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Characteristics of ORP variation in subsurface wastewater infiltration system (SWIS) under hydraulic loading rate (HLR) fluctuation

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ABSTRACT

Subsurface wastewater infiltration system (SWIS) is a small-scale land treatment technology used for sewage deep purification, especially for nitrogen removal, based on the combined effects of physical, physical–chemical, and biological mechanism. Although it has been accepted widely that the oxidation–reduction potential (ORP) in the matrix bed plays a crucial role in the SWIS purification process, the ORP variation characteristics have not been revealed completely. To make it clear, a SWIS with mixed matrix was constructed in greenhouse. The system worked successfully under a drying–wetting alternate operation with five different hydraulic loading rates (HLRs) for over 4 months. The ORP was monitored in the depths of 25, 40, 65, 95, and 145 cm in the matrix bed using depolarization ORP detection probes. Results indicated that with the increase of HLR, the ORP variation was more obvious. ORP variation of the different matrix layers was different, the ORP of the upper matrix layer would produce a rising–descending variation in drying–wetting alternate operation and the middle matrix layer was on the contrary. The ORP fluctuation of the lower matrix layer was little. Results suggested that the fluctuation of HLR did not affect the periodic variation of ORP in each depth of matrix bed, but it would affect the variation range. And different temperatures can lead to changes in ORP.

Keywords: Subsurface wastewater infiltration system (SWIS); Oxidation–reduction potential (ORP); Drying–wetting alternate; Hydraulic loading rate (HLR)

1. Introduction

As a commonly used type of sewage treatment, the subsurface wastewater infiltration system (SWIS) is suitable for on-site wastewater treatment [1,2]. SWIS has many advantages, such as simple operation, low investment, low energy consumption, and good handling effect [3,4]. SWIS is based on ecological principles to remove major pollutants such as suspended solids (SS), organics, nitrogen, and phosphorus, in order to reduce the harm of sewage and recycle wastewater [5]. Up to now, the main research has focused on system design, treatment performance, pollutant-removal mechanisms, insufficient oxygen supply, and redox microenvironment changes [1–6].

The redox microenvironment is an important factor affecting the stable operation of wastewater land treatment system. Good redox microenvironment is conducive to microbial

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synthesis and endogenous metabolism, and it also affects the activity of microorganisms [7,8]. At the same time, it is beneficial to improve the degradation efficiency of adsorbed organic matter on the surface of microorganism in the matrix, and then to improve the removal efficiency of pollutants in SWIS [9,10]. The oxidation–reduction potential (ORP) in SWIS is quite different from the case in water and soil, because the matrix of SWIS is a kind of artificial multiphase with specially controlled flow manners, in which ORP is not only influenced by air, minerals, and microorganisms, but also by almost all the manually controlled and coupled conditions, such as varying hydraulic loadings, varying organic loadings, and drying–wetting alternate operation. Water is a pure phase, and its ORP mainly depends on dissolved oxygen (DO). As for soil, it is a stable natural multiphase, and the ORP is relatively complicated due to the depth, DO of soil water, air in soil, organic contents, ion concentration, mineral species, particle size distribution, and microorganisms [10–12]. In the conventional ORP monitoring method, there are some drawbacks, such as memory effect and long response. Especially in SWIS mixed complex multiphase systems, the impact is obvious [12,13]. Compared with the conventional ORP monitoring method, the depolarization ORP monitoring method has many advantages such as high accuracy and fast response. In general, the precise potential obtained by the conventional method for 48 h can be obtained within 2 min [10–12]. In SWIS, the content of oxygen decreases with the increase of matrix depth, and the ORP in SWIS fluctuates between –400 and 800 mV. In the ORP characterization of redox reaction, the ORP of the aerobic environment is larger than 300 mV, the ORP of the anaerobic environment ranges from –200 to 300 mV, and the ORP for the completely anaerobic environment is less than –200 mV [12,13]. Meanwhile, the alternation of aerobic environment and anaerobic environment would affect the pollutants removal efficiency [10,12]. In order to visualize the changes of SWIS redox environment, it is crucial to do simulation experiments to monitor the changes of the redox environment in real time.

Studies have shown that factors affecting ORP include influent type, hydraulic loading rate (HLR), environmental temperature, and matrix microorganism [12,13]. Among them, HLR is an important factor affecting the pollutants removal of SWIS [14]. According to previous studies, the suitable ranges of HLR for SWIS are between 0.04 and 0.20 $m^3/m^2·d$ [13–15]. Meanwhile, the smaller the HLR, the longer the residence time of the sewage, and the higher the pollutants removal efficiency. However, not all pollutants removal efficiency increases with the decrease of HLR [10–15]. Similarly, temperature changes will also affect the microbial activity of the matrix bed, which will lead to the fluctuation of ORP [16]. The study of SWIS redox microenvironment is limited to some aspects, such as the ORP variation, the pollutants removal, and the temperature effects. The quantitative description of ORP variation in SWIS has not been further considered [12]. Therefore, if we discuss the variation characteristics of ORP under HLR fluctuation, we can obtain the variation characteristics of redox microenvironment in SWIS. In this paper, we discussed the variation characteristics of ORP on the same matrix bed and different matrix bed under HLR fluctuation. The impact of two temperatures on ORP was evaluated under the same HLR. Furthermore, it provides reference for promoting the practice and application of SWIS.

