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Achieving enhanced denitrification via hydrocyclone treatment on mixed liquor recirculation in the anoxic/aerobic process

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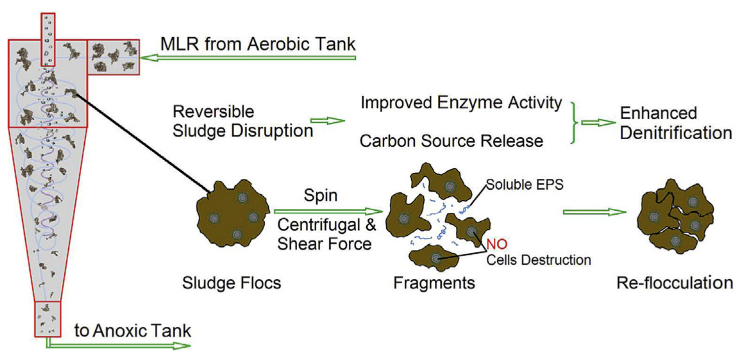
HIGHLIGHTS

- A hydrocyclone was firstly applied for MLR treatment in the A/O process.
- Activated sludge was disrupted by the hydrocyclone followed by outer EPS desorption.
- Increased microbial activity and carbon source release were simultaneously achieved.
- Nitrate removal was increased by 13.6% as well as 15.56% increase of TN removal.

GRAPHICAL ABSTRACT



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ABSTRACT

This work presents the novel application of hydrocyclones for mixed liquor recirculation (MLR) treatment in the anoxic/aerobic (A/O) process to enhance the denitrification process. An exhaustive investigation on treated activated sludge and A/O effluents was conducted in batch and continuous operation tests. The median diameter of the sludge flocs was decreased from 78.82 μm to 15.77–23.31 μm, and the extracellular polymeric substances (EPS) desorption was observed, thus leading to the release of the soluble chemical oxygen demand (SCOD). A marked increase in the BOD_5/TN ratio was consequently achieved, which supplied the carbon source and improved the biodegradability of the MLR. The hydrocyclone treatment also enabled a 7.17% ± 0.93% specific oxygen utilization rate (SOUR) increase at the optimal hydrocyclone intensity of 0.13 MPa, owing to the desorption of positioned microbial secretion from the microorganism cells. The nitrate reductase and nitrite reductase were also improved by 15.13% ± 1.16% and 17.61% ± 1.55%, respectively. The nitrate removal efficiency was enhanced by 13.6%, and the nitrogen oxide gases varied slightly; this behavior was consistent with the variations in the key enzymes involved in denitrification. The A/O process operated in the mode of hydrocyclone-treated MLR, compared with in the conventional mode, resulted in a 15.56% higher TN removal, and the other effluent parameters remained stable. Hydrocyclone disruption is thus a convenient and energy-efficient process with broad implications in denitrification development.

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1. Introduction

The anoxic/aerobic (A/O) process, also known as the modified Ludzack–Ettinger system, has been the most commonly used biological process in wastewater treatment plants (WWTPs) over the past 100 years, owing to its simplicity, high efficiency and low cost (van Loosdrecht and Brdjanovic, 2014). Along with the increasingly severe effects of eutrophication, the disadvantages of insufficiently removing nutrients, especially the total nitrogen (TN) demand, has hindered the development of the A/O process and makes it difficult to meet stricter regulations (Du et al., 2017; Mulkerrins et al., 2004; Rosal et al., 2010). In conventional A/O processes nitrification and denitrification is affected by parameters such as temperature, dissolved oxygen (DO), pH, carbon source, and C/N ratio (Venkata Nancharaiah and Venugopalan, 2011). The denitrification process, which is the subsequent process of nitrification, utilizes the remaining organics as electron donors and converts the generated nitrogen oxides into nitrogen. Most large-scale applications, including domestic and industrial plants, have confirmed the difficulty of this operation. The critical bottlenecks for achieving adequate nitrogen removal consequently involve enhancing the denitrification process.

