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**EFFICIENCY OF AN ANAEROBIC SEQUENCING BATCH
REACTOR (AnA^2/O^2 SBR) IN THE TREATMENT OF
TEXTILE WASTEWATER**

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อธิปัทนากร

จาก

บัณฑิตวิทยาลัย มหาวิทยาลัยมหิดล

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The objectives of this research were to study the efficiency of an Anaerobic Sequencing Batch Reactor(AnA²/O² SBR) in the removal of COD, TKN, TP and color from textile wastewater. The 3 similar Anaerobic SBRs were operated on 4-hours static fill, 17-hours react, 1.5-hours settle, 0.5-hour draw out and 1-hour idle period. This experimental research was planned to be 3² factorial design with 9 running conditions and scheduled to control the anoxic time at 2, 4 and 6 hours, and the Solid Retention Time (SRT) was set at 40, 60 and 80 days.

Under 9 running conditions, the results showed that the COD, TKN, TP and color removal efficiency were in the range of 80.7-90.7%, 82.0-94.6%, 56.8-79.9% and 29.1-51.5%, respectively. From statistical analysis of data, under 2,4 and 6-hours anoxic time, it was found that there were no significant differences in COD, TP and color removal efficiency ($p < 0.05$), but the removal efficiency of TKN at the 2-hours anoxic time was significantly higher than that of 4 and 6-hours anoxic time ($p < 0.05$). In addition, under 40,60 and 80-days SRT, it was illustrated that the efficiency of COD and color removal at 80-days SRT was significantly higher than that of 40 and 60-days SRT ($p < 0.05$). However, the efficiency of TKN and TP removal at 40 and 80-days SRT was significantly lower than that of 60-days SRT ($p < 0.05$).

The optimum running condition of Anaerobic SBR in the treatment of textile wastewater was at 2-hours anoxic time and 60-days SRT which yielded COD, TKN, TP and color removal efficiency of 82.8%, 94.6%, 75.3% and 34.5%, respectively.

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งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาประสิทธิภาพการกำจัด ซีโอดี ทีเคเอ็น ฟอสฟอรัส และ สีนํ้าเสียจากการฟอกย้อม โดยใช้แบบจำลองระบบบำบัดน้ำเสียแบบแอนแอโรบิก เอสบีอาร์ จำนวน 3 ถึงปฏิบัติการ โดยกำหนดเวลาเติมนํ้าเสีย 4 ชั่วโมง ทำปฏิบัติการ 17 ชั่วโมง ตกตะกอน 1.5 ชั่วโมง ระบายน้ำทิ้ง 0.5 ชั่วโมง และพักระบบ 1 ชั่วโมง การทดลองนี้เป็น Experimental Research โดยออกแบบเป็น 3² Factorial Design แบ่งออกเป็น 9 สภาวะทดลอง โดยควบคุมช่วงเวลาแอนออกซิกที่ 2, 4 และ 6 ชั่วโมง และระยะเวลาเก็บกักตะกอนที่ 40, 60 และ 80 วัน

ผลการทดลองทั้ง 9 สภาวะ พบว่าประสิทธิภาพการกำจัดซีโอดี ทีเคเอ็น ฟอสฟอรัส และ สีนํ้าอยู่ระหว่างร้อยละ 80.7-90.7, 82.0-94.6, 56.8-79.9 และ 29.1-51.5 ตามลำดับ จากการวิเคราะห์ข้อมูลทางสถิติที่ช่วงเวลาแอนออกซิก 2, 4 และ 6 ชั่วโมง พบว่า ประสิทธิภาพการกำจัดซีโอดี ฟอสฟอรัส และ สีนํ้า ไม่แตกต่างกันอย่างมีนัยสำคัญทางสถิติ ($p < 0.05$) ในขณะที่ประสิทธิภาพการกำจัดทีเคเอ็นที่ช่วงเวลาแอนออกซิก 2 ชั่วโมง สูงกว่าที่ 4 และ 6 ชั่วโมงอย่างมีนัยสำคัญทางสถิติ ($p < 0.05$) นอกจากนี้ เมื่อวิเคราะห์ข้อมูลทางสถิติที่ระยะเวลาเก็บกักตะกอน 40, 60 และ 80 วัน พบว่าประสิทธิภาพการกำจัดซีโอดี และ สีนํ้าที่ระยะเวลาเก็บกักตะกอน 80 วันสูงกว่าที่ 40 และ 60 วันอย่างมีนัยสำคัญทางสถิติ ($p < 0.05$) ในขณะที่ประสิทธิภาพการกำจัดทีเคเอ็น และ ฟอสฟอรัสที่ระยะเวลาเก็บกักตะกอน 40 และ 80 วัน น้อยกว่าที่ 60 วันอย่างมีนัยสำคัญทางสถิติ ($p < 0.05$)

สภาวะที่เหมาะสมในการควบคุมระบบแอนแอโรบิก เอสบีอาร์ ในการบำบัดน้ำเสียจากการฟอกย้อม คือ ช่วงเวลาแอนออกซิก 2 ชั่วโมง และระยะเวลาเก็บกักตะกอน 60 วัน โดยให้ประสิทธิภาพการกำจัดซีโอดี ทีเคเอ็น ฟอสฟอรัส และ สีนํ้าร้อยละ 82.8, 94.6, 75.3 และ 34.5 ตามลำดับ

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CHAPTER I

INTRODUCTION

1.1 Rationales and Justifications

The textile industry is one of the most important industries in Thailand. Wastewater from textile processing industries produce high quantities of effluent with varying composition. The major pollutant types in textile wastewater are refractory organics load, dyes, nutrients (nitrogen and phosphorus) and toxicants etc. These pollutants are difficult to be treated by conventional biological treatment process, since organic matters containing in textile wastewater, are moderately biodegradable organic load. Textile wastewater were found to be major inhibitors of the nitrifying bacteria in aerobic treatment system, thus hampering nitrogen removal (1), and aerobic condition is also unable to remove phosphorus in wastewater effectively. In addition, dyes are generally very resistant to degradation under this aerobic condition (2), resulting in more pollutants entering the receiving water body and further affecting the biological life and aesthetic merit as well.

In general, the conventional activated sludge or combined with physico-chemical pretreatment have been used to treat wastewater from textile operating process. However, it have not been accepted by the textile industries due to its low removal efficiency, not be able to meet effluent standards and high operating costs.

A sequencing batch reactor (SBR) is a fill and draw activated sludge treatment system (3). The single tank batch system can be used for the treatment of wastewater generated by rural municipalities and industries (4). The Anaerobic Sequencing Batch Reactor can be operated to achieve a high efficiency of carbon oxidation, nitrogen reduction and phosphorus removal simultaneously. It was, thus, to select as a cost efficient alternative for the removal of organic matters, nitrogen and phosphorus and as also a method for improving color removal in textile wastewater.

In this research , the sequential operation of an Anaerobic Sequencing Batch Reactor (AnA²/O² SBR) has been used to investigate simultaneous removal of COD, TKN, TP and color in textile wastewater.

1.2 Research Objectives

1.2.1 Main Objective

To investigate the organic, nutrient and color removal efficiency from textile wastewater by using an Anaerobic Sequencing Batch Reactor (AnA²/O² SBR).

1.2.2 Specific Objectives

1) To determine the chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), total phosphorus (TP) and color removal efficiencies of textile wastewater using an Anaerobic Sequencing Batch Reactor (AnA²/O² SBR) under the anoxic time of 2 or 4 or 6 hours.

2) To determine the chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), total phosphorus (TP) and color removal efficiencies of textile wastewater

using an Anaerobic Sequencing Batch Reactor (AnA²/O² SBR) under the solid retention time (SRT) of 40 or 60 or 80 days.

3) To determine the acceptable of the chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), total phosphorus (TP) and color removal efficiencies of textile wastewater using an Anaerobic Sequencing Batch Reactor (AnA²/O² SBR) with optimal running condition of anoxic time and solid retention time.

1.3 Research Hypotheses

1) The longer anoxic time is, the more total kjeldahl nitrogen (TKN) and color removal efficiencies are.

2) The longer solid retention time is, the more chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), total phosphorous (TP) and color removal efficiencies are.

1.4 Scope of Study

1.4.1 Influent textile wastewater used in this experiment was obtained from a textile factory located in Samutprakarn province.

1.4.2 The composition of wastewater are the mixture of various types of dyeing and printing dye such as reactive dye, acid dye, vat dye and large amount of chemicals using in the desizing , bleaching, scouring and washing processes.

1.4.3 The seeding and acclimatization processes were provided prior to the experimental running.

1.4.4 Wastewater was treated with an Anaerobic Sequencing Batch Reactor (AnA²/O² SBR) in 4 hours filling, 17 hours reacting, 1.5 hours settling, 0.5 hour withdrawing and idle time 1 hour.

1.4.5 Statistical analysis was used to justify the optimal running condition of anoxic phase and solid retention time.

1.5 Research Variables

1.5.1 Independent variables

- Anoxic time
- Solid retention time (SRT)

1.5.2 Dependent variables

- Chemical oxygen demand (COD)
- Total kjeldahl nitrogen (TKN)
- Total phosphorus (TP)
- Color

1.5.3 Control variables

- Dissolved oxygen (DO)
- Influent pH
- Mixed Liquor Suspended Solid (MLSS)

1.6 Limitation of Research

Textile wastewater used in this experiment was obtained from a textile industry by grab sampling at a specific time. The raw wastewater was taken in containers and carried to the Laboratory Section of Sanitary Engineering, Faculty of Public Health, Mahidol University for further usage under designed and experiment in a Lab-scale basis.

1.7 Definition of Keywords

1.7.1 *Chemical Oxygen Demand (COD)* : The chemical oxygen demand (COD) is a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant.

1.7.2 *Total kjeldahl nitrogen (TKN)* : Organics nitrogen and ammonia nitrogen.

1.7.3 *Total phosphorous (TP)* : Phosphorus that usually found in aqueous solutions include the orthophosphate, polyphosphate and organic phosphate.

1.7.4 *Sequencing Batch Reactor (SBR)* : A fill - and- draw activated sludge treatment system. The unit process involved in the SBR and conventional activated sludge systems are identical. Reaction and sedimentation/clarification are carried out in both system.

1.7.5 *An Anaerobic Sequencing Batch Reactor (AnA²/O² SBR)* : A modified SBR operating under short sequences of Anaerobic-Anoxic-Oxic conditions which can

be performed to achieve a high efficiency of carbon oxidation, nitrogen reduction and phosphorus removal simultaneously.

1.7.6 *Nitrification* is the biological process by which ammonia is converted first to nitrite and then to nitrate.

1.7.6 *Denitrification* is the biological process by which nitrate is converted into nitrogen gas.

1.7.7 *Anaerobic process* is biological treatment process that occur in the absence of oxygen.

1.7.8 *Anoxic denitrification* is the process by which nitrate-nitrogen is converted biologically into nitrogen gas in the absence of oxygen. This process is also known as anaerobic denitrification.

1.7.9 *Solid Retention Time (SRT)*: The mass of solids in the reactor divided by the mass of solids removed from the system each day.

1.8 Conceptual Framework

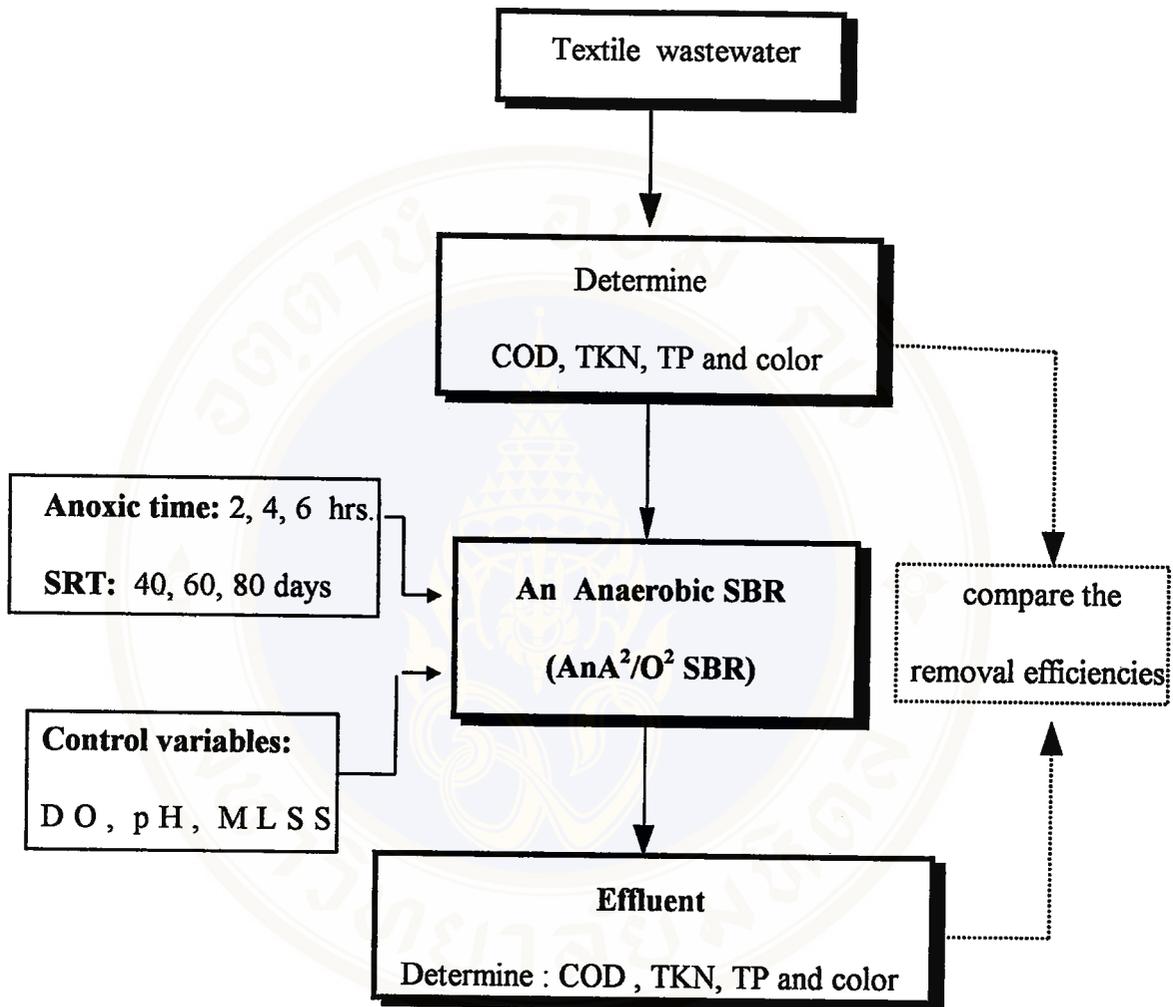


Figure 1.1 Conceptual framework

CHAPTER II

LITERATURE REVIEW

2.1 Textile Wastewater(5)(6)(7)

2.1.1 Nature of Textile Industries and Characterization of Wastewater

The textile industry contributes significantly to the pollution load on water body. Wastewater from operation processes are characterized by high volume and extreme variability in composition, which can include non-biodegradable dyes and toxic substances. At some point in the manufacture of most textile goods, chemical wet processing operations are necessary to properly prepare, purify, color or finish the product. This results in the production of wastewater whose pollution load arises not only from the removal of impurities from the raw materials themselves but also from the residual chemical reagents used for processing.

The chemical composition of textile mill effluents is also changing rapidly as a result of shifting consumers' preferences. Most significant is the current popularity of cotton fabrics and bright colors leading to greater usage of reactive and azo dyes, respectively. An even more important cause of shifting wastewater composition are the new and tighter restrictions on discharged effluents and consumer goods.

The consumption of process water is generally specific to the type of material or final products, as these dictate the nature of the transformation process. Large amounts of water are generally required for wet processing, such that the textile industry generates large volumes of effluent which are extremely variable in composition and pollution load.

The U.S. Environmental Protection Agency has grouped the industry into various categories representing the different industrial activities. The EPA categorization and typical characteristics of the wastewater generated by each of the activities are given in Table 2.1.

Manufacturing processes for each of these industrial categories have been used to highlight the operations responsible for wastewater generation. As an example, Figure 2.1 represents the manufacturing process of a woven cotton fabric finishing process of a woven cotton fabric finishing mill.

Table 2.1 Established wastewater characteristics for the textile categories of activity (8).

| <i>Parameters</i> | <i>US.EPA Categories</i> | | | | | | |
|-------------------------------|--------------------------|----------|----------|----------|----------|----------|----------|
| | <i>1</i> | <i>2</i> | <i>3</i> | <i>4</i> | <i>5</i> | <i>6</i> | <i>7</i> |
| <i>BOD₅/COD</i> | 0.2 | 0.29 | 0.35 | 0.54 | 0.35 | 0.3 | 0.31 |
| <i>BOD₅ (mg/l)</i> | 6,000 | 300 | 350 | 650 | 350 | 300 | 250 |
| <i>TSS (mg/l)</i> | 8,000 | 130 | 200 | 300 | 300 | 120 | 75 |
| <i>COD (mg/l)</i> | 30,000 | 1,040 | 1,000 | 1,200 | 1,000 | 1,000 | 800 |
| <i>Oil and grease (mg/l)</i> | 5,500 | - | - | 14 | 53 | - | - |
| <i>Total chrome (mg/l)</i> | 0.05 | 4 | 0.014 | 0.04 | 0.05 | 0.42 | 0.27 |
| <i>Phenol(mg/l)</i> | 1.5 | 0.5 | - | 0.04 | 0.24 | 0.13 | 0.12 |
| <i>Sulfide (mg/l)</i> | 0.2 | 0.1 | 8.0 | 3.0 | 0.2 | 0.14 | 0.09 |
| <i>Color (ADMI)</i> | 2,000 | 1,000 | - | 325 | 400 | 600 | 600 |
| <i>pH</i> | 8.0 | 7.0 | 10 | 10 | 8.0 | 8.0 | 11 |
| <i>Temp.(°F)</i> | 82 | 144 | 70 | 99 | 102 | 67 | 100 |
| <i>Water usage(us gal/lb)</i> | 43 | 40 | 1.5 | 13.5 | 18 | 8.3 | 18 |

Categories description:

1-Raw wool scouring, 2- Yarn and fabric manufacturing, 3-Wool finishing, 4- Woven fabric finishing, 5- Knitted fabric finishing, 6- Carpet manufacturing, 7-Stock and yarn dyeing and finishing.

