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QUICK START-UP OF MUDANJIANG WASTEWATER TREATMENT PLANT AND FACTORS INFLUENCING PHOSPHOROUS REMOVAL

P. HUANG[1*]
S. QIN[1]
Q. ZHAO[1]
X. GUO[2]

[1]*School of Municipal and Environmental Engineering*
Harbin Institute of Technology, 202 Haihe Road
Harbin, 150090, China
[2]*Department of environment science and engineer*
Zhongkai University of Agriculture and Technology
Guangzhou, 510225 ,China

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*to whom all correspondence should be addressed
e-mail: huangpeng1976@yahoo.com

ABSTRACT

Successful start-up of a full-scale wastewater treatment plant (WWTP) is a key issue for the succeeding operation of WWTP on the one hand and the nutritious phosphorus removal is of great concern on the other. After the construction of Mudanjiang WWTP with a flow rate of 100,000 m^3 d^{-1} in Heilongjiang Province of China, a novel way of start-up through feeding wastewater continuously into the system was attempted against the conventional start-up method of inoculating activated sludge in the aeration tank by feeding wastewater intermittently. Activated sludge was cultivated and proliferated in the aeration tanks instead of dosing acclimated sludge from other source. After one-month's start-up operation, MLSS, SV and SVI increased to 2.5 kg m^{-3}, 30% and nearly 80% respectively, which indicated that quick and simple start-up had been achieved. After successful start-up, an investigation into phosphorus removal was conducted with the emphasis on influencing factors such as ORP and NOx-N concentration etc. When the aeration tank was switched from aerobic to anaerobic mode, phosphorus removal efficiency of 80% could be realized within the whole treatment system. Experimental results revealed that an ORP of -140 mV and NO_X-N of 2 mg l^{-1} were critical for the anaerobic phosphorus release, and DO in the range of 1.7-2.5 mg l^{-1}, BOD_5/TP of 20-30 and SVI of 70~80 as well as SRT of 5 days were the optimal phosphorus removal conditions for the aeration tanks.

KEYWORDS: biological phosphorus removal; anaerobic; aerobic; start-up; wastewater treatment plant

1. INTRODUCTION

The conventional way of start-up of a full-scale wastewater treatment plant (WWTP) is to inoculate a large amount of fresh activated sludge to the aeration tank and acclimate the sludge for the high removal of COD and nutrient such as nitrogen and phosphorus [1]. Although inoculating activated sludge with intermittent wastewater feeding has been a proven technology widely adopted [2] during start-up, it is estimated that 600 tons of activated sludge with water content of 80% will be needed for Mudanjiang WWTP start-up to attain half of the designed MLSS in aeration tanks, which brings great difficulty in transportation of activated sludge and consumes strong manual power. Therefore, there is a demand for finding a quick way of WWTP start-up after its construction.

For the WWTP near rivers and closed water bodies in urbanized areas, there are growing demands for the introduction of advanced treatment processes for both nitrogen and phosphorus removal, because both nitrogen and phosphorus are considered as the major elements for algal bloom in most internal waters [3]. As is well-known, biological processes for phosphorous removal from wastewater are gaining interest as an effective alternative to physical-chemical precipitation [4]. These processes are based on “luxury uptake” and “over plus accumulation”, which express the ability of a biological sludge, submitted to cyclic anaerobic/aerobic conditions, to accumulate phosphorus in excess with respect to its necessities in the presence of oxygen [5].

The scope of this study is to find a novel start-up way of Mudanjiang WWTP through feeding wastewater continuously into the system against the conventional start-up method of inoculating activated sludge in the aeration tank by feeding wastewater intermittently. Special microorganisms such as phosphorus accumulating organisms (PAOs) survived and expressed strong de-phosphorous capacity during start-up process are also examined. Besides, the factors influencing phosphorous removal during steady operation are also investigated.

2. MATERIALS AND METHODS

Wastewater Characteristics

The Mudanjiang WWTP was designed to treat the municipal wastewater of a flow rate of 100,000 m^3 d^{-1} The characteristics of raw wastewater quality are summarized in Table 1.

