitrogen removal and operated under intermittent aeration (Period I). The pilot plant was constituted by the following units: one biological reactor (V = 240 L) followed by a vertical settler (V = 46 L) for solids separation. In order to minimize the oxygen load during non-aerated phases, an oxygen depletion reactor (ODR) (V = 53 L) was placed in the internal recycling (RAS) line. Basing on previous literature (Di Bella and Mannina, 2020) the cycle duration was set at 60 minutes, alternating 30 minutes of aeration with 30 minute of non-aeration. In Period II, one anaerobic side-stream reactor (ASSR) (V = 176 L with HRT = 4 hours) was added in the RAS line, with the aim to implement the OSA configuration. The pilot plant was fed with real wastewater collected from the Campus of Palermo University (Italy), with an influent flow rate of 20 L h^{-1}. The main features of the influent wastewater are reported in Table 1.

Table 1. Main features of the influent wastewater (in brackets the standard deviation)

Parameter	Units	Period I	Period II
COD	mg/L	1140 (±63.05)	992 (±194.24)
NH_4-N	mg/L	28 (±1.38)	18 (±4.77)
PO_4-P	mg/L	13.02 (±2.02)	10.94 (±0.67)
TSS	mg/L	959 (±42.77)	895.77 (±85.36)

2.2. Experimental Campaign

The duration of the experimental campaign was 50 days and was split into two different periods, namely Period I and Period II, respectively. In particular, in Period I the pilot-plant was managed under a CAS configuration (duration: 20 days). In Period II, a CAS-OSA layout was implemented by introducing an ASSR reactor in the RAS line characterized by a HRT of 4 hours (duration: 30 days).

2.3. Analytical Methods

The operational parameters, such as pH, oxidation-reduction potential (ORP) and DO were acquired by using dedicated probes coupled to a multimeter (WTW 3340).

Chemical oxygen demand (COD), ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), orthophosphate (PO_4-P), total and volatile suspended solid (TSS and VSS, respectively) concentrations, biological oxygen demand (BOD) and Total Nitrogen (TN) were measured according to literature (APHA, 2012). The sludge settling features were assessed by the sludge volume index (SVI). Extracellular polymeric substances (EPS) and the soluble microbial products (SMP) were extracted and measured in agreement with literature (Le-Clech et al., 2006); proteins and carbohydrates content was assessed according to literature (Lowry et al., 1951; DuBois et al., 1956).

The excess sludge produced daily (ΔX) [kgSS d^{-1}] was evaluated as the sum of TSS in the effluent, the TSS of the wasted sludge and the TSS in the collected samples. ΔX included both primary and secondary (biological) sludge. Primary sludge was evaluated considering only the daily amount of influent settleable suspended solids. The secondary sludge was assessed as the difference between ΔX and the primary sludge.

The biomass stoichiometric and kinetic parameters were assessed by means of respirometric batch tests as reported by Mannina et al. (2016). Specifically, the maximum growth rate (μ_H), the endogenous decay coefficient (b_H), the maximum yield coefficient (Y_H) and the active fraction of heterotrophic biomass (f_{XH}), as well as the maximum yield coefficient (Y_A) and the maximum growth rate (μ_A) of autotrophic biomass were assessed.

Dissolved and gaseous N_2O concentrations were evaluated in accordance with the procedure reported by Mannina et al. (2018) by using a Gas Chromatograph (GC) (Agilent 8860) with an Electron Capture Detector (ECD). The N_2O emission factor (EF_{N2O}) was assessed according to Mannina et al. (2016).

3. Results and discussion

3.1. Nutrients removal performances

Figure 1a shows the trend profile of total COD removal efficiency. The observed results suggested a good behaviour of the system throughout experiments, with no significant effect of the implementation of the OSA configuration. Concerning ammonium removal, (Figure 1b) the implementation of OSA configuration promoted a slight worsening of the system performance, with a decrease of the removal efficiency from 86 to 76%.

3.2. Excess sludge production

It was observed a slight decrease of the cumulative sludge produced in Period II compared to that of Period I (Figure 2), thus confirming that the implementation of the OSA configuration can promote a further decrease of sludge production, even in a system operated with intermittent aeration, which is in general characterized by a reduced sludge production compared to a conventional system characterized by continuous aeration.

3.3. Sludge properties and EPS composition

In terms of EPS, on average a progressive reduction of the total EPS was observed from Period I to Period II, with the implementation of the OSA configuration. This result suggested that EPS destructuration occurred with the configuration change, likely due to the fact that biomass stayed under anaerobic conditions, thus suffering a stress condition. Figure 3 shows, the EPS values measured during experiments.