2. Materials and methods

2.1. Simulation system

The simulation device was constructed in a greenhouse as shown in Figs. 1 and 2. The literatures show that when the diameter of the soil column is larger than 10 cm and the height is larger than 120 cm, the ratio of the column diameter to the particle size of the filler is larger than 50, and the side wall effect can be eliminated to the greatest extent [5,6]. Therefore, to simulate the sewage treatment process, the experiment device was designed as 100 cm long, 60 cm wide, and 200 cm deep. In addition, the material of the device was plexiglass, and in order to prevent the growth of moss, a shade cloth was used to cover the outside of the experimental device. The device was filled with four different matrixes to a total height of 185 cm. The lower layer was filled with pebbles of height 20 cm. Above the pebbles layer, a mixture of 80% soil and 20% sand in volume ratio with a height of 70 cm was added. The middle layer was filled with the thickness of 70 cm mixed substrate, which was composed of farmland soil, coal slag, and activated sludge with a volume ratio of 6:3:1. The upper layer consisted of farmland soil with a thickness of 25 cm. Tall fescue and ryegrass were planted on top of the matrix, mainly for landscape planting. Inflowing

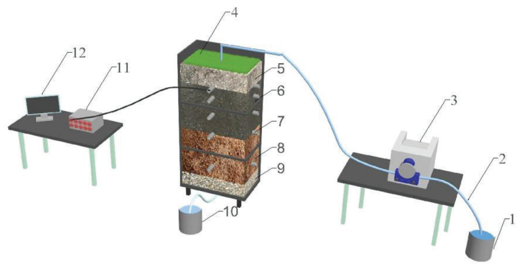

Fig. 1. Schematic diagram of the SWIS: (1) wastewater bucket; (2) inflowing pipe; (3) peristaltic pump; (4) tall fescue and ryegrass; (5) farmland soil; (6) mixed substrate; (7) ORP monitoring hole; (8) farmland soil and fine sand; (9) pebble; (10) collect bucket; (11) data acquisition system real-time online collection; and (12) computer.

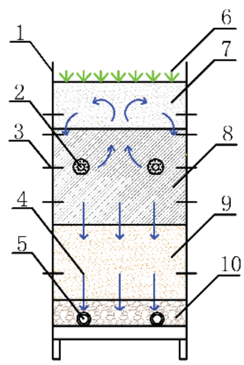

Fig. 2. The internal structure diagram of the SWIS: (1) infiltration system body; (2) dispersing pipe; (3) monitoring hole; (4) flow direction; (5) collecting pipe; (6) tall fescue and ryegrass; (7) farmland soil; (8) mixed substrate; (9) farmland soil and fine sand; and (10) pebble.

pipe (inner diameter, 5 mm) was 90 cm long and was installed at 80 cm from the top of the device. Two evenly perforated collecting pipes (internal diameter, 7 mm) were laid horizontally on the bottom of the device. Moreover, five monitoring holes (internal diameter, 40 mm) were arranged in different positions: 25, 40, 65, 95, and 145 cm from the top of the matrix bed. The drying and wetting time was controlled by the electronic and automatic control system, and the peristaltic pump was used to regulate the flow of water.

2.2. Matrix properties

The farmland soil was obtained from Shenbei New Area (China) and air-dried after filtering. The pH of the farmland soil was 6.7, and the particle size was 0.002–0.05 mm. The coal slag was taken from the boiler room of a university in Shenyang (China), which was an anthracite combustion product. The activated sludge was taken from the aeration tank in Shenyang Northern Sewage Treatment Plant (China) and grounded after air-dried. Fine sand was taken from a sand field in Shenyang (China), with a porosity of 52.3% and a permeation rate of 3.6×10^{-3} cm/s. Pebbles were purchased from a market (diameter is 5–10 mm). At the same time, the pH of mixed matrix was 7.1, the organic matter content was 6.2%, and the particle size was 0.002–0.05 mm.

2.3. Wastewater properties

The wastewater was selected from the subsurface sewage infiltration demonstration project of campus domestic sewage. In general, it was necessary to run SWIS continuously for a period (usually 50–90 d) before starting experiment to cultivate the microorganisms and establish a stable status, and meanwhile, to leach most of the impurities in matrix. After the effluent water quality was stable, the water quality indicators were tested: temperature, 16°C and 27°C; pH, 7.2–7.3; chemical oxygen demand (COD_{cr}), 210–250 mg/L; biochemical oxygen demand (BOD_5), 85–120 mg/L; NH_4^+–N, 31–59 mg/L; total nitrogen (TN), 48–87 mg/L; total phosphorus (TP), 3–4 mg/L; SS, 69–79 mg/L; NO_3^-–N, 3–21 mg/L; and NO_2^-–N, 0.8–2 mg/L.

