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# Simulation and control strategy for the variational influent of WWTP

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**Abstract:** With the development of activated sludge model, the simulation software for the design and operation of wastewater treatment plant (WWTP) was produced and has been widely used. The dynamic change of the quality and flow of influent are major factors causing the unstable operation of wastewater treatment process. As a basic model, ASM1 model was used for the simulation of activated sludge process, and double exponential model was selected for the simulation of secondary sedimentation tank. The influences of influent change to the aeration tank and secondary sedimentation tank were investigated, and the relationship among influent change, the quality of effluent and the level of sludge blanket in secondary sedimentation tank was established. On the basis of the simulation results, the operation of the WWTP could be adjusted under the dynamic change of the influent. Furthermore, the controlling strategy combined the feed-forward on the influent flow and the feedback on the level of sludge blanket in the secondary sedimentation tank was studied.

**Keywords:** modeling; dynamic simulation; static simulation; controlling strategy; influent

## Introduction

The dynamic variation of influent is an important factor influencing operation of wastewater treatment plants in China. Most wastewater treatment plants are operated in steady status and use high security coefficient. However the wastewater quality fluctuates sharply during a season, a week or a day. The economic benefit and steadiness of wastewater treatment plant decrease correspondingly. In order to solve the unsteadiness in operation of wastewater treatment plant, the tendency to be instrumentation, automation and systematization increases. But simple on-off control, sequence control and logic control are dominating. The debug and operation are experiential and half-experiential. Therefore, the operation and control of wastewater treatment plant are difficult to satisfy the demand. Secondary sedimentation tank is a key to the control of effluent and the influent exerts significant effects on its operation.

There are reports referred to influent flow or dynamic simulation of activated sludge process. For example, Lee *et al.*(1999) dealt with the improvement in modeling of the dynamics of activated sludge process using a distributed parameter approach. Jiang *et al.* (2004a) did sensitivity analysis on parameters such as influent load, dynamic parameters, based on the uncertainty analysis of various parameters in activated sludge model. Although they found that influent load had great effect on optimal design, they stressed on how to choose the value of parameters. Jiang *et al.* (2004b) developed a computerized simulating system of activated sludge process, which combined ASM1 model and Takacs's (model of secondary sedimentation tank). Some advices to innovate the A/O process were suggested. The emphasis of their research was the effluent quality, SRT and DO. Zou *et al.* (2004) got the relationship between influent flow and recycle flow based on hydraulic transfer and secondary clarifier models. But the key point was the control of recycle sludge. Seldom research is about the influence of dynamic variation of influent. The aim of this paper was to study the influence of dynamic variation of influent by simulation and analysis. The relationship among dynamic variation of influent, sludge level of secondary sedimentation tank and effluent quality was studied. The optimum operation conditions and control methods were determined.

## 1 Simulation system

Wastewater treatment process is a complex biological system. Modeling of activated sludge processes has received considerable attention. Activated sludge models(ASM1(Henze, 1999), ASM2 (Henze *et al.*, 1994), ASM2D(Henze *et al.*, 1998) and ASM3 (Gujer *et al.*, 1999)) for aeration tank and one-dimensional, two-dimensional and three-dimensional models describing secondary sedimentation tank have been presented. ASM2 has been further used for the anaerobic and phosphorus removal processes. ASM3 is the consummation of ASM1 and clearer in conception description, even though there is still some work to be done in the parameter calibration. However, contrast to ASM3, ASM1 has been proven to be a successful one and is used more widely

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(Guo *et al.*, 2004; Tian *et al.*, 2004; Peng *et al.*, 2005). The determination and calibration of parameter have been studied enough (Nowak *et al.*, 1999; Cui *et al.*, 2003; Liu and Gu, 2004; Xiao and Gu, 2003; Chen and Peng, 2003). The disadvantage and difference between simulation and experiment are more obvious. As this paper focuses on the carbon removal of influent, ASM1 is chosen to simulate the biological reactor. At the same time, one-dimensional double exponential model (Takacs *et al.*, 1991) is used to simulate secondary sedimentation tank, which has strong compatibility. There are detailed description on parameters and models in it. The dynamic variation of sludge level in secondary sedimentation tank can be simulated.

## 2 Set of parameters

The data and parameters used in simulation are shown in Tables 1 and 2. They are chosen from references of successful cases, present study, as well as those suggested by IAWQ.

