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# An innovative integrated oxidation ditch with vertical circle (IODVC) for wastewater treatment

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**Abstract**: The oxidation ditch process is economic and efficient for wastewater treatment, but its application is limited in case where land is costly due to its large land area required. An innovative integrated oxidation ditch with vertical circle(IODVC) system was developed to treat domestic and industrial wastewater aiming to save land area. The new system consists of a single-channel divided into two ditches(the top one and the bottom one by a plate), a brush, and an innovative integral clarifier. Different from the horizontal circle of the conventional oxidation ditch, the flow of IODVC system recycles from the top zone to the bottom zone in the vertical circle as the brush is running, and then the IODVC saved land area required by about 50% compared with a conventional oxidation ditch with an intrachannel clarifier. The innovative integral clarifier is effective for separation of liquid and solids, and is preferably positioned at the opposite end of the brush in the ditch. It does not affect the hydrodynamic characteristics of the mixed liquor in the ditch, and the sludge can automatically return to the down ditch without any pump. In this study, experiments of domestic and dye wastewater treatment were carried out in bench scale and in full scale, respectively. Results clearly showed that the IODVC efficiently removed pollutants in the wastewaters, i.e., the average of COD removals for domestic and dye wastewater treatment were 95% and 90%, respectively, and that the IODVC process may provide a cost effective way for full scale dye wastewater treatment.

**Keywords**: integrated oxidation ditch; vertical circle; domestic wastewater; dye wastewater treatment

## Introduction

Oxidation ditches have been used extensively in many countries for over 40 years since the first oxidation ditch was established at Voorschoten of the Netherlands. Besides the original Pasveer ditch some new types of oxidation ditches have been developed, i.e., Jet aeration channel, Carrousel oxidation ditch(Mandt, 1984), Orbal ditch(Mike, 1995; Yan, 1998), oxidation-ditch process using falling water as aerator (Nakasone, 1995) and integrated oxidation ditch (Steusel, 1987; Velez, 1988; Wang, 2001). The oxidation ditch process is economical and efficient for wastewater treatment. Due to low sludge loading rate, the conventional oxidation ditch process is efficient for COD removal and nitrification. To date, thousands of wastewater treatment plants worldwide are operated based on the oxidation ditch principle, i.e., over 9200 municipal oxidation ditch installations in USA and about 40 in China(EPA, 2000; Yan, 1998). However, the main disadvantage of conventional oxidation ditch processes is that it requires more land area than other activated sludge processes. As a result, their application is limited in where land cost is expensive (EPA, 2000).

Liu and Xia (Liu, 2001) developed an innovative integrated oxidation ditch with vertical circle(IODVC) aiming to reduce land requirements for this process. The purpose of this paper is to investigate feasibility of this IODVC system for wastewater treatment. The IODVC system was tested for domestic wastewater treatment at bench scale and dye wastewater treatment at full scale, respectively. The impact of salt concentration on COD removal in the IODVC for dye wastewater treatment was discussed as well.

## 1 Materials and methods

### 1.1 Configuration of IODVC system

The IODVC consists of a single-channel, a brush, and a clarifier(Fig. 1). A brush is used as aerator in the ditch, and its rotated speed and submersion depth can be adjusted. The single channel is divided into two ditches by a plate, the top one and the bottom one. Different from the horizontal circle of the conventional oxidation ditch, the flow of IODVC recycles from the top to the bottom in vertical circle as the brush is running. As a result, the different zones, aerobic in the top and anoxic and anaerobic in the bottom, are formed. In the steady state of IODVC, the volumes of anaerobic, aerobic and anoxic zones amount to 10%, about 50%—70%, and about 35%—20% of the total ditch, respectively, based on the calculation through determining DO concentration in different zones. Nitrification process happens in the aerobic zone, and denitrification process takes place in the anoxic and anaerobic zones. In this new system, the clarifier is set at the opposite end of brush in the ditch, and the sludge can return to the down ditch without any pump. Land area required for the IODVC was about half of that for conventional oxidation ditches with intrachannel clarifier(Liu, 2001).

