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Enhancing combined biological nitrogen and phosphorus removal from wastewater by applying mechanically disintegrated excess sludge

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ABSTRACT

The goal of the study was to evaluate the possibility of applying disintegrated excess sludge as a source of organic carbon to enhance biological nitrogen and phosphorus removal. The experiment, performed in a sequencing batch reactor, consisted of two two-month series, without and with applying mechanically disintegrated excess sludge, respectively. The effects on carbon, nitrogen and phosphorus removal were observed. It was shown that the method allows enhancement of combined nitrogen and phosphorus removal. After using disintegrated sludge, denitrification effectiveness increased from 49.2 ± 6.8% to 76.2 ± 2.3%, which resulted in a decline in the NO_x–N concentration in the effluent from the SBR by an average of 21.4 mg NO_x–N/L. Effectiveness of biological phosphorus removal increased from 28.1 ± 11.3% to 96.2 ± 2.5%, thus resulting in a drop in the $PO_4^{3-}-P$ concentration in the effluent by, on average, 6.05 mg $PO_4^{3-}-P$/L. The application of disintegrated sludge did not deteriorate effluent quality in terms of COD and NH_4^+-N. The concentration of NH_4^+-N in both series averaged 0.16 ± 0.11 mg NH_4^+-N/L, and the concentration of COD was 15.36 ± 3.54 mg O_2/L.

1. Introduction

One of the main problems in wastewater treatment plants is to obtain stable and highly efficient removal of biological nutrients. In many cases there is an unfavourable ratio of organic carbon compounds to nitrogen (N) and phosphorus (P) compounds in influent wastewater (i.e. too little organic matter to guarantee efficient denitrification and biological phosphorus removal). A simple method to improve the effectiveness of nutrient removal is to add commercially available organic compounds (i.e. methanol, ethanol, acetic acid), called "conventional" carbon sources (Cho et al., 2004; Mokhayeri et al., 2009). Because these processes generate additional operational costs, alternative solutions to the problem are currently being sought.

In the last few years, several studies were conducted which tested the application of disintegrated waste (excess) activated sludge (WAS) or return activated sludge (RAS) to enhance biological nutrient removal from wastewater (Biradar et al., 2010; Dytczak et al., 2007; Kampas et al., 2009; Kim et al., 2009; Müller, 2000; Park et al., 2004, 2011; Soares et al., 2010; Yan et al., 2013). The results of these studies showed that organic compounds obtained in the disintegration process are the proper substrate for denitrifying bacteria and phosphorus accumulating organisms (PAOs). It is even

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believed that these compounds have better properties as electron donors than acetate or fermented sewage sludge, that they provide faster denitrification rates and higher rates of phosphorus release (Soares et al., 2010). According to the cited researchers, the explanation for this phenomenon could be related to the kinds of organic matter present in the analysed sludge. Several natural organic compounds are released from activated sludge flocs during disintegration of sludge, and generally these compounds are easily assimilated. Kampas et al. (2007) showed that the soluble chemical oxygen demand (SCOD) in mechanically disintegrated sludge consisted of proteins (30%), carbohydrates (13%) and volatile fatty acids (VFA) (12%); 45% of the organic compounds were not identified. In comparison, Soares et al. (2010) documented that the main products during acidic fermentation of primary sludge are VFA, which constitute 69–94% of SCOD.

The main drawback of using disintegrated sludge as a carbon source is an increase of biological reactor loading by the nutrients (Kampas et al., 2007; Kim et al., 2009; Soares et al., 2010), thus not only organic carbon but also N and P compounds are released as a result of floc destruction. Kampas et al. (2007) noticed that because of a low SCOD:P ratio in the mechanically disintegrated sludge, its use as an alternative organic carbon source may lead to worse effectiveness of P removal from wastewater. A significant decrease in biological phosphorus removal effectiveness caused by the input of ozonated excess sludge was observed by Zhang et al. (2007, 2009). Otherwise, Huysmans et al. (2001) and Meng et al. (2013), who also dealt with ozonation, showed that disintegration of RAS caused only a slight increase in the $PO_4^{3-} - P$ concentration in the bioreactor effluent. Similar results were obtained by Lin et al. (2012), who used combined chlorine dioxide and ultrasonication as a method for sludge disintegration. Park et al. (2011) observed, however, an increase in the effectiveness of biological phosphorus removal once the supernatant, separated from the ozonated sludge, was introduced into the bioreactor. These results show that it cannot definitely be concluded how disintegrated sludge, when returned to the reactor, influences biological phosphorus removal. This question needs further investigation.

