*Desalination and Water Treatment*
www.deswater.com

doi: 10.1080/19443994.2013.848416

53 (2015) 909–918
January

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# Treatment of municipal wastewater by a magnetic activated sludge device

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Received 29 April 2013; Accepted 12 September 2013

ABSTRACT

Activated sludge process is one of the biological treatment methods for wastewater. The conventional activated sludge exposes a variety of disadvantages, such as sludge expansion, little biomass and loose flocs structure. Therefore, the conventional activated sludge needs to be improved. Compared with conventional activated sludge, the magnetic separation technology could overcome the disadvantages and improve the performances of conventional activated sludge. In this paper, a magnetic activated sludge device was built to conduct a pilot-scale study for 124 days from municipal wastewater. The effects of conventional activated sludge and magnetic activated sludge on removing the organic matters and nitrogen were compared. In addition, the sedimentation performance of the magnetic activated sludge and the variations of the biomass concentration were also investigated. The measuring cylinder experiment showed that sludge velocity reduced from 90 to 56% after 2 min of settling ($SV_2$) with the variations of magnetic powder ($Fe_3O_4$) dosage from 0 to 120 g/L. When the magnetic powder was added to aeration tank, the concentrations of mixed liquor volatile suspended solids (MLVSS) increased gradually and reached the maximum value of 7.35 g/L. The leakage of biomass was not observed during the magnetic activated sludge process, indicating that magnetic powder could maintain a high concentration of activated sludge. Also, the magnetic powder had no negative influence on the growth of the activated sludge. Both processes did not have significant difference in removing chemical oxygen demand (COD) (above average: 75.13% removal) and biochemical oxygen demand for five days (above average: 92.79% removal). In contrary to the conventional activated sludge process, magnetic activated sludge process had higher removal efficiency in removing ammonium nitrogen ($NH_4$-N) (88.68 ± 7.98% removal). The average total nitrogen (TN) removal efficiencies of both processes were 37.56 ± 14.35% and 42.35 ± 22.65%, respectively. The lower COD/TN might affect denitrification efficiency.

*Keywords:* Conventional activated sludge; Magnetic powder ($Fe_3O_4$); Magnetic activated sludge; Municipal wastewater

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## 1. Introduction

With the development of China's economy, the lack of water resources is becoming a major issue resulting from untreated or substandard wastewater [1]. Activated sludge process, being one of the aerobic biological treatment methods for wastewater, was widely used for municipal and industrial wastewater treatment [2,3]. However, due to the fluctuation of wastewater quality and flow, conventional activated sludge exposed to a variety of disadvantages, such as sludge expansion, little biomass, and loose flocs structure. In order to overcome the weaknesses of activated sludge and intensify removals of wastewater pollutants, improving conventional activated sludge is essential.

Magnetic technology is a method for the magnetization of matters by the magnetic field. It is widely used for wastewater treatment. In recent years, the effects of magnetic technology on activated sludge process have been studied by some authors [4–11]. These investigations mainly focused on two aspects. Firstly, the investigations mainly focused on the effects of magnetic field on microbes [4–7]. Ji et al. [4] proved that magnetic field induction of 20 mT had a positive effect on bacterial growth in activated sludge. Raja Rao et al. [5] reported that the influence of magnetic field enhanced the growth ratio of microbes. Lebkowska et al. [6] showed that the magnetic field had a positive effect on activated sludge biomass growth and dehydrogenase activity. Wang et al. [7] proved that an intensity of 48.0 mT magnetic field could enhance the activities and growth of nitrite-oxidizing bacteria by the long-term cycle experiments and fluorescence in situ hybridization analysis. Secondly, the investigations mainly focused on the effects of magnetic field on pollutants degradation [8–11]. Jung et al. [8] showed that a magnetic field of 450 mT increased the efficiency of phenol biodegradation by 30% compared with the control sample. Lebkowska et al. [9] found that the decreases of formaldehyde and COD concentrations using a static magnetic field of 7 mT were greater by 30 and 26% in comparison with the control, respectively. Zhu et al. [10] observed that the maximum biodegradable ratio of polyhydroxyalkanoates (PHA) was noted at 11 mT during the famine period. Liu et al. [11] found a significant 30% increase on maximum nitrogen removal ratio by using the magnetic system. These investigations illustrated that magnetic field could enhance the growth of microbes and improve removal efficiencies of some pollutants.

