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On intensive process of quantity and quality improvement of wastewater treatment plant under rainfall conditions

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ABSTRACT

The large quantity and sharp appearance of influent flow of combined sewerage system always exceed the hydraulic capacity of wastewater treatment plant (WWTP) and the deterioration of the performance of WWTP and the discharge of bad effluent water quality to surface water occur during rainfall events. To determine the influence of rainfall, the upriver combined sewerage system and the performance of WWTP were simulated by InfoWorks CS and Biowin software, respectively. Three kinds of intensive processes, i.e. chemically enhanced primary treatment (CEPT), CEPT combined with secondary treatment and CEPT combined with secondary treatment with decreased hydraulic retention time were proposed based on the original process of WWTP. The results showed that the proposed wastewater treatment processes are all powerful to weaken the adverse impacts of rainfall on WWTP and to reduce greatly the pollution to receiving waters during the rainfall events.

Keywords: Rainfall; Combined sewerage system; Wastewater treatment plant; Intensive process

1. Introduction

Influent flow is one of the most important parameters determining the design and operation of wastewater treatment plant (WWTP) [1]. It increases substantially during rainfall events [2]. Influent flow variations over two orders of magnitude are not uncommon for combined sewerage systems. As flushing roads and buildings, the rainwater contains an enormous quantity of pollutants, such as organics, nitrogen, phosphorus, suspended solids, and heavy metals [3–6]. As a result, during rainfall events, the hydraulic capacity of WWTP may be exceeded, and the deterioration of the performance of WWTP and bad effluent water quality may occur. On the other hand, the requirements of effluent have become increasingly stringent with regard to the discharge of wastewater effluent to surface waters [7]. This requires that WWTP has an efficient treatment under rainfall condition and should treat all influent flow. For this reason, the predictions of rainfall influence and retrofits of treatment process are beneficial for the stable operation of WWTP during rainfall events.

Special attention has been given to the impacts of rainfall on WWTP during last few decades. A three year study was undertaken by Giokas et al. [1] to investigate the effect of wastewater flow fluctuation on the treatment process under wet weather conditions. They found that the retention time and dilution

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played the most significant role in the performance of treatment process. The retention time was reduced as the wastewater flow increased, and the performance of WWTP was in the deterioration. Low concentration of influent pollutants was observed as the dilution of high incoming wastewater. Similar outcomes were obtained by Wilén et al. [8]. According to their results, the increased rainfall flow changed the properties of incoming wastewater and affected the process performance and effluent quality, especially for the nitrification and denitrification of secondary treatment.

The performance of Rya and Sjölunda WWTPs in Sweden was evaluated by Hanner et al. [9]. It was reported that the capacity of Rya WWTP was exceeded during storm water condition and the effluent phosphorus concentration exceeded the effluent standard. For Sjölunda WWTP, a rapid progress of increasing flow in a few minutes was observed, and WWTP can not comply with the effluent standards during storm water condition.

Linear regression techniques were used by Mines et al. [7] to determine the relationship between rainfall intensity and influent flow as well as pollutant concentrations for 24 WWTPs. Moderate to strong correlations were observed between monthly average rainfall intensity and influent flow for all 24 WWTPs. Of the 24 WWTPs evaluated, 23 showed a negative-slope trend for the rainfall intensity versus influent BOD and TSS, indicating that influent BOD and TSS values decreased with the increase in rainfall intensity. For the data relating influent BOD and TSS loads to effluent BOD and TSS concentrations, 15 of the 24 WWTPs followed the positive-slope trend, indicating that an increase in the influent BOD and TSS loads would result in an increase in the effluent BOD and TSS loads.

Besides the statistical analysis, modeling and simulation have also been used in the evaluation of rainfall influence on WWTP in recent years. El-Din and Smith [2] used an artificial neural network (ANN) model to make short-term predictions of wastewater inflow rate that entered Gold Bar WWTP in Canada. Several wet weather scenarios were simulated with maximum flow and variable pollutant loading based on the activated sludge model (ASM) No. 1 [10]. The results showed that daily influent flow of WWTP was much more variable during wet weather. Despite influent TKN loads increased by approximately 25%, the nitrogen removal performance was only slightly affected by rainfall, whereas the influent and effluent COD loads increased due to a hydraulic flush of soluble inert compounds by rainfall runoff.

The ASM3-based model and the ANN model were applied by Ráduly et al. [11] to assess the performance of WWTP during storm events. According to the simulation results, the capacity of WWTP to remove pollutants was exceeded at the peak moment of influent flow reached. Intense rain events resulted in high particulate concentrations of influent due to the first-flush effect and subsequently led to dilution of the influent particulate concentrations.

Although some studies have been conducted regarding the influence of rainfall on WWTP operation, most studies just focused on the general impacts of rainfall compared with the dry weather conditions. Little attention has been devoted to response operation of WWTP by considering the dynamic variation of influent flow and pollutant concentrations under different rainfall intensities. Furthermore, the widely used cost-effective control measures response to the adverse impacts of rainfall, such as bypass, storage tanks for rainwater, and step-feed process, usually hardly have good effects on improving pollutant removal rate. Therefore, the purpose of this study was to investigate the dynamic variation of influent flow and pollutant concentrations and to propose an intensive wastewater treatment process to characterize the response operation of WWTP under different rainfall intensities.

