NEW BIOLOGICAL PHOSPHORUS REMOVAL CONCEPT SUCCESSFULLY APPLIED IN A T-DITCH PROCESS WASTEWATER TREATMENT PLANT

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ABSTRACT

Luofang Wastewater Treatment Plant adopted a new concept of enhanced biological phosphorus removal in combination with a traditional Triple Ditch (T-Ditch) process to optimize the efficiency of biological phosphorus removal. The new concept included the addition of a thickener and anaerobic cell ahead of the T-Ditch system. Recorded data shows that the modified system is operating successfully with effluent which is much better than most T-Ditch systems. It also shows that it has better treatment efficiency than other complicated biological treatment processes with the same wastewater characteristics and same temperature conditions.

KEYWORDS

Organic Carbon, Nutrient Removal, Triple Ditch

INTRODUCTION

Luofang Wastewater Treatment Plant is located in Shenzhen, China. The original plant was built in 1995 utilizing a normal two-stage activated sludge (AB) process that was designed for 100,000 m^3/day of treatment capacity. The Modified University Cape Town (MUCT) process concept was used in the second stage of the two-stage system. In 1998, an additional 250,000 m^3/day of treatment capacity was added. The new plant expansion included a unique concept of enhanced biological phosphorus removal in combination with the traditional Triple Ditch process. Three years of operational data demonstrates the benefits of the enhanced recycle mode of operation and mixed liquor solids management.

METHODS

The Triple-Ditch, often referred to as a T-Ditch, is a three-ditch system that operates without separate clarifiers. It is the modified BioDenitro process developed by Tholander in the early 1970's (Tholander et al, 1976) as shown in Figure 1. The T-Ditch was initially developed to treat larger wastewater flow volumes that were not easily accomodated in vertical loop reactor ditch systems. The first and third oxidation ditches are designed to provide de-nitrification and settling by alternating the mode of operation. The middle ditch serves as a continuous aeration zone and provides flow distribution between the first and third ditch. The BioDenitro, T-Ditch process uses a two-phase, six-step operation and is schematically illustrated in Figure 1. The system is operated as a sequencing batch reaction process by internally moving the mixed liquor suspended solids between the outside ditches. Therefore, clarifiers are not required.

The T-Ditch system can be sized to provide a treatment capacity for the removal of carbon organics and nitrogen with nitrification and de-nitrification, but not enhanced biological phosphorus removal. To enhance the capability of biological phosphorus removal, the T-Ditch design was modified with a new concept of biological phosphorus removal (Yang, et al, 1999). Two Bio-P components were added to the front of the T-Ditch systems as shown in Figure 2. Mixed liquor recycle flows are constantly pumped from the bottom of each side-ditch near the openings, between the side-ditches and center ditch. The recycled flow is then directed to a sludge thickener. This process modification, shown in Figure 2, was part of the 1998 plant upgrade intended to achieve enhanced biological phosphorus removal.