Table 1. Characteristics of wastewater quality in Mudanjiang WWTP

Parameter	Value (mean)
COD (mg l^{-1})	400
BOD_5 (mg l^{-1})	100
SS (mg l^{-1})	200
TN (mg l^{-1})	20
TP (mg l^{-1})	4
NH_4^+-N (mg l^{-1})	11

Wastewater Treatment Processes of Mudanjiang WWTP

The schematic of the Mudanjiang WWTP is shown in Figure 1. The system mainly consists of anaerobic ditch and the subsequent aerobic ditches, which is the so-called enhanced biological phosphorous removal (EBPR) [6]. The innovative features of this system are to realize phosphorous removal by intermittent aeration and to create alternative anaerobic and aerobic condition in the whole system.

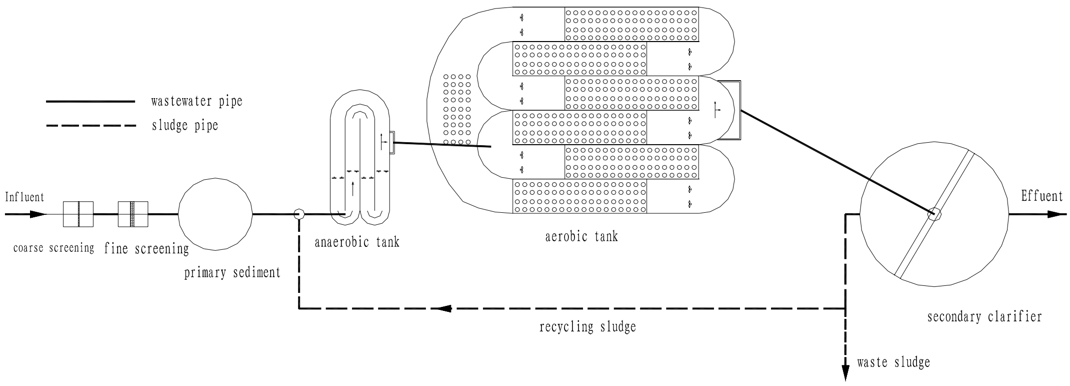

Figure 1. Schematic of Mudanjiang WWTP

Start-up operation

Temperature is one of the most important factors influencing microorganism growth and metabolism activity. It has been proven in some experiments that bacterial DNA will reach to its highest content at 20^{o}C, which indicates that the highest amount and activity of microorganism within activated sludge has been obtained at this temperature condition because microorganism is proportional to DNA content. Besides, under the appropriate operating conditions such as sufficient DO as well as plentiful nutrients in wastewater, such microorganism as floc-forming bacteria will thereby select gradually and grow to dominance [7] in the form of activated sludge.

On the basis of the above-mentioned consideration, the Mudanjiang WWTP was started up in the middle of May because wastewater temperature was about 20^{o}C. Wastewater flow rate was controlled at 1667 m^3 h^{-1} (i.e. 40,000 m^3 d^{-1}) in the first 10 days and then was increased to 2900 m^3 h^{-1} (i.e. about 70,000 m^3 d^{-1}) for the following 7 days. After trial operation of 17 days, flow rate was increased to the design value of 4200 m^3 h^{-1} (i.e. about 100,000 m^3 d^{-1}). After another 5 days' operation, the secondary clarifier effluent met the designated discharge standard, which indicated the success of system start-up.

During the start-up period, DO concentration was kept at 8 mg l^{-1} at the nearby of the inlet for the first 4 days then decreased gradually to keep at 2.0-3.0 mg l^{-1} thereafter. The return rate of activated sludge was set at 100% of influent. When the MLSS concentration reached the design value, excess sludge was discharged from secondary clarifier. Sludge return rate was decreased to 70% after 15 days and further decreased to 50% after another 5 days. The concentration of the return activated sludge was about 8500 mg l^{-1}. Good effluent quality and activated sludge characteristics further demonstrated the success of process start-up within one month.

Analytical methods

During system start-up, such parameters as COD, MLSS, SV, SVI and microorganism species were monitored daily. When the system ran steadily, the parameters of COD, DO, volatile fatty acid (VFA), T-P and NO_X-N for both influent and effluent were analyzed according to the standard methods.