From the above descriptions, we could conclude that these investigations more focused on the effects of magnetic induction on active sludge growth and pollutants biodegradation by external magnetic field. In addition, some researchers also reported the effect of magnetic powder on the activated sludge [12,13]. Activated sludge is supplemented with magnetic powder to create a magnetic activated sludge. The magnetic activated sludge process could maintain a high concentration of mixed liquor suspended solids (MLSSs) in the reactor, which would likely affect cell metabolism and bacterial growth [11,14]. However, the previous reports have more focused on milk wastewater and synthetic wastewater and were only conducted in the laboratory [12,13]. There were few researches on magnetic activated sludge process treating municipal wastewater in anoxic/aerobic system. Therefore, this study aimed to build up a set of magnetic activated sludge device (MASD) for the long-time field experiment. Magnetic powder ($Fe_3O_4$, a kind of magnetite) was introduced in activated sludge in order to form magnetic activated sludge. Magnetic powder was repeatedly recycled by a magnetic separator (a rotating magnetic drum). Meanwhile, the MASD without magnetic powder was considered as control system (conventional activated sludge process). The sedimentation performance of activated sludge, the change of biomass concentrations and removals of organic matter and nitrogen from municipal wastewater were investigated.

## 2. Materials and methods

### 2.1. Experimental setup

The MASD was made of 5 mm carbon steel. The inside and outside of the MASD were brushed with anti-corrosion paint to prevent oxidation. The reactor has the dimensions of $5.05\,m \times 1.60\,m \times 2.30\,m$ (length, width and depth, respectively) with the total valid volume of $14.5\,m^3$. The MASD consists of an anoxic tank, an aerobic tank, a settling tank, a holding tank and a magnetic separator (a rotating magnetic drum). The anoxic tank has the dimensions of $1.44\,m \times 1.60\,m \times 1.8\,m$ (length, width and valid water depth, respectively) with the hydraulic retention time of 2.7 h. The aerobic tank has the dimensions of $2.45\,m \times 1.60\,m \times 1.8\,m$ (length, width and valid water depth, respectively) with the hydraulic retention time of 3.53 h. The setting tank has the dimensions of $1.16\,m \times 1.60\,m \times 1.8\,m$ (length, width and valid water depth, respectively) with the hydraulic retention time of 1.67 h. Piping arrangement included inlet pipes, sludge pipes, air pipes and outlet pipes. Other accessories of the MASD included valves for controlling return activated sludge and dosing pumps

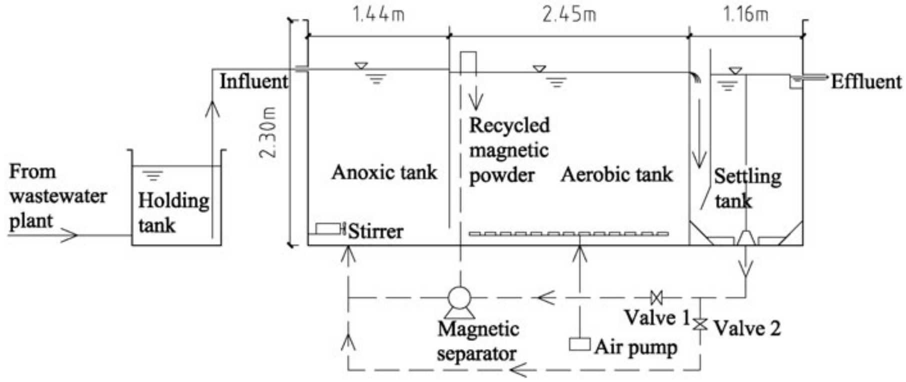


Fig. 1. Schematic diagram of the MASD.

for pumping raw domestic sewage and activated sludge. A schematic diagram of MASD has been described in Fig. 1. The reactor was inoculated with aerobic flocculent sludge from a municipal wastewater plant in China. The domestic sewage and a small amount of industrial wastewater were treated by sequencing batch reactor (SBR) process in the municipal wastewater treatment plant.

In the course of magnetic activated sludge, activated sludge was supplemented with magnetic powder in order to form the magnetic activated sludge. The magnetic powder exhibited a strong attractable magnetic property, and was easily deposited on the surface of the rotating magnetic drum by magnetic attraction in the process. Also, they were scraped by a scraper. Consequently, the rotating magnetic drum, being considered as an activated sludge/magnetic powder separator, was installed on the pipeline of return activated sludge for constantly forming the magnetic activated sludge by recycling magnetic powder to aerobic tank. Meanwhile, the activated sludge which did not contain the magnetic powder was circulated to anoxic tank.

The MASD was automatically controlled by the means of a programmable logic controller. The flow rates of the influent, return sludge and aeration were constantly recorded.