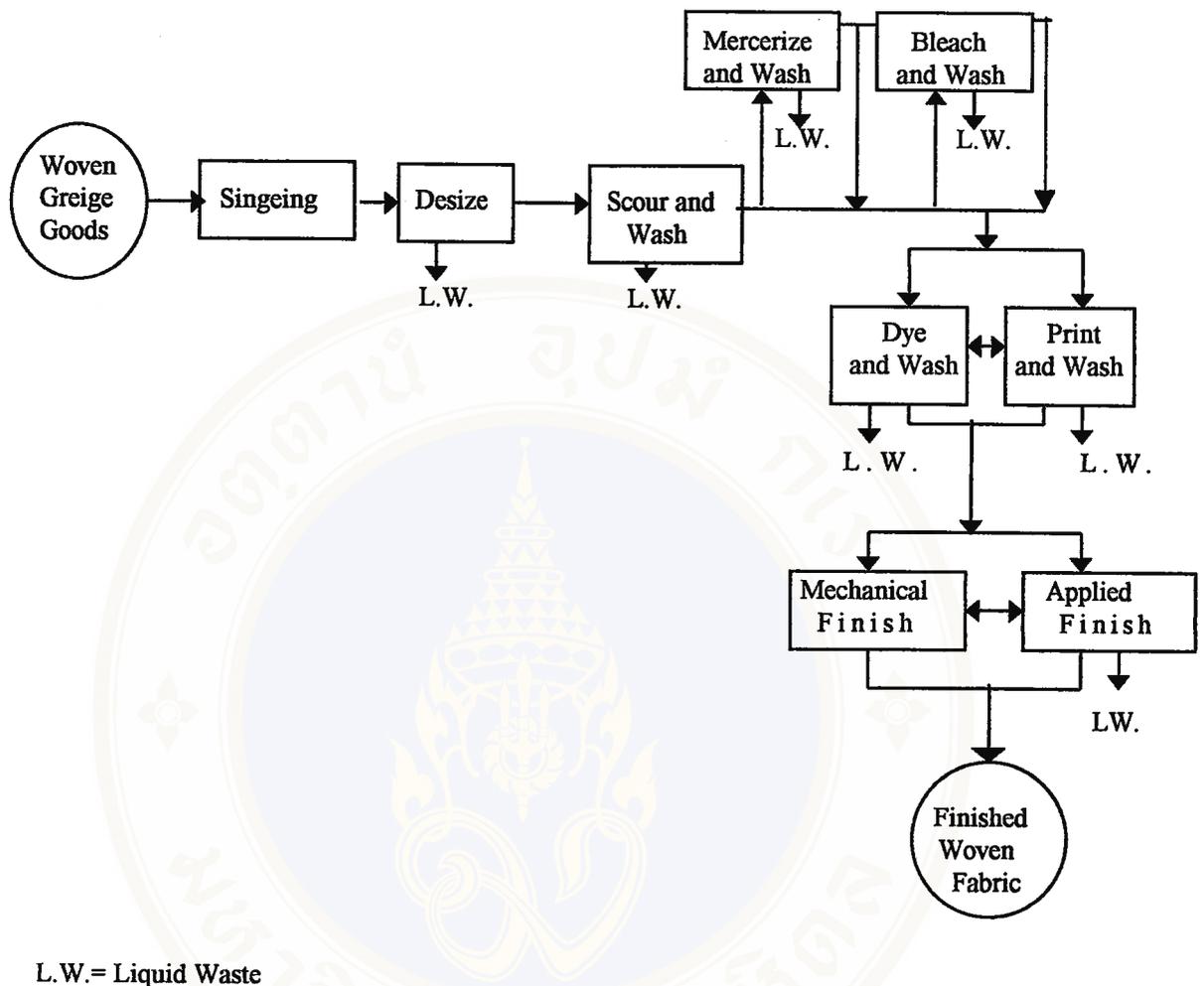


Figure 2.1 Manufacturing process of woven cotton fabric finishing mills(5)

2.1.2 Main Wastewater Sources

Process wastewater compositions vary widely due to the variety of recipes, techniques, machinery, raw materials and fabrics. The main sources of wastewater generated by the textile wet-processing industry originate from the washing(or scouring) and bleaching of natural fibers and from the dyeing and finishing steps. Given the great variety of fibers, dyes, process aids and finishing products in use, these

processes generate wastewater of great chemical complexity and diversity which are not adequately treated in conventional wastewater treatment plant.

Desizing

Desizing removes the substance applied to the yarn in the sizing operation by swelling /solubilising, hydrolyzing, or oxidizing the size into a soluble form. The method of desizing vary according to the size used. Desizing can be as simple as hot washing with detergents for synthetic sizes or more complicated, for example enzyme augmented degradation, for starch and modified starch.

Scouring

Scouring can be applied to both natural and synthetic materials to remove applied or natural substances. The intensity of the scouring process is dependent on the type of material.

Cotton is scoured to remove natural waxes, pectin, spinning oils and other non-cellulosic components using hot alkaline solutions (usually caustic soda or soda ash) containing detergents or soaps. Cotton scouring waste liquors are thus chemically aggressive and may be toxic. Along with desizing, cotton scouring generates very high BOD concentrations.

When synthetic sizes are used desizing and scouring are usually carried out in a single operation. 100% synthetic fabrics (woven or knitted) require only light scouring in order to remove sizes and lubricants and the process is not normally a significant source of organic or suspended solids pollution.

Bleaching

Bleaching removes the natural yellowish coloring of cotton and other fibers, thereby increasing its whiteness. This operation is generally required if the finished fabric is to be white or dyed a light color. It is an oxidation process usually brought about using hydrogen peroxide, sodium hypochlorite or sodium chlorite and auxiliary chemicals. Bleaching wastewater usually has a high solid content with low to moderate BOD levels.

Mercerizing

Mercerization is performed most exclusively on pure cotton fabrics, which are treated by a concentrated caustic soda bath and a final acid wash in order to neutralize them. Its purpose is to impart luster and also to increase dye affinity and tensile strength. Mercerization wastewater have low BOD and total solids levels but are highly alkaline prior to neutralization.

Dyeing

Dyeing is carried out to add color to the fabric. Identification of generic types of dye wastewater is complicated by the diversity of both the dye chemistry and the operational modes of the dyeing process itself.

Printing

Printing, like dyeing, is a method for applying color to a fabric. The color which is usually in the form of a paste, is deposited on the fabric using a variety of

machinery and techniques. The fabric then is treated with steam, heat, or chemicals to fix the color. Textile printing generates varying amounts and types of pollutants such as suspended solid, urea (nutrient), solvent, aquatic toxicity and color .

2.1.3 Major Pollutant Types

The major pollutant types identified in textile wastewater are summarized in Table 2.2 along with their main origin in the textile manufacturing process. Textile effluents can have a high organic load mainly due to the removal of grease, dirt and/or sizing agents in the desizing and scouring steps. Probably the most cumbersome partial waste flows of textile processing come from the dyehouse as water-soluble, residual dyes are difficult to remove in conventional treatment plants. Another problem originating mainly in the dyehouse is the nutrient load due to the need for dyebath additives. Also the use of large amounts of alkali in the bleaching, desizing, scouring and mercerizing steps, as well as in reactive dyeing, can have a strong impact on reactor performance and costly pH adjustments may be necessary.

Table 2.2 Major pollutant types in textile wastewater(6)(9).

| <i>Pollutants</i> | <i>Major chemical types</i> | <i>Main processes of origin</i> | <i>Major relevance/impact on biological treatment</i> |
|----------------------------|--|--|---|
| <i>Organic load</i> | Starches, enzymes, fats, greases, wax, surfactants Acetic acid | Desizing Scouring Washing Dyeing | High demand on aeration systems Activated sludge bulking problems |
| <i>Color</i> | Dyes, scoured wool impurities | Dyeing Printing Scouring | Insufficient removal in bioreactors |
| <i>Nutrients (N,P)</i> | Ammonium salts, urea, phosphate-based buffers and sequestrants | Dyeing Printing | Not removed in anaerobic processes Increased complexity and sensitivity of aerobic processes(biological nutrient removal required) |
| <i>pH and salt effects</i> | NaOH, mineral/organic acids, sodium chloride, silicate, sulfate, carbonate | Scouring Desizing Bleaching Mercerizing Dyeing Neutralization | Inhibition/collapse of bioreactors |
| <i>Sulfur</i> | Sulfate, sulfide and hydrosulphite salts, sulfuric acid | Dyeing | Sulfate-reduction in anaerobic reactors |
| <i>Toxicants</i> | Heavy metals, reducing agents(e.g. sulfide), oxidizing agents(e.g. chlorite, peroxide, dichromate, persulphate), biocides, quaternary ammonium salts | Desizing Bleaching Dyeing Finishing Printing | Inhibition of sensitive microbial groups(nitrifiers, methanogens) in bioreactors |
| <i>Refractory organics</i> | Surfactants, dyes, resins, synthetic sizes(e.g. PVA), chlorinated organic compounds, carrier organic solvents | Scouring Desizing Bleaching Dyeing Washing Finishing | Insufficient removal in bioreactors Possible accumulation in biomass aggregates/films, leading to inhibition |

Organic load

Scouring and desizing effluents are major contributors to the organic load in textile effluents. Traditional sizes such as starches and their derivatives are readily biodegradable under aerobic and anaerobic conditions. However, bulking of activated sludge occurs frequently if a large proportion of the wastestream consists of desizing wastewater.

Dyes

Dye molecules consist of a chromagen, i.e. an aromatic structure absorbing visible light and which anchors the dye into or within the fibers. There are about 12 classes of chromogenic groups, the most common being the azo type which makes up to 60-70% of all textile dyestuffs produced followed by the anthraquinone type. A second classification of dyes is based on their mode of application to textiles and distinguishes acid, reactive, metal-complex, disperse, vat, mordant, direct, basic and sulfur dyes.

Nutrients (nitrogen, phosphorus)

Dyebath additives and print pastes containing nitrogen and phosphorus (e.g. urea, ammonium acetate, ammonium sulfate and phosphate buffers) are the main sources of nutrients in the textile effluent.

Toxicants

Toxicants or hard-to-treat wastes are heavy metal, reducing agent, oxidizing agent include etc. There are persistent , resist treatment or interfere with the operation of waste treatment facilities. They often contain nonbiodegradable or inorganic materials. Biological processed that occur in waste treatment systems generally cannot remove or break down these wastes (9).

pH and salt effects

Acids and alkalis are used in the dyeing process depending on the dye class involved and large quantities of alkali are used in bleaching, desizing, scouring and mercerizing. Extremes of pH have to be avoided in order to maintain good reactor performance in biological systems.

2.2 Principles of Removal Pollutant in Wastewater

The main objective of the SBR process is to remove soluble and insoluble organics from the wastewater and to convert this material into a flocculent microbial suspension that settles well in a conventional gravity clarifier. A number of modifications of the SBR process have been developed to accommodate specific wastewater characteristics and/or operational needs. As a general rule, the nature of the wastewater will dictate the preferred process modification, primarily for the purpose of maintaining mixed liquor settling quality. Nowadays, the object of wastewater treatment has been further enlarged to the point of control of eutrophication. Consequently, for SBR process under anaerobic and anoxic and oxic conditions, there

has been paid more attention to evaluate it as a method for effective removal of COD, nitrogen and phosphorus and as a method for improving of color removal in textile wastewater.

2.2.1 Bacteria Growth (3)

Effective environmental control in biological waste treatment is based on an understanding of the basic principles governing the growth of microorganisms. The following discussion is concerned with the growth of bacteria, the microorganisms of primary importance in biological treatment.

Bacteria can reproduce by binary fission, by a sexual mode, or by budding. Generally, they reproduce by binary fission (i.e., by dividing, the original cell becomes two new organisms). The time required for each fission, which is termed the generation time, can vary from days to less than 20 min. For example if the generation time is 30 min, one bacterium would yield 16,777,216 bacteria after a period of 12 hours. This computed value is a hypothetical Figure, for bacteria would not continue to divide indefinitely because of various environmental limitations such as substrate concentration, nutrient concentration, or even system size.

2.2.1.1 Growth in Terms of Bacterial Numbers

The general growth pattern of bacteria in a batch culture is shown in Figure 2.2. Initially, a small number of organisms are inoculated into a fixed volume of culture medium, and the number of viable organisms is recorded as a function of time. The growth pattern based on the number of cells has four more or less distinct phases.

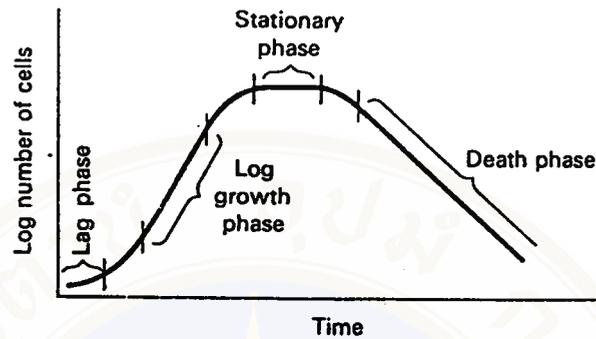


Figure 2.2 Typical bacterial growth curve in terms of numbers. (3)

1. **The lag phase.** Upon addition of an inoculum to a culture medium, the lag phase represents the time required for the organisms to acclimate to their new environment and begin to divide.

2. **The log-growth phase.** During this period the cells divide at a rate determined by their generation time and their ability to process food (constant percentage growth rate)

3. **The stationary phase.** Here the population remains stationary. Reasons advanced for this phenomenon are (a) that the cells have exhausted the substrate or nutrients necessary for growth, and (b) that the growth of new cells is offset by the death of old cells.

4. **The log-death phase.** During this phase, the bacteria death rate exceeds the production of new cells. The death rate is usually a function of the viable population and environmental characteristics. In some cases, the log-death phase is the inverse of the log-growth phase.

2.2.1.2 Growth in Terms of Bacterial Mass

The growth pattern can also be discussed in terms of the variation of the mass of microorganisms with time. This growth pattern consists of the following four phases:

1. *The lag phase.* Again, bacteria require time to acclimate to their nutritional environment. The lag phase in terms of bacterial mass is not as long as the corresponding lag phase in terms of numbers because mass begins to increase before cell division takes place.

2. *The log-growth phase.* There is always an excess amount of food surrounding the microorganisms, and the rate of metabolism and growth is only a function of the ability of the microorganism to process the substrate.

3. *Declining growth phase.* The rate of increase of bacterial mass decreases because of limitations in the food supply.

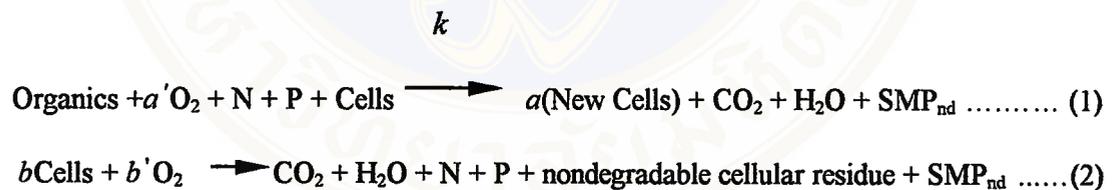
4. *Endogenous phase.* The microorganisms are forced to metabolize their own protoplasm without replacement because the concentration of available food is at a minimum. During this phase, a phenomenon known as lysis can occur in which the nutrients remaining in the dead cells diffuse out to furnish the remaining cells with food (known as "cryptic growth").

2.2.2 Organic Matter Removal (3)(10)

2.2.2.1 Organic Matter Removal under Aerobic Condition

In aerobic condition, organic matter is removed from wastewater by biological metabolism, oxygen is consumed by the organism, and new cell mass is

synthesized. The organisms also undergo progressive auto-oxidation (endogenous decay) of their cellular mass. Figure 2.3 depicts the course of bio-oxidation of an organic wastewater. When a wastewater is mixed with acclimated biological sludge, there may be an immediate sorption of readily degradable organics. These organics are stored within the cell for subsequent oxidation. This phenomenon is called biosorption. As aeration proceeds, removal of the remaining organics occurs. The oxygen uptake rate is initially high as the sorbed organics are degraded and then decreases as the residual substrate decreases. Cellular synthesis occurs in proportion to the organic removal. Nitrogen and phosphorus are taken up for cellular synthesis. When the available substrate is exhausted, continued aeration results in oxidation of the biomass through endogenous respiration. These phenomena are described by Equations (1) and (2) :



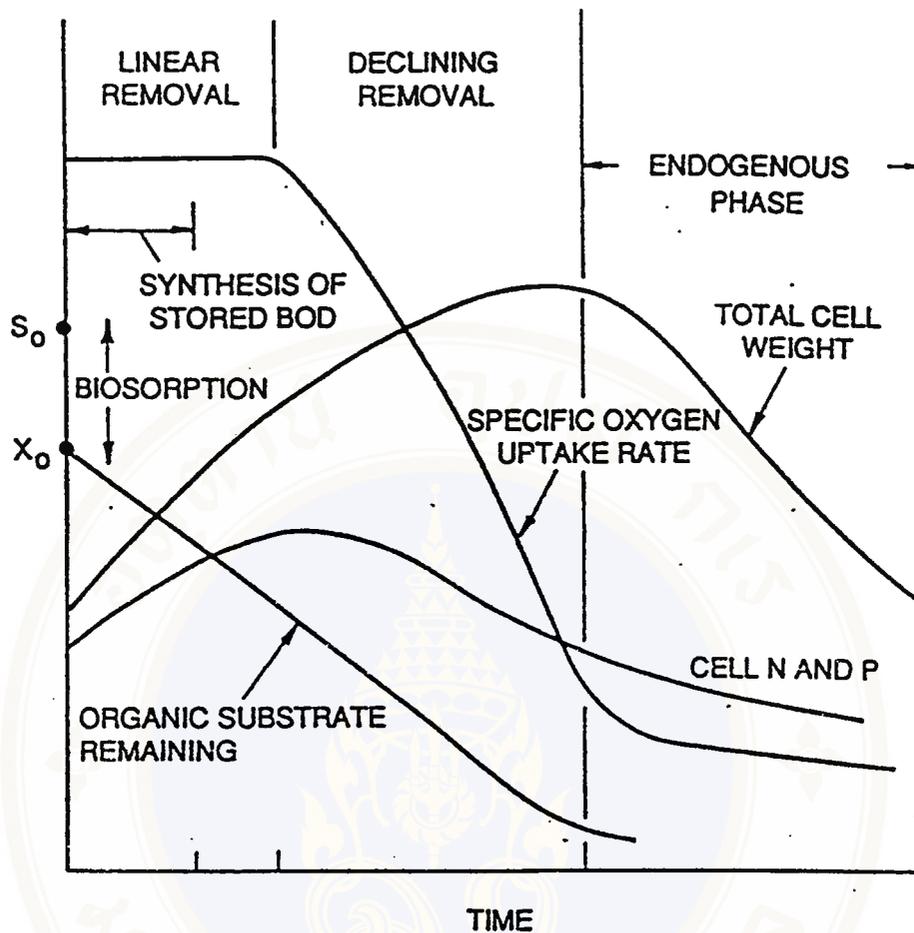


Figure 2.3 Aerobic biological treatment.(10)

In Equation (1), a' is the oxygen equivalent of the fraction of organic matter removed that is oxidized to end products (i.e., CO_2 and H_2O). Term a is the fraction of organic matter removed that is synthesized into biomass, and k is a temperature-dependent reaction rate coefficient that is related to the biodegradability of the specific wastewater. In Equation (2), the coefficient b is the fraction per day of degradable biomass that is endogenously oxidized, and b' is the oxygen required to support the endogenous decay.