Figure 1 - Triple Ditch System

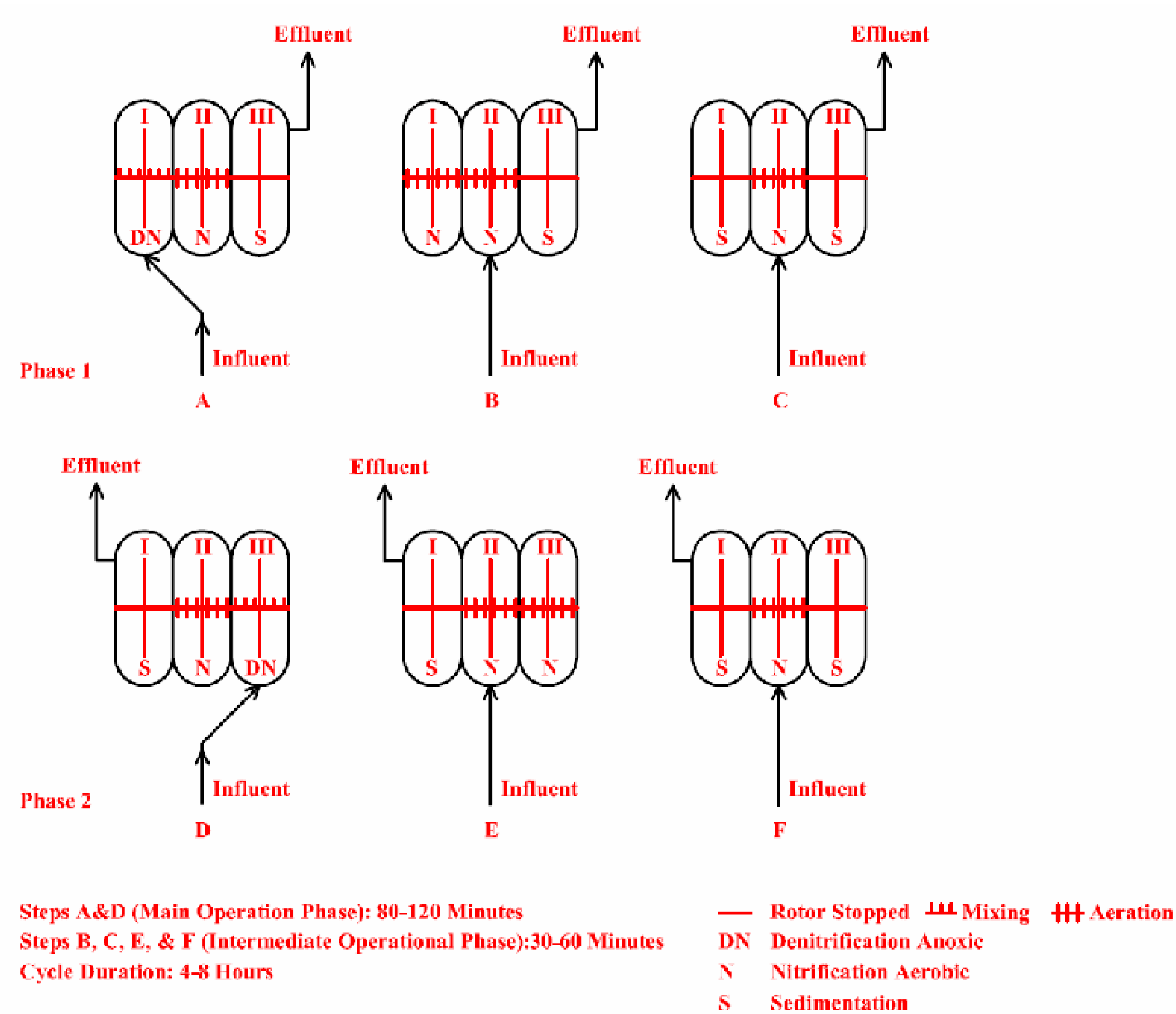
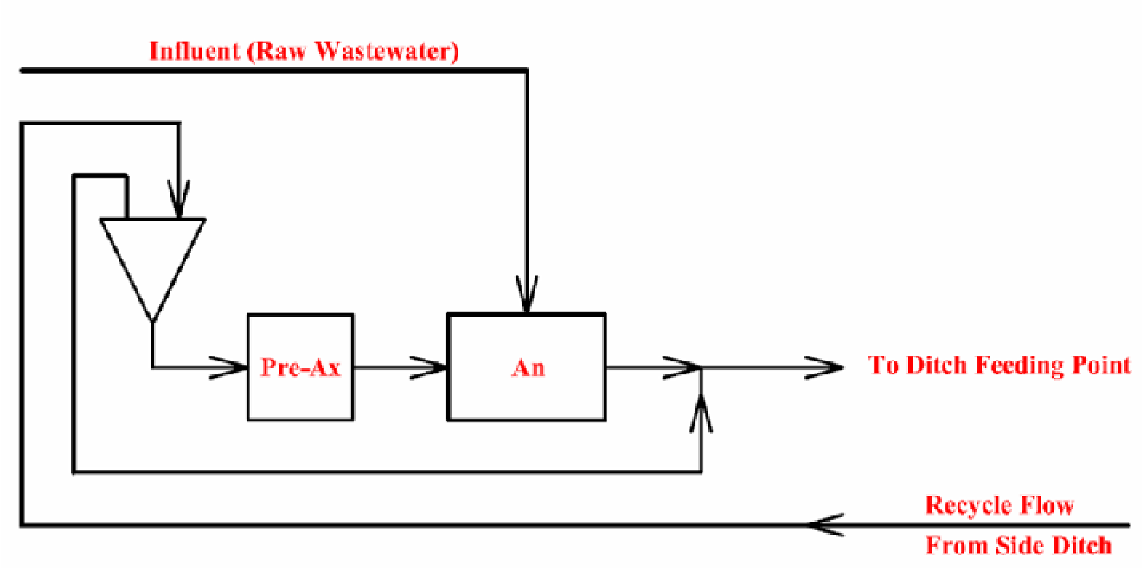


Figure 2 - Process for Enhanced Biological Phosphorus Removal



The sludge thickener is a rectangular tank with a total volume of 9515 m^3, which functions as a pre-de-nitrification zone. There is a sludge collector in the bottom of the tank with 14 sludge withdrawal pipes for sludge removal. The tank has a design detention time of 0.8 hours with a sludge loading rate of about 600 kg/m^2/day. Half of the recycled flow is pumped to the anaerobic cell through the sludge blanket as concentrated return sludge. The other half, as supernatant, is returned directly to the feeding point of the subsequent T-Ditches. The influent raw wastewater is added to the anaerobic cell where it undergoes anaerobic metabolism with the formation of short chain volatile fatty acids (VFA) as end products. The design hydraulic detention time for the anaerobic cell is about 0.65 hours with a mixed liquor suspended solids concentration of 2,800 mg/L. The concentrated sludge, after denitrifying in the thickener sludge blanket, goes to the anaerobic cell and is mixed with the raw wastewater for the release of phosphorus. Normal facultative bacteria cannot metabolize the primary short chain fatty acids such as acetic acid, therefore, allowing the acids to accumulate in the anaerobic cell. Certain bacteria designated as "phosphate removing bacteria" or Bio-P bacteria, have the ability to utilize acetic acid for cell synthesis while releasing stored phosphate contained in the cell as polyphosphate. Growth of the phosphate removing bacteria under anaerobic conditions produces a significant increase in microbial cell population with excess acetic acid stored inside the cells as a poly-β-hydroxybutyrate (PHB) acid polymer. Two Bio-P components with sludge thickeners, anaerobic cells and four T-Ditch systems were built and designed to process a total flow of 250,000 m^3/day.