**Table 1 Designed parameters for simulation of wastewater treatment plant**

| | First sedimentation tank | Aeration tank(part of oxygen deficient) | Aeration tank (aerobic part) | Secondary sedimentation tank |
|---|---|---|---|---|
| Type | Radial flow | Plug flow | Plug flow | Radial flow |
| Depth of tank, m | 4 | 4 | 4 | 4 |
| Area, $m^2$ | 400 | 200 | 625 | 500 |
| Retention time, h | 3.2 | 6.6 | | 4 |
| Designed load, $m^3/(m^2 \cdot h)$ | | | | 1 |

Note: In this research, the retention time of aeration tank is short

**Table 2 Operation parameters of aeration tank**

| Return sewage, $m^3/h$ | Return sludge, $m^3/h$ | Part of oxygen deficient | Aerobic part | |
|---|---|---|---|---|
| | | Aeration | Aeration, $kgO_2/h$ | Alpha |
| 5000 | 500 | 0 | 100 | 0.65 |

By investigating wastewater quantity and quality of some cities, such as Zhuzhou, Luzhou, Wuhan, it is found that the maximum flow in a day is 2—3 times of the minimum and the maximum organic concentration of sewage value is about 3—4 times of the minimum. COD concentration and flux are positively related, but the evolvement for COD concentration lags behind that of flux. Thus, Fig.1 and Table 3 are also used in simulation.

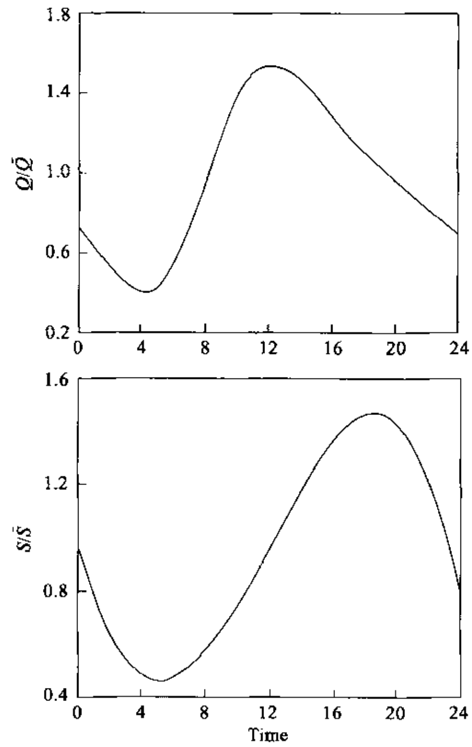


Fig.1 Variation of influent in a day for WWTP
a. influent flow; b. influent SS

**Table 3 Designed influent for simulation of wastewater treatment plant**

| Designed water quantity, $m^3/d$ | SS, $g/m^3$ | VSS, $g/m^3$ | COD, $g/m^3$ |
|---|---|---|---|
| 12000 | 300 | 210 | 525 |

## 3 Results and discussion

### 3.1 Static simulation of flow

The effects of influent flow on operation of secondary sedimentation tank are discussed. From Fig. 2, it could be easily seen that there is an obvious critical point in the process at which the optimum operation flux is obtained. Comparatively small change of flux near the critical point will change the sludge level in secondary sedimentation tank. The

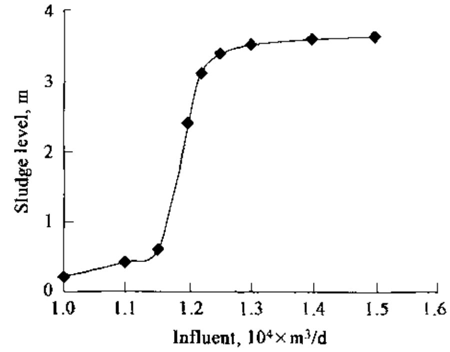


Fig.2 Variation of sludge level with influent in secondary sedimentation tank

height of sludge bed increases quickly and this leads to the effluent worse, as shown in Fig.3.