3.4. Nitrous Oxide production

Concerning N_2O emission from the system, the data measured in Period I highlighted higher concentrations in the biological reactor during aeration, compared to that measured in the final settler. Data achieved in Period II, after the implementation of the anaerobic reactor in the recycling line are under elaboration and will be available soon.

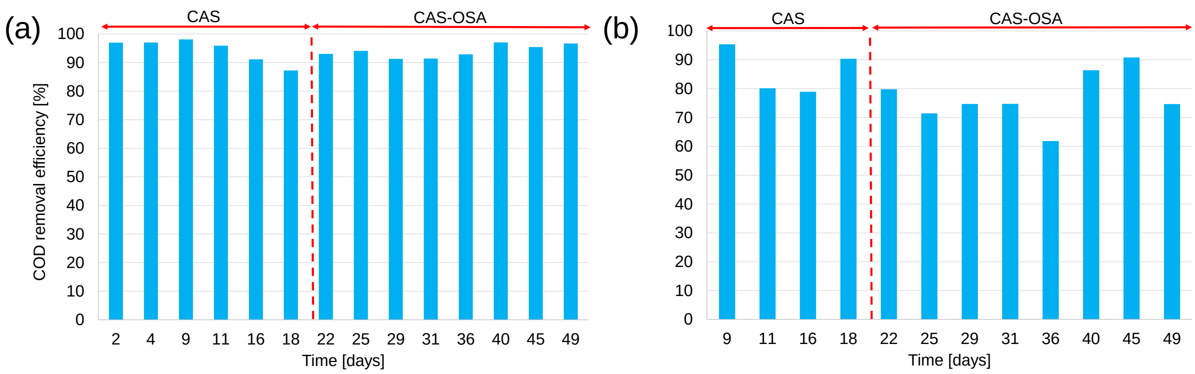

Figure 1. Removal efficiency for COD (a) and ammonium, respectively.

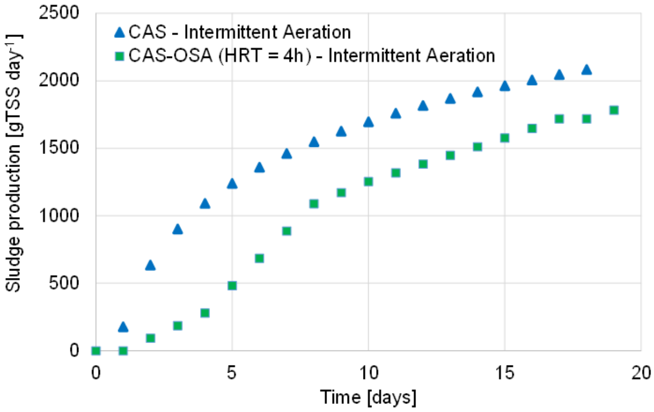

Figure 2. Trend profile of sludge production during experiments.

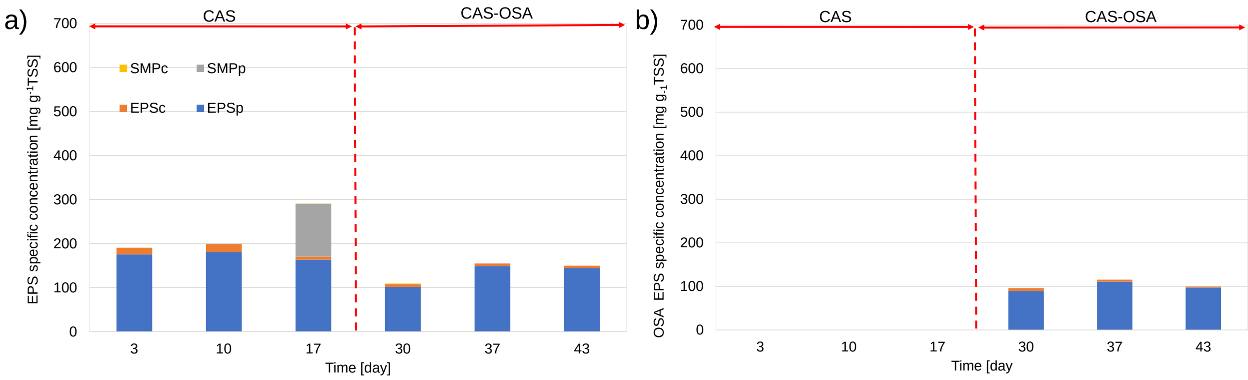

Figure 3. Specific EPS and SMP concentrations in the biological (a) and anaerobic reactor (b), respectively.

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