Optimization of a Cyclic Activated Sludge Technology Process for Organic Matters Oxidization & NH_3-N Removal in Town Sewage Treatment Plant

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Philosophy

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ABSTRACT

In recent years, water pollution incidents have frequently occurred in various parts of China. For example, surface water bodies such as Taihu Lake in Wuxi, Dianchi Lake in Yunnan, Chaohu Lake in Anhui, have experienced serious outbreaks of eutrophication, massive algal blooms and cyanobacteria crisis. Sewage treatment plants with the promulgation of a series of environmental policies from government are faced with more stringent discharge standards and requirements.

The Cyclic Activated Sludge Technology (CAST) has been applied in the municipal wastewater treatment plants in the city of Wuxi. This study investigates the concurrent removal of organics, nitrogen and phosphorus in municipal sewage by the CAST process. The aim of this study is optimization of the CAST process for organic matters oxidization and NH_3-N removal in town sewage treatment plant. The general process of CAST has the ability to remove organic matters, nitrogen and phosphor. However, when the facilities achieved a high level of nitrogen removal, filamentous sludge bulking would be a common problem and the removal efficiency would be limited. This thesis aims to develop a novel CAST process to optimize CAST reaction operation and the DO control during aeration period and finally culture a stronger activated sludge. And also, the removal efficiency of organic matters and ammonia nitrogen would be greatly enhanced to mitigate the eutrophication of Taihu Lake in treating high nitrogen concentration wastewater. The full-scale study of the organic and nitrogen removal was carried out in a Sewage Treatment Plant in Wuxi near Taihu Lake. The optimum operation cycle was concluded and also the other operation strategy. Results showed that the CAST process was capable of removing organic matter, Suspended Solid (SS), and Total Phosphorous (TP) with high removal efficiencies (up to 85%). However, the removal of nitrogen and non-biodegradable organic substances were not as satisfactory.

The residual Chemical Oxygen Demand (COD) concentration in effluent had an obvious relationship with the effectiveness of the prior anaerobic process, and could be reduced to as low as 50 mg/L by incorporating coagulation and sedimentation units to the CAST process. In addition, a number of operating conditions had been found to be as important factors of achieving favorable nitrification and the significant increase of ammonia nitrogen removal rates (up to 95%). These conditions include: the DO concentration which was controlled below 0.5 mg/L during first 30 minutes of the inflow/aeration stage, 2.0～4.0 mg/L during pure aeration, and had the DO level guaranteed above 2.5 mg/L for at least 20 minutes at the end of aeration stage.

Under specific operating conditions, sludge return ratio set at more than 20% and with proper DO concentration gradient between anoxic zone and aerobic zone of CAST system, have also been found to be as factors of achieving the synergistic effect of Simultaneous Nitrification and De-nitrification and Sequential Nitrification and

De-nitrification, and increasing Total Nitrogen removal rates up to 60%. These conditions were: the DO concentration was controlled below 0.5 mg/L during first 30 minutes of the inflow/aeration stage, 2.0～3.0 mg/L during pure aeration stage, and the DO concentration was maintained below 0.5 mg/L in anoxic zone during the whole process.

In conclusion of this study, the essential operating parameters of the advanced CAST process were successfully optimized: the organic matters oxidization and NH_3-N removal rate were increased and the sludge bulking condition was well controlled and final the effluent from town sewage treatment plant was successfully met the stringent discharge standards, without having the process hardware upgraded. The results also show that the CAST could be also modified for treating the influent of high nitrogen loading and fluctuating conditions.

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LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
AOR	*Actual Oxygen Required*
BAF	*Biological Aerated Filter*
BOD/BOD$_5$	*Biochemical Oxygen Demand (5 days)*
CAST	*Cyclic Activated Sludge Technology*
COD	*Chemical Oxygen Demand (Potassium Dichromate Method)*
EBPR	*enhanced biological phosphorus removal*
MLSS	*Mixed Liquor Suspended Solids*
MLVSS	*Mixed Liquor Volatile Suspended Solids*
PAC	*Polyaluminiu Chloride*
PAM	*Polyacrylamide*
PFAC	*Polymeric Ferric Aluminum Chloride*
PFS	*Polymeric Ferric Sulfate*
SND	*Simultaneous Nitrification and De-nitrification*
SOR	*Standard Oxygen Required*
SQND	*Sequential Nitrification and De-nitrification*
SVI	*Sludge Volume Index*

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, water pollution incidents have frequently occurred in China. For example, Taihu Lake in Wuxi, Dianchi Lake in Yunnan, and Chaohu Lake in Anhui, have experienced serious outbreaks of *cyanobacteria*. Taihu Lake is located in the eastern coast of China, a densely populated and highly industrialized region. In the past twenty years, the lake has been subjected to increasing pressure from various interlinked human activities, including industrial pollution, fertilizer and pesticide application and eutrophication, among others (Bi & Liu, 2004). In fact, the water quality of Taihu Lake has sharply deteriorated. Past and current policies and measures have been reviewed, after which new policy options have been proposed (Wang, *et al*, 2009; Wang *et al.*, 2004). These include improving the fishery management, strengthening cross-provincial collaboration, initiating efforts to reduce flood disaster, and increasing investments on new environmental protection technologies. The Jiangsu Provincial government launched the “Comprehensive Management of the Water Environment in Taihu Lake Basin Implementation Plan” to implement water pollution control. The aim of this project is to increase the emission targets of chemical oxygen demand (COD) and gradually include ammonia nitrogen and total phosphorus emission targets. In the past, the government focused on COD. Currently, total phosphorus and total nitrogen are also becoming major concerns because they are the key indicators of the occurrence of blue algae outbreak. Therefore, with the promulgation of a series of environmental policies from the government, sewage treatment plants in the Taihu Lake Basin face stricter discharge standards.

1.2 Introduction of the Project

The Cyclic Activated Sludge Technology (CAST) has been applied to a number of municipal wastewater treatment plants in Taihu Lake Basin. The full-scale study of the optimization of organic matter oxidization and ammonia nitrogen removal has been carried out in a sewage treatment plant in Wuxi. Results demonstrated the capability of CAST to remove organic matter, suspended solid (SS), and total phosphorous (TP), with a high removal efficiency of up to 85%. However, the removal of nitrogen and non-biodegradable organic substances are not as satisfactory.

The trial operation of the current research was worked out in a sewage treatment plant, which adopted the process of anaerobic hydrolysis plus CAST. The main effluent quality of the plant fulfilled the first class discharge standard of "Wastewater Discharge Standards" (GB 18918-2002). Occasionally, however, fluctuations of effluent quality and the problems of low ammonia nitrogen removal efficiency occur. The continuous deterioration of the water quality of Taihu Lake triggers the proliferation of *cyanobacteria*. Water quality control and governance measures for this watershed have been enacted to address the issue. Owing to the gravity of the situation, these measures have attracted significant attention from the local and central governments. To control the situation of eutrophication and ensure the quality of drinking water from the intake points of Taihu Lake, sewage treatment plants in the Taihu Lake valley should improve its organic and ammonia nitrogen removal efficiency to adhere to the new discharge regulation of “Water Pollutant Discharge Limits for Urban Sewage Treatment Plants and Industries in the Taihu Region” (local standard of Jiangsu Province, DB32/1072-2007). This was jointly promulgated by Jiangsu Environmental Protection Bureau and Jiangsu Quality and Technical Supervision Bureau on July 8, 2007.

The municipal sewage characteristics and pollutant components of China are different compared with other countries. Thus, the application of CAST technology is still in the exploratory stage and learning from the mature experience of other countries is difficult. Therefore, in combination with the actual situation of sewage treatment plant with CAST technology, a series of tests at the site has been carried out. The purpose of these tests is to strengthen and further improve the organic and ammonia nitrogen removal efficiency by optimizing the process parameters, in accordance with different water loadings, but without the need for extra wastewater treatment unit and energy consumption.

Through nearly two years of trials and studies, the running performance of the wastewater treatment plant has been greatly improved, despite the absence of a new processing unit. Indicators of the effluent water pollutants have shown values that are extremely close to the new discharge standards requirements. Nevertheless, a relatively high COD concentration of influent and the original design flaws of the anaerobic unit resulted in the inability to maintain stable COD concentration of effluent below 50 mg which is required to meet the new discharge standards. On this basis, coagulation and precipitation jar tests have been separately carried out using the end waters from anaerobic tank and CAST tank. Adequate experimental data show that the sewage treatment plant can ensure that the quality of its effluent water meets the new discharge standards of DB32/1072-2007. This has been achieved by bringing extra coagulation-precipitation-filtration units into the existing CAST unit but without new biological treatment processes.

The learning and studying process has allowed for the exploration and accumulation of successful experiences. These experiences could be referenced for the long-term stable operation of other CAST sewage treatment plants in China and may provide scientific reference and theoretical bases for the promotion and application of CAST technology in Mainland China. Specifically, the experiences can be applied to CAST sewage treatment plants faced with the need to start improving water treatment performance as required by the more stringent wastewater discharge standard.

1.3 Introduction of the Main Process－CAST

Activated sludge process is very effective in treating wastewaters and is widely used all over the world (Matsuo and Kurisu, 2001). From the handbooks of UK wastewater practice (1997), the activated-sludge process is referred to as a method of treating sewage and other biodegradable wastewaters by aerating and agitating the liquid in admixture with activated sludge (mixed liquor), and subsequently separating it from the treated effluent by settlement. Most of the separated sludge is recycled. The excess is removed for disposal as surplus activated sludge. Sequencing batch reactor (SBR) is mainly used based on the activated sludge system. The present SBR technology has been developed by Irvine and Goronzy in the U.S. and Australia (Silverstein and Schroeder, 1983).

Many modified SBR processes are emerging. One of these is CAST, an improved process which has a broader application. It has taken only 20 years to create SBR. Since then, this technology has greatly improved and has become popular due to its simple structure and convenient control system. A common CAST reactor consists of a simple structure, in which the process of aeration, sedimentation, and drainage can be continuously and dynamically finished in a variable volume reactor in front of which the biological selector is set. The design of the biological selector should strictly follow the theory of "matrix accumulation and regeneration" of the activated sludge. Suitable conditions for the growth of microorganisms are created to make the activated sludge go through a high-load of absorption phase (matrix accumulation) in the biological selector and the subsequent lower-loading of matrix degradation phase in the main reaction zone (Goronszy, *et al*., 1996). The entire process of matrix degradation and sludge regeneration are completed after the two phases. A reasonably designed biological selector can effectively inhibit the growth of filamentous bacteria, overcome sludge bulking, and improve the stability of the system. Meanwhile, phosphorus can be fully and effectively released in the biological selector at the same time as demonstrated by Goronszy *et al*. (1996).

In a typical CAST system, the activated sludge returned from the main reaction zone mixes and contacts with the effluent in the biological selector. The activated sludge periodically experiences the high organic loading in biological selector and low organic loading in main reaction zone. Small particles of sludge that are capable of flocculability are easily formed after the two phases. This kind of sludge can adsorb considerable amounts of organic matters because of its large surface area. By providing the environment with an appropriate dissolved oxygen (DO) level in the main reaction zone, the oxic and anoxic conditions can be formed from the surface to the interior of the microbial flocs with the reduced environment of dissolved oxygen gradient. As a result, nitrification and denitrification processes can be simultaneously achieved in the surface and the interior of the microbial flocs. Thus, achieving a good nitrogen removal rate is possible.

Simultaneous nitrification and denitrification (SND) is one of the main theories of CAST process. Different micro-environments are separately formed in the internal, center, and outside areas of zoogloeas, which are conducive to SND and phosphorus removal. On the other hand, process control for DO level is important for the CAST system. The ideal DO concentration control curve for the aeration tank is one in which DO concentration is controlled below 0.5 mg/L, and the small oxygen environment is formed in the first 1.5

hours of the inflow/aeration stage. In addition, DO concentration can only be controlled to above 2.0 mg/L in the final aeration stage. The results of SND may be achieved during the previous condition, in which the amount of oxygen is slight.

Compared with the completed sequential nitrification and denitrification (SQND), the SND has the following advantages: 25% reduction of oxygen demand during nitrification stage, lower energy consumption, 40% reduction of organic carbon source demand during denitrification stage, lowered operation costs, 30%–40% reduction of the volume of reaction through the shorter reaction time, faster denitrification reaction rate brought about by the fact that the denitrification reaction rate of nitrite is higher than that of nitrate by about 63%, 55% reduction of sludge production during the nitrification process, and lower alkalinity demand (Zhang *et al*, 2004).

1.4 Objectives

Considering the experimental research, design, and the operation experiences from several municipal wastewater treatment plants that apply CAST in Mainland China, several sections of the CAST process must be optimized based on the new regulation formulated for the Taihu Lake basin. First, in order to meet the stricter discharge standards, the removal efficiency of organic matters and ammonia nitrogen should be improved. Additionally, most of the operation settings in traditional sewage treatment plant using CAST are based on the old handbook. Practical knowledge as regards the new standard is lacking. This may cause energy wastage due to over treatment of the sewage or the disqualification of effluent because of insufficient treatment. At the same time, additional sewage treatment units or tanks designed for use after the CAST process are absent in the traditional sewage treatment plants. Therefore, it is uncertain whether or not the effluent from CAST tank can fully conform to the new discharged standards. As a result, it is also uncertain whether or not the town sewage treatment plant can legally discharge the effluent into the water body. Auditioned coagulation-precipitation-filtration units might be the solution.

1.4.1 General Objective

Based on the above considerations, the general objective of this study is to improve the performance of organic matters oxidization and NH_3-N removal in town sewage treatment plant with CAST process which could help the municipal wastewater treatment plants to successfully meet the stringent discharge standards in Taihu Lake.

1.4.2 Specific Objectives

The detail objectives of this study are as follows:

1) To conclude the optimal operation strategy of CAST cycle;
2) To improve the removal capacity of the entire treatment system in relation to organic matters and ammonia nitrogen in the CAST process;

3) To optimize all the operating points in the plant to reach the best possible treatment effect of the CAST process; and
4) To assess the capacity of coagulation-precipitation-filtration units in improving the degradation rate of residual COD in the town sewage treatment effluent through the jar test and trial run.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Water Pollution

2.1.1 Water Pollution Issues

Environmental issues have become critical in ensuring the sustainability of the planet. Global warming is attracting attention in relation to global sustainability. Specifically, water environmental issues have become extremely critical and urgent concerns. After the 1950s, the world population grew quickly and industries developed rapidly. Thus, the status of world water resource has worsened quickly as reflected by the alarming "water crises" being experienced throughout the world. On one hand, the demand for water has increased at a surprising rate. On the other hand, serious water pollution has affected large volumes of water resources used for consumption.

The "Report on the China Wastewater Treatment Industry (2010-2015)" states that approximately 200 tons of garbage are poured into rivers, lakes, and creeks per day around the world; one liter of polluted water contaminates 8 liters of fresh water;

all rivers flowing through major Asian cities are polluted; 40% of the American water resource basin is polluted by processed food scrap, metal, fertilizer, and insecticide; and water quality of 5 out of 55 European rivers has become merely passable. In the 20th century, world population has doubled and the amount of water used for human consumption has increased 5 times. Many countries in the world are facing water crises, and throughout the world, 1.2 billion people lack water and another 3 billion lack hygienic water facilities.

The occupancy volume of water resource per capita of China is low, and spatial distribution is unbalanced. Statistical data from the 10th (Autumn) China International Water Supply and Water Treatment Technology Equipment Exhibition (2009) reveal that the total amount of water resource of China is 281 million cubic meters, which is the sixth in the world. With the accelerated urbanization and industrialization of China, the demand gap of water resource is increasing daily. Against this background, wastewater treatment has become the new emerging industry. At present, it is in the same level of importance as tap water production and supply as well as reclaimed water reuse industries.

2.1.2 Control of Sewage

Sewage: In developing countries, an estimated 90% of wastewater is discharged directly into rivers and streams without treatment. Even in modern countries, untreated sewage, poorly treated sewage, or overflow from under-capacity sewage treatment facilities can send disease-bearing water into rivers and oceans. In the US, 850 billion gallons of raw sewage are sent into US rivers, lakes, and bays every year because of leaking sewer systems and inadequate combined sewer/storm systems that overflow during heavy rains (Healing Our Waters, 2010). Leaking septic tanks and other sources of sewage can cause groundwater and stream contamination. By the end of 2005, of the 661 cities in China, 383 cities have been able to establish d 792 wastewater treatment plants. Wastewater treatment rate increased from 34% in 2000 to 52% in 2005 (Report on China Wastewater Treatment Industry, 2010-2015), and wastewater treatment technology route and management mechanisms were formed and adjusted to the situation of the country. With the increasing attention on environmental protection from the state and governments at all levels, the wastewater treatment industry in China is growing rapidly. The total volume of wastewater treatment increases yearly along with the continuous increase in town wastewater treatment rates. Nevertheless, the present wastewater treatment industry in the country is still in the primary development stage.

Science provides many practical solutions to minimize the present level at which pollutants are introduced into the environment as well as to remediate (cleaning up) past problems. All of these solutions come with corresponding costs, both societal and monetary. There are many choices on the personal and societal levels that can affect the amount of pollution a town or country is forced to live with. Enforcing existing laws, reducing nutrient and pesticide pollution, improving storm water management and watershed monitoring, eradicating deforestation, and reducing pollution from oil and petroleum liquids can all help control water pollution. However, faced with the major source of water pollution called sewage, improved wastewater treatment method is one of the most important control systems that can be used to combat this. For many years, the main goal of treating sewage has been to simply to reduce its content of suspended solids, oxygen-demanding materials, dissolved inorganic compounds, and harmful bacteria (Krantz & Kifferstein, 2006). In recent years, more emphasis has been placed on improving the system as well.

2.2 Wastewater Treatment

2.2.1 Background of Wastewater Treatment

The use of engineering principles for improving water quality has had a long history as demonstrated by water and wastewater treatment. Wastewater can be treated close to where it is created (e.g., in septic tanks, biofilters, or aerobic treatment systems), or collected and transported via a network of pipes and pump stations to a municipal treatment plant. Sewage collection and treatment is typically subject to local, state, and federal regulations and standards. Industrial sources of wastewater often require specialized treatment processes. Wastewater treatment is the process of removing contaminants from wastewater and household sewage, both runoff (effluents) and domestic. It includes physical, chemical, and biological processes that remove physical, chemical, and biological contaminants (Waste-water treatment technologies, 2003). Its objective is to produce a waste stream (or treated effluent) and solid waste or sludge suitable for discharge or reuse back into the environment. Such materials are often inadvertently contaminated with many toxic organic and inorganic compounds.

Removal of waste from wastewater can be accomplished through a variety of physico-chemical and biological process alternatives (Environmental Sanitation Reviews, 1989). Bio logical processes offer economic advantages (Balakrishnan & Eckenfelder, 1969, Barnard, 1973). Among the three typical types of wastewater treatment, microbiological process is the most reasonable because it employs and enhances the function of bacteria in the natural environment (Henze, 2002). However, the operation of biological treatment process has long been empirical in nature. Design and operation of processes are based on past experiences. Such experience-based technology is satisfactory as long as conventional pollutant removal is targeted. The two main types of biological treatment plants, namely, biofilters and activated sludge plants, offer different conditions of living that are reflected in the biology. The most varied microorganism life is found in biofilters, because the design and operation of these filters allow changing environments where different microorganisms can flourish. In the activated sludge process, the microorganisms are evenly distributed and are not nearly as varied in terms of species. At present, however, removal of wider varieties of pollutants with high efficiency and with low energy or resource consumption has become a requirement.

2.2.2 Wastewater Characteristics

Wastewater components can be divided into a few main groups as shown in Table 2.1 (Henze, 2002). The composition of different types of wastewater is shown, based on domestic wastewater and municipal wastewater without any essential industrial influence.

Table 2.1 Components in wastewater (Henze, 2002)

Component	**Of special interest**	**Environmental effect**
Micro-organisms	Pathogenic bacteria, virus and worms eggs	Risk when bathing and eating shellfish
Biodegradable organic materials	Oxygen depletion in rivers, lakes and fjords	Changes in aquatic life(less diversity)
Other organic materials	Detergents, pesticides, fat, oil and grease, coloring, solvents, phenol, cyanide	Toxic effect, aesthetic inconveniences, bio accumulation
Nutrients	Nitrogen, phosphorus, ammonia	Eutrophication, oxygen depletion, toxic effect
Metals	Hg, Pb, Cd, Cr, Cu, Ni,	Toxic effect, bio accumulation
Other inorganic materials	Acids, for example hydrogen sulphide, bases	Corrosion, toxic effect
Thermal effects	Hot water	Changes in living conditions of flora and fauna
Odour (and taste)	Hydrogen sulphide	Aesthetic inconveniences, toxic effect
Radioactivity	Toxic effect, accumulation	

2.2.3 Biological Treatment Method

Types of biological sewage treatment methods that are generally applied can be divided into the ones listed below.

- Biological aerated filter: This is a reactor filled with filter media by attaching highly active biomass to treat pollutants.
- Rotating biological contactor: This is based on mechanical treatment systems. Microorganisms present in media disks can break down and stabilize organic pollutants.
- Activated sludge: This contains a variable and mixed community of microorganisms in an aerobic aquatic environment. Sludge use dissolved oxygen to promote the growth of biological floc that substantially removes organic materials. The microorganisms in activated sludge oxidize a portion of the organic matters during its respiration, providing energy for their life processes; the other portion of the organic matter is used as material for cell synthesis which increases the activated sludge. SBR is a significant type of activated sludge treatment method which is widely applied in normal domestic environment in the world.

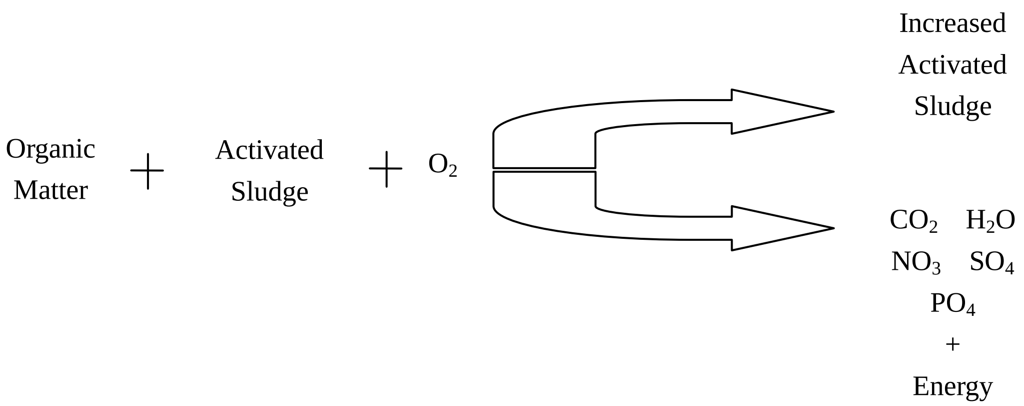

Figure 2.1 Biological activities involved in removal of organic matter in activated-sludge process (Handbooks of UK wastewater practice, 1997)

2.3 Introduction of SBR

2.3.1 History of SBR

In the early 1880s, Dr. Angus Smith investigated the activated sludge treatment method. He found that the oxidation of organic matter was hastened by aerating the wastewater. The easy and simple method was studied subsequently by a number of investigators. In 1914, sewage treatment using the activated-sludge process evolved from the fill-and-draw system, which was developed by Ardern and Lockett. The SBR is a modern development of this system. Its success is due to modern technology, particularly the programmable logic controller, which controls operational sequences. The process shown in Figure 2.2 has a single rectangular reaction tank, in which the various sequences of wastewater fill and aeration, activated-sludge settlement, and effluent decanting are carried out.

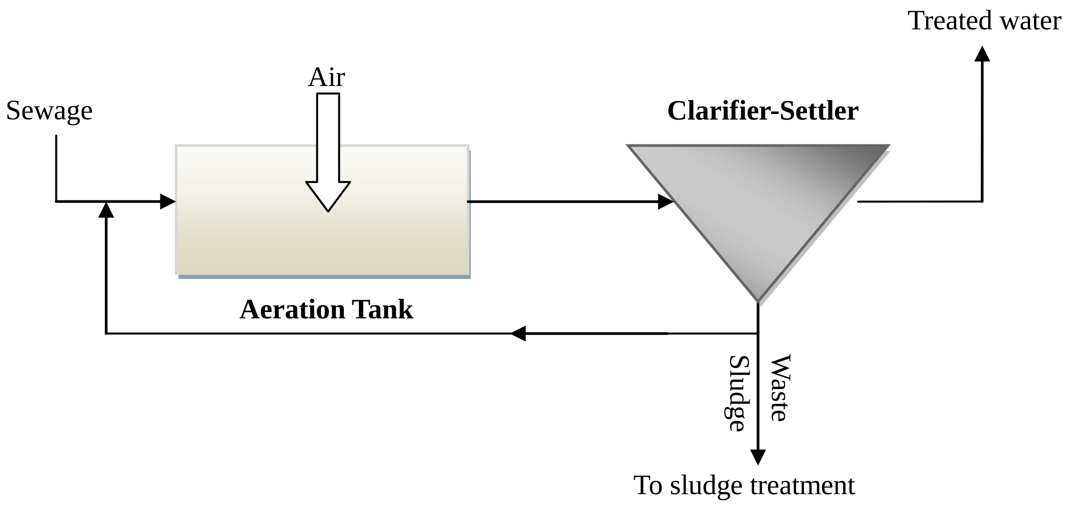

Figure 2.2 Activated sludge process

2.3.2 Traditional Treatment Technology

SBR is the enhanced model of activated sludge process. Five phases have been added, thereby increasing the efficiency of pollutant removal. Figure 2.3 shows an example of the operating sequence of the SBR system. The cycle time in SBR operation can be modified based on the different components of the influent.