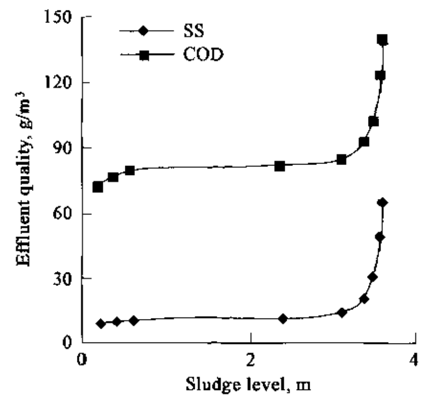


Fig.3 Relationship between sludge level and effluent quality

As plotted in Figs.4 and 5, the maximum MLSS is reached at the critical point in aeration tank and secondary sedimentation tank. With the increase of flow, the solid load in aeration tank and secondary sedimentation tank increases correspondingly. When the flow is large enough, the sludge bed increases, but effluent quality does not change. Then, the whole system will lose steadiness and the solid load will decrease. The system loses its self-control ability.

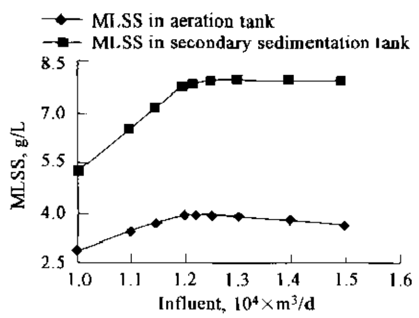


Fig.4 Relationship between influent and MLSS

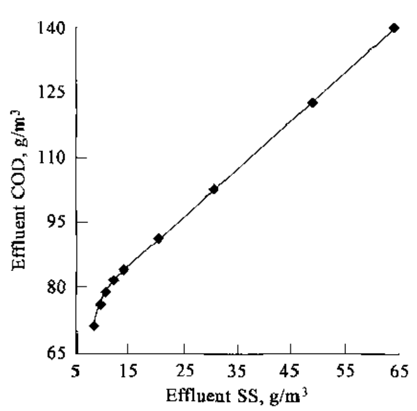


Fig.5 Contrast of SS and COD for effluent

## 3.2 Static simulation results of water quality

The designed influent is 12000 m$^3$/d. The SS and COD values varied. For the static simulation of water quality, there is also a critical point during the process. Above the critical point, the small change of effluent SS leads to strong change of sludge level, as plotted in Figs.6 and 7. The sludge bed expands quickly and effluent quality becomes worse. With the increase of influent concentration, the effluent sludge in secondary sedimentation tank and mixture concentration in aeration tank raise obviously. When reaching the critical point, the overload of secondary sedimentation tank leads to sludge level rising and effluent quality worsening, as shown in Figs.8 and 9.

When the concentration is smaller than the designed concentration, the increase of influent SS leads to small increase of effluent quality, while the increment of COD is obvious. When the influent concentration arrives at the steady status point, the increment of influent would not impact the concentration of mixture in aeration and secondary sedimentation outflow sludge, as illustrated in Fig.8.

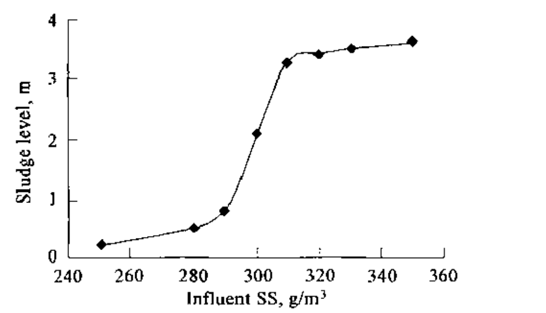


Fig.6 Variation of sludge level with the influent SS in secondary sedimentation tank

