Enhancement of A/O process by hydrocyclone

Yuan-yuan FANG[1,a], Zhen-hua WANG[2,b], Yi LIU[3,c], Yan-hong Zhang[4,d],

Hua-lin WANG[5,f*]

[1,2,3,4,5] State-Key Laboratory Of Chemical Engineering, East China University Of science and technology, Shanghai 200237, China

[a]fangyuanyuan3014@163.com, [b]wzh_ecust@126.com, [c]liuyi2974245@163.com, zhyh75@ecust.edu.cn, [f*]samwhl@163.com

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Abstract. A modified anoxic/oxic (A/O) process was represented by coupling suspended-growth activated sludge and hydrocyclone, simply termed "AOH" process. The nitrate mixture liquid was firstly transported into hydrocyclone and then returned into the anoxic zone in AOH process. Sludge flocs were disrupted and organic carbon substances including extracellular polymeric substances (EPS) and cytoplasm were released into aquatic phase by the effects of pressure gradient, shear stress, cavitation, turbulence and impingement of hydrocyclone. These soluble organic carbon substances were consumed as complementary carbon sources for denitrification reaction, and also consumed by the heterotrophic aerobic bacteria. The end products were carbon dioxides and water. The denitrification reaction was enhanced because of the addition of complementary carbon sources and the removal efficiency of nitrogen (N) was improved. The cryptic growth of sludge was achieved by hydrocyclone, and the production of sludge was reduced. The results of this study showed that the average effluent N concentration of AOH was decreased 14.1 mg/L, the average N removal efficiency was improved 21.5%, the average observed biomass yield (Y_{obs}) of AOH was decreased 0.110 mg MLSS/mg COD , and the total excess sludge production of AOH was decreased mg TSS, compared with A/O.

Introduction

Anoxic-oxic process has been widely applied to wastewater treatment in municipal wastewater treatment plants (WWTPs). However, sometimes municipal wastewater does not contain sufficient amounts of biodegradable organic carbon substances, Which making them less suitable for nitrogen removal via the nitrification-denitrification process [1, 2]. Municipal wastewater is characterized by low organic strength and high nitrogen matter content. Human activities have greatly increased N loadings into the environment, and the excess N reaching aquatic ecosystems has resulted in eutrophication. In the biological, N removal is achieved through nitrification by autotrophs and denitrification by heterotrophs. Nitrification occurs under aerobic condition in which ammonium-N is oxidized firstly to nitrite, then to nitrate [3]. Denitrification reaction in which carbon sources are required occurs under anoxic condition. Denitrifying bacteria utilizes organic substrate as electron donor to reduce nitrate to nitrogen gas [4]. Because municipal wastewater is limited in organic carbon sources, and thus an external soluble carbon sources are often added to achieve denitrification. Generally, the extra carbon sources could be organic carbon substances in the form of methanol, ethanol, acetic acid or glucose [5]. The important disadvantage of the addition of direct organic carbon substances is the high operational cost.

With the widespread application of conventional activated sludge treatment process, waste activated sludge (WAS) is the unpleasant by-product for its large volume and offensive odor. The generation of WAS is considerably huge. The management and disposal expenses are substantially costly, which has been estimated to take up 50-60% of the total operational costs in WWTPs [6]. Moreover, the annual produced WAS has been and will continue to increase in the foreseeable future. However, the prohibitions of conventional sludge treatment and disposal methods including land filling have been proposed by the economic, environment and legal regulations. Hence, a promising process aimed for WAS reduction during the operation process is urgently needed.

