Treatment of Municipal Wastewater with Micro-pressure Swirl Reactor

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Abstract. The experiment used micro-pressure swirl reactor (MPSR) as the object to investigate removal of pollutants and distribution of dissolved oxygen (DO). The results show that the average removal rates of chemical oxygen demand (COD), ammonia nitrogen (NH4+-N), total phosphorus (TP) and total nitrogen (TN) were 92.4%, 98.6%, 98.0% and 73.8%, respectively. In aeration stage, DO at outlet and central points was obviously different, and the anoxic and aerobic zones were formed naturally. Such as Spirostomum, Macrobiotus and Amphileptus observed during microbiological examination, which indicates a good operating state in MPSR.

1. Introduction
Such as sequencing batch reactor (SBR) activated sludge process[1], cyclic activated sludge technology (CAST)[2], anoxic/aerobic activated sludge process (A/O) and anaerobic/anoxic/aerobic activated sludge process (A2/O)[3,4], were widely used at urban sewage treatment plants in China. Municipal wastewater treatment facilities now are facing increasingly stringent effluent quality standards. To improve the removal rate of chemical oxygen demand (COD) and nitrogen, increasing biological activity was an important mean, which was promoted by increasing oxygen supply for assimilation and dissimilation of microorganisms. However, mechanical oxygen aeration was widely considered as one of the most expensive components in wastewater treatment, accounting for 55% of the total energy consumption of wastewater treatment plants[5]. More wastewater treating reactors should be developed to meet the stringent environmental regulations. Micro-pressure swirl reactor (MPSR) was based on SBR. Increasing the height of reactor outlet can produce micro-pressure, the micro-pressure extended the path length of bubble, and leaded to the spatial difference of liquid velocity and dissolved oxygen (DO) concentration[6]. Due to the unique gas-liquid flow pattern, there are both anoxic and aerobic zones in MPSR, simultaneous nitrification and denitrification (SND) can both occur in MPSR, organic compound and nitrogen removal were concurrently achieved. The realization of simultaneous nitrification and denitrification can save the reactor volume, which has great practical value. MPSR had a great attraction to small and medium-sized urban sewage treatment plants.
2. Material and Methods

2.1. Description of the Micro-pressure Swirl Reactor and Operating Conditions
The main body of the experimental device was shown in figure 1. The reactor had a total operational volume of 36L and was made of plexiglass. MPSR was operated in sequencing batch mode, with cycle time of 12h including 5min of feeding, 8h of aeration, and 10min of effluent withdrawal, and the surplus of cycle was the settling time. The municipal wastewater was treated at the temperature was \((20 \pm 1)^\circ\text{C}\), the total aeration was \(1.5\text{L·min}^{-1}\), the sludge residence time (SRT) was \((22 \pm 2)\) days.

![Figure 1. Schematic diagram of test device.](image)

2.2. Experiment Water Quality and Sludge
The inoculated sludge was taken from a biochemical tank of a sewage treatment plant at Changchun. The initial sludge concentration was 3000 mg·L\(^{-1}\). In this work, synthetic wastewater was used to simulate domestic sewage. The reagents used for the preparation of synthetic wastewater were soluble starch, beefextract, peptone, sodiumacetate (CH\(_3\)COONa), ammonium chloride (NH\(_4\)Cl), potassium dihydrogen phosphate (KH\(_2\)PO\(_4\)), sodium hydrogen carbonate (NaHCO\(_3\)), magnesium-sulfate (MgSO\(_4\)), Calcium-chloride (CaCl\(_2\)), Ferrous-sulfate (FeSO\(_4\)), Zinc-chloride (ZnCl\(_2\)), Copper-sulfate (CuSO\(_4\)), Aluminum-chloride (AlCl\(_3\)).

2.3. Analysis Methods
Sampling for measurement at the end of each cycle of aeration, the results of each cycle effluent are the average of three parallel samples. COD was measured by potassium dichromate oxidation method, ammonia nitrogen (NH\(_4^+\)-N) by Nessler reagent spectrophotometry method, total nitrogen (TN) by alkaline potassium persulfate digestion spectrophotometry method, total phosphorus (TP) by ammonium molybdate spectrophotometry method.Temperature, DO were monitored by WTW Multi 340i meter.Looking microbial phase by Leica DM5000B.