Fill: Wastewater is distributed throughout the settled sludge through the influent distribution. It can provide good contact between the microorganisms and the substrate. Static fill creates an environment favorable for floc-forming organisms versus filamentous organisms in a high substrate concentration (F:M). Mixed fill mixes influent organics with the biomass. The fill phase has anoxic and anaerobic conditions also the denitrification process.

Aerated fill: Aeration of the contents of the reactor is undertaken to begin the aerobic reactions completed in the react step--recues the aeration time.

React (mixed react mode): In this phase, biological reactions and complete nitrification in aerobic reactions are completed. Denitrification and phosphorus removal can be achieved in anoxic conditions and anaerobic conditions, respectively.

Settle: The settle can provide quiescent condition for clearer effluent and concentrated settled sludge.

Draw: The decanter is used in this phase to remove the treated effluent.

Idle: The length of the idle step varies depending on the influent flow rate and the operating strategy.

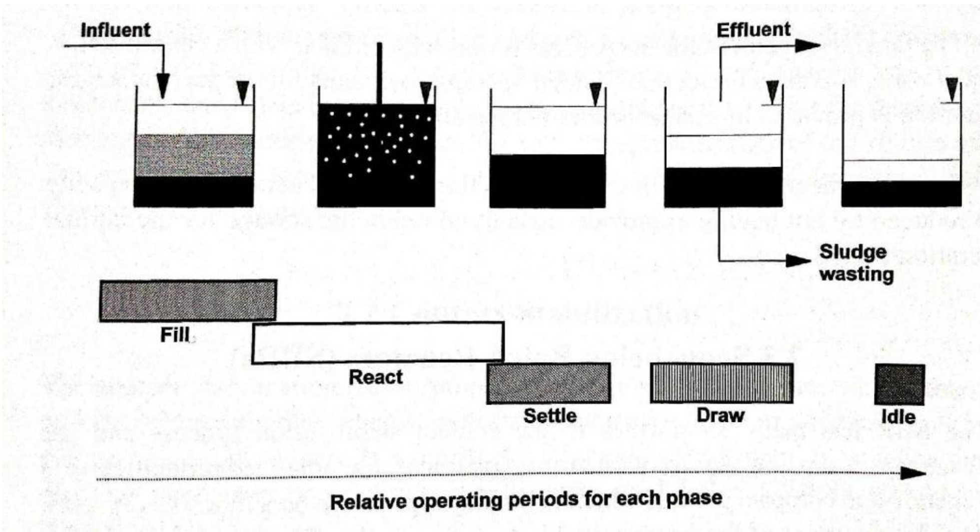

Figure 2.3 Cycle of typical SBR system (Handbooks of UK wastewater practice, 1997)

There are two major classifications of SBRs: the **intermittent flow (IF)** or "true batch reactor," which employs all the steps, and the **continuous flow (CF)** system, which does not follow all the steps. Both have been used successfully in various U.S. and worldwide installations. SBRs can be designed and operated to enhance the removal of nitrogen, phosphorus and ammonia, in addition to the removal of TSS and BOD. The intermittent flow SBR accepts influent only at specified intervals and, in general, follows the five-step sequence. Generally, two IF units are in parallel. Given that this system is closed to the influent flow during the treatment cycle, two units may be operated in parallel, with one unit open for intake while the other runs through the remainder of the cycles. In the continuous inflow SBR, influent flows continuously during all phases of the treatment cycle. To reduce short-circuiting, a partition is normally added to the tank to separate the turbulent aeration zone from the quiescent area.

The SBR system is typically found in packaged configurations for onsite and small communities or cluster applications. The major components of the package include the batch tank, aerator (Fig. 2.4), mixer, decanter device, process control system, pumps, piping, and appurtenances. Aeration may be provided by diffused air or mechanical devices. SBRs often have specific sizes to provide mixing and are operated by the process control timers. Mechanical aerators have the added value of potential operation as mixers or aerators. The decanter is a critical element in the process. Several decanter configurations are available, including fixed and floating units. At least one commercial package employs a thermal processing step for the excess sludge produced and wasted during the “idle” step.

Figure 2.4 Batch tank with aerator and decanter devices

2.3.3 Resurgence of SBR

The key to the SBR process is the control system, which consists of a combination of level sensors, timers, and microprocessors. Programmable logic controllers can be configured to suit the needs of the owners. This provides a precise and versatile means of control.

Clearly wastewaters that are discharged continuously cannot be treated in one batch tank unless large storage basins are provided. Thus, the batch treatment system must be composed of more than one batch tank. Although it was noted that these systems resulted in more reliable treatment performance, the complexities of operation resulted in the development of present day continuous flow reactors. Early use of SBR was abandoned in favor of conventional flow constant volume treatment systems. This is due to the operational complexities and the design difficulty of the SBR by the poor performance of programmable logic controller.

Interest in SBR system was revived in the late 1950s and 1960s. In the 1970s, in-depth studies and applications of SBR were implemented (EPA, 1999) owing to the development of new equipment and technologies. These developments include the popularity of computer application, the improvement on particular software to appropriately control and operate the facilities, and the development and application of various types of on-line automatic monitoring technologies and automation equipment, such as automatic solenoid valve.

Recent advances in process control and the need to provide more reliable and consistent treatment necessitate the reevaluation of present biological treatment practices. Several variations of SBR processes have been reported in literature. One of these is the CAST, which has been developed specifically for large-scale domestic wastewater treatment application (10,000–200,000 ton) (Demoulin, *et al*., 1997).

2.3.4 Advantages and Disadvantages of SBR

The main advantages of the SBR technology are the ability to follow hydraulic and pollutant loading fluctuations better than continuous systems, use of less energy, and higher operational reliability of settling; in addition, there are no fluid flows influencing the settling of sludge floc in the settling phase.

A further advantage of the SBR technology is that it can be easily equipped with technological machinery even in the case of low performance demand, e.g., below 100 m^2/day. This is not the same for a continuous system. Under a similar capacity, there are no suitable low capacity waste-water pumps available in commercial distribution that can be used. At the same time, there is a risk that the pipes with a small cross-section in a continuous system may get blocked.

The operation of SBR is extremely flexible and simple particularly in its physical ability to meet many different treatment objectives (Kin, 2008). SBR can control all specific phases to meet different treatment objectives. Therefore, the alternation between aerobic, anoxic, and anaerobic phases is established and controlled in time.

Depending on the reaction phase (nitrification rate, denitrificaiton rate, and phosphorus release and uptake rates) which is adapted to wastewater characteristics, a possible control strategy is proposed based on the identification of the endpoint of a biological reaction. Switching to the next phase shortly after the detection of the reaction end-point optimizes both the process performance and the economics of the plant.

Compared with conventional treatment systems, SBR still has its disadvantages (Coelho, 2000). A higher level of sophistication is required, especially for larger systems comprising timing units and controls. Higher level of maintenance associated with more sophisticated controls, automated switches, and automated valves are also required. Potential discharging of floating or settled sludge during the draw or decant phase is a possibility owing to SBR configurations. Potential plugging of aeration during selected operating cycles is another disadvantage although this depends on the aeration system used by the manufacturer. Moreover, SBR requires the potential for equalization, which is dependent on the downstream processes. Discontinuous influent feeding and effluent discharge are disadvantages of SBR that are due to the variable level and volume that induce the complexity of moving equipment. Similarly, SBR is susceptible to extreme cold and must be buried and/or insulated in areas with such extreme temperature conditions.

2.3.5 Types of SBR Processes

Faced with the disadvantages of SBR and the present water crisis, modifications in the SBR process are necessary to allow it to provide more reliable and consistent treatments, alter the treatment process appropriately to enhance nutrient removal, and enhance the flexibility of the process to treat variable flows. Such modifications may include minimum operator interaction, organized anoxic or anaerobic conditions in the same tank, and good oxygen contact with microorganisms and substrate.

In the 1980s, Professor R. Irvin (Notre Dame University, USA) rebuilt the first SBR sewage treatment plant in Culver City in the state of Indiana. Consequently, the full-scale application of SBR has spread throughout the U.S. as well as Canada, Australia, Japan, and China. Accordingly, these SBR wastewater treatment plants were built with different process variations.

There are several major variations of SBR: Intermittent Cyclic Extended Aeration System (**ICEAS**), Modified Sequencing Batch Reactor (**MSBR**), **UNITANK**, Intermittently Decanted Extended Aeration (**IDEA**), Demand Aeration Tank and Intermittent Aeration Tank (**DAT-IAT**), and **CAST**, among others.

2.4 Nitrification and Denitrification in CAST System

Using full-scale reactor facilities it was learned that the effluent nitrate nitrogen concentration could be manipulated from high values of around 20 mg/L to typical values of less than 2 mg/L and the ammonia nitrogen concentration was typically less than 0.5 mg/L and the organic nitrogen concentration less than 1.5 mg/L (Goronszy, 1979). Biological nitrogen removal is consisted of nitrification and denitrification. It is generally believed to provide the most economical means of controlling nitrogen in wastewater events (Coelho, et al, 1999). Nitrification has two processes with two groups of autotrophic bacteria. First, ammonia oxidized to nitrite by autotropic ammonia oxidizing bateria (typically nitrosomonas nitrosomonas, nitrobacter and nitrospira). Further, dissolved nitrite oxidized to nitrate by Nitrobacter species (Melbourne Water, 2004). Dissolved nitrate in the presence of BOD is reduced to nitrogen gas by heterotrophic bacteria (typically pseudomonas), which use the nitrate as an alternative oxygen source Nitrate formation is normally regarded as the rate limiting step in nitrification (Yang & Alleman, 1992). Because nitrification requires aerobic conditions, Irvine (1985) stated the fill and aeration process must be sufficiently long and the dissolved oxygen must be greater than 0.5 mg/L to allow both the enrichment of nitrifying microorganisms and the conversion of ammonia nitrogen and ammonia nitrate. Mixed liquor from the aerobic zone would be recycled to the biological selector which was anaerobic. Biological oxidation of the carbonaceous material would create anoxic conditions hence reducing the nitrates to nitrogen gas (Environmental Sanitation Reviews, 1989). This mode of operation overcame the problem of low denitrification rates associated with the use of endogenous carbon as the carbon source and provide a viable alternative for nitrogen removal without supplemental carbon addition (Irvine et al., 1983; Chin et al., 1985). Although nitrification occurred easily, conditions for denitrification required more carful manipulation. A laboratory-scale using domestic sewage, carried out by Pallis & Irvine (1985), found that an anoxic/aerobic fill process can promote denitrification with the intermittently air supplying and the denitrification rages were noted to be higher than those after fill process. Later, it has been found that the primary sludge was using as another carbon source (Abufayed & Schroeder, 1986). The Utility of primary sludge in denitrification would depend on the denitrifier's ability to hydrolyse and assimilate the compounds released. The release of organic carbon from the sludge was also significantly higher than that of nitrogenous matter. In this case, less ammonia nitrogen will be introduced into the denitrification system.

Nitrification-denitrification via nitrite was a new biological nitrogen removal process (Wu, et al., 2007). Compared with conventional biological nitrogen removal process via nitrate, it could save aeration energy, shorten reaction time and save denitrification carbon source consumption (Albeling & Seygried, 1992; Ruiz, et al., 2003). This transformed the environment of the CAST tank into an anaerobic and anoxic situation and provided carbon source (organic in influent) to residual nitrate ammonia from the front running cycle for completing the denitrification process (SQND). In view of the designated application for large scale plants and the usage of the process advantages offered by the co-current nitrification/denitrification (co-N/DN) the following process features were developed (Demoulin, et al., 2001). Simultaneous removal of organic carbon, nitrogen and phosphorus from sewage has been shown to be feasible with the SBR in Morimoto & Kodama's (1987) laboratory-scale study. The control of biological nitrification-denitrification has been used to vary the operation of activated sludge facilities. Cold climate co-N/DN and redox controlled EBPR were demonstrated in the Austrian Grossarl plant, (Demoulin, et al., 1997), in 1994 for the first time in Europe. The first such plants to use this technology in Germany are the Potsdam (FRG, 90,000 p.e.) and Neubrandenburg (FRG, 140,000 p.e.) facilities (Demoulin and Goronszy, 1999) which came online in early 1999. Henze (1991) showed that, to obtain complete denitrification, the COD/N ratio in wastewater needs to be sufficiently high. Nitrate or nitrite (NOx) can be used as electron acceptors in anoxic condition, which is advantageous because both N and P were removed in the same process (Kerrn Jespersen and Henze, 1993; Kuba, et al., 1993).

However, Goronszy also found out that the facilities which achieved a high level of nitrogen removal using a single aeration sequence rarely had a filamentous sludge bulking problem. This condition also concluded out (Horan, *et al.,* 1994) the introduction of multiple mixing sequences within a cycle with and without aeration as a means of potentially enhancing denitrifying mechanisms also identified with sludge bulking. High nitrogen removal and filamentous sludge bulking control identified with an approximate balanced oxygen demand and oxygen supply. Low fill-ratio volumes provided high levels of nitrification with also identified with filamentous sludge bulking when oxygen supply greatly exceeded oxygen demand. Therefore, the control of operating with multiple aeration sequences and excessive aeration intensity within a cycle will did a great help to control the sludge bulking which was studied in this project.

2.5 Conclusion of Literature Review and Deficiency of Former Studies

2.5.1 Conclusion of Literature Review

As introduced before, Water pollution issue became extremely critical and urgent concerns in the world. Serious water pollution has affected large volumes of water resources used for consumption. The use of engineering principles for improving water quality has had a long history as demonstrated by water and wastewater treatment. SBR is a significant type of wastewater treatment method which is widely applied in normal domestic environment in the world. CAST is one of variations of SBR process which has been developed for large-scale domestic wastewater treatment. Although the programmable logic controllers have been configured to suit the needs of CAST control and improve the treatment efficiency, the effluent of CAST might not meet the discharge standard in Taihu lake area. From the reference cases in Appendix III, it can be found that the ammonia nitrogen concentration of effluent has difficulty to meet the Taihu standard (<5 mg/L) and also the COD concentration (<50 mg/L). As a built-up sewage treatment plant using CAST process under the conventional operation parameters, the best way to enhance the treatment efficiency is to optimal the organic matters oxidization and ammonia nitrogen removal rate, which is less cost and save the construction work.

2.5.2 Deficiency of Former Studies

However, as studied before, the higher efficiency of nitrogen removal in CAST system might lead to sludge bulking due to the multiple aeration sequences and excessive aeration intensity. There is lack of study on the CAST operation parameters for the TN, TP removal under high influent TN concentration. Therefore, a study of the stable and reliable operation was necessary to be conducted to well enhance the treatment efficiency and also prevent excessive filamentous sludge bulking. The full-scale study of the organic and nitrogen removal was carried out in a Sewage Treatment Plant in Wuxi near Taihu Lake. This thesis, studying the improved performance of CAST process, will firstly help the town sewage treatment plant around Taihu Lake to meet the stringent discharge standard and further be significant for the CAST technology studies under high nitrogen concentration condition.

CHAPTER 3

METHODOLOGY

3.1 Description of CAST Process in Sewage Treatment Plant

3.1.1 Introduction of Sewage Treatment Plant with CAST Process

Generally, one sewage treatment plant, which uses the CAST process, mainly adopts anaerobic hydrolysis. This type of wastewater treatment plant is built to provide service to the residents living in a town, which might also sustain the minority of industrial wastewater. The wastewater treating capacity is from 2×10^4 m^3/d to 5×10^4 m^3/d. For example, a Sewage Treatment Plant in Wuxi City is a typical CAST treatment plant that can treat about 2.5×10^4 m^3/d sewage per day comprising 80% domestic wastewater and 20% industrial wastewater. As a sewage treatment plant using the activated sludge for nitrogen and phosphorus removal, it has a relatively long sludge age. This kind of activated sludge has a stable nature, it could be directly thickened and dewatered, and is loaded for outsourcing as a commissioned dealing by special sludge treatment factory but without any digesting. Figure 3.1 shows the flowchart of a typical sewage treatment plant with CAST process.

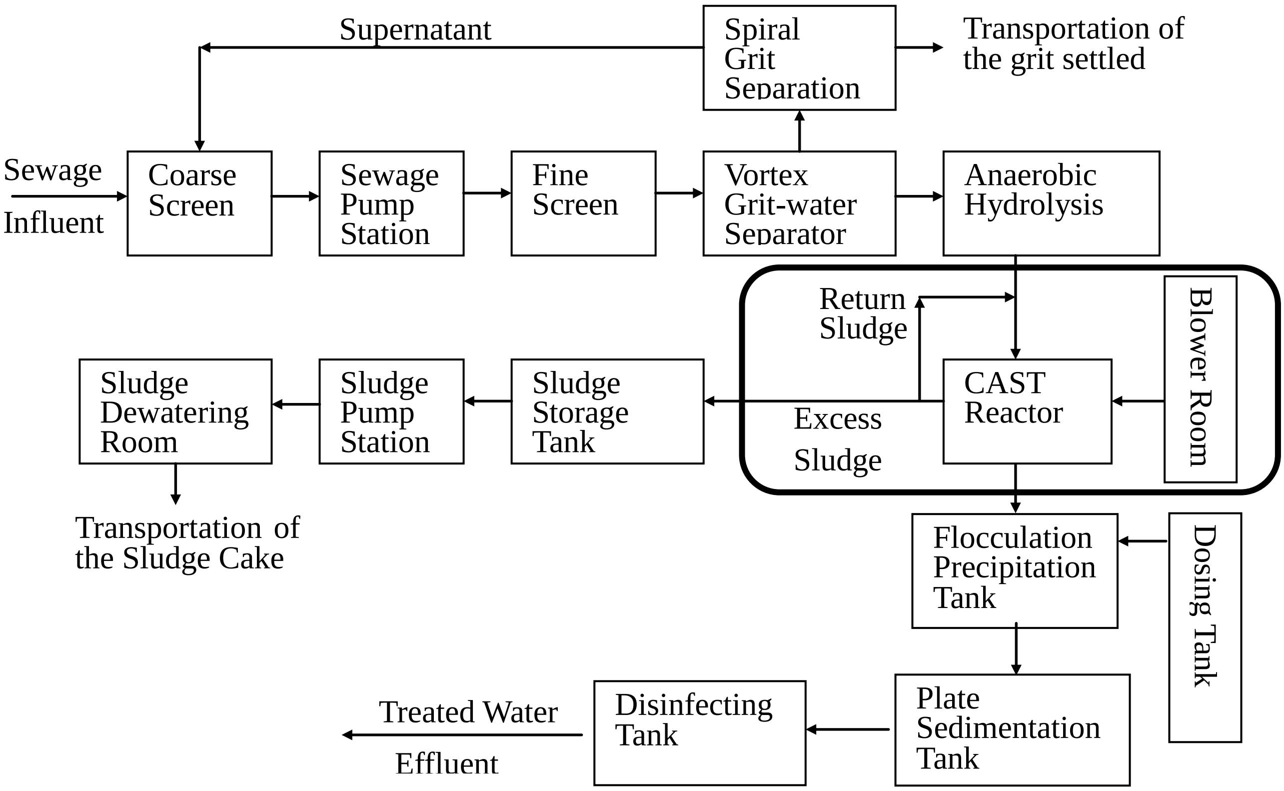

Figure 3.1 Flowchart of typical sewage treatment plant with CAST process (e.g., Wuxi Qianhui Sewage Treatment Plant)

3.1.2 Main Structures and Process Parameters in Typical Sewage Treatment Plant Using CAST Process

3.1.2.1Coarse Screen and Sewage Pump Station

Most small wastewater treatment plants, which are based on the activated sludge process, are generally designed without primary settling facilities (Goronszy, 1979). These plants are available as in-ground, above ground, pre-engineered or pre-fabricated units with some of the geometrical arrangements incorporating a clarifier unit as an integral but separated unit to the aeration vessel. A sewage treatment plant applies the semi-underground wet-pumping station for primary lifting pumps, jointly installed with the coarse grid. Figure 3.2 shows an image of a typical general treatment plant. The station has the reinforced concrete structure; the pumps are installed in the lower part, while the control room is located in the upper part. The civil construction scale has been completed for the equipped sewage with the capacity of 50,000 m^3/d amount and a set of equipment has been installed using submersible pump with wet-installation. Generally, there are three grid channels, one of which is the channel for transcending. Five or more sets of 3.0 kW manual and automatic dual-purpose sealing gates for all sides with suspension mode are also installed. Two sets of coarse grid with 900 mm width and 20 mm paling spacing will be installed as well. Screenings are outward-transported after treatment by the screw press-transportation machine. The system temporarily sets three self-coupling pumps with parameters of Q=450 m^3/hr, H=14 m, and N=30 kW for primary sewage lifting. Two sets are used and another set is on standby.

Figure 3.2 Primary lifting pumps with coarse grid

3.1.2.2 Fine Screen and Vortex Grit-Water Separating Tank

The fine screen shown in Figure 3.3 and the vortex grit-water separating tank are mainly used for removing the large particles of suspended solids and inorganic gravels with diameters above 0.2 mm in the sewage. The fine screen and the vortex grit-water separating tank are built together. The fine screen is located in the front section of the water inlet of the grit-water separating tank. The number of grid channels depends on the design capacity, although three-grid channels are popular for 50,000 m^3/d. Five sets of 3.0 kW manual and automatic dual-purpose sealing gates with suspension mode for all sides are installed for convenient maintenance beyond and after the screen channels. Two sets of mechanical rotating screenings with 900 mm width and 5 mm paling spacing are also installed. Screenings are outward-transported after treatment by the screw press-transportation machine. Two vortex grit-water separating tanks are also built. Gravels are outward-transported after dewatering treatment by the spiral grid separator. A set of pumps is installed for lifting the sand settling with parameters of Q=25 m^3/hr, H=10 m, and N=1.5 kW.

Figure 3.3 Fine screen before the vortex grit-water separation tank

3.1.2.3 Anaerobic Hydrolytic Tank

The anaerobic hydrolytic tank adapts the semi-underground rectangular reinforced concrete structure shown in Figure 3.4. In this example, the civil construction scale meets the recent 25,000 m^3/d sewage treatment capacity with the size of $36 \times 32 \times 6.5 m^3$. The effective depth is 6 m with the hydraulic retention time of 8.3 hr and volume loading of capacity 0.70 $kgBOD_5/m^3 \cdot d$. Moreover, 2304 m^3 of Φ150-diameter and 2 m-high flexible packing and 4 sets of under liquid circulation blenders with the largest service area of 200 m^2 are installed in the anaerobic hydrolysis tank.

Figure 3.4 Anaerobic hydrolytic tank

3.1.2.4 CAST Tank and Distributing Well

As mentioned previously, cyclic activated sludge system was developed from SBR by Prof. Goronszy. The design of CAST requires the replacement of the pre-react

Tank in SBR with a smaller and better designed biological selector shown in Figure 3.5. Comparing with SBR, CAST offers significant savings in capital cost, including mechanical and electrical costs, operation and maintenance costs, and smaller land area requirements.