2.4. Analysis method

The COD, BOD, SS, NO_3^-–N, NO_2^-–N, NH_4^+–N, TN, and TP concentrations of the water samples were analyzed according to the standard methods [17]. In this study, five depolarization ORP detection probes were used to monitor ORP. ORP was analyzed through embedded sensors, and the readings were recorded every 30 min. All data analysis methods were carried out using the computer software package Origin and Matlab. The SWIS flow chart was drawn by 3ds Max, and the internal structure of SWIS was drawn by CAD.

2.5. Experimental operation

During the experimental period, the intermittent operation mode was adopted as a method of oxygen recovery [13]. Each cycle of the intermittent operation included a drying period of 8 h and a wetting period of 8 h, indicating that one drying–wetting cycle of the intermittent operation was of 16 h.

2.5.1. Experiment 1

To investigate the effect of HLR fluctuation on ORP of different matrix bed. The ORP variation of the five different matrix beds (25, 40, 65, 95, and 145 cm) in the SWIS were measured at 27°C when the HLRs were 0.04, 0.06, 0.10, 0.14, and 0.18 $m^3/m^2 \cdot d$.

2.5.2. Experiment 2

In order to obtain the effect of HLR on ORP in same matrix bed. When the five different matrix beds were 25, 40, 65, 95, and 145 cm, the variation of ORP was monitored at 27°C under five different HLRs (0.04, 0.06, 0.10, 0.14, and 0.18 $m^3/m^2 \cdot d$).

2.5.3. Experiment 3

In drying–wetting alternate operation, the ORP variation in five different matrix beds was studied at temperatures of 16°C and 27°C with the HLR of 0.04 $m^3/m^2 \cdot d$.

3. Results and discussion

3.1. Variation of ORP in different matrix bed during HLR fluctuation

The ORP variation under HLR fluctuation in drying–wetting alternate operation is presented in Fig. 3. It can be seen that the ORP at 40 cm of the matrix layer was higher than 25 cm under the drying–wetting alternate operation, and then the ORP gap gradually reduced. This may be due to that under the lower HLR, the 25 cm depth was basically unaffected by the influent sewage, and the 25 cm maintained good intercommunication with the outside air and also had a significant ability to deliver O_2 downward [2]. On the contrary, 40 cm depth was affected by a small amount of DO carried by the influent sewage and the O_2 transported from the surface. The O_2 content at 40 cm depth was slightly higher than that at 25 cm, so the 40 cm ORP was higher than 25 cm. When the HLR increased, the sewage content and the amount of DO carried by the influent sewage were gradually increased at 25 cm depth. At the same time, the O_2 supply capacity from the surface layer to lower layer gradually weakened, so the ORP gap between 25 and 40 cm gradually narrowed. On the other hand, the ORP at 65 cm was always higher than that at 95 cm. This phenomenon was due to the fact that the influent sewage infiltrated from 65 to 95 cm, and the amount of DO carried by the influent sewage at 65 cm was much higher than that at 95 cm. According to the ORP variation, the matrix bed was divided into three layers: 25 and 40 cm as the upper matrix layer, 65 and 95 cm as the middle matrix layer, and 145 cm as the lower matrix layer. Fig. 3(a) shows the changes of ORP in SWIS under the HLR of 0.04 $m^3/m^2 \cdot d$. The ORP of the matrix bed in the upper and lower matrix layers remained stable, and this phenomenon indicated that ORP of the upper and lower matrix layers was not affected by the drying–wetting alternate operation. According to the experimental data, the redox environments in the upper and lower matrix layers were maintained in aerobic and completely anaerobic environment, respectively. The lower layer ORP remained stable because the sewage flows through the matrix bed and the