A small portion of the organics removed for synthesis (Equation (1)) and endogenous metabolism (Equation (2)) remains as nondegradable cellular residue and

SMP_{nd} (nondegradable soluble microbial products). The nondegradable cell residue is approximately 20 percent of the volatile suspended solids generated in Equation (1). The SMP_{nd} varies from 2 to 10 percent of the influent degradable SCOD and depends on the organic composition of the raw wastewater and sludge age.

2.2.2.2 Organic Matter Removal under Anaerobic Condition

Removal of organic matter under anaerobic condition of organic and inorganic matters in the absence of molecular oxygen. The major application have been, and remain today, in the stabilization of concentrated sludge produced from the treatment of wastewater and in the treatment of some industrial wastes. More recently, it has been demonstrated that diluted organic wastes can also be treated anaerobically.

The biological conversion of the organic matter under anaerobic conditions through to occur in the three steps as shown in Figure 2.4, the first step is the process involves the enzyme-mediated transformation (hydrolysis) of higher-molecular-mass compounds into compounds suitable for use as a source of energy and cell carbon. The second step (acidogenesis) involves the bacterial conversion of the compounds resulting from the first step into identifiable lower molecular-mass intermediate compounds. Fermentation of carbon compounds under anaerobic condition in the first and second steps are illustrated in Figure 2.5. The third step (methanogenesis) involves the bacterial conversion of the intermediate compounds into simpler end products, principally methane and carbon dioxide.

Theoretical Stages

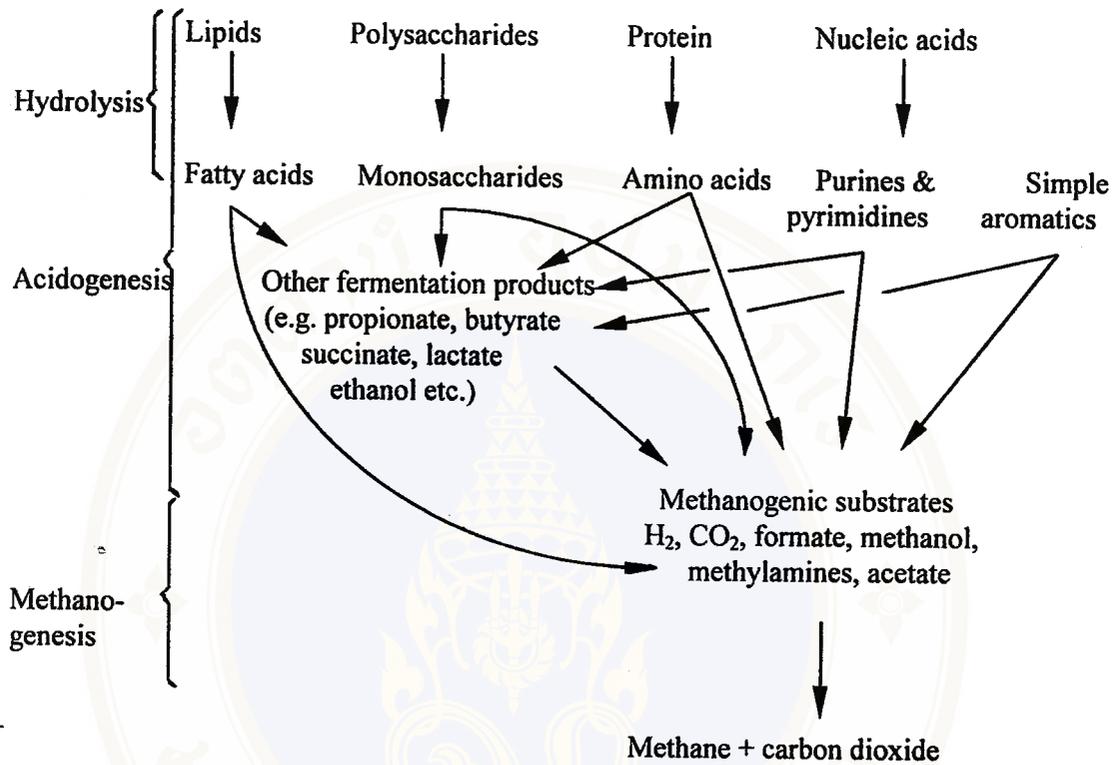
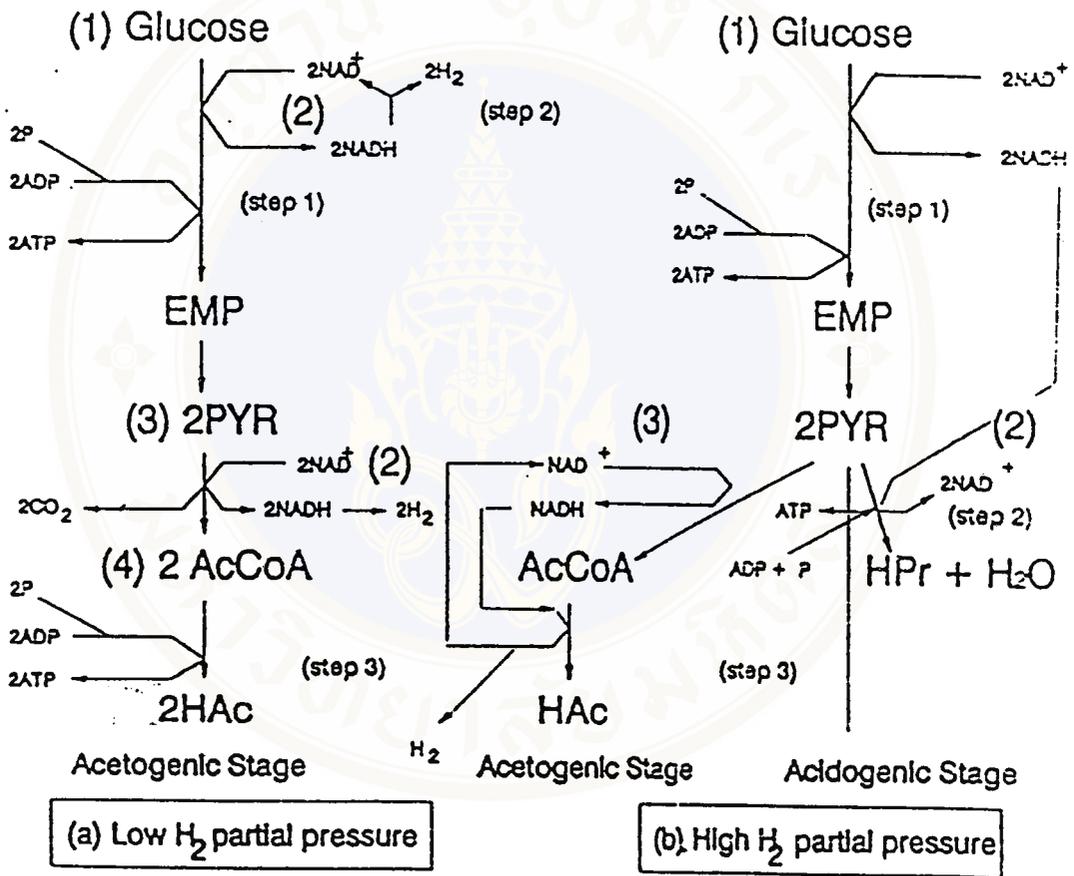
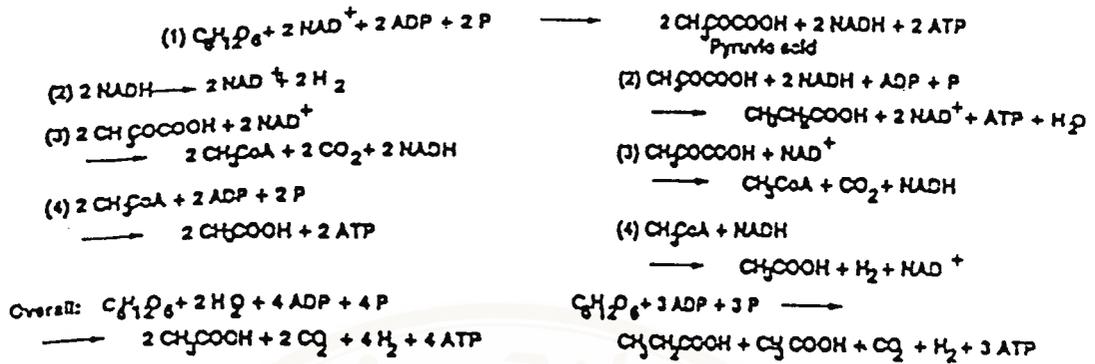


Figure 2.4 Schematic diagram of the carbon patterns flow in anaerobic digestion.(3)



(Abbreviations: EMP - Embden-Meyerhof pathway; PYR - pyruvic acid; AcCoA - acetyl coenzyme A; HPr - propionic acid; HAc - acetic acid).

Figure 2.5 Fermentation of carbon compounds under anaerobic condition.(48)

2.2.3 Nitrogen Removal (10)

The major processes considered in the removal of nitrogen are : Biological nitrification and denitrification. The nitrification process is to transform ammonia-

nitrogen into nitrate by the use of nitrifying bacteria under aerobic conditions. Denitrification converts nitrate to nitrogen gas by use of denitrifying bacteria, under anoxic conditions. The processes of biological nitrification and denitrification are illustrated in Figure 2.6.

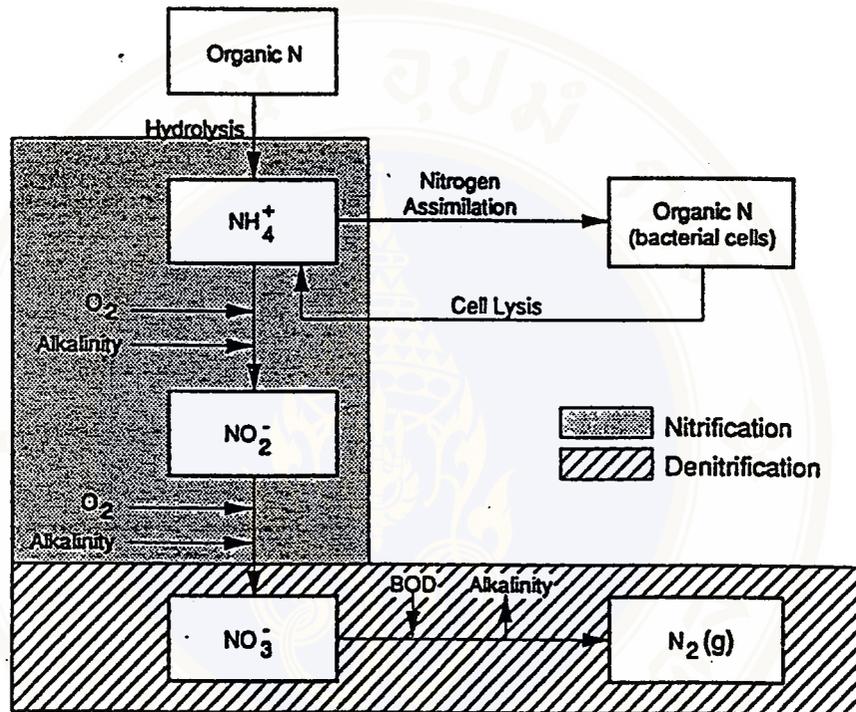


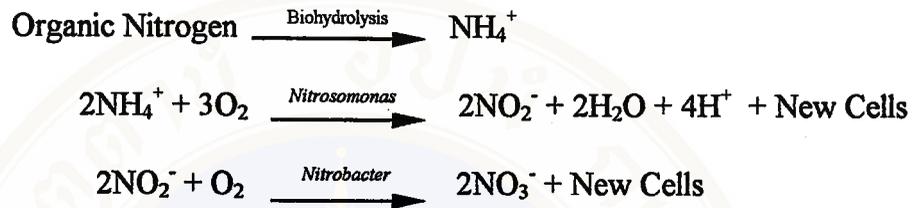
Figure 2.6 Nitrogen transformations.(10)

2.2.3.1 Nitrification

The biohydrolysis reaction is mediated by a wide range of heterotrophic organisms and seldom limits the rate of nitrogen oxidation. The oxidation of ammonia to nitrate is a sequential reaction. It is carried out under strictly aerobic conditions by only a few species of chemoautotrophic organisms (*Nitrosomonas* and *Nitrobacter*), which derive their energy from the oxidation reaction and their carbon source from alkalinity. As such, they are more sensitive to the mixed liquor conditions of pH,

temperature, toxic etc., and grow more slowly than the heterotrophs that consume BOD.

The reactions which occur during biological nitrification are summarized below:



For 1 g $\text{NH}_3\text{-N}$ oxidized to $\text{NO}_3\text{-N}$,

- 4.33 g of O_2 are consumed.
- 7.15 g of alkalinity (as CaCO_3) are destroyed.
- 0.15 g of new cells are formed.
- 0.08 g of inorganic carbon are consumed

Influence of the Environmental Factors on Nitrification(12)

If the alkalinity of the water is too small, it can be exhausted, resulting in a substantial reduction in pH, which will inhibit the nitrification process.

The effect of pH is significant since nitrification results in production of free acid, which will tend to depress the pH. A narrow optimal range between pH 7.5 to 8.6 exists, but systems acclimated to lower pH conditions have successfully nitrified. The effect of temperature has been studied extensively, and it has been concluded that nitrification is more strongly inhibited at low temperature than is carbonaceous BOD

removal. Nitrification rates at 10°C are only about one quarter those at 30°C even in attached growth processes.

Dissolved oxygen concentrations about 1 mg/l(3) are essential for nitrification to occur. If DO levels drop below this value, oxygen becomes the limiting factor and nitrification slows or ceases. The nitrification process is particularly susceptible to variations in waste strength and flow. It is to be noted that changing ammonia-nitrogen to nitrate-nitrogen does not facilitate nitrogen removal, but does elimination of oxygen demand.

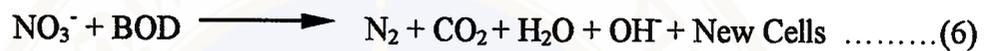
At a decreased SRT, the oxygen utilization rate due to carbon oxidation increases, thereby decreasing the penetration of oxygen. Conversely, at a high SRT, the low oxygen utilization rate permits higher oxygen levels within the floc, and consequently, higher nitrification rates occur. Therefore, to maintain the maximum nitrification rate, the bulk mixed liquor dissolved oxygen concentration must be increased as the SRT is decreased(10).

Nitrifiers are slow-growing organisms and they are accordingly particularly susceptible to toxicants. Certain heavy metals and organic compounds are toxic to nitrifiers. The presence of toxic compounds causes a change in the environmental conditions for the nitrifying population, and they are therefore, a threat to any nitrification plant. Any inhibition of the nitrification process results in a decrease in the maximum specific reaction rate of the nitrifying organisms. A change in the maximum specific reaction rate can be compensated for by a longer solid retention time in a wastewater plant (13).

2.2.3.2 Denitrification

The biological process of denitrification involves the reduction of nitrate nitrogen, NO_3N , to nitrogen gas, N_2 . Denitrification is a two-step process in which the first step is a conversion of nitrate in nitrite. The second step carries nitrate through intermediates to nitrogen gas. This two-step process is normally termed “dissimilation”.

Equation 6 summaries the reaction which occur during denitrification.



For 1 g $\text{NO}_3\text{-N}$ reduced to N_2

- 3.7 g of COD are consumed.
- 0.45 g of VSS are produced.
- 3.57 g of alkalinity are produced.

Influence of the Environmental Factor on Denitrification (12)(13).

- In denitrification system, dissolved oxygen concentration is the critical parameter. The presence of DO will suppress the enzyme system needed for denitrification. In suspended cultures the oxygen concentration should be below 0.5 mg/l.
- Temperature effects the removal rate of nitrate and the microbial growth rate. The organisms are sensitive to changes in temperatures. Denitrification can be performed in the temperature range 5°C - 35°C .
- Alkalinity is produced during the conversion of nitrate to nitrogen gas resulting an increase in pH. The most studies showed that highest rate of denitrification occur within the range of 7.0-7.5.

- The carbon source has an effect on the denitrification rate. Methanol yields a higher rate because it is easily degradable. Organic matter in raw wastewater has a slower reaction rate whereas endogenous energy sources give the slowest removal. Here it will be the hydrolysis processes, which limit the rate. Complete denitrification could be achieved with a TCOD/TKN ratio of 7 (14).