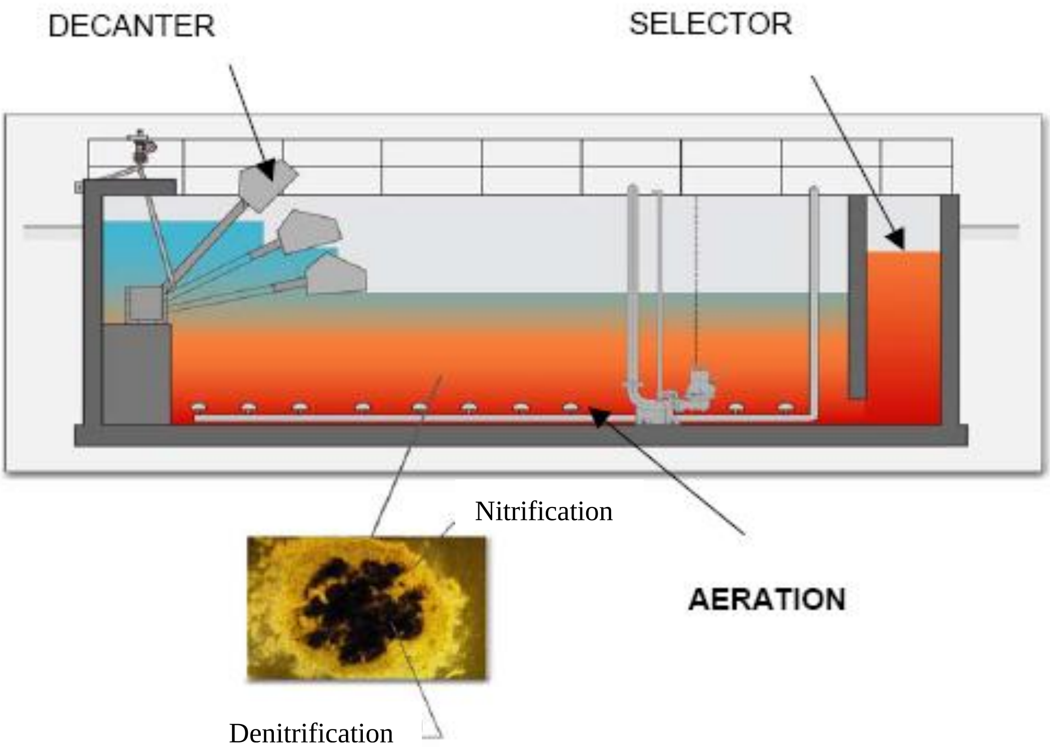

Figure 3.5 Structure of one CAST Tank (Grundfos, 2004)

The CAST process is generally applied as a type of semi-underground reinforced concrete structure. If its civil construction scale is designed to meet the 25,000 m^3/d sewage treatment capacity, the tank must be separated into four sub-tanks by partition walls similar to what has been done on the four modules in the sewage treatment plant, where each module measures 36 m×20 m×6 m. A set of manual and automatic dual-purpose weir gates with a power of 5.5 kW is installed. The running stages of all four CAST modules are mutually staggered. Each module or single-sub tank consists of three parts, namely, the biological selector, the anoxic zone, and the oxic zone. The multiple-tank system requires a higher level of operation and would be better suited for large flow rates (Irvine and Richer, 1976, Ketchum, *et al*., 1979). The multi tanks operated in parallel with each tank in a different phase of operation.

CAST has special features compared with the SBR system. The development of CAST technology started in Australia as early as 1965 (Goronszy, 1979). With the special biological selector zone, there is no need for an anoxic-mixing sequence and therefore, it is replaced by a simple fill-aerate sequence. The selector simplifies the operation of the process and ensures the biological selection of predominantly floc-forming microorganisms over all loadings, particularly at less than the designed load. Using of biological selector zones, regulating the fill sequence for filamentous sludge bulking control and co –N/DN can help to regulate the kinetics of oxidation reduction potential (ORP) depletion for enhanced biological phosphorus removal (EBPR) (Goronszy and Rigel, 1991). The selector also increases the operational safety, reduces the effluent concentration, and allows the facility to be built in a more cost effective manner. Likewise, the selector assists with the selection of poly **P** micro-organisms as well as in the process of removing **P** biologically without chemical addition. Meanwhile, the development of computer technology has simplified the operation and biorate control processes, providing more reliable and consistent treatment. This means that the treatment process is altered appropriately to enhance nutrient removal as required by the SBR variation.

In this process, sewage first flows into the biological selector shown in Figure 3.6, mixes with 10% return sludge pumped from the oxic zone, and subsequently flows into the anoxic and oxic zones. Setting the biological selector has two purposes; to prevent sludge bulking and phosphorus releasing and to achieve denitrification reaction. In the case of Wuxi, an excess sludge pump with parameters of Q=100 m^3/hr, H=10 m and N=3.7 kW, has been installed for each sub tank, with the purpose of lifting excess sludge to the sludge storage tank. A set of mechanical cantilevered rotating decanters with weir length of 8 m is matched for each CAST module. Maximum decanting capacity is 1670 m^3/h, maximum decanting depth is 2.3 m, and the weir loading is 37.56 L/s.

Figure 3.6 Biological selector in CAST sub-tank

After decanting, the treated water is allowed to flow into effluent pumping station through the main outlet pipe. The design parameters for aeration tanks are as follows: effective volume of each module- 3800 m^3, hydraulic retention time- 17.3 hr, volume of biological selector- 200 m^3, effective volume of anoxic zone- 380 m^3, sludge loading- 0.1kgBOD_5/kgMLSS/d (top surface), sludge age- 20 days, effective sludge age- 10.5 days, sludge yield- 0.875kgDS/kgBOD_5, maximum depth- 6.0 m, minimum depth- 3.84 m, decanting depth- 2.16 m, mixture liquid suspended solid (MLSS)- 5600 mg/L at the lowest water level, and mixture liquid suspended solid (MLSS)- 3500 mg/L at the highest water level. Food/micro-organism ratio (F/M), also organic loading, is a measure of the organic loading rate of a wastewater treatment system, i.e. the ratio between the daily BOD load and the quantity of activated sludge in the system (microbes). In the activated-sludge process, the loading rate expressed as Kilograms of BOD per kilograms of mixed liquor or mixed liquor volatile suspended solids per second (mg/kg s) or pounds of BOD per pound of mixed liquor or mixed liquor volatile suspended solids per day [Kg BOD/d/Kg MLSS or MLVSS]. Typically, this parameter recognizes that micro organisms should have the right amount of organic food for sewage treatment to operate successfully. Too much food causes poor effluent quality and too little food can cause sludge bulking problem. Because in downtown sewage treatment plant, the mass of BOD_5 coming is uncontrollable every day. Therefore, controlling MLSS controls the operation F/M, i.e., by wasting the correct amount of sludge everyday during selected cycles which means control the MLSS by sludge age.

Aside from the special features stated above, CAST also possesses the advantages listed below (Demoulln, 2001).

- Simultaneous N/DN, which allows operation even without mixing equipment. Proper oxygen demand/supply operation control by BIORATE in combination with the SELECTOR allows control over this process.
- A clear water withdrawal system for high rate decanting, which allows drawing off up to 2.5 m of solid-free effluent without complex valve

arrangements. SBR systems are limited to approximately 1 m of decant depth.

- Presence of "normal" and "high flow" operating protocols. These are standard features that are not found in the SBR systems. Typically, SBR systems have just one cycle, the adjustment possibilities of which can be confusing for the operator.
- Equalization basins for influent or effluent equalization are not necessary.
- It uses least odor potential technology.
- It provides a better BIO-P using the SELECTOR effect.
- Filamentous sludge bulking in SBR systems can only be avoided if shock filling is carried out, which requires influent equalization and pumping. CAST is tolerant to shock loading by organic and/or hydraulic load fluctuations.
- A fast settling coarse granulated activated sludge is produced, which dewaters readily.

3.1.2.5 Blower Room

The air blaster system provides air supply to 4 groups of CAST tanks. As applied in the case of Wuxi shown in Figure 3.7, these blowers are divided into 2 groups with 3 blowers for each group. Of these, one is designated to be on standby. The air supplying capacity of each blower is approximately 70 m^3/min amount and the air pressure is

0.58 MPa. In order to meet the requirements of process control for air volume and air pressure, frequency conversion multiple grade centrifugal blowers are used, with air flow-rate regulating capacity of 5%–100%.

Figure 3.7 Six blowers in the air blaster system

3.1.2.6 Sludge and Dewatering Room

The excess sludge from the CAST tank should be pumped to the sludge storage tank by the excess sludge pump. The type of semi-underground reinforced concrete structure is popularly used for the sludge tank. The hydraulic retention time is approximately 10 hr. To prevent the release of phosphorus under anaerobic condition in the sludge tank, perforated pipes are set in the sludge storage tank. Subsequently, the excess sludge stored in sludge tank is pumped to the belt thickenening and press filter for the treatment of thickening and dewatering treatments. The size of the dewatering room is 20 m×18 m, with clearance height of 5.5 m. In addition, 2 sets of belt thickening and press filters should be installed within the room. The treatment capacity of each filter is 30-58 m^3/h. The solid content of sludge after dewatering is approximately 20%. Two sets each of sludge supplying pumps, flush pump for washing belt, air compressors as well as a set of flocculent adding equipment must be matched with the dewatering system. The dosage of flocculent (PAM, polyacrylamide) with a concentration of 0.5% is 2–4 Kg/tDS. A set of horizontal screw conveyors and a set of tilted conveyors are installed for transporting sludge outside after dewatering for further treatment (Figure 3.8).

Figure 3.8 Sludge transporting after dewatering

3.1.2.7 UV Disinfection Tank

In a typical sewage treatment plant, the disinfection system is usually at the end of the sewage treatment process. Two disinfection channels could be set, of which one is a standby unit. Each disinfection channel sets 13 UV disinfection modules, and the total power is 10 kW.

3.1.2.8 Output Pumping Station

The plant also applies the semi-underground wet-pumping station type of output pumps. The station has the reinforced concrete structure, in which the pumps are installed at the lower part, and the operation and maintenance rooms are located in the upper part. The system regularly sets three or more self-coupling submersible pumps with parameters of Q=450 m^3/hr, H=14 m, and N=30 kW for output pumping. Of the three, two sets are used and one set is on standby.

3.2 Initial Conclusions of the Full-Scale Experiments

One Sewage Treatment Plant which near Taihu Lake has been selected as the site for the full-scale experiments based on the fact that it is a typical town sewage treatment plant adhering to the CAST process. Optimizing the CAST process in this plant can be significant in the future applications of sewage treatment plants of other towns. Further, if other town sewage treatment plants utilizing the CAST process can apply the optimization process proposed in this project, the results can help mitigate the water environment situation in the Taihu Lake basin.

With the low organic concentration of the sewage influent, the effluent water quality of the this Sewage Treatment Plant basically meets the originally designed discharge standards (i.e., the main controlled pollutants COD $\leq$ 90 mg/L, NH_3-N $\leq$ 8 mg/L, TP $\leq$ 1 mg/L) even before the process optimization experiments and trial runs were conducted. However, the water quality of effluent showed slight fluctuations, and the ammonia nitrogen removal rate was below the standard.

In order to meet the new standards contained in the “Water Pollutant Discharge Limits for Urban Sewage Treatment Plants and Industries in Taihu Region” (local standard of Jiangsu Province, DB32/1072-2007), the sewage treatment plant showed the need to improve the stability of the treating system through experiments and trial runs. Through these experiments, the plant management wanted to ensure the smooth relationships among the organic compound removal rate and four different process control parameters, such as pH value, dissolved oxygen, sedimentation time and temperature, during a limited period of time. The relationships between the nitrogen removal rate and the four parameters must be determined as well. The experiments and the relationships ultimately aim to meet the new discharge standard of the Jiangsu Environmental Protection Bureau and Jiangsu Quality and Technical Supervision Bureau (COD$\leq$ 50 mg/L, NH_3-N $\leq$ 5 mg/L, TP $\leq$ 0.5 mg/L).

In addition, due to the limited means of detection of upstream pollutant discharge units, the water quality of influent flow into the Sewage Treatment Plant is not stable. Thus far, control over the over-standard discharge of these units has been ineffective. This condition creates problems for the management, which affect the normal operation of the Sewage Treatment Plant. One of the special cases pertains to a large amount of high concentration wastewater discharged into the sewage treatment system, which was previously undiscovered. The concentration of COD temporarily reached more than 1000 mg/L, which exceeded by at least two times the influent standard. These conditions directly led to the death of autotrophic and heterotrophic bacteria as well as the mass rearing of filamentous bacteria. As a result, COD removal rate significantly decreased, and ammonia removal rate went down to close to zero. Meanwhile, the biochemical sludge proceeded to bulking and sludge-water separation effect was poor.

Due to the intermittent aeration mode, it is difficult for typical CAST systems to achieve COD removal rates greater than 85%. However, when the COD concentration of influent is below 300 mg/L, and the influent has good biodegradability (B/C>35%), COD concentration in the effluent can be controlled below 45 mg/L, which is close to the 85% COD removal rate, by improving the bacteria activity of sludge and culturing the dominant bacteria.

After creating favorable conditions for the proliferation of nitrification bacteria through optimization on operating points, it can be expected that the ammonia nitrogen removal rate would be restored and improved by up to 85% in one or two months. Based on this, cultivation of denitrifying bacteria should be considered in order to improve the removal rate of total nitrogen in sewage.

Nearly all reactions, including carbonation, nitrification, denitrification and phosphorus removal, occur in the main reaction zone of the CAST tank, resulting in various flora existing together at the same time and competing with each other. For this reason, the optimum removal rates of organic matters, nitrogen, phosphorus, and so on would not be achieved at the same time. In particular, the obvious effect of reciprocal inhibition between the phosphorus-accumulating bacteria and the denitrifying bacteria appears. For this reason, nitrogen removal rate usually increases with the decrease of phosphorus removal rate. The situation is considered a limitation of the CAST process. To address this limitation, a combination of chemical phosphorus removal units with biological phosphorus removal process should be considered to ensure that the nitrogen and phosphorus levels could meet the discharge standard in a stable manner.

All of the surface areas of the CAST tank could be used for settling during the sedimentation stage. Thus, the solid flux capacity and water-sludge separation effect is better than the secondary sedimentation tank of traditional activated sludge process (Goronszy, 1997). The settlement process of the CAST system occurs in a static environment without hydraulic interference, thereby guaranteeing good separation effect. Therefore, for a typical CAST system, satisfactory SS removal rate and low residual SS concentration in the effluent can be easily achieved. However, when the coagulation-precipitation system is increased after the CAST process, further removal of residual COD should consider deep treating units, such as those that use a kind of filter to prevent the risk of SS exceeding the standard.

3.3 Laboratory Analysis

3.3.1 Chemical Oxygen Demand (COD)

Chemical oxygen demand is an indirectly measurement of the organic compound amount in water. Almost all organic compounds can be fully oxidized to carbon dioxide with a strong oxidizing agent under acidic conditions. In this experiment, COD has been tested according to GB/T 11914-1989.

3.3.2 Biochemical Oxygen Demand 5 Days (BOD_5)

Biochemical oxygen demand is a chemical procedure, which is used for determining the amount dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at the specified temperature (20℃) for 5 days. In this experiment, BOD_5 has been tested according to GB/T 7488-1987 using DO meter SG6 made by Mettler-Toledo(Water and Wastewater Monitoring Analysis Method, 2002).

3.3.3 Ammonia Nitrogen Test (NH_3-N)

Nitrogen is a nutrient in the environment, which is necessary to sustain growth of most organisms. Nitrogen exists in several forms such as nitrate, nitrite, and organic nitrogen such as proteins, amino acids or ammonia. Ammonia is a colorless, gaseous compound with a sharp distinctive odor, which is highly soluble in water. In this experiment, the ammonia nitrogen value is determined by distillation-titration method according to GB/T 7478-1987.

3.3.4 Nitrate and Nitrite Nitrogen (NO_3^--N, NO_2^--N)

Nitrate nitrogen is commonly used lawn and agricultural fertilizer. It is also a chemical formed in the decomposition of waste materials, such as manure or sewage. With the presence of cadmium (Cd), NO_3^- can be reduced almost quantitatively to nitrite (NO_2^-). In this experiment, nitrate nitrogen is determined by nitrate-spetro-photometric method with phenol disulfonic acid according to GB/T 7480-1987.

Nitrite (NO_2^-) is determined through formation of a reddish purple azo dye produced at pH 2.0 to 2.5 by coupling diazotized sulfanilamide with N-(1-naphthyl)-ethylenediamine dihydrochloride (NED dihydrochloride). Photometric measurements can be made in the range 5 to 50 μg N/L if a 5-cm light path and a green color filter are used. In this experiment, nitrite nitrogen is determined by nitrite-spetro-photometric method according to GB/T 7493-1987.

3.3.5 Kjeldahl Nitrogen (TKN)

The Kjeldahl method is an analytical chemistry method for the quantitative determination of nitrogen in chemical substances. The method consists of heating a substance with sulfuric acid, which decomposes the organic substance by oxidation to liberate the reduced nitrogen as ammonium sulfate. In this experiment, TKN is determined by distillation spectrophotometric method according to GB/T 11891-1989.

3.3.6 TP (Total Phosphorus)

Wastewater is relatively rich in phosphorus compounds, which is a nutrient used by organisms for growth. Phosphorus occurs in natural water and wastewater bound to oxygen to form phosphates. It comes from a variety of sources including agricultural fertilizers, domestic wastewater, detergent, industrial process wastes and geological formations. The discharge of wastewater containing phosphorus may cause algae growth in quantities sufficient to cause taste and odor problems in drinking water supplies. Dead and decaying algae can cause oxygen depletion problems which in turn can kill fish and other aquatic organisms in streams.

Therefore, phosphorus removal is an essential role of wastewater treatment plants and testing for phosphorus in the plant effluent is critical. In this experiment, the total phosphorus was tested by Molybdenum-antimony anti-spectrophotometric method according to GB/T 11893-1989.

3.3.7 Mixed Liquor Suspended Solid (MLSS) and Suspended Solid (TSS)

Suspended solids are an important indicator of water quality. A well mixed sample was filtered through a weighed standard glass-fibre filter and the retained residue dried and reweighed. The filter was dried at 103-105℃. In this experiment, the suspended solid was tested according to GB/T 11901-1989 by suspended substances gravimetric method.

3.4 Evaluation Experiments

3.4.1 Evaluation of the Anaerobic Hydrolysis Effect

The evaluation of the hydrolysis effect on the anaerobic hydrolysis tank through continued testing of the COD and BOD_5 values in the sewage was conducted before and after the hydrolysis treatment. The improvement of B/C value can be assessed in this experiment, together with the COD removal rate of the anaerobic hydrolysis tank. The designated requirement of 20% was used as the basis for evaluation. The biodegradability of sewage in the secondary biological treating system directly affects the organic matter removal efficiency of the biochemical system and the residual COD level in effluent after the biochemical treating process.

3.4.2 Evaluation of Raw Water for Toxic Substrate

In implementing the evaluation, the authors ensured that the sewage was not impacted by toxic substrates, such as substances with high salinity, phenols, heavy metals and so on. The verification was done by testing the value of salinity, minerals, oil, etc., both in the influent and the treated waters in the oxic tank.

The removal rate of the biochemical system to organic matters or nitrogen may be greatly affected by salinity above 8000 mg/L or by the existence of other toxic components.

3.4.3 Evaluation of MLVSS and SVI

The evaluation aims to access the activity and the settling ability of activated sludge in the oxic tank through continuous testing and analysis for Mixed Liquor Volatile Suspended Solid (MLVSS) / Mixed Liquor Suspended Solid (MLSS) value and the Sludge Volume Index (SVI) value. Extremely low sludge activity and insufficient microbial biomass tend to affect the removal efficiency for both organic matters and nitrogen.

3.4.4 Jar Test with Bio-Treatment Effluent

The discharge wastewater quality parameters of the local standard of Jiangsu Province DB32/1072-2007 show that the requirement of effluent quality for sewage treatment plants in the Tai Lake valley is nearly equal that for reclaimed water reuse. Advanced treatment processes or units that are commonly adopted for reclaimed water reuse are biochemical process (from micro-organisms removal, denitrogenation, and dephosphorization), chemical precipitation (separating heavy metal ions), flocculation (from removing micro-organisms and turbidity), activated carbon adsorption (removing trace organic pollutants), ion-exchange (removal of inorganic ions, lower salinity), ultra-filtration, microfiltration and reverse osmosis (removal of suspension and total soluble solids), and chemical oxidation (decomposition of organic macromolecules, deodorant).

Based on the indicators, all the indexes, except COD, can meet the new discharge standard after the process optimization of the Sewage Plant. However, solid theoretical and practical proof showing that COD can reach the standard (<50 mg/L) with assured stability is still lacking which meansCOD might over discharge standard.

As a result, enhancing the coagulation precipitation system can be the main part of the advanced treatment processes from an economic perspective.

Coagulation precipitation experiment (jar test) can be used in verifying whether or not advanced treatment processes are practical and reasonable. This can also be used as a theoretical basis for choosing coagulants and deciding on the optimum dosage.

3.4.5 Jar Test with Influent

Due to the absence of a primary settling tank in this Sewage Treatment Plant, experiments were performed before and after bio-treatment in order to assess the two different COD removal effects of coagulation precipitation process. The result should determine whether the plant would use the coagulation precipitation on influent (as pretreatment) or effluent (subsequent treatment) for better use of the CAST process in the future.

3.4.6 Observation of Microbe Form in the Activated Sludge

In a typical secondary wastewater treatment process, the activated sludge in the aerobic tank is the main component of biological wastewater treatment. The activated sludge consists of microbes (bacteria, fungi, yeast, actinomycetes, and protozoa), epigenetic animals (rotifers, nematodes), and other solid substances in wastewater (Li, *et al*., 2007). In this study, we aim to evaluate the growth status of these microbial and epigenetic animals in the activated sludge. Another objective is to guide the debugging of nitration reaction by observing the structure of the activated sludge and the shape and features of the zoogloea and protozoan.

Many previous studies have shown that the propagation condition of amoeba protozoa has an obvious indicative function to nitration reaction as found by Li, *et al*. (2000). The positive correlation between the growth of two kinds of amoeba protozoa (*Arcella gibbosa* and *Arcella vulgaris*) and the propagation of nitrifying bacteria have also been presented.

3.5 Operation of the Project

3.5.1 Control Parameters Setting

One important task we focused on was the enhancement of nitrogen removal efficiency. Thus, the process parameters for optimization listed below are based on the consideration of increased nitrogen removal. These process control conditions considered the maximum benefit for full nitrification reaction. The effect of denitrification and the total nitrogen removal efficiency were gradually considered after obvious expansion of denitrifying bacteria was observed.

3.5.1.1 Organic Carbon Source

In nitrification, denitrifying bacteria belong to the kind called autotrophic bacteria. Concentration of organics should not be their growth constraint. In fact, nitrification reaction occurs after the completion of carbonation reaction. This means that it is conducive for denitrifying bacteria growth and proliferation when organic carbon concentrations are below a specific concentration (BOD $\leq$ 20 mg/L) of the mixture. In other words, if the BOD concentration of the mixture is relatively high, the heterotrophic bacteria may proliferate more rapidly than he autotrophic bacteria because of the higher growth rate of the former. Thus, the autotrophic bacteria could not become the priority of the species, which seriously affects the nitrification reaction. Food to microorganism (F/M) ratio is a control parameter to control the wasting of biological growth (Mishoe, 1999). The “food” in the ratio is the BOD entering the process and the “microorganisms” are the activated sludge solids in the aeration tanks (MLSS/MLVSS). The detail relationship of activated sludge process and F/M ratio was explained in Table 3.1. In this experiment, the F/M ratio was controlled over 0.2 kg BOD/kg MLSS, also during operation cycle, the exceed aeration may cause the low F/M which near 0.05 kg BOD/kg MLSS.

Table 3.1Activated sludge process ranges for F/M Ratio Control (Mishoe, 1999)

Activated Sludge Process Ranges for F/M Ratio Control

Process Range Names	Common SWT ASP Names	F/M Range
Extended Aeration	Extended Aeration Sequencing Batch Reactors Race Track or Orbital Ditch	0.05-0.15 Lb CBOD5/1 Lb MLTSS
Standard Activated Sludge	Conventional Activated Sludge Contact Stabilization Step Aeration Complete (or Homogenous) Mix Others used with nutrient removal	0.25-0.5 Lb CBOD5/1 Lb MLTSS
Hi-Rate Activated Sludge	HRAS based on desired removal §75 to 60% efficiency)	1.0-10 Lb CBOD5/1 Lb MLTSS

In denitrification, organic carbon source in raw sewage is used as the major electronic donor; the more sufficient the carbon source, the more thoroughly the process is carried out. In theory, denitrification reaction only occurs when BOD_5/NH_3-N > 2.86. Actual operation data show that this process can normally proceed when BOD_5/NH_3-N > 3.0. Ammonia nitrogen removal rate can exceed 85%, and the total nitrogen removal rate can exceed 65% when BOD_5/NH_3-N ratio is at the range of 4–6.

Primary evaluation

According to the previous operation data of the sewage plant which BOD_5/NH_3-N > 3.0, organic carbon source should not be the limiting factor of nitrification and denitrification reactions.

3.5.1.2 Sludge Retention Time

To ensure the survival of the denitrifying bacteria as well as maintain a certain amount of denitrifying bacteria with stable performance in the aerobic tanks, the retention time (sludge age) of microbes in the reactor should be more than the minimum denitrifying bacteria generation time. Moreover, in practical operation, the general sludge age of the system should be taken as more than three times that of the minimum denitrifying bacteria generation time, and not less than 10 days. Nitrification generally occurs after the completion of carbonation.