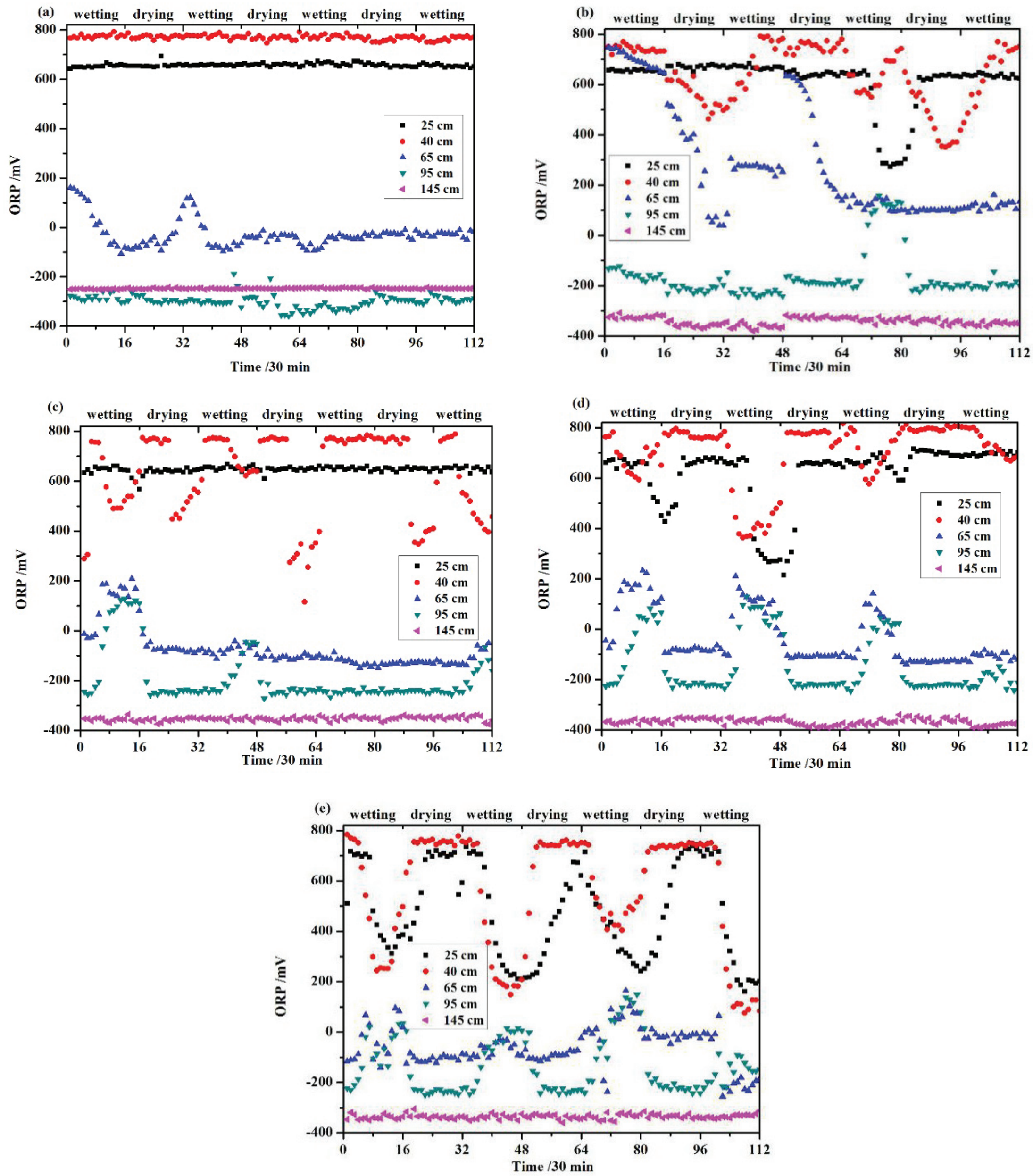

Fig. 3. Effect of HLR fluctuation on ORP in different matrix bed of SWIS during drying–wetting alternate operation. (The following abscissa indicated that data were recorded every 30 min, and the abscissa 16 was 8 h. The abscissa above indicated the simulation system 2 status in drying and wetting. The ordinate represented the ORP): (a) the HLR was 0.04 $m^3/m^2 \cdot d$; (b) the HLR was 0.06 $m^3/m^2 \cdot d$; (c) the HLR was 0.10 $m^3/m^2 \cdot d$; (d) the HLR was 0.14 $m^3/m^2 \cdot d$; and (e) the HLR was 0.18 $m^3/m^2 \cdot d$.

reaction of the pollutants was relatively sufficient, and DO was exhausted. Therefore, the ORP in the lower layer was in a stable state [12,13]. Meanwhile, the ORP at the middle matrix layer was gradually fluctuated during the drying–wetting alternate operation and then remained stable. One possible explanation was that the amount of DO carried by the influent sewage was limited at low HLR during the wetting period. During the drying period, the middle matrix layer was mainly affected by atmospheric reoxygenation, and thus the ORP recovered. Experiments showed that 65 cm depth was anaerobic environment and 95 cm depth was completely anaerobic environment.

Figs. 3(b) and (c) show the variation trends of ORP in SWIS under the HLR of 0.06 and 0.10 $m^3/m^2 \cdot d$. It should be noted that the impact of HLR fluctuations on ORP was significant. The ORP of the upper matrix layer was affected by the drying–wetting alternate operation, and it recovered rapidly after falling. In addition, with the increase of HLR, the ORP in the upper matrix layer alternately changes in a rising–decreasing trend under drying–wetting alternate operation. However, this phenomenon only occurred at the depth of 40 cm and did not change alternately at 25 cm after the system stabilized. At the depth of 40 cm, the ORP fluctuates between 500 and 800 mV. The redox environment of the upper matrix layer still maintains an aerobic environment. On the other hand, the ORP changes most drastically in the middle matrix layer. In the drying–wetting alternate operation, the ORP gradually decreases and finally remains stable at 65 cm depth. However, there was a decreasing–increasing trend at the depth of 95 cm. It can be speculated that the residual DO in the sewage causes a slight increase of ORP when the impact loading of influent was stable. And the larger the HLR, the more significantly the ORP changed. From the experimental data, one can see that the redox environment of the middle layer was anaerobic and completely anaerobic interconverting environment. In addition, the lower layer decreases with the increase of HLR, but it always maintains anaerobic environment. Therefore, the increase of HLR had a significant effect on the ORP in the middle and lower layers of SWIS.