A modified A/O process in this study was represented by coupling suspended-growth activated sludge and hydrocyclone, simply termed "AOH" process. A typical conventional hydrocyclone had a tangential inlet and consisted of a conical section opened at its apex and bottom, which joined to a cylindrical section at the apex. The top of the cylindrical section was closed with a plate through which passed an axially mounted overflow pipe. The nitrate mixture liquid was firstly transported into hydrocyclone and then returned into the anoxic zone in AOH process. The conical hydrocyclone was first patented in1891 by Bretney, and has been used for industrial purposes for more than 100 years. The internal flow field of the hydrocyclone was complex, and the flow in the hydrocyclone was often described as a combination of an outer helical downward flow and an inner helical upward flow. The tangential velocity increased from the hydrocyclone wall towards the center, reached a maximum value and then rapidly decreased [7]. Shear stress and the intensity of turbulence in the hydrocyclone were also very strong. Hydrocyclone can be used to partly disrupt microbial cells and release organic carbon sources including EPS and cytoplasm into aquatic phase by the effects of pressure gradient, shear force, cavitation, turbulence and impingement [8]. These soluble organic carbon substances were consumed as complementary carbon sources for denitrification reaction, and also consumed by the heterotrophic aerobic bacteria. The end products were carbon dioxides and water. The denitrification reaction was enhanced because of the addition of complementary carbon sources and the removal efficiency of nitrogen (N) was improved. The cryptic growth of sludge was achieved by hydrocyclone, and the production of sludge was reduced. The aims of this study were to investigate: (1) the performance of AOH for organic carbon and nitrogen removal; (2) the effect of hydrocyclone on the disruption of microbial cells and release of organic carbon sources; (3) the reduction of excess sludge for AOH.

Experiment

Hydrocyclone Design. A hydrocyclone with diameter of 35 mm was designed in this study. The parameter of the hydrocyclone was shown in table.1. The hydrocyclone geometry was shown in fig.1.

Table. 1 Hydrocyclone parameters

parameter	D(mm)	θ(°)	D_c(mm)	D_d(mm)	L(mm)	h(mm)	H(mm)	W(mm)
value	35	8	3.5	8	35	5	10	8

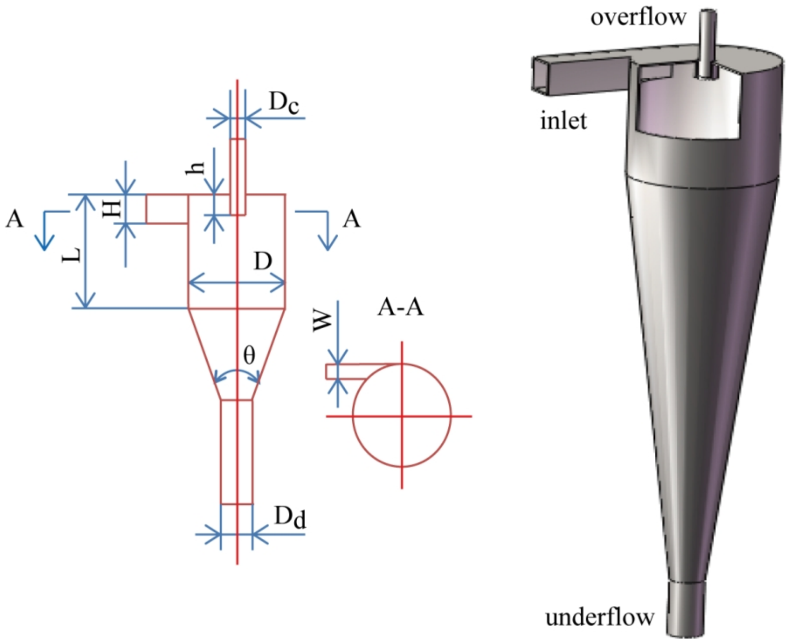
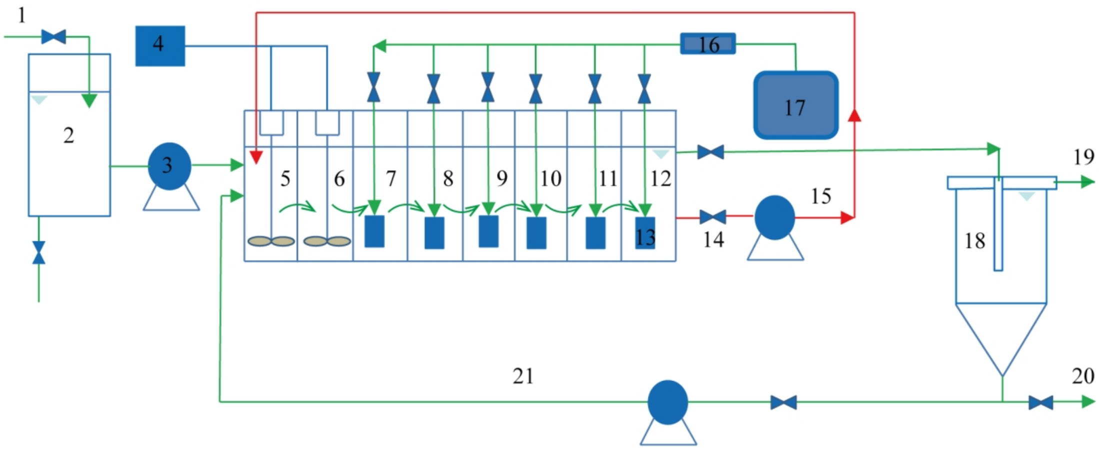