Primary evaluation

According to the actual operation experience of a number of sewage treatment plants utilizing the CAST process, good ammonia-nitrogen removal performance can be achieved when the sludge age is controlled within the range of 15–20 days. In addition, the sludge retention time can be reduced to approximately 10–15 days in summer when the temperature is relatively high. Measures to increase the sludge return ratio and the MLSS concentration should be adapted to enhance the sludge age of the existing bio-chemical system.

3.5.1.3 Dissolved Oxygen

Given that oxygen plays the role of the electronic carrier in the process of nitrification, the DO concentration certainly affects the nitrification process. The DO concentration should be maintained within the range of 2–3 mg/L in the mixture, and the critical DO concentration for denitrifying bacteria should be within 0.5–0.7 mg/L. Studies have shown that ammonia nitrogen can still be nitrified completely when DO concentration is below 2 mg/L, but a long sludge retention time is required. Therefore, in order for the design to meet the nitrification condition, the dissolved oxygen concentration should be set above 2 mg/L in general.

Primary evaluation

Controlling the DO concentration based on aeration time and in the absence of experimental data or other operating experiences is not an ideal situation. It is often misunderstood that the higher the DO concentration, the better the nitrogen removal rate of the CAST process. The main advantage of the CAST process for nitrogen removal is the combination of two kinds of reaction, namely, SND and SQND.

An extremely high DO level may lead to disintegration of the flocculent sludge which, in turn, immediately affects the water-sludge separating performance of the mixture. According to the operating experiences of other sewage treatment plants using the CAST process, the DO concentration should be controlled within the 2–4 mg/L range during the pure aeration stage. The DO detector can be installed at the return sludge pipe between the main aeration zone and the biological selector. It can be directly installed at the main aeration zone of the CAST tank as well.

3.5.1.4 The Temperature

Temperature not only affects the growth rate of nitrifying and denitrifying bacteria, but also the activity of these bacteria. The most appropriate temperature range for nitrification is 20–30 ℃. Nitrification rate speeds up with the increase of temperature when the temperature is within the 5–35 ℃ range. However, when the temperature is over 30 ℃, the rate decreases because degeneration of protein reduces the activity of the nitrifying bacteria. Life activities of nitrifying bacteria would virtually cease if the temperature is below 5 ℃. According to a large number of operating experiences from other biochemical systems, the temperature in the oxic tank is maintained within 20–30 ℃. Water temperatures of above 35 ℃ or below 10 ℃ can lead to the significant drop of the biochemical effect of the treatment system. As such, the water treatment result of the plant being studied can be improved in the near future with the rising trend of temperature. During winter, when the temperature is always low, measures to restrict the COD concentration in influent and extend the sludge retention time may be helpful in ensuring good organic and nitrogen removal efficiencies.

Primary evaluation

Controlling the DO concentration based on aeration time and in the absence of experimental data or other operating experiences is not ideal. The temperature would be less likely a limiting factor of denitrifying bacteria proliferation. In fact, temperature in spring shows a rising trend.

3.5.1.5 pH Value and Alkalinity

Denitrifying bacteria are very sensitive to the change of pH value; the best pH range is from 7.5–8.5 (Chen, *et al*., 2005). Meanwhile, the reaction rate of nitrification decreases significantly when the pH value is below 7.0. Nitrification stops when the pH value is higher than 9.6 or less than 6.0. Given that 7.14 g alkalinity would be consumed per 1 g ammonia nitrogen degradation during the nitrification reaction (without considering the alkalinity amount produced during the denitrification and carbonation processes), approximately 180 mg/L alkalinity would be consumed for full nitrification of 25 mg/L ammonia nitrogen. Generally, alkalinity is often insufficient for sewage, which should be fully nitrified.

Primary evaluation

With reference to numerous research data and practical experiences, the appropriate pH range for short-nitrification is from 7.5–8.5; the best pH range for a typical CAST system is approximately 7.9 (Chen *et al*., 2005).

The pH value should be maintained around 7.9 in the oxic zone and within the 7.0–7.5 range in anoxic zone during the initial trial run period. The best choice for both the adding points of alkali liquor and the pH detecting points should be the post-middle part of the main reaction zone. The dosing pumps should be controlled by the pH on-line detector. Thus, the pH threshold for starting and stopping could be set within 7.6–8.2 during the initial trial run period.

3.5.1.6 Toxic Substances

Numerous harmful substances, including NO_X-N complex cation, ammonia with high concentration and other organic matters in wastewater, can inhibit the nitrification reaction. The inhibition effect from the harmful matters is embodied in two aspects: the interference on cell metabolism of microorganism, which would be displayed within a relatively long time, and the destruction of oxidative ability of the nitrifying bacteria, which would be displayed in a short time. In general, the impact from the same kind of toxic substance on nitrite bacteria is typically stronger than that on nitrate bacteria. Heavy metals that have inhibitory function on nitrifying bacteria include Ag, Hg, Ni, Cr, and Zn, among others. Toxic effects range from strong to weak. Other matters containing nitrogen and sulfur, such as thiourea, cyanides and aniline, are toxic as well. Other toxic substances include phenol, fluorides, CIO_4, K_2CrO_4, and trivalent arsenic.

Primary evaluation

Based on the assessment of the technical parameters described above, the nitrification effect in oxic tank should significantly improve in 15 days if the activated sludge with the appropriate temperature and the sludge age, pH level and alkalinity, dissolved oxygen, and other parameters are controlled within the ideal situation. Otherwise, the influent should be tested for toxic substances. The presence of toxic substances inhibits the growth and propagation of nitrifying bacteria.

3.5.1.7 Summary

In view of the operational situation of the sewage plant and the experiences of other plants using a similar process, the nitrogen removal efficiency of the CAST system depends largely on the control conditions of the DO level in different reaction regions. Therefore, the proposed trial run designed by the author of the current study, which is also intended to strengthen the nitrogen removal rate, is mainly based on dissolved oxygen level control.

The proposal is likewise based on factors, such as the biodegradability of raw water and sludge acclivity. The results of the jar test experiments are discussed primarily in order to identify further suggestions. Those for the trial run phase include sufficient evaluation of new types of industrial wastewater before ingathering and strict control of raw water with a low B/C ratio or a high peak value of COD concentration.

3.5.2 Optimal Operating Strategy

3.5.2.1 Operation Arrangement

The CAST was initially operated in cycles of 7 hours. One cycle consisted 100 min of influent and aeration (influent flow rate 750 m^3/h), 4 hours of aeration, 35 min of settling and 45 min of effluent withdrawal (withdrawal flow rate 1670 m^3/h). After four cycles, the microbial flocculation was well prepared. Refer to the past full scale activated sludge facilities (Goronszy, *et al*., 1997), there are two different aeration durations, which are 4.5 hours and 2 hours. The duration of aeration depends on the high and low COD and NH_3-N concentration. The duration of settling is 1 hour. According to a SBR pilot study for microbial flocculation producing (Qiu & Li, 2009), the aeration stage is 6 hours. However, the COD and NH_3-N concentration was slightly decreased after 2.5 hour and 3 hour of aeration respectively. The settling stage in this study was 2 hours for the removal of COD and TP, TN. Typically, a mode of cyclic operation, which cycles are of four hours duration with two hours allocated to combined aeration and mixing and two hours allocated to settle and decant, is universally used for single and multi basin installation activated sludge facilities (Goronszy, 1979). Thus, in this project, after preparation of microbial flocculation, the CAST was operated in cycles of 6 hours. One cycle consisted 45 min of influent and aeration (influent flow rate 2225 m^3/h), 135 min of aeration, 2 hours of settling and 1 hour of effluent withdrawal (withdrawal flow rate 1670 m^3/h). The sludge age was controlled for 10 days and this cycle was operated for 3 life cycles (30 days). The HRT of this CAST is 6.84 hour. During the 30 days, 20 cycles was used to find out the best aeration and settling stage for the next step of experiment. In each cycle, 1 liter of wastewater sample was taken from the same point of CAST reaction tank D nearly decantor at 0 min, 10 min, 20 min, 30 min, 45 min, 60 min, 90 min, 120 min, 150 min, 180 min for aeration reaction and 195 min, 210 min, 225 min, 240 min 255 min 270 min, 285 min and 300 min for anaerobic reaction. This 1 liter sample was tested for the SV30，COD_{cr}, BOD_5, NH_3-N, NO_3-N, NO_2-N,TKN, TP, and MLSS.

3.5.2.2 Data Analysis and Curve Drawing

All laboratory data were collected and analyzed to find out the best time for aeration and settle in the Laboratory Center in Sewage treatment plant in Wuxi. The test parameter has 20 values in the same time point. Mean and Median value of these 20 sets of data were calculated. The mean is generally considered less useful than the median when working with censored geochemical data in this project. Such data are usually so skewed that the mean is not a typical value. Quantile statistics, such as the median and interquartile range (IQR, or Q75-Q25) provide more robust measures of central tendency and variability (Lee & Helsel, 2006). Thus, each test parameter has 20 median values changing by time and the changing curve of each test parameter indicate the best time of aeration and or settle. These changing curves will explain and analysis separately in the following paragraphs.

The testing data was then analysis by box plots, which is a kind of visual presentation of data to extract useful information (Chau & Muttil, 2007). As the influent wastewater quality differs from time to time, box plots provide a better summary of data than the mean calculation. The box plot show a measure of central location (the median), two measures of spread or variation (the range and inter-quartile range), the skewness (from the orientation of the median relative to the quartiles) and potential outliers (marked individually). The line across the box represents the median, which is the point where 50% of the data is above it and 50% below it. The bottom of the box is at the first quartile, Q_1 (where at most 25% of the data fall below it) and the top is at the third quartile, Q_3 (where at most 25% of the data is above it). The box itself represents the middle 50% of the data. The whiskers are the lines that extend from the bottom and top of the box to the lowest and highest observations inside the rage defined by a lower limit of Q_1-1.5(Q_3-Q_1) to an upper limit of Q_3+1.5(Q_3-Q_1), where (Q_3-Q_1) is the inter-quartile range.

3.5.3 Trial Run for Improving Nitrogen Removal and COD Removal Efficiencies

3.5.3.1 Improving Nitrogen Removal Efficiency

Nitrogen removal rate may be affected by temperature, DO, alkalinity, and many other factors. Thus, studies on optimization programs have focused on this topic.

3.5.3.2 Time Arrangement

Phase I: A DO level of <0.5 mg/L was maintained during the preceding 30 min of the inflow/aeration stage; the DO concentration was maintained within 0.5–1.5 mg/L for 30 minutes before the inflow completion and DO concentration of pure aeration was maintained within 2.0–4.0 mg/L. DO level of ≥ 2.5 mg/L was maintained at the end of the aeration stage at the oxic zone (this should be at least 20 minutes or more), after which DO level below 1.0 mg/L in the anoxic zone was maintained for the longest possible time.

Phase II: A DO level of <0.5 mg/L was maintained during the preceding 30 min of the inflow/aerations stage; DO concentration of 0.5–1.0 mg/l was maintained for 30 min before the inflow completion and DO concentration of pure aeration was maintained within 2.0–3.0 mg/L. A DO level of ≥ 2.5 mg/L was maintained at the end of the aeration stage at the oxic zone (this should be at least 20 min or more), after which DO below 0.5 mg/L in the anoxic zone was maintained for the longest possible time.

Indications

The DO level was controlled as close as possible to the operating points described above. It was adjusted along the progress of the trial run and with the trial run results. The pH value, sludge age, and other process parameters should meet the conditions to the greatest extent. Otherwise, the effectiveness of debugging would not be guaranteed.

The sludge return ratio of CAST was set at 20% or more. The ratio determined the total nitrogen removal rate to a great extent. Meanwhile, increasing the speed of the returning pump for nitration liquor was considered after 15 days of the trial run. This is because it may promote the propagation of the denitrifying bacteria.

3.5.3.3 Curve Drawing

The trail run period for improving nitrogen removal rate was implemented for approximately 50 days. The concentration of nitrate nitrogen 30 min after aeration completion and the removal rates of the system for both total nitrogen and ammonia nitrogen were detected every day. Meanwhile, the changing trends of nitrate nitrogen and DO levels with time in one operation cycle were evaluated every five days. Three groups of changing curves were inducted. These are summarized as follows:

1). Changing curve of the total nitrogen and ammonia nitrogen removal rate during the entire trial run period (approximately 40 days);

2). Changing curve of nitrate nitrogen concentration in the CAST tank during the entire trial run period (approximately 40 days); and

3). Changing curve of nitrate nitrogen and DO level vs. time in one operation cycle.

3.5.3.4 Sampling Time/Interval

1). For the water quality sampling and analysis of influent, water sampling time was set in the middle of the inflow time: if the water inflow time was one h, the sampling time was set to half an hour after the start of the water inflow procedure.

2). For total nitogen and ammonia nitrogen sampling and analysis, the sampling time was set as 30 min after the completion of aeration.

3). For total nitogen and ammonia nitrogen sampling and analysis, the sampling time was set 10 min before the completion of decanting; this was sampled from the decanter.

4). The sampling interval for the parameters that should be sampled in one cycle was every 15 min.

5). On-line monitoring of DO was conducted.

6). Those times/sections mentioned above were taken for at least one sampling every day.

7). This process lasted for a minimum of 30 days.

3.5.3.5 Other Points for Attention

The nitrifying bacteria culture generally needs 15 days to create obvious effects under optimum conditions in the aeration tank. Establishing the dominant microflora of nitrifying bacteria requires 30 days on average. Longer time is required in winter. The recovery period of nitrifying bacteria generally needs 10 days after being impacted. Therefore, it is very important to implement the proposed trial run accurately.

Many cases show that the possibility of total phosphorus exceeding the discharge standard is high when high ammonia nitrogen removal rate is achieved. Thus, the chemical phosphorus removal system should be considered in advance; it can also be considered in relation to the coagulation and precipitation units.

Although Polyacrylamide (PAM) or Polyaluminiu Chloride (PAC) may be helpful in sedimentation and improvement of phosphorus removal rate, direct addition of these chemical compounds into the aeration tank should be strictly prohibited. These have negative impact on microbial metabolism, especially during the domestication stage.

3.5.4 Improving COD Removal Efficiency

COD removal rate may be affected by activated sludge, DO, suspended solid, biodegradability, aeration time, and other factors.

3.5.4.1 Time Arrangement

Phase I: The activity of sludge was improved through proper measurement of excess sludge discharge and continuous training of heterotrophic microorganisms; the MLSS value was adjusted by maintaining it within the range of 2500–4000 mg/L to allow the MLVSS/MLSS value to reach 0.8.

Phase II: The limiting degree for the organic matter removal of the biological system was determined through a 15-day continuous assessment the BOD5 and COD values of both influent and effluent, as well as the changing trend of COD concentration in one operation cycle.

The jar test with the bio-treatment effluent and influent was conducted during the two phases of the trial run.

3.5.4.2 Curve Drawing

Based on the changes in COD value during the entire trial run period and in individual operation cycles, together with the experiment results of the jar test, three groups of changing curves were plotted. These are summarized as follows:

1). The curves which represent the changes in COD concentration both in the influent and effluent;

2). The curves of COD and DO concentration vs. time during one operation cycle;

3). The changing curve of residual COD concentration vs. coagulant dosage.

3.5.4.3 Sampling Time/Interval

1). For the water quality sampling and analysis of influent, water sampling time was set in the middle of the feeding time: if the water feeding time was one h, the sampling time should be half an hour after the start of the water feeding procedure.

2). For effluent COD or BOD_5 sampling and analysis, the sampling time was set 10 min before decanting is over. The sample was taken directly from the decanter.

3). Initially, the sampling interval for parameters that should be sampled in one operation cycle was every 10 minutes.

4). On-line monitoring of DO was performed.

5). The time/section sampling mentioned above was taken at least once every day.

6). This process lasted for a minimum of 10 days.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Evaluation and Jar Test Results

4.1.1 Evaluation of Anaerobic Hydrolysis Effect

The BOD_5 and COD concentration data were obtained based on the two-month condition of the influent and effluent of the anaerobic tank at the same time once per day. The results are shown in Table 4.1.

Table 4.1 BOD_5, COD, and B/C ratio of influent and effluent of the anaerobic tank

Date	Influent			Effluent from anaerobic tank		
	COD (mg/l)	BOD (mg/l)	B/C (%)	COD (mg/l)	BOD (mg/l)	B/C(%)
1	254	75.89	29.88	247.3	101.7	41.12
2	156.5	42.47	27.14			
3	132.1	40.42	30.60			
4	114.8	24.5	21.34	106.4	24.5	23.03
5	147.5	44.7	30.31	148.3	40.8	27.51
6	175	56.5	32.29	182	57.3	31.48
7	334	124	37.13	376	173	46.01
8	118	26.9	22.80	119	30.8	25.88
9	163	49	30.06	176	47.4	26.93
10	177.2	53.8	29.06	158.2	53.4	25.83

For processing convenience, BOD_5 and COD weekly average values for influent/effluent were calculated as one cycle. The changes in B/C ratio before and after the anaerobic hydrolysis process are shown in Figure 4.1. Respective trends during the whole observation period are likewise shown.

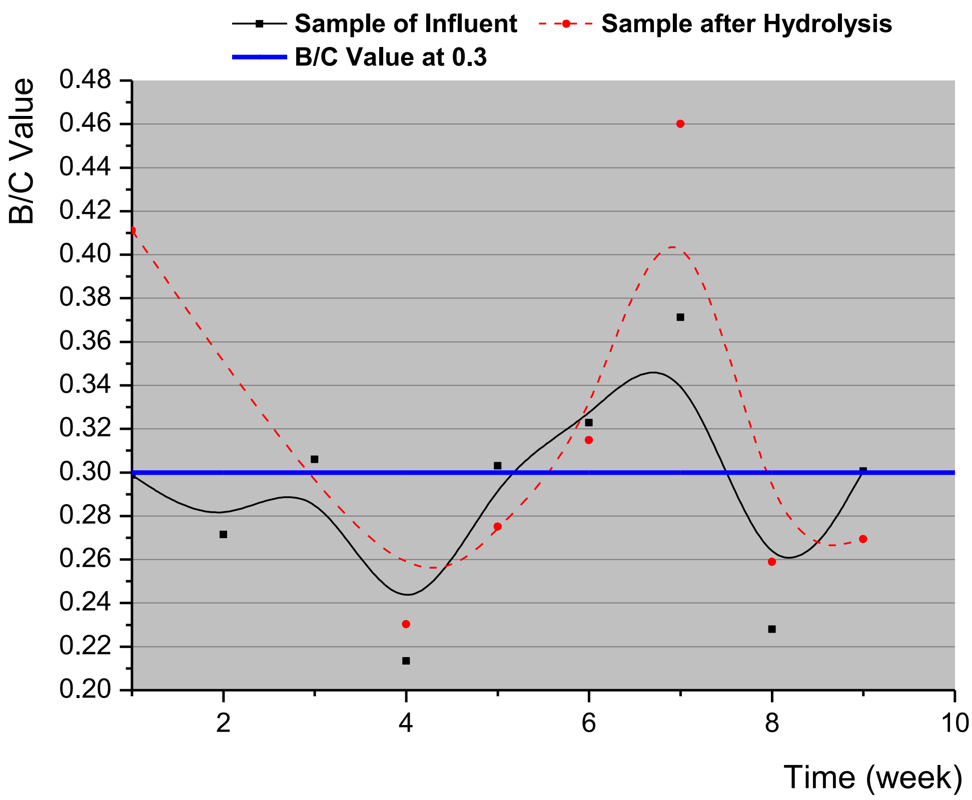

Figure 4.1 Changing trends in B/C ratio before/after the anaerobic hydrolysis process

Table 4.1 indicates that the B/C ratios of raw water coming from the sewage plant are generally below 0.3, and its biodegradability is relatively poor. The main reason for the latter is the inability of the power of the blenders to meet the requirement of the huge amount of industrial waste water received by the sewage treatment plant, especially those of printing and dyeing wastewater. The insufficient blender power, which causes the bad effect of mixing anaerobic sludge with waste water, leads to the continuous decrease in the effective volume of the anaerobic tanks while the system is running, the accumulation of large amounts of excess sludge, and the failure to meet the target hydraulic retention time (HRT) of eight hours in accordance with the original design. Basically, the anaerobic sludge lost its role in hydrolysis. The limited increase of the B/C ratio after the anaerobic hydrolysis process is shown in Table 4.1. Moreover, the COD removal efficiency is less than 20% of the expected result.

The overall connectivity among the four parts of the anaerobic tank and the absence of an accident tank for water storage affect the sequence (such as resetting of new sufficient blenders), which may lead to the failure of the anaerobic tank transformation. In turn, this situation causes the non-improvement of the poor biodegradability and minimizes the ability to effectively control residual COD concentration below 50 mg/L after the anaerobic hydrolysis process. This occurs when sewage with relatively high organic concentration is encountered, which is caused by the exceedingly large proportion of industrial waste water.

The following suggestions are provided for the long-term stable operation of a sewage plant. First, good biodegradability of the sewage should be ensured. Types of industrial wastewater as well as its proportion in relation to the total influent should be effectively controlled and monitored until the anaerobic tank transformation is finished. Second, setting up an accident tank should be considered. This can perform the rectification work when the second phase of the project is implemented. Specifically, a more powerful blender should be installed along with the implementation of flexible packing procedures. These measures can significantly enhance the hydrolysis effectiveness of the anaerobic tank and further ensure that the organic matter removal efficiency after treatment via the biological system can be maintained at a high level.

4.1.2 Evaluation of Raw Water for the Toxic Substrate

Owing to the restriction of the detection method, continuous analysis of the concentration of the toxic substances, such as water with high salinity, mineral oil, cyanide compounds, and phenols of the water samples from the upstream pollution discharge units (factories) cannot be conducted. Through sampling inspections of big quantity pollution discharge units, it has been found that the tail-water salinity of house dye generally remains at 3500–4000 mg/L, and the content of the mineral oil of tail-water from individual steel factories is maintained at around 3–5 mg/L. Although these concentrations of salinity and mineral oil do not reach the fatal concentration levels for microorganisms (8000 mg/L and 20 mg/L), the peak concentrations of the tail-water pollutants caused by house dye production process adjustment and one-trial discharge of high concentration of liquid emulsion by steel factories can lead to destructive impact on the entire biochemical system. Finally, the concentration of cyanide compounds in fluent reached 0.035 mg/L.

Based on the biochemical system paralysis inflicted on the sewage plant in the middle of March 2008, and the large volume of floating oil on the surface of the CAST tank, we proposed that regular selective inspections and sampling analysis of dyehouses and steel factories with large pollutant quantity be conducted, with a particular focus on the concentration of the pollutants, such as mineral oil and cyanide compounds. At the same time, we proposed the enhancement of the capacity of the biochemical system to remove the effects of organics, ammonia, and nitrogen by effectively increasing metabolic frequencies and microorganism activities.

4.1.3 Evaluation of MLVSS and SVI Values

The detection method is limited because it is incapable of inspecting and analyzing the MLVSS value of the biochemical tank. However, based on the fact that the SS concentration of the tail-water in the anaerobic tank remains above 300 mg/L and no primary sedimentation tank has been set up for the entire water treatment process, it can be inferred that the ratio value of MLVSS/MLSS would be less than 80%. At present, this has been recognized by the majority of the municipal sewage treatment plants in Mainland China as the common fault in using CAST or SBR as the main process. In other words, setting up a primary sedimentation tank can possibly improve the removal efficiency of COD.

The inspection of the sludge volume index (SVI) value in CAST tanks was during the mode running. The SVI value was conducted every day but for convenience of description, the average values of the running data for every five days were calculated. These statistics are presented in Table 4.2, and the SVI changing trend during the entire detection process is shown in Figure 4.2.