3. RESULTS AND DISCUSSION

3.1. Biomass increase during system start-up

During system star-up, biomass increase is of great concern for a biological treatment system. Therefore, both MLSS and SVI were measured during start-up with the variations of MLSS and SVI shown in Fig. 2 and 3, respectively. Within the first 7 days of start-up (Figure 2), MLSS in aeration tanks increased very slowly because of poor sludge settle ability (Figure 3), too much inorganic component and some activated sludge escaped out from clarifier with effluent. As the flow rate increased after 10 days start-up running, wastewater nutrients were enough for floc-forming bacteria to proliferate and growth and MLSS increased apparently. After 22 days' operation, MLSS concentration was about 2500 mg l^{-1} and SVI was 70-80 respectively, which indicated the successful start-up and the realization of steady operation.

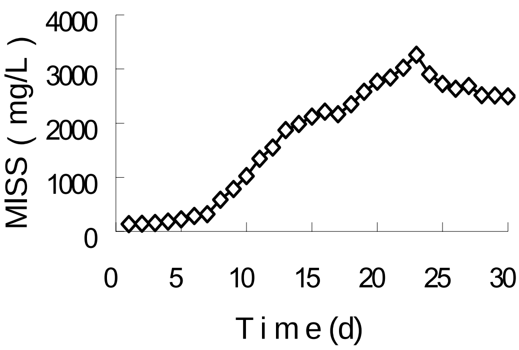

Figure 2. MLSS variation during system start-up

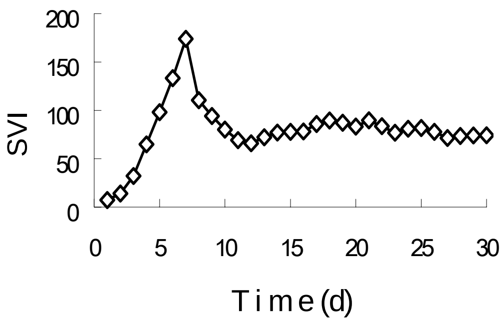

Figure 3. SVI variation during system start-up

3.2. Microbial species found in the biological treatment system

During system start-up, there was an abundance of microorganism found in the activated sludge within the system. Protozoa survived in the activated sludge were mainly sarcodina such as *Mastigamoeba invertans* (Figure 4a), *Actinophrys* and *Filamoeba nolandi* (Figure 4b). When biomass increased in the middle stage of start-up, a large amount of flagellate emerged and the dominant species were *Bodo alexeieffii* and *Cercomonas*. At the end of start-up, ciliates such as *Pparamecium*, *Litonotus* (Figure 4c) and *Vorticella* (Figure 4e) appeared to be the main protozoa. After the start-up process and system was operated at a steady state with an effluent meeting the discharge standard, protozoan were mainly *Vorticella, Rotaria* (Figure 4f) *and Opercularia*

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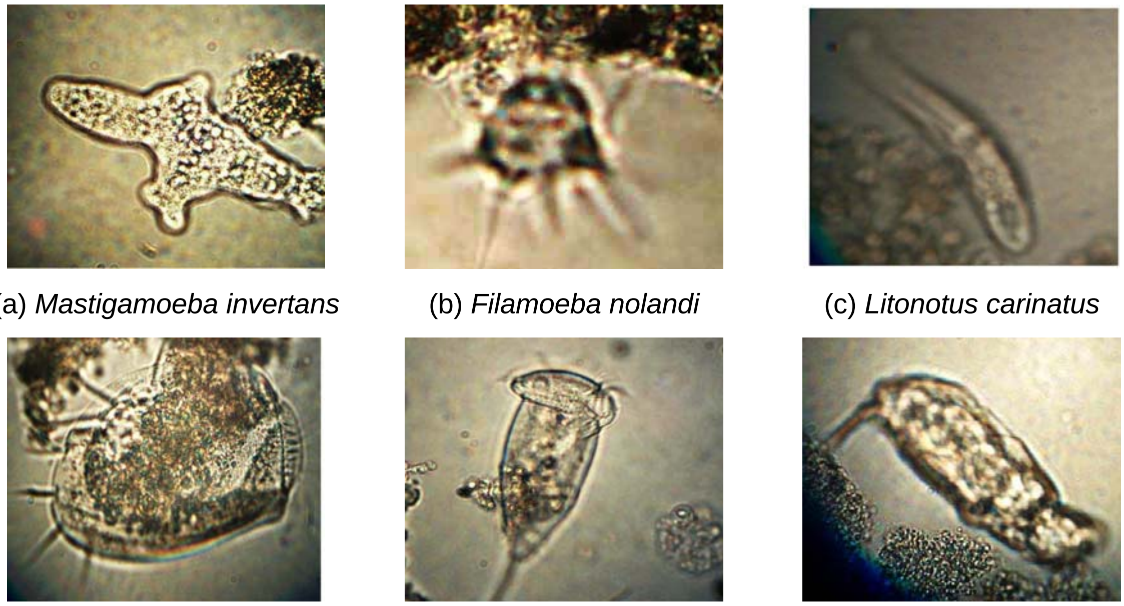
3.3. VFA effect on phosphorous removal

