6-5 Effective Operation and Management of Anaerobic-Anoxic-Oxic (A^2/O) Process

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ABSTRACT

Previous studies show that PHA (poly hydroxy alkanoate) in activated sludge participates in the biological phosphorus removal on the wastewater plant. We examined the relationship between phosphorus removal and PHA concentration under anaerobic, anoxic and oxic conditions in the laboratory.

After we arranged the actual operating data, such as ratio of return sludge, influence of rainfall and ratio of nitrate feed and so on, we examined the best operation for phosphorus removal from principal of management, and drew up effective operation and management of A^2/O process.

KEYWORDS : Phosphorus removal, PHA shortage, Optimization Method of Influent Load

INTRODUCTION

Tokyo, the capital of Japan, is divided into two districts, western Tama Area and 23 Ward Area (Fig.1).

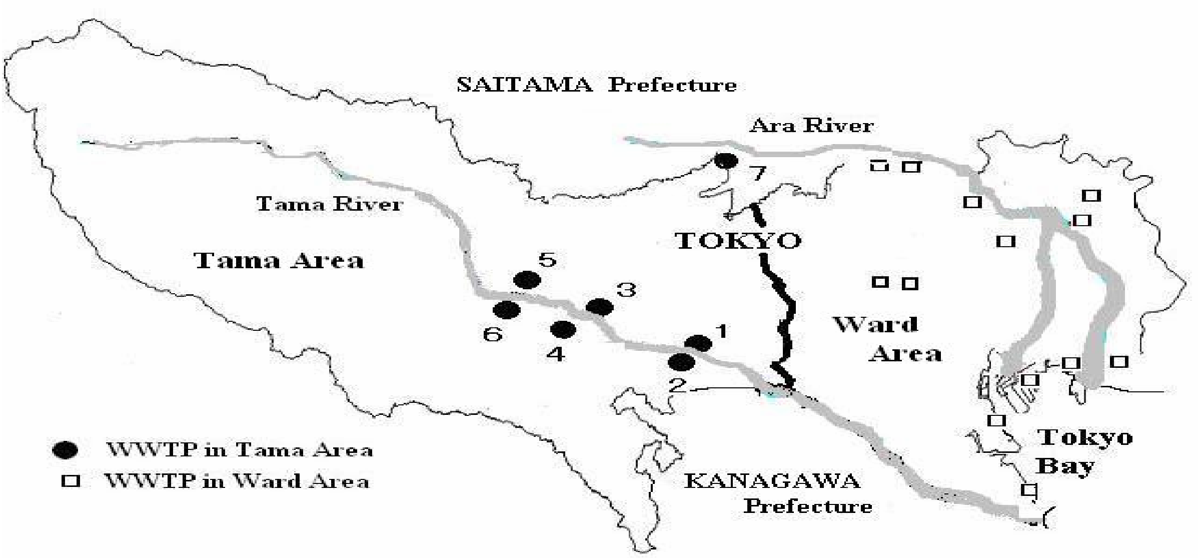


Figure 1 Wastewater Treatment Plant in Tama area

Seven all wastewater treatment plants in Tama Area have introduced A^2/O process that is effective for removal of nitrogen and phosphorus. However, in some cases, for example after heavy rainfalls, phosphorus removal becomes unstable.

A^2/O process costs more than conventional activated sludge process. Therefore, we examined the mechanism of biological phosphorus removal in the laboratory and determined the effective operation for the both water quality and the cost.

METHODOLOGY

1. Examination of management from experimentation

Previous studies show that PHA (poly hydroxy alkanoate) in activated sludge participate stability of management in biological phosphorus removal. Because of drawn up the suitable management, we examined the relationship between PO_4-P and PHA concentration in each anaerobic, anoxic and oxic condition.

1.1 How to measure PHA

Figure2 shows the flow chart of PHA measurement. We use benzoic acid for internal standard in analysis. After activated sludge was freeze-dried, PHA in it was methyl esterified with methanol sulfate and extracted with chloroform. In addition, this extracted PHA was measured with FID-GC. Standard solution was made from, 3-hydroxy sodium butyric acid, with the same procedure as the pretreatment of samples.

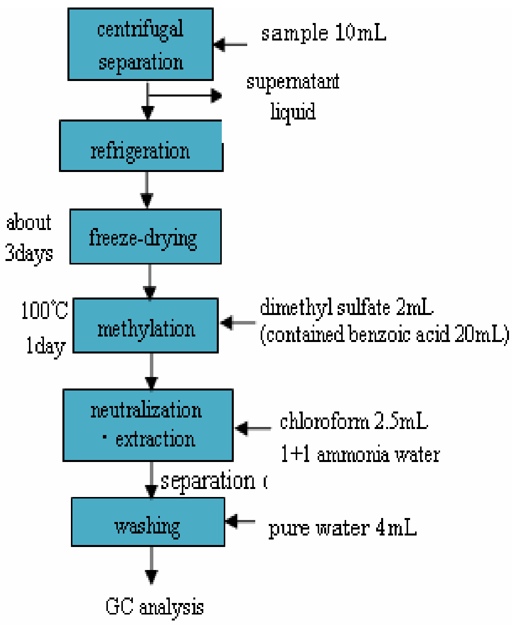


Figure2. Flow chart of the examination of PHA

Table1. Condition of GC analysis

Kind of column	GL sciences Inc. NEUTRA BOND-1 30m×0.25mm
Carrier gas	Helium
Ratio of split	1:20
Temperature of injection	250 degrees
Temperature of detector	280 degrees
Temperature of column	From 60 degrees to 260degrees

Table1 shows analysis condition of GC.

Figure3 shows structural formula of PHA. The composition of influent water would vary at the actual facilities and PHA except 3HB in the influent water was assumed existence. We, therefore, compared the chromatograms at the start and at the end both of the anaerobic condition and the oxic condition, examining the existence of the peak acting the same way as 3HB.

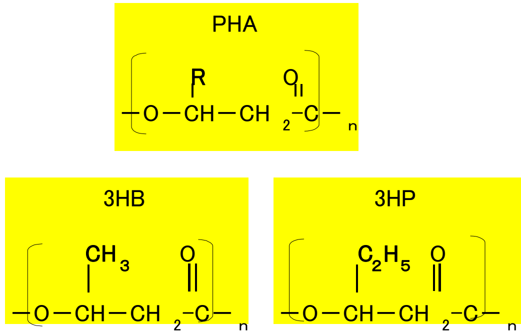


Figure3.structure type of PHA

Figure4 shows the chromatogram of activated sludge, the beginning and the end of anaerobic condition.