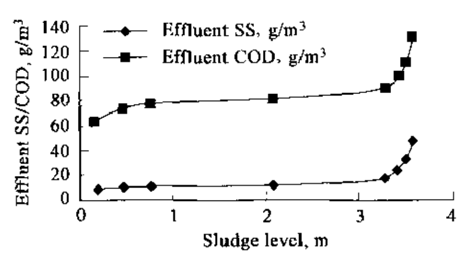


Fig.7 Relationship between sludge level and outflow quality

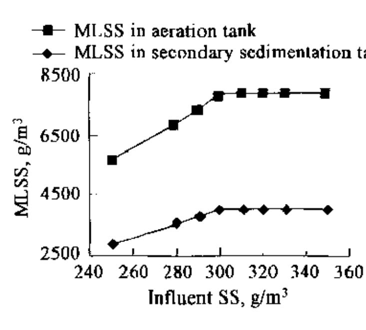


Fig.8 Relationship between influent SS and MLSS

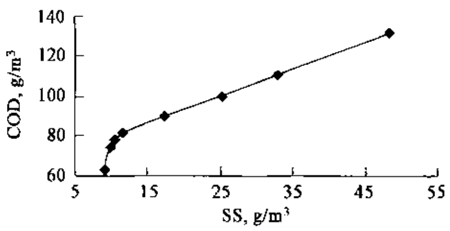


Fig.9 Contrast of effluent SS and COD

It could be concluded that the wastewater treatment system can accept influent with different concentrations. At a certain point, the system begins to lose its steadiness. The system would not lose steadiness completely until reaching the critical point. Before the critical point, the system is operated normally.

### 3.3 Dynamic simulation of influent flow

The contrast of sludge level with different influent flow is obtained by dynamic simulation. As shown in Fig.10a and Fig.10b, the flow increases and goes beyond the designed value. The effluent fluctuates strongly. As the influent may be too high or too low, the change leads to the fluctuation of sludge level. But on the whole, the steady operation of wastewater treatment plants could be ensured and the effluent quality could be satisfied. The lower flow impacts little effect on effluent SS and COD. However, the higher flow has significant influence.

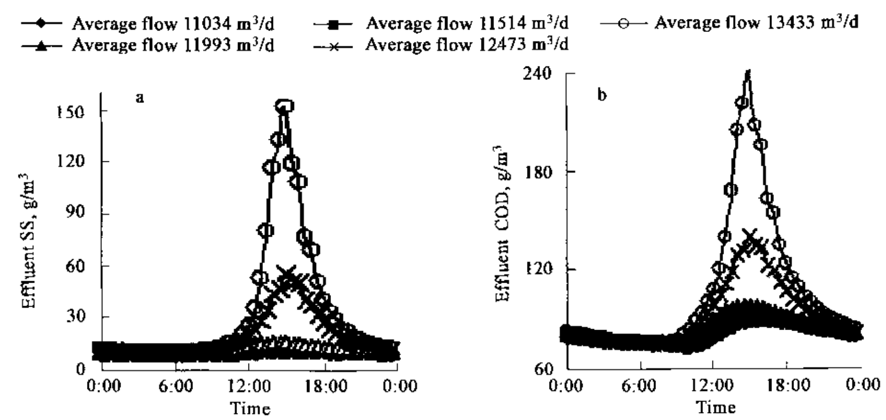


Fig.10 Variation of effluent with the same dynamic range but different influent
a. SS; b. COD

When the sludge level fluctuates strongly (for example, the sludge level increases suddenly), it does not indicate that the secondary sedimentation tank has lost its ability and the effluent quality is over the standard. When the sludge level rises slowly, it is indicated that the secondary sedimentation tank is approaching unsteadiness and the effluent quality is worse.

The wastewater treatment plant was simulated using the data mentioned above as input. The results are plotted in Fig.11. As shown in Fig.11a, with the increase of influent, the sludge level of secondary sedimentation tank increases accordingly. This leads to the disturbance to mixture of sludge and wastewater

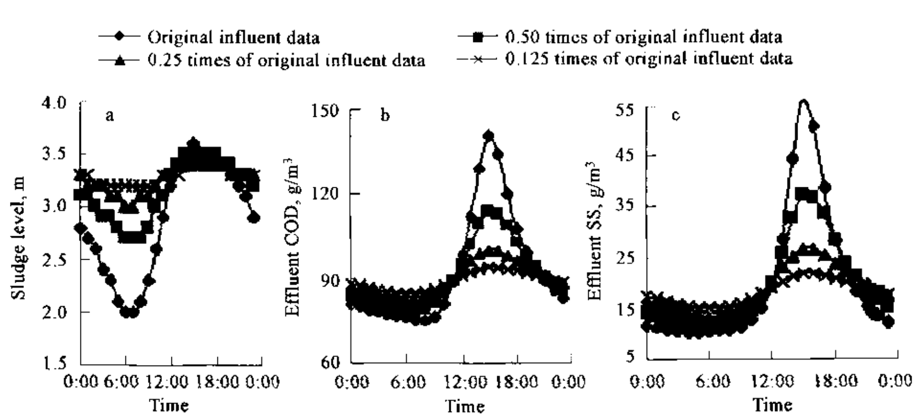


Fig.11 Variation of sludge level with different influent range
a. sludge level; b. COD; c. SS

and it is bad for the sedimentation of sludge flocs. Therefore, the adjustment of influent has effect on the operation of secondary sedimentation tank and plays an import role in wastewater treatment plants.