Table 4.2 SVI values in CAST tanks

Time (day)	5	10	15	20	25	30	35
SVI	60.7	65.3	64.8	65.0	84.9	80.1	80.4

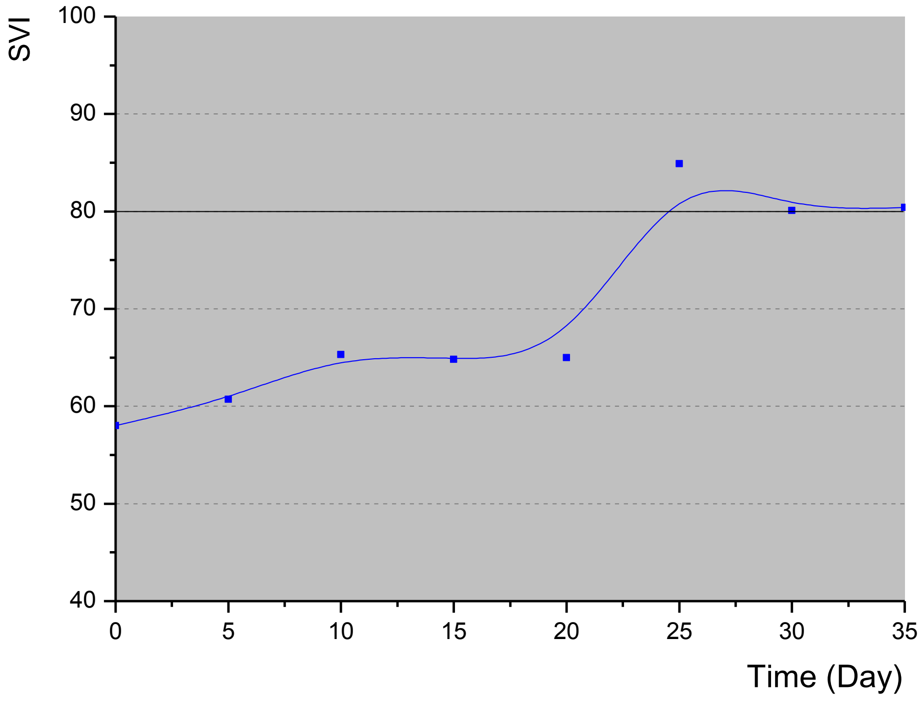

Fig. 4.2 Variations in the trend of SVI values in CAST tanks

After the occurrence of the high organic load paralysis to the sewage treatment system in mid-March 2008, sludge bulking occurred in the CAST tanks, and SVI value increased to above 300. A large number of filamentous breeding was found through microscopic observation. The sludge bulking caused a serious impact to the removal effect of organic matter, leading to the poor sludge settling ability of the CAST tank. The SVI value of the biochemical tanks was controlled at 60 by discharging the large number of dead sludge and stimulating aeration for improved sludge activity at the initial phase of the trial run (Figure 4.2).

Meanwhile, since the COD of influent was relatively lower at that time and both sludge concentration and the propagation rate of the microbes in the tank were not as high as those of the present, SVI value rose slowly and remained stable at 80–90 after 20–25 days. The SS value of supernatant after half-hour sedimentation in the CAST tank remained below 20mg/l. This indirectly reflects reasonable and effective sludge control. However, since sewage sludge dewatering machine has not been put into use, which led to ineffective periodic sludge discharge, aging sludge and floating sludge in CAST tank were both found one month after the trial run. In addition, SVI value was tested to be over 180. COD removal ratio and SS value of effluent also continued to deteriorate.

The following suggestions are proposed for the long-term stable operation of the sewage plant. The theory of "zero discharge of excess sludge" should not be applied to this municipal sewage treatment plant due to the high COD and ammonia-nitrogen concentration in the influent. The sludge volume index (SVI) is the most frequently used index reflecting the sludge concentration and condensation settlement. The plant should conduct periodical detections of the SVI value to track sludge bulking and initiate reasonable discharging of excess sludge. Once sludge bulking occurs, the plant can inhibit the propagation of the filamentous bacteria by increasing the sludge return ratio of the system. This increases the sludge activity to ensure the removal effect of organic compounds and improve the settlement ability of sludge. At the same time, the propagation of the filamentous bacteria can be temporarily controlled through the addition of a chemical agent.

4.1.4 Jar Test on the Bio-Treatment of Effluent

For influents with average COD concentration larger than 400 mg/L and poor biodegradability, it is extremely difficult to control the residual COD level in effluent below 50 mg/L. Some advanced treating units must be applied following the CAST system to ensure that the residual COD concentration meets the new discharge standard. The design indicator of the influent is 500 mg/L for COD of the sewage treatment plant studied. Given that dying waste water occupies most of the influent, it is necessary to increase deep treatment units after the CAST process, with the prerequisite foundation of optimization on process control conditions.

In this experiment, six beakers with three different biochemical effluents were subjected to jar tests comprising the first batch of samples. Polyferric sulfate (PFS) and Fe-Al chloride (PFAC) were used.

PFS solutions (0.2, 0.3, 0.4, 0.5, 0.6, and 0.7 mL) with 10% concentration were added to the six beakers with 1000 mL effluent samples. The samples were stirred for 1 minute with uniform speed. The COD concentrations of the supernatant after the half-hour sedimentation are shown in Table 4.3.

PFAC was added to the other six 1000 mL effluent samples with the following volumes: 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7 mL. The samples were stirred for 1 minute with uniform speed. The supernatant COD data after the half-hour sedimentation of this jar test are shown in Table 4.4.

Table 4.3 Jar test results using PFS as coagulant

Dosage / Sample	COD concentration. (mg/L)						Maximum COD removal ratio (%)
	20ppm	30ppm	40ppm	50ppm	60ppm	70ppm	
Sample-1 COD=100.10mg/l	76.90	73.24	73.24	70.32	65.24	60.54	39.5
Sample-2 COD=79.85mg/l	54.50	46.03	43.23	65.97	53.79	67.41	45.9%
Sample-3 COD=86.53mg/l	67.41	62.36	79.85	55.21	68.86	68.14	36.2

Table 4.4 Jar test results using PFAC as the coagulant

Sample \ Dosage	COD concentration (mg/L)						Maximum COD removal ratio (%)
	30ppm	40ppm	50ppm	60ppm	70ppm	80ppm	
Sample-1 COD=100.10mg/l	88.02	91.02	81.33	78.37	83.55	88.02	21.7
Sample-2 COD=79.85mg/l	79.85	76.17	79.85	73.07	77.64	78.37	8.5
Sample-3 COD=86.53mg/l	80.41	82.36	80.26	75.21	78.86	80.14	13.1

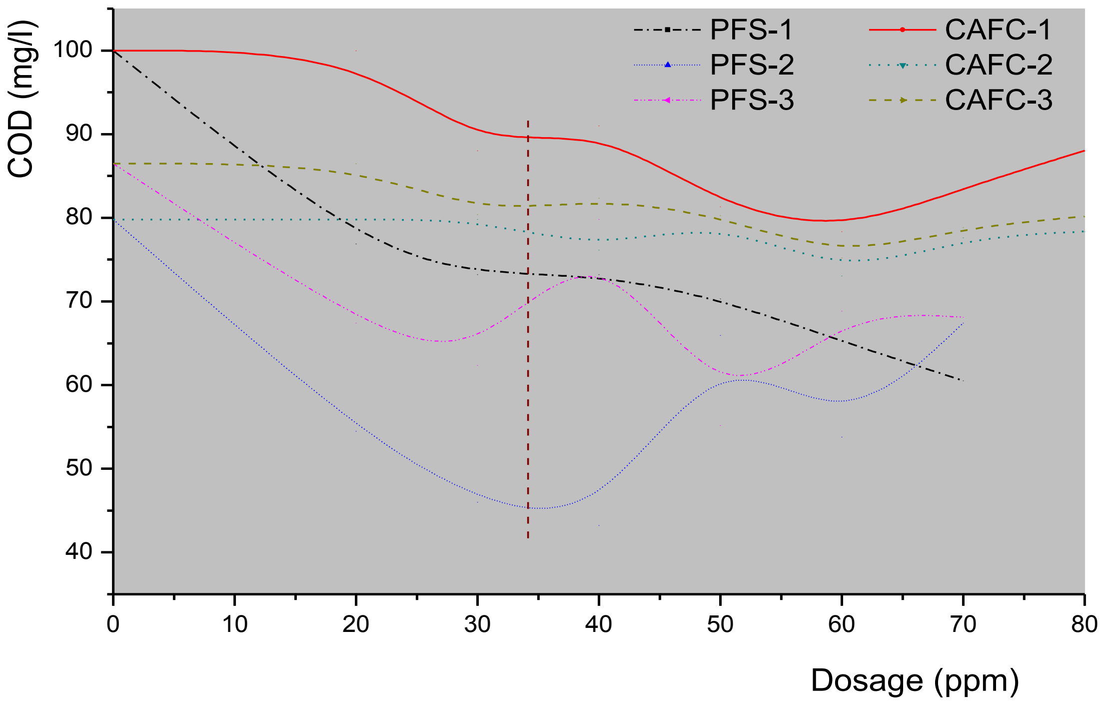

Figure 4.3 Comparison of jar test results with two different coagulants (PFS vs. PFAC)

PFAC as coagulant had less significant effect compared with PFS (Tables 4.3 and 4.4 and Figure 4.3). The removal effect on the COD of effluent samples that used PFS as coagulant ranged within 35%– 45%, while that on the COD of effluent samples that used PFAC ranged within 10%–20%.

In order to determine the optimum dosage and the average COD removal ratio, another set of five effluent samples were used with PFS as the coagulant. The COD change curves according to the dosage of coagulation, which are based on the calculated average COD values of the five samples, are shown in Table 4.5 and Figure 4.4.

Table 4.5 Jar test results using PFS as coagulant (second batch)

Dosage / Sample		COD concentration (mg/L)						Max. COD removal ratio (%)
		30ppm	40ppm	50ppm	60ppm	70ppm	80ppm	
Sample-1	56.6	51.4	50.9	47.2	37.7	47.4	45.3	33.4
Sample-2	52.4	37.7	36.3	32.2	26.0	39.1	28.0	50.4
Sample-3	66.0	50.2	35.6	35.6	32.2	29.4	46.0	55.4
Sample-4	63.8	52.6	41.8	30.1	31.5	33.5	32.8	52.8
Sample-5	60.2	44.7	39.8	34.6	42.5	41.6	37.7	42.5
Mean Value	59.80	47.32	40.88	35.94	33.98	38.20	37.96	43.2

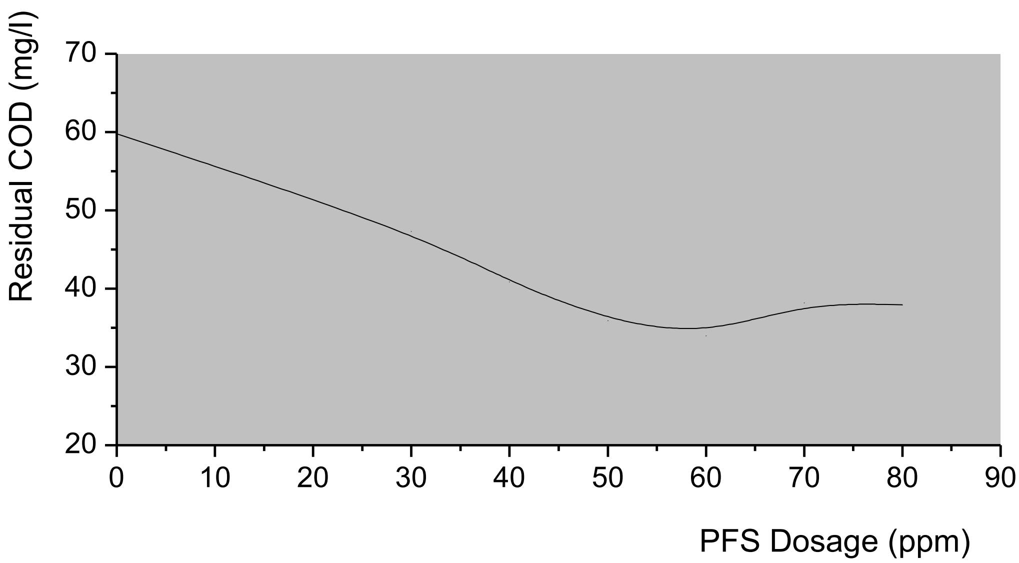

Figure 4.4 hanging curve of the residual COD concentration vs. PFS dosage

When the dosage of PFS reached the optimal point (50–60 ppm), coagulation precipitation reactions obtained an additional 33%–55% of COD removal with effluent treated by the biochemical system (Figure 4.4). Average removal effect was approximately 40%. The residual COD concentration of sewage with COD concentration of 50–75 mg/L after the biological treatment in the CAST tank also remained at a value below 50 mg/L, which was the discharge standard. This was achieved after treatment in the coagulation precipitation units. In effect, by adding PFS as coagulant, the sewage plant achieved satisfactory COD removal effect.

In addition, residual SS concentration after the coagulation precipitation reactions was tested. Data show that the SS concentrations from all the tests results are higher than 20 mg/L. Given that the settlement velocity of the common sedimentation tank is far greater than the CAST tank for the whole surface area of the CAST tank, the settlement effect of the former may be inferior to that of the latter. From this, it can be predicted that residual SS concentration from the precipitation units would not meet the new discharge requirements (SS $\leq$ 20 mg/L). At the same time, since the standard of SS $\leq$ 20 mg/L is already close to the requirement for water reuse, using some form of filtering units should be an important consideration.

4.1.5 Jar Test on Influent

Six beakers with three different sewage plant influents underwent jar tests. PFS (0.3, 0.4, 0.5, 0.6, 0.7 and 0.8mL with 10% concentration) was added as coagulant to each beaker containing 1000 mL influent samples. These were stirred for 1 minute with uniform speed. The COD concentrations of supernatant tested after the half-hour sedimentation are shown in Table 4.6.

Table 4.6 Jar test results using PFS as coagulant for influent

Sample \ Dosage		COD concentration (mg/L)						Maximum COD removal ratio (%)
		30ppm	40ppm	50ppm	60ppm	70ppm	80ppm	
Sample-1	314.5	277.50	265.70	236.90	231.20	235.9	239.2	26.5
Sample-2	206.6	171.4	140.1	161.5	135.3	145.8	152.6	34.5
Sample-3	156.5	137.7	120.2	100.1	95.1	97.8	105.4	39.2
Sample-4	126.5	102.2	91.8	77.6	79.8	65.9	68.9	47.9
Mean Value	201.0	172.2	154.5	144.0	135.4	136.4	141.5	32.6

The average COD removal rate of coagulation and precipitation of influent reached approximately 30% (Table 4.6). This indicates that the effect of using coagulation and precipitation units on influent as pretreatment is slightly worse (i.e., more than 40% of COD removal rate) than the effect of using the coagulation and precipitation units on effluent as the advanced treatment. In addition, “the higher the organic concentration of the influent, the worse the COD removal rate of the coagulation and precipitation units (as pretreatment)” reflects that the content of the insoluble organic matter in influent did not increase with the increase of COD concentration. As a result, coagulation and precipitation pretreatment cannot obtain the desired removal effect on the COD for influent with high organic concentration. In contrast, for influent with low organic concentration, the residual COD concentration in effluent could stably reach the standard after undergoing the biochemical process and coagulation unit as the advanced treatment. However, if the coagulation units of the pretreatment can be used together with the primary settling tank, setting up the whole treatment system is a worthy consideration. This can help in achieving the COD removal effect and the high performance ratio.

4.1.6 Observation on Microbe Form in the Activated Sludge

The trial run of this study began from the CAST tank, which had been idle for a long time. Thus, the whole process of activated sludge domestication and organism propagation were not observed completely. During the sludge recovery period, large amounts of cysts were observed, together with some filamentous bacteria, *actinomycetes*, wreckage of fixed-ciliates, and the framework materials that consisted of activated sludge floc. On the other hand, living organisms, such as vorticella and rotifer, were not found easily. After three to four days with sufficient aeration, it was found through microscopic study that the species of swim-ciliates increased rapidly, and that a small amount of living epistylis began to appear in the sludge. With continuous domestication, many fixed-ciliates (mainly epistylis) were found. All kinds of rotifer were likewise observed. At this stage, the quality of the effluent water leveled off. In addition, ammonia nitrogen removal effect was achieved, which indicates the occurrence of nitrification reaction.

After over a month, several kinds of daphnia were observed in the biofacies, indicating that the activated sludge was mature, and organisms were living in an appropriate environment. This is a sign of the completion of the initial activated sludge domestication.

During the latter period of trial run, nematodes and paramecium were found several days after the bio-system was impacted by influent with high organic concentration. At the same time, as the sludge aged, zoogloea that usually facilitated flocculation began to grow. All these indicate that the water quality of the effluent became poor; particularly, the nitrogen removal rate of the system declined sharply. Meanwhile, data for the sarcodina organism were not gathered due to procedural limitations. This should be a major concern of future studies.

4.2 Running Mode Setting for Optimal Operating Strategy

4.2.1 COD and BOD Removal Efficiency

The removal of COD (BOD) can be accomplished in a number of aerobic suspended growth and required sufficient contact time between the wastewater and heterotrophic microorganisms and sufficient oxygen and nutrients. During the initial biological uptake of the organic material, more than half of it is oxidized and the remainder is assimilated as new biomass, which may be further oxidized by endogenous respiration. From the Table 4.7 and Figure 4.5, it can be found that COD concentration dropped quickly at the first 60 min. After 2 hours aeration reaction, the COD concentration was 46 mg/L which is below 50 mg/L (Discharge standard). And in the next 3 hours reaction, the COD concentration has slightly fluctuation ±3. The highest COD removal rate was near 83%. The residual COD (BOD) might due to the unsure of sufficient nutrient (N and P) which might not enough for the amount of COD to be treated

The removal of BOD can be accomplished in a number of aerobic suspended growth and required sufficient contact time between the wastewater and heterotrophic microorganisms and sufficient oxygen and nutrients. BOD concentration, as a part of COD, is decreased constantly during the first 90 min (from the Table 4.9 and Figure 4.6,). The residual BOD concentration is below the discharge standard (10 mg/L) after 2 hours reaction. And as the same situation of COD, the BOD concentration has nearly no decrease in the following 3 hours. The maximum BOD removal rate is about 95%.

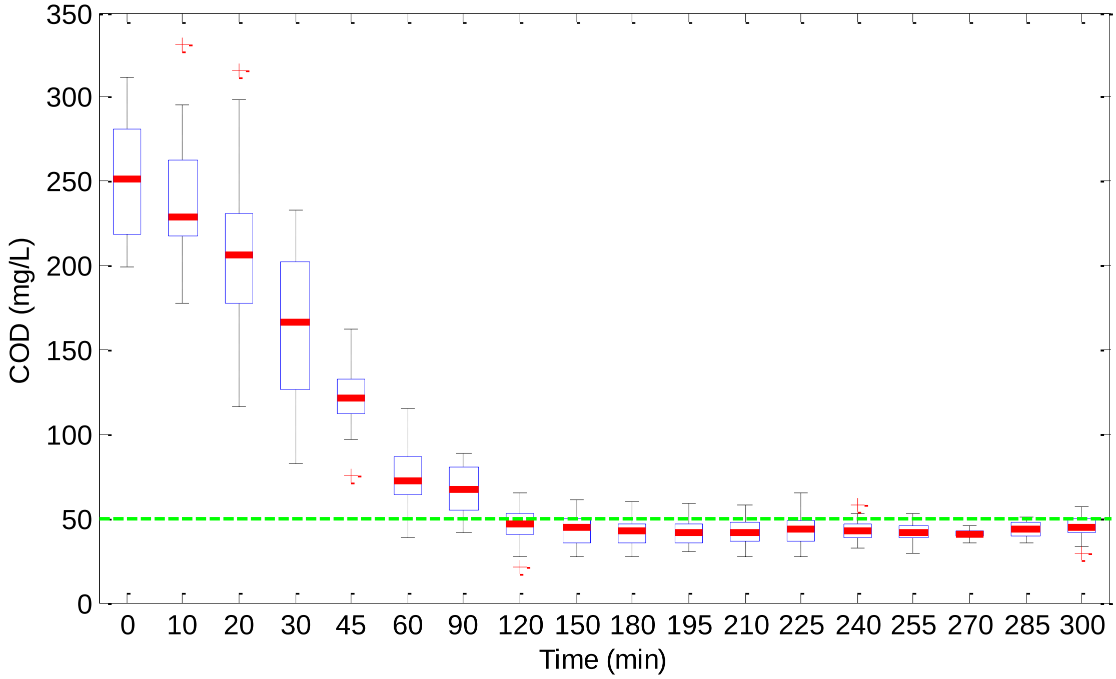

Figure 4.5 Changing curve of the COD concentration vs. Time

Table 4.8 Mean value and median value of COD Concentration VS Time (Removal percentage based on median value)

Time (min)	COD Mean Value (mg/L)	COD Median Value (mg/L)	COD Removal Percentage (%)
0	250	251	0
10	238	228	5
20	209	206	16
30	164	166	34
45	121	122	52
60	74	72	70
90	67	67	73
120	45	46	82
150	43	44	83
180	42	42	83
195	41	41	83
210	42	42	83
225	43	43	83
240	43	42	83
255	41	41	83
270	41	41	84
285	43	43	83
300	45	45	82

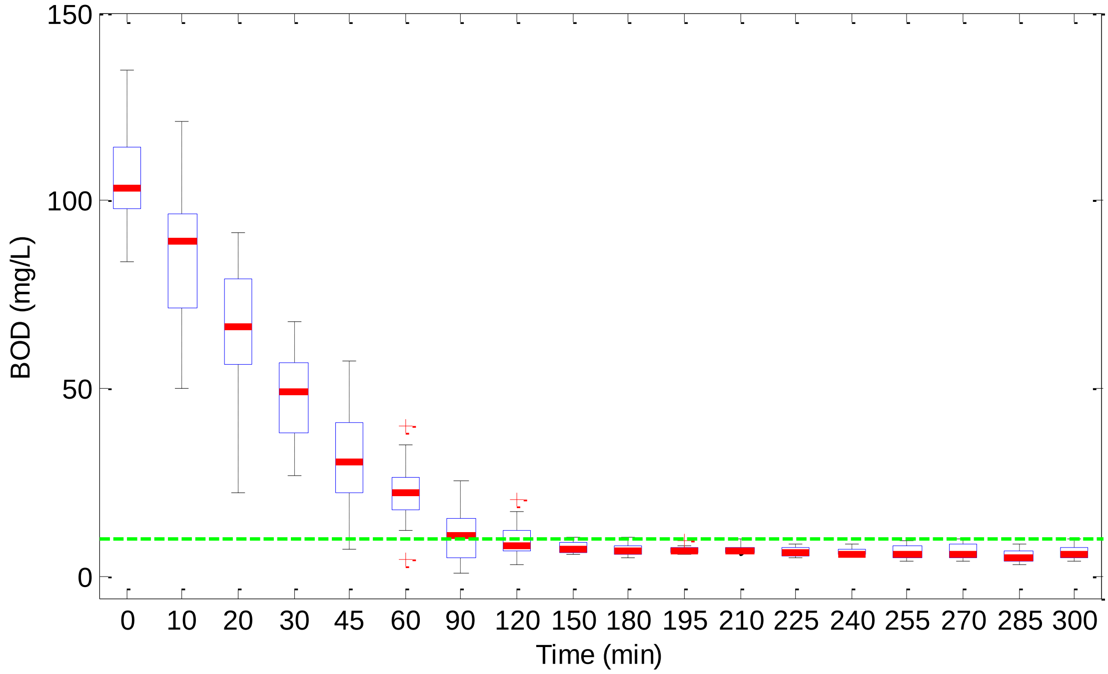

Figure 4.6 Changing curve of the BOD concentration vs. time

Table 4.8 Mean value and median value of BOD Concentration VS Time (Removal percentage based on median value)

Time (min)	BOD Mean Value (mg/L)	BOD Median Value (mg/L)	BOD Removal Percentage (%)
0	106	103	0
10	86	89	13
20	65	67	35
30	48	49	52
45	31	31	70
60	22	22	78
90	11	11	90
120	10	8	92
150	8	7	93
180	7	7	93
195	7	7	93
210	7	7	93
225	7	6	94
240	7	6	94
255	7	6	94
270	7	6	94
285	6	5	95
300	6	6	94

4.2.2 Nitrogen Removal Efficiency

As with BOD removal, nitrification can be accomplished in suspended growth. A more common approach is to achieve nitrification along with BOD removal in the same single-sludge process. From Figure 4.7 and Table 4.9, it can be found that the NH_3-N concentration dropped quickly after 30 min aeration reaction. And at the 90 min, the NH_3-N concentration was below the discharge standard (5 mg/L). The decreasing nearly stopped till 150 min which indicate nearly all nitrification reaction was finished and Nitrogen in ammonia was converted into nitrite and nitrate by nitrification bacteria. The highest removal rate was about 98% and the final concentration of ammonia nitrogen is about 0.6%.

As mentioned before, nitrate-nitrogen, nitrite-nitrogen and TKN were analyzed the wastewater sample. In this project concentration of total nitrogen was the sum of the concentration of nitrate-nitrogen, nitrite-nitrogen and TKN. The TKN concentration was decreased from 25.2 mg/L to below 1 mg/L during aeration stage. However, the concentration of nitrate-nitrogen was increasing due to the nitrification reaction and nitrite-nitrogen was only the interim product of nitrification and denitrification reaction. Therefore, total nitrogen concentration did not have significant decrease during first 3 hour (Figure 4.8 and Table 4.10). Once the CAST tank stopped aeration and changed into settle stage. The denitrification reaction started immediately which directly reflected in a sharp decreasing TN concentration. Denitrification occurs after nitrification and the electron donor source is from endogenous decay. The process illustrated is generally termed as postanoxic denitrificaiton as BOD removal has occurred first and is not available to drive the nitrate reduction reaction. When a postanoxic denitrification process depends solely on endogenous respiration for energy, it has a much slower rate of reaction than for the preanoxic processes using wastewater BOD. The sum concentration decreased during 180-240 min. Although, theoretically the TN should not show the significant decreasing during this period, the sample taking and analysis might interfere the results. Repeated tests might need to carry out to further analysis the TN concentration change with the time. In 240min, which also means 1 hour settle, the concentration of total nitrogen was 14.6 mg/L which is slightly lower the discharge standard (15 mg/L). Decline rate of total nitrogen concentration got slower and the final concentration is 11.5 mg/L with 70% removal rate.