## 2.2. Operation condition

The whole reaction process of the MASD was divided into two stages. During the first phase of 58 days of operation (Phase I, conventional activated sludge), no magnetic powder was added to the aerobic tank. The leakage of activated sludge was observed on the 57th–58th day (Fig. 4(c)). In order to maintain the high biomass concentration, magnetic powder was added to the aerobic tank from the 59th day. During the 59–124 days of operation (Phase II, magnetic activated sludge), magnetic powder dosage of 120 g/L was added to the aerobic tank based on the result that $SV_2$ showed little variations with more than the magnetic powder dosage of 120 g/L (Fig. 2). The loss of magnetic powder was supplemented at a rate of 8 kg/d due to the fact that recovery efficiency of magnetic powder could not reach 100% by the magnetic separator and a small amount of magnetic powder might be precipitated in the MASD system. During phase I, the magnetic drum did not work by closing the valve 1 and opening valve 2. Return activated sludge collected from the setting tank was pumped back to the anoxic tank directly at the rate of 4.6 $m^3$/h. During phase II, the magnetic drum worked by opening the valve 1 and closing valve 2. Return magnetic activated sludge collected from the setting tank was pumped back to the magnetic drum for separating the magnetic powder from activated sludge at the rate of 4.6 $m^3$/h, and then activated sludge was

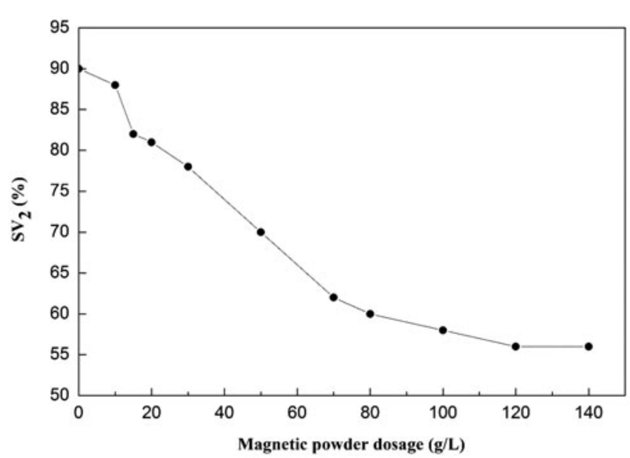


Fig. 2. Effect of magnetic powder dosage on sludge velocity ($SV_2$) when the MLVSS concentration was 11 g/L.

recycled to anoxic tank. The length of the magnetic drum was 40 cm with 40 cm internal diameter. The magnetic drum rotated at a frequency of 40 rpm and had the surface field strength of 280 mT. During phase I, oxygen was provided by using a set of aeration system at a rate of $0.4\,m^3/min$ to ensure oxygen distribution. During phase II, oxygen was provided at a rate of $0.6\,m^3/min$ due to the poor oxygen diffusion under the high biomass concentration. The average influent flow was $51.21 \pm 5.45\,m^3/d$, and the HRT was 7.27 h. The temperature of the MASD was kept at 21.0 ± 2.0℃. During the whole experiment period, no sludge was intentionally withdrawn, except for the leakage of biomass during phase I and samples taken for measuring the MLSS and MLVSS. Other operation parameters are shown in Tables 1 and 2.

The samples for MLSS and MLVSS were taken from the aerobic tank every day for 124 days (June–September). Dissolved oxygen (DO) was measured in both the anoxic tank and the aerobic tank. The samples of influent and effluent for COD, TN, $NH_4$-N and suspend solids (SS) were taken every day for 124 days. The samples of influent and effluent for biochemical oxygen demand for five days ($BOD_5$) were taken every two days for 124 days.

Table 1
Operation parameters of the experiment

| Parameters | Maximum | Minimum | Average standard deviation |
|---|---|---|---|
| COD/TN | 6.86 | 2.83 | 4.72 ± 0.89 |
| $BOD_5$/TN | 2.34 | 0.32 | 1.21 ± 0.39 |
| Sludge return ratio (%) | 3.36 | 0.91 | 2.16 ± 0.56 |
| Dissolved oxygen of anoxic tank (mg/L) | 0.65 | 0.10 | 0.40 ± 0.15 |
| Dissolved oxygen of aerobic tank (mg/L) | 3.50 | 0.93 | 2.07 ± 0.67 |

Note: $n = 124$ samples, except for $BOD_5$ (62 samples).

Table 2
F/M values of the experiment

| Parameters | Initial value | Final value |
|---|---|---|
| F/M (kg COD/kg MLVSS. d) | 1.18 | 0.22 |
| F/M (kg $BOD_5$/kg MLVSS. d) | 0.35 | 0.065 |

### 2.3. Sewage and sludge

The municipal wastewater and the activated sludge were collected from the same wastewater plant. The municipal wastewater composed of washing wastewater, flushing water, and a small amount of the industrial wastewater. The influent of the MASD was derived from the filtered effluent through thick grid and thin grid. Its characteristics are shown in Table 3.