On the chromatogram of activated sludge, the same pattern of peak as 3HB existed around 9.1 minutes of GC retention time. Moreover, it was the same change as 3HB in aerobic, so we concluded that it was PHA. This peak was estimated to be 3-hydroxy valerianic acid (3HP). We applied calibration gradient and intercept of 3HB to quantitate it. We expressed corresponding peak of 3HB about 5.4minutes on chromatogram, and other peak is about

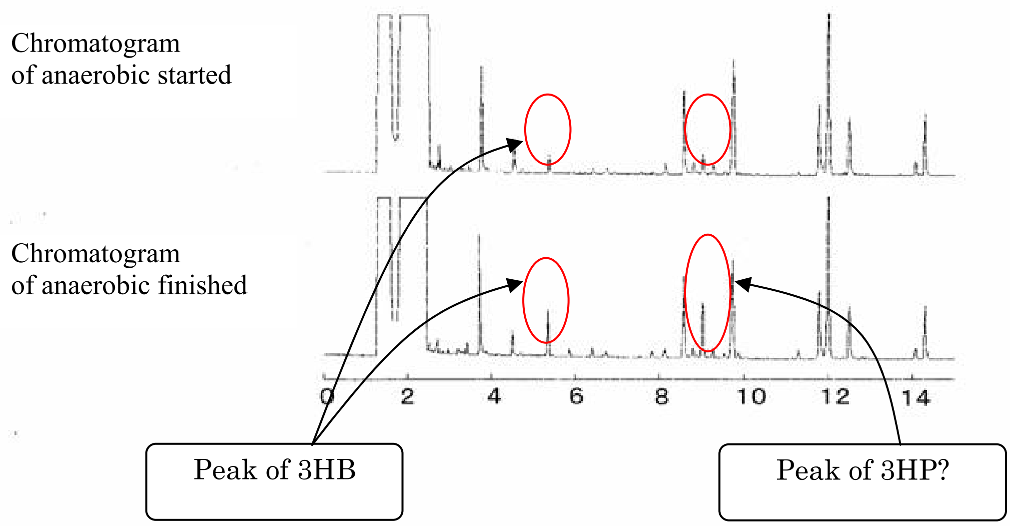


Figure4. Chromatogram of PHA analysis (started and finished in anaerobic condition)

9.1munuites. Moreover, it was the same change with 3HB in aerobic, so we conclude that it was PHA. We guess that this peak is 3-hydroxy valerianic acid (3HP). We applied calibration gradient and intercept of 3HB. We expressed PHA (3HB+3HP) concentrations that are reduced as carbon concentration.

1.2 Confirmation of principle of biological phosphorus removal

We examined both behaviors of PO_4-P concentration and PHA concentration in activated sludge at each processes in the laboratory, with mixed influent water and return sludge.

Under the anaerobic condition, after return sludge of A^2/O process and influent water are mixed in the ratio 3:10(return sludge rate 30%) in beaker of 2L, we covered on the surface of the water by bag of polyethylene which cut off in a circle in the same size of the inside diameter (This work was for contact to get fewer mixing liquid and air, decrease dissolution of oxygen), and mixed by stirrer. We made a hole of 1cm square in the cover, sucked up it by pipet. In oxic condition, we remove the cover and aerate mixing liquid, suck up as anaerobic, we compare PO4-P concentration with PHA concentration in activated water.

1.3 Evaluation of actual treatment capacity

In actual A^2/O process plants, we regard maximum the volume of water of treatment at perfect nitrification as the capacity of treatment.

We measured nitrification velocity in the laboratory and examined mixture specific characteristic in the oxic condition, and calculated average of NH_4-N concentration of effluent water from ratio of tracer outflow in average of retention time. When average of NH_4-N concentration of effluent water is almost zero, we evaluated the capacity of treatment about each A^2/O process plants in wastewater treatment plants.

Mixture specific characteristic was examined as follow. Each volume of influent water, return sludge and nitrate feed was fixed, from started examination before few hours to finished getting the aeration tank water. After lithium chloride was thrown in the entrance of the oxic tank instantaneously, we took samples exit of the oxic tank as regular interval by autosampler (Fig.5).

We poured the lower 50mL of samples into centrifugal precipitation tubes except for floating sludge. It added hydrochloric acid of two drops in sample, be standing condition before measurement. To add hydrochloric acid prevent from floating sludge and prevent

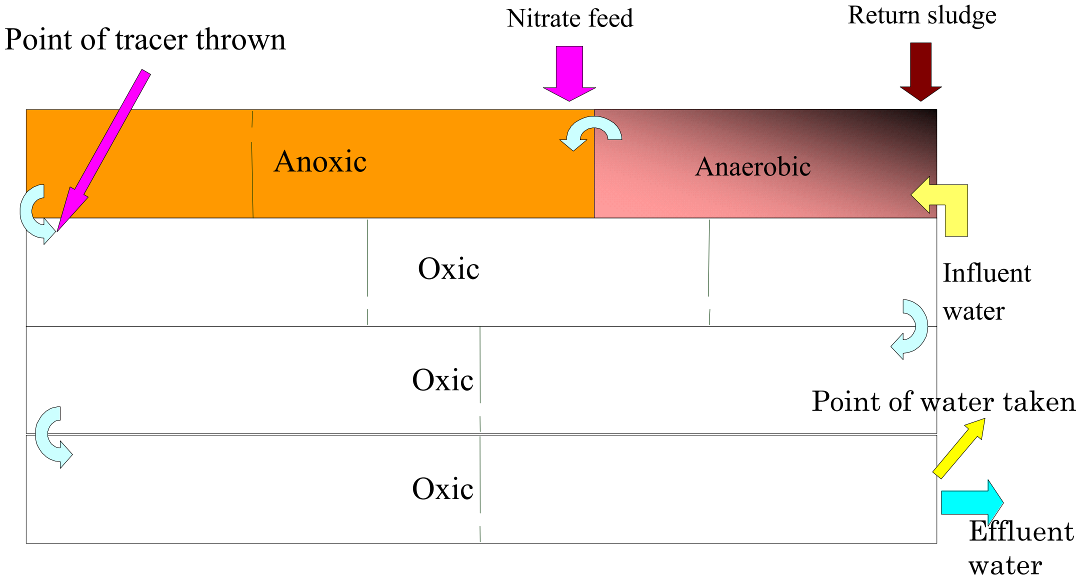


Figure5. Examination of mixture specific characteristic

from adsorbing lithium ion to centrifugal precipitation tube. We measured supernatant liquid by atomic absorption spectrophotometer.