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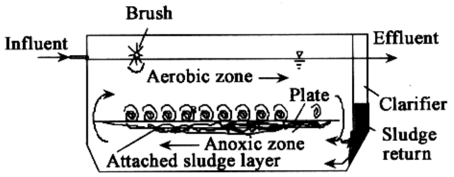

Fig.1 Schematic diagram of the IODVC system

## 1.2 Operation conditions

### 1.2.1 Bench scale

Bench-scale experiment of the IODVC system was carried out in Research Center for Eco-Environmental Sciences(RCEES), Chinese Academy of Sciences in Beijing. The effective volume of IODVC is 33 L. The raw municipal wastewater came from a sewer near RCEES. Its characteristics are listed in Table 1. The hydraulic retention time(HRT) was adjusted through influent flow. The influent flow was low in the beginning and then increased gradually to a set value to investigate impacts of decreasing HRT on COD and $NH_4^+$-N removals. Throughout the operating period, the temperature varied between 10—30℃. Sludge retention time (SRT) was determined and adjusted by daily discharging parts of excess sludge.

**Table 1 The characteristics of the wastewater and operation conditions of the system**

| Raw wastewater | Range | Mean | Operation conditions | Range |
|---|---|---|---|---|
| pH | 7.0—8.1 | 7.4 | HRT, h | 6—25 |
| SS, mg/L | 50—511 | 152 | SRT, d | 30—40 |
| $BOD_5$, mg/L | 100—280 | 168 | F/M, kg COD/(kg·MLSS·d) | 0.12—0.25 |
| COD, mg/L | 273—911 | 420 | MLSS, g/L | 1.9—4.9 |
| $NH_4^+$-N, mg/L | 30—80 | 59.2 | | |
| $NO_3^-$-N, mg/L | 1.8—10.2 | 5.8 | | |
| TN, mg/L | 32—90 | 65 | | |

### 1.2.2 Full scale

Based on the bench-scale experimental results, a full-scale IODVC system was designed and built for treating DCB (3, 3'-dichlorobenzidine) wastewater in a dye company, Shandong Province of China. The average influent flow of the DCB wastewater was 30 $m^3/d$, and the characteristics of raw DCB wastewater are summarized in Table 2. The design capacity of the IODVC system was 33 $m^3/d$, and details of its configuration are listed in Table 3. Fig. 2 shows the full-scale IODVC system and pre-treatment units for the DCB wastewater treatment.

**Table 2 The characteristics of raw DCB wastewater**

| Parameters | Range | Average | Parameters | Range | Average |
|---|---|---|---|---|---|
| $COD_{Cr}$, mg/L | 11600—33686 | 22480 | *T*, ℃ | 40—60 | – |
| $BOD_5$, mg/L | 800—900 | 885 | pH | 13.75—13.98 | 13.9 |
| NaOH, % | 0.7—2.28 | 1.49 | Color, DT* | – | 20000 |
| $NH_4^+$-N, mg/L | 1148—1347 | 1247.9 | SS, mg/L | 1600—1900 | 1700 |
| TN, mg/L | 1236—1540 | 1388 | Flow rate, $m^3/d$ | 20—50 | 30 |

Note: * DT = dilution times

It is very difficult to biologically treat raw DCB wastewater because of its high COD and $NH_4^+$-N concentrations, high pH value, and low BOD/COD ratio. In order to ensure a stable operation of the IODVC system, some pre-treatment units were used, including pH adjust, stripping tank, micro-electrolysis filtration and anaerobic reactor. As a result, pH, $COD_{Cr}$, $NH_4^+$-N and SS in the influent of the IODVC system were 6—8, 910—3940 mg/L, 120—150 mg/L and 210—730 mg/L, respectively(Table 4).