### 2.4. Magnetic powder

The magnetic powder, derived from the magnet mine plant (Henan, China), was used as the seeding material. The main chemical composition is $Fe_3O_4$. It was ground in ring mill and sized by the coulter counter method. The magnetic powder with a mean particle size of 13 μm was used for seeding purpose. The specific gravity of magnetic powder is $5.0\,g/cm^3$.

### 2.5. Analytical methods

COD, $BOD_5$, SS, MLSS, and MLVSS were measured based on the Standard Methods for the Examination of Water and Wastewater [15]. TN and $NH_4$-N were analyzed by the colorimetric method with a spectrophotometer (Genesys TM-5, Spectronic Inc., USA). pH and DO were measured using a acidity meter (FE20, MRTTLER TOLEDO Co., Switzerland) and a dissolved oxygen analyzer (HQ30d, HACH Co., USA), respectively.

In general, the measurement of sludge volume after 30 min of settling ($SV_{30}$) is used for describing sedimentation performance of sludge. In our experiment, the measurement of sludge volume after 2 min of settling ($SV_2$) was carried out by settling method due to the fact that our measuring cylinder

Table 3
The characteristics of wastewater through thick grid and thin grid

| Indexes | Minimum | Maximum | Average standard deviation |
|---|---|---|---|
| COD (mg/L) | 100.00 | 160.00 | 122.34 ± 16.77 |
| $BOD_5$ (mg/L) | 19.70 | 52.00 | 31.56 ± 8.01 |
| SS (mg/L) | 38.00 | 166.00 | 70.94 ± 18.39 |
| TN (mg/L) | 16.90 | 39.40 | 26.45 ± 4.0 |
| $NH_4$-N (mg/L) | 7.33 | 22.80 | 13.75 ± 3.17 |
| pH | 7.86 | 7.13 | 7.55 ± 0.10 |

Note: $n = 124$ samples, except for $BOD_5$ (62 samples).

experiment showed that activated sludge was stably precipitated after 2 min, when magnetic powder was added to the activated sludge (Fig. 2).

## 3. Results and discussion

### 3.1. Effect of magnetic powder dosage on activated sludge sedimentation

The experiment was conducted in a 1L measuring cylinder (H39 cm × D7 cm). The concentration of activated sludge derived from SBR tank reached 11 g/L by gravity thickening. The magnetic powder used in the experiment was magnetized by a magnet. The magnet has the dimensions of 30 mm × 15 cm (diameter and thickness) with the magnetic field of 280 mT. The thickened activated sludge was added to the 1 L measuring cylinder. Meanwhile, the different magnetic powder dosages were added to the measuring cylinder. $SV_2$ was recorded after 2 min.

Fig. 2 illustrated the effect of magnetic powder dosage on sludge velocity ($SV_2$) when MLSS concentration reached 11 g/L. The result indicated that $SV_2$ gradually reduced with the increase of magnetic powder dosage. It reduced from 90 to 56%, when the magnetic powder dosage was between 0 and 120 g/L. After the magnetic powder dosage exceeded 120 g/L, $SV_2$ almost had little variation. The result showed that magnetic powder could improve sedimentation performance of activated sludge. The reason may be that the addition of magnetic powder made the size of flocs larger due to the combination of each other by magnetic force. In addition, because the density of magnetic powder is 5.0 g/cm$^3$, activated sludge with magnetic powder was quickly precipitated. Based on the above two reasons, the sedimentation performance of activated sludge was improved. The result of the research was similar to those of some researchers [16,17]. It is very important for maintaining the operation of the MASD under the condition of high-concentration activated sludge.

### 3.2. Change of biomass concentrations in magnetic activated sludge

The variations of MLVSS concentration in the MASD system were shown in Fig. 3. During the 0–58 days (Phase I), MLVSS concentration gradually increased. When MLVSS concentration reached 3.93 g/L, the effluent of SS concentration sharply increased, indicating that there was leakage of biomass (Fig. 4(c)). On 59th day, the magnetic powder of 120 g/L was added to the aerobic tank. During the 59–124 days (Phase II), MLVSS concentration gradually increased again and reached the maximum value of 7.35 g/L. The leakage of biomass was not observed during phase II, revealing that magnetic powder could maintain the high concentration of activated sludge. Moreover, the growth ratio of MLVSS during phase II (0.042 g/L.d) was higher than that of phase I (0.038 g/L.d), as can be seen in Fig. 3. This proved that magnetic powder had no significant negative influence on the growth of the activated sludge. It has been also reported that magnetic powder did not exert an influence on microbial growth in activated sludge [18].