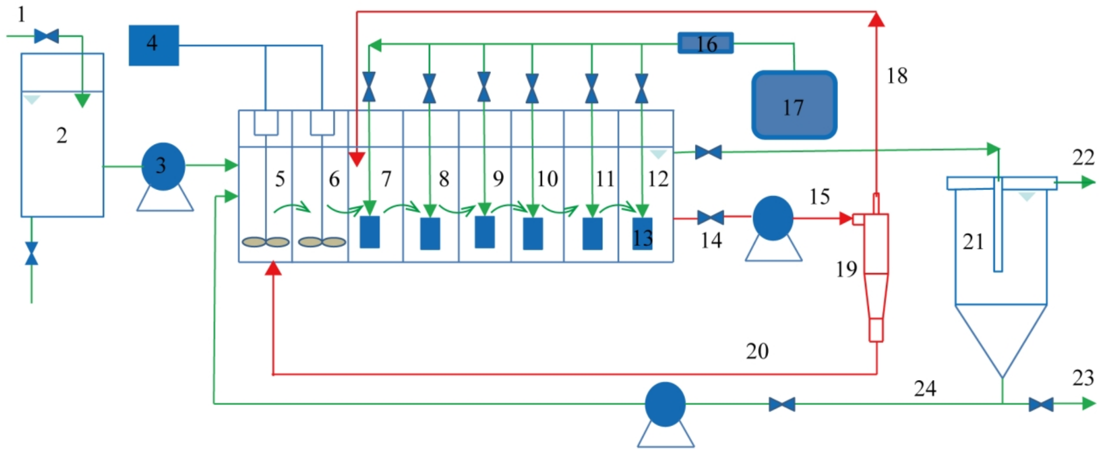
Fig. 1 Hydrocyclone geometry

Experimental Set-up. A pilot-scale A/O reactor was consisted of influent tank, anoxic zone, oxic zone and settling tank. The reactor was made from plexiglass with the total effective volume of 600L, Which was divided into 8 compartments by baffles. The first two compartments were anoxic zone, while the remaining six compartments were oxic zone. The volume ratio of anoxic to oxic zone was 1:3. The mechanical mixers were installed in the anoxic compartments to suspend biomass. The oxic zone was aerated by air diffusers located at the bottom of oxic compartments. Compressed air was supplied to the oxic zone with the dissolved oxygen (DO) concentration of above 2mg/L by blowing air. The influent, sludge return and internal recycling were controlled by the peristaltic pumps. Two same above-mentioned reactors were designed in this study. Hydrocyclone was not installed in the first reactor and the nitrate mixture liquid was directly returned into anoxic zone. The designed hydrocyclone was installed in the second reactor after the acclimation of 20 day. The schematic diagram of A/O and AOH system were presented in fig.2 and fig.3.



1-feed; 2-tank; 3-peristalticpump; 4-stirrer; 5,6-Anoxic tank; 7,8,9,10,11,12-Oxic tank; 13-diffuser; 14-valve; 15-nitrate recycling flow; 16-air flow meter; 17-air pump; 18-settling tank; 19-effluent; 20-excess sludge; 21-return sludge flow

Fig. 2 The schematic diagram of A/O



1-feed; 2-tank; 3-peristalticpump; 4-stirrer; 5,6-Anoxic tank; 7,8,9,10,11,12-Oxic tank; 13-diffuser; 14-valve; 15-nitrate recycling flow; 16-air flow meter; 17-air pump; 18-Hydrocyclone overflow; 19-Hydrocyclone underflow; 20-Hydrocyclone; 21-settling tank; 22-effluent; 23-excess sludge; 24-return sludge flow

Fig. 3 The schematic diagram of AOH

Mixing velocities of anoxic tank in every reactor were kept at 60r/min. The two reactors were fed with real city domestic wastewater everyday. The wastewater was firstly fed to anoxic tank, then, the wastewater flowed into the oxic tank. The main characteristics of the influent wastewater were described in Table.2. The two reactors were inoculated with activated sludge taken from MinHang Wastewater Treatment Plant (ShangHai, China). The start-up phase was operated at outdoor temperature for 20 d and reached to the steady status. The operating conditions of running stage were summarized in table.3.