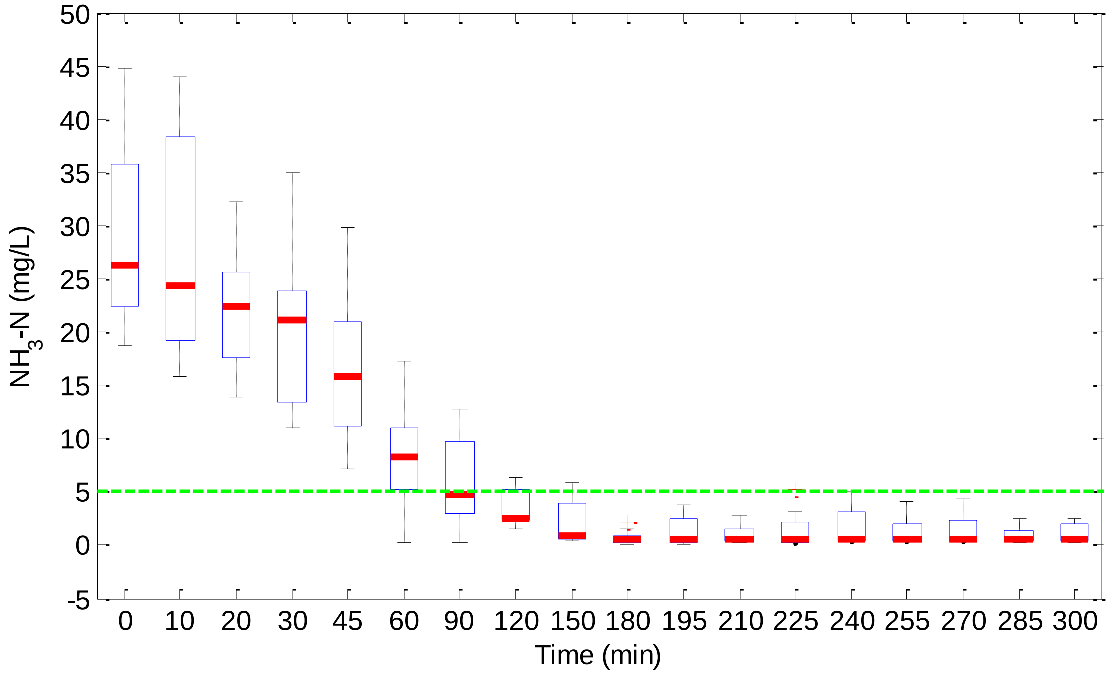

Figure 4.7 Changing curve of the NH_3-N concentration vs. time

Table 4.9 Mean value and median value of NH_3-N Concentration VS Time (Removal percentage based on median value)

Time (min)	NH_3-N Mean Value (mg/L)	NH_3-N Median Value (mg/L)	NH_3-N Removal Percentage (%)
0	29.1	26.3	0
10	28.8	24.4	7
20	21.8	22.4	15
30	20.2	21.2	20
45	16.7	15.8	40
60	8.6	8.2	69
90	5.8	4.8	82
120	3.5	2.6	90
150	2.1	0.9	96
180	0.6	0.5	98
195	1.2	0.5	98
210	1.0	0.5	98
225	1.3	0.6	98
240	1.7	0.5	98
255	1.2	0.5	98
270	1.4	0.6	98
285	0.9	0.5	98
300	1.1	0.6	98

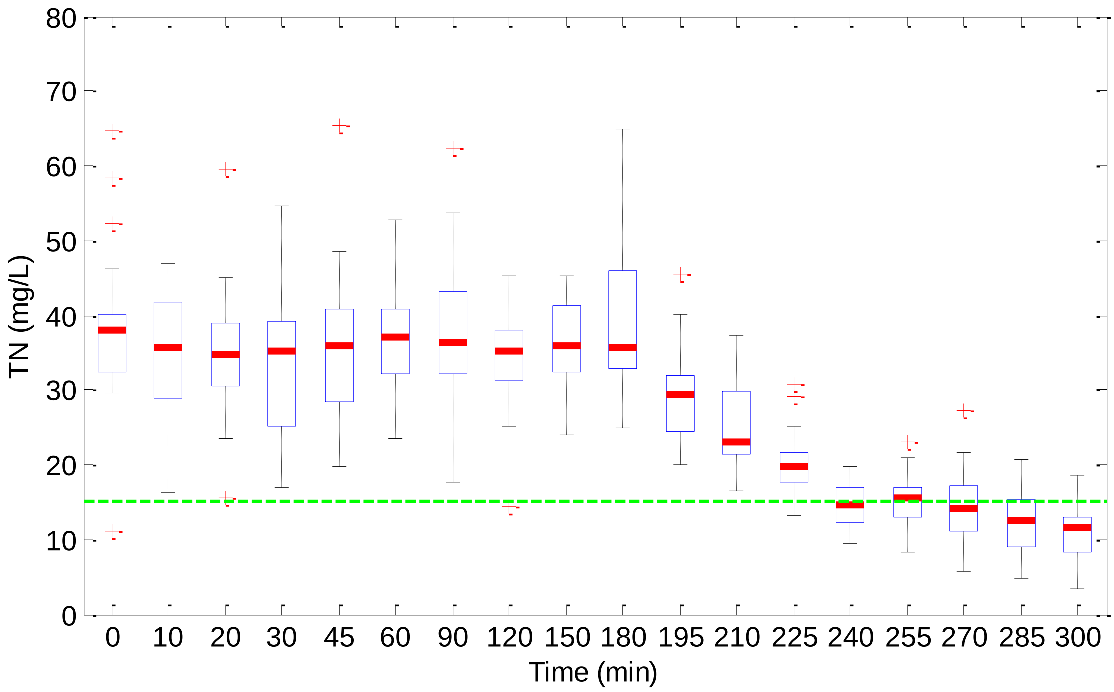

Figure 4.8 Changing curve of the TN concentration vs. time

Table 4.10 Mean value and median value of TN Concentration VS Time (Removal percentage based on median value)

Time (min)	TN Mean Value (mg/L)	TN Median Value (mg/L)	TN Removal Percentage (%)
0	38.3	37.9	0
10	34.8	35.6	6
20	34.7	34.8	8
30	33.1	35.1	7
45	35.7	36.0	5
60	36.9	37.0	2
90	37.7	36.4	4
120	34.2	35.3	7
150	36.2	36.0	5
180	38.9	35.7	6
195	29.2	29.3	23
210	25.6	23.1	39
225	20.3	19.8	48
240	14.7	14.6	62
255	15.1	15.6	59
270	14.5	14.1	63
285	12.2	12.5	67
300	11.1	11.5	70

4.2.3 Total Phosphorus (TP) Removal Efficiency

Phosphorus removal is generally done to control eutrophication because phosphorus is a limiting nutrient in most freshwater systems. The phosphorus in the influent wastewater is incorporated into cell biomass, which subsequently is removed from the process as a result of sludge wasting. It can be concluded from Figure 4.9 and Table 4.11, at the beginning of aeration reaction, the highly concentration of initial COD and ammonia nitrogen were consume a lot of dissolved oxygen (DO). Because the aeration air amount was constant, the DO stayed in a low level at the beginning and the CAST tank was in a hypoxic state. Phosphorus accumulating organisms are encouraged to grow and consume phosphorus in systems that use a reactor configuration that provides phosphorus accumulating organisms wish a competitive advantage over other bacteria. The reactor configuration utilized for phosphorus removal is comprised of an anaerobic condition. Therefore, under anaerobic conditions, phosphorus accumulating organisms would assimilate fermentation products into storage products within the cells with the concomitant release of phosphorus from stored polyphosphates. In this case, phosphorus bacteria released the phosphorus and the TP concentration was increased to nearly 5 mg/L during first 10 min. And under aerobic conditions, energy is produced by the oxidation of storage products and polyphosphate storage products and polyphosphate storage within the cell increases. In the following aeration reaction, the phosphorus was absorbed by bacteria and the concentration was decreasing to below 0.5 mg/L. When the settling stage started which DO decreased, the TP concentration had a slightly increasing. After one hour settling, the TP concentration decreased to 0.38 mg/L which was below the discharge standard (0.5 mg/L) and the final TP concentration was 0.34 mg/L and the removal efficiency was nearly 90 %.

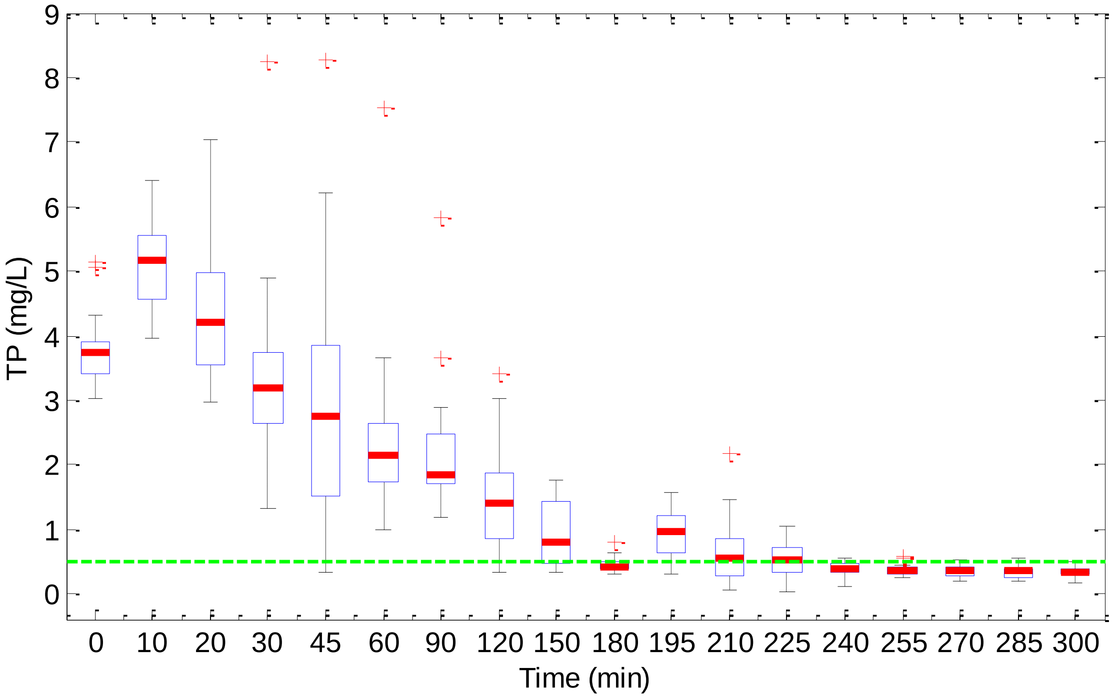

Figure 4.9 Changing curve of the TP concentration vs. time

Table 4.11 Mean value and median value of TP Concentration VS Time (Removal percentage based on median value)

Time (min)	Mean Value (mg/L)	Median Value (mg/L)	Removal Percentage (%)
0	3.79	3.76	0
10	5.13	5.17	-38
20	4.39	4.22	-12
30	3.43	3.19	15
45	2.92	2.76	26
60	2.43	2.15	43
90	2.22	1.84	51
120	1.51	1.40	63
150	0.96	0.82	78
180	0.46	0.42	89
195	0.92	0.97	74
210	0.67	0.56	85
225	0.53	0.52	86
240	0.39	0.38	90
255	0.37	0.37	90
270	0.35	0.36	90
285	0.35	0.35	91
300	0.34	0.34	91

4.2.4 MLSS and TSS Performance

Activated sludge consists of a mixed community of microorganisms. The function of microorganisms is metabolizing and transforming the organic and inorganic substances into environmentally acceptable forms and using the carbonaceous organic matter as energy source for the production of new cells. The MLSS in CAST reaction tank consists of bacteria and higher organisms. Bacteria constitute the majority of microorganisms. Aerobic and anaerobic bacteria both exist in the activated sludge and some preponderance species have ability to live in either the presence of or lack of dissolved oxygen. The success of activated sludge process is depending on establishing a mixed community of microorganisms that will remove and consume organic waste material. And the microorganisms also will aggregate and adhere in the bioflocculation process. The species of microorganism that dominates a system depends on environmental conditions, process design, the operation cycles of plant and the characteristics of the influent (Water Environment Association, 1987). The MLSS concentration in the reactor was expected to decrease as the fill period progresses. This expectation due the incoming feed which diluting the original MLSS concentration. MLSS will show an increase during the aeration phase because of substrate assimilation and cell multiplication (Irvine *et al.*, 1977).

The mixed liquor suspended solids (MLSS) separated by flocculation and gravity sedimentation from treated wastewater after aeration. One of the goals of sedimentation is to create an effluent low in total suspended solide (TSS) in the upper portion of CAST tank and a thickened activated sludge composed of flocs in the bottom portion in tank.

After consuming organic and other nutrient, the microorganisms would growth and the MLSS would increase. Observed from Figure 4.10 and Table 4.12, at the earlier 30 min of the cycle, MLSS was increased from about 2700 mg/L to about 3500 mg/L. Then MLSS stayed in range of 3500 mg/L for the following half hour. MLSS has a great growth in the following one hour due to the microorganism using COD as organic source. In the third hour of aeration reaction, the carbon source easily digested from COD was nearly exhausted, the microorganism was internal consume and the MLSS had a significantly decrease. At the end of aeration reaction, the MLSS can keep in 3000 mg/L. The figure indicated that the best aeration stage for MLSS was no more than 2 hours. SVI also gave out the supporting data to prove it (Figure 4.11 and Table 4.13). The sludge volume index (SVI) is the volume in milliliters (MLSS) occupied by 1 g of a suspension after 30 min settling (SV30). As mentioned before, the SVI typically is used to monitor settling characteristic of activated sludge and other biological suspensions. In the last 1 hour aeration, the SVI was increased which indicated the filamentous type of the bacteria was increasing is the activated sludge system. The bacteria contributed to the increase of SVI (SVI > 150 mg/L) were also known as filamentous bulking (Richard, *et al.*, 2003). In the third hour of aeration, the SVI values were over 100 mg/L which indicated the growth of filamentous bacteria. When In the settling stage, the SS was settling immediately and reached the discharge standard (20mg/L) at the 225 min (45 min of settling). The SS concentration achieved the lowest point 15 mg/L at 255 min (75 min of settling). Because the denitrification reaction and other activated sludge reaction, part of settled sludge were floating with nitrogen and part were bulking. Therefore, the SS had an obviously increase in the left settling stage. In the end of setting stage, the SS concentration was 30 mg/L which exceeded discharge standard.

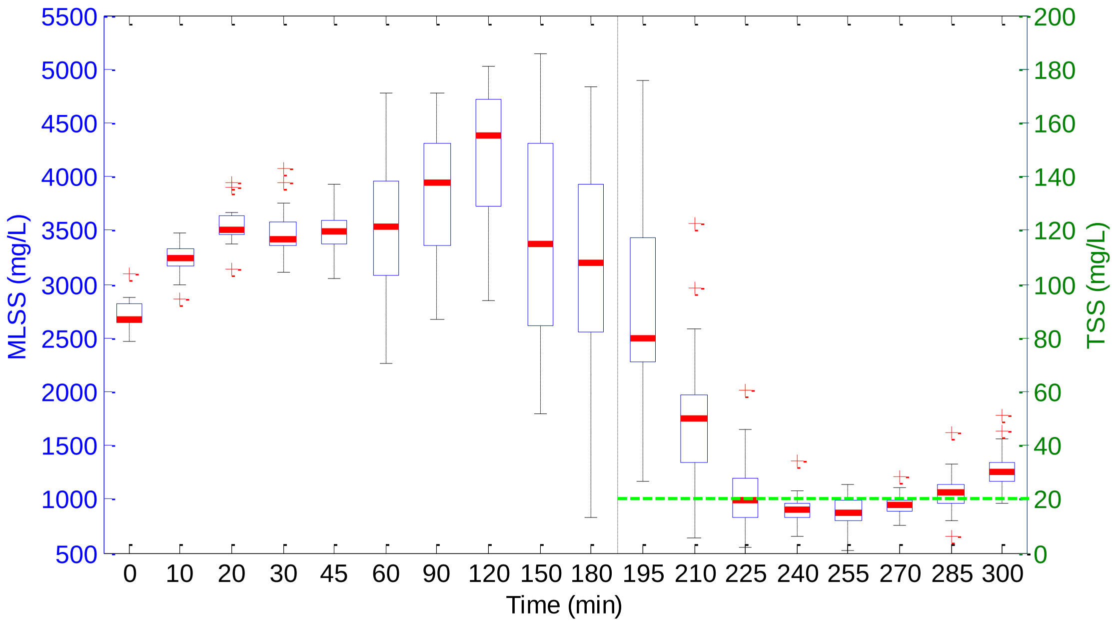

Figure 4.10 Changing curve of the MLSS/TSS concentration vs. time

Table 4.12 Mean value and median value of MLSS/TSS Concentration VS Time

Time (min)	MLSS/TSS Mean Value (mg/L)	MLSS/TSS Median Value (mg/L)
0	2717	2678
10	3236	3239
20	3542	3510
30	3482	3420
45	3497	3487
60	3533	3538
90	3823	3946
120	4217	4379
150	3352	3375
180	3178	3193

Time (min)	MLSS/TSS Mean Value (mg/L)	MLSS/TSS Median Value (mg/L)
195	92	80
210	50	50
225	22	19
240	16	16
255	15	15
270	18	18
285	23	22
300	31	30

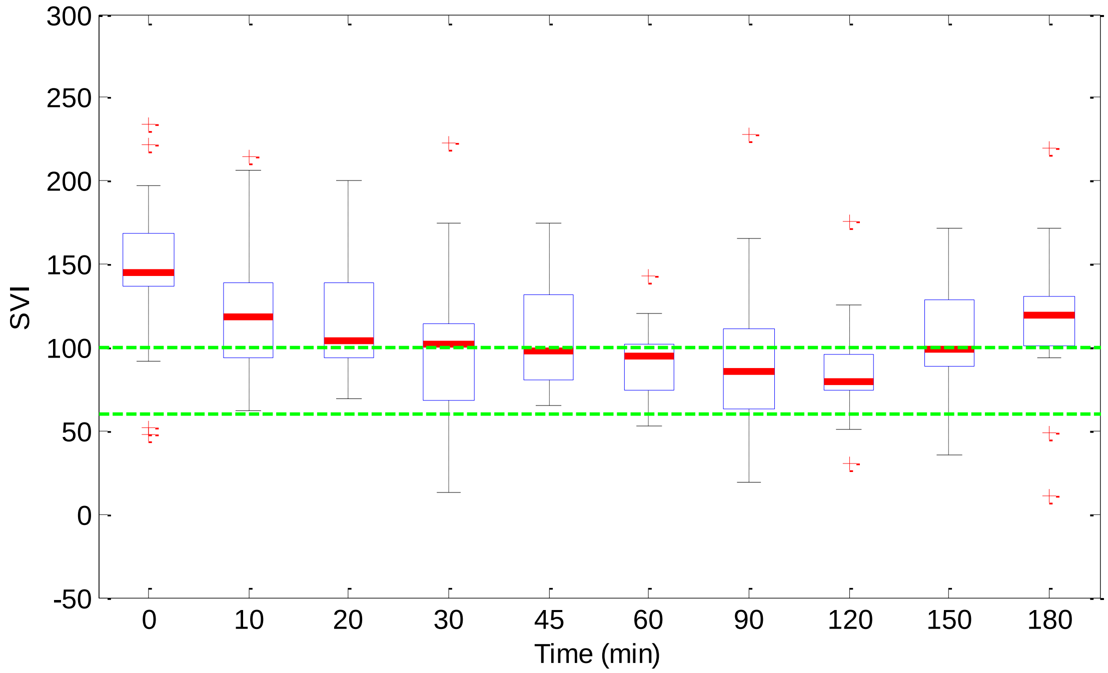

Figure 4.11 Changing curve of SVI vs. Time

Table 4.13 Mean value and median value of SVI vs. Time

Time (min)	Mean Value	Median Value
0	148	145
10	120	118
20	116	104
30	99	102
45	108	98
60	91	94
90	93	85
120	87	80
150	104	99
180	118	119

In activated sludge operation, there are types of microbiological problems that can occur (Richard, *et al*., 2003). These include dispersed (non-settleable) growth, pin floc problems, zoogloeal bulking and foaming, polysaccharide ("slime") bulking and foaming, nitrification and denitrification problems, toxicity, and filamentous bulking and foaming. In sewage treatment plant, the filamentous bulking and foaming was one of the most concern microbial problems. The best approach to troubleshooting the activated sludge process is based on microscopic examination. The wastewater samples were observed under microscope. There were two main types of bacteria performance observed during this period. At the beginning of the test, most of the bacterial floc was irregular and filament which showed in Figure 4.12 (a) and (b), the bacterial was lack of structure and filamentous bacterial was dominant in the activated sludge. It proofed the high SVI value in the earlier period of aeration reaction. After this test running for several days, the compact structure of bacteria can be observed (Figure 4.12 (e), (f)). The ciliates and rotifers also can be observed ((Figure 4.12 (g), (h)) which was the sign of the well performance of bacteria. Excess aeration also caused bacteria problems showed in Figure 4.12 (c), (d), the floc presented open structures and slightly filamentous bacteria can be found. The growth of filamentous bacteria in the excess aeration period was due to the low COD concentration at the end of aeration stage. The lack of organic source induced the growth of filamentous bacteria.   The high SVI value and low MLSS value also can be proofed by this observation. Therefore, if COD concentration cannot show a clear decrease, excess aeration might lead to the bad performance of activated sludge and also results the unsatisfactory MLSS and SVI value. And as studied for nitrification in Chapter 2, low fil-ration volumes provided high levels of nitrification which also identified with filamentous sludge bulking when oxygen supply greatly exceeded oxygen demand. Therefore, an approximate balanced oxygen demand and oxygen supply was a very important factor to control the filamentous sludge bulking control.