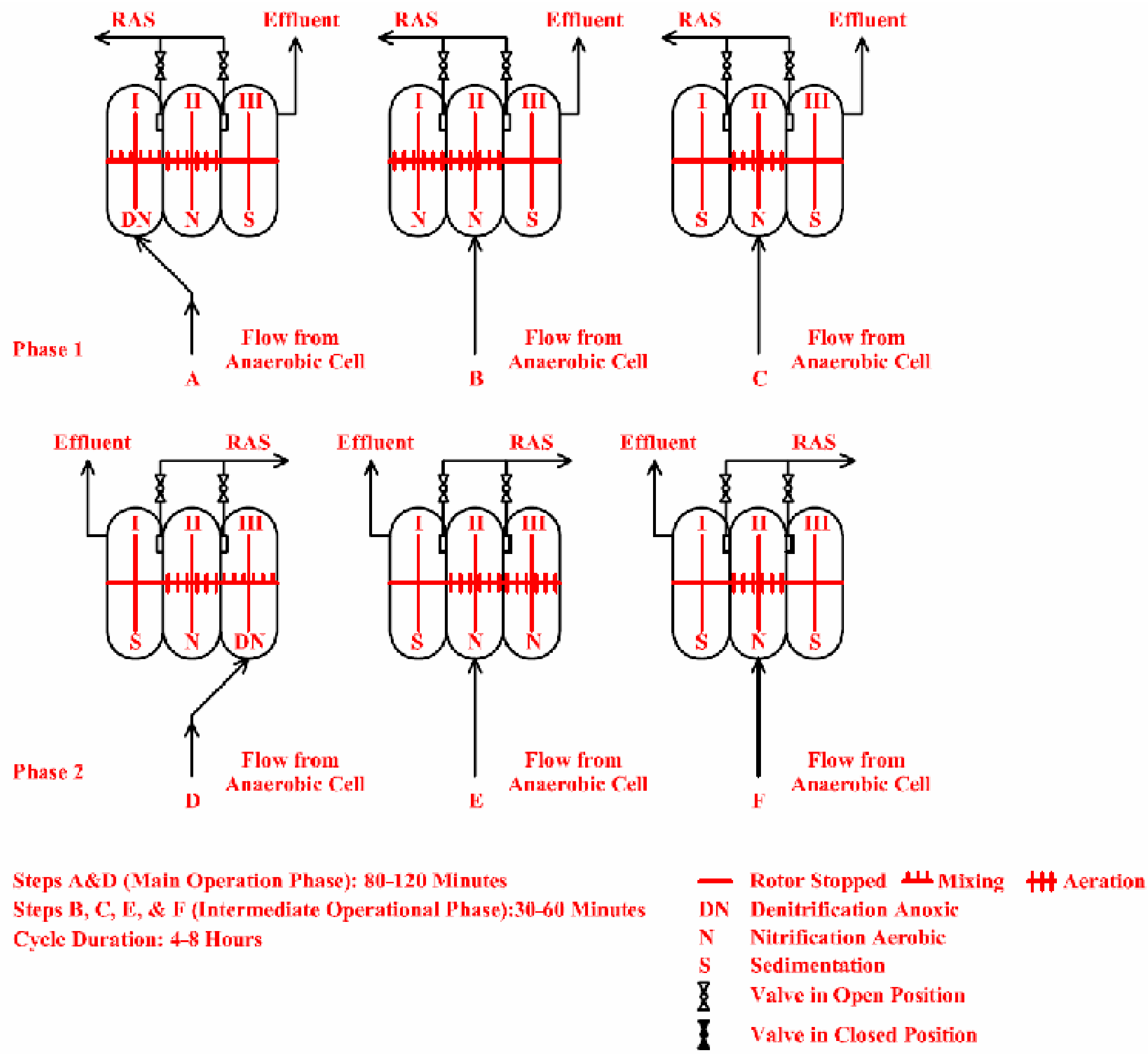
The flow rate from the sludge thickener to the anaerobic cell is kept to a minimum, typically less than half of the raw wastewater flow rate; this allows an increase in the de-nitrification reaction in the sludge blanket of the thickener. It also helps to maintain the desired anaerobic conditions in the anaerobic cell, as well as a high concentration of short chain VFAs. The thickened sludge at the bottom of the sludge blanket helps to maintain the complete removal of DO and oxidized forms of nitrogen in the return sludge from the alternating cell of the T-Ditch. Sludge thickening allows a sufficient amount of activated sludge to enter the anaerobic cell without a large amount of fluid. Minimizing the fluid flow avoids dilution of the VFAs in the anaerobic cell and a reduction of the actual anaerobic retention time.

The mixed liquor of the anaerobic cell is then combined with the supernatant flow to the T-Ditch system for de-nitrification, organic carbon removal, nitrification, settling and discharge as shown in Figure 3. Four T-Ditch systems were built in the plant for handling a total of 250,000 m3/day of the design flow. Each system contains 28 brush style aerators and 16 underwater mixers. The design hydraulic detention is 15.2 hours. The design average MLSS is 4000 mg/L with a sludge age of 11 days. The system discharge is controlled by mechanical weirs.