2.2.4 Phosphorous Removal (3)(15)

Phosphorus appears in wastewater as orthophosphate(PO_4^{3-}), polyphosphate (P_2O_7) and organically bound phosphorus. The last two components may account for up to 70 percent of the influent phosphorus. Microbes utilize phosphorus during cell synthesis and energy transport. As a result, 10 to 30 percent of the influent phosphorus is removed during secondary biological treatment. Additional uptake beyond that needed for normal cell maintenance and synthesis is required to achieve low effluent concentration levels. Under certain aerobic conditions more phosphorus than is needed may be taken up by the microorganisms. Phosphorus may be released from cells under anoxic conditions. Biological phosphorus removal is accomplished by sequencing and producing the appropriate environmental conditions in the reactor.

The proposal of the metabolism of biological phosphorous removing bacteria under anaerobic and aerobic/anoxic conditions are shown in Figure 2.7.

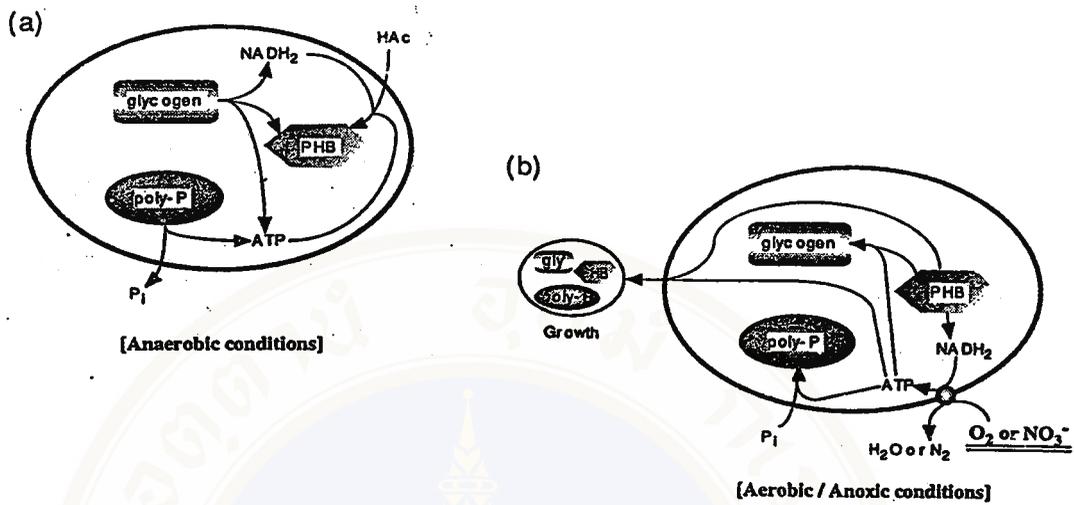


Figure 2.7 Schematic diagram of the metabolism of biological phosphorus removing organisms. (a) Anaerobic (b)Aerobic/Anoxic condition (11)

2.2.4.1 Phosphorus Removal under Anaerobic Condition

Acetate and other fermentation products are produced from fermentation reactions by normally occurring facultative organisms in the anaerobic zone. These fermentation products are derived from the soluble portion of the influent BOD and that there is not sufficient time for the hydrolysis and conversion of the influent particulate BOD. The fermentation products as lower fatty acid, e.g., acetic acid (HAc) are preferred and readily assimilated and stored by the microorganisms capable of excess biological phosphorus removal. This assimilation and storage is aided by the energy (ATP) made available from the hydrolysis of the stored polyphosphates (Poly-P) during the anaerobic period and excretion of phosphate (P_i). The stored polyphosphate provides energy for active transport of substrate and for formation of acetoacetate, which is converted to polyhydroxyl alkanoates, e.g. poly- β -

hydroxybutyrate(PHB). The phosphorus-removing microorganisms can assimilate the fermentation products in the anaerobic phase means that they have a competitive advantage compared to other normally-occurring microorganisms in activated sludge systems. Thus, the anaerobic phase results in a population selection and development of phosphorus-storing microorganisms.

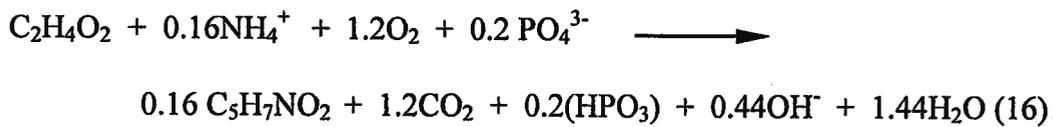
The degradation of polyphosphate under anaerobic conditions can, in a simplified manner, be



2.2.4.2 Phosphorus Removal under Aerobic or Anoxic Condition

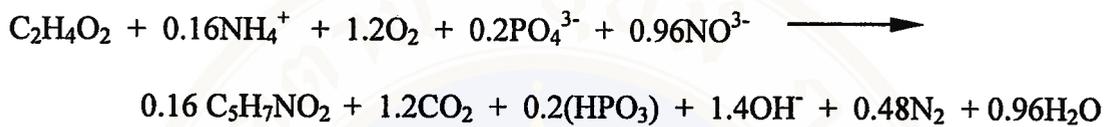
During the aerobic or anoxic phase, oxygen (O_2) or nitrate (NO_3^-) is utilized as an electron acceptor for the oxidation of the stored PHB, leading to growth and phosphate uptake with excess amounts stored as polyphosphates (Poly-P). The level of biological phosphorus removal achieved is directly related to the amount of substrate that can be fermented by normally occurring microorganisms in the anaerobic phase and subsequently assimilated and stored as fermentation products by phosphorus-removing microorganisms, also in the anaerobic phase.

The accumulation of polyphosphate under aerobic conditions can be described in a simplified manner as follows, for instance taking acetate as carbon source.



Poly-p

Under anoxic condition, based on the same assumption as above, the expression looks like;



Poly-P

Influence of Environmental Factor on Phosphorus Removal

- With O_2 being an easily accessible final electron acceptor, facultative aerobic/anaerobic bacteria will not switch over to fermentative metabolism as long as DO is present. Fatty acids will not be formed, and P release will not occur.
- Similarly to DO, nitrates disturb anaerobic acetogenesis in two different ways: by inhibiting fermentation (acetogenic organism can use nitrates as final electron acceptors) or by consuming readily biodegradable substrate during denitrification.
- Availability of fermentation substrate products needed by the phosphorus-storing bacteria relative to the amount of phosphorus that must be removed.
- The longer contact time in anaerobic phase results in the fermentation of particulates or materials that are more slowly converted to fatty acids.
- Sludge age is a very important parameter in enhanced biological phosphorus removal since the development of the minimum necessary culture of PAOs can be obtained when sludge age is low (Rodrigo). Whereas if the sludge is high,

the deterioration of the enhanced biological phosphorus removal and frequently this process has been imputed to the development and domination in the biological culture of other microorganisms known as 'G bacteria' (Glycogen bacteria)

'G bacteria' are capable of surviving in an alteration anaerobic/aerobic process. They can take up a substrate, like PAOs, at anaerobic stages and use it later at and aerobic stage. 'G bacteria' are considered to accumulate and use intracellular carbohydrate instead of polyphosphate as the internal source of energy and their predominance in the sludge population is believed to cause the decline of phosphorous removal.

2.2.5 Color Removal

Wastewater from textile finishing industries is complex and highly colored. Coloration of the liquid effluent results from wastage and washing during dyeing and printing processes, with the degree of coloration being dependent on the color/shade dyed and the type of dye used.

Water insoluble dyes(e.g. disperse and vat dyes) can be remove from the effluent by physical means such as flocculation. However, since the introduction of water soluble dyes , e.g. reactive dyes, conventional biological treatment processes are no longer able to achieve adequate color removal.

2.2.5.1 Color Removal under Anaerobic Condition

The decolorization of some component dyes of the effluent and of a mixture of dyes was achieved under anaerobic conditions, indicating that the bacteria were able to break the chromophoric bonds in the dye molecules(17).

Referring to Figure 2.8, the primary and secondary sludge are the carbon sources for anaerobic digestion. The carbon is converted to methane and carbon dioxide, during which process electrons are released. These electrons cascade down the electron transport chain to a final electron acceptor such as nitrate , sulfate or an azo reactive dye. The electrons with the dye by reducing the azo bonds and thus causing decolorization.

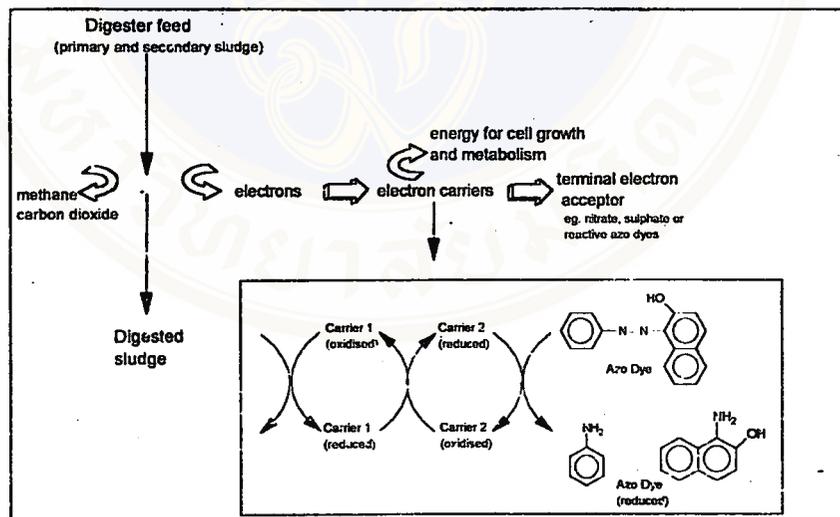


Figure 2.8 Mechanism for azo reduction under anaerobic conditions.(20)

2.2.5.2 Color Removal under Aerobic Condition

Anaerobic biological treatment alone does not completely degrade organic dyestuffs present in wastewater, the aromatic amines (that are generally more toxic than the dye itself) generated by anaerobic reduction may be effectively treated using aerobic biological treatment(18). After aeration these amines were mineralized by different members of the bacteria culture.

Thus, total degradation of azo dye was achieved by using and alternating anaerobic-aerobic treatment(19). This makes the anaerobic-aerobic sequence a plausible solution to the treatment problem. Haug (19) proposed pathway or degradation of an azo dye a mixed bacteria community as shown in Figure 2.9.

Influence of Environmental Factors on Color Removal

- The availability of a supplementary carbon source

A source of reduction equivalents, resulting from the degradation of a suitable carbon source, is essential to ensure decolorization and maintain the anaerobic population in the treatment system. In other words, a labile carbon source (other than the dyes) is required for decolorization to take place (20).

- Presence of nitrate nitrogen

Azo compounds are not decolorized until all nitrite (and hence NO_3^-) has been denitrified(21).

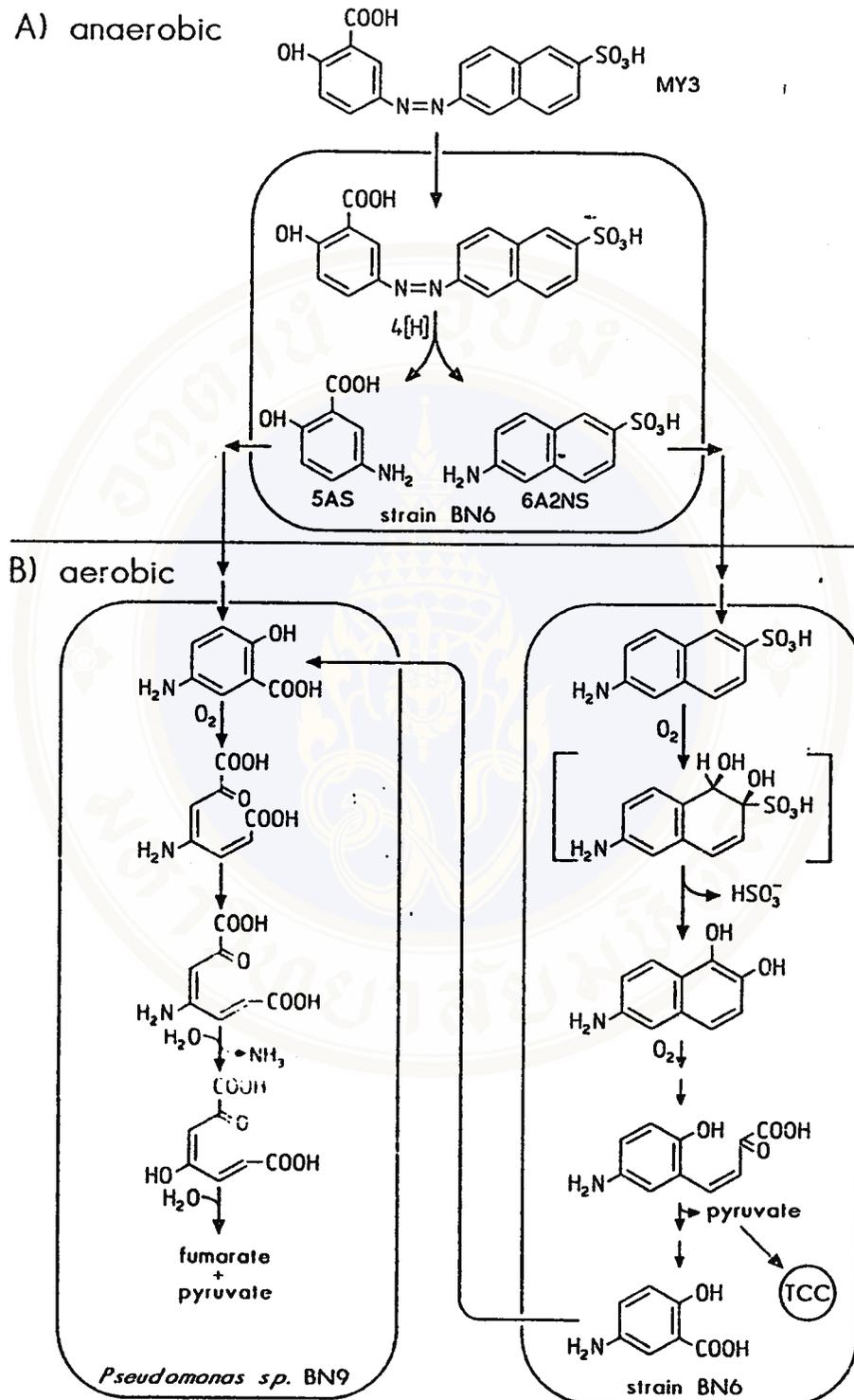


Figure 2.9 Proposed pathway for degradation of an Azo Dye by a mixed bacterial community.(19)

- SRT

Complex wastewater typically require a long sludge age to accommodate their low rates of degradation(22). Due to the batch nature of the textile production process it is necessary to implement high SRT in the biological reactor(8).

2.2.6 Acclimatization of Bacteria to Chemicals (8)

Acclimatization describes the bacteria “getting used to” a particular waste. When a new compound is introduced to a living biomass, the population of microorganisms may not be able to biodegrade the material initially. As time passes, however, the biomass may become active towards the material. This process, of course, is the acclimatization of sludge. The acclimatization phenomenon occurs due to one or more characteristics of mixed bacteria cultures:

(1) Bacteria are conservative. Although a bacterium may possess the genetic information necessary to produce enzymes to degrade a particular new compound, it will not spend the energy and actually synthesize the necessary enzymes unless the compound is present. This lagging response to a new compound is called “induction”.

(2) Population dynamics affect the removal of a new compound in mixed cultures. If a particular strain of bacteria acclimatizes and the co-existing populations do not acclimatize the compound, the strain has a competitive advantage. Food is available to a strain which can increase its relative predominance in the total population. Sometimes the strain can be a minor part of the population prior to the introduction of a new compound, and gradually grows into a much larger proportion.

This corresponds generally to a decrease in the effluent COD/BOD ratio. This gross effect is often referred to as the acclimatization of the biomass.

(3) A bacteria strain capable of degrading the new compound may not be present as a component of the existing biomass. When this happens no acclimatization can take place in the system. This phenomenon accounts for the situation where a particular new component will be degraded in one plant and yet will pass through another plant untouched, even though conditions may be similar.

In textile finishing and dyeing wastewater treatment many new compounds are only present occasionally, due to the batch nature of the process. A biomass has become acclimatized to a new compound and then the compound disappears from the influent wastewater due to a process change. The acclimatization population will lose its activity toward the novel compound because the daughter cells will not exhibit activity toward the compound, if it was not present during cell division. Thus the number of bacteria having activity towards the compound is rapidly reduced due to a dilution effect.

A biomass can lose acclimatization during plant shutdowns. In this case different selection pressures are brought to bear on the biomass than are present during normal operation. During plant shutdowns the food is cut off. The bacterial population crashes and only those bacteria that are predisposed toward survival are left. Spore-forming bacteria such as *Bacillus* leave a fair seed behind, but bacteria such as *Pseudomonas*-very important in the breakdown of aromatic compounds die off to very low levels. Another problem that can upset the acclimatization of the plant is that of shocks due to pH, high load of BOD or toxic conditions.

2.3 Sequencing Batch Reactor(SBR)

A sequencing batch reactor(SBR)is a fill - and - draw activated sludge treatment system. The unit processes involved in the SBR and conventional activated-sludge systems are identical. Aeration and sedimentation/clarification are carried out in both systems. However, there is one important difference. In conventional plants, the processes are carried out simultaneously in separate tanks, whereas in SBR operation the processes are carried out sequentially in the same tank.

2.3.1 Process Description.

The SBR technology provide a lot of flexibility to design. The elementary and the geometrical layout have no limitation, the reactor can be any size and shape. The SBR process has five basic operating modes or periods, each of which is named according to its primary function. The periods are FILL, REACT, SETTLE, DRAW (or DECANT) and IDLE in a time sequence. Figure 2.10 is a schematic diagram of the SBR process. Central in this Figure is one tank which is pictured in each of the five period of one cycle. Also shown is the percent of the maximum liquid volume and total cycle time that may be dedicated to each period and the purpose of and aeration policy used for each period. The SBR system may be composed of one or more tank that are carried out in sequence as follow (23).