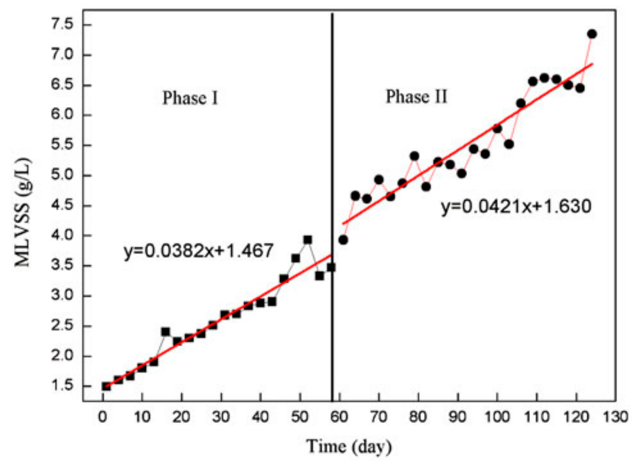


Fig. 3. The changes of MLVSS concentration with the time. ■: MLVSS concentration of Phase I. ●: MLVSS concentration of Phase II. Phase I: no magnetic powder was added to the aerobic tank. Phase II: the magnetic powder was added to the aerobic tank.

The higher the sludge concentration, the lower the sludge loading ratio. The final F/M ratio of the experiment was 0.22 kg COD/kg MLVSS.d. Mark et al. found that deceasing sludge loading ratio could reduce sludge production in aerobic wastewater treatment [19]. It would theoretically be possible to reach the situation in which the amount of energy provided by substrate equals the maintenance demand of micro-organisms by increasing biomass concentration [20]. When the micro-organisms were close to the state, they utilize most of the substrates for maintenance purpose and consequently less for growth. It is impossible to maintain the high sludge concentration for conventional activated sludge by the means of sedimentation. The magnetic powder could maintain the high activated sludge concentration as shown in Fig. 3. The similar phenomenon has been reported by Ying et al. [21] who observed that the concentration of MLVSS increased gradually when using the magnetic activated sludge process with continuous aeration for treating milking parlor wastewater without withdrawal of excess sludge.