2. Methods

2.1. Study area

An urban catchment with an area of 41.4 km^2 and more than 1.18 million people in Tianjin was selected as study area. Tianjin has a typical warm temperate continental monsoon climate with significant rainfall variability. The average annual rainfall is 518 mm and nearly 70% of rainfall is concentrated in summer.

The study area is covered by three kinds of land surface, that is, pavement, roof, and green land. The remote sensing image of study area was processed by the supervised classification technique to obtain the area and proportion of various land surfaces, as shown in Fig. 1.

2.2. Upriver combined sewerage system

In the study area, the rainfall and wastewater are conveyed through the upriver combined sewerage system to the WWTP and then discharged into receiving river. To obtain the influent flow and water quality of WWTP, the upriver combined sewerage system was modeled by InfoWorks CS software.

2.2.1. Model setup

The sewerage system is combined, which collects both wastewater and rainfall runoff. The combined

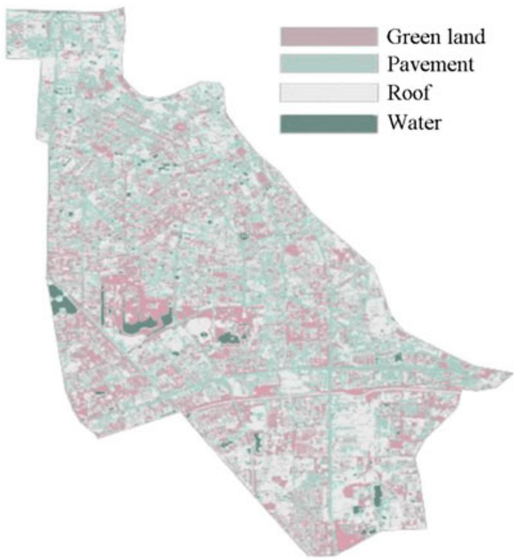

Fig. 1. Land surfaces of study area.

sewerage system consists of 252.26 km pipes. The property files of catchment, inspection wells, pipes, and pump stations were generated by ArcGIS and then imported into InfoWorks CS. The model of combined sewerage system was built and shown in Fig. 2.

The study area was divided into 939 subcatchments and a mixture of rainfall-runoff volume and runoff-routing models was used to calculate the runoff and pollutant loads in each subcatchment [12,13]. The influent flow and water quality received by WWTP were obtained by InfoWorks CS model.

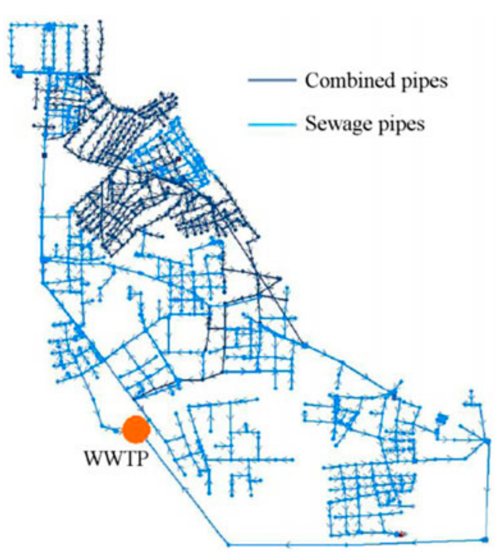

Fig. 2. Model of combined sewerage system.

2.2.2. Model calibration and validation

The parameters of InfoWorks CS model were shown in Table 1.

The results of InfoWorks CS model were validated according to the measured data. The comparison between measured and simulated values of WWTP influent flow was shown in Fig. 3. The results indicated that simulated values are basically consistent with the measurements and the reliability of InfoWorks CS model was validated.

2.3. Wastewater treatment plant

2.3.1. Model setup

The simulation of WWTP was carried out with the help of Biowin software. Biowin software, based on the activated sludge/aerobic digestion model, can trace simulated components in different units, compare different treatment processes and estimate the influence of operating condition changes on processes [15,16].

The WWTP is composed of old and expanded systems with a designed treating capacity of $45 \times 10^4\,m^3\,d^{-1}$. The average influent flow is about $36.74 \times 10^4\,m^3\,d^{-1}$. The processes of both systems consist of primary treatment (grit tank and primary clarifier) and secondary treatment (A/O process and secondary clarifier). According to the process and designing data, the simulated process was built and shown in Fig. 4.

2.3.2. Model calibration and validation

Parameters of Biowin model were calibrated based on the measured data of 1st to 10th May 2011, and the COD fractionation was fixed by Zhou et al. [17]. Fbs (readily biodegradable substrate), Fxsp (noncolloidal slowly biodegradable substrate), Fus (nonbiodegradable soluble substrate), and Fup (nonbiodegradable particulate substrate) were adjusted to 0.2, 0.75, 0.074, and 0.09, respectively. Other default parameters of software were adopted during the simulation.