Table. 2 The main characteristics of the influent wastewater

Parameter	COD	TN	NH_4^+-N	NO_3^--N	PH
Range(mg/L)	219-306	52-79	29-51	0.6-2.3	6.5-7.5

Table. 3 The operating conditions of A/O and AOH

Parameter	Influent flux(L/h)	T (°C)	HRT (h)	MLSS (mg/L)	Internal recycling ratio (%)	Return Sludge ratio (%)
Value	60	25±5	10	3000±500	500	100

Analytical Methods. The analysis of SCOD, COD, NH_4^+-N, NO_3^-N, TN and MLSS were carried out according to standard methods (APHA, 1998). Polysaccharide (PS) measurement was determined using the anthrone-sulfuric acid method. Protein (PN) measurement was determined using the folin-phenol method. All samples were analyzed after filtrating with 0.45μm filter membrane. DO, PH and temperature were respectively measured by DO(AZ8403, China), PH(PHS-3E, China) meters and thermometer.

Results and Discussions

Sludge Floc Disintegration. Some microbial cells were disrupted by hydrocyclone, extracellular and intracellular matters were released into liquid as secondary growth matrixes. PS and PN were the main components of sludge flocs. The parameters including SCOD, PS and PN were used to describe the disintegration effect of hydrocyclone. The SCOD, PS and PN concentrations of nitrate mixture liquid were tested before it entered into the hydrocyclone and after it flowed out the hydrocyclone. The SCOD concentrations at the inlet, overflow and underflow of the hydrocyclone were shown in fig.4. The inlet average SCOD concentration was 29.6 mg/L, the average overflow and underflow SCOD concentrations were 40.1 mg/L and 42.1 mg/L, respectively. The average overflow and underflow SCOD concentrations were improved 10.5 mg/L and 12.5 mg/L. The average disintegration efficiencies were 35.6% and 42%, respectively. The PS concentrations at the inlet, overflow and underflow of the hydrocyclone were shown in fig.5. The inlet average PS concentration was 11.8 mg/L, the average overflow and underflow PS concentrations were 18 mg/L and 19.4 mg/L, respectively. The average overflow and underflow PS concentrations were improved 6.2 mg/L and 7.6 mg/L. The average disintegration efficiencies were 53.3% and 64.5%, respectively. The PN concentrations at the inlet, overflow and underflow of the hydrocyclone were shown in fig.6. The inlet average PN concentration was 1.13 mg/L, the average overflow and underflow PN concentrations were 3.72 mg/L and 4.03 mg/L, respectively. The average overflow and underflow PN concentrations were improved 2.59 mg/L and 2.9 mg/L. The results showed that some sludge flocs were well disrupted at damaging zone by the hydrocyclone, and that extracellular and intracellular organic substances were released into the mixture liquid.

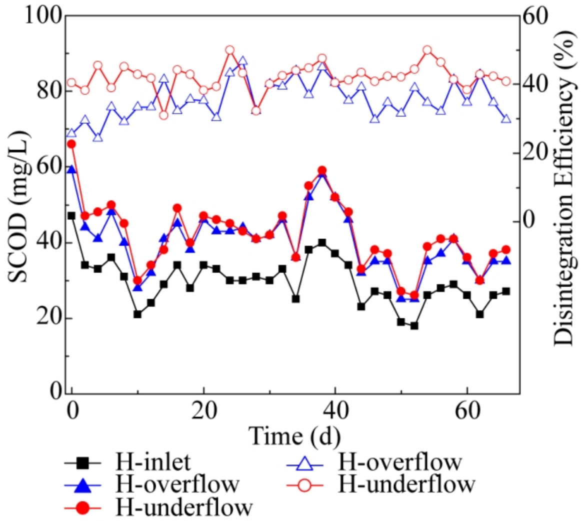


Fig. 4 The SCOD concentrations at the inlet, overflow and underflow of the hydrocyclone