As shown in Figure 3, the middle ditch operates as a continuous aeration cell while the side -ditches operate in a sequence of mixing, aeration, and settling phases. The mixed flow from the Bio-P component, as shown in Figure 2, is fed to a side-ditch with a mixing condition as a first step of the sequence for denitrifying the oxidized nitrogen. The middle ditch aerates the flow as it passes to the settling ditch on the opposite side. The system then progresses to the second step by shifting the influent to the middle ditch while the side-ditch starts the extended aeration step before it advances to the pre-settling step. After the pre-settling step, the system starts its second phase while the two side-ditches exchange their operational mode. The recycle flow is continuously pumped to the Bio-P component from each side cell during the preceding steps.

During the first step of operation, the effluent from the anaerobic cell provides an organic carbon source to feed the side-ditch which is being mechanically mixed. This allows the nitrates and nitrites present in the mixed liquor that was displaced from the aeration cell to be reduced by de-nitrification to nitrogen gas. The mixed liquor flowing through the side-ditch during the biological reaction step is transferred to the center ditch for aeration. A partial recycle stream is returned to the Bio-P system at the side-ditch transfer point typically having a higher suspended solids concentration.

Figure 3 - Modified T-Ditch System with Return Activated Sludge Control



Aeration in the reaction side-ditch and middle aeration ditch supplies oxygen for microbial metabolism of the wastewater organic compounds and nitrification, as well as the turbulence for complete mixing within the cell. When the microbial mixture moves into the aeration cell, the facultative bacteria metabolize the carbonaceous organic compounds and the ammonia-nitrogen compounds are oxidized. In the presence of excess DO or nitrified nitrogen sources, the Bio-P bacteria metabolize the stored poly-β-hydroxybutyrate (PHB) acid polymer while taking up the excess soluble phosphorus and converting it to a polyphosphate polymer inside the cell. The Bio-P organisms metabolize the stored PHB and accomplish enhanced phosphorus uptake in the aeration cell.

The aerated mixed liquor is passed on to the companion side-ditch acting as a clarifier through the bottom transfer points. The supernatant of the side-ditch in a sedimentation mode is discharged as final effluent with the displacement of the mixed liquor from the aeration middle ditch. Excess sludge is removed from the side-ditch in the sedimentation mode by gravity or waste activated sludge (WAS) pumps. A better solids balance is created in the system by maintaining more solids in the middle aeration cell as compared to a conventional T-Ditch system without the Bio-P recycle. Subsequently, a lower solids level results in a reduced depth of the sludge blanket in the side-ditch, producing a better supernatant to be discharged from each side-ditch with lower suspended solids.

RESULTS AND DISCUSSION

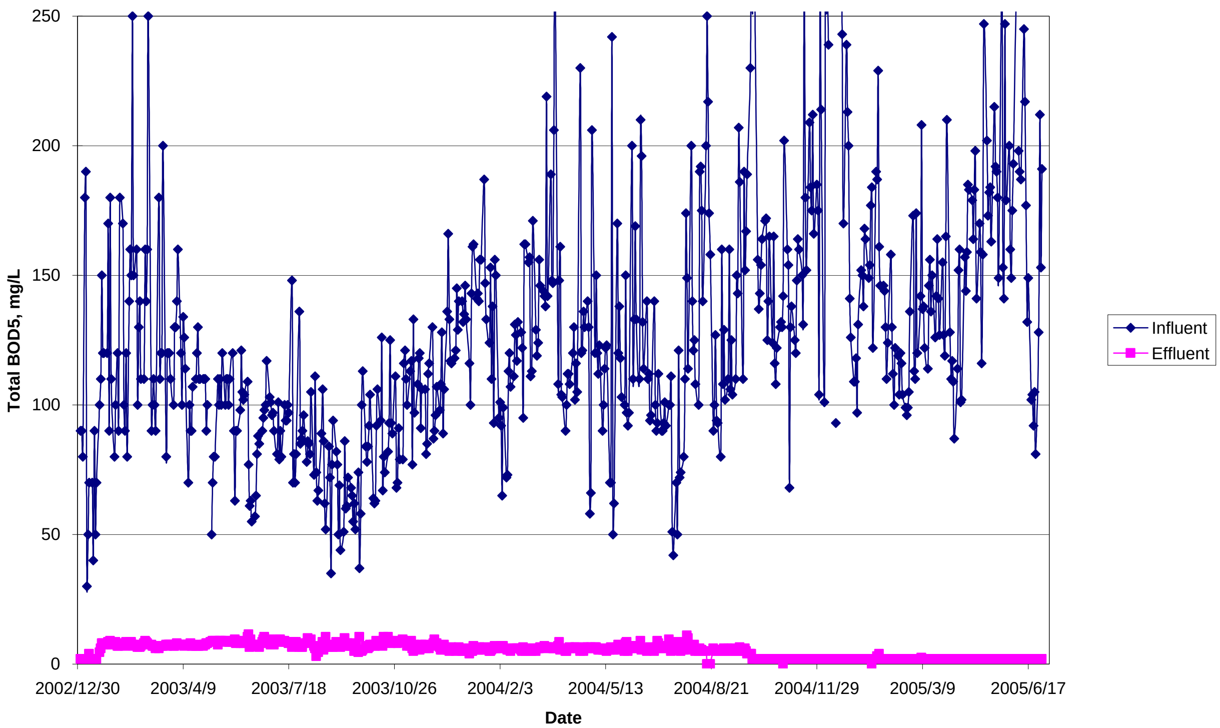
The expanded portion of the plant with the modified T-Ditch systems has been successfully operating since 1998. Currently, the new system can treats 130,000 m^3/day wastewater with two thickener and two anaerobic cells, as well as two modified T-Ditch systems. The other two T-Ditch systems are temporarily out of service. The actual operational detention times are as follows: 1.5 hours for the sludge thickeners, 1.2 hours for the anaerobic cells, and 14 hours for the T-Ditch systems. The process performance from January 1, 2003 to June 30, 2005 is summarized in Table 1. The table includes both the effluent data from the new modified T-Ditch (M-T-Ditch) and the data collected from the old AB Process plus MUCT process (AB+MUCT).