2. Examination of effective operation for arrangement of data of operation result

It became stable nitrogen removal, but phosphorus removal often became unstable. Therefore, we examined stable phosphorus removal and the cost of management decrease.

We examined influence of rainfall, effect of dosing primary sludge in anaerobic tank, effect of bypass of primary sedimentation tank and effect of the cost of management.

RESULTS

1. PHA measurement

1-1 Behavior of PO_4-P concentration and PHA concentration in anaerobic and oxic conditions.

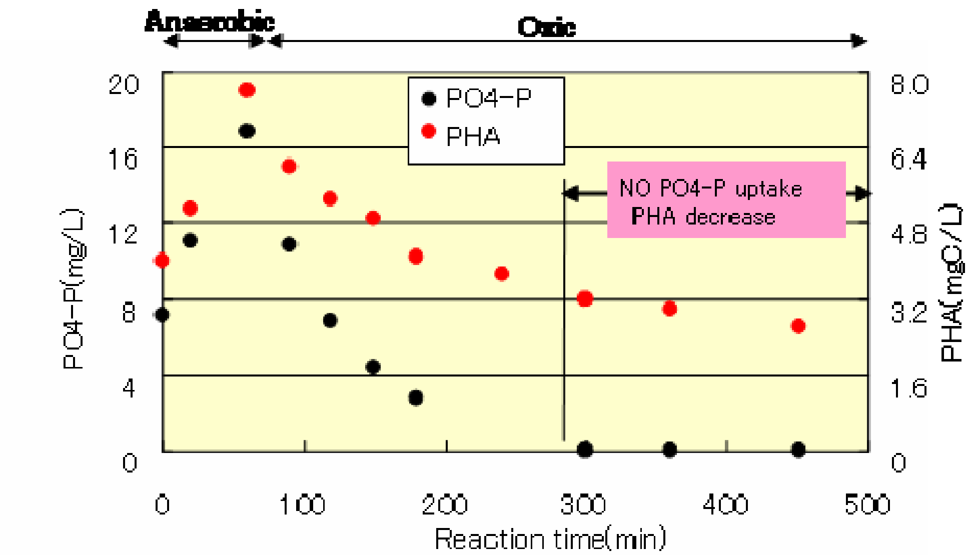


Figure6. Relationship between PO_4-P concentration and PHA in activated sludge under anaerobic and oxic conditions

In beaker, PHA concentration in activated sludge and PO_4-P concentration in the mixed liquor were examined under anaerobic and oxic conditions.

PHA concentration and PO_4-P concentration showed almost same behavior, increased under the anaerobic condition and decreased under the oxic condition (Fig.6).

1-2 Relationship between PHA concentration in activated sludge and phosphorus absorption rate

We examined relationship between PHA concentration in activated sludge at the start of aeration and phosphorus absorption. The more PHA in activated sludge holds at the start of aeration the faster the activated sludge absorbs phosphorus (Fig.7).

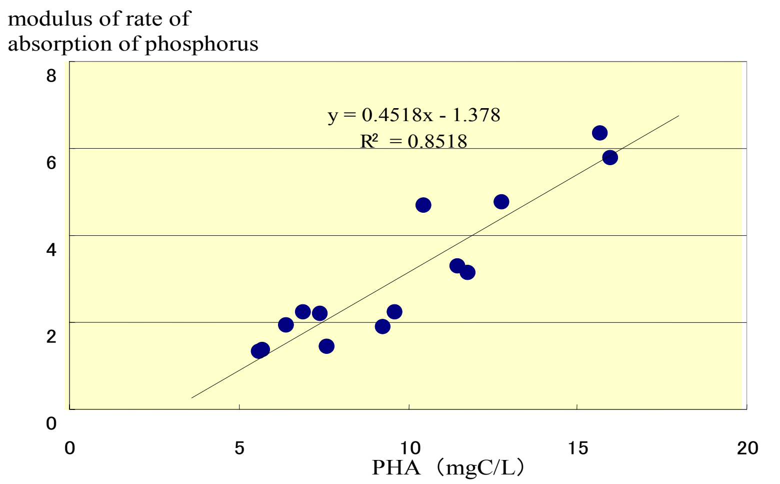


Figure7. Relationship between PHA concentrations in activated sludge and the modulus of phosphorus absorption rate

1-3　Phosphorus absorption rate in oxic condition

Figure8 shows relationship between aeration time and PO_4-P concentration in oxic tank.

If aeration time was transformed logarithmically, phosphorus absorption can be approximated by straight line, and we can calculate the modulus of phosphorus absorption rate.

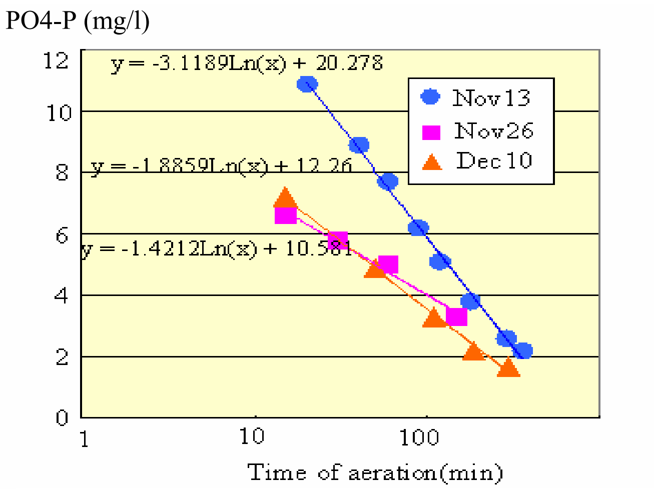


Figure8. Relationship between aeration time and PO_4-P concentration in oxic tank

Figure9 shows behavior of PHA concentration in activated sludge in oxic condition. Immediately after the aeration started, PHA decrease rate is low but after that PHA decrease rate is higher immediately after aeration started, and then decrease like straight line.