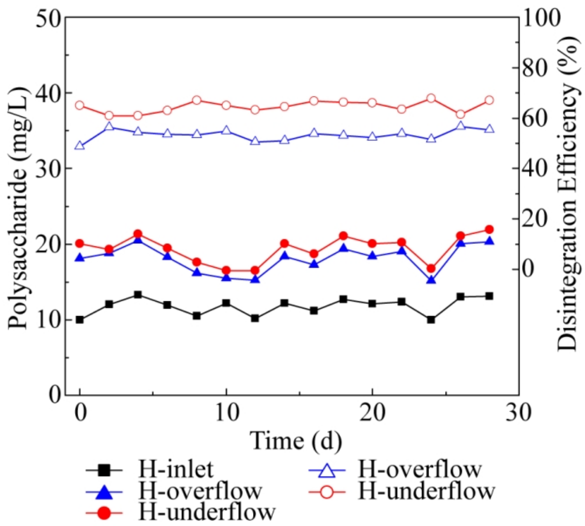


Fig. 5 The PS concentrations at the inlet, overflow and underflow of the hydrocyclone

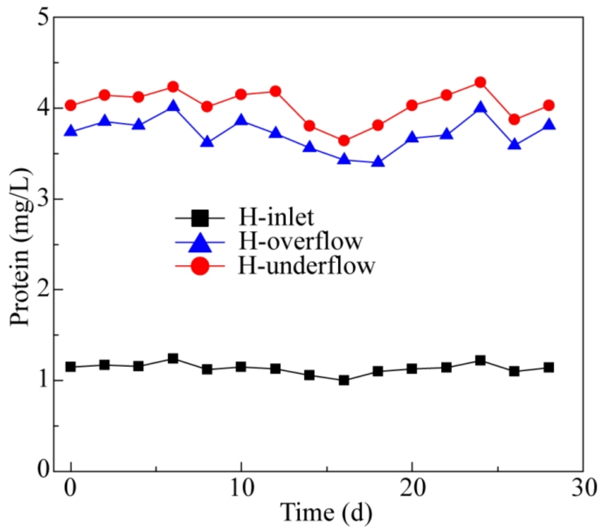


Fig. 6 The PN concentrations at the inlet, overflow and underflow of the hydrocyclone

COD Removal. The COD concentrations of the influent and effluent of the two reactors and removal efficiencies during the whole operation period were shown in fig.7. The influent COD concentration fluctuated from 219 mg/L to 306 mg/L, and the average influent COD concentration was 258.5 mg/L. After the acclimation for 20 day, the hydrocyclone was installed in AOH. Then, the average effluent COD concentrations of A/O and AOH were 65.3 mg/L and 25 mg/L. The average removal efficiency of COD reached 74.7% and 89.9%, respectively. Compared with A/O, the average effluent COD concentration of AOH was decreased 40.3 mg/L, the average COD removal efficiency was improved 15.2%. The results from this study indicated that AOH achieved good COD removal than conventional A/O.

Sludge floc was a micro-bioreactor. The structure and particle size of sludge floc governed the mass transfer resistance of its interior to surface, and also influenced the penetration of enzymatic substances and the release of metabolic products from sludge flocs [9]. DO concentration within the center of the sludge floc was less than at the surface. With sludge floc particle size increasing from 100 to 250 μm, the DO concentration in the floc centers decreased 10%-55%, respectively [10]. Similar phenomenons occurred for the distributions of NH_4^+-N and NO_3^--N in sludge flocs. The more compacted sludge floc was, the more high mass transfer was. With the increasing particle size of sludge flocs, substrates were more difficult to be transported into the interior of sludge flocs. Large Sludge flocs were broken up into small sludge flocs in hydrocyclone, and the interiors of flocs also became loose. Microflocs leaded to a deep diffusion of oxygen which subsequently leaded to an enlargement of the aerobic volume inside the flocs [11]. The mass transfer was facilitated and the specific surface areas of sludge flocs markedly got more lager. The activities of Sludge flocs were improved because of the effect of the hydrocyclone, the shear force could stimulate the respiration activities of microorganisms [12,13]. In a word, COD can be removed further in AOH.