Table 1 - Three Years Operation Data, 2003-2005

	Influent Average (mg/l)	Effluent Average M-T-Ditch (mg/l)	Effluent Average AB + MUCT (mg/l)	%Removal M-T-Ditch	%Removal AB + MUCT
BOD_5	130	5	7	96	94
TSS	180	5	7	97	96
COD	240	17	21	93	91
TN	25	7.4	12	70	52
NH_3-N	14	0.3	2.4	98	83
TP	3.0	0.3	0.5	90	83

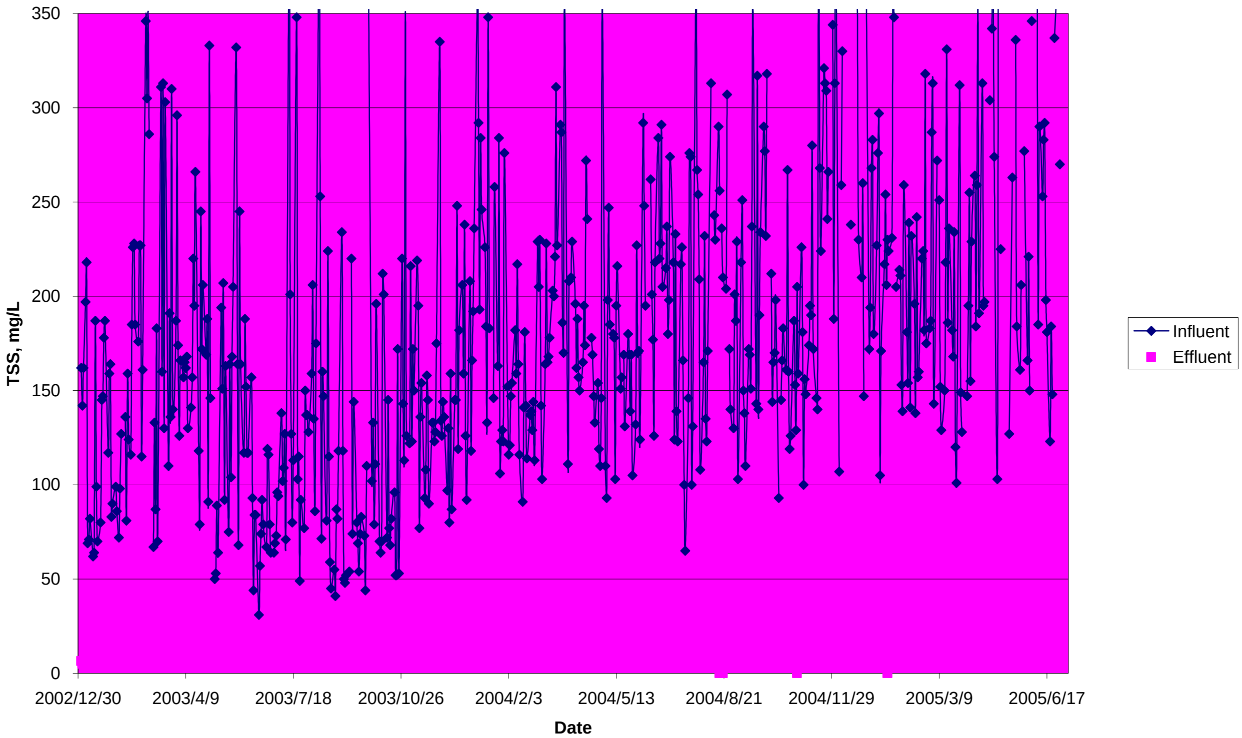
The influent and effluent BOD_5 are plotted in Figure 4. The influent BOD_5 ranged from 35 mg/L to 350 mg/L, while the effluent was constantly below 10 mg/L. The data showed that the influent BOD_5 increased during the year 2004, while the effluent BOD_5 decreased to below 2 mg/L, indicating an improvement of the treatment efficiency. The effluent BOD_5 averaged 5 mg/L with a standard deviation of 2.5 mg/L for the sample period, indicating an average of 96 percent removal efficiency.

