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Application of Oxic-Settling-Anaerobic (OSA) Process for Excess Sludge Reduction and Valorization: A Pilot Plant Experiment †

Santo Fabio Corsino *, Alida Cosenza, Federica De Marines, Daniele Di Trapani, Alice Sorrenti, Francesco Traina, Michele Torregrossa and Gaspare Viviani

Dipartimento di Ingegneria, Università Degli Studi di Palermo, Viale delle Scienze Ed. 8, 90128 Palermo, Italy
* Correspondence: santofabio.corsino@unipa.it; Tel.: +39-09123861965

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Abstract: In this study, the effects of different operating conditions on excess sludge minimization in an oxic-settling-anaerobic (OSA) process were evaluated. The experiment involved two systems operating in parallel, one implementing the OSA process and a conventional activated sludge (CAS) system as control, both configured according to a pre-denitrification scheme. Five periods (P1–P5) were studied, during which the OSA was operated under different layouts, which differed from the returned sludge to the anoxic (A) or aerobic (B) mainstream reactors and the hydraulic retention time in the anaerobic reactor of the OSA system (8–12 h). The excess sludge production in the OSA plant was lower in all the investigated configurations, indicating that successful sludge minimization was achieved. Specifically, the sludge production was lowered by approximately 12% (P1), 29% (P2), 40% (P3), 26% (P4) and 41% (P5). Scheme A enabled the establishment of the uncoupling metabolism and the extracellular polymeric substance (EPS) destructuration. In contrast, scheme B enabled the establishment of the maintenance metabolism in addition to the uncoupling metabolisms, whereas cell lysis and EPS destruction were minimized. This allowed for obtaining higher sludge reduction yield (26–40%) without compromising the effluent quality.

Keywords: activated sludge; anaerobic side stream reactor; nutrients removal; oxic-settling-anaerobic (OSA); sludge minimization

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1. Introduction

The conventional activated sludge (CAS) process is the most commonly used method for biological wastewater treatment, although it is characterized by several drawbacks [1]. Among these, excess sludge management, including its treatment and disposal operation, is arising as one of the most concerning topics in the last decade [2]. Thus, reducing the excess sludge production has become a current research hotspot. To accomplish this, several studies have explored the use of innovative technologies based on physical–chemical or biological processes [3]. Among the biological processes, the oxic-settling-anaerobic (OSA) has received great attention from the scientific and technical communities because it handles the problem of sludge at its origins [4]. It involves the modification of a conventional activated sludge scheme by inserting an anaerobic side-stream reactor (ASSR) in the returned activated sludge line [5]. Excess sludge reduction in the OSA process takes place through the combination of several mechanisms, comprising uncoupling metabolism, sludge decay, extracellular polymeric substances (EPSs), destructuration and selection of slow-growing bacteria [6]. The role of these mechanisms seems to be related to the ASSR operating conditions. Nevertheless, knowledge about the relationships between the operating conditions of the OSA process is still lacking [7].

Therefore, the present study was aimed at providing more insights and increasing the knowledge about the mechanisms occurring in an OSA process operating under different conditions and configurations and their implications referred to excess sludge reduction and process performances.

2. Materials and Methods

2.1. Pilot Plant Configuration

The experiment involved two systems operating in parallel: (i) a CAS plant configured according to a pre-denitrification scheme (anoxic + aerobic reactors) in which an ASSR was inserted in the sludge returned line, namely OSA, and (ii) a control plant geometrically identical to the OSA without the ASSR, namely CAS-C (CAS-control). The raw municipal wastewater was pumped to the anoxic reactor of both the plants with a constant flowrate of 1.4 L h^{-1}. The anoxic and the aerobic reactors had the same operating volume, equal to 23.5 L, thereby resulting in an (hydraulic retention time) HRT of 16.8 h. From the aerobic reactor, the mixed liquor passed to a vertical clarifier (16 L) in which the effluent wastewater and the thickened sludge were separated. The sludge was returned in the anoxic reactor and in an ASSR in the CAS-C and OSA, respectively, with a flowrate of 1.4 L h^{-1} (Return Activated Sludge, RAS-1), while the effluent was discharged. The ASSR had a variable operating volume of 11.2–16.8 L, resulting in an HRT of 8 h and 12 h. The mixed liquor from the ASSR was returned to the anoxic reactor or the aerobic reactor according to scheme A and scheme B, respectively. An internal flow recirculation (RAS-2, 8.4–9.8 L h^{-1}) returned the mixed liquor enriched in nitrate to the anoxic reactor to allow for denitrification.

2.2. Experimental Setup

The pilot plants were operated for 152 days divided into five periods, namely Periods 1–5. During Period 1 (39 days), the OSA plant operated according to scheme A with an HRT in the ASSR equal to 8 h. In Period 2 (35 days), the plant layout was the same as the previous period, whereas the HRT in the ASSR was increased by 50% (12 h), to trigger the occurrence of decay phenomena and cell lysis. In Period 3 (35 days) the OSA layout was changed to scheme B, in which microorganisms were subjected to a longer famine period. In Period 4 (28 days), the OSA operated with scheme B, while reducing the HRT in the ASSR to 8 h. Lastly, in Period 5 (15 days) the HRT in the ASSR was again increased to 12 h, while maintaining the same plant layout (scheme B). The biomass concentration was maintained at approximately 3 gTSS/L in both the OSA and CAS-C plants, by daily purging a known volume of sludge from the aerobic reactor.