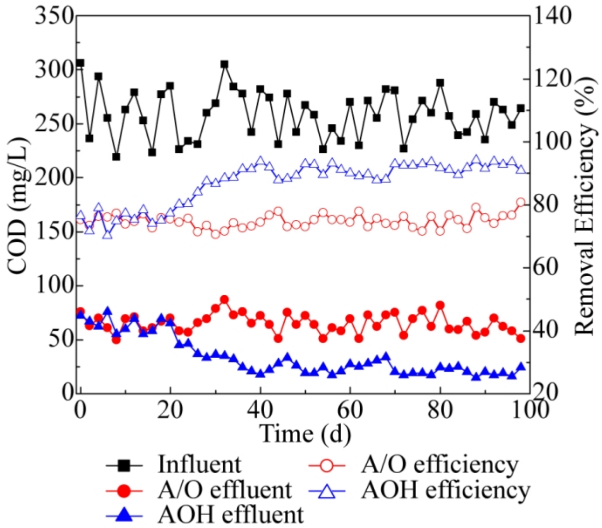


Fig. 7 COD removal

Nitrogen Removal. The TN concentrations of the influent and effluent in different reactors and removal efficiencies during the whole operation period were shown in fig.8. The average influent TN concentration was 65.1 mg/L. After the installment of hydrocyclone, the average effluent TN concentrations of A/O and AOH were 36.4 mg/L and 22.3 mg/L. The average removal efficiency of TN reached 43.8% and 65.3%, respectively. Compared with A/O, the average effluent TN concentration of AOH was decreased 14.1 mg/L, the average TN removal efficiency was improved 21.5%. The results from this study indicated that AOH achieved good TN removal than conventional A/O.

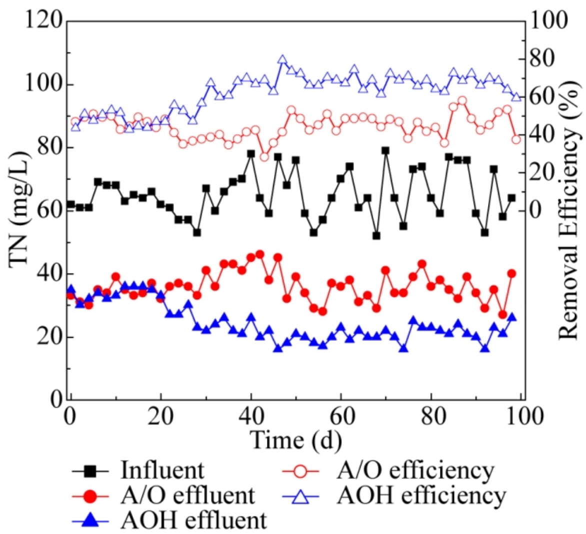


Fig. 8 TN removal

The NH_4^+-N concentrations of the influent and effluent in different reactors and removal efficiencies during the whole operation period were shown in fig.9. The average influent NH_4^+-N concentration was 40.4 mg/L. After the installment of hydrocyclone, the average effluent NH_4^+-N concentrations of A/O and AOH were 4.3 mg/L and 2.6 mg/L. The average removal efficiency of NH_4^+-N reached 89% and 93.5%, respectively. Compared with A/O, the average effluent NH_4^+-N concentration of AOH was decreased 1.7 mg/L, the average NH_4^+-N removal efficiency was improved 4.5%. The results from this study indicated that AOH achieved good NH_4^+-N removal than conventional A/O.

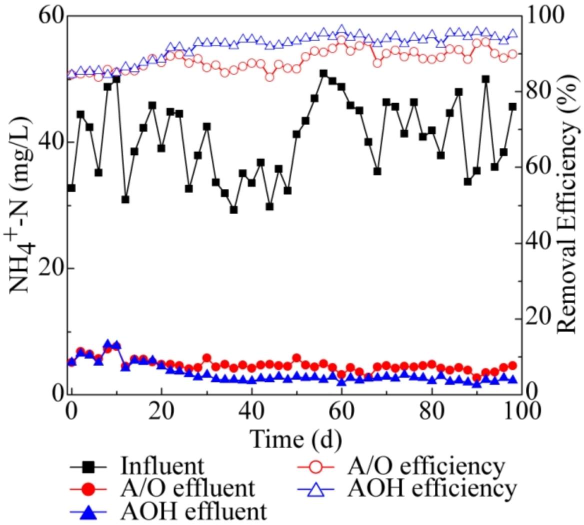


Fig. 9 NH_4^+-N removal

The NO_3^--N concentrations of the influent and effluent in different reactors and removal efficiencies during the whole operation period were shown in fig.10. The average influent NO_3^--N concentration was 1.2 mg/L. After the installment of hydrocyclone, the average effluent NO_3^--N concentrations of A/O and AOH were 29.8 mg/L and 20.1 mg/L. Compared with A/O, the average effluent NO_3^--N concentration of AOH was decreased 9.7 mg/L. The results from this study indicated that AOH achieved good NO_3^--N removal than conventional A/O.