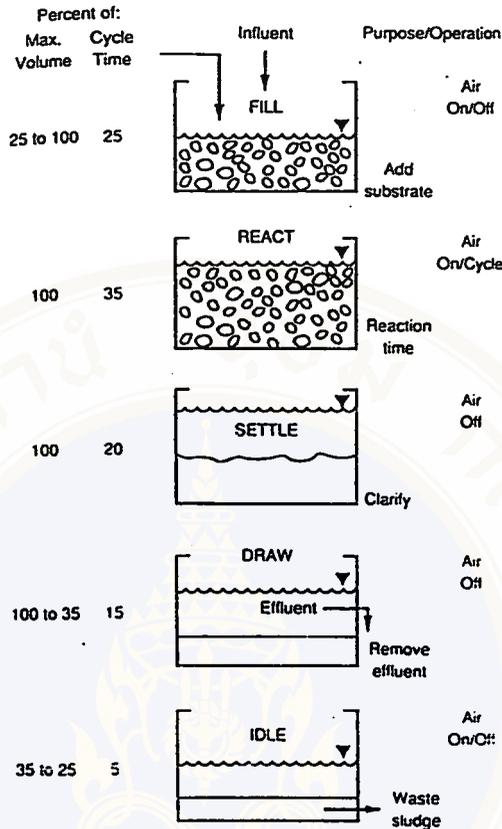


Figure 2.10 Typical SBR operation for one cycle (23).

1. FILL

The influent to the tank may be either raw wastewater (screened and degrittled) or primary effluent. The influent may be either pumped in or allowed to flow in by gravity. When more than one tank is used and the influent is added by gravity, some device(e.g. an adjustable weir or an automated valve) must be operated such that the flow is diverted to one tank or the other.

The tank may be an earthen ditch, an oxidation ditch, a rectangular basin or any other concrete or metal type structure. During FILL the influent wastewater is added to activated sludge which remained in the tank from the previous cycle. The

liquid volume increases from the initial level (shown to be 25 percent of the total in Figure 2.10) to the maximum of 100 percent. Actually the initial volume may be as great as 70 percent or more of the maximum, and the period can be designed to terminate before the maximum level is reached by limiting the FILL time to a predetermined maximum. The initial volume is determined based on a number of factors including desired loading and detention time. The time of FILL is shown to be 25 percent of the total cycle time in Figure 2.10 but will be more or less depending upon the extent of diurnal variations in the hydraulic flow rate.

The full-scale SBR study had an average time of FILL of approximately 50 percent of the total average cycle time. The initial volume averaged roughly 60 percent of the maximum liquid volume. FILL is terminated when the tank is either full (as determined by a level indicator) or when a maximum time for FILL is reached. The wastewater flow is then diverted to another tank in the SBR system.

2. REACT

Reactions which were initiated during FILL are completed during REACT. As in FILL, alternating conditions of high and low DO may be required. While Figure 2.10 suggests that the liquid level remains at the maximum throughout REACT, sludge wasting can take place during this period as a simple means for controlling the sludge age. For example, the sludge age in days would be equal to the reciprocal of the fraction of the maximum liquid volume wasted each day. While 35 percent of the total cycle time is shown in Figure 2.10 to be dedicated to REACT this can vary from a low of zero to more than 50 percent.

The end of REACT may be dictated by a time specification or a level controller. Use of the level controller is actually quite simple. In a two tank system, when the liquid level in the tank in FILL reaches some predetermined level, signal is sent to the controller which cuts-off all mixing or aeration devices operating in the tank in REACT. In a three tank system a simple control which ends REACT in the first tank when the “second” tank ends FILL (or the “third” tank begins FILL) can be easily implemented.

3. SETTLE

In the SBR, solid separation takes place quiescently in a tank which may have a volume of more than ten times that of a secondary clarifier in a conventional continuous flow activated sludge plant. This major advantage results from the fact that the aeration tank serves as the clarifier during a period that no flows enter the tank. Because all of the activated sludge remains in the tank until some fraction must be wasted, there is no need for underflow hardware normally found in conventional classifier. In way of contrast, mixed liquor is continuously removed from a conventional activated sludge aeration tank and passed through the clarifier only to have a major portion of the sludge returned to the aeration tank.

The time in SETTLE should be fixed between 0.5 and one hour so that the sludge blanket remains below the withdrawal mechanism during DRAW but does not rise (because of gas formation) before DRAW is completed.

4. DRAW

The withdrawal mechanism may take one of many forms. It may be as simple as a pipe fixed at some predetermined level with the flow regulated by either an automatic valve or a pump, depending upon the hydraulic grade line of the system. Alternatively an adjustable weir or a floating weir at or just beneath the liquid surface can be used. As with the fixed mounted pipe, discharge from the weir can be regulated by an automatic valve or a pump.

The time dedicated to DRAW can range from 5 to more than 30 percent of the total cycle time, with 45 minutes being a typical draw period. The time in DRAW, however, can not be overly extended because of possible problems with rising sludge.

5. IDLE

After DRAW, the tank is ready to receive additional wastewater but because the tank which is in FILL may not have reached the maximum liquid level, the tank just completing DRAW must wait. The period between DRAW and FILL is termed IDLE. This time can however be used effectively. As Figure 2.10 shows, sludge can be wasted during idle. The frequency of sludge wasting can range between once every two to three months depending upon system design. The sludge was wasted during one of the four cycles each day by pumping settled sludge (approximately 0.1 percent of maximum liquid volume) over a ten to fifteen minutes period.

Alternatively, IDLE can be eliminated altogether by terminating FILL in the tank receiving the wastewater as soon as the tank in DRAW reaches the minimum liquid level. This would not force sludge wasting to take place during REACT since

wasting can easily take place during either the end of SETTLE or any time during DRAW.

2.3.2 Process Application

In the early 1960s, with the development of the new technology and equipment, interest was revived in the fill-and-draw systems. Improvements in aeration devices and control systems have allowed the development of fill-and-draw systems to achieve their present level of efficiency, which now enables SBR technology to compete successfully with conventional systems. All wastewater commonly treated by conventional activated-sludge plants can be treated with SBRs.

The SBR can be operated to achieve any combination of carbon oxidation, nitrogen reduction, and phosphorus removal. Reduction of these constituents can be accomplished with or without chemical addition by changing the operation of the reactor. Phosphorus can be removed biologically without coagulant addition, phosphorus release and BOD uptake will occur in the anaerobic phase, with subsequent phosphorus uptake in the aerobic phase. By modifying the reaction times as illustrated in Figure 2.11 , nitrification or nitrogen removal can also be accomplished. Overall cycle times may vary from 3 to 24 hours. A carbon source in the anoxic phase is required to support denitrification, either an external source or endogenous respiration of the existing biomass.

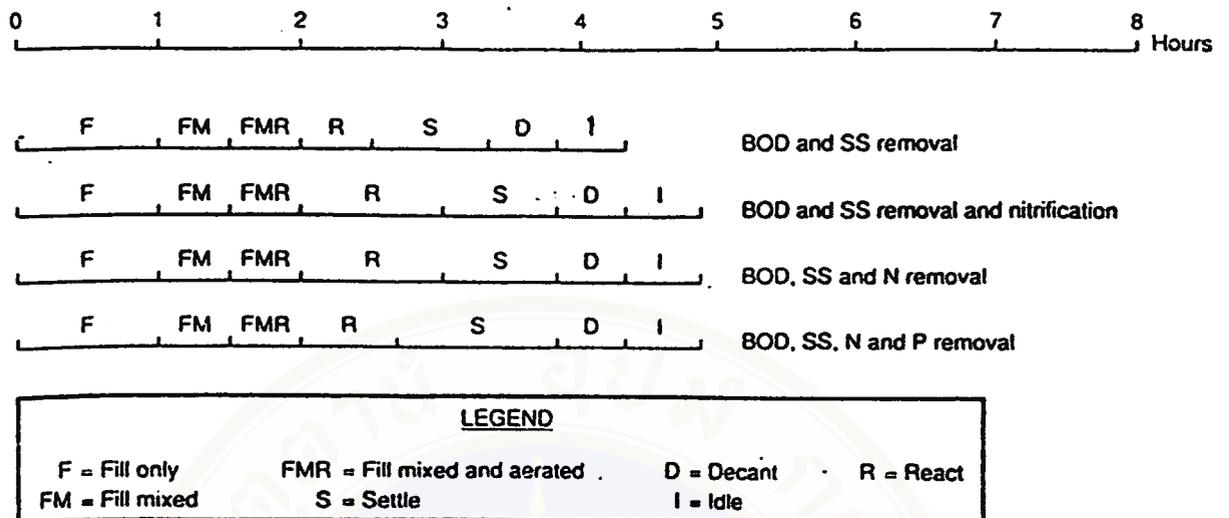


Figure 2.11 Suggested SBR operating strategies for the removal of carbon, nitrogen and phosphorus. (3)

2.3.3 Simultaneous Nitrogen and Phosphorus Removal in SBR

A simplified scheme with the principal actions of the responsible organisms and the different intermediate steps in the degradation of carbonaceous, nitrogenous, and phosphorous compounds is given in Figure 2.12. Organic N is ammonified along the different treatment steps, and consumed partly for normal cell synthesis (not indicated on the Figure). In a low-loaded system, nitrification occurs, *Nitrosomonas* converts ammonia-N into nitrites, the latter product serving as a substrate for *Nitrobacter*, giving nitrate as the final oxidation product. Nitrates recycled to an anoxic zone and, depending on the process configuration, also to the anaerobic zone are consumed by denitrifying organisms. These consume part of the organic substrate, and release N_2 and/or N_2O into solution. Denitrifying organisms capable of polyphosphate storage (e.g., *Moraxella*) thereby replenish the polyphosphate pool. In the absence of nitrates, organic matter is converted into acetate by acidogenic

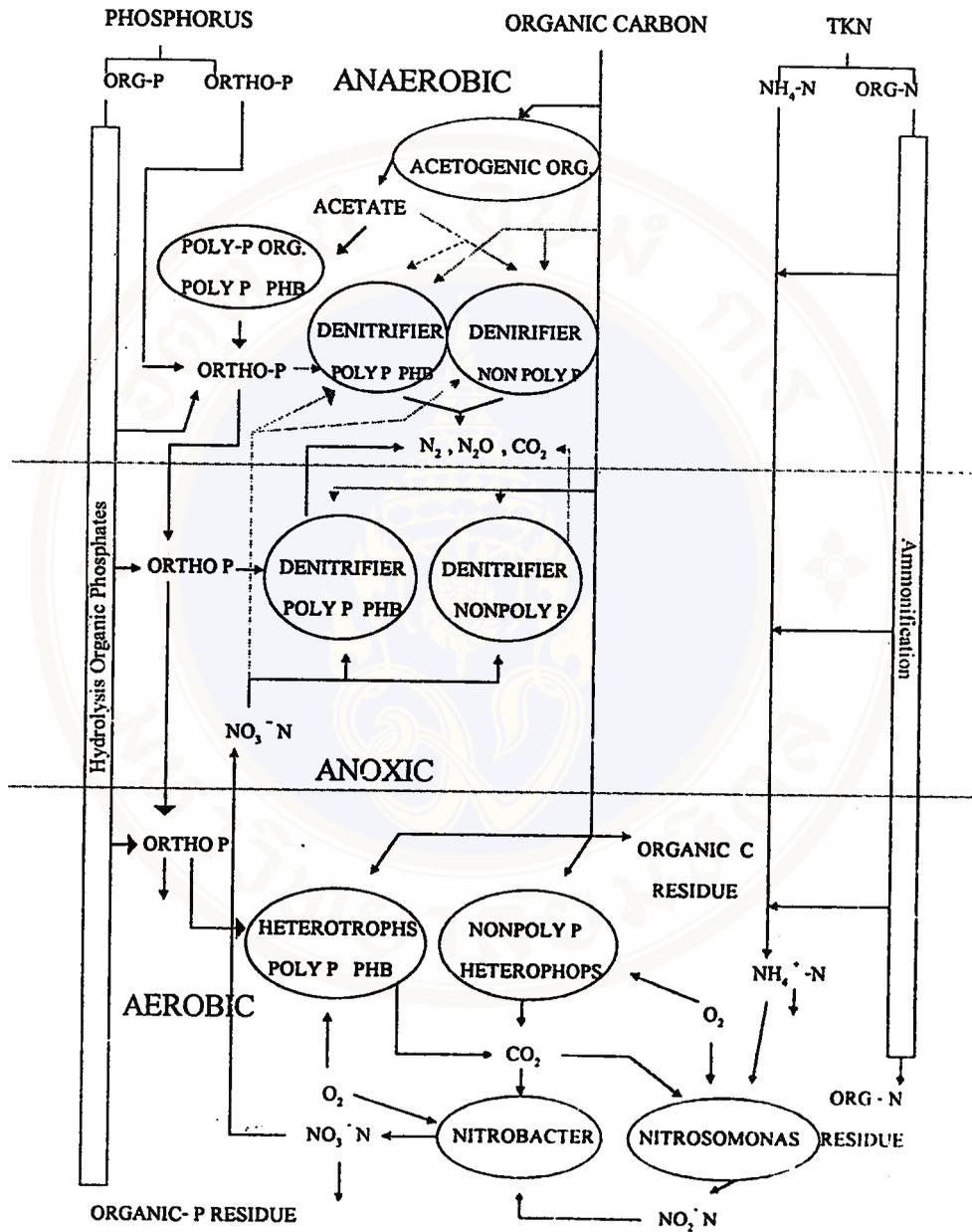


Figure 2.12 Schematic view of the mechanisms of biological wastewater treatment including nutrient removal.

organisms (e.g., *Aeromonas*). The acetate is absorbed by polyphosphate organisms, converting it into PHB and releasing orthophosphate. In the aeration zone, remaining biodegradable organic matter is oxidized by heterotrophic organisms. Dissolved CO₂ is used as the carbon source by the autotrophic nitrifying organisms. Polyphosphate organisms further consume the PHB stock for growth and polyphosphate accumulation.

2.3.4 Factors Affecting Simultaneous Biological Nutrient (N and P)

Removal (12)

- Configuration of alternating conditions in the treatment processes. In the case of simultaneous nitrification and denitrification, aerobic condition is required for nitrification and anoxic condition is required for denitrification. However the anaerobic stage is prerequisite ahead of aerobic stage for biological phosphorus release and aerobic stage is necessary for the accumulation of released phosphorus. Anoxic stage enhances phosphorus uptake, as nitrate provides the facility of electron acceptor.

- Type of carbon source for the energy of cell metabolism effects significantly in the simultaneous removal of N and P. Easily biodegradable carbon substrate have significant effect. Tam et. al. (24) found that, for acetate, time required for complete denitrification and P release was shorter than methanol at the same concentration. Glucose was the least effective substrate hence they did not recommend it for biological N and P removal.

- Concentration of COD in relation to nutrients has great effect on simultaneous nutrient removal. Since organic substrate competition between

phosphorus accumulating organism (PAO) and denitrifying bacteria might frequently occur, plant configuration that exert selective pressure in favor of PAO denitrifying bacteria are strongly recommended. Such kinds of plants are particularly suitable for low COD/TKN ratio wastewater, where lack of carbon affects the nutrient removal efficiency(25).

- The effect on the alkalinity is similar to nitrification and denitrification, since the effect of phosphorus removal is marginal(12).

- Biological phosphorus removal will be adversely affected in biological combined nitrogen and phosphorus removal systems unless the DO concentration in the aerobic zones remains 1.5-3 mg/l. If the DO is too low, they claim that phosphorus removal may be reduced, nitrification will be limited, and a poor settling sludge may be developed. If too high, denitrification performance could be limited due to the increase in DO recycled to the first anoxic zone. A resultant higher nitrate nitrogen concentration could then affect the phosphorus release performance of the anaerobic zone(26).

- A longer SRT condition is prerequisites for improving nitrification. However, phosphorus removal capacity corresponds to the amount of wasted sludge and its phosphorus content. For a shorter SRT , polyphosphate accumulating organisms (PAOs) can release a higher phosphorus level and accumulate more polyphosphate in anaerobic and aerobic stages, respectively. The process during a shorter SRT yields a better performance in terms of phosphorus removal. Consequently, The difficulties in selecting SRT yields a better performance in terms of

phosphorus removal. Consequently, the difficulties in selecting SRT arise which simultaneously remove nitrogen and phosphorus(27).

2.3.5 Advantage

1. The SBR is easily operated with or without biological phosphorus and nitrogen removal by providing anaerobic, anoxic and aerobic conditions in a proper time sequence.
2. Without employing the sludge recycle strategies common to conventional biological nutrient removal facilities.
3. SBR carries out the fractions of equalization, aeration and sedimentation in a time sequence rather than in the conventional space sequence of continuous flow system.
4. The SBR can provide substantial savings in energy and cost by removing organic compounds found in hazardous waste biologically, rather than with activated carbon.
5. The SBR tank serves as an equalization basin and therefore can easily tolerate peak flows and shock loads of BOD without deterioration of effluent quality. The SBR can be used to retrofit continuous flow extended aeration plants at minimal cost.
6. The systems with a wide range in flow and /or organic loading and system that require extremely close control of effluent quality are particularly suited for SBR.
7. Can not be washed out of mix liquor solids by hydraulic surges because they can be held in the tank as long as necessary. Solid-liquid separation occurs under

nearly ideal quiescent conditions. Short circuiting is non-existent during the settle period.

8. Because the DO concentration is zero or near zero during anoxic fill it provides for a greater oxygen driving gradient during the react period. This could achieve somewhat higher overall oxygen transfer efficiency with the same aeration equipment.

9. The SBR can be operated to achieve nitrification, denitrification, or phosphorus removal without chemical addition. Filamentous growth can be easily controlled by varying the operating strategies during FILL.

10. The SBR technology provides a lot of flexibility to design. The geometrical layout has almost no limitations; the reactor may be circular, rectangular, square or even be built as an earth basin.

11. Low land requirement little yard piping, since no clarifiers.

12. It was found that a sequence of short aerobic/anoxic phases appears to be better than the usual sequence (one aerobic phase followed by one oxic phase). The optimized process saves up to 50% on extra BOD supply and up to 30% on aeration time

2.3.6 Disadvantage

1. The high energy that must be dissipated during discharge of the treated effluent.

2. Increased operator attention.

3. Clogging of diffusers because of the periodic settlement of the sludge.

2.4 Related Researches

Nigam P, Mullan GM, Banat IM and Marchant R. (17) studied microbial process for the decolorization of textile effluent containing azo, diazo and reactive dyes. The results showed that the decolorization of some component dyes of the effluent and of a mixture of dyes was achieved under anaerobic conditions, indicating that the bacteria were able to break the chromophoric bonds in the dye molecules.