Figs. 3(d) and (e) show the ORP changes of the matrix bed when the HLR was 0.14 and 0.18 $m^3/m^2·d$. According to the previous studies, the increase of HLR would lead to the increase of organic pollutants in the matrix, and thus the O_2 consumption increased [15]. Under the high HLR, the ORP fluctuations of the matrix bed above 95 cm were obvious. When the HLR was 0.06 and 0.10 $m^3/m^2·d$, the trend of ORP in matrix bed was identical. The upper layer was an aerobic environment when it was drying, and it was an anaerobic environment when it was wetting. During the drying period, O_2 could transport by convection and diffusion into the system to the upper layer, so the upper layer restores to an aerobic environment [5]. The higher the HLR, the lower the ORP, and the stronger the reducibility of the SWIS. It can be seen that the fluctuation of HLR only affects the magnitude of ORP variation. During the wetting period in the middle layer, ORP was significantly increased by the influence of DO carried by the sewage [18,19]. Meanwhile, the middle layer was an anaerobic environment. During the drying period, the DO in the matrix bed was not grown in time, and ORP fluctuated around 0 mV, thus the matrix bed was a normal anaerobic environment [10,11]. On the other hand, due to the buffering effects of the lower layer, the vertical permeation of the redox environment did not have a large effect on the lower layer, and the lower layer still maintains a completely anaerobic environment [11].

3.2. Variation of ORP in same matrix bed during HLR fluctuation

The redox microenvironment of the SWIS had obvious stratification phenomenon, which was related to the depth of matrix bed [12]. Fig. 4 shows the variation of ORP in same matrix layer during HLR fluctuation under drying–wetting alternate operation. As can be seen from figure, the ORP