The measured values and simulated values of effluent COD, TN, TP, and SS in May 2011 were shown in Fig. 5. The results showed that the simulated values have the same tendency and agree well with the measured ones. It was concluded that the established Biowin model can successfully simulate the process of WWTP.

2.4. Simulated rainfall

The simulated rainfall was designed by the rainfall intensity equation of Tianjin expressed as:

Table 1
Parameters of InfoWorks CS model from Zhang et al. [14]

Land surface	Convergence parameter	Runoff model	Gradient (%)	Initial loss (m)	Fixed runoff coefficient	Initial infiltration rate (mm h^{-1})	Steady infiltration rate (mm h^{-1})	Decay rate (d^{-1})
Pavement	7	Fixed	0.2	0.002	0.8	–	–	–
Roof	7	Fixed	0.2	0.001	0.9	–	–	–
Green land	10	Horton	0.2	0.006	–	79.38	13.42	4.34

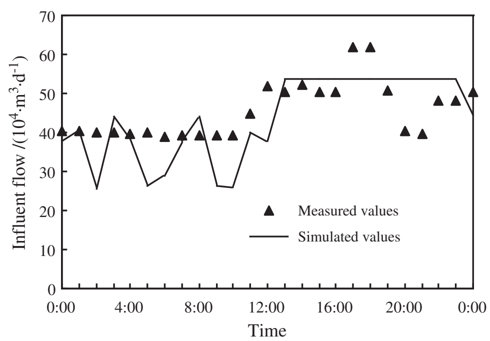

Fig. 3. Influent flow of WWTP on 18 June, 2009.

$$q = \frac{3833.34(1 + 0.85 \times \lg P)}{(t + 17)^{0.85}} \tag{1}$$

where q is the mean rainfall intensity, P is the rainfall return period, t is the rainfall duration.

2.5. Intensive process of WWTP

It is difficult to predict properly the effect of process modification in practice as many factors affect the wastewater treatment process. However, the process modification can be efficiently carried out and guide the operation of WWTP with the help of Biowin software. Here, three intensive processes were proposed to treat the impacts of rainfall on WWTP, that is, the chemically enhanced primary treatment (CEPT), CEPT combined with secondary treatment, and CEPT combined with secondary treatment with decreased hydraulic retention time (HRT).

2.5.1. Chemically enhanced primary treatment

CEPT uses coagulants for enhanced removing of pollutants at the primary stage of wastewater treatment [18,19]. The increased removal efficiency is mainly attributed to the charge-neutralization and bridge-aggregation ability of coagulants [20,21]. CEPT can treat several times of influent flow than that of traditional treatment for the same tank volume. A widely used coagulant polyaluminum chloride (PAC) was selected here for its low dosage, low cost and high efficiency [22–24]. The proposed model of CEPT was shown in Fig. 6.

2.5.2. CEPT combined with secondary treatment

After CEPT, the remaining pollutants can be further treated by the secondary treatment to improve the removal efficiency. By this retrofit, the reductions

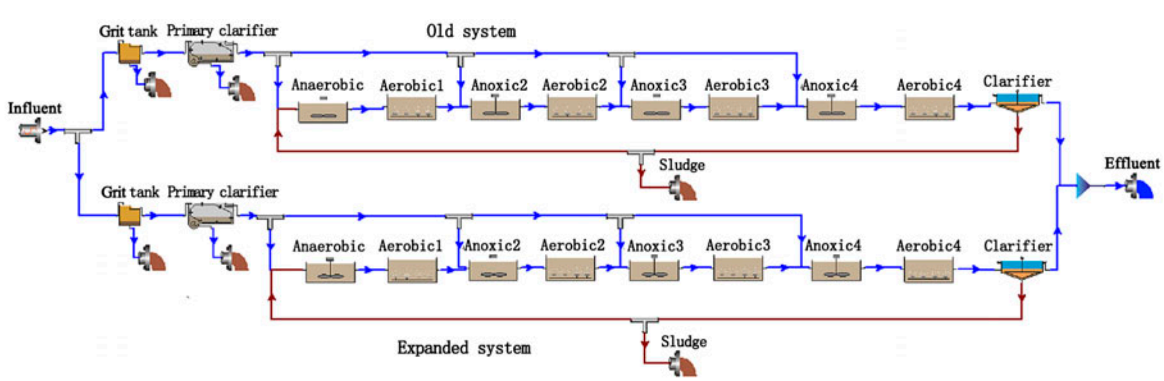

Fig. 4. Processes of example WWTP.