After the installment of hydrocyclone, the effluent TN concentration of AOH was apparently decreased than A/O. The main reason was that effluent NO_3^--N concentration of AOH was decreased than A/O. Denitrification was the important step for the removal of N. Denitrifying bacteria utilized organic substrate as electron donor to reduce nitrate to nitrogen gas. Because municipal wastewater was limited in organic carbon, so the denitrification reaction was restrained. The effluent N concentration was high and unsatisfied. The microbial cells were partly disrupted by hydrocyclone and the organic carbon substances were released into the liquid phase. These soluble organic carbon substances were used as complementary carbon sources for denitrification reaction [14,15]. The denitrification reaction was enhanced because of the addition of carbon source and the removal efficiency of N was improved. With the reduction of NO_3^--N concentration, the inhibition on nitrification reaction of NO_3^--N accumulation was weakened. Moreover, because the particle size of sludge floc reduced, substrate, NH_4^+-N and DO can be further transported into the interior of sludge flocs [16,17]. The NH_4^+-N was more adequately oxidized to transform into NO_3^--N in AOH than in A/O.

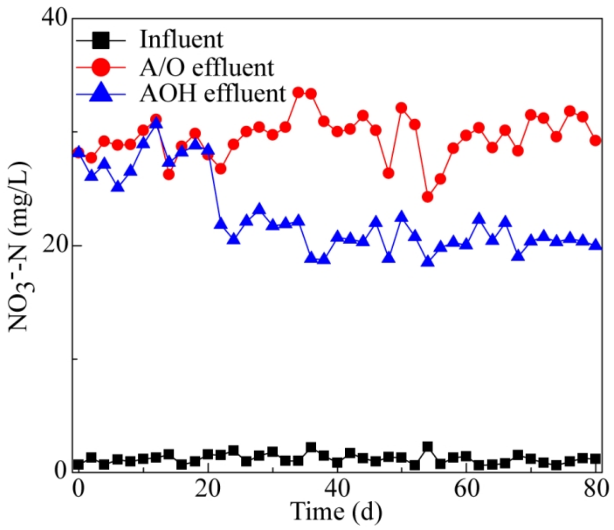


Fig. 10 NO_3^--N removal

Excess Sludge Reduction. The observed biomass yields (Y_{obs}) and excess sludge productions of A/O and AOH were shown in fig.11 and fig.12. After the installment of hydrocyclone, the average Y_{obs} of A/O and AOH were 0.575 mg MLSS/mg COD and 0.465 mg MLSS/mg COD, and the average Y_{obs} of AOH was decreased 0.110 mg MLSS/mg COD than A/O. The total excess sludge productions of A/O and AOH were 12740 g TSS and 9176 g TSS, and the total excess sludge productions of AOH was decreased 3564 g TSS than A/O. The results showed that reduction of excess sludge was accomplished by hydrocyclone.

Generally, activated sludge flocs (ASF) were consisted of bacterial cells enveloped by a matrix of large polymeric molecules, the EPS. By definition, EPS were located at or outside the cell surface. EPS had been shown to be a rich matrix of polymers including PS, PN, glycoprotein, nucleic acids, phospholipids and humic acids [18]. EPS can be used by bacteria as sources of carbon and energy, and the enzymes for the degradation of these polymers were abundant in biological wastewater treatment system. The extracellular enzymes, which were also localized close to the cells, can hydrolyze the sorbed organic matter. PS lyase can lead to the dissolution of EPS, the smaller molecular substances that were produced as a result of EPS degradation could be used as carbon and energy sources for cell growth under the nutrient limiting condition [19]. 50% of EPS produced by aerobic granules could be utilized by their producers under aerobic starvation condition [20]. Biofilm extracellular polymeric substances (EPS) were biodegradable by their own producers and by other microorganisms when they were starved [21]. The soluble microbial products (SMP) were defined as soluble cellular components that were released during cell lysis. They had moderate formula weights and were biodegradable [22]. Some sludge flocs were disrupted by the hydrocyclone, the extracellular and intracellular organic substances including EPS and SMP were released into the mixture liquid as complementary carbon sources. These organic carbon sources were consumed for denitrification reaction, and were also consumed as substrates by heterotrophic aerobic bacteria to obtain energy. The end products were carbon dioxides and water. The cryptic growth of sludge was achieved by the hydrocyclone, the production of sludge was reduced [23,25].