3. Results and Discussion

3.1. Removal Efficiency of Pollutants
During the 57 cycles operation the pollutants removal performances were illustrated in figure 2. The average influent COD, NH\(_4^+\)-N, TP and TN were 271.54, 29.80, 3.01 and 32.84 mg·L\(^{-1}\). The average concentrations in the effluent were 20.09, 0.4, 0.064 and 8.53 mg·L\(^{-1}\), the corresponding removal efficiency was 92.4%, 98.6%, 98.0% and 73.8%. From figure 2a, it can be observed that the COD concentration in the influent decreased constantly from 389.8 to 183.6 mg·L\(^{-1}\) from cycle 5 to cycle 13. However, the COD concentration in the effluent remained at about 20 mg·L\(^{-1}\). It shows that the MPSR had a good water quality anti-shock performance. It was possible that activated sludge extracellular polymeric substances (EPS) was abundant. When the organic pollutants were reduced, EPS was
digested and decomposed to provide energy and carbon source to maintain bacterial growth\cite{7}. Figure 2b shows the system had a strong removal efficiency on NH$_4^+$-N, although the influent NH$_4^+$-N fluctuated about 12 mg·L$^{-1}$ from cycle 13 to cycle 17, the effluent NH$_4^+$-N remained below 0.5 mg·L$^{-1}$. In figure 2c, the influent NH$_4^+$-N fluctuates dramatically from cycle 13 to cycle 17, which leads to a great change in influent TN. But the effluent TN kept at 8.5 mg·L$^{-1}$ during this period, so the removal efficiency of TN flows accordingly. Figure 2d illustrates that the effluent and removal efficiency of TP were stable greatly during the experiment. It can be seen that the MPSR has maintained a strong phosphorus removal capacity in this experiment.

![Figure 2. COD, NH$_4^+$-N, TN and TP concentrations and removal efficiencies.](image)

3.2. Dissolved Oxygen Distribution in Aeration Stage

Affected by the circulation flow pattern in MPSR and oxygen mass transfer theory, concentration of oxygen had a gradient from centrality to outlet. The dissolved oxygen duration was measured at the 9th, 21st, 33rd, 41st and 53rd aeration stages (the monitoring points are shown in figure 3a). Figure 3b was based on the average value of five monitoring data. The results show that the DO at 1 and 2 points were not consistent during the aeration stage, especially during the period of 0-5 hours. The difference of DO between the two points is large. The maximum difference occurs at the 5th hour of aeration, which was 0.5 mg·L$^{-1}$. This indicates that if the reactor size and aeration intensity match reasonably, a larger difference of DO concentration will be formed inside the reactor, and then anoxic anaerobic zones will be formed at the same time in the same space to meet the macro environment of SND\cite{8}.

Under the action of aeration in perforated aeration pipe, the mixed liquid around the main reaction zone circulates in the outer ring driven by the moving bubbles, and the liquid in the middle zone circulates under the action of the mixed liquid with high velocity around the reactor\cite{9}, which was the reason for the difference of DO concentration in the reactor.
3.3. Microbiological Examination

The reproductive metabolic activity of microorganisms can directly reflect the effect of sewage treatment fruit[10]. Microscopic microscopic images observed on August 15 of MPSR were shown in figure 3. Spirothestum, Macrobiotus and Amphileptus can be seen clearly which can show that the MPSR operates smoothly, and the effluent quality was good and clear.

Figure 3. DO monitoring point and change curve.

Figure 4. Sludge morphology in MPSR.

4. Conclusions

The micro-pressure swirl reactor treating urban wastewater shows that the average concentrations in the effluent were 20.09, 0.4, 0.064 and 8.53 mg·L⁻¹, which met the Class A standard of Chinese urban sewage pollutant discharge standard[11], the corresponding removal efficiency was 92.4%, 98.6%, 98.0% and 73.8%. Through monitoring DO at two representative sites of the reactor, it was found that both anoxic and aerobic zones could be formed in the reactor during the aeration period. Spirothestum, Macrobiotus and Amphileptus appearance intimades that MPSR has a good operation and stable removal efficiency.

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