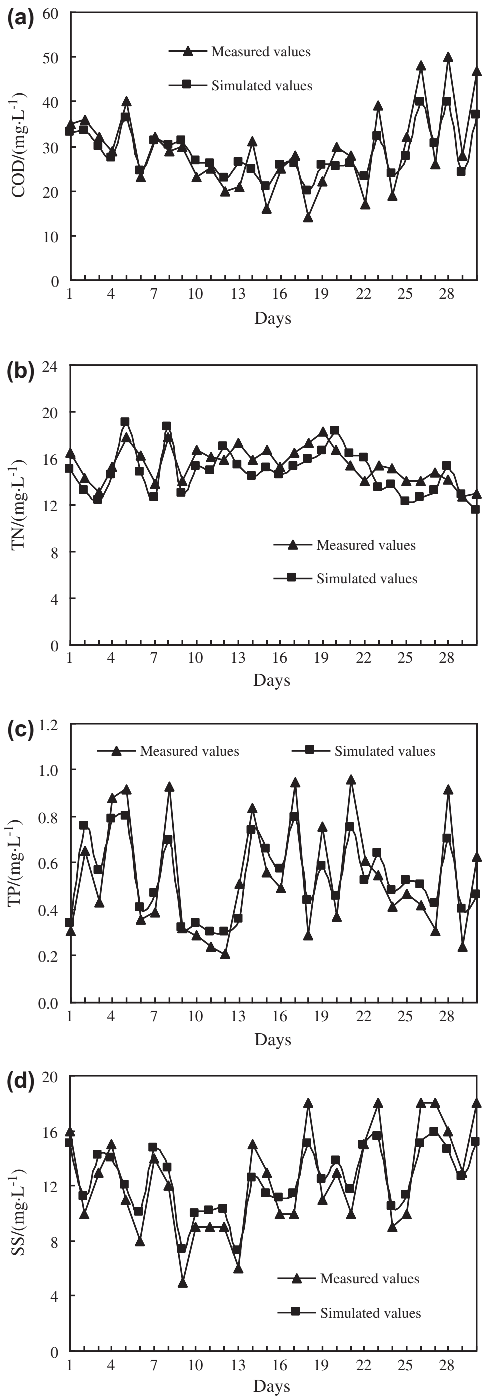

Fig. 5. Measured and simulated values of effluent pollutants in May 2011 (a) COD; (b) TN; (c) TP; (d) SS.

of space and cost of subsequent biological unit are achieved due to the decreased organic loadings following CEPT [18].

The CEPT combined with secondary treatment (the combined process) was modeled based on the original process of WWTP. All the influent water was

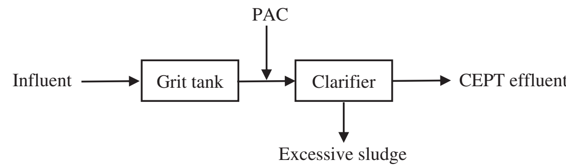

Fig. 6. Schematic diagram of chemically enhanced primary treatment.

firstly treated by CEPT. Then, the CEPT effluent within designed treating capacity ($45 \times 10^4\,m^3\,d^{-1}$) was further treated by the secondary treatment, while the excessive part of CEPT effluent was discharged into rivers.

2.5.3. CEPT combined with secondary treatment with decreased HRT

Many pollutants are removed by CEPT. As a result, the water quality after secondary treatment can achieve the required discharge standard with a shorter HRT (the first level B criteria of *GB18918-2002*). By reducing the HRT of secondary treatment, the treating capacity of secondary treatment is enhanced and the CEPT combined with secondary treatment with decreased HRT (the combined process with decreased HRT) increases the rate of total pollutant removal.

3. Results and discussion

3.1. Influence of rainfall on WWTP

The rainfall events were designed by the rainfall intensity equation of Tianjin (mentioned in section 2.4). The rainfall return period (P) was chosen as 0.5a, 1a, 2a, 5a, 10a, and 20a, respectively. The simulated rainfall started at 0:00 am and lasted for 2 hours. The operation of combined sewerage system in 24 hours was simulated by InfoWorks CS model. The influent water and water quality of InfoWorks CS model was inputted in Biowin model to study the influence of rainfall on WWTP operation.

3.1.1. Influent flow

The influent flow under different rainfall return periods was shown in Fig. 7. After the rainfall begins, the influent flow increases significantly in a short time and then remains at the level of maximum carrying capacity of sewerage system. The maximum carrying capacity of sewerage pipe appears early and lasts for long time with the increase in rainfall return period

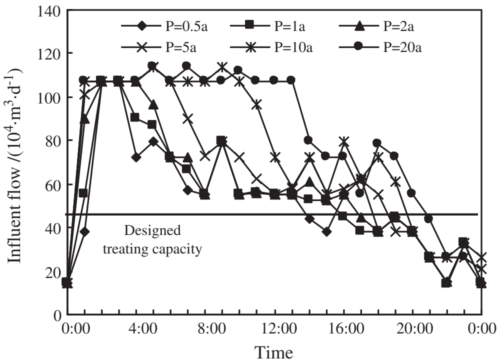

Fig. 7. The influent flow under different rainfall return periods (The rainfall started at 0:00 am and lasted for 2 h).

and rainfall intensity. It is obvious that the influent flow greatly exceeds the designed treating capacity ($45 \times 10^4\,m^3\,d^{-1}$). The similar hydraulic overloading of WWTP caused by rainfall was also reported by El-Din and Smith [2] and Hanner et al. [9].