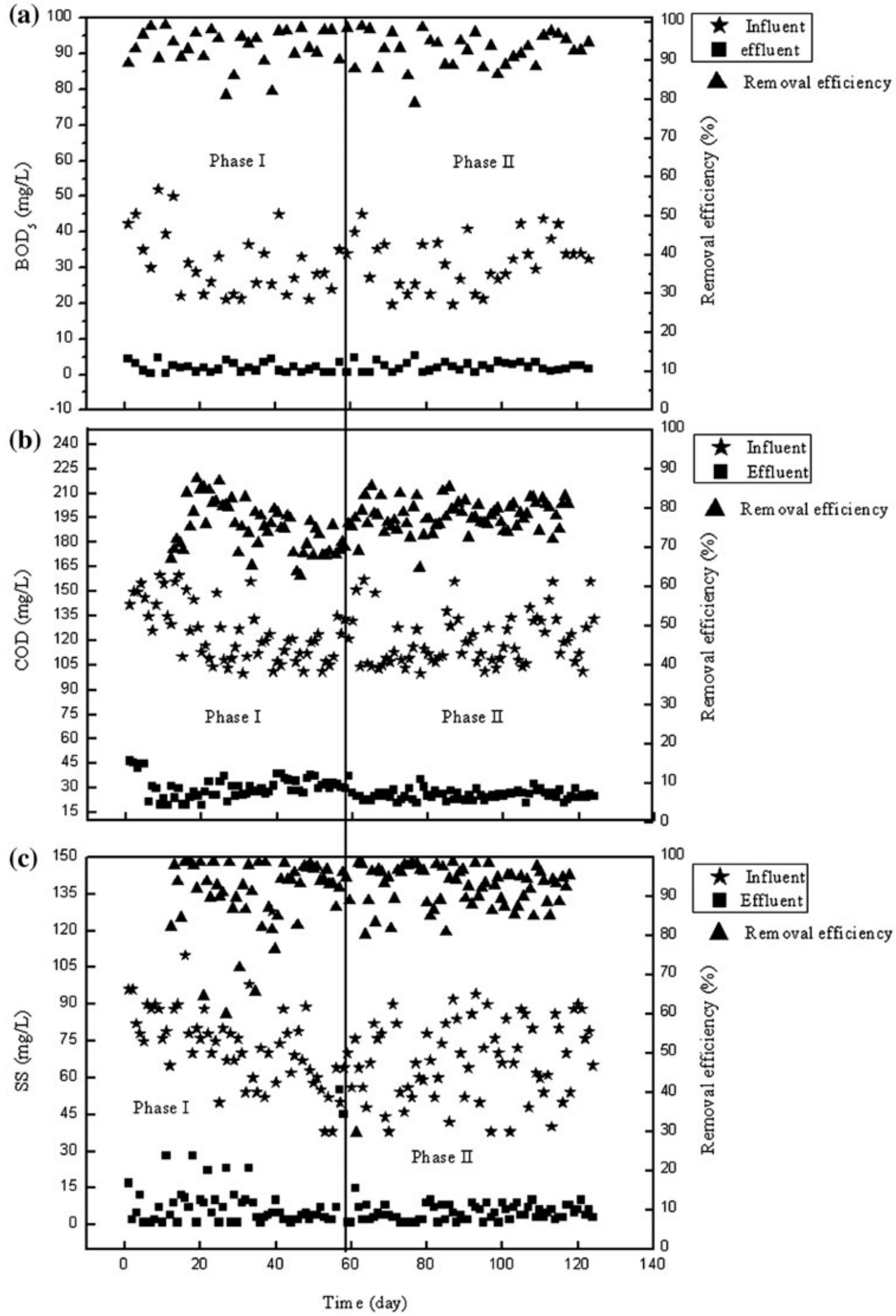


Fig. 4. The variations of COD, $BOD_5$ and SS with the time: (a) the influent, effluent concentrations and removal efficiencies of $BOD_5$; (b) the influent, effluent concentrations and removal efficiencies of COD; and (c) the influent, effluent concentrations and removal efficiencies of SS. Phase I: no magnetic powder was added to the aerobic tank. Phase II: the magnetic powder was added to the aerobic tank.

During phase II, MLVSS concentrations increased from 3.47 to 7.35 g/L by adding the magnetic powder to aerobic tank. There was long sludge retention time (SRT) during the whole experiment process. The SRT of the biomass in the biological system can be calculated by using Eq. (1) [22]:

$$\mathrm{SRT} = \frac{v_r \times x_r}{q \times x_{runoff} + x_{ex} \times q_{ex}} \quad (1)$$

where SRT is sludge retention time (d), $v_r$ is volume reactor ($m^3$), $x_r$ is biomass concentration of reactor ($kg/m^3$), $q$ is the amount of sludge discharge ($m^3/d$), $x_{runoff}$ is the concentration of sludge in runoff, $x_{ex}$ is the concentration of sludge in effluent ($kg/m^3$), and $q_{ex}$ is the amount of sludge in effluent ($m^3/d$). Since the system was operated with no sludge wastage in effluent during the Phase II, Eq. (1) can be simplified as Eq. (2):

$$\mathrm{SRT} = \frac{v_r \times x_r}{q \times x_{runoff}} \quad (2)$$

From Eq. (2), it can be seen that if there was no sludge discharge in the system, then $q$ is equal to zero and consequently SRT tends to infinity (complete sludge retention). During the Phase II, there was no sludge discharge intentionally, indicating that sludge reached complete retention. Zero sludge production could be achieved at high sludge concentration (15–23 g/L) and food to micro-organism (F/M) ratio as low as about 0.07 kg COD/kg MLSS d in a pilot submerged membrane bioreactor (MBR) with complete sludge retention [23,24]. In our experiment, zero sludge was achieved at high sludge concentration (3.47–7.35 g/L) and F/M ratio as low as about 0.09 kg COD/kg MLSS.d.

### 3.3. Removals of organic matters and SS

The variations of COD, $BOD_5$ and SS concentrations in the influent, effluent and removal efficiencies were given in Fig. 4. For COD and $BOD_5$ items, the average influent concentrations were 122.34 ± 16.77 mg/L and 31.56 ± 8.01 mg/L, respectively. The average removal efficiencies of COD and $BOD_5$ items, the average influent concentrations were 122.34 ± 16.77 mg/L and 31.56 ± 8.01 mg/L, respectively. The average removal efficiencies of COD and $BOD_5$ during phase I (75.13 ± 6.02% and 93.55 ± 4.72%, respectively) were not significantly different from those of phase II (78.17 ± 3.94% and 92.79 ± 4.54%, respectively). It revealed that magnetic powder had no influence on the degradation performance of organic matters and organic matters could be oxidized well under the condition of high biomass concentration.