Figure 4 - Influent and Effluent BOD_5



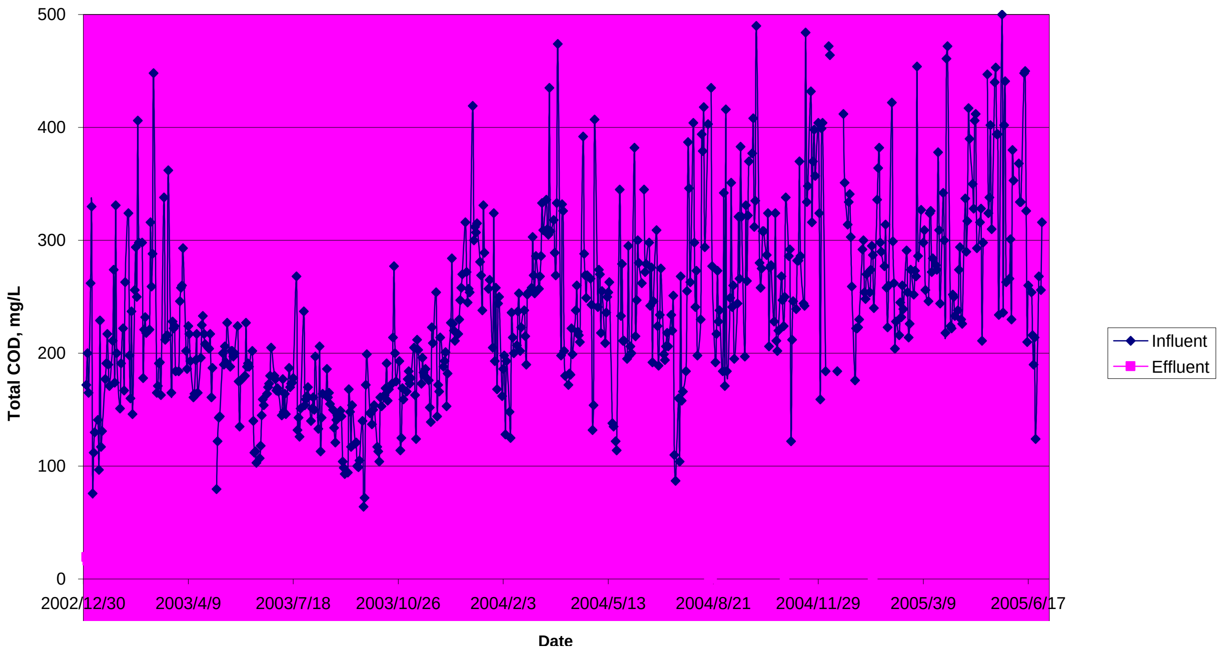
The influent TSS varied significantly during the two and a half year sample period as indicated in Figure 5. The maximum incoming TSS was about 450 mg/L, while the minimum influent TSS was at 40 mg/L. The influent TSS averaged 180 mg/L with a standard deviation of 80 mg/L, showing the large variation of the influent suspended solids. The system effluent TSS was maintained at 5 mg/L with a standard deviation of only 1.5 mg/L.

Figure 5 - Influent and Effluent TSS



The influent and effluent COD data is shown in Figure 6. The data sample shows that the influent COD had an increase similar to the influent BOD_5 during the sample period. It increased from 150 mg/L to 250 mg/L. The effluent COD however, was maintained below 20 mg/L averaging 17 mg/L with a standard deviation of 4 mg/L.

Figure 6 - Influent and Effluent COD



The influent and effluent total nitrogen data is shown in Figure 7 and the ammonia-nitrogen data is shown in Figure 8. The influent total nitrogen ranged between 8 mg/L and 48 mg/L, while the effluent total nitrogen typically was below 10 mg/L. The influent total nitrogen averaged 25 mg/L with a standard deviation of 6.5 mg/L. The effluent total nitrogen averaged 7.5 mg/L with a standard deviation of 3 mg/L, indicating the effluent total nitrogen was very stable. The influent ammonia-nitrogen had a variation similar to the total nitrogen while the effluent ammonia-nitrogen was very low. The average effluent ammonia-nitrogen was below 0.3 mg/L for the sample period with a standard deviation of 0.3 mg/L.