With the help of InfoWorks CS model, the dynamic variation of WWTP influent flow in 24 h was revealed under different rainfall return periods. It was concluded that, even for the case of $P = 0.5$a rainfall, the influent flow cannot be treated all by the example WWTP and the excessive part is discharged into rivers. The large discharge increasing with the rainfall return period is a leading cause of degradation in the quality of the receiving water. In addition, the operation of WWTP is also impacted by this high variable hydraulic condition.

3.1.2. Quality of influent water

The simulated values of influent COD, TN, TP and SS were shown in Fig. 8 for $P = 0.5$a rainfall. It was found that the influent concentrations of TN and TP decrease gradually after the rainfall starts. This result is due to the strong dilution effect caused by the rainwater, which has low concentration of TN and TP compared with those of wastewater. The dilution effect of large influent flow was also found by Gernaey et al. [25] and Mines Jr. et al. [7]. As the rainfall stops, the concentrations increase gradually to their original values of wastewater. However, there are rapid increases in COD and SS values at initial period, especially for SS. The result might be explained that the soil and dust contributing to COD and SS on land surface are flushed into sewerage system by rainfall runoff. As the flushing effect of rainfall runoff is becoming weak, the rainfall runoff dilutes the high concentration of pollutants of sewage in combined sewerage system. As the rainfall runoff is becoming small, the quality of influent water is recovering to that of sewage. The trends of COD and SS concentrations are in consistent with the findings of Ráduly et al. [11], which presented a similar variation of pollutant concentration due to the first-flush effect and dilution effect of rainfall.

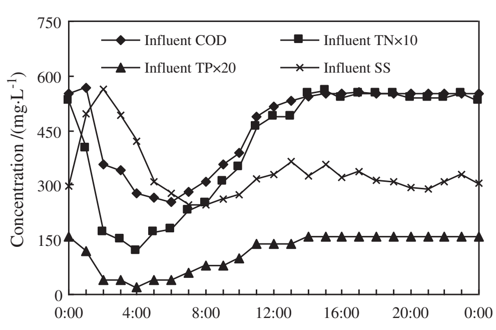

Fig. 8. Values of COD, TN, TP and SS of influent flow ($P = 0.5$a rainfall).

3.1.3. Quality of effluent water

The values of effluent COD, TN, TP, and SS of WWTP were shown in Fig. 9. The results indicated that the effluent concentrations of COD, TN, TP, and SS behave similarly to those of influent water. The minimum value of every pollutant appears later than that of influent because of the hydraulic retention time of WWTP. Unlike the influent values, the increase in effluent COD and SS values are not obvious at initial phase, which implies that the treatment process still has a high removal rate for COD and SS during the rain.

3.2. Intensive process of WWTP

Though the pollutant concentrations are diluted by rainwater during rainfall events, the total pollutant loads would increase due to large influent flow. Therefore, the influence of rainfall on WWTP operation is mainly reflected in the rapid growth of influent flow, the large total pollutant loads and the sharp increase of overflow discharged into rivers. In order to solve these problems, the intensive process to enhance the treating capacity and removal rate of WWTP was proposed. The performance of the proposed processes was simulated by Biowin software.

3.2.1. Chemically enhanced primary treatment

Simulations were run under different PAC dosage conditions for $P = 0.5$a rainfall. The simulated values of effluent COD, TN, TP, and SS were shown in

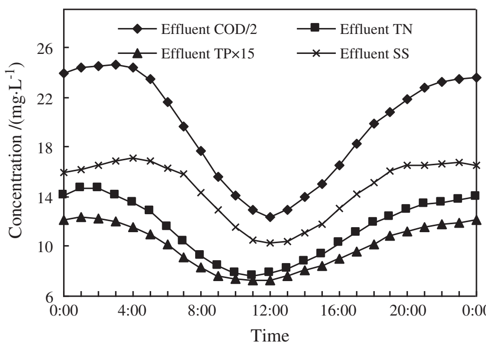

Fig. 9. Values of COD, TN, TP, and SS of effluent water of WWTP ($P = 0.5$a rainfall, the maximum treating capacity is $45 \times 10^4\,m^3\,d^{-1}$).

Fig. 10. The results indicated that the increase in PAC dosage enhances the treatment efficiency and the effluent concentrations of COD, TN, TP and SS decrease continuously. The effect of PAC was also proved by Exall and Marsalek [26] and Moghaddam et al. [27]. However, the process of CEPT has a less effect on TN removal compared with other pollutants. Similarly, no significant effect of PAC was observed on nitrogen compounds removal in the study of Teli et al. [28]. The removal rates of pollutants are not increased observably when the dosage of PAC is over $70\,mg\,L^{-1}$. So the optimum PAC dosage for CEPT was selected as $70\,mg\,L^{-1}$. At this time, the removal rate of COD, TN, TP, and SS are 63.12, 23.10, 82.63, and 80.91%, respectively, and they are 1.94, 1.81, 3.23, and 1.36 times larger than those of original primary treatment.