Sakai et al. [25] observed that COD removal efficiency was between 85 and 94%, under conditions where no sludge was removed for treating the synthetic sewage (COD 2,030 mg/L and $BOD_5$ 1,500 mg/L) by the magnetic activated sludge process. Ying et al. [13] reported that the average removal efficiency of COD reached 91% when using the magnetic activated sludge process with the continuous aeration and intermittent aeration processes for treating the milking parlor wastewater. Compared with the studies of Sakai and Ying, the lower removal efficiency of the organic matters was observed in our experiment, which may be the reason that the influent concentrations of municipal wastewater were lower than those of synthetic sewage and milking parlor wastewater. However, the effluents of COD and $BOD_5$ were below 50 and 10 mg/L, respectively, meeting the urban wastewater discharge standard limit, China (GB18918-2002). It showed that complete sludge retention had no influence on the degradation of pollutions. The similar study had been reported by Cicek et al. who observed that there was no significant variation on COD removal efficiencies with different SRT from 2 to 30 days in the pilot-scale side-stream MBR-treating synthetic wastewater [26].

The average value of influent SS concentration was 70.94 ± 18.39 mg/L during the whole experiment process. Except the higher effluent observed on 57th–58th day, the SS average removal efficiencies during phase I and phase II were 90.89 ± 9.00% and 92.68 ± 4.97%, respectively. It indicated that the removal efficiency of phase II was still high, although the biomass concentration increased from 3.93 to 7.35 mg/L. The reason may be that the sedimentation performance of sludge was enhanced by the addition of the magnetic powder. Faster sedimentation was observed in magnetic activated sludge process because of the larger density of flocs [27]. The compact flocs helped improve sludge sedimentation performance and, consequently, enhanced the effluent of SS. It was obvious that the addition of magnetic powder was useful for the improvement of activated sludge exhibiting poor settleability, especially under the condition of the high biomass concentration.

### 3.4. Removal of nitrogen

The variations of influent $NH_4$-N concentration were from 7.33 to 22.80 mg/L with an average of 13.75 ± 3.17 mg/L during the whole experiment process (Fig. 5(a)). The average removal efficiencies during phase I and phase II were 70.16 ± 13.86 mg/L and 88.68 ± 7.98 mg/L, respectively. The result showed that the efficiency of nitrification was much better during phase II than that of phase I. The efficiency of nitrification depends on the amount of nitrifying autotrophs and their growth environment [13]. Maintaining a long SRT to ensure the growth of nitrifying autotrophs had been reported by several authors