Haug W, Schmidt A, Nortemann B Hempel DC, Stolz A and Knackmuss HJ. (19) stated that under anaerobic conditions the sulfonated azo dye Mordant Yellow 3 was reduced by the biomass of a consortium aerobically with 6-aminonaphthalene-2-sulfonic acid. Stoichiometric amounts of the aromatic amines 6-aminonaphthalene-2-sulfonate and 5-aminosalicylate were generated and excreted into the medium. After re-aeration of the culture, these amines were mineralized by different members of the bacterial culture. Thus, total degradation of a sulfonated azo dye was achieved by using an alternating anaerobic-aerobic treatment. The ability of the mixed bacterial culture to reduce the azo dye was correlated with the presence of strain BN6, which possesses the ability to oxidize various naphthalenesulfonic acids. It is suggested that strain BN6 has a transport system for naphthalenesulfonic acids which also catalyzes uptake of sulfonated azo dyes. These dyes are then gratuitously reduced in the cytoplasm by unspecific reductases.

Goronszy MC and Tomas H. (22) studied the efficiency of the aerobic SBR in treating a textile wastewater. Fill sequences were 3.5 hours, aeration sequence were varied to assess limit on biodegradability ; times of 2-14 hours were used. Settle sequences were always of a one hour duration. The result showed that cycle time of 4-12 hours in aerobic phase, using the same fill volume generated a statistically similar COD concentration in effluent of around 200 mg/l. The total COD and color removal efficiency were 75 % and 30% respectively.

Raveedran 1989 (28) studied the efficiency of SBR operating in 8 hours per cycle. The SBR was operate on 1 hour anoxic fill, 5.5 hours react (anoxic 2 hours, 2 hours oxic, 1 hour anoxic, 0.5 hour oxic), 1 hour settle and 0.5 hour decant. The results showed that SRT was the most important parameter in the removal of nitrogen and phosphorous. Optimum SRT at 12.5 days was found which yielded total phosphorous and total nitrogen removal efficiency of 89 % and 83% respectively.

Rahman RA (29) identified the influence of variables on biodecolourization by using the method of factor analysis. Six variables were subjected to analysis. There were temperature, pH , dye and glucose concentration, degree of aeration and biomass concentration. The results showed that the most influential variables were dye , glucose concentration and temperature.

Wanner J, Cech JS and Kos M.(30) proposed a new arrangement of biological process for COD, nitrogen and phosphorus removal. The process consists of

the anaerobic, nitrification and denitrification reactor. The detention times for each phases were anaerobic phase 3 hours , oxic phase 3.5 hours, anoxic phase 4 hours, settling time 1 hour ,drawing and filling time 0.5 hour.

Overall hydraulic detention time was 1 day, target sludge age was 20 days. The results showed that COD, total nitrogen and total phosphorus removal efficiency were 96%, 77% and 79%, respectively.

Zaoyan Y, Ke S, Guangliang S, Fan Y, Jinsham D and Huanian M.(31) studied the anaerobic-aerobic treatment of a dye wastewater by combination of RBC with activated sludge. The results showed that the COD decreased from 600-900 mg/l of influent to about 150 mg/l of effluent. The dilution times of color decreased from 200-500 times to 80 times, when the HRT and COD RBC-area load of anaerobic and aerobic RBC were 7-8 hours and 4.5-5 hours and 40-50 g/m². D and 30-40 g/m² respectively. The MLSS in the tank were about 100-300 mg/l.

Demuynck C, Vanrolleghem P, Mingneau C, Liessens J and Verstraete(32) studied a SBR operating in a sequence of short aerobic/anoxic phases. The total cycle time is 6 hours and 4 cycles performed per day during normal operation. The time schedule of the different phases, given anaerobic filling (67 min.), aerobic 1 (150 min.), anoxic (60 min.) aerobic 2 (30 min.) settling 45 min., decanting 15 min., respectively. The results showed that the average phosphorus concentration was below 1 mg/l. Remark that the dissolved oxygen was controlled at 2.0 mg/l.

Bortone G., Cech JS, Germirli F, Bianchi R. and Tilche A.(33) studied the feasibility of the biological removal of nitrogen from mixed textile (80%) and municipal wastewater (20%). The three modified “Ludzack Ettinger” bench scale plants were used. The experiment was designed into two run. In the first run, the influence of anoxic-oxic reactor volume ratio was investigated. In plant 1, 2 and 3 the anoxic volume were varied 2.4, 4.5 and 6.3 liter, respectively and SRT were controlled at 20 days. The results demonstrated that COD, NH₄-N and TP removal efficiency of plant 1, 2 and 3 were in range of 80.5%-81.2%, 86.7%-93.7% and 38.2%-43.6%, respectively.

In the second run, the effect of sludge age on the stability of nitrification was investigated. The SRT were varied to 20, 40 and 60 days. The results concluded that, Nitrification efficiency was almost quite high during the stability of nitrification but did not correspond to the adopted sludge age of 20 days. Nitrification (denitrification process can be satisfactorily applied to the treatment of troublesome wastewaters from textile industry providing that long sludge ages are adopted.)

Subramaniam K, Greenfield PF, Ho KM, Johns MR and Keller J.(34) studied the efficient biological nutrient removal in the abattoir wastewater using combined anaerobic Sequencing Batch Reactor treatment. The feeding wastewaters were received from the anaerobic stabilization ponds. Operating cycle of SBR was consisted of Non-aerated fill, Aerated mixed react 1, Non-aerated mixed React, Aerated mixed React 2. The hydraulic retention time (HRT) and solids retention time(SRT) were 1.5 days and 20 days, respectively.

The results showed that the removal of COD, TKN, TP and SS were greater than 95%, 92%, 90% and 94%, respectively.

Bortone G, Malaspina F, Stante L and Tilche A.(35) studied an anaerobic/aerobic Sequencing Batch Reactor (A/A SBR) with separated batch biofilm nitrification treating piggery wastewater. The results showed very good nutrient removal efficiencies about 98% for nitrogen and more than 90% for phosphorus.

Carliell CM, Barclay SJ, Naidoo N Buckley CA, Mulholland DA and Senior E.(36) studied the anaerobic decolorization of reactive dye by using 5-stage Bardenpho reactor for investigation. They found that 80% of the dyes (mainly azo dye) studied were decolorized and decolorization occurs after nitrate removal, except for C.I. reactive blue 49 (an anthraquinone dye) was not significantly decolorized as well as C.I. reactive yellow 95. This has been attributed to possible these structure are more stable and inhibitory or toxic compounds in printing dye respectively.

Carliell CM, Barclay SJ, Naidoo N, Buckley CA, Mulholland DA, and Senior E.(37) studied decolorized mechanism of an azo reactive dye using thin layer chromatography (TLC) and proton nuclear magnetic resonance spectroscopy (NMR). They found that decolorization was dependent on the reduction potential of the solution and that decolorization occurs after nitrate removal. This suggested that the decolorization reaction did not depend on the interaction of the bacteria with the dye molecule, but rather the reducing conditions provided by the bacteria and in such

conditions the azo bonds in the dye molecule were broken followed by breaking of the amine linkages between the chromophore and the reactive group and within the reactive group itself.

Bortone G, Cech JS, Bianchi R, and Tilche A.(38) studied the efficiency of the anaerobic reactor for COD removal, the selective pressure on the microbial community and the enhanced biological phosphorus removal. In anaerobic tank 40% of the influent COD was removed with a reaction time of only 45 minutes. The activated sludge showed a very high presence of Poly-P bacteria; anaerobic P release was noticed during the anaerobic phase was around 3.3 mg PO₄-P g VSS h⁻¹. Sludge settleability was always good . The final effluent PO₄-P concentration was always lower than 1 mg/l.

Knapp JS and Newby PS (39) studied the microbiological decolorization of an industrial effluent containing a diazo-linked chromophore. They found that decolorization was favored by strictly anaerobic condition and highly proteinaceous media. The effluent with initial absorbances of 100 units at λ_{\max} were rapidly decolorized 85% in 2 days.

Pansuwan J (40) studied the A²O SBR process (anoxic-anaerobic-aerobic) treating real textile wastewater with different color origin i.e. disperse, reactive, and sulfur dyes . The reduction efficiency of organic matter expressed as the filtrate COD was 79.1, 59.8 and 60.6 percent for those dyes respectively. The color removal efficiency was 11.2, 5.1 and 8.0 percent of ADMI units and 75,15.7 and 31.2 percent

of SU units. The total kjeldahl nitrogen removal efficiency was 93.7-95.6 for all three dyes wastewater. Also the total phosphorous removal efficiency was 29.8, 14.2 and 25.7 percent respectively.

Stern RS, Szpyrkowicz L and Grandi FZ (41) studied the efficiency of Denitrification-Nitrification process in the treatment of printing wastewater. The SRT, MLSS and DO in nitrification was controlled at 40-45 days, 5,300 mg/l and 2-3 mg/l respectively. The result showed that COD, NH₄-N and color removal efficiency were > 90%, >92% and 75-80%, respectively.

Loyd KC, Boardman GD, and Michelsen DL.(42) investigated textile wastewater treatment by aerobic biological treatment and anaerobic biological pretreatment followed by aerobic treatment in laboratory scale, they found that anaerobic-aerobic sequence produced significantly greater color reduction than aerobic treatment alone (88% and 28%), BOD 91%, COD 77% and TOC 82% . In the anaerobic - aerobic sequence, 46% of the color reduction occurred during anaerobic treatment, and a 2% increase in color occurred during aerobic treatment . The aerobic treatment alone produced a 28% color reduction during dilution and seeding and a slight color increase from the aerobic treatment. And the second study, they studied the anaerobic SBRs operated on a repetitive cycle of fill, react, settle and withdraw and aerobic SBR using the same cycle as the anaerobic water. The cycle time were less than 5 min for filling and withdrawing and varied from 5 min. to 24 hours for reacting and from 30 minutes to 1 hr. for settling depending on the detention time desired for the

experiment. In SBR with 5 min reaction time and 30 min. settle time, color was reduced 15% by hour 8. ,and then increased slightly through the remainder of the experiment (48 hours). Based on both color and TOC reduction (approximately 20%), it appeared that the biomass floc initially adsorbed the dyestuff, but that the dyestuff was subsequently degraded and released. This was observed as a continuous darkening and lightening of the floc throughout the experiment.

Boe RW, Boardman GD, Dietrich AM, Michelsen DL, and Pudki M.(43) used effluent from a primary clarifier of a local POTW receiving 75% textile dye wastewater as influent to the pilot plant. Two systems were evaluated: the first consisted of anaerobic reduction followed by aerobic treatment, and the second consisted of anaerobic reduction chemical reduction using thiourea dioxide , followed by aerobic treatment. The anaerobic step had hydraulic retention times of 6 and 12 hours with 2000-3000 mg/l biomass. Treatment of the wastewater using 12-hr anaerobic retention time achieved average color reductions of 55-60%. For the total system, color reduction of 65-70% were obtained, achieving an effluent of 560-590 ADMI color units. The 6-hr anaerobic retention time achieved only 15-20% color reduction, and the system eventually failed completely.

Brown D and Laboureur P. (44) studied four solutions of commercial anthraquinone dyes in distilled water, using and anaerobic sludge inoculum, and found that three of the four were significantly degraded. In this study, Acid Blue 80 was only slightly degraded. Though the source of inhibition was not identified. Additional

results, which were later confirmed by Brown and Hamberger, indicated that on anthraquinone dye, Acid blue 25, may be structurally altered under anaerobic conditions to produce an insoluble anthraquinone pigment. Thus, the types of dyes and substituent groups found in the wastewater greatly influence the treatment selection. Dyes or other compounds that are inhibitory to biological treatment may be pretreated or segregated and treated in a separate treatment process. In some cases, a high concentration of inhibitory compounds may preclude the use of biological treatment.

Nigam P, Mullan GM, Banat IM and Marchant R.(45) studied the decolorization of effluent from the textile industry by a microbial consortium under anaerobic condition. The results summarized that decolorization was dependent upon the presence of a carbon and energy source in addition to the textile dyes. This microbial consortium was capable of dye decolorization when utilizing cheap and readily available carbon sources such lactose, starch and distillery waste. Color was removed 76% from textile plant effluent after 3 days.

Basibuyuk M and Forster CF (46) studied the anaerobic aerobic filters using the simulated dyeing wastewater. The anaerobic and aerobic time were 6 and 16 hours respectively. They found that this process can remove COD and color more than 92 % and 99% respectively. Furthermore, the high flow rates associated with the hydraulic shock caused serious disruption to the operation of the process.

Malpei F, Andreoni V, Daffonchio D and Rozzi A(47) reported that inhibition and toxicity of dyes and anaerobic biodegradability of textile print-paste thickeners with adding milk whey as co-substrate. The results showed that low degradation was found in the order of 30-35 % on COD , moreover increasing the thickener load to the reactor caused failure of the process. They concluded that possible reasons for the malfunction were thought to be inhibition of the methanogenesis due to chemicals present in the thickener and the high ammonia concentration derived from hydrolysis of urea in the thickener.

Karcharnubarn (48) studied the efficiency of a SBRs in the removal of organics, nitrogen, phosphorus from mackerel wastewater plant. The 3 similar sequencing batch reactors were operated on 5-hours static fill, 16-hours react, 1-hour draw act and 1-hour idle period. The most suitable running condition of SBR were at 3-hours anoxic time and 20 days SRT which yielded COD, TKN and TP removal efficiency of 98.10%, 97.44% and 99.28%, respectively.

CHAPTER III

MATERIALS AND METHODS

The textile wastewater was treated with an Anaerobic Sequencing Batch Reactor (AnA²/O² SBR) by varied anoxic time and solid retention time (SRT). Chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), total phosphorus (TP) and color were analyzed to determine their removal efficiencies. Analysis of variance was tested to evaluate the difference between varied treatment combinations.

3.1 Research Design

A laboratory scale of AnA²/O² SBRs were used to study the removal of chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), total phosphorus (TP) and color from the textile wastewater. This experimental research was planned to be 3² factorial experimental design, and scheduled to study the influence of anoxic time and SRT simultaneously on that removal. The experiment was divided into three groups corresponding to 9 experimental conditions. The anoxic times were set at 2, 4 or 6 hours and SRTs were set at 40, 60 or 80 days.



Table 3.1 Operational conditions during experimental runs

| <i>Group</i> | <i>Experimental Condition</i> | <i>Experimental Model Number</i> | <i>SRT (days)</i> | <i>Anoxic time (hours)</i> |
|--------------|-------------------------------|----------------------------------|-------------------|----------------------------|
| 1 | 1 | 1 | 40 | 2 |
| | 2 | 2 | 40 | 4 |
| | 3 | 3 | 40 | 6 |
| 2 | 4 | 1 | 60 | 2 |
| | 5 | 2 | 60 | 4 |
| | 6 | 3 | 60 | 6 |
| 3 | 7 | 1 | 80 | 2 |
| | 8 | 2 | 80 | 4 |
| | 9 | 3 | 80 | 6 |

3.2 Research Model

A schematic drawing of the experimental unit which was used in the study is given in Figure 3.1. The system consist of 3 reactors, feeding pump, influent wastewater containers, valves, air compressors, air diffusers, microprocessor time controllers, electric stirrers and effluent treated wastewater containers.

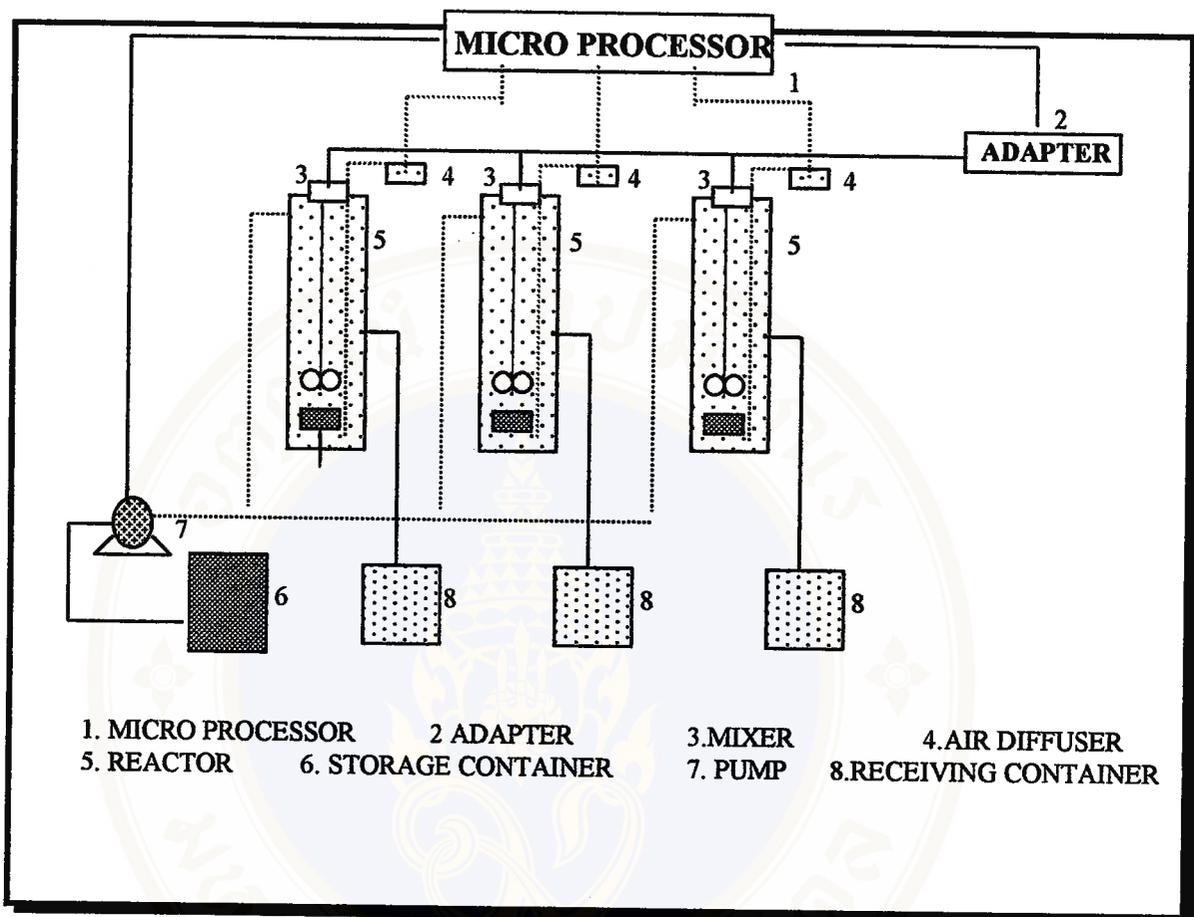


Figure 3.1 A schematic drawing of an Anaerobic Sequencing Batch Reactor (AnA²/O² SBR).