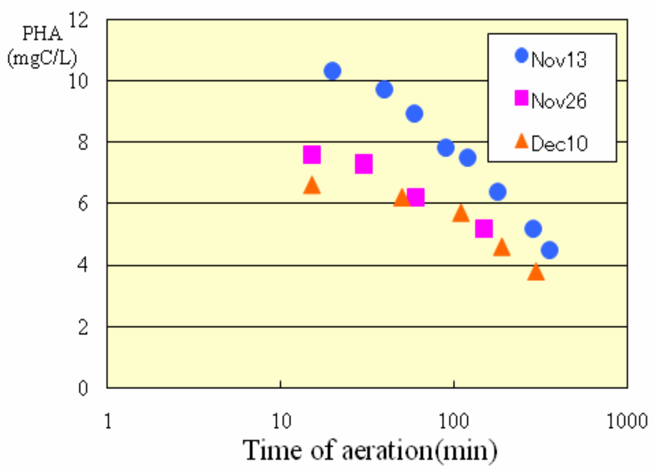


Figure9. Relationship between treating time and PHA concentration in activated sludge in oxic tank

Figure10 shows the result of examination of relationship between acetic acid concentration and PHA concentration for one of the method of knowing behavior of PHA in oxic condition. Both condition in anaerobic and oxic, storage bacteria of phosphorus was absorbed acetic acid, it synthesize PHA. We guess the gradient of graph to be small because of another bacteria spend acetic acid and likewise storage bacteria of phosphorus in oxic condition.

So we guess because decrease of quantity of PHA immediately after aeration started was small, it absorbed remaining organic acid in mixed liquor and absorbing PO_4-P and synthesizing PHA at the same time, the balance of quantity of PHA consumption and quantity of PHA synthesis shows. After useful organic acid is nothing, PHA is only consumption and it decrease like straight line per logarithm of aeration time.

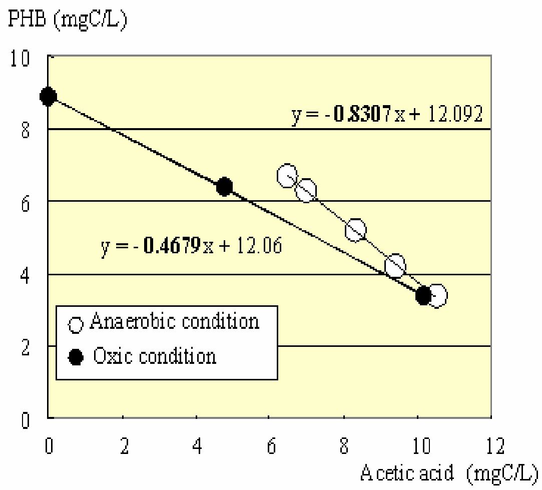
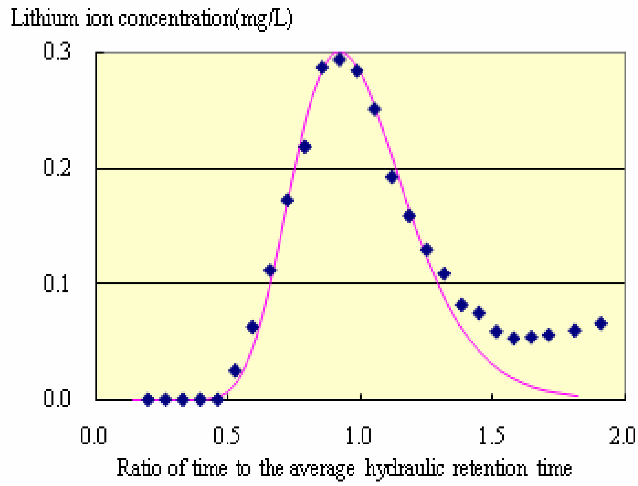


Figure10. Relationship between acetic acid concentration and PHB concentration in activated sludge

1-4 Evaluation of actual treatment capacity of oxic tank

Figure11 shows the tracer concentration of the outflow on the ratio of time to the average hydraulic retention time and the approximate lognormal curve.



The volume of influent water 650 m^3/day

The volume of return sludge 80 m^3/day

The volume of nitrate feed 650 m^3/day

Time to the average hydraulic retention time 317min

Capacity of oxic tank 6122 m^3

Cross section of reaction tank 51 m^3

Hole of partition of square measure 1×1 m^3

Place of peak 0.92

Standard deviation 0.228

$$y = \frac{\exp\left\{-(\ln x + 0.083)^2 / 2(0.228)^2\right\}}{0.228\sqrt{2\pi}}$$

Figure11. Outflow characteristic curve of the oxic tank

First, we made graph of result of mixture specific characteristic examination from lithium ion concentration of effluent water and ratio of time to the average hydraulic retention time. In addition, we made the approximate curve from this graph purpose of knowing the volume of effluent any time. The best approximate curve is logarithmic normal distribution curve.

The result is almost the same it to pass of peak. However, there is the difference by inches because nitrate feed reached the end of oxic tank. Therefore, outflow characteristic curve is higher than approximate curve. We need the outflow characteristic curve only from the start to peak for calculating the actual treatment capacity of aerobic tank, so we use the approximate curve to calculate.

In the case of A^2/O process, it needed finishing nitrification in oxic tank. However, it was difficult to know maximum volume of outflow to be 0mg/L NH_4-N concentration of the end of oxic tank, we calculated it to be 0.1mg/L NH_4-N concentration of the end of oxic tank.

Table3. Calculated NH_4-N concentration in effluent water

Ratio of the average retention time	Ratio of outflow (%)	Calculated NH_4-N concentration in effluent water (mg/L)	
0.37	0.01	0.00	
0.41	0.03	0.00	
0.45	0.10	0.00	
0.50	0.30	0.01	
0.55	0.78	0.02	
0.61	1.72	0.03	
0.67	3.18	0.03	
0.74	4.99	0.01	
0.82	6.62	-0.06	→0
0.90	7.42	-0.15	→0
1.00	7.02	-0.24	→0
・・・	・・・	・・・	
Total	100	0.10	

Table3 shows calculated NH_4-N concentration in effluent water.

Ratio of the average retention time and ratio of outflow (%) in Table3 was calculated by outflow characteristic curve. NH_4-N concentration in effluent water was calculated by rate of decrease of NH_4-N and ratio of circulation.