As demonstrated in Fig.11b and Fig.11c, the effluent SS and COD increase with the increase of influent. The reason for this is as follows. The increment of influent brings impact to aeration tank and the removal of organic material. Disturbance is brought to secondary sedimentation tank, which leads to the increase of SS in effluent. Therefore, during the operation of wastewater treatment plants, the sudden increase of influent should be paid more attention because it will result in the effluent quality out of discharge standard.

### 3.4 Dynamic simulation of influent quality

Under the same dynamic condition, the simulation results of different average influent SS are plotted in Fig.12. The influent SS (or COD) has effect on sludge concentration at the top of secondary sedimentation tank, as illustrated in Fig.12a. The hysteresis effect occurs because of mixing of sludge and wastewater and form of plug flow. Thus under the dynamic condition, the influent SS (COD) exerts significant influence on aeration tank. However, as far as sludge level and concentration are concerned, influent SS (COD) has small effect on secondary sedimentation tank.

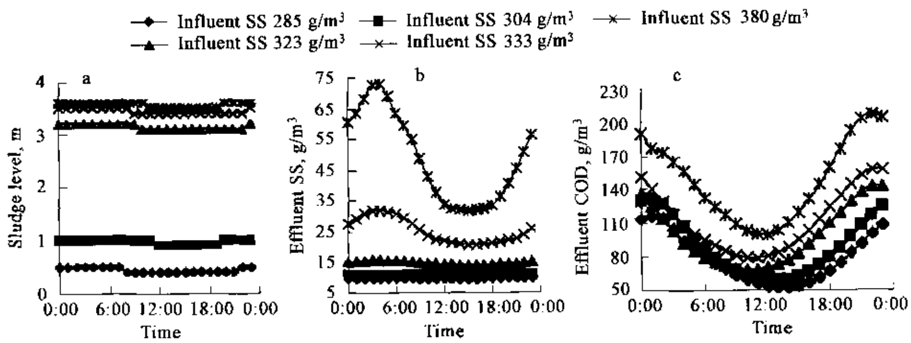


Fig.12 Variation with time in the same range of influent SS (COD)
a. sludge level; b. effluent SS; c. effluent COD

As shown in Fig.12b and Fig. 12c, the variation of influent SS strongly influences the effluent COD, while influences effluent SS slightly. The influent quality exerts effect on operation of biological reactor at first. Only when the biological reactor operates unsteadily, does it influence the water in secondary sedimentation tank. The effect of influent on effluent quality shows after 11 h.

It is found from Fig.13a that the variation of influent SS concentration has nothing to do with the sludge level in secondary sedimentation tank. The outflow SS does not fluctuate much with the variation of influent SS concentration, as plotted in Fig.13b. With the fluctuation of influent SS concentration, the outflow COD changes obviously as shown in Fig.13c. All these figures explain that the outflow SS is mainly controlled by operation of secondary sedimentation tank, while the effluent COD is controlled by operation of aeration tank.

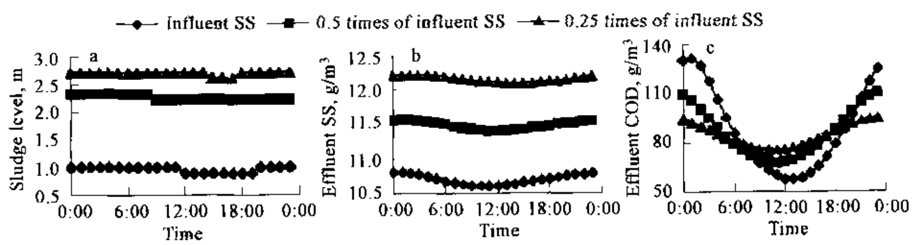


Fig.13 Variation with different influent SS
a. sludge level; b. effluent SS; c. effluent COD

## 4 Analysis of control policy

It could be concluded that the hydraulic factor influences the operation of secondary sedimentation tank. The influent COD influences the operation of aeration tank by biological effect. Based on these, the method using movable effluent weir in aeration tank is given.