**Table 3 The configurations of full-scale IODVC system for treating DCB wastewater**

| Ditch | Parameter | Brush | Parameter |
|---|---|---|---|
| Length, m | 7.0 | Length, m | 1.0 |
| Width, m | 2.0 | Diameter, m | 0.86 |
| Effective depth, m | 2.5 | Submersion depths, m | 0.12—0.15 |
| Effective volume, $m^3$ | 35 | Rotation velocity, r/min | 43 |
| | | Rotor power, kW | 1.5 |

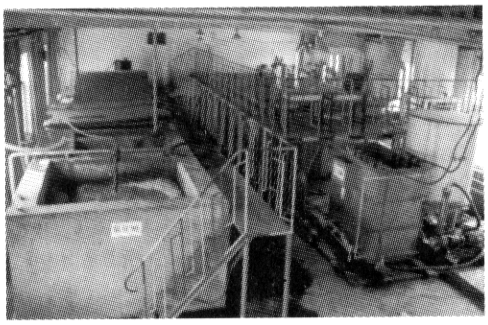

Fig.2 The full-scale IODVC system for DCB wastewater treatment

**Table 4 The characteristics of the fed wastewater and operation conditions in the full-scale IODVC process**

| Raw wastewater | Range | Operation conditions | Parameter |
|---|---|---|---|
| pH | 6.0—8.4 | HRT, h | 24—33 |
| SS, mg/L | 210—730 | SRT, d | 30 |
| $NH_4^+$-N, mg/L | 120—150 | F/M, kg COD/(kg MLSS·d) | 0.28—0.50 |
| COD, mg/L | 910—3940 | MLSS, g/L | 2.1—3.4 |

The full-scale DCB wastewater treatment plant was operated for one year from January to December 2002. The inoculated sludge was from a WWTP in a coke plant during start-up phase of the IODVC. Operation conditions for the IODVC are listed in Table 4. Temperature of the mixed liquor in the IODVC system changed between 12 and 30℃, and DO was maintained at 3.5—4.8 mg/L throughout the operation period. The glucose liquor at a concentration of 5 mg/L was added to the influent because of refractory DCB wastewater. Results showed that addition of glucose solution was very effective for the IODVC stable running. $NaH_2PO_4$ solution was added into the IODVC system to meet nutrient needs of microbial growth due to little phosphorus in DCB wastewater.

### 1.2.3 Analysis

Influent flow, dissolved oxygen (DO), pH, and temperature in the IODVC were measured daily throughout the operation period. SS, COD, $NH_4^+$-N, and $NO_3^-$-N in both influent and effluent, MLSS and MLVSS were regularly analyzed according to Standard Methods (CESP, 1998). $BOD_5$ was determined with a BOD Trak™ (Hach Company, USA). COD was measured with a CTL-12 COD meter (Huatong Company, China). The DO concentration was measured by an YSI Model 52 dissolved oxygen meter(YSI Incorporated Company, USA). The pH value was monitored by a pH meter(pHS-3C, China). Flow velocity in oxidation ditch was determined by the method of micropropeller with an LS 10 Kinemo meter (Chongqing Hydrological Meter Company, China).

## 2 Results and discussion

### 2.1 Bench-scale experiment

### 2.1.1 COD and $NH_4^+$-N removals

Fig. 3 shows experimental results of the COD removal in the IODVC system. Average COD removal was 95%, and its maximum was 98.5%. This result shows that COD removal in the IODVC is similar to that in the conventional oxidation ditch(Liu, 1996).

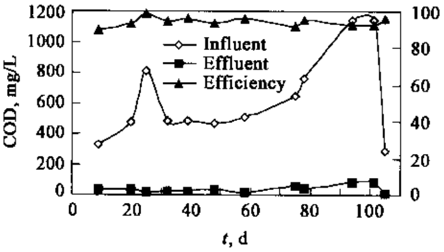

Fig.3 Removal of COD in bench scale IODVC experiment

Changes of $NH_4^+$-N concentration in the influent and effluent of the IODVC and $NH_4^+$-N removal rate are shown in Fig. 4. The $NH_4^+$-N concentration in the effluent of IODVC was between 0.5—1 mg/L, except occasionally over 5 mg/L. Generally, $NH_4^+$-N was removed through nitrification under the aerobic condition.