Table4 shows result of calculated about each wastewater treatment plants. This was calculated in case of the minimum value of rate of nitrification.

Table4. Evaluation of actual treatment capacity of each plant

	*Rate of nitrification (mg/L・min)	**Influence concentration of NH_4-N (mg/L)	Treatment capacity (m^3)	Ratio of treatment capacity	***Unification of condition: Treatment capacity (m^3)	***Unification of condition: Ratio of treatment capacity
A	0.08	19	32,530	1.2	28,488	1.0
B	0.07	22	21,259	1.0	22,497	1.0
C	0.08	22	28,428	1.8	28,428	1.8
D	0.065	22	12,843	0.7	17,820	1.0
E	0.05	19	32,940	0.7	54,545	1.1
F	0.08	24	11,584	0.8	11,568	0.8
G	0.08	21	51,629	1.5	49,484	1.4

*used minimum value each wastewater treatment plants

**used maximum value of effluent of the primary sedimentation tank

***Calcurated Rate of nitrification(0.08),NH_4-N concentration(22mg/L),Ratio of circulation(1.2)

Average of treatment capacity for a year is calculated to replace rate of nitrification with average of it. Treatment capacity and ratio of treatment capacity in unification of condition was calculated to compare with treatment capacity each wastewater treatment plants.

In this result, C wastewater treatment plant has the best capacity, proved to maintain stable quality of treated water, because of load of 1.8 times influent water.

2. Examination of effective operation for arrangement of data of operation result

2-1 Adjustment of rate of return sludge

Influent water and return sludge flow in anaerobic tank in A^2/O process. Return sludge contain hardly useful organic matter which activated sludge can use. Therefore, we guess if

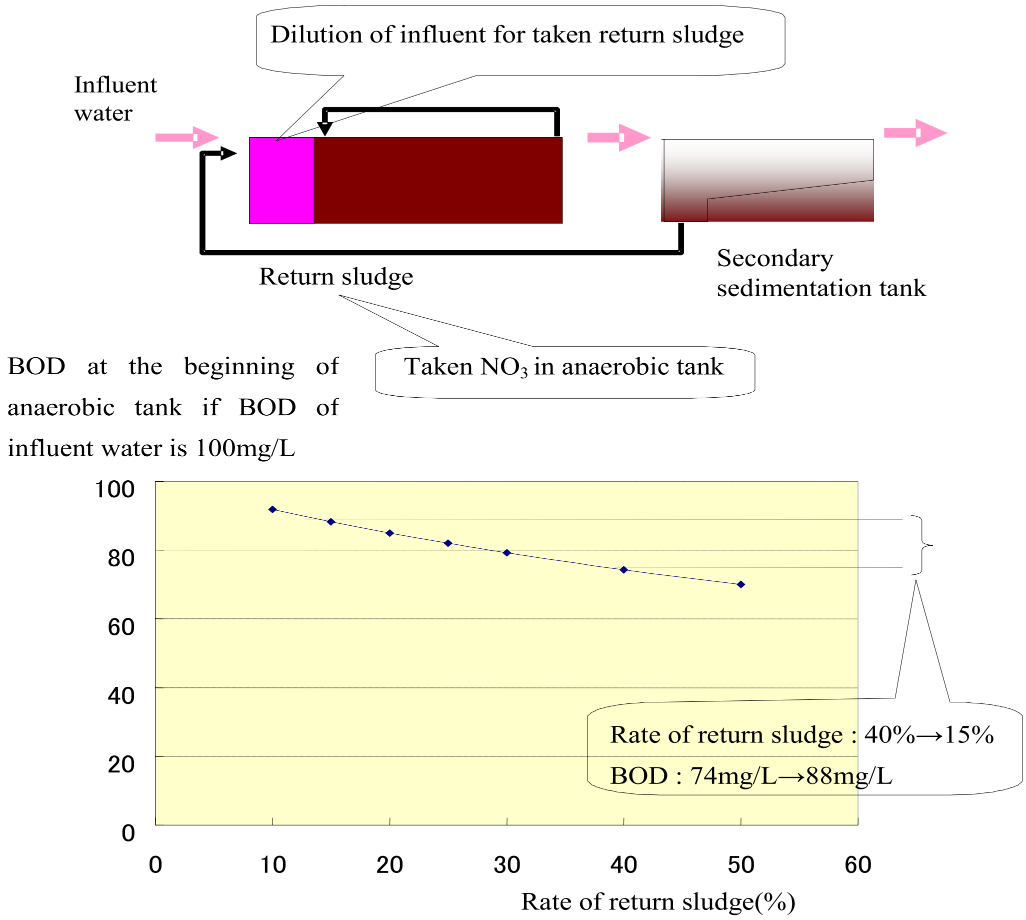


Figure12. Effect of rate of return sludge lowered

rate of return sludge is low, organic matter concentration in mixed liquor in anaerobic tank is increase, so dilution of influent water is decrease. In addition, nitric acid that is obstacle to release phosphorus is decrease in anaerobic tank.

Therefore, we inspected BOD in anaerobic tank, when rate of return sludge was lower from

40% to 15%. In addition, we examined quantity of surplus sludge and quantity of various electric power when rate of return sludge decrease actually, we checked effect rate of return sludge lowered.

Figure12 shows inspection of BOD change as BOD of influent water is 100mg/L when rate of return sludge changed.

When rate of return sludge decrease 40% to 15%, BOD in anaerobic tank increase 19% $(((88mg/L-74mg/L)/74mg/L)\times 100=19\%)$. It has the same effect bypass of primary sedimentation tank or dosing primary sludge in anaerobic tank constantly that has the difference quantitatively. In addition, it has cut of cost of sludge treatment to decrease rate of return sludge. We conceive that quantity of solid of surplus sludge is almost the same if quantity and quality of influent water do not change. In this condition, rate of return sludge decreases, quantity (the capacity) of surplus sludge decreases for concentration of sludge in secondary sedimentation tank. For this result, operation time of centrifugal thickener is shortened.

Table5 shows the concrete example of data that compared with two wastewater treatment plants in two years.