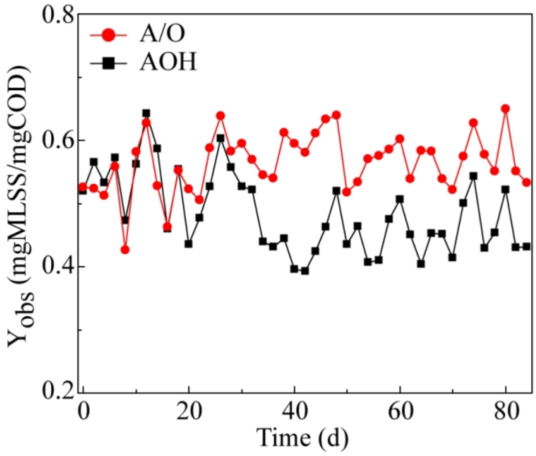


Fig. 11 The observed biomass yields of A/O and AOH

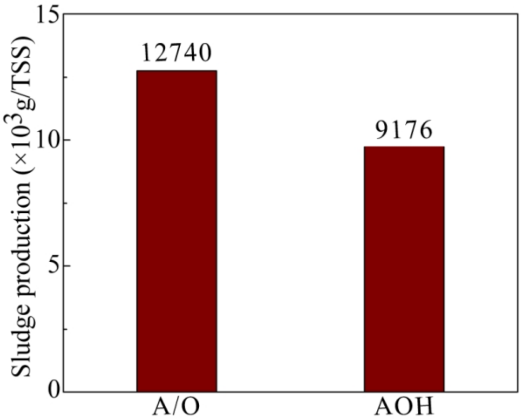


Fig. 12 The excess sludge productions of A/O and AOH

Conclusions

In summary, the modified A/O process showed good removal capacity. Some sludge flocs were well disrupted at damaging zone by the hydrocyclone, the extracellular and intracellular organic substances were released into the mixture liquid. After the installment of hydrocyclone, the average overflow and underflow SCOD concentrations of hydrocyclone were improved 10.5 mg/L and 12.5 mg/L, and the average disintegration efficiency were 35.6% and 42%, respectively. The average overflow and underflow PS concentrations of hydrocyclone were improved 6.2 mg/L and 7.6 mg/L, and the average disintegration efficiency were 53.3% and 64.5%, respectively. The average overflow and underflow PN concentrations of hydrocyclone were improved 2.59 mg/L and 2.9 mg/L. Compared with A/O, the average effluent COD concentration of AOH was decreased 40.3 mg/L, and the average COD removal efficiency was improved 15.2%. The average effluent TN concentration of AOH was decreased 14.1 mg/L, and the average TN removal efficiency was improved 21.5%. The average effluent NH_4-N concentration of AOH was decreased 1.7 mg/L, and the average NH_4^+-N removal efficiency was improved 4.5%. The average effluent NO_3^--N concentration of AOH was decreased 9.7 mg/L. AOH achieved good COD, NH_4^+-N and NO_3^--N removal than conventional A/O. After the installment of hydrocyclone, the effluent TN concentration of AOH was apparently decreased than A/O. The main reason is that effluent NO_3^--N concentration of AOH was decreased than A/O. Some sludge Flocs were disrupted by the hydrocyclone, extracellular and intracellular organic substances including EPS and SMP were released into the mixture liquid as complementary carbon sources for denitrification reaction. The denitrification reaction was enhanced because of the addition of carbon sources, and the removal efficiency of N was improved. These organic carbon sources were consumed during denitrification reaction, and also were consumed as substrates by heterotrophic aerobic bacteria to obtain energy. The end products were carbon dioxides and water. The cryptic growth of sludge was achieved by the hydrocyclone, and the production of sludge was reduced. The average Y_{obs} of AOH was decreased 0.110 mg MLSS/mg COD than A/O. The total excess sludge production of AOH was decreased 3564 g TSS than A/O.

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