The effluent water quality of CEPT with a PAC dosage of $70\,mg\,L^{-1}$ was shown in Fig. 11. According to the results, the effluent water quality of CEPT meets the third level criteria of *Discharge Standard of Pollutants for Municipal WWTP* (*GB18918-2002*) of China, as shown in Table 2. The COD concentration of effluent cannot meet the requirement of national effluent standard of Japan; however, the concentrations of TN, TP, and SS of effluent satisfy that of Japan ($COD \leqslant 120\,mg\,L^{-1}$, $TN \leqslant 60\,mg\,L^{-1}$, $TP \leqslant 8\,mg\,L^{-1}$, $SS \leqslant 150\,mg\,L^{-1}$). The effluent criterion of Environmental Protection Agency of America (EPA) for pH, BOD, and SS is 6–9, 85% (30 day average removal rate) and 85% (30 day average removal rate), respectively. It was found that the removal rate of effluent SS of CEPT is close to the requirement of EPA. The other two indicators cannot be compared as they were not considered in our study. All influent water can be treated by CEPT, and no overflow is discharged into rivers. At this time, the maximum treating capacity is increased to $114 \times 10^4\,m^3\,d^{-1}$, which is 2.53 times larger than the designed treating capacity of WWTP. Therefore, the proposed CEPT is very useful and powerful in greatly reducing the amount of overflow and improving the quality of receiving waters.

3.2.2. CEPT combined with secondary treatment

The combined process under different PAC dosage conditions was studied. The values of COD, TN, TP, and SS of secondary effluent were shown in Fig. 12. The results indicated that the concentrations of COD, TN, TP, and SS of secondary effluent decrease with the increase in PAC dosage. The pollutant removal rates of secondary effluent will not increase obviously when the dosage of PAC is over $30\,mg\,L^{-1}$. Furthermore, with the increase in PAC dosage, the ratios of carbon/nitrogen and carbon/phosphorus of CEPT effluent are reduced, and they are adverse to the subsequent secondary treatment. For these reasons, the optimum PAC dosage of CEPT for the combined process should be selected as $30\,mg\,L^{-1}$ rather than $70\,mg\,L^{-1}$ for the above CEPT. When the PAC dosage of CEPT is $30\,mg\,L^{-1}$, the sec-

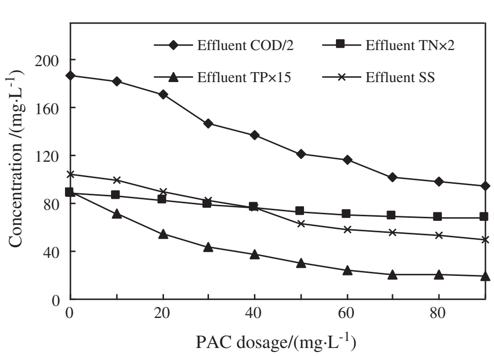

Fig. 10. Effluent COD, TN, TP, and SS with respect to PAC dosage in CEPT ($P = 0.5$a rainfall, the maximum treating capacity is $114 \times 10^4\,m^3\,d^{-1}$).

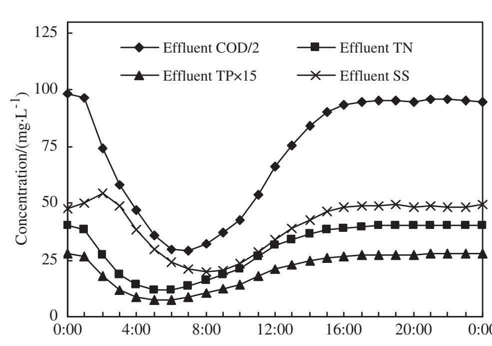

Fig. 11. Effluent water quality of CEPT ($P = 0.5$a rainfall, $70\,mg\,L^{-1}$ PAC dosage, the maximum treating capacity is $114 \times 10^4\,m^3\,d^{-1}$).

Table 2
Discharge standard of pollutants for municipal WWTP of China (GB18918-2002, unit: $mg\,L^{-1}$)

Level	COD	TN	TP	SS
First level A	50	15	0.5	10
First level B	60	20	1	20
Third level	120[a]	–	5	50

[a]The criteria is performed according to the COD removal rate when the influent COD value exceeds 350 $mg\,L^{-1}$. The COD removal rate should be larger than 60%.

ondary removal rate of COD, TN, TP, and SS are improved by 4.46, 7.45, 8.27, and 5.77%, respectively, compared with those of original secondary treatment. It was found that the proposed combined process is more efficient in removing pollutants than that of single CEPT studied by Haydar and Aziz [18] and Mahmoud [29]. Meanwhile, the secondary treatment facility is also avoided of being idle.

At this time, the water quality of CEPT effluent and secondary effluent in the combined process were shown in Fig. 13. It was found that the water quality of secondary effluent is improved from the original first level B to the first level A criteria specified in *Discharge Standard of Pollutants for Municipal WWTP* (*GB18918-2002*) of China, as shown in Table 2. The secondary effluent removal rates also meet the requirements in *Council Directive of 21 May 1991 concerning Urban Wastewater Treatment* (*91/271/EEC*) of European Union (the minimum pollutant removal rates of COD, TN, TP, and SS are 75, 70–80, 80 and 90%, respectively).