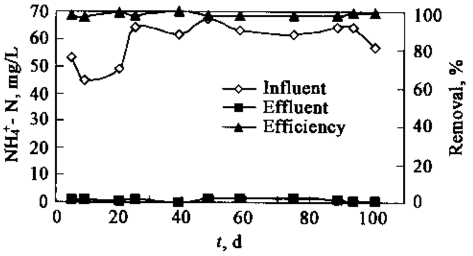

Fig.4 Removal of $NH_4^+$-N in bench scale IODVC experiment

### 2.1.2 TN removal

Denitrification occurs in the anoxic zone and is inhibited by dissolved oxygen. Krul (Krul, 1976) reported that the nitrate reduction increased when the DO-concentration was below 0.1 mg/L. An anoxic zone could be formed inside a biological floc, even when the bulk liquid had a significant concentration of dissolved oxygen(Rittmann, 1985). When average concentrations of the dissolved oxygen were between 0.1 and 0.5 mg/L, denitrification and nitrification could simultaneously occur in a single oxidation ditch. In this IODVC system, the anoxic zone could be formed in the bottom of the ditch through adjusting the brush submersion depth to control oxygen supply, and the anoxic zone and the anoxic interior of biological flocs could exist at the same time. It was observed that the sludge attached under the plate to grow and form a sludge layer(Fig. 1). The thickness of the layer gradually increased to 65 mm during about 100 days. The volume of the sludge layer accounted for about 10% of the total volume of the ditch. The experimental results showed that the maximum of 90% TN removal was obtained in IODVC.

### 2.1.3 Oxygen supply

One of the functions of the brush is aeration. It transfers atmospheric oxygen to the mixed liquor in the ditch. Both organic matter(COD) removal and nitrification consume DO. The brush submersion depth, brush rotation speed as well as temperature and HRT affect the DO concentration in the ditch (Liu, 1996).

In this experiment, aerobic and anoxic zones were formed in the IODVC when brush speed was 60 r/min and the depth of brush submersion was 20—25 mm. The DO concentration in the aerobic zone was over 2 mg/L at the flow velocity 0.25 m/s, and that in anoxic zone was less than 0.5 mg/L.

### 2.1.4 Sludge characteristics

In this IODVC system, the sludge gradually became black and granular. The ratio of MLVSS and MLSS was stable at 0.75—0.82, which means little inert solids accumulated in biomass. The MLSS varied between 1.9 and 4.9 g/L, and SVI was 50—268 ml/g throughout the operating period. Although sometimes SVI was high, the SVI had little impact on SS in the effluent(Fig. 5).

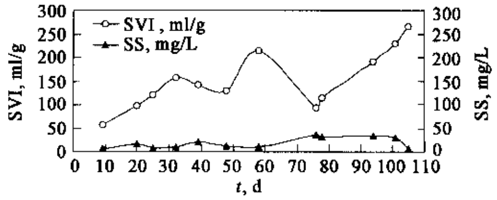

Fig.5 SS in the effluent and SVI in the bench scale IODVC system

### 2.2 Full-scale application

### 2.2.1 COD and $NH_4^+$-N removals

In this case, the average concentrations of color, COD and SS in the effluent of the IODVC system were 50 DT, less than 200 mg/L, and 50 mg/L, respectively, which met with the discharge standard for the industrial wastewater of China (GB8978-1996). The results of COD and $NH_4^+$-N removals are shown in Fig. 6 and Fig. 7, respectively. The average concentrations of COD and $NH_4^+$-N in the influent were 1691 mg/L and 140 mg/L, respectively, and their removal efficiencies were 91.1% and 84%, respectively, at 24—33 h of HRT and 30 d of SRT. Meanwhile, the SS removal was 83% in IODVC system. IODVC operations remained stable for organic pollutant removal although sometimes the influent flow was 1.4 times of its design capacity. This result clearly showed that the IODVC system had the strong capacity of resisting hydraulic shock load.