Table.5 Effect of cut of cost for decreased rate of return sludge

Name of plant	Business year	Period of comparison	Sewage volume (m^3/day)	Quantity of solid (t/day)	Rate of return sludge (%)	Quantity of surplus sludge(m^3/day)	Electric power of thickener and dewatered(kWh/day)	Electric power of sedimentation tank(kWh/day)	Electric power of amount of blast(kWh/day)
C	2005	May.-Oct.	61,780	8.7	32%	662.9	1,446	3,232	6,704
	2004		61,167	8.0	45%	930.9	1,872	3,365	6,861
	Ratio of the year before to theyear		101%	108%		71%	-426	-133	-157
F	2005	May.-Oct.	231,493		25%	3648.3	6,499	17,850	33,842
	2004		231,318		44%	4757.0	6,704	19,471	31,555
	Ratio of the year before to theyear		100%			77%	-205	-1,621	2,288

Both of it was the same operation about aeration tank at 2004 and 2005 (Same aeration tanks are in operation), we can compare kinds of electric power and so on. In this result, we proved to decrease surplus sludge for rate of return sludge lowered. So electric power of thickener, dewatered and sedimentation tank was lowered.

However, F wastewater treatment plant increased electric power of aeration volume. The data of quality of solid for F wastewater treatment plant was nothing, we could not compare quality of influent water (compare pollutant load), but influx volume of bonding oxygen (NO_3-O) in anaerobic tank decreased, so we guessed aeration volume was increased. We conclude to have at least effect of the lower cost of sludge treatment for rate of return sludge lowered.

2-2 Stopped operation recycled nitrate feed in case of primary effluent

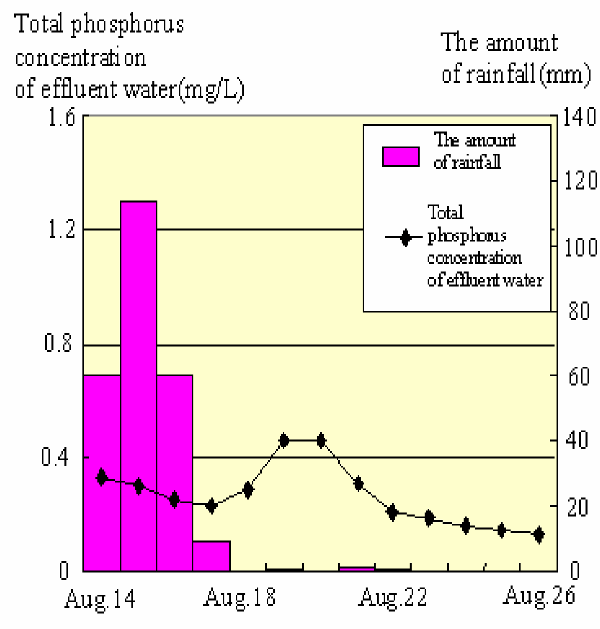


Figure13. Continued operation of A^2/O process (D wastewater treatment plant)

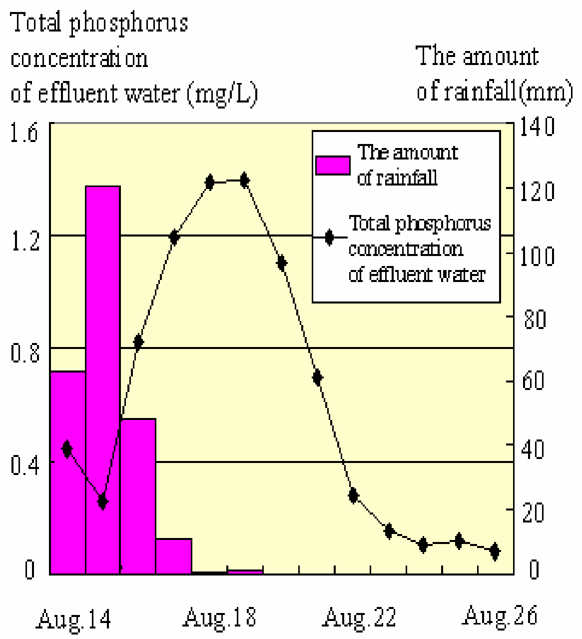


Figure14. Changed operation of AO process (E wastewater treatment plant)

Figure13 and Figure14 show comparison total phosphorus concentration of effluent water between continued operation of A^2/O process and changed operation of AO process for inspection of effect of stopped operation recycled nitrate feed in case of primary effluent. Both wastewater treatment plants were almost the same rainfall because of rainfall for typhoon. D wastewater treatment plant continued operation of A^2/O process because of examination of dosing primary sludge. On the other hand E wastewater treatment plant did bypass primary sedimentation tank while changed operation of AO process, made efforts stability of quality of effluent water. D wastewater treatment plant required 7days to recover it and total phosphorus concentration in effluent water was high, 1.5mg/L. On the other hand, increase of it in E wastewater treatment plant was not so high 0.5mg/L at peak. In this result, we conclude stopped operation recycled nitrate feed in case of primary effluent has an effect shortening of recovering time of phosphorus concentration in treated water and control of peak of it.

2-3 Effect and cost of bypassing primary sedimentation tanks and primary sludge dosing

Adding solids into reaction tanks, which would be removed at the primary sedimentation tanks, bypassing primary sedimentation tanks and primary sludge dosing can increase aeration volume and sludge treatment volume. Aeration volume in reaction tank changes for quality of influent water and so on, it is difficult to inspect, but we can inspect it to a certain degree, because separate sewerage system is not so influenced by rainfall and we examine in the long term.

Figure15 shows ratio of A^2/O process to conventional activated sludge process about aeration volume in reaction tank with dosing primary sludge.

In this examination, A^2/O process operates to stop nitrate feed as AO process in this year because of stability of phosphorus removal. That is to say, nitric acid did not supply in reaction tank from recycled nitrate feed in this year. Ratio of A^2/O process to conventional activated sludge process about aeration volume in reaction tank was less than 1 before dosing primary sludge, but dosing primary sludge day after day, it was over 1, and we prove to be increased aeration volume in reaction tank.