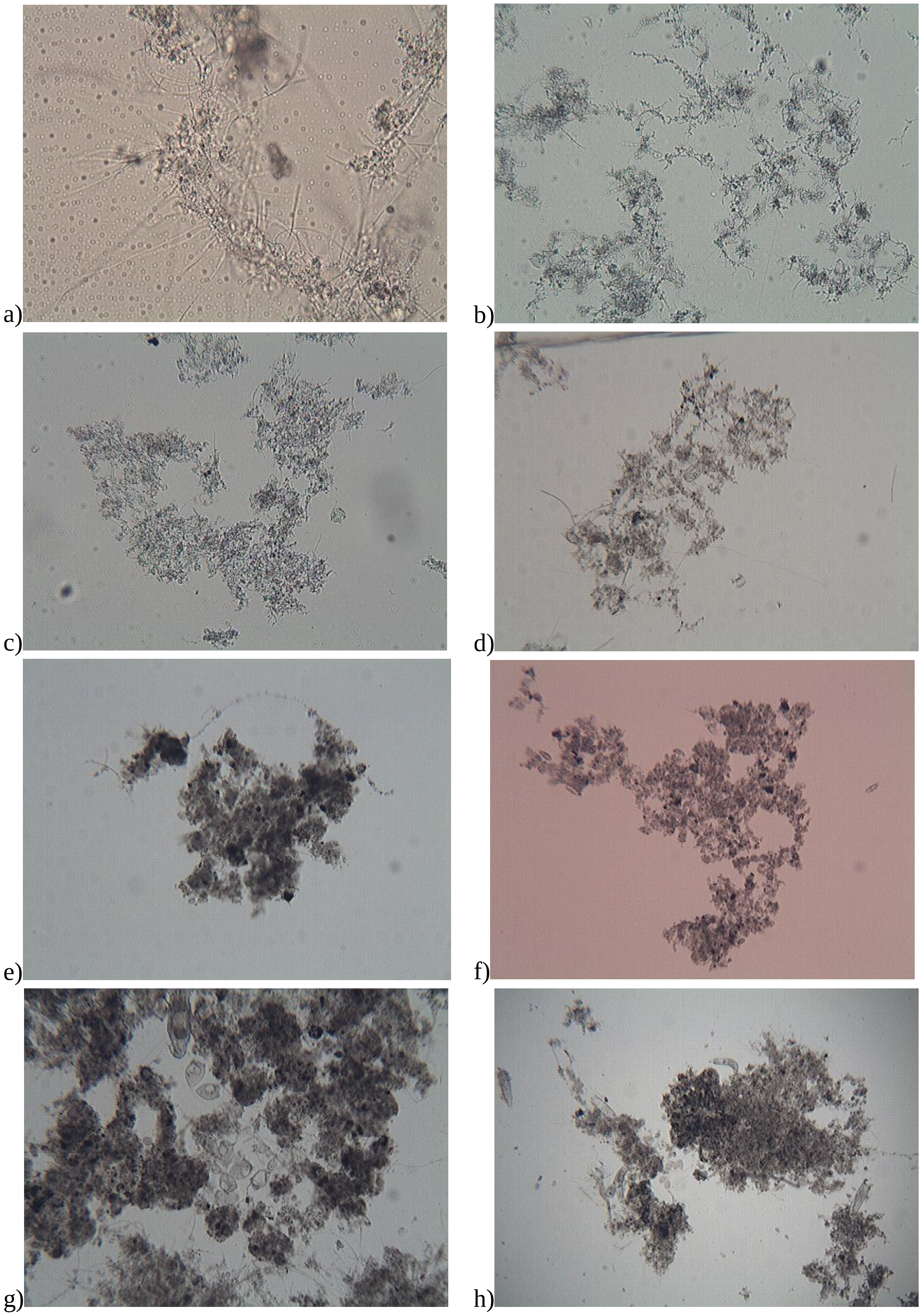

Figure 4.12 Microscopic changes observation: a) Irregular, sprawled flocs with filament (x100 mag); b) Poor floc formation with filament (x40 mag); c) Irregular, open flocs (x40 mag); d) Irregular flocs with poor formation (x40 mag); e) Compact flocs (x40 mag); f) Compact floc with open structure (x40 mag); g) Compact floc with colony ciliates (x40 mag); h) Compact floc structure with ciliates and rotifers (x40 mag)

After the 30 days operation data analysis, it can be found that:

- Although, NH_3-N concentration was below the discharge standard in the 90 min of aeration stage, only after 2 hours aeration, COD and BOD concentration can reach the discharge standard.
- 3 hours aeration was not contribute to the activated sludge performance.
- For settling stage, TP and TN concentration only reach the discharge standard after 1 hour settle.
- When settling stage more than 1 hour, the effluent SS and SVI had a non-expected increase.

Concluded above, the detailed running mode parameters were as follows: Inflow/aeration and pure aeration for 2 hours, sedimentation for 1 hour and decanting/sludge discharging /idling for 1 hour. This total running cycle took 4 hour and was the best choice to conduct a sewage treatment in the CAST reaction tank and also the following COD and NH_3-N removal running tests. The running was different to the detailed running mode parameters setting by Hu, *et al.*(2006) which were as follows: inflow/aeration- 45 min, pure aeration- 115 min, sedimentation- 35 min, and decanting/sludge discharging/idling- 45 min. And the F/M ratio is 0.12 BOD/MLSS/d and volumetric ORL is 0.36 kgBOD/m^3/d.

The ultimate running mode obtained a range of adjustments by referring to the operating experience of the plant for the past year. Adjustments were made in accordance with the aeration and sedimentation time demands.

4.3 Trial Run for Improving NH_3-N and TN Removal Efficiencies

The detection of NH_3-N, TN, and NO^{3-}-N lasted for approximately two months. The NH_3-N and NO^{3-}-N value of influent and effluent water samples were tested every working days (0 means no results on that day). Detailed data are presented in Table 4.14. The changing trends of the NH_3-N and TN removal rates during the entire debugging period are shown in Figure 4.13. The changing trend of nitrate nitrogen concentrations (30 minutes after completion of pure aeration) is shown in Figure 4.14.

Table 4.14 Ammonia nitrogen/Total nitrogen/Nitrate nitrogen data

	NH_3-N			TN			NO_3^--N
	Influent (mg/l)	Effluent (mg/l)	Removal efficiency (%)	Influent (mg/l)	Effluent (mg/l)	Removal efficiency (%)	30 minutes after aeration (mg/l)
1	24.64	25.62	-4.0	33.60	28.80	14.3	0.40
2	23.10	23.38	-1.2	32.70	29.40	10.1	0.36
3	25.76	16.94	34.2	35.60	26.90	24.4	1.26
4	15.68	16.80	-7.1	19.50	18.70	4.1	0.02
5	15.26	13.86	9.2	20.40	19.60	3.9	1.15
6	17.08	15.12	11.5	21.60	18.90	12.5	0.95
7	20.02	17.92	10.5	22.00	19.80	10.0	1.60
8	18.76	14.98	20.1	22.30	20.50	8.1	2.74
9	23.52	12.88	45.2	26.90	22.40	16.7	6.22
10	17.64	16.38	7.1	22.00	17.90	18.6	1.04
11	19.25	16.32	15.2	24.20	19.20	20.7	1.98
12	11.63	6.28	46.0	15.20	10.90	28.3	2.26
13	20.44	10.90	46.7	24.60	21.50	12.6	7.52
14	18.05	6.69	62.9	18.30	17.20	6.0	8.21
15	17.07	4.25	75.1	23.00	18.90	17.8	10.50
16	22.25	3.36	84.9	26.40	19.80	25.0	9.65
17	19.1	5.28	72.4	23.50	19.20	18.3	10.22
18	18.5	2.60	85.9	23.70	17.60	25.7	11.18
19	20.4	2.77	86.4	31.10	20.20	35.0	12.96
20	26.1	5.88	77.5	36.80	25.90	29.6	13.25
21	16.1	5.11	68.3	20.40	17.40	14.7	8.68
22	24.8	1.89	92.4	30.20	15.30	49.3	13.45
23	21.5	1.40	93.5	24.90	13.50	45.8	10.45
24	14.2	0.71	95.0	18.00	12.10	32.8	8.28
25	16.1	0	100.0	20.50	15.70	23.4	11.90
26	16.0	0	100.0	18.40	13.60	26.1	9.95
27	23.9	3.81	84.1	31.90	14.20	55.5	7.19
28	12.6	3.08	75.6	15.50	6.40	58.7	2.60
29	12.7	0.49	96.1	14.10	7.80	44.7	4.25
30	17.9	0	100.0	19.30	7.90	59.1	3.68
31	17.8	0	100.0	21.60	8.60	60.2	4.54
32	17.36	1.40	91.9	23.10	10.30	55.4	3.22
33	19.5	0.98	95.0	26.20	14.20	45.8	5.88
34	22.1	9.66	56.3	25.20	11.90	52.8	0.25
35	20.9	9.52	54.4	24.40	16.20	33.6	3.36
36	20.6	5.81	71.8	24.40	15.40	36.9	6.72

	NH$_3$-N			TN			NO$_3^-$-N
	Influent (mg/l)	Effluent (mg/l)	Removal efficiency (%)	Influent (mg/l)	Effluent (mg/l)	Removal efficiency (%)	30 minutes after aeration (mg/l)
37	14.6	8.12	44.4	17.50	10.60	39.4	0.18
38	21.8	10.9	50.0	28.80	13.80	52.1	0.12
39	18.6	6.58	64.6	28.00	17.70	36.8	4.44
40	22.3	17.6	21.1	31.70	20.10	36.6	0.06
41	24.6	16.7	32.1	31.40	20.80	33.8	0.02
42	23.2	21.3	8.2	26.50	21.70	18.1	0
43	19.7	18.3	7.1	24.10	19.00	21.2	0
44	15.0	17.6	-17.3	18.90	17.80	5.8	0
45	9.10	5.18	43.1	11.20	6.60	41.1	0
46	11.6	4.83	58.4	15.40	6.90	55.2	0
47	23.52	2.38	89.9	28.50	15.70	44.9	6.55
48	15.68	5.04	67.9	19.40	12.60	35.1	3.22

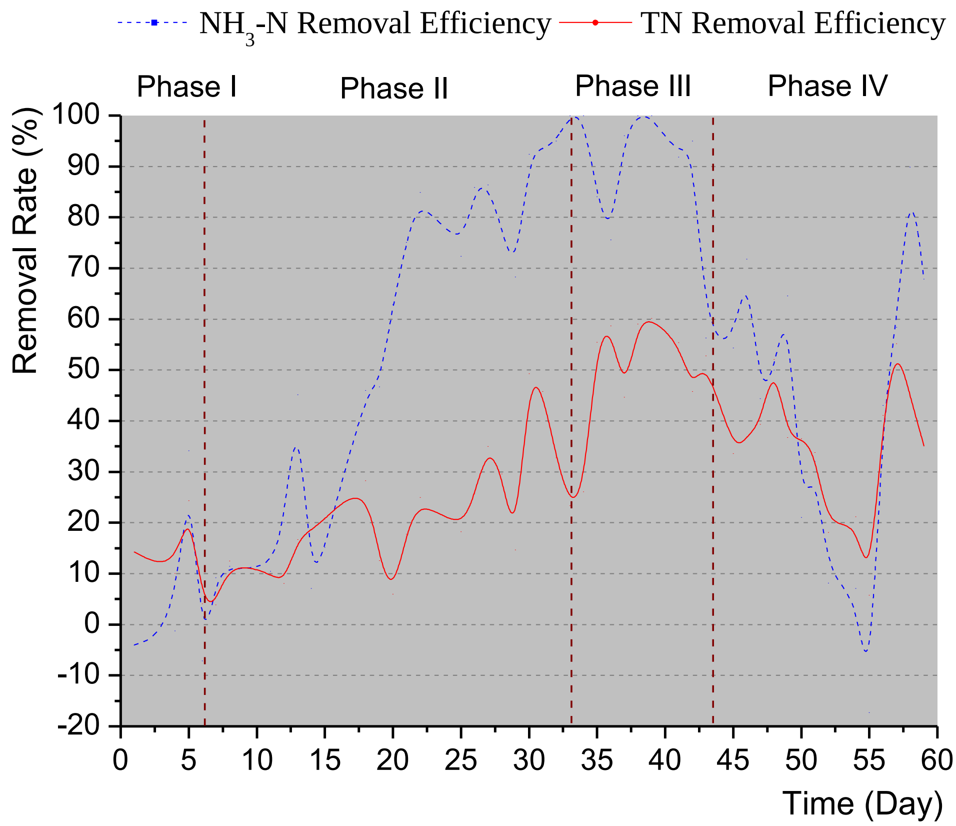

Figure 4.13 Changing trends of total/ammonia nitrogen removal rates

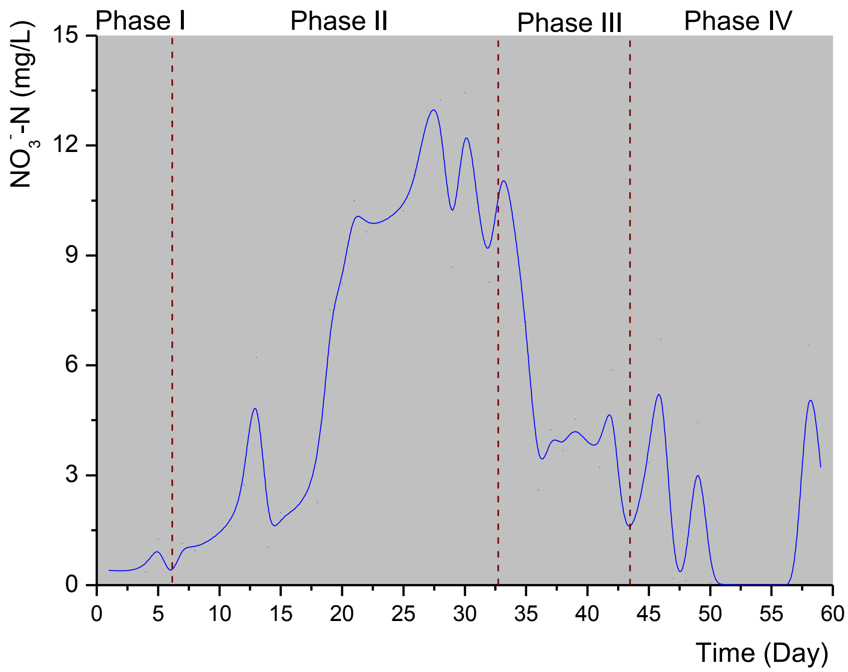

Figure 4.14 Changing trend of nitrate nitrogen, 30 minutes after completion of the pure aeration stage

4.3.1 Results of Phase I

Nitrate ammonia concentrations were extremely low (close to zero) about 30 minutes after the pure aeration stage (Figures 4.3.1 and 4.3.2). During this phase, the ammonia nitrogen removal rate of the system remained low and even became negative. This means that ammonia in sewage were removed but increased instead. To identify the cause, detection of nitrogen in influent was conducted. In addition, nitrate and nitrite nitrogen only occupied approximately 3% of the total nitrogen, which was negligible. In contrast, the organic nitrogen ratio of the total nitrogen was slightly higher or approximately 20%. When ammonia nitrogen removal rate was negative, the corresponding organic nitrogen amount in the influent was high; it also transformed into ammonia nitrogen after the anaerobic condition (Figure 4.13). These results agree with those presented in the study of Lin (2007). Nitrification did not happen in the CAST tanks at the same time, which led to the increase of ammonia nitrogen after treatment.

4.3.2 Results of Phase II

When the relevant process control parameters, including pH value, C/N ratio, sludge age, temperature and DO level in the oxic tank, did not act as restriction factors on nitrification reaction, the nitrification reaction rate can be determined mainly by the number of nitrifying bacteria. Therefore, the main task in this phase is to create favorable conditions to foster the growth of nitrifying bacteria. This was achieved by controlling the DO concentration at a high level after the carbonation reaction was completed. The growth of nitrifying bacteria was also achieved by maintaining the mixture of CAST tanks, both during the sedimentation stage and the decanting stage, in order to maintain the aerobic state for a long time. Given that denitrifying bacteria have longer generation time than autotrophic bacteria, sludge age should be prolonged properly.

The culture for denitrifying bacteria achieved initial success after 10 days (Figure 4.14). The concentration of nitrate ammonia in the mixture gradually increased, and the ammonia nitrogen removal rate of the CAST system rose rapidly.

After 25 days, the ammonia nitrogen removal rate reached nearly 80%, and ammonia nitrogen was not detected after 35 days. At this point, the culture of denitrifying bacteria had fully met the requirements of trial run, while the total nitrogen removal rate remained exceptionally low. In order to strengthen the total nitrogen removal efficiency of the system as well as to verify the mechanism for nitrogen removal, the concentration of nitrate ammonia in the CAST tanks was recorded. The changing curve during one operation cycle is shown in Figure 4.15.

Nitrate ammonia concentration in the CAST tank reached the peak at approximately 100 min of the operation cycle (Figure 4.15). A slight decrease was observed in the subsequent operation time. The DO concentration in CAST tanks was maintained at a high level, which could be attributed to the inhibition factor of the denitrifying bacteria propagation. In addition, heterotrophic bacteria are very active in environments with sufficient oxygen. As a result, the environment with low soluble carbon source may have also inhibited the denitrification reaction due to the full carbonization reaction in the oxic tank.

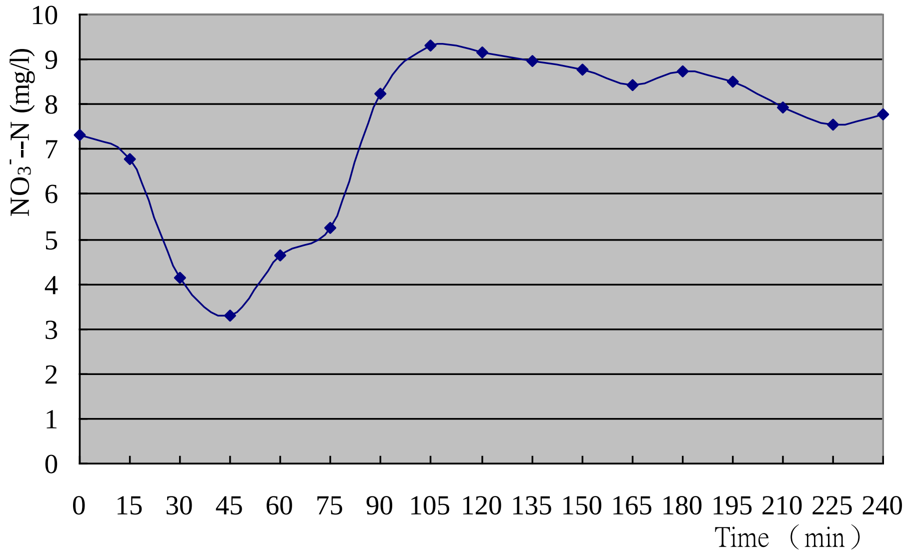

Figure 4.15 Changing curve of nitrate nitrogen concentration during one operation cycle

4.3.3 Results of Phase III

In order to improve the total nitrogen removal effect, the third phase of the trial run was conducted. The total nitrogen removal effect obtained a preliminary enhancement because of the appropriate adjustments of the DO level for different reaction stages during the third phase of the trial run (Figures 4.3.1 and 4.3.2). This could reach higher than 50%. The nitrate ammonia concentration in the CAST tanks, which was detected 30 minutes after pure aeration completion, began to decline sharply during this phase (Figure 4.14). This is attributed to the control of DO level to within less than 0.5 mg/L during the first 30 minutes of inflow/aeration period. During the remaining portion of inflow/aeration stage, subsequent increase in the DO concentration within 0.5–1.0 mg/L promoted the SND. Maintaining the DO level at a range of 2.0–3.0 mg/L during the pure aeration stage, as well as DO concentration in the oxic zone of CAST tanks above 2.5 mg/L for at least 20 minutes after the completion of aeration can help ensure smooth nitrification process. Denitrification reaction proceeded easily because the DO level decreased rapidly during the sedimentation stage. After supplying optimum DO level conditions for both nitrifying and denitrifying bacteria, good nitrogen removal effect was finally achieved.

However, the total nitrogen removal rate of CAST system never exceeded 60% during the entire trial run process (Figure 4.13). It is believed that one of the causes is the application of perforated pipes in the anoxic zone of CAST tanks instead of using the diving mixer, which has a smaller oxygenation capacity. In this situation, the DO level cannot be controlled below 0.5 mg/L in the anoxic zone which led to partial occurrence of the sequential denitrification process in the biological selector instead of full occurrence in the anoxic zone. The other reason is the sludge return ratio. The nitrate ammonia concentration in the oxic zone remained at a high level 30 minutes after the completion of aeration (Figure 4.14). This means that this part of nitrite liquor was not fully consumed by denitrification reaction due to the small return ratio of 10%. The two factors mentioned above may have possibly led to the low total nitrogen removal rate of the system.

4.3.4 Results of Phase IV

Given that the CAST system lacked proper excess sludge discharge for long-term use, the activated sludge was subjected to the aging condition after one month of trial run. After 45 days of trial run, the plant encountered the flow of industrial wastewater with high COD concentration and unknown composition. Moreover, because of the low pH level in the subsequent days, a large number of autotrophic nitrifying bacteria under the aging condition died. The ammonia nitrogen removal rate of the CAST system decreased sharply after the shocking event (Figure 4.13). Ten days after the situation was found, the running mode of the system was adjusted by prolonging the aeration time and discharging the mass of dead sludge. As a result, the propagation of nitrifying bacteria and the ammonia nitrogen removal rate were recovered gradually. During the course of events, the nitrite nitrogen in CAST tank decreased rapidly after the death of numerous nitrifying bacteria. In one instance, the number was close to zero (Figure 4.14). The rising trend was observed 15 days after the shock event. On the other hand, from the changing curve of the total nitrogen removal rate shown in Figure 4.13, the total nitrogen removal rate did not decrease considerably with the death of nitrifying bacteria. This can be attributed to the nature of the denitrifying bacteria as a kind of facultative organism. When the bio-system was shocked by the sewage with high organic concentration, the low DO concentration environment was unable to produce significant impact to the denitrifying bacteria. The changing curve of nitrate nitrogen shown in Figure 4.14 verifies the completion of the denitrifying reaction in the system.

4.3.5 Analysis of Mechanism of Total Nitrogen Removal in CAST

For the purpose of analyzing further the whole nitrogen removal process of the CAST system, the changing curve of total nitrogen concentration in influent and effluent was investigated. This was also done in order to provide a more comprehensive theoretical basis for future CAST system design and operation. The results are shown in Figure 4.16.

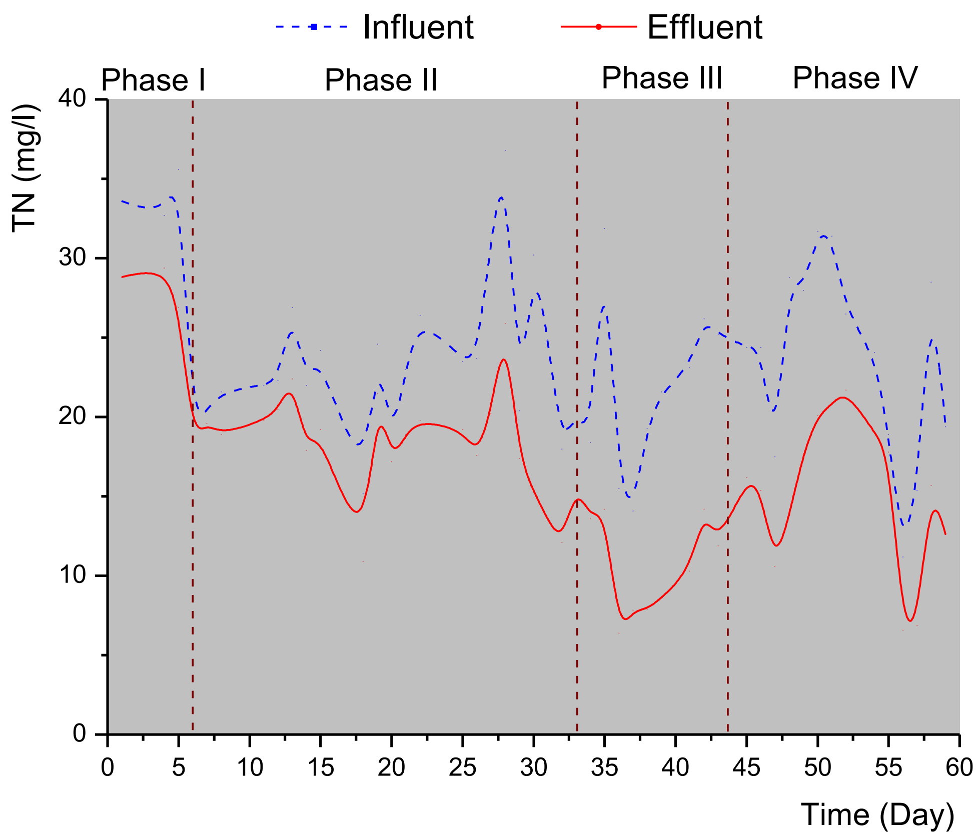

Figure 4.16 Changing curve of total nitrogen concentration in influent and effluent

TN concentration decreased to a certain degree after the CAST process during the first phase (Figure 4.16). However, the removal rate was exceedingly low. As the nitrification reaction in the traditional sense did not occur during this phase, it could be inferred that total nitration decreased due to SND. With the propagation of nitrifying bacteria during the second phase of the trial run, ammonia nitrogen removal rate was promoted obviously, while the total nitrogen removal rate remained extremely low. Although the traditional sequencing nitrification denitrification reaction probably began to happen partially, the high DO level maintained in the CAST tanks weakened the SND effect. In the third stage, the residual nitrate ammonia left from the anterior running cycle could have been used for denitrification by controlling the DO level below 0.5 mg/L during the inflow/aeration stage. Subsequently, with sufficient carbon source and a gradual increase in DO level, the SND effect may have occurred over a period of time. Total nitrogen was partially removed. With further increase of the DO level and the reduction of carbon source, the SND effect became weak, and the nitrifying effect of SQND began to predominate, leading to the increase of nitrate ammonia concentration. Nitrate ammonia concentration in the mixture reached a high level after the completion of aeration. Many bulbs were seen on the liquid surface, which also indicated the occurrence of denitrification reaction. Thus, good total nitrogen removal rate was attained by adhering to good ammonia nitrogen removal effect as the premise.

The failure to observe the TN value within 30 min after the completion of aeration stage during the whole trial run period was a setback. This study, therefore, failed to verify the synergistic effect of SND and SQND. However, related studies show that if the changing curve of TN concentration within 30 min after the completion of aeration is applied, TN removal effect should be clearly differentiated into two parts, namely, SND and SQND. Further, the best nitrogen removal effect of the CAST system can be achieved only when the two parts of the reaction occur synergistically (Hu *et al*., 2006).