Also, some conflicting reports can be found in the case of examining the possibility of using disintegrated sludge as a carbon source to enhance biological nitrogen removal from wastewater. Most of the information indicates that using this alternative carbon source can cause an increase in the efficiency of denitrification and, consequently, a reduction in total nitrogen concentrations in the treated wastewater (Dytczak et al., 2007; Kim et al., 2009; Yan et al., 2013; who used the following disintegration methods: ozonation; alkaline hydrolysis and gamma-ray irradiation; and alkaline hydrolysis, respectively, in their work). On the other hand, Meng et al. (2013) noted a drop in N removal effectiveness when ozonated RAS was introduced to the bioreactor. The authors supposed that this could have resulted from the increase in the N load in the bioreactor released during biological treatment of the disintegrated sludge. Additionally, they hypothesised that as a result of ozonation (performed with low ozone doses), mainly not easily biodegradable compounds with long molecular chains were produced that negatively influenced N removal.

The objective of this research was to evaluate the possibility of increasing the effectiveness of combined N and P removal from wastewater by using excess sludge subjected to mechanical disintegration. In the experiment, the sequencing batch reactor (SBR) was used because it allows to thoroughly analyse the performance of processes responsible for C, N and P elimination from wastewater. Since previous research (Zubrowska-Sudol et al., 2010) showed that hydrodynamic disintegration is one of the least energy-consuming methods of disintegration, which was also confirmed by other researchers (Biradar et al., 2010), and also consequently due to the fact that minimising costs related to obtaining alternative organic carbon sources is the most relevant factor influencing their practical usage (Biradar et al., 2010; Boehler and Siegrist, 2007; Kampas et al., 2009), this way of disintegration was used in this study.

2. Materials and methods

2.1. *Materials*

The experiments were conducted in a laboratory scale model of the SBR with a working volume of 28 L. The SBR was inoculated with activated sludge (inoculum volume equal to 5 L, inoculum concentration: 1%) from a full biological nutrient removal WWTP, BioDenipho (PE = 2 100 000), which guaranteed the presence of nitrifiers, denitrifiers and PAOs in the biomass.

Synthetic wastewater was used as a feed, containing 114 mg peptone, 38 mg starch, 38 mg glucose, 55.4 mg glycerol, 122 mg ammonium acetate, 120 mg ammonium bicarbonate, 30 mg $Na_2HPO_4 \cdot 12H_2O$ and 9 mg KH_2PO_4 in 1 L. The influent was found to have the following values throughout the duration of the experiment: chemical oxygen demand (COD): 392.7 ± 22.7 mgO_2/L; total nitrogen (TN): 83.4 ± 4.1 mgN/L, total Kjeldahl nitrogen (TKN): 82.0 ± 4.2 mgN/L; $NH_4^+ - N$: 61.2 ± 3.9 mg $NH_4^+ - N/L$; $PO_4^{3-} - P$: 9.2 ± 0.7 mg $PO_4^{3-} - P/L$, total phosphorus (TP): 9.8 ± 0.8 mgP/L, pH: 7.8 ± 0.1.

The thickened excess sludge used in the experiment originated from the same WWTP as the SBR inoculation. At this plant, sludge is concentrated by centrifuges equipped with automatic concentration level control, which allows to obtain a stable value of TS equal to 4.4 ± 0.1%. The percentage value of volatile total solids (VTS) averaged 68.6 ± 2.5%. Sludge was delivered from the plant every 3 days and stored in a temperature of 4 °C.

2.2. *Disintegration setup*

Thickened excess sludge disintegration was conducted in a lab device containing a multi-use rotor driven by a motor with a power of P = 2.2 kW, revolutions n = 2800/min (patent no. 214335), installed in a 10 L tank as described in detail in Zubrowska-Sudol and Walczak (2014).

A 10 L sample of sludge was used for each disintegration and the process was conducted at an energy density of 140 kJ/L. Results of the previous stage of research showed that relatively high efficiency of organic carbon release was obtained with this level of energy density and that no significant