Figure 7 - Influent and Effluent Total Nitrogen

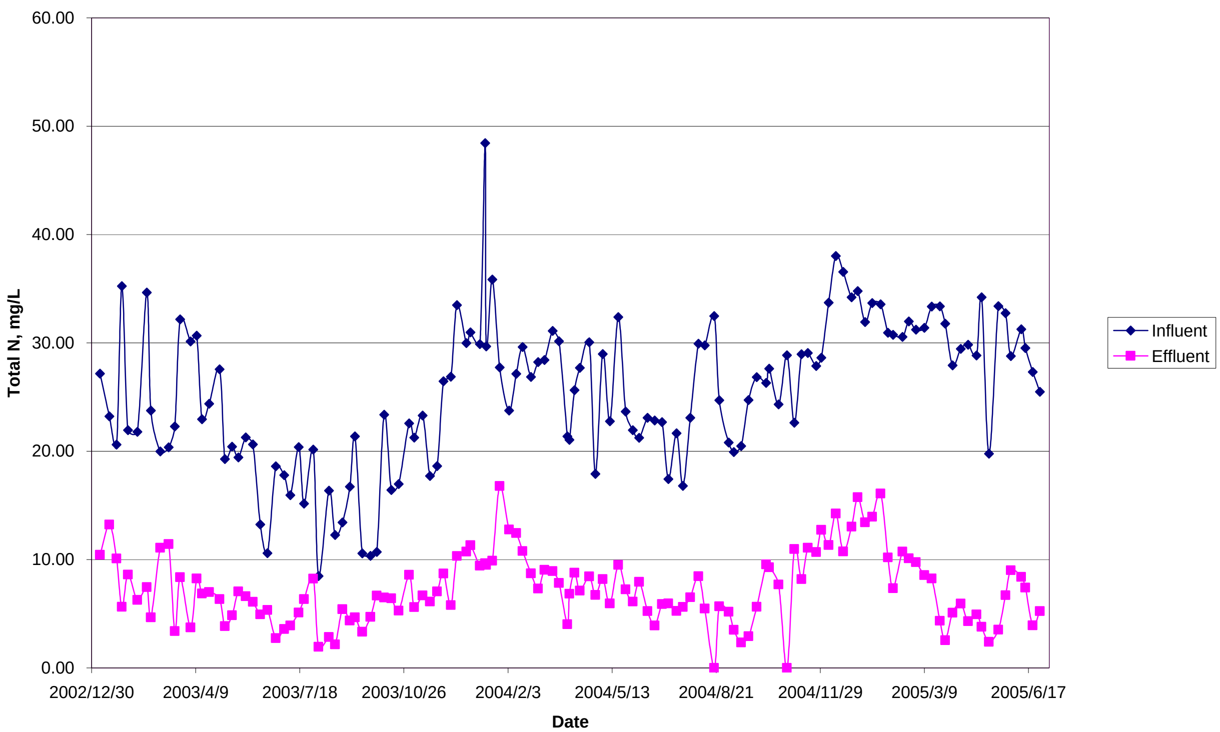
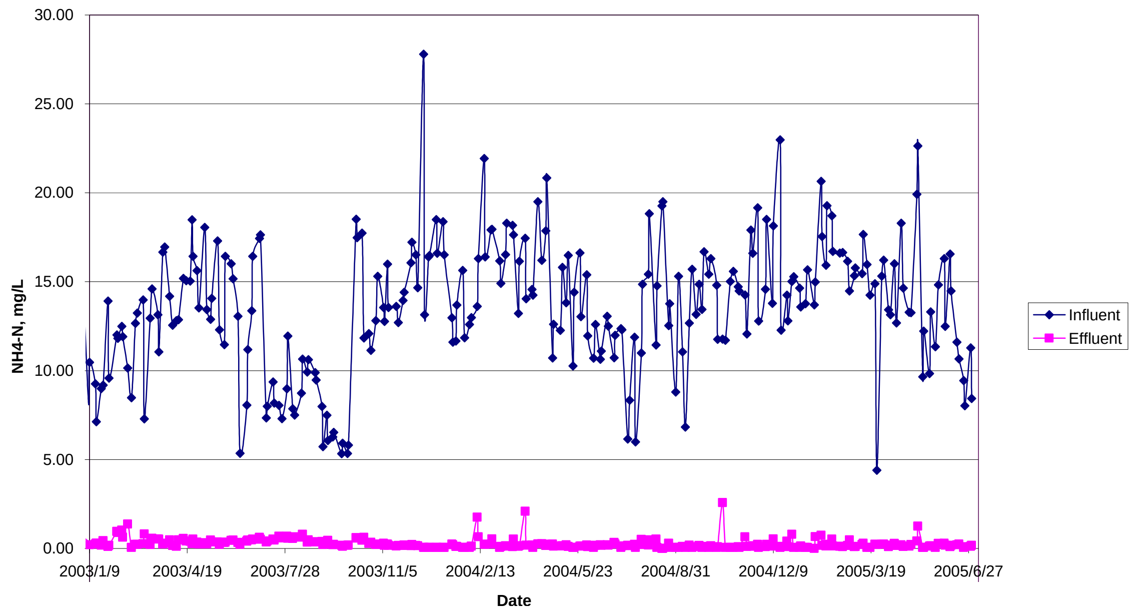
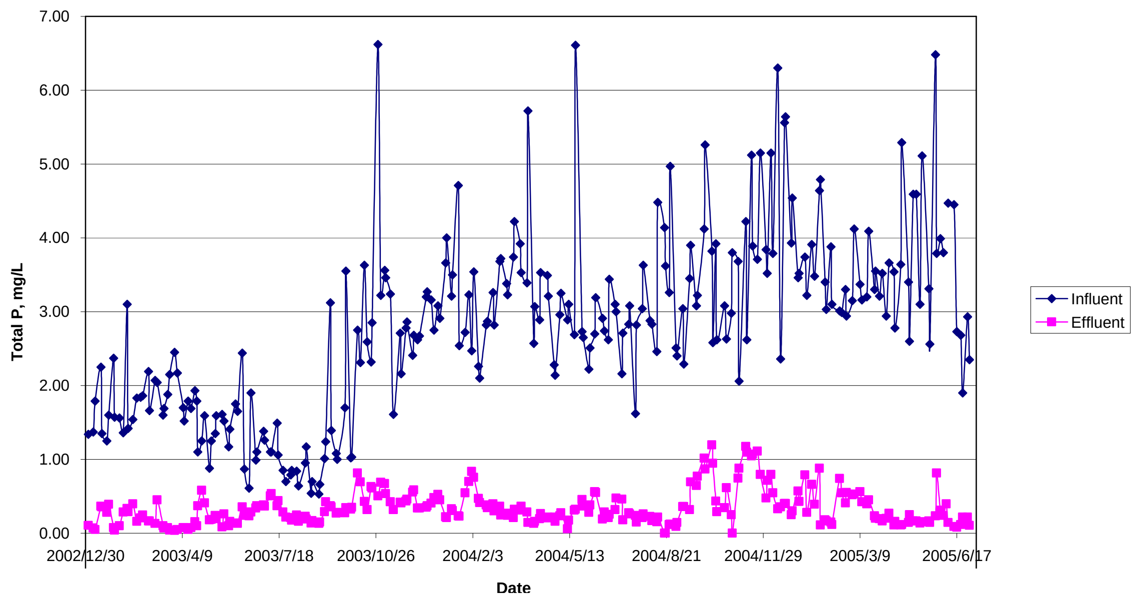