4.4 Trial Run for Improving COD Removal Efficiency

Biodegradability of sewage was relatively poor, which was why the B/C ratio of sewage in the hydrolysis tank remained under 30% during the trial run process. In addition, through continuous detection of BOD_5 value, residual BOD_5 concentration can be maintained below 5 mg/L, which should prove the occurrence of a thorough carbonization reaction. Thus, the refractory and insoluble organic matters proved to be the main reasons for the relatively high residue COD concentration of the CAST system. In the following trial operation which last more than one and a half month, the COD concentrations in influent and effluent were tested. The detailed data are shown in Table 4.15.

Table 4.15 COD concentrations in influent and effluent and the removal rates

	COD						
	Influent (mg/l)	Effluent (mg/l)	Removal efficiency (%)		Influent (mg/l)	Effluent (mg/l)	Removal efficiency (%)
1	254	99.34	60.9	26	162	55.2	65.9
2	331.7	88.02	73.5	27	156	34.9	77.6
3	697.03	74.35	89.3	28	139	48.1	65.4
4	236.9	67.41	71.5	29	515	50.3	90.2
5	176.8	66.69	62.3	30	79.1	61.4	22.4
6	138.5	74.7	46.1	31	93.3	45	51.8
7	156.5	50.25	67.9	32	144	48.8	66.1
8	179.4	58.77	67.2	33	166	55.2	66.7
9	186.3	44.63	76.0	34	177.6	60.2	66.1
10	132.9	44.93	66.2	35	175	55.2	68.5
11	132.1	32.8	75.2	36	346	65.2	81.2
12	108.7	27.36	74.8	37	356	61.4	82.8
13	110.1	54.5	50.5	38	306	66.7	78.2
14	180.4	25.28	86.0	39	250	58.1	76.8
15	200.1	26.02	87.0	40	252	58.8	76.7
16	114.8	21.23	81.5	41	243	65.2	73.2
17	146.7	66.12	54.9	42	280	55.9	80.0
18	203	53	73.9	43	272	70.3	74.2
19	167	63.8	61.8	44	268	77.6	71.0
20	142	50.3	64.6	45	288	47.4	83.5
21	155	63	59.4	46	181	50.3	72.2
22	160	71.78	55.1	47	155	40.4	73.9
23	156	46	70.5	48	190	37.7	80.2
24	152	56.6	62.8	49	149	30.1	79.8
25	148	44.9	69.7				

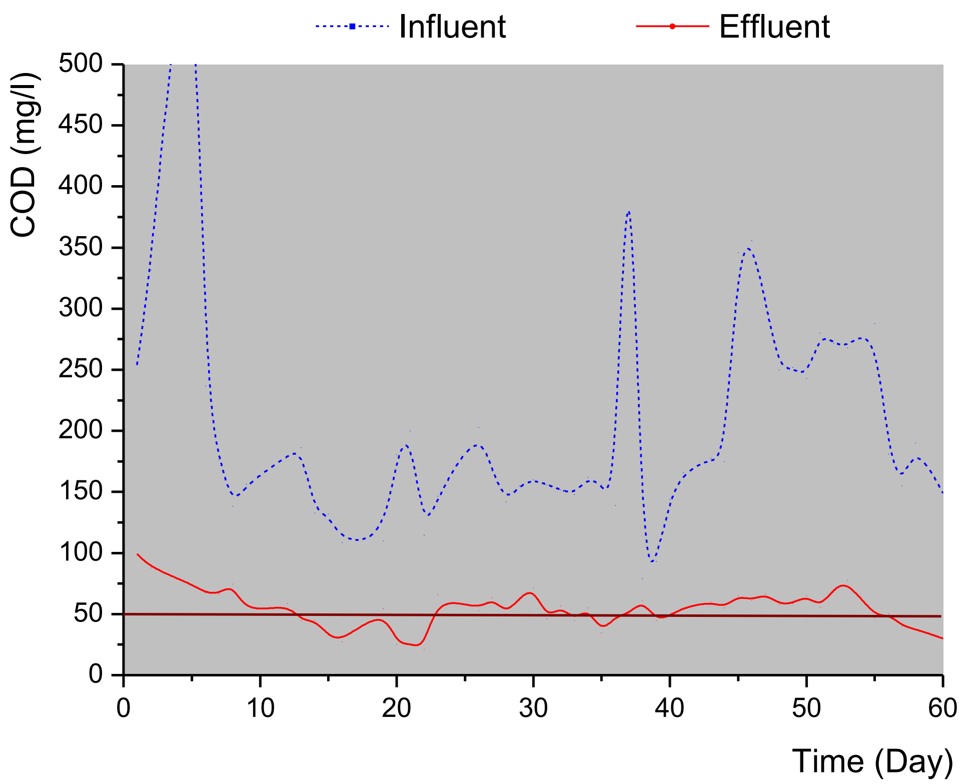

Figure 4.17 Changing trend of COD values in influent and effluent

Residual COD concentration in the effluent did not change significantly with the change of COD concentration of influent in the CAST system (Table 4.15 and Figure 4.17). When the trial run was carried out for 10 days, the MLSS concentration in the CAST tank was measured as approximately 2.8 g/L. Basically, the residual COD concentration of effluent fluctuated within the range of 30–65 mg/L.

Given that pH, sludge age, DO, environmental temperature, and other process control parameters did not restrict carbonization reaction, the quantity of heterotrophic carbonization bacteria was the major factor influencing the reaction.

Therefore, increasing the concentration of activated sludge and continuously improving its activity can contribute to the removal capacity of biochemical systems for organic compounds assuming that the SS value in the effluent do not exceed the standard.

To determine the most economical and reasonable aeration time, COD concentration change and its relationship with DO was assessed during a single operation cycle of CAST. Details are presented in Table 4.16 and Figure 4.18.

Table 4.16 COD concentrations within a single operation cycle

Item / Time per cycle（min）	COD concentration (mg/l)		
	Sample-1 (COD=346mg/l)	Sample-2 (COD=280mg/l)	Sample-3 (COD=155mg/l)
Initial	55	60	50
15	310.7	180.4	128.2
30	322.0	266.0	145.5
45	338.8	262.1	147.8
60	284.5	154.2	80.8
75	105.6	79.4	45.4
90	77.7	56.6	42.3
105	63.9	54.5	44.6
120	62.8	54.5	42.6
Effluent	65.2	55.9	40.4

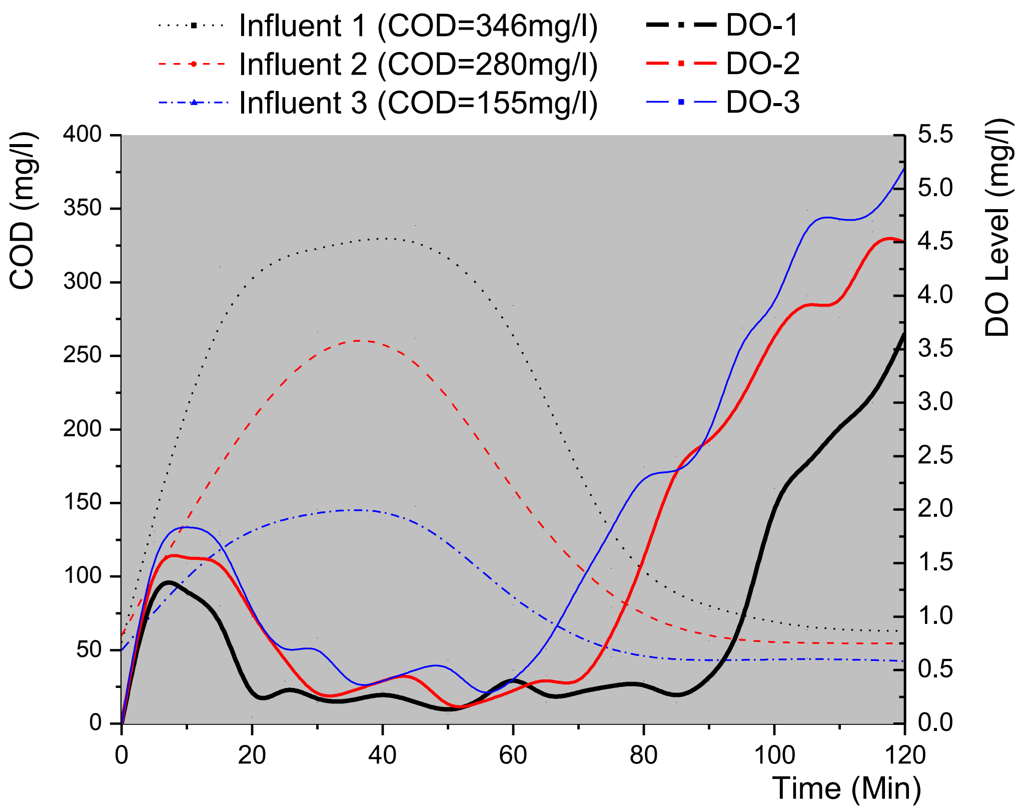

Figure 4.18 Changing trend of COD concentration and DO level vs. reaction time during one operation cycle

DO level rapidly increased during the first minutes of the reaction (Figure 4.18). This was because the oxygenation rate in the reactor was far greater than oxygen consumption rate at the beginning of the reaction. In the following reaction process, the DO level slowed down simultaneously with the increase of COD degradation. In the latter reaction process, improvement of the COD removal efficiency became insignificant. This means that the carbonation reaction has already stopped when the pure aerostation process proceeded for 30–60 minutes after the completion of inflow. In other words, the time of aeration and the sludge age were not the main factors restricting organic degradation. The nitration reaction only occurred when the carbonization reaction in the CAST system ended.

Using the residual BOD_5 value as reference, it was determined that after the COD concentration of 40–60 mg/L was achieved, continuous aeration did not change the COD concentration further, and the organic matter reached a non-degradable level. Once the organic materials in sewage reached the non-degradable level, oxygen consumption rate became minimal, which was sufficient enough for endogenous respiration of microbes. Despite the onset of the nitration reaction, oxygen consumption rate of nitrobacteria is far less than those of heterotrophic microorganisms. This resulted in the significant increase of DO value in the reactor, marking the end of carbonation reaction.

4.5 Comparison between the conventional CAST with the novel CAST

From all above the results, Table 17 below was conclude to compare the conventional CAST, the CAST plant existing and running in mainland China, and also the novel CAST process which studied in this project with special DO control. The Data showed in conventional CAST is the conclusion from Wastewater Engineering (2003) and the data showed in the existing CAST plant is concluded from the four significant CAST plant applying in Mainland China in Appendix III which shows the reference cases. DO was controlled in this special way by controlled below 0.5 mg/L during first 30 minutes of the inflow/aeration stage, controlled at 2.0–4.0 mg/L during pure aeration stage and keep above 2.5mg/L for at least 20 minutes at the end of the aeration stage. The sludge age was set to 10 days to keep the MLSS between 3000-3500 mg/L. These two items have not much different compare to the conventional CAST and existing CAST plant. However, it can be found that under the special control of DO and a half shorter HRT, the F/M ratio and Volumetric OLR were near to the conventional CAST setting and significant higher than other four plants. The control setting can achieve a well sludge setting time and remain the SVI between 80 to100 which was lower than other CAST plants. Under these parameters setting, the pollutant removal efficiency of novel CAST can show great differences to the others. The most indicated removal efficiency was TN. Although the wastewater engineering gave out the best NH_3-N and TN removal should both be 70%, part of existing CAST plants cannot reach this target. Zengcheng Sewage Treatment Plant of Guangdong Province showed their NH_3-N removal efficiencies around 60%. TN removal efficiency is even harder to reach 70% which most between 30%-50%. In the novel CAST process, the NH_3-N can reach 90% removal efficiency stably. Despite the TN removal efficiency cannot reach 70% in conventional CAST process, it was still higher than other exiting CAST plant running in Mainland China. Other pollutants like COD and TP, the removal efficiency of novel CAST was obviously higher than the conventional CAST and most of the existing CAST plant and also the SS remained in the effluent.

	Conventional CAST	Existing CAST Plant	Novel CAST
DO control	2-4 mg/L	2-4 mg/L	Special Control
HRT	>12 hr	13 hr	6.84 hr
F/M ratio	0.2-0.4 BOD/MLSS/d	0.075 BOD/MLSS/d	**0.12** BOD/MLSS/d
Volumetric OLR	0.4-0.9Kg BOD/m^3/d	0.27 Kg BOD/m^3/d	0.36 Kg BOD/m^3/d
MLSS	3000-5000 mg/L	3500	3000-3500 mg/L
SVI	<200	100-150	80-100
SRT	15-20 days	8-12 days	10 days
COD removal efficiency	80%	70%-85%	83%
NH_3-N removal efficiency	70%	30%-80%	>90%
TN removal efficiency	70%	30%-50%	60%
TP removal efficiency	80%	60%-80%	>90%
SS	Around 20mg/L	Around 20mg/L	<15mg/L

Table 4.17 Comparison between Conventional CAST, existing CAST and novel CAST

The observation of microbiology in the activated sludge showed the differences between the conventional CAST system and novel CAST. In the Conventional CAST system, filamentous bacteria dominated in the activated bacteria and *Nemathelminthes* dominated in the protozoa which was bigger size protozoa with stronger movement. This strong movement would destroy the sludge floc into small pieces. Due to the dominated filamentous bacteria and small pieces of floc, the activated sludge was not easier to settle down and cause the higher SS in effluent. And some filamentous bacteria species would produce gas and this small gas bubble bound with small pieces of sludge floc which might form foaming and bulking. The special DO control with the setting treatment cycle were cultured an entire different microbiology culture differing from conventional CAST system. The dominated activated bacteria were most in bacillus and spherical form and the dominated activated protozoa were *Vorticella* and *Epistyles.* The Compact sludge floc structure was formed from the bacillus and spherical bacteria which adhered by protein secreted from *Vorticella* and *Epistyles.* Therefore, the bigger size activated sludge with compact structure would have better performance of settling and SQND and lower SS in effluent.

CHAPTER 5

CONCLUSIONS

The conventional CAST operation performs low nitrogen removal efficiency under high influent nitrogen concentration and fluctuating conditions. When the typical advanced CAST process, operated by 2 hours aeration and 1 hour settle, was applied in a sewage treatment in the CAST reaction tank, sufficient nitrification could be achieved with well filamentous sludge bulking control and ammonia nitrogen removal rate exceeded 95% under the following conditions: the DO concentration was controlled below 0.5 mg/L during the first 30 minutes of the inflow/aeration stage and controlled at 2.0–4.0 mg/L during pure aeration stage. It can also be achieved by ensuring that the DO concentration was above 2.5 mg/L for at least 20 minutes at the end of the aeration stage.

SND and SQND could be achieved and TN removal could be increased up to 60% with the appropriate return ratio (>20%) and reasonable DO concentration gradient between the anoxic zone and aeration zone of the CAST system operation sequence. The detailed conditions were: the DO concentration was controlled below 0.5 mg/L during the first 30 minutes of the inflow/aeration stage, controlled at 2.0–

3.0 mg/L during pure aeration stage, and maintained below 0.5 mg/L in the anoxic zone during the whole treatment process.

In order to meet the increasingly stringent water discharge standards, the CAST process was optimized in this work for achieving a satisfactory removal rate for pollutants including ammonia nitrogen, total nitrogen, total phosphorus, and BOD after improving the process control conditions. The only concern is that the residual COD in the end of the biological process may exceed 50 mg/L, which is above the new discharge standard. The majority of the fraction of the residual COD is refractory and insoluble organic compounds. Thus, compared with second-stage biological treating process, applications of physico-chemical methods as advanced treating units are more economical and efficient. Moreover, despite the good performance of the CAST process in removing biodegradable organic compounds (as measured in BOD) as well as the flexibility of the system in adjusting aeration time, the purpose of obtaining significant increase in BOD or ammonia nitrogen removal rates could not be achieved simply by increasing the second-stage bio-treating process or by biological aerated filter (BAF) after the CAST system.

For sewage treatment plants in a municipality that apply CAST as its main treating process, if the amount of industrial wastewater, especially with such severe polluting effluent as printing and dyeing wastewater taking up a great proportion in the influent sewage, the residual COD concentration in the treated effluent has close relationship between the anaerobic hydrolysis effects. This is particularly true when the printing and dyeing wastewaters are taking up a considerable proportion of the influent sewage. The residual COD can be controlled below 50 mg/L by increasing the number of coagulation-precipitation-filter units after the CAST process. Moreover, control could be made more effective by the hydrolysis and carbonization process that are integrated with the CAST process.

For secondary sewage treatment plants that are designed without primary sedimentation tanks, the VSS/SS values of activated sludge in both anaerobic and aerobic tanks comprise one of the main reasons behind the poor hydrolysis effect in the anaerobic tank and low activity of sludge in the aerobic tank.

Finally, for sewage treatment plants in a municipality that apply CAST as its main treating process, the species of nitrification bacteria are more fragile than heterotrophic bacteria. Therefore, the more fastidious microbial population requires a better optimized set of operating condition. Only in an approximate balanced oxygen demand and oxygen supply, the filamentous sludge bulking can be well controlled with a nigh nitrogen removal efficiency.

In conclusion, the essential operating parameters of the advanced CAST process were successfully optimized in this study and the stringent discharge standards were successfully met, without having the process hardware upgraded.

APPENDIX I

LIST OF TESTING EQUIPMENTS

EQUIPMENT	MAIN TECHNICAL DATA	BRAND
Six united- Electric Furnace	Electricity：220V ±10%, 50Hz Power：6000W Working temperature range：0°C～100°C	Jiangyin BAOLI
Biochemical Incubator LRH—150	Electricity：220V ±10%50Hz Power：450W Working temperature range：0°C～60°C Size：500×460×800mm	Shanghai YIHENG
DO Meter SG6	Measuring range：0.00～99.00mg/L (ppm) Working air pressure：500～1100 Mbar Working temperature range：0°C～60°C Error range： ±0.5% Electricity：6Vdc,70mA, battery of 4*AA/LR6，1.5V or NIMH,1.2V rechargeable battery	Mettler-Toledo
Sterilizer yx280B	Electricity：220V ±10%50Hz Power：2KW ±10% Working temperature range：124°C～126°C Volume：18L	Shanghai SANSHENG
Visible-Spectrophotometer 7202B	Optical system：single beam Spectrum band width：5 nm Wavelength range：325—1000 nm	UNICO

EQUIPMENT	MAIN TECHNICAL DATA	BRAND
	Wavelength precision： ±2 nm Wavelength reproducibility：1 nm Stray light：≤0.5%T Photometric range：0～125%T，-0.097～2.500A 0～1999C（0～1999F） Photometric precision： ±0.5%T Size：370×280×160 mm	
Ultraviolet- Spectrophotometer UV—1100	Electricity：220V/10%50Hz or 110V/60Hz Power：2KW±10% Wavelength range：200～1000 nm Spectrum band width：4 nm Wavelength precision： ±2nm Wavelength reproducibility：1nm Photometric precision： ±0.5%T Photometric reproducibility：0.3%T Stray light：≤0.31T% Stability： ±0.002A/h Display mode：128*64 bit LCD Installation mode： Automatic Photometric range：-0.3～3.0A，0～200%T Light source：deuterium lamp、tungsten lamp	Shanghai Oumai
Analytical Balance AL104/01	Maximum weighting：110 g Scale division value：0.001 g Actual division value：0.1 mg Repeatability：0.0001 g Linear：-/+0.0002 g Typical stable time：4.0 min Calibrating-weight：100 g	Mettler-Toledo

EQUIPMENT	MAIN TECHNICAL DATA	BRAND
Vacuum Pump 2XZ	Speed：1400 r/min Power：0.25KW Diameter of air inlet：15mm Temperature rise of pump oil ：≤40°C	WUXI
pH Meter SG2	Measuring range：pH0.00～14.00， -1999～1999mV Working temperature range：-5℃～105℃ Resolution：0.01pH，1mV，0.1° Error limit： ±0.01PH, ±1mV, ±0.5° Isopotential point：PH7.00	HACH

APPENDIX II

LIST OF TESTING METHODS

NO.	ITEM	DETECTION METHOD	PERFORM STANDARD
1	Water temperate	Thermometer or reversing thermometer	GB/T 13195--1991
2	Chemical Oxygen Demand (COD)	Potassium dichromate method	GB/T 11914--1989
3	Biochemical oxygen demand (BOD_5)-5 days	Dilution and inoculation method	GB/T 7488--1987
4	Total Nitrogen (TN)	Alkaline potassium persulfate digestion-UV spectrophotometric method	GB/T 11894--1989
5	Ammonia Nitrogen (NH_3-N)	Distillation-Titration Method	GB/T 7478--1987
6	Nitrate (NO_3^--N)	Nitrate-spectro-photometric method with phenol disulfonic acid	GB/T 7480—1987
7	Nitr9te (NO_2^--N)	Nitrite-spectro-photometric method	GB/T 7493—1987
8	Kjeldahl Nitrogen (TKN)	Distillation spectrophotometric method	GB/T 11891--1989

NO.	ITEM	DETECTION METHOD	PERFORM STANDARD
9	Total Phosphorus Phosphate (TP)	Molybdenum-antimony anti-spectrophotometric method	GB/T 11893--1989
10	pH	Glass electrode method	GB/T 6920--1986
11	Dissolved Oxygen (DO)	Iodimetric method	GB/T 7489--1987
12		Electrochemistry probe method	GB/T 11913--1989
13	Suspended Solid （SS）	Suspended substances Gravimetric method 103～105°C	GB/T 11901-1989
14	Total Dissolved Solids	Gravimetric method 180°C±1°C	GB/T 5750-2006
15	Total Alkalinity	Volumetric method	GB/T 6276.1-1996
16	Turbidity	Spectrophotometric method and turbidity comparison by physical method	GB/T 13200-1991
17	Chroma	Colorimetric method with platinumcobalt and Dilution method	GB/T 11903-1989
18	Petroleum Oil, Animal and Vegetable Oil	Infrared photometric method	GB/T 16488-1996
19	Total Cyanide	Part 1 Determination of total cyanide	GB/T 7486--1987
20	Volatile Phenol	After distillation by means of 4-AAP spectrophotometric method	GB/T 7490-1987

NO.	ITEM	DETECTION METHOD	PERFORM STANDARD
21	Chloride	Silver nitrate titration method	GB-T 11896-1989
22	Thesum of Calcium and Magnesium	EDTA titrimetric method	GB/T 7477-1987
23	Sulfate Radicals	Gravimetric method	GB/T 11899-1989
24	Remaining Chloride	N,N-diethyl-p- phenylenediamine spectrophotometric method	GB/T 11898--1989
25	Anionic Surfactant	Methylene blue pectrophotometric method	GB/T 7494--1987
26	Total Coliform Group	Multi-tube zymolytic method and membrane filter method	GB/T 5750

APPENDIX III

LIST OF REFERENCE CASES

Case-1 Tiger Beach Sewage Treatment Plant of Dalian City

Design capacity 80000 m^3/d, the average water quality of influent and effluent. (Fang, *et al*., 2007)

Influent/Effluent water quality parameters of Case-1

Item	BOD_5	*COD*	*SS*	*TN*	NH_3-*N*	*TP*
Influent（mg/L）	100	200	180	25	18	2.6
Effluent（mg/L）	≤12	≤35	≤20	≤14	≤1.5	≤1
Removal rate	≥88	≥85	≥87	≥40	≥90	≥60

Case-2 Zengcheng Sewage Treatment Plant of Guangdong Province

Design capacity 10000 m^3/d of first phase project. (Cheng, Liu, and Jiang, 2005)

Influent/Effluent water quality parameters of Case-2

Item	BOD_5	*COD*	*SS*	*TN*	NH_3-*N*	*TP*
Influent（mg/L）	120	200	150	30	25	3
Effluent（mg/L）	≤20	≤60	≤20	≤15	≤10	≤0.5
Removal rate	≥83	≥70	≥87	≥50	≥60	≥83

Case-3 Pengzhou Sewage Treatment Plant of Chendu City

Design capacity 30000 m^3/d. (Zhang, 2006)

Influent/Effluent water quality parameters of Case-3

Item	BOD_5	*COD*	*SS*	*TN*	NH_3-*N*	*TP*
Influent（mg/L）	180	350	200	--	40	3
Effluent（mg/L）	≤20	≤60	≤20	--	≤10	≤1
Removal rate	≥88	≥83	≥90	--	≥75	≥65

Case-4 The Portage/Catawba Island Wastewater Treatment Plant (USA)

Design capacity 30000 m^3/d, with the cumulative frequency of 90% calculation method. (Goronszy *et al*., 1996)

Influent/Effluent water quality parameters of Case-4

Item	BOD_5	*COD*	*SS*	NO_3-*N*	NH_3-*N*	*TP*
Influent（mg/L）	74	212	388	10	32.6	7.3
Effluent（mg/L）	6.5	38	≤11	4.3	3.9	2.2
Removal rate	≥90	≥85	≥95	≥55	≥88	≥70

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