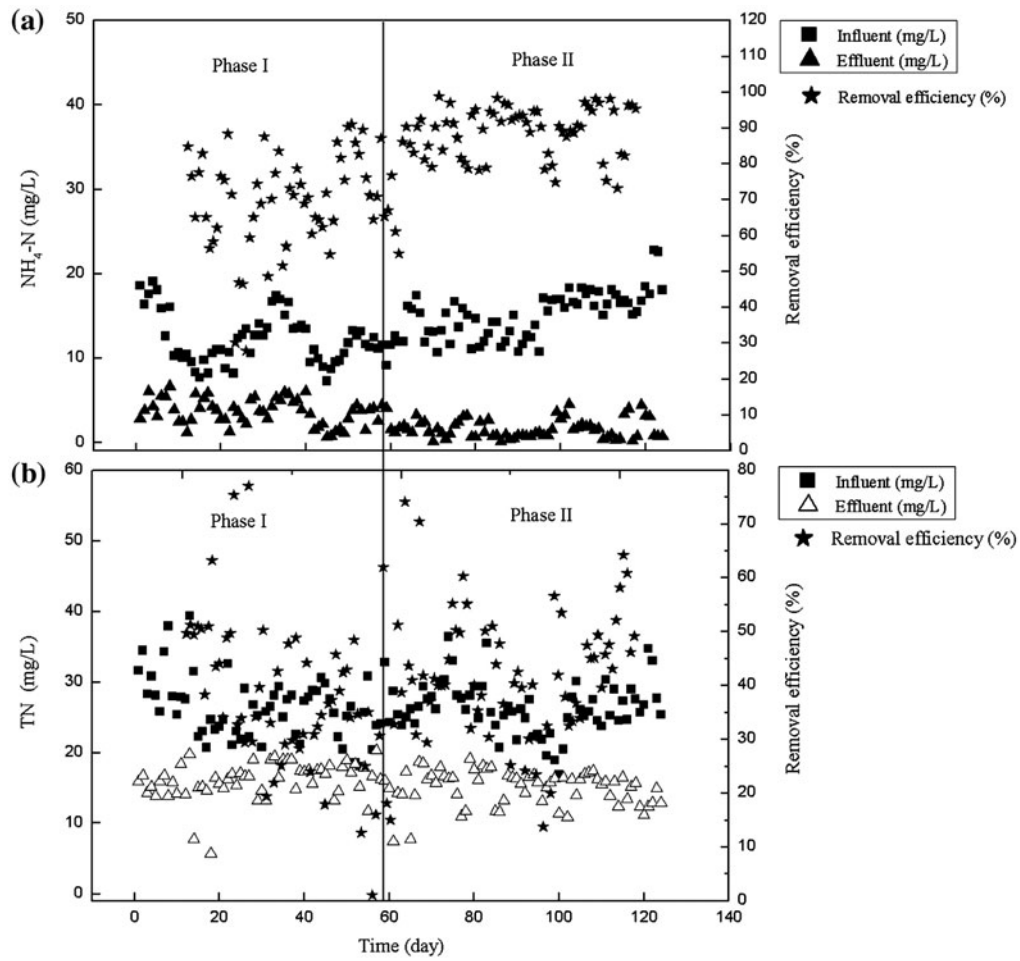


Fig. 5. The variations of $NH_4$-N and TN with the time: (a) the influent, effluent concentrations and removal efficiencies of $NH_4$-N; and (b) the influent, effluent concentrations and removal efficiencies of TN. Phase I: no magnetic powder was added to the aerobic tank. Phase II: the magnetic powder was added to the aerobic tank.

[28,29]. Pollice et al. have observed that MBR could accomplish organic matter oxidation and nitrification with HRT of 10–30 days [28]. Teck et al. also believed that the rather long SRT might lead to the increase of the slow-growing nitrifying autotrophs and support their dominance [29]. In our experiment, there is an infinite SRT due to the fact that activated sludge was not removed from the system, resulting in better nitrification performance at the later period (Phase II). In addition, food-to-micro-organism (F/M) ratio is considered to be important factors for the selection of nitrifying autotrophs [30]. It is suggested that the F/M ratio should be maintained at lower than 0.4 mg COD/mg VSS.d in order to achieve stable nitrification and total nitrogen removal from thin-film transistor liquid crystal display wastewater containing monoethanolamine and tetra-methyl ammonium hydroxide [30]. In our study, the increase of MLVSS resulted in the variation of F/M ratio from initial 1.18 kg COD/kg MLVSS d to final 0.22 kg COD/kg MLVSS d. It was likely that the lower F/M ratio led to the gradual increase of nitrifying autotrophs, which improved the effluent of $NH_4$-N. It was reported that the lower F/M ratio inhibited the growth of heterotrophic organism in the system due to the lack of enough organic carbon [31]. In general, nitrifying autotrophs would be relegated to those zones where heterotrophic growth was severely limited [32]. Therefore, the lower F/M ratio revealed the preference for nitrifying autotrophs in comparison with the heterotrophic organism. The competition of the different population depends on the predominance among the factors. Fig. 5 indirectly showed the results of competition of the different population by the variation of effluent $NH_4$-N concentrations under the condition of the variation of F/M ratio.

The variations of influent TN concentration were from 16.90 to 39.40 mg/L with an average of 26.45 ± 4.00 mg/L during the whole experiment process (Fig. 5(b)). The average TN removal efficiencies during phase I and phase II were 37.56 ± 14.35% and 42.35 ± 22.65% with the effluent values of 16.07 ± 2.61 mg/L and 15.03 ± 2.46 mg/L, respectively, which exceeded the urban wastewater discharge in China (⩽15 mg/L). Denitrification was promoted by recycling the nitrite/nitrate formed via nitrification back to the anoxic tank. Meanwhile, the denitrifying bacteria need more carbon source. During the whole experiment process, the average COD/TN was 4.72 ± 0.89, which was lower than that of the conventional demand in the denitrification process. The lower COD/TN generally had effect on denitrification efficiency.

## 4. Conclusions

Magnetic powder ($Fe_3O_4$) improved the sedimentation performance of activated sludge and could maintain the high biomass concentration. The magnetic powder had no significantly negative influence on the growth of the activated sludge.

Magnetic activated sludge process had no significant influence on the removals of COD and $BOD_5$. The organic matters could be oxidized well under the condition of high biomass concentration.

Compared with the conventional activated sludge, there was better nitrification performance during the magnetic activated sludge process. The increase of MLVSS resulted in the variation of F/M ratio from initial 1.18 kg COD/kg MLVSS d to final 0.22 kg COD/kg MLVSS d. The lower F/M ratio revealed the preference for nitrifying autotrophs in comparison with the heterotrophic organism. The lower COD/TN might affect denitrification efficiency.

In order to prevent pipeline jam and further increase the recovery efficiency of magnetic powder ($Fe_3O_4$), the size selection of magnetic powder ($Fe_3O_4$) and the improvement of magnetic separator should be further researched.

## Acknowledgments

Financial support provided by Science and Technology Research Program of Chongqing (No. cstc2011ggC20016) and Youth Fund of Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences (No. Y23H030M10) are gratefully acknowledged.

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