Attempts have been made to optimize the above factors by using aeration strategy optimization (Lochmatter et al., 2013; Zhang et al., 2013), biological process improvement (Rahimi et al., 2011) and carbon source supplementation (Strong et al., 2011). Many studies have focused on mechanical sludge disintegration to release the organics by improving the efficiency of the denitrification process (Zhang et al., 2016; Kampas et al., 2007). Moreover, the limited mass transfer of nutrients and isolated microorganism cells caused by microbial secretion usually inhibits biological nutrient removal. Typically, sludge disruption is accompanied by the desorption of embedded extracellular polymeric substances (EPS) and inner-pore secretion through treatment methods such as ultrasound, because of its cavitation effects, and centrifugal devices, because of their shear force; these methods ultimately enhance the microbial activity. Floc disruption, in contrast to microorganism destruction, is caused by moderate sludge treatment and both releases organics in terms increasing the soluble chemical oxygen demand (SCOD) and enhances the activity of denitrifiers (Zubrowska-Sudol and Walczak, 2014; Calderer et al., 2014). Li et al. (2009) have also induced a 20–40% specific oxygen utilization rate (SOUR) increase in treated sludge by using low-energy ultrasound with a disintegration degree of less than 20%, owing to the detached micro-floc aggregates. Schläfer et al. (2000) have increased the biological activity in sludge by using ultrasonic intake at a frequency of 25 kHz and a power input of 0.3 W/L, and they have attributed the enhancement to the improved mass transfer of the gas and nutrients at the solid-liquid interface of the sludge flocs. A similar energy density level has been determined in a study by Sorys and Zielewicz (2007) on utilizing sludge ultrasonic disintegration to increase the aerobic microorganism activity. Most literature reviews have confirmed the feasibility of using mechanical sludge disruption to increase carbon source supplementation and microbial activity with batch tests rather than continuous denitrification processes. Furthermore, cost-effective approaches that can persistently disrupt sludge are urgently needed.

The hydrocyclone, a centrifugal device composed of a tangential inlet with a cylindrical and conical shape, has been widely used in separation processes (Cullivan et al., 2004). The dispersed phase particles, including the activated sludge, are disrupted in the hydrocyclone, owing to periodic changes in the centrifugal force directions caused by the combined revolving and rotation movements and the shear stresses caused by velocity differences between the flow layers (Huang et al., 2017; Xu et al., 2016). Activated sludge is composed of biological aggregates and contains several levels of organization. The porous structures of activate sludge are embedded with polymer matrixes. The frequent collisions caused by the hydrocyclone spinning loosen the structured particles and improve the desorption of the substances within the pores (Wang et al., 2006; Kraipech et al., 2005). Therefore, the potential advantages of hydrocyclone treatment include enhanced sludge disruption. Successfully controlling sludge floc disruption rather than microorganism destruction is one of the proposed mechanisms for enhancing denitrification by using hydrocyclones.

In this study, mixed liquor recirculation (MLR) was treated by using a hydrocyclone in batch tests and a 50 L/h conventional lab-scale A/O process. Continuous operation was implemented, and the treated activated sludge and effluent were subjected to a series of characterizations. The process improvement was evaluated by comparing the changes in the microbial activity in terms of the SOUR, SCOD release, supernatant fraction concentration and nitrate nitrogen and nitrite nitrogen variation in both the treated and untreated MLR. The effects of hydrocyclone application on the MLR and A/O effluent indexes, including the COD, NH_4-N, TN and settleability, were investigated. Furthermore, the mechanism of the hydrocyclone treatment for enhancing the denitrification process was evaluated. The findings presented in this work may provide a promising strategy for achieving adequate nitrogen removal at very low cost.

2. Materials and methods

2.1. Wastewater and sludge samples

The raw wastewater used in this study was collected from the effluent line of the primary sedimentation tank of the Minhang WWTP, which performs nutrient removal by using the A/O process (Shanghai, China). The raw wastewater was first pumped into a 1.5 m^3 intermediate tank before descending by gravity flow into the A/O reactor. The A/O influent characteristics were as follows: COD, 343 ± 22 mg/L; B/C ratio, 0.41 ± 0.03; NH_4-N, 45.2 ± 3.7 mg/L; and TN, 62.2 ± 7.2 mg/L. The appropriate amount of $NaHCO_3$ was added each day to maintain the pH. The activated sludge was collected from the aerobic phase of the same WWTP. The experiment was run from April 15, 2015 to November 15, 2015 with a temperature range from 6.3 to 38.7 °C.

2.2. MLR treatment during the A/O process by using the hydrocyclone

The experiments were performed in a 50 L/h lab-scale A/O reactor with a working volume of 800 L, and they included 4 h anoxic periods followed by a 12 h aerobic period. The A/O reactor was made of transparent Plexiglas with eight compartments separated by baffles to achieve anoxic/aerobic conditions. A mechanical stirrer with two paddles was installed in the anoxic compartments to suspend the biomass. The rates of aeration in the six aerobic compartments were 2.5, 2.5, 2, 2, 1.5 and 1.5 L/min, respectively, to ensure that the DO concentration was 2–4 mg/L in each aerobic compartment. The average sludge retention time (SRT) of the A/O was 18 days, and the mixed liquor suspended solid (MLSS) in the reactor was controlled at 3.8–5 g/L. This density was nearly the same as that of the MLR because of the inhibited sludge sedimentation caused by stirring and aeration. The internal recycling ratio was maintained at 400%. Approximately 25 L/h of the returned sludge was collected from the secondary clarifier and pumped back to the anoxic tank by a centrifugal pump.

Most nitrified sewage was removed from the aerobic through the anoxic stages by a peristaltic pump for denitrification. A