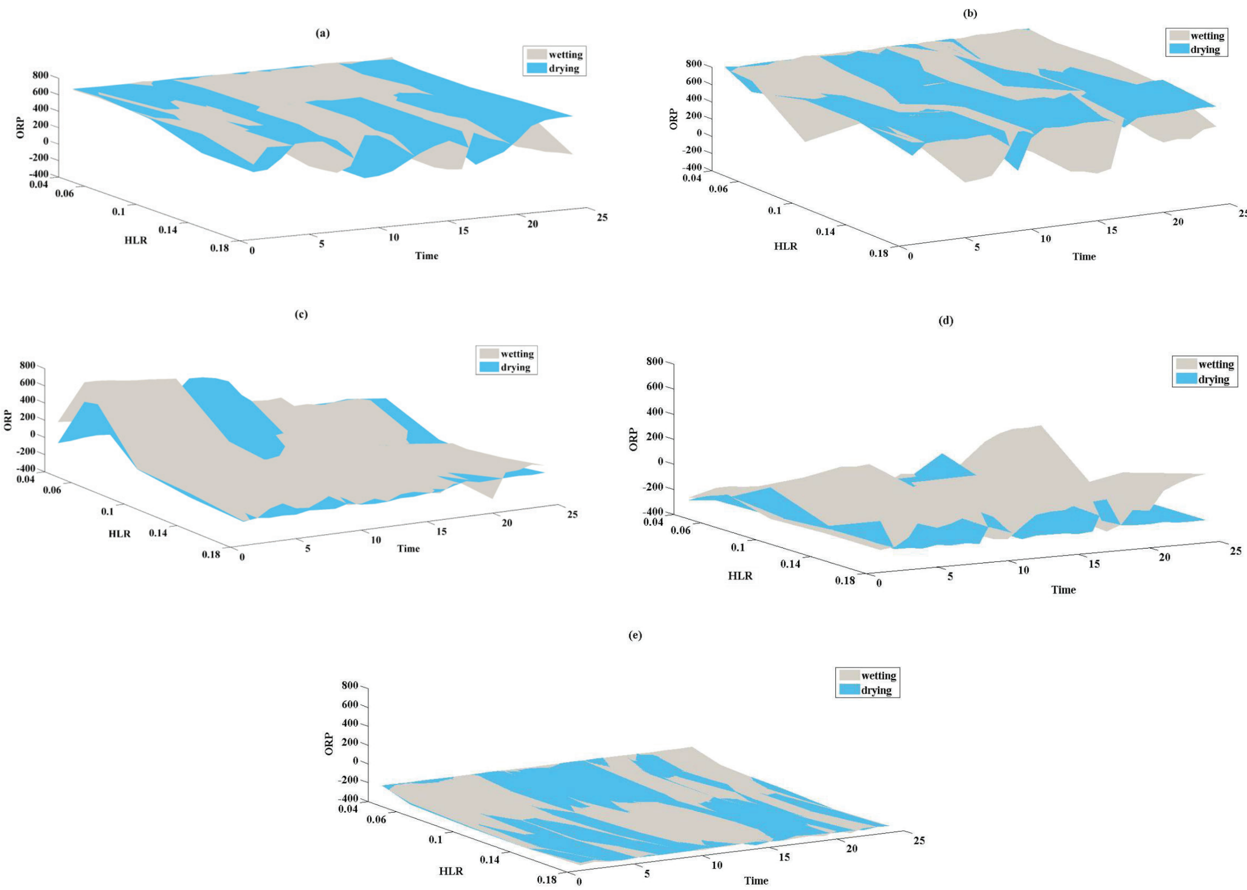

Fig. 4. Effect of HLR fluctuation on ORP in drying–wetting alternate operation in the same matrix layer. (The X-axis indicated the HLR/$m^3/m^2·d$, the Y-axis indicated time/30 min (record every 30 min), the Z-axis represented the ORP/mV): (a) the depth was 25 cm; (b) the depth was 40 cm; (c) the depth was 65 cm; (d) the depth was 95 cm; and (e) the depth was 145 cm.

variation of the matrix bed was non-linear correlation and there was a penetration phenomenon. According to the variation rule of HLR, the HLR was divided into three types: 0.04 $m^3/m^2{\cdot}d$ as the low HLR, 0.06 and 0.10 $m^3/m^2{\cdot}d$ as the medium HLR, 0.14 and 0.18 $m^3/m^2{\cdot}d$ as the high HLR. Figs. 4(a) and (b) show the variation trends of ORP in the upper layer under HLR fluctuation. It should be noted that the ORP of the upper layer did not change at low HLR, and the ORP at the depths of 25 and 40 cm was maintained at 670 and 800 mV, respectively. During the medium HLR, the ORP at 25 cm depth remained at 670 mV, the 40 cm depth ORP fluctuated between 280 and 780 mV under the wetting period, and the ORP fluctuated from 480 to 780 mV under the drying period. Under high HLR, the fluctuation range of 25 cm was 210–670 mV under drying–wetting alternate operation. Meanwhile, the ORP in 40 cm depth fluctuated from 540 to 780 mV at drying period, and that of wetting period was 140 to 780 mV. With the increase of HLR, the fluctuation of ORP in the upper layer was more obvious in drying–wetting alternate operation. It can be speculated that after wetting, the capillary water began to spread in the matrix bed and diffuse into the upper layer. Then, as the sewage flow area increases, the water content of the upper layer gradually increases and part of the DO in the system was rapidly decomposed by the organic pollutants, so the ORP of the upper layer decreases rapidly [1]. In addition, the sewage in the upper layer continued to diffuse during drying period, and the sewage content in the upper layer gradually decreased due to the gravitational potential of the sewage. Therefore, the ORP increased [20]. As can be seen from the comparison of Figs. 4(a) and (b), the ORP at the depth of 40 cm was slightly higher than the ORP at 25 cm. This may be due to the distribution of ryegrass and fescue roots in the range of 20–30 cm at the matrix depth. The root effect of plant roots was also one of the factors affecting the microenvironment of the matrix bed [21]. Plants could transfer O_2 through the roots to the matrix bed and then form an aerobic environment around the rhizosphere. However, the O_2 of plant roots can only be transmitted to the upper layer, and the aerobic respiration and secretions of the roots have a certain degree of reducibility, which affects the redox environment of the surrounding soil [20].

Figs. 4(c) and (d) show the ORP variation in the middle layer. The results showed that the environment in the middle layer was in an anoxic–anaerobic alternate state. In the low HLR, the ORP fluctuated within a small range, the 65 cm depth ORP fluctuated in the range of –90 to 160 mV in the wetting period, and fluctuated from –80 to 40 mV in the drying period. Meanwhile, the ORP at 95 cm fluctuated around –300 mV, and 65 and 95 cm in the middle layer were always maintained in anaerobic and completely anaerobic environment, respectively. This was because during the wetting period, DO was consumed by the upper layer aerobic microorganisms, and the remaining DO infiltrates into the middle matrix layer, which causes a slow increase in ORP. During drying period, the above effects slowed down; under the medium HLR, at the depth of 65 cm, the ORP fluctuation range was –120 to 520 mV during the drying period, and the ORP fluctuated between 80 and 740 mV under the wetting period. However, at the depth of 95 cm, the ORP fluctuated from –170 to 240 mV under drying state, and the ORP fluctuated between –250 and 100 mV under wetting state. The middle layer always maintained aerobic—anaerobic alternating and anaerobic—completely anaerobic alternating environment, respectively. In the high HLR, the trends of ORP in the middle layer were basically the same as that in the medium HLR, ORP fluctuated in a small range in which the ORP at the depth of 65 cm fluctuated within the range of –160 to 170 mV during wetting period, and that of –120 to –8 mV during drying period. While the ORP at the depth of 95 cm fluctuated around –210 mV. When the HLR was low, the total amount of DO in the influent sewage was little, and it was fully consumed before flowing through the middle layer; when the HLR increases, the total amount of DO in the influent sewage was higher, and thus the hydraulic retention time became larger [11]. Therefore, the contact time of the pollutants, DO, and the matrix microorganisms carried by the inflow sewage was increased, and DO was consumed in a large amount. In summary, as the HLR changing from lower to higher, the rising range of ORP and the fluctuation of HLR in the middle layer were in normal distribution [12].