Biological phosphorus removal is initiated in the anaerobic zone where acetate (and propionate) is taken up by phosphorus-storing bacteria and converted to carbon storage products that provide energy for growth in the subsequent aerobic zones [8]. The readily biodegradable COD (rbCOD) is the primary source of VFA for the phosphorus-storing bacteria [9]. The conversion of rbCOD to VFA occurs quickly through fermentation and generally 7-10 mg of acetate results in about 1 mg P removal, which means that the more acetate, the more cell growth, and thus, more phosphorous removal are obtained [10].

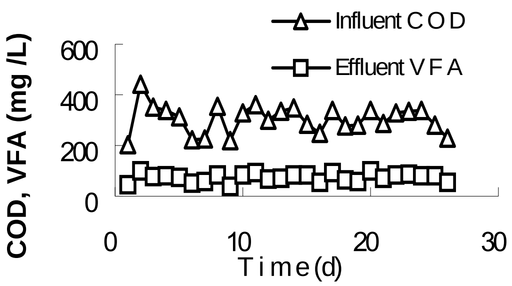
The influent COD of Mudanjiang WWTP was less than the design value of 400 mg l^{-1}, which led to the effluent TP more than 1 mg l^{-1} owing to the VFA shortage. To raise the VFA concentration, the hydraulic retention time was extended to 3 days for the primary sedimentation tank from the beginning of July so that primary sedimentation might function as fermentation unit before primary sludge waste. As show in Fig. 5, the conversion of COD to VFA was significant. As a result, VFA/COD was increased from 0.1 to 0.25 and TP of effluent decreased from above 1.0 mg l^{-1} to 0.5 mg l^{-1}, correspondingly



(a) *Mastigamoeba invertans* (b) *Filamoeba nolandi* (c) *Litonotus carinatus*

(d) *Aspidisca dentate* (e) *Vorticella campanula* (f) *rotaria*

Figure 4. Microbial species found in aeration tanks



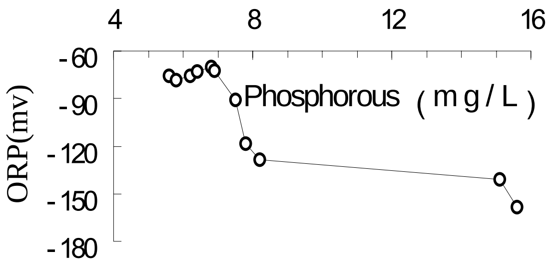


Figure 5. COD and VFA variations vs. time *Figure 6.* ORP effect on phosphorous release

ORP is related to the energy released through POM bio-chemical process. ORP value changes with the concentration variations of electron accepter, reactant and products. ORP can reflect POM activity during anaerobic phosphorous release. POM uptake phosphorous when OPR value are positive and vice versa [11]. It has been proven in some studies that PHB accumulate rapidly in the cell when ORP are below -100 mV and poly-phosphorate granule in wastewater decrease quickly.

Fig.6 shows that slight ORP variation will not cause great change of phosphorous concentration when ORP is below -140 mV. When ORP value was above -140 mV however, phosphorous concentration in wastewater increases greatly. This phenomenon indicated that ORP of -140 mV is a turning point for phosphorous concentration variation.