### 2.2.2 Impact of salt concentration on COD removal

It is well known that high salt concentration affects the microbial activity very much. In this case, $H_2SO_4$ solution

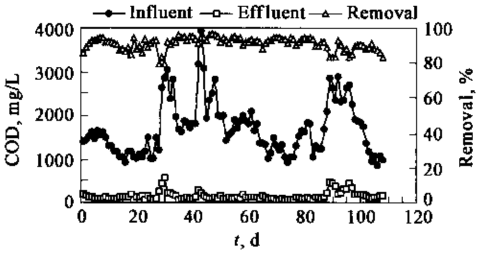

Fig.6 COD removal in the full-scale application of the IODVC system

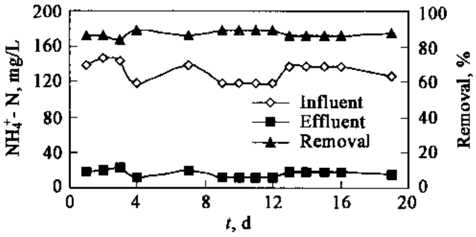

Fig.7 $NH_4^+$-N removal in the full-scale application of the IODVC system

was added to adjust the pH value because of high pH value in DCB wastewater. A large amount of salt was produced in the pH adjustment process. Fig. 8 shows the relationship of the salt concentration and the COD removal. The COD removal in the IODVC system decreased from 94.4% to 84.7% when the salt concentration increased from 5200 mg/L to 8200 mg/L. Moreover, the COD removal decreased sharply to 79% at 11400 mg/L salt concentration, which means the activity of activated sludge was inhibited. As a result, COD concentration in the effluent was over 200 mg/L. Microscope examination showed that the protozoa and metazoan in activated sludge were diminished (Fig. 8).

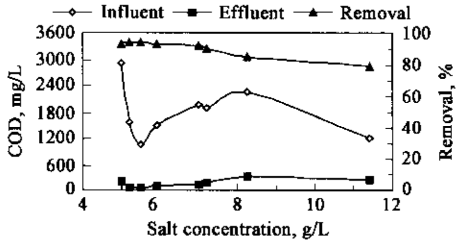

Fig.8 Effect of salt concentration on COD removal in the full-scale IODVC system

### 2.2.3 Impact of temperature on COD removal

Temperature is a key factor affecting biological wastewater treatment. Fig. 9 shows the impact of temperature on COD removal at the loading rate of 0.30 kg COD/(kg MLSS·d) in this IODVC system. The COD removal increased from 75% to 94% along with the temperature increasing from 12 to 23℃. Although the temperature was continually increased from 23 to 25℃ in the following days, the improvement of COD removal was little.

## 3 Conclusions

The IODVC system can treat both domestic and DCB wastewater effectively. Compared with a conventional oxidation ditch, the IODVC system not only has similar organic pollutant removal performance, i.e., average of COD removals for domestic and dye wastewater treatment by IODVC were 95% and 90%, respectively, but also saves land area by about 50%. For DCB wastewater treatment, salt concentration had great impact on COD removal.

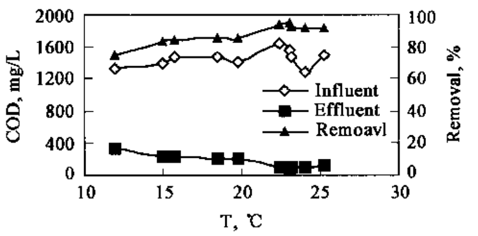

Fig.9 Effect of temperature on COD removal in the full-scale IODVC system

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