Fig. 4(e) shows the trend of ORP in the depth of 145 cm, the ORP was mainly maintained at –300 mV and the environment was completely anaerobic. It can be seen from the figures that with the increase of HLR, the ORP of the lower layer was not affected by drying–wetting alternate operation, but ORP decreased slightly as HLR increasing. This was because in the lower layer, the soil water potential of the matrix bed was always saturated or supersaturated, and the water content of this layer was constant. When water flowed into the lower layer, the residual DO was depleted, and the O_2 carried by the influent did not substantially affect the redox environment, thus the ORP in lower layer was not affected by drying–wetting alternate operation [10–13].

3.3. Influence of temperature on ORP of SWIS

ORP of SWIS was a comprehensive result of various redox reactions, which was sensitive to temperature [16]. The changes of ORP at different temperatures were analyzed. When the HLR was 0.04 $m^3/m^2{\cdot}d$ in drying–wetting alternate operation, the ORP at 16°C and 27°C was studied, respectively. The ORP changes in five matrix beds are shown in Fig. 5.

As shown in Fig. 5(a), ORP at the depth of 25 cm was stable between 650 and 670 mV at 16°C and 27°C, indicating that the temperature had little effect on the surface of SWIS. It was probably due to that the O_2 content of the upper layer was substantially saturated. With the increase of temperature, the microorganism activity and O_2 consumption in the matrix bed increased, but the convection of O_2 in the air and the diffusion of the matrix bed could satisfy the microorganism consumption, so the ORP at 25 cm depth remained stable [11]. As shown in Fig. 5(b), the ORP at the depth of 40 cm remained stable at 790 mV in the temperature 16°C, while the ORP showed a rising–descending trend in drying–wetting alternate operation at 27°C. According to the analysis, in the wetting period, the sewage content at 40 cm depth increases with the increase of the sewage influent, and the transfer rate of DO became faster, which was beneficial to maintain ORP stable at the temperature 16°C. On the other hand, when the