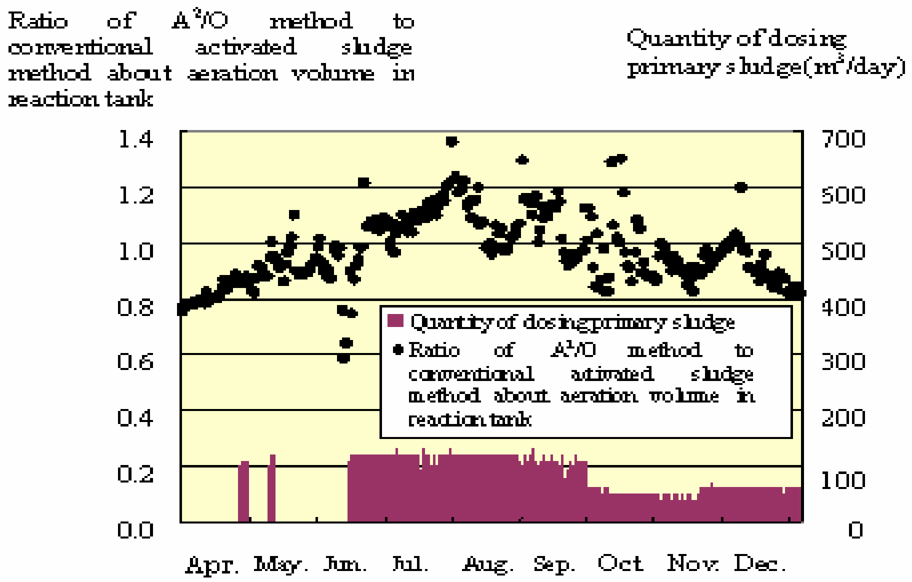


Figure15. Ratio of A^2/O process to conventional activated sludge method about amount of blast in reaction tank with dosing primary sludge

DISCUSSION

Activated sludge synthesizes PHA using organic substance in influent water under anaerobic condition and consumes PHA under oxic condition. If the consumption of PHA in an oxic tank exceeded the synthesis of it, PHA in activated sludge is decreased during the circulation between the reaction tank and the secondary sedimentation tank (Fig.16).

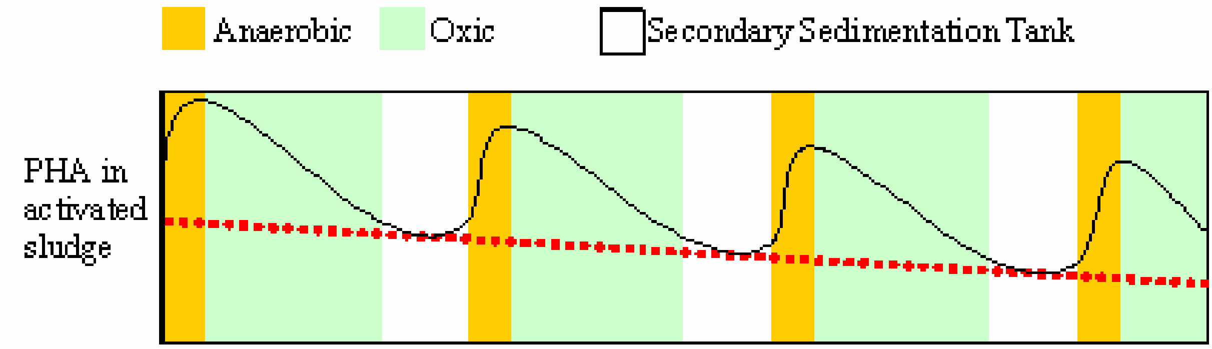


Figure16 Transition of PHA in activated sludge (Deterioration of phosphorus removal)

As PHA in activated sludge decreases, phosphorus absorption rate also decreases. If PHA in activated sludge continues to decrease and reached certain level, it is thought to be unable to absorb all phosphorus of influent water, and phosphorus concentration gradually rises in treated water.

Phosphorus removal appears to be easy to unstable when treatment volume is much less than the capacity because PHA is exhausted by excess aeration after finishing nitrification.

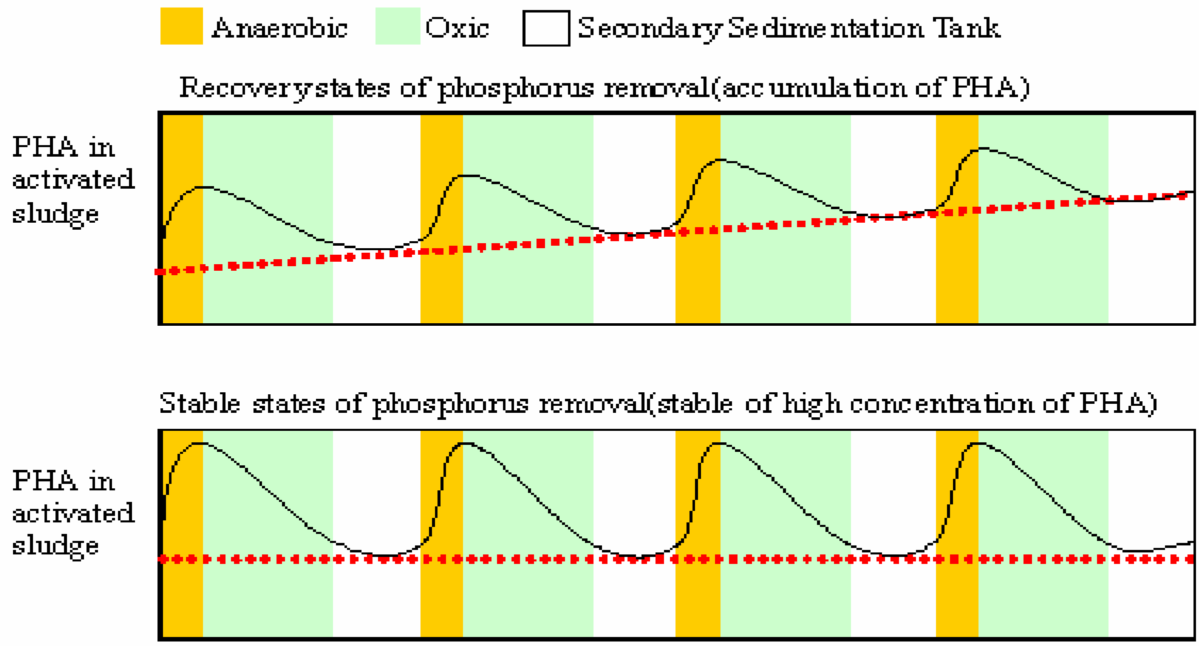


Figure17 Transition of PHA in activated sludge (Recovery and stable conditions of phosphorus removal)

On the other hand, if treated water volume is increased so much that nitrification is finished at the end of the oxic tank, PHA in activated sludge gradually increases and keeps a high level (Fig.17). On this condition, phosphorus concentration in treated water settles low level.