3.2.1 Wastewater Sampling and Characteristics

The wastewater was sampled from the storage tank of a textile factory in Samutprakran province by grab sampling and put into plastic containers and storage in the refrigerator prior to use in the experiment. The primary composition of the wastewater are dyes, auxiliaries, starch, detergents, thickener, solvent and other organic compounds, as well as acids, alkalis, salts and other inorganic constituents. The major dyes used mainly are reactive dye. Influent wastewater were controlled pH

to 7.1 ± 0.1 before filling to the reactors. The characteristics of wastewater which used in this experiment were analyzed and shown in Table 4.1.

The mixed culture biomass from the return sludge of Sri-Phraya Central Wastewater Treatment Plant was used as a seed to the reactors. The biomass was collected at the plant three times during the experimental period. The average concentration of the sludge was 7,700 mg/l.

3.2.2 Reactor system

3.2.2.1 Reactor

Three reactors with cover plate and rubber stopper operating in parallel sequence were used in this experiment. The unit was made of (acrylic) plastic with dimension of 7 inches (width) x 19.5 inches (height) as illustrated follow. The high water level and low water level marks were at 10 liters and 5 liters respectively. Volume of influent feed and effluent withdrawn were 5 liters in each cycle.

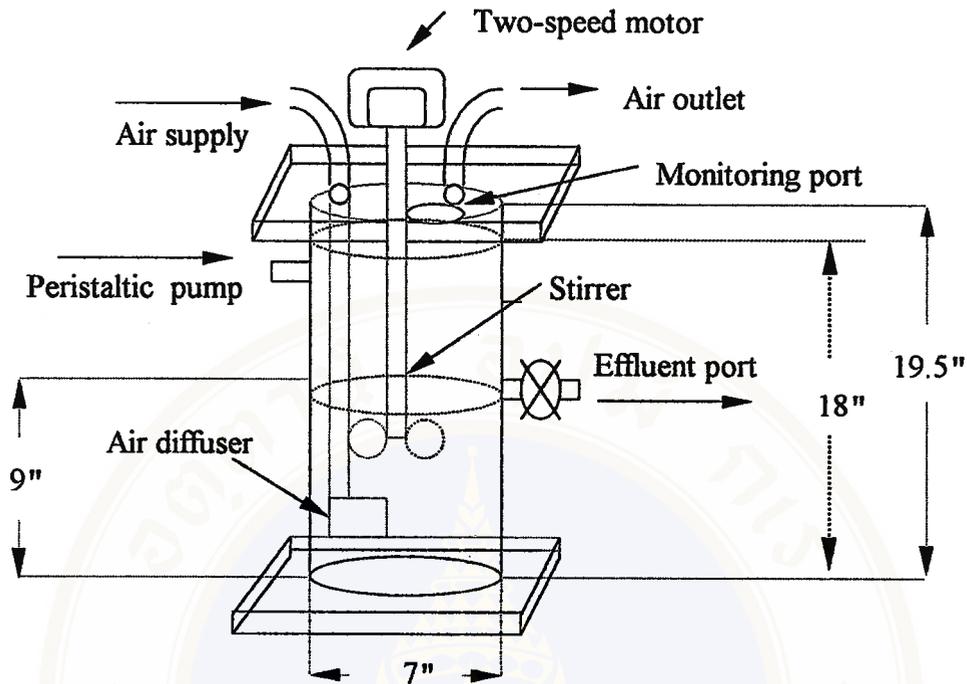


Figure 3.2 A schematic drawing of an Anaerobic Sequencing Batch Reactor (AnA²/O² SBR) dimension.

3.2.2.2 Air Diffusers

Air was pumped by air pump passing through tubing to air porous stones fitted at the bottom of the reactor. Valves were used to control the quantity of air to the reactors. In order to supply air periodically, air pumps were controlled by microprocessor time controller.

3.2.2.3 Stirrers and Two-Speed Motor

Stirrers controlled by two-speed motors were rotated in order to keep biomass in suspension. These were operated the time by the time controllers. Rapid mixing in aerobic time or slow mixing in anoxic time were operated by the more or less rotation.

3.2.2.4 Micro Processor Time Controller

The microprocessor time controllers were used to control the operation schedule of each cycle of the experiment. There were filling time, reaction time, settling time, withdraw time and idle time.

3.2.2.5 Pump

The adjustable peristaltic pump(Cole - Parmer : model 7518-10) with three pump heads was used for feeding wastewater from storage container to reactors. This pump was controlled by time controller.

3.2.2.6 Storage and Receiving Containers

Storage and receiving containers were made of plastic. The volume of storage and receiving containers were 20 liters and 6 liters, respectively. Storage container was used to storage the influent wastewater during on filling period and receiving containers were used to receiving the effluent during on drawing period.

3.2.2.7 Adapters

Adapters were used to transform the AC to DC current and supplying to agitator motor.

3.3 Procedures and Analytical Methods

This research was initially started with seeding and acclimatization period. In the experimental period, AnA²/O² SBRs were conducted to determine the most effective treatment combination. The sampling and analysis schedules were performed

systematically. The experimental procedures were shown in Figure 3.3 and described as following.

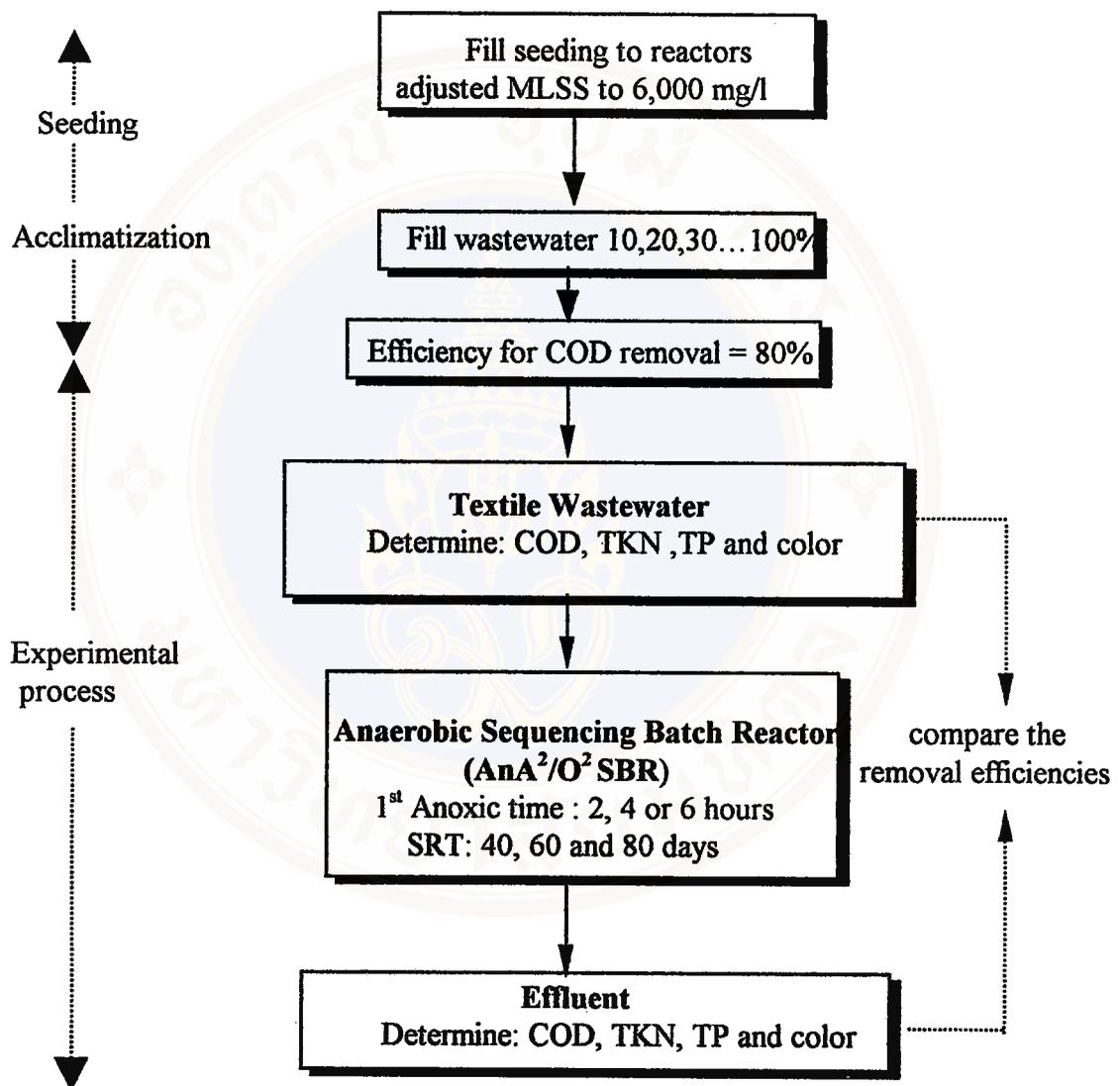


Figure 3.3 Summary of the experimental procedures

3.3.1 Experimental Procedures

3.3.1.1 Seeding and Acclimatization

The reactors were seeded with sludge biomass obtained from Sri-Phraya Central Wastewater Treatment Plant to give the mixed liquor suspended solids concentration about 6,000 mg/l .

Volume of seeded sludge used was calculated as follows:

$$\text{volume of seeded sludge used} = \frac{\text{controlled MLSS(mg/l)}}{\text{MLSS seed sludge(mg/l)}} \dots\dots\dots (1)$$

In acclimatization period, the textile wastewater was gradually increased step by step from 10 percent of working volume capacity (0.5 liter) in the initial step to 100 percent capacity (5 liters) in the final step. Each 10% increasing was performed after the COD remove efficiency was reached at the steady state condition.

Throughout the acclimatization period, dissolved oxygen in last aerobic stage was controlled nearly 2 mg/l and MLSS was not discharged.

All reactors were operated with a cycle time of 24 hours under same operation time. Each operation time consisted of 5 hours filling, 3 hours on the first anoxic time, 5 hours on the first oxic time, 3 hours on the second anoxic time and 5 hours on the second oxic time, 1.5 hours settling, 0.5 hour drawing and 1 hour idle time as illustrated in Figure 3.4. This start-up procedure has been previously successfully tested by Karcharnubarn(48).

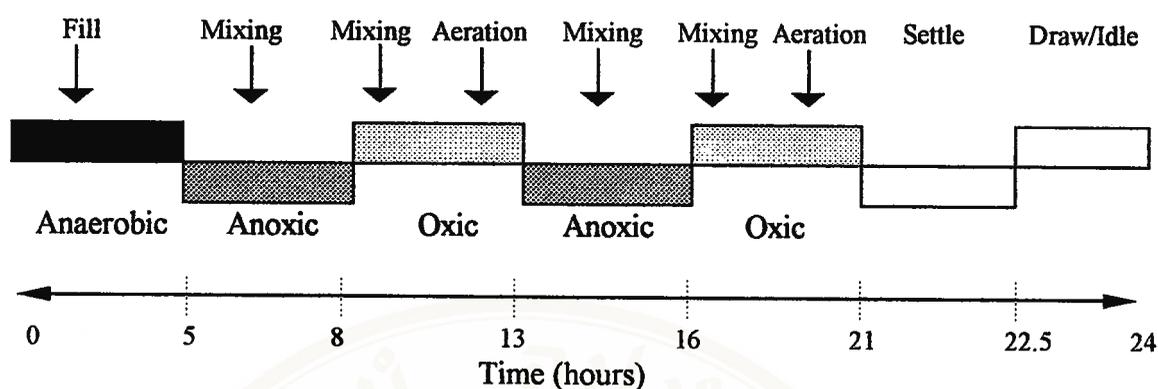


Figure 3.4 Operation pattern of AnA²/O² SBRs during seeding and acclimatization period.

3.3.1.2 Experimental Process

The experimental process was divided into three groups. In each group, the first anoxic time in reaction period was divided into 3 conditions (reactors) as:

Group 1, the first anoxic time were varied from 2, 4 or 6 hours, whereas the SRT were kept at 40 days.

Group 2, the first anoxic time were varied from 2, 4 or 6 hours, whereas the SRT were kept at 60 days.

Group 3, the first anoxic time were varied from 2, 4 or 6 hours, whereas the SRT were kept at 80 days.

In each group, SRT was maintained constantly by wasting the sludge as calculated in equation (3) and summarized in Table 3.2 while the first anoxic time was varied as presented in Figure 3.5

Table 3.2 Wasted sludge volume

| <i>Group</i> | <i>SRT</i> | <i>Wasted sludge (ml/d)</i> |
|--------------|------------|-----------------------------|
| 1 | 40 | 250 |
| 2 | 60 | 167 |
| 3 | 80 | 125 |

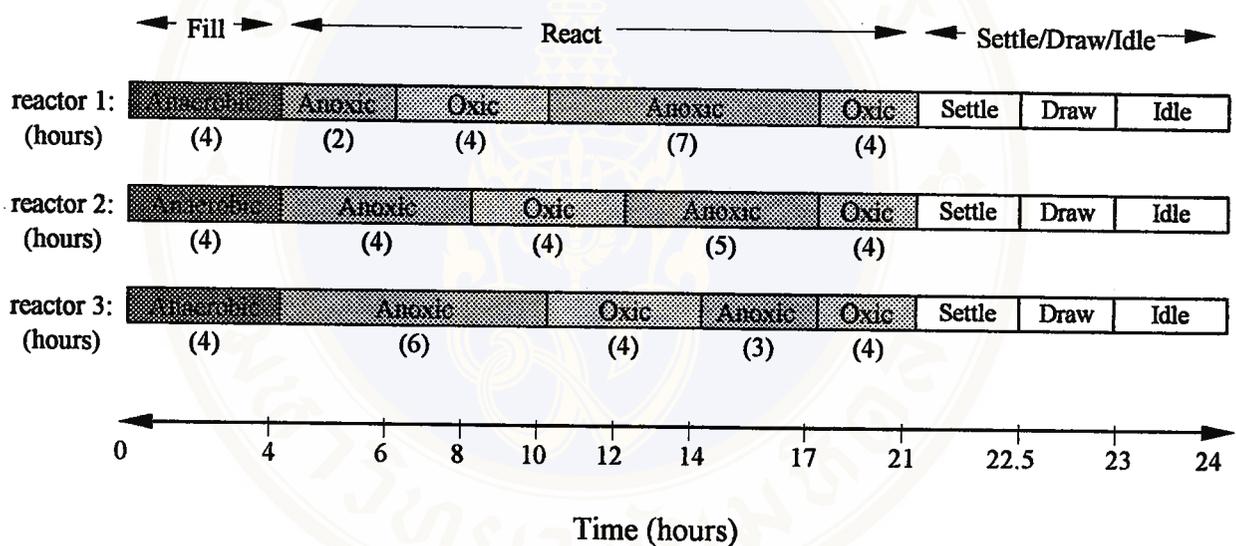


Figure 3.5 Operation pattern of AnA²/O² SBRs during the experimental running period.

$$SRT (/d) = \frac{MLSS (mg/l) \times Working\ volume\ of\ SBR (l)}{Wasted\ MLSS (mg/l) \times Wasted\ MLSS\ volume (l/d)} \dots\dots\dots (2)$$

Wasted MLSS (mg/l) x Wasted MLSS volume (l/d)

Assuming completely mixing, so MLSS ≅ Wasted MLSS

$$Wasted\ MLSS\ volume (l/d) = \frac{Working\ volume\ of\ SBR (l)}{SRT (/d)} \dots\dots\dots (3)$$

3.3.1.3 Operation Step for the Control of An A²/O² SBR

Prior to the treatment, the pH of wastewater samples was adjusted about 7 with concentrate sulfuric acid (96%w/w).

Fill period : 5 liters of textile wastewater was pumped from storage container by peristaltic pump to give fill phase of 4 hours. The liquid level in the reactor to rise from 50 percent of capacity (at the end of idle) to 100 percent.

Reaction period : Reaction time was separated into 4 stage and incorporated a fifth (anaerobic fill) stage. The time controller were used to control reaction time.

Anaerobic time : The stirrers and aerator were turned off.

Anoxic time : The wastewater and MLSS were completely mixed by stirring.

Oxic time : The aerator and mixing was simultaneously operated to provided air throughout the reactor.

Draw sludge period : Sludge was withdrawn directly from reactor within last 10 minutes of the reaction time. Mixed liquor was wasted according to the controlled SRT.

Settle period : The stirrer and aerator were stopped by controlling of time controller. Settling period was about 1.5 hours.

Draw period : The clarified effluent was flowed by gravity into receiving container. Drawing period was about 0.5 hour.

Idle period : Idle period was set about 1 hour , but was earlier of extend further depending on the settle and draw period.

3.3.2 Analytical Method

Influent and effluent samples were collected by grab sampling daily. Influent samples were collected from the storage container, effluent and mixed liquor samples were taken from the outlet end. Samples from each point of An A²/O² SBRs were collected, stored and measured following the procedure prescribed by Standard Methods(49). Color was analyzed after centrifuged at the rate of 10,000 round per minutes in 15 minutes by American Dye Manufacturers Institute (ADMI) method(50) using Shimadzu double beam scanning spectrophotometer model 160 A. Reagent grade chemicals were used in this study. Other parameters such as pH and DO were measured with glass and membrane electrode method respectively.