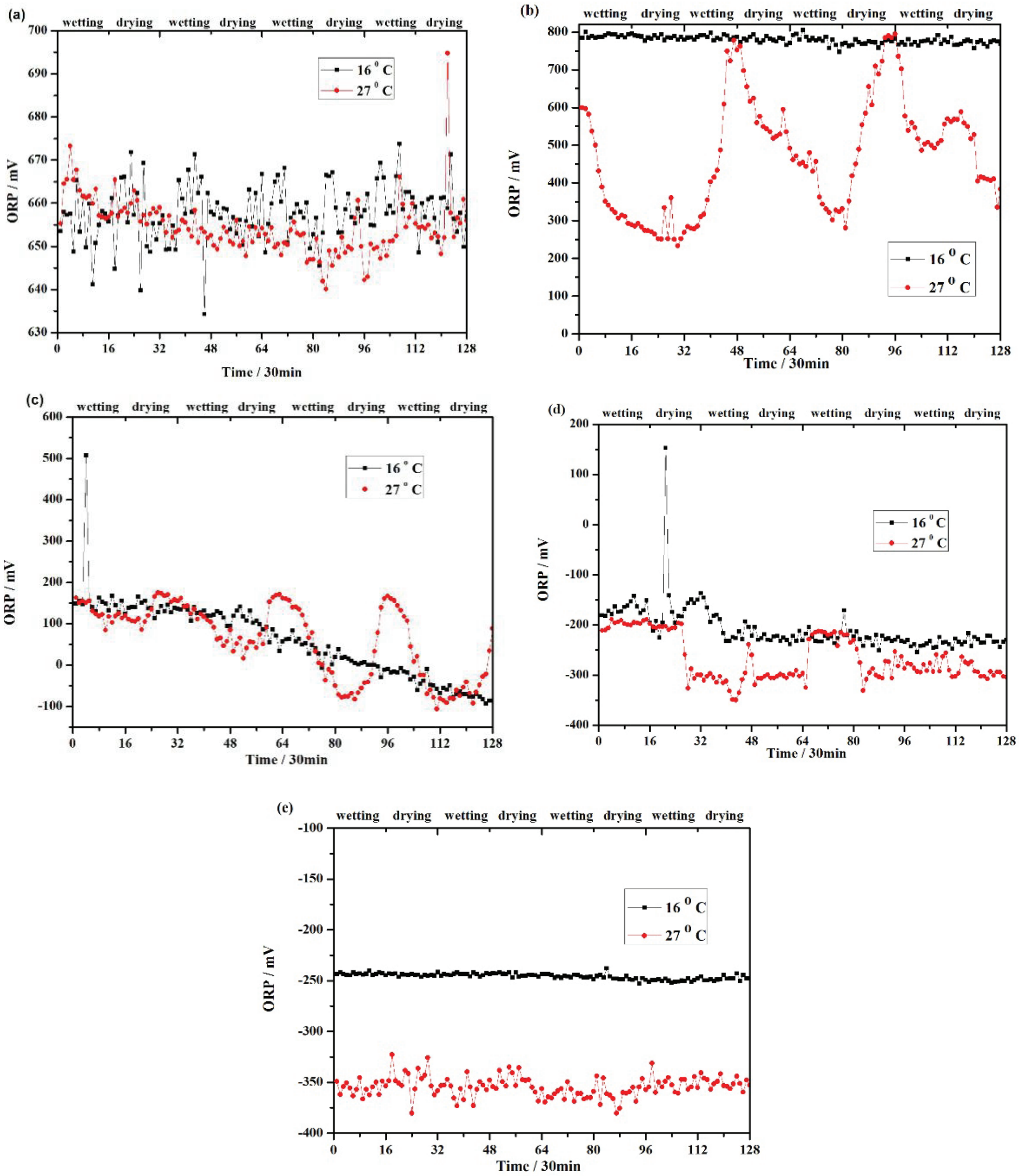

Fig. 5. In the same matrix depth, the influence of temperature on ORP in drying–wetting alternate operation. (The following abscissa indicated that data were recorded every 30 min, the abscissa above indicated the simulation system 2 status in drying and wetting. The ordinate represented the ORP): (a) the depth was 25 cm; (b) the depth was 40 cm; (c) the depth was 65 cm; (d) the depth was 95 cm; and (e) the depth was 145 cm.

temperature was 27°C, the microorganism activity in the matrix bed increased and the oxygen consumption increased. However, the rate of reoxygenation did not meet the oxygen requirement of the matrix bed, and thus ORP changed alternately at 27°C.

As shown in Fig. 5(c), the ORP of the matrix bed at the depth of 65 cm decreases in wetting operation and increases in drying operation at two temperatures. And it can be seen that the variation at 27°C was larger than 16°C. This phenomenon may be due to that the O_2 diffusion and convection capacity at the depth of 65 cm were limited, and the ORP changes were mainly due to the DO carried by the influent [11,16]. With the increase of temperature, the rate of DO transfer was low, the microorganism activity was strong, and the aerobic rate was fast. Therefore, at 27°C, ORP decreased significantly in the wetting period and increased slightly in the drying period. As shown in Figs. 5(d) and (e), the ORP trends of 95 and 145 cm on the matrix bed were the same at two temperatures. The ORP at 27°C was about 100 mV lower than that at 16°C. However, apart from the amplitude changes at 95 cm, ORP in other matrix layers remained stable. It can be surmised that at higher temperature, the upper microorganism consumes more O_2 in decomposing organic matter. As a result, the residual DO in the water infiltrating downward was less than that in the lower temperature, so the ORP was lower at 27°C [16].

4. Conclusions

A novel SWIS was operated under five HLRs and two temperatures. This study demonstrated that the HLR fluctuation could lead to the variation of ORP in drying–wetting alternate operation. However, it did not affect the periodic variation of the ORP in each matrix depth and only resulted in a difference in the magnitude of the variation. Matrix ORP results showed that during the operation of low HLR, the ORP fluctuation of the SWIS maintained stable. During the medium HLR, the ORP in the depths of 25 and 145 cm were stable, and the ORP in the depth of 40 cm was in rising–declining trends at drying–wetting alternate operation, while the middle layer (65 and 95 cm) was opposite to 40 cm depth. The upper layer (25 and 40 cm) of the matrix bed was in rising–declining trends at drying–wetting alternate operation during the high HLR, and the middle layer (65 and 95 cm) was on the contrary, the lower layer (145 cm) was remained stable. During the drying–wetting alternate operation under the HLR fluctuation, the ORP fluctuation of each matrix depth was nonlinear and there was a phenomenon of penetration. On the other hand, with the increase of temperature, the ORP in the depth of 25 cm was basically unchanged, while the change amplitude of ORP was the largest in the depth of 40 cm. The matrix bed had the same ORP variation in the depths of 65, 95, and 145 cm, but the ORP at low temperature was higher than that at high temperature.

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