In examination of stopped operation recycled nitrate feed in case of primary effluent, we proved it had an effect to recover phosphorus removal. If influent water dilute until come to primary effluent for rainfall, anaerobic tank cannot keep in anaerobic condition because of organic substance shortage in influent water, carrying in dissolved oxygen and nitric acid in anaerobic tank, and so on. In this condition, if it is stopped operation to recycle nitrate feed, anoxic condition changes anaerobic condition in anoxic tank, so quicken to release phosphorus in anoxic tank (Fig.18).

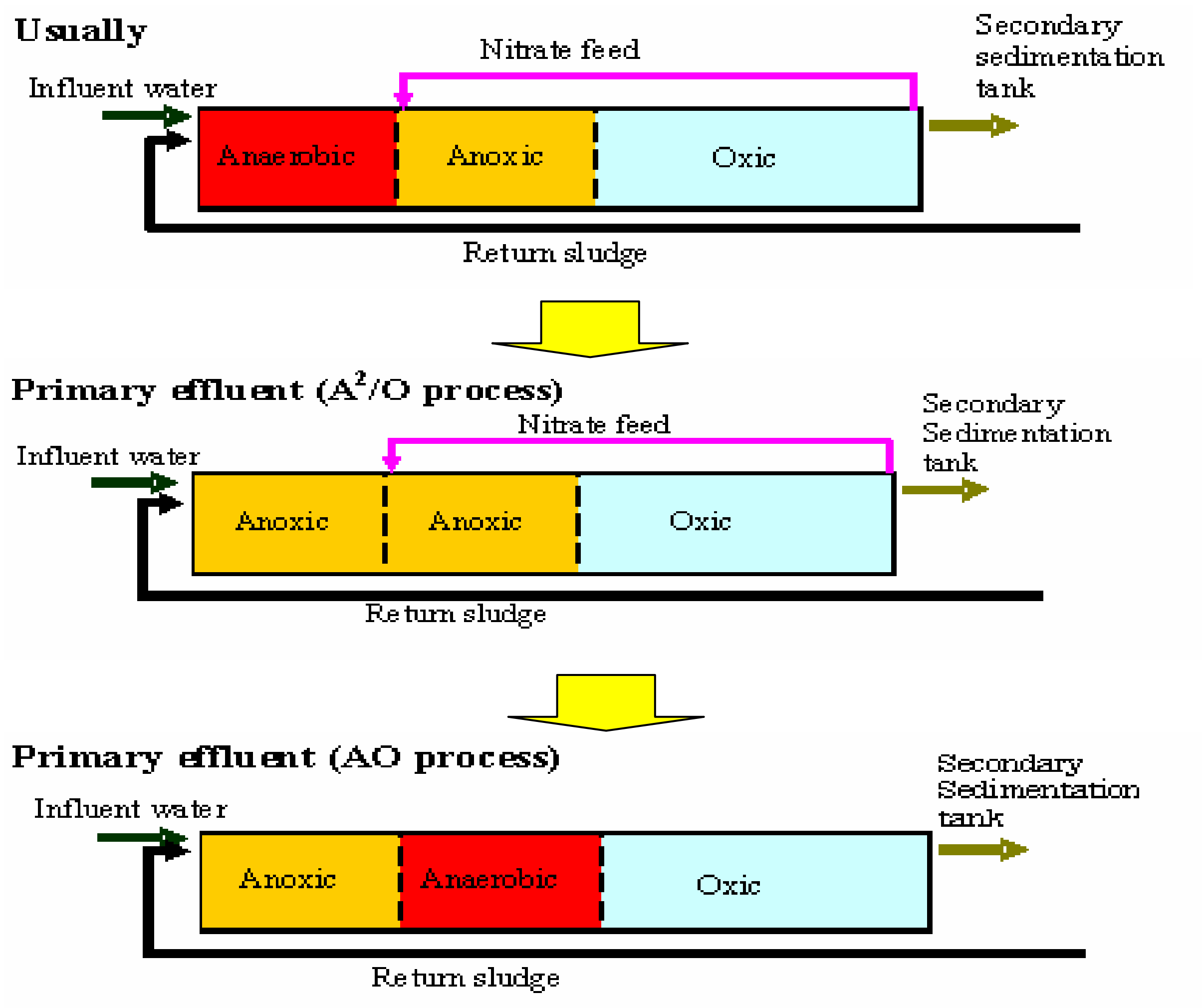


Figure18 Conditions of reaction tank for influent water and operation condition

CONCLUSIONS

As a result of these studies, we drew up a manual regarding effective operation and management of A^2/O process. Table6 shows conditions of operation under no influence of rainfall on influent water.

Phosphorus removal appears to be easy to unstable when treatment volume is much less than the capacity. That is because PHA in activated sludge is exhausted, if no ammonia nitrogen keeps remaining in treated water.

Therefore, in actual facilities, we determined that treatment water volume is as maximum as possible that satisfies perfect nitrification. If it is difficult to increase treatment water volume, we can restrict aeration and nitrification on the former part of the oxic tank.

Table7 shows conditions of operation and management at rainfall for reference.

Table6 Effective operation and management at no influence of rainfall

Heading	The most suitable operation	Standard of change of operation
Volume of treated water	Maximum treated water volume of finished nitrification	Institute from Temperature of influent
Rate of return sludge	About 15-25%	As little as possible(extent of phosphorus does not elute in secondary sedimentation tank)
Rate of nitrate feed	About 85-120%	Institute to check NO_3-N concentration in anoxic tank
MLSS in oxic tank	About 1,000～1,500mg/L	1,500mg/L in low temperature of influent
DO in oxic tank	About 1-3mg/L (Differ in facilities)	NH_4-N concentration in treated water is less than 1mg/L
NH_4-N concentration in oxic tank	About 0.5-1.0mg/L Average in a day	

Table7. Effective operation and management at influence of rainfall

Heading	The most suitable operation	Standard of change of operation
Volume of treated water	As greater as possible	Confirm secondary sedimentation tank
Rate of return sludge	Standard as about 15%	May fix minimum volume
Rate of nitrate feed	Same as usual	Do not change in usual rainfall
Bypass of primary sedimentation tank and thrown raw sludge	No enforcement	Increase of cost of management Effect is small if it does not execute it
Addition of PACl(Poly Aluminum Chioride)	Execute if in case of law violation	