3.5. NOx-N effect on phosphorous release

When NOx-N concentration increased, the residual phosphorous concentration decreased (Fig. 7), which meant that no phosphorous were released when high concentration of NOx-N was present. This is caused by ORP increase because of NOx-N existing in the anaerobic zone. Significant amounts of nitrate enter the anaerobic zone, the acetate also can be depleted before it is taken up by the PAOs, and treatment progress will be hindered.

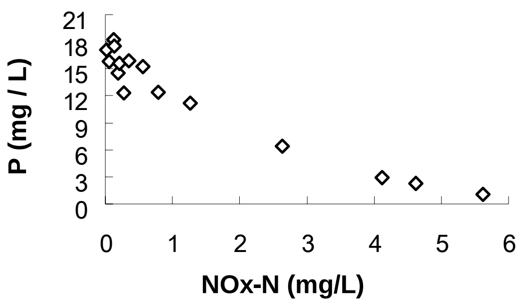


Figure 7. NOx-N effect on phosphorous release

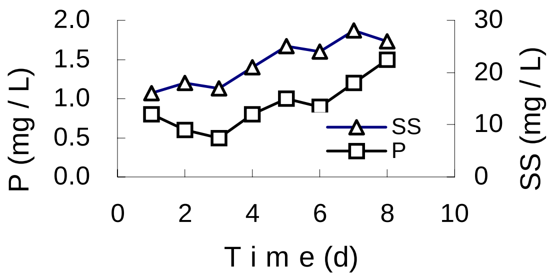


Figure 8. phosphorous and SS relatio when DO was 3-4 mg l^{-1}

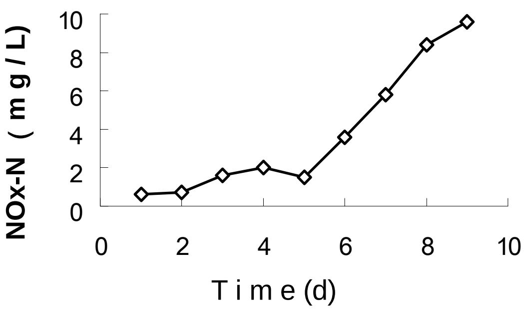


Figure 9. NOx-N concentration in anaerobic zone

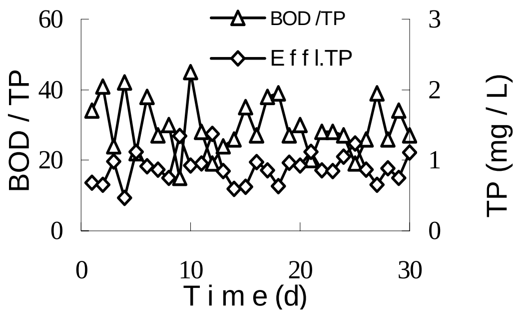


Figure 10. Relationship betweeBOD/TP and effluent TP when DO was 3-4 mg l^{-1}

3.6. DO concentration effect on phosphorous

During system start-up and since then, DO concentration in aerobic zone were controlled at 3-4 mg l^{-1}, phosphorous concentration decreased within the first several days and then began to increase to above 1.0 mg l^{-1}. Phosphorous and SS concentration in the secondary clarify effluent were measured and the result was shown in Fig.8. Simultaneously, NOx-N concentration in anaerobic zone was also measured (Fig. 9) It can be noted in Fig. 8 and Fig. 9 that high level of DO will result in the increase of effluent SS and NOx-N concentration in anaerobic zone as well as low efficiency of phosphorous removal.

As is known, nitrification will take place in aerobic zone when extra DO exists. Sludge return to anaerobic zone will release the NO_X-N, the available DO of sludge will make ORP increase in this zone. As described above, phosphorous release will be restrained. High DO concentration in aerobic zone can also make activated sludge grow at an endogenous respiration stage, which leads to cell lysis and phosphorous release. Agglomerate capability of activated sludge are also weakened, granular sludge suspend in wastewater and increase effluent SS.