Figure 8 - Influent and Effluent NH4-N



Influent total phosphorus concentration also increased during the sample period as shown in Figure 9. It increased from 2 mg/L to about 3.5 mg/L. During the last 12 month period, the effluent total phosphorus was below 1.0 mg/L, with most of the data below 0.5 mg/L. The average effluent total phosphorus was about 0.3 mg/L with a standard deviation of 0.2 mg/L, a clear indication of a stable low effluent total phosphorus discharge.

Figure 9 - Influent and Effluent Total Phosphorus



The data supports an improved biological nutrient removal capability often not achieved by a standard T-Ditch configuration (EPA, 1993; WEF, 1993) especially for total phosphorus removal. While most existing T-Ditch systems had effluent BOD_5 and TSS values above 20 mg/L, this modified system has reduced these parameters to a 5 mg/L level. The effluent ammonia-nitrogen discharged from most existing T-Ditch systems was at 5 mg/L or higher, while the effluent total phosphorus data is all above 3 mg/L. This modified system has decreased both the ammonia-nitrogen and total phosphorus discharge levels to 0.3 mg/L, less than 10% of comparable discharges from a standard T-Ditch system.

As indicated in Table 1, all the data indicates that the modified T-Ditch system has demonstrated better effluent quality than the complicated AB plus MUCT two-stage systems when both systems were fed exactly the same wastewater at the exact same operational temperature. The effluent total phosphorus from the new process was about 40 percent lower than the AB plus MUCT two-stage system.

With the addition of simple recycles to the system, more solids have been moved to the center ditch. A higher population of microorganisms in the center ditch with continuous aeration increases the overall reaction rates, especially for nitrification and phosphorus uptake, allowing the system to produce a stable high quality effluent. The higher reaction rates also provide more endogenous respiration by the organisms, producing a stable sludge condition. The anaerobic condition in the anaerobic cell prevents the growth of filamentous bacteria, which creates a better microorganism population and better sludge settling capability. The lower solids quantity in the side clarifying ditch produces a deeper supernatant layer in the discharging ditch, and allows a high quality effluent to be discharged from the system.

One of the key design aspects is the return sludge thickener, which plays a very important role in phosphorus removal within the system. Existing biological phosphorus removal processes have a high anaerobic recycle rate. Recycle flows that contain no readily biodegradable organic carbon source will dilute the carbonaceous organic concentration and VFA concentration in the anaerobic cell. A 1.0Q recycle means the available VFA and readily biodegradable organic carbon (RBCOD) in the anaerobic cell are reduced by one half. In the developed sludge thickener concept, the recycle flow to the anaerobic cell is decreased to 0.5Q. This means, the VFA dilution caused by the recycle is about 25 %. By reducing the dilution factor, the VFA concentration in the anaerobic cell will increase by 33% as compared with a 1.0Q anaerobic recycle system.

The conversion of biodegradable COD is dependent on the population of heterotrophic organisms and the hydraulic retention time, which is the actual retention time based on the combination of raw wastewater flow and recycled flow through the anaerobic cell. It requires a minimum recycle flow to maximize the actual hydraulic retention time (HRT).

With the reduced recycle flow, the recycle flow to the anaerobic cell drops from 1.0Q to 0.5Q. The total flow through the anaerobic cell is decreased from 2.0Q to 1.5Q. This will increase the actual HRT by 33% for the anaerobic cell. The longer anaerobic HRT allows heterotrophic bacteria to convert more non-VFA RBCOD to VFAs through acid fermentation. The increase of VFA concentration enhances the poly-ß-hydroxybutyrate (PHB) storage for the Bio-P bacteria.

This in turn, creates a higher driving force for phosphorus uptake in the following aerobic reaction. In addition, the maximum hydraulic retention time created by the minimum recycle flow provides the Bio-P bacteria more opportunity to absorb the VFA and convert it to PHB.

All of the above factors provide the basis for determining that this modified system, with a new concept of incorporating a sludge thickener in the recycle stream, is capable of achieving improved treatment efficiency. Effluent quality is superior to that of traditional T-Ditch systems and many other processes. The treatment results have demonstrated the superior advantages of this new concept.

CONCLUSION

The data shows that the modified system with the Bio-P components has operated very successfully with excellent effluent, much better than most T-Ditch systems. It also shows that it has better treatment efficiency than other complicated biological treatment processes with the same wastewater and same temperature conditions. It indicates that the concept used in this design is working properly for the plant, especially for its biological nutrient removal. This concept has also been successfully used in the other biological nutrient removal systems such as the Aqua MSBR® system (Yang, et al., 2004). It is sincerely believed that this concept could be successfully used in many other biological nutrient removal systems to improve performance.

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