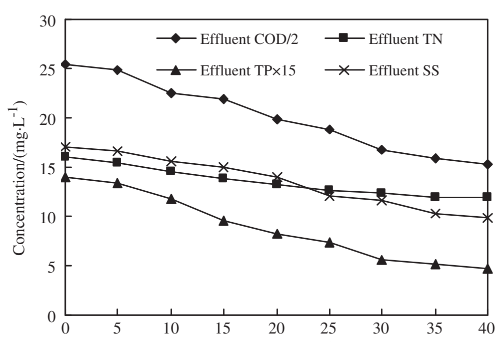

Fig. 12. Secondary effluent COD, TN, TP, and SS with respect to PAC dosage in the combined process ($P = 0.5$a rainfall, the maximum treating capacity of CEPT and secondary treatment is $114 \times 10^4\,m^3\,d^{-1}$ and $45 \times 10^4\,m^3\,d^{-1}$, respectively).

3.2.3. CEPT combined with secondary treatment with decreased HRT

Different HRT conditions were simulated for $P = 0.5$a rainfall. The values of COD, TN, TP and SS of secondary effluent in the old system and expanded system were shown in Fig. 14. The results showed that the decrease in HRT of secondary treatment increases the values of COD, TN, TP, and SS of secondary effluent in the old system and expanded system. When the HRT is reduced to a certain value, the concentration of effluent pollutant exceeds the specified values in *Discharge Standard of Pollutants for Municipal WWTP* (*GB18918-2002*) of China. According to the results, the concentration of TN will exceed the discharged standard ($\geqslant 20\,mg\,L^{-1}$) when the HRT of old system is 7.43 h, and the expanded system is 6.78 h. Under this condition, the largest treating capacity is $61 \times 10^4\,m^3\,d^{-1}$, which is 1.35 times larger than the designed capacity of original secondary treatment.

3.3. Comparison of pollutant removal rates among different processes

For $P = 0.5$a rainfall, the pollutant removal rates of different processes were compared. The original

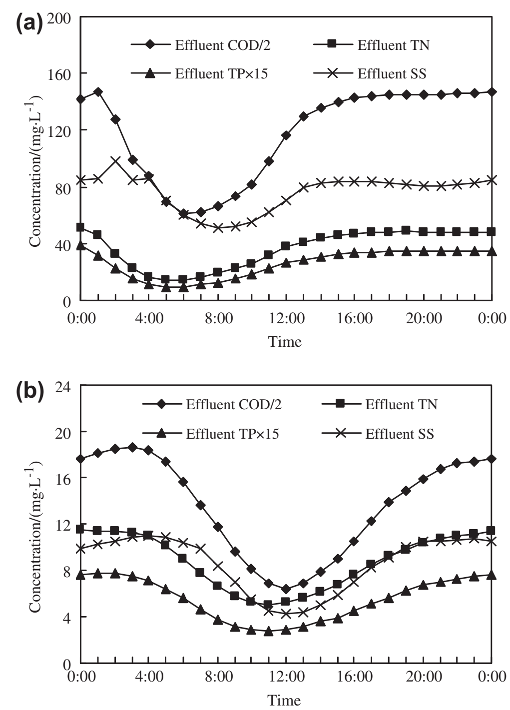

Fig. 13. Effluent water quality of CEPT combined with secondary treatment (a) water quality of CEPT effluent, (b) Water quality of secondary effluent ($P = 0.5$a rainfall, 30 $mg\,L^{-1}$ PAC dosage, the maximum treating capacity of CEPT and secondary treatment is $114 \times 10^4\,m^3\,d^{-1}$ and $45 \times 10^4\,m^3\,d^{-1}$, respectively).

process of example WWTP is called as Process 1, where the influent water beyond the designed treating capacity $45 \times 10^4\,m^3\,d^{-1}$ is discharged into rivers. The CEPT with $70\,mg\,L^{-1}$ PAC dosage is called as Process 2, where the maximum treating capacity of CEPT is increased to $114 \times 10^4\,m^3\,d^{-1}$ and all effluent water is discharged into rivers without secondary treatment. CEPT combined with secondary treatment is called as Process 3, where all the influent water is firstly treated by CEPT with $30\,mg\,L^{-1}$ PAC dosage and the effluent within $45 \times 10^4\,m^3\,d^{-1}$ is treated by original secondary treatment further while the excessive part is discharged into rivers. CEPT combined with secondary treatment with decreased HRT is called as Process 4, all the influent water is firstly treated by CEPT with $30\,mg\,L^{-1}$ PAC dosage and the effluent within $61 \times 10^4\,m^3\,d^{-1}$ is treated by secondary treatment with decreased HRT further while the excessive part is discharged into rivers.