A movable outflow weir is located at the top of aeration tank. When the influent is low, the weir is set down. The hydraulic load of secondary sedimentation tank is stabilized and the hydraulic retention time is decreased. The proportion of small floc in sludge would not increase, the outflow quality is ensured. On the other hand, when the influent is high, the weir is raised to increase the volume of aeration tank and ensure the hydraulic load of secondary sedimentation tank. Thus, the secondary sedimentation tank can be operated steadily all the time. The schematic of weir is shown in Fig.14. For the design of movable weir, the simulated influent is 12500 $m^3/d$.

As shown in Fig.15, the inclusion of movable weir is of benefit to operation of secondary sedimentation tank. The sludge level decreases. The effluent SS and COD decrease about 10 $g/m^3$. This strategy reduces the influence of high hydraulic load on operation of the whole system.

The dynamic simulation results with average influent SS being 330 $g/m^3$ are illustrated in Fig.16. Both the effluent COD and SS drop about 5 $g/m^3$. The sludge level decreases slightly. In a word, the movable weir can be used to modulate the effect of water quality on operation of system. But this effect is not as good as those shown in Fig.15.

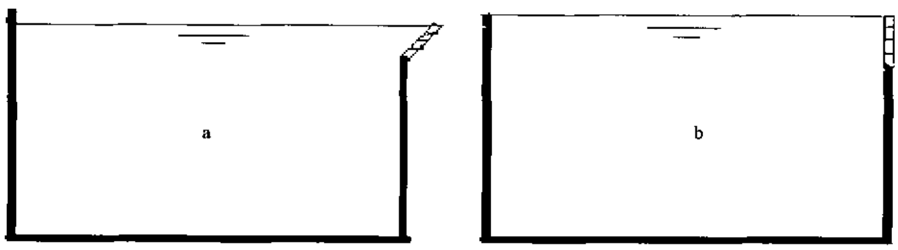


Fig.14 Schematic of movable outflow weir in aeration tank

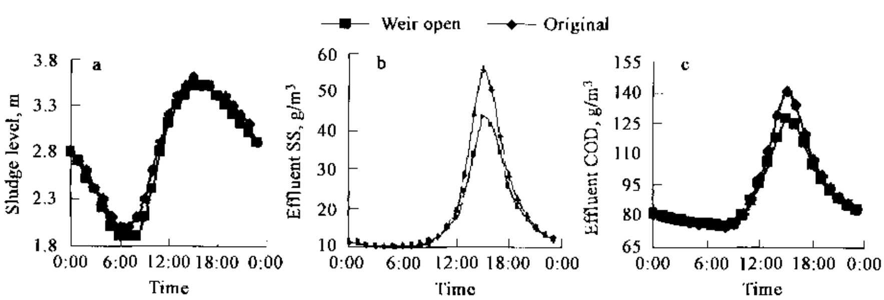


Fig.15 Simulated sludge level(a), effluent SS(b); effluent COD(c)

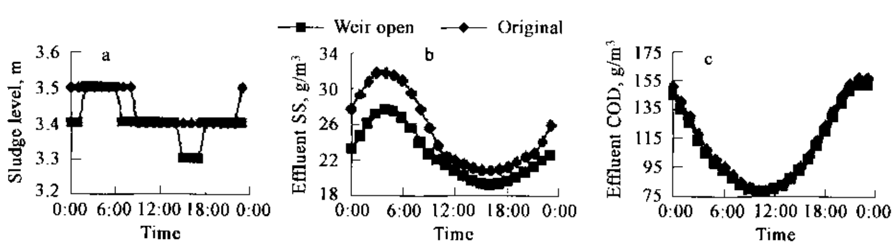


Fig.16 Simulated variation of sludge level(a), effluent SS(b), effluent COD(c)

## 5 Conclusions

The influences of wastewater quality and flow on an activated sludge treatment process are simulated in this paper. The following conclusions are obtained.

The wastewater flow impacts effects on aeration tank and secondary sedimentation tank by hydraulic characteristic and load. The quality influences aeration tank and secondary sedimentation tank by load.

With the variation of quality and flow, the system has a range in which steady operation is reached. The best operation point can be found in this range. This is helpful to the online dynamic control for wastewater treatment plants.

An effluent weir set in aeration tank is recommended to reduce the influence of influent variation, which is a good control strategy. It enhances the resistance of the system to the wastewater variation. The strategy has potential value in the practice.

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