When SS and P/VSS were 20 mg l^{-1} and 6% respectively, effluent SS have great relativity with P/VSS and effluent granular phosphorous will reach up to 1 mg l^{-1}. By controlling DO at 1.7-2.5 mg l^{-1} in aerobic zone in the later operation, phosphorous concentration may be expected to decrease to below 1.0 mg l^{-1}.

3.7. BOD/TP effect on phosphorous removal in aerobic zone

Influent BOD/TP has great impact on phosphorous removal. Low BOD in aeration tank will lead to low-loading operation and extend aeration, PHB in the cell will be consumed excessively to maintain the metabolish balance. The capabiblity of phosphorous up-take will be restrained.

Fig.10 shows that when BOD_5/TP is high in aerobic zone, effluent TP is low, and *vice verse*. In order to keep steady phosphorous removal efficiency and effluent TP less than 1.0 mg l^{-1}, BOD_5/TP should be controlled at 20-30.

3.8. SVI effect on phosphorous removal in aerobic zone

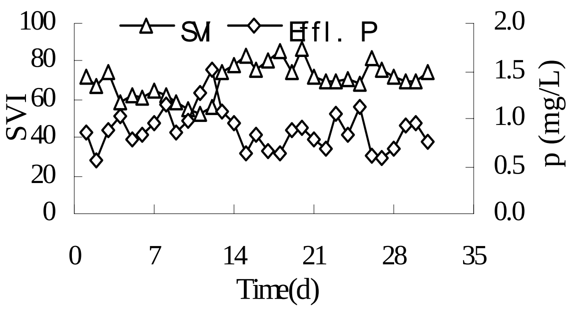
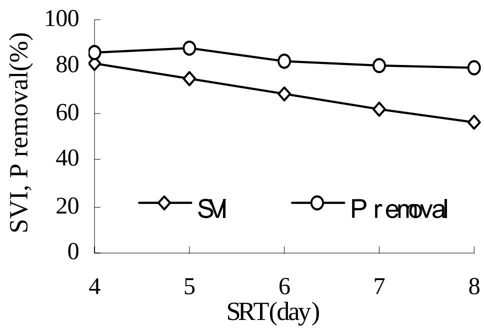


Figure 11. SVI effect on phosphorous removal



Figrue 12. SRT effect on phosphorous removal

Phosphorus removal was influenced by SVI (Figure 11). Within the first two weeks' normal operation (July 1-14), SVI was in the range of 50-70, high effluent phosphorous up to 1.6 mg l^{-1} had been detected. By reducing aeration strength and shut off inlet blower to control SVI at 70-90 after July 15, however, effluent phosphoroys was below 1 mg l^{-1}.

3.9. SRT effect on phosphorous removal in aerobic zone

Two adverse effects on phosphorous removal are associated with light loading and long SRT as show in Fig.12. This is ascribed that phosphorus removed is proportional to the amount of biological phosphorous-storing bacteria, the less phosphorous storing biomass production results in less phosphorous removal. On the other hand, the biological phosphorous bacteria are in an extended endogenous phase at longer SRT, which will deplete more of their intracellular storage products. If the intracellular glycogen is depleted, less efficient acetate and PHB storage will occur in the anaerobic zone, thus making the overall BPR process less efficient.

4. CONCLUSIONS

This paper has presented a novel quick start-up procedure of full-scale Mudanjiang WWTP and affecting factors for phosphorous removal during operation. Through feeding raw wastewater into the system continuously, activated sludge were cultivated and proliferated in the aeration tanks instead of dosing acclimated sludge. The whole start-up process just took one month.

By converting primary sedimentation to primary fermentation tank and activated sludge was fermented for three days, VFA/COD was increased from 0.1 to 0.25 and effluent TP correspondingly decreased from above 1.0 mg l^{-1} to 0.5 mg l^{-1}.

In the anaerobic zones, it revealed that an ORP of -140 mV and NO_X-N of 2 mg l^{-1} were critical points for the anaerobic phosphorus release. For the better phosphorus removal, DO should be maintained in the range of 1.7~2.5 mg l^{-1} in aerobic zones, BOD_5/TP ratio in 20~30 and SVI in 70~90, SRT for 5 days, respectively

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