For $P = 0.5a$ rainfall, the effluent pollutant loads of the above four processes were shown in Fig. 15. According to the results, the effluent pollutants, especially SS are reduced by Process 2. Although Process 2 is weak on TN removal than that of Process 1, it can be still adopted as a countermeasure for its low cost, high removal rate for other pollutants and the treatment of large influent flow under the rainfall condition. For Process 3 and Process 4, all the influent water is treated, and the pollutant removal efficiency is dramatically improved with the help of secondary treatment. Compared with Process 1, the effluent COD, TN, TP, and SS of Process 3 are further reduced by the ratios of 59.87, 26.08, 62.04, and 77.44%, respectively. Compared with Process 3, the effluent loads of COD, TN, TP, and SS of Process 4 are further reduced by ratios of 27.21, 20.89, 26.58, and 34.28%, respectively. This improvement is mainly attributed to the decreased HRT leading to the enhanced treating capacity of the secondary treatment. The secondary treating capacity of the Process 4 is increased by the ratio of 34.67% compared wih that of Process 3. It was found that the advantage of the decreased HRT is obvious, and the effluent pollutant loads are further reduced greatly for Process 4.

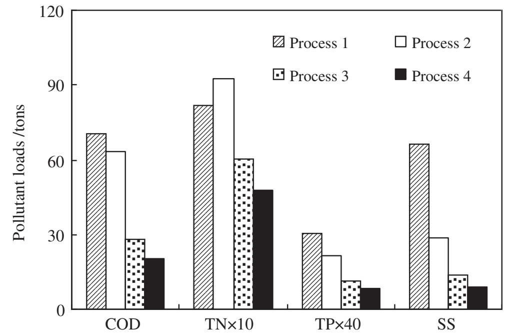

Fig. 15. Effluent pollutant loads of four processes for $P = 0.5a$ rainfall (Process 1, the original process of WWTP, the maximum treating capacity is $45 \times 10^4\,m^3\,d^{-1}$; Process 2, CEPT, $70\,mg\,L^{-1}$ PAC dosage, the maximum treating capacity is $114 \times 10^4\,m^3\,d^{-1}$; Process 3, CEPT combined with secondary treatment, $30\,mg{\cdot}L^{-1}$ PAC dosage, the maximum treating capacity of CEPT and secondary treatment is 114×10^4 and $45 \times 10^4\,m^3\,d^{-1}$, respectively; process 4, CEPT combined with secondary treatment with decreased HRT, $30\,mg\,L^{-1}$ PAC dosage, the maximum treating capacity of CEPT and secondary treatment is 114×10^4 and $61 \times 10^4\,m^3\,d^{-1}$, respectively).

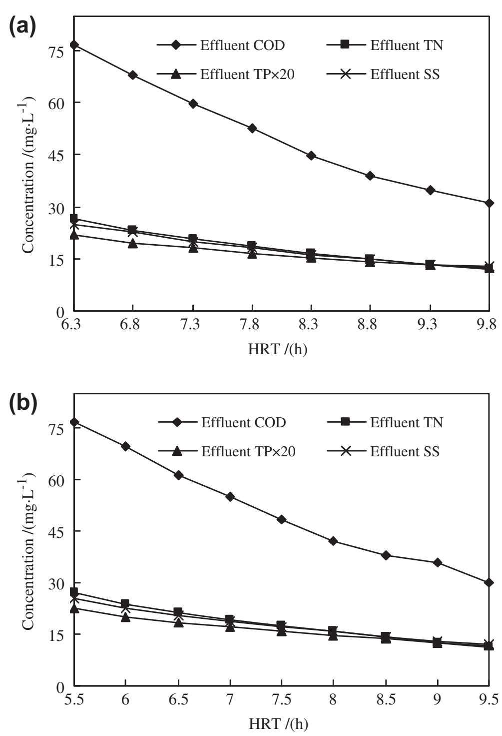

Fig. 14. Concentrations of secondary effluent pollutants with respect to HRT of secondary treatment in the combined process (a) old system, (b) expanded system ($P = 0.5a$ rainfall, $30\,mg\,L^{-1}$ PAC dosage, the maximum treating capacity is $114 \times 10^4\,m^3\,d^{-1}$).

4. Conclusions

The upriver combined sewerage system and the wastewater treatment process of WWTP were simulated by InfoWorks CS and Biowin software, respectively. The results showed that the influence of rainfall on WWTP operation is mainly reflected in the rapid growth of influent flow, the large total pollutant loads and the sharp increase in overflow discharged into rivers. The steady operation of WWTP is also impacted under this high hydraulic load condition.

In order to solve the problems, three kinds of intensive processes were proposed, that is, CEPT, CEPT combined with secondary treatment, and CEPT combined with secondary treatment with decreased HRT. The results showed that the effluent pollutants are reduced greatly by the proposed processes, especially the last two. Compared with the original process of WWTP, the effluent COD, TN, TP, and SS of CEPT combined with secondary treatment are further reduced by the ratio of 59.87, 26.08, 62.04, and 77.44%, respectively. Compared with the CEPT combined with secondary treatment, the effluent COD, TN, TP, and SS of CEPT combined with secondary treatment with decreased HRT are further reduced by the ratio of 27.21, 20.89, 26.58, and 34.28%, respectively. The results indicated that the proposed wastewater treatment processes are all powerful to weaken the adverse impacts of rainfall on WWTP and to reduce the pollution to receiving waters successfully during the rainfall events.

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