2.3. Analytical Methods and Calculations

All the chemical–physical analyses were performed according to standard methods [8]. The excess sludge production (ΔX) was evaluated as the mass of solids extracted daily, including the treated effluent and the waste sludge. Moreover, the observed yield coefficient (Y_{obs}) was calculated as the ratio between the cumulative mass of total suspended solids (TSS) produced and the cumulative mass of chemical oxygen demand (COD) removed.

3. Results and Discussion

Performances of Excess Sludge Reduction

The excess sludge was purged daily from the OSA and CAS-C plants to maintain a constant TSS concentration. Figure 1 shows the trends of the cumulative sludge production during each experimental period (a) and the observed yield coefficients obtained in the OSA and CAS-C plants (b).

The average daily amount of excess sludge produced in the control plant varied during each experimental period, depending on the raw wastewater characteristics (Figure 1a). Nonetheless, the excess sludge production in the OSA plant was lower in all the investigated configurations, indicating that successful sludge minimization was achieved. Specifically, the sludge production was lowered by approximately 12% (P1), 29% (P2), 40% (P3), 26% (P4) and 34% (P5), thereby suggesting that the OSA process resulted in higher or lower sludge reduction efficiencies depending on the different operating conditions and configurations implemented. In more detail, the highest reduction efficiencies were obtained when the OSA plant was operated according to scheme B (Period 3 and Period 5), whereas scheme A (Period 1 and Period 2) determined a lower effect of excess sludge minimization. Therefore, at equal HRT in the ASSR (P2 vs. P3, P5), a more extended substrate-deficiency condition determined a greater stressor for biomass than a longer oxygen-lack state. In contrast, by operating under the same layout (P1 vs. P2 and P3, P5 vs. P4), a higher HRT in the ASSR enabled it to achieve better sludge minimization performances.

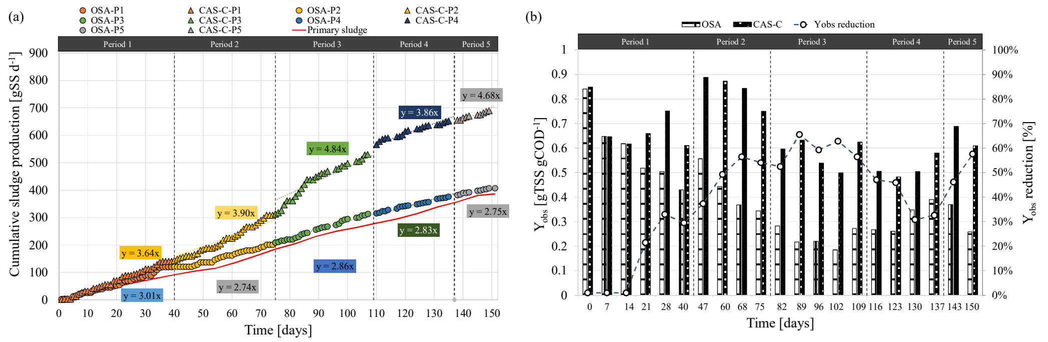

Figure 1. Cumulative excess sludge production in the OSA and CAS-C plants (**a**); trends of the observed yield coefficient and reduction obtained in the OSA and CAS-C (**b**).

The observed yield (Figure 1b) in the CAS ranged between 0.51 gTSS $gCOD^{-1}$ and 0.89 gTSS $gCOD^{-1}$ in agreement with the results reported in plants fed with real wastewater [9,10]. The Y_{obs} slightly decreased in Period 1 to a steady value close to 0.43 gTSS $gCOD^{-1}$. The Y_{obs} further decreased at steady state in Period 2 to 0.34 gTSS $gCOD^{-1}$. Thus, the increase in the HRT in the ASSR when scheme A was implemented produced a Y_{obs} reduction from 30% to 55%. Similar findings were reported in a recent study carried out by Vitanza et al. [11]. Nonetheless, when the plant layout was changed from scheme A to B, the Y_{obs} reduction increased to 65%. At steady value in Period 3, the observed yield in the OSA was close to 0.20 gTSS $gCOD^{-1}$ (0.60 gTSS $gCOD^{-1}$ in the control), which was comparable to the value obtained in a recent study [6], although with a lower HRT in the anaerobic reactor (12 h vs. 5 days). The lower HRT in the ASSR in Period 4 caused a slight decrease in Y_{obs} reduction that attested close to 40% on average (steady value of 0.33 gTSS $gCOD^{-1}$). In contrast, the restoring of the operating conditions in Period 3 (Period 5) resulted in a new decrease in the observed yield (value and percentage), indicating that the capacity of sludge reduction was recovered.

4. Conclusions

The excess sludge production in the OSA plant was analyzed in this study. The highest reduction efficiencies were obtained when the OSA plant was operated according to scheme B (Period 3 and Period 5), whereas scheme A (Period 1 and Period 2) determined a lower effect of excess sludge minimization. Therefore, at equal HRT in the ASSR (P2 vs. P3, P5), a more extended substrate-deficiency condition determined a greater stressor for biomass than a longer oxygen-lack state. In contrast, by operating under the same layout (P1 vs. P2 and P3, P5 vs. P4), a higher HRT in the ASSR enabled it to achieve better sludge minimization performances. Nevertheless, higher HRT in the ASSR caused a worsening in the effluent quality.

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