The methods for analyzing of each parameter and sampling points were described in Table 3.3. The chemical reagents and analytical apparatus used in this experiment were summarized in Table 3.4.

Table 3.3 Analytical methods and sampling points

| <i>Parameters</i> | <i>Methods</i> | <i>Sampling Points</i> | | |
|-------------------|--|------------------------|----------------|-----------------|
| | | <i>Influent</i> | <i>Reactor</i> | <i>Effluent</i> |
| <i>COD</i> | Dichromate close reflux method | * | | * |
| <i>TKN</i> | Kjeldahl digestion method | * | | * |
| <i>TP</i> | Persulfate digestion and Ascorbic method | * | | * |
| <i>Color</i> | ADMI method | * | | * |
| <i>MLSS</i> | Gravimetric method | | ** | |
| <i>DO</i> | Membrane electrode method | | * | |
| <i>pH</i> | Glass electrode method | * | * | * |

note * : analyzed everyday except color

** : analyzed 3-4 times/week

Table 3.4 The chemical reagents and analytical apparatus

| Parameters | Apparatus | Chemical reagent |
|------------|---|---|
| COD | <ul style="list-style-type: none"> • Digestion vessels with lined screw caps • Heating block • Hot air oven | <ul style="list-style-type: none"> • Sulfuric acid (conc) • 1,10-Phenanthroline monohydrate • Ferrous sulfate heptahydrate • Ferrous ammonium sulfate • Potassium dichromate • Silver sulfate • Mercuric sulfate |
| TKN | <ul style="list-style-type: none"> • Digestion Apparatus <ul style="list-style-type: none"> ◆ Digestion tubes ◆ Digestion heating • Distillation Apparatus | <ul style="list-style-type: none"> • Sulfuric acid (conc) • Potassium sulfate • Mercuric (II) oxide (red) • Sodium hydroxide • Sodium thiosulfate pentahydrate • Boric acid |
| TP | <ul style="list-style-type: none"> • Spectrophotometer • Hot plate | <ul style="list-style-type: none"> • Sulfuric acid (conc) • Potassium persulfate • Sodium hydroxide • Ascorbic acid • Ammonium molybdate • Potassium antimonyl tartrate |
| Color | <ul style="list-style-type: none"> • Centrifuge • Spectrophotometer | |
| MLSS | <ul style="list-style-type: none"> • Analytical balance • Desiccator • Hot air oven • Filtration apparatus • Suction flask | |
| DO | <ul style="list-style-type: none"> • DO meter | |
| pH | <ul style="list-style-type: none"> • pH meter | |

3.4 Statistical Analysis

3.4.1 Descriptive Analysis :The influent, effluent and efficiencies of chemical oxygen demand, total kjeldahl nitrogen , total phosphorous and color removal were described as Mean values, Minimum values, Maximum values, and standard deviation (SD).

3.4.2 The two-way Analysis of Variance test (ANOVA) was performed by using Sigmastat program. P-value of 0.05 was used to test for statistically significant differences among the levels of dependent variables.

3.4.3 Regression analysis was performed to decided whether SRT or anoxic time affecting the removal of pollutants by using forward stepwise regression and predict them by using polynomial regression.

CHAPTER IV

RESULTS

4.1 Influent Wastewater Characteristics

The average characteristic values of influent wastewater samples used in this experiment were BOD 444 mg/l, COD 1,047 mg/l, TKN 89.9 mg/l, TP 18.4 mg/l, color 544 ADMI and pH 7.2 as presented in Table 4.1.

Table 4.1 Influent wastewater characteristics during the research period

| <i>Parameters</i> | <i>Mean</i> | <i>Range</i> | <i>SD</i> |
|--------------------|-------------|--------------|-----------|
| <i>pH</i> | 7.2 | 7.0-7.2 | 0.06 |
| <i>BOD(mg/l)</i> | 444 | 400-490 | 47.9 |
| <i>COD(mg/l)</i> | 1,047 | 773-1,290 | 106 |
| <i>TKN(mg/l)</i> | 89.9 | 42.7-161 | 33.2 |
| <i>TP(mg/l)</i> | 18.4 | 9.4-27.9 | 4.6 |
| <i>Color(ADMI)</i> | 544 | 308-1,128 | 170 |

4.2 Seeding and Acclimatization

The experiment was started with seeding and acclimatization period. Sludge biomass was obtained from Sri-Phraya Central Wastewater Treatment Plant. The initial feed mixed liquor suspended solids (MLSS) concentration around 6,000 mg/l. The chemical oxygen demand in influent were in average at 1,331 mg/l, TKN of 73.0 mg/l and TP of 13.5 mg/l.

The filling of wastewater was gradually increased from 10 to 100 percent of volume capacity. In each 10% step increase were performed after the COD removal efficiency was reached to the steady state condition. The overall performance was approximately 2 months (9 August - 7 October 1999). The COD removal efficiency of AnA²/O² SBR in acclimatization period was shown as following.

Table 4.2 COD removal efficiency under steady state condition during acclimatization period

| Percentage of filling wastewater | COD removal efficiency (%) | | |
|-------------------------------------|----------------------------|-----------|-----------|
| | reactor 1 | reactor 2 | reactor 3 |
| 10% | 84.0 | 88.3 | 85.6 |
| 20% | 83.4 | 85.0 | 84.7 |
| 30% | 83.3 | 84.7 | 83.2 |
| 40% | 80.8 | 81.8 | 81.3 |
| 50% | 89.6 | 92.2 | 91.2 |
| 60% | 86.0 | 85.3 | 87.4 |
| 70% | 85.2 | 85.1 | 87.1 |
| 80% | 86.0 | 86.9 | 86.7 |
| 90% | 83.8 | 85.4 | 84.8 |
| 100% | 81.0 | 82.0 | 82.4 |

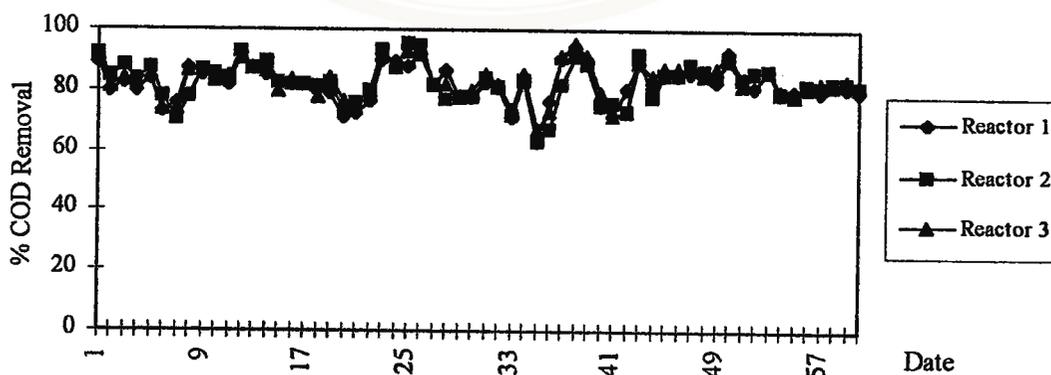


Figure 4.1 COD removal efficiency during acclimatization period.

In acclimatization period, mixed liquor suspended solids(MLSS) concentration in reactors were average 5,041 mg/l. as illustrated in Figure 4.2

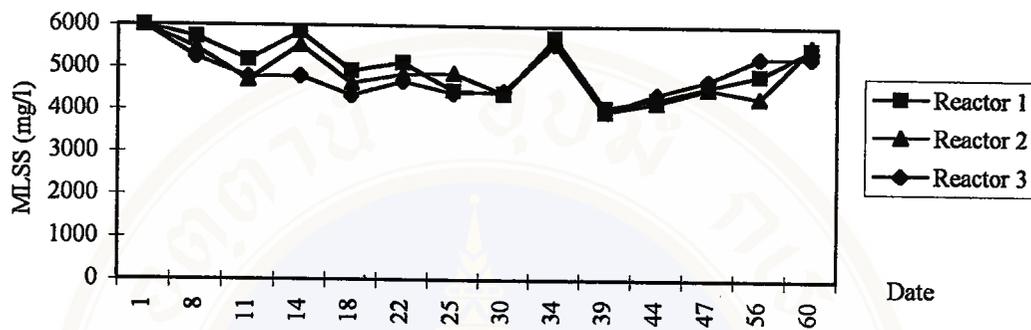


Figure 4.2 Mixed liquor suspended solids concentration during acclimatization period.

4.3 Removal Efficiency of Anaerobic Sequencing Batch Reactors (AnA²/O² SBRs)

AnA²/O² SBRs were used to investigate simultaneous removal efficiencies of COD, TKN, TP and color in textile wastewater. The overall running period of experiment was about 5 months (October 1999 to February 2000).

The results presentation were divided into two section , overall and steady state running periods. In each section, the presentation were divided into three groups namely group 1, group 2 and group 3. The details of results were described as following:

4.3.1 Overall Running Period

4.3.1.1 Group 1: Solid retention time of 40 days and Anoxic time of 2 , 4 and 6 hours

AnA²/O² SBRs were performed with 40 days SRT and anoxic time in reactor 1, 2 and 3 of about 2 hours, 4 hours and 6 hours respectively. The experiment was operated from 11 October to 10 November 1999. The removal efficiencies of COD, TKN, TP, and color were presented in Table 4.3 and the average removal efficiencies of these pollutants were shown in Figure 4.3.

Table 4.3 The COD, TKN, TP, and color removal efficiencies of AnA²/O² SBRs in group 1 (SRT of 40 days, Anoxic time of 2, 4 and 6 hrs).

| <i>Parameters</i> | | <i>Condition 1</i> | <i>Condition 2</i> | <i>Condition 3</i> |
|-------------------------------|-------|-------------------------|-------------------------|-------------------------|
| | | <i>(Anoxic 2 hours)</i> | <i>(Anoxic 4 hours)</i> | <i>(Anoxic 6 hours)</i> |
| <i>COD</i> <i>(n=31)</i> | Min. | 71.9 | 74.0 | 73.2 |
| | Max. | 87.7 | 85.1 | 85.3 |
| | Mean. | 80.5 | 79.9 | 79.3 |
| | SD. | 3.7 | 2.7 | 3.0 |
| <i>TKN</i> <i>(n=31)</i> | Min. | 51.8 | 76.0 | 60.1 |
| | Max. | 98.5 | 93.2 | 98.3 |
| | Mean. | 81.7 | 86.1 | 85.1 |
| | SD. | 11.4 | 5.3 | 7.9 |
| <i>TP</i> <i>(n=31)</i> | Min. | 68.6 | 69.1 | 46.1 |
| | Max. | 93.6 | 93.9 | 96.6 |
| | Mean. | 80.5 | 80.9 | 81.1 |
| | SD. | 7.0 | 7.7 | 10.4 |
| <i>Color</i> <i>(n=18)</i> | Min. | 15.4 | 17.6 | 15.2 |
| | Max. | 57.9 | 59.4 | 60.2 |
| | Mean. | 30.6 | 31.2 | 31.6 |
| | SD. | 10.4 | 10.3 | 11.0 |

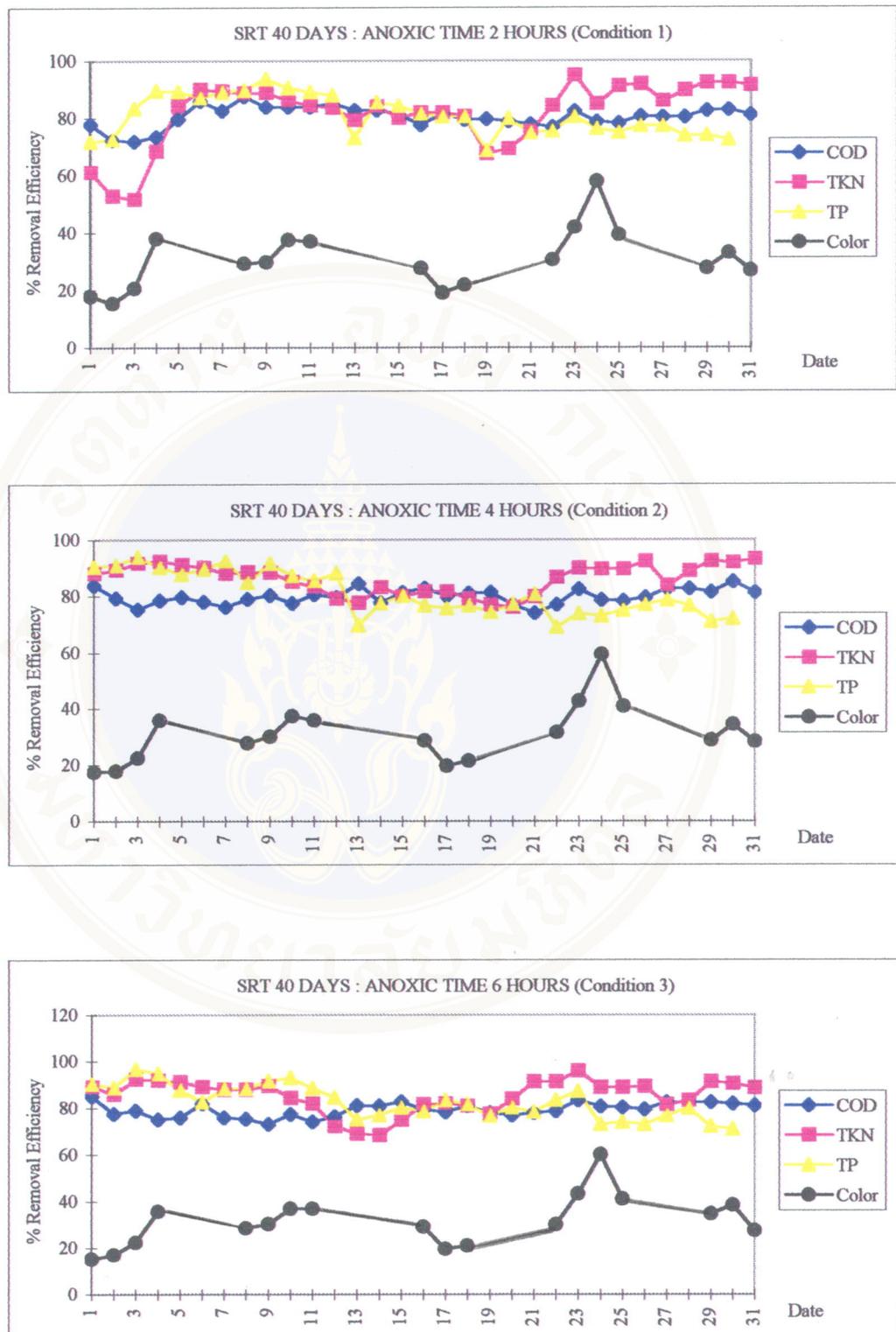


Figure 4.3 The average removal efficiencies of COD, TKN, TP and color under condition 1, 2 and 3 (SRT of 40 days, Anoxic time of 2, 4 and 6 hrs)

Experimental condition 1: AnA²/O² SBRs were performed with 40 days SRT and 2 hours anoxic time. The removal efficiencies of COD, TKN, TP and color were in the range of 71.9% - 87.7% (average 80.5%), 51.8% - 98.5% (average 81.7%), 68.6% - 93.6% (average 80.5%) and 15.4% - 57.9% (average 30.6%) respectively.

Experimental condition 2: AnA²/O² SBRs were performed with 40 days SRT and 4 hours anoxic time. The removal efficiencies of COD, TKN, TP and color were in the range of 74.0% - 85.1% (average 79.9%), 76.0% - 93.2% (average 86.1%), 69.1% - 93.9% (average 80.9%) and 17.6% - 59.4% (average 31.2%) respectively.

Experimental condition 3: AnA²/O² SBRs were performed with 40 days SRT and 6 hours anoxic time. The removal efficiencies of COD, TKN, TP and color were in the range of 73.2% - 85.3% (average 79.3%), 60.1% - 98.3% (average 85.1%), 46.1% - 96.6% (average 81.1%) and 15.2% - 60.2% (average 31.6%) respectively.

4.3.1.2 Group 2: Solid retention time of 60 days and Anoxic time of 2 , 4 and 6 hours

AnA²/O² SBRs were performed with 60 days SRT and in reactor 1, 2 and 3 of about 2 hours, 4 hours and 6 hours anoxic time, respectively. The experiment was operated from 4 December 1999 to 9 January 2000. The removal efficiencies of AnA²/O² SBRs obtained during the experiment of group 2 were presented in Table 4.4 and the average removal efficiencies of these pollutants were shown in Figure 4.4.

Table 4.4 The COD, TKN, TP, and color removal efficiencies of AnA²/O² SBRs in group 2 (SRT of 60 days, Anoxic time of 2, 4 and 6 hrs).

| <i>Parameters</i> | | <i>Condition 4</i> | <i>Condition 5</i> | <i>Condition 6</i> |
|-------------------------------|-------|-------------------------|-------------------------|-------------------------|
| | | <i>(Anoxic 2 hours)</i> | <i>(Anoxic 4 hours)</i> | <i>(Anoxic 6 hours)</i> |
| <i>COD</i> <i>(n=35)</i> | Min. | 79.8 | 81.7 | 79.8 |
| | Max. | 89.9 | 90.5 | 89.0 |
| | Mean. | 84.9 | 85.8 | 85.3 |
| | SD. | 2.7 | 2.7 | 2.4 |
| <i>TKN</i> <i>(n=35)</i> | Min. | 49.9 | 45.0 | 45.0 |
| | Max. | 99.6 | 99.2 | 100 |
| | Mean. | 82.9 | 84.3 | 83.7 |
| | SD. | 15.0 | 13.0 | 12.7 |
| <i>TP</i> <i>(n=35)</i> | Min. | 41.5 | 62.9 | 44.7 |
| | Max. | 91.8 | 90.5 | 92.4 |
| | Mean. | 78.3 | 79.7 | 78.0 |
| | SD. | 10.6 | 7.2 | 10.4 |
| <i>Color</i> <i>(n=16)</i> | Min. | 12.1 | 22.5 | 21.9 |
| | Max. | 51.1 | 50.6 | 51.6 |
| | Mean. | 32.8 | 33.6 | 33.8 |
| | SD. | 10.4 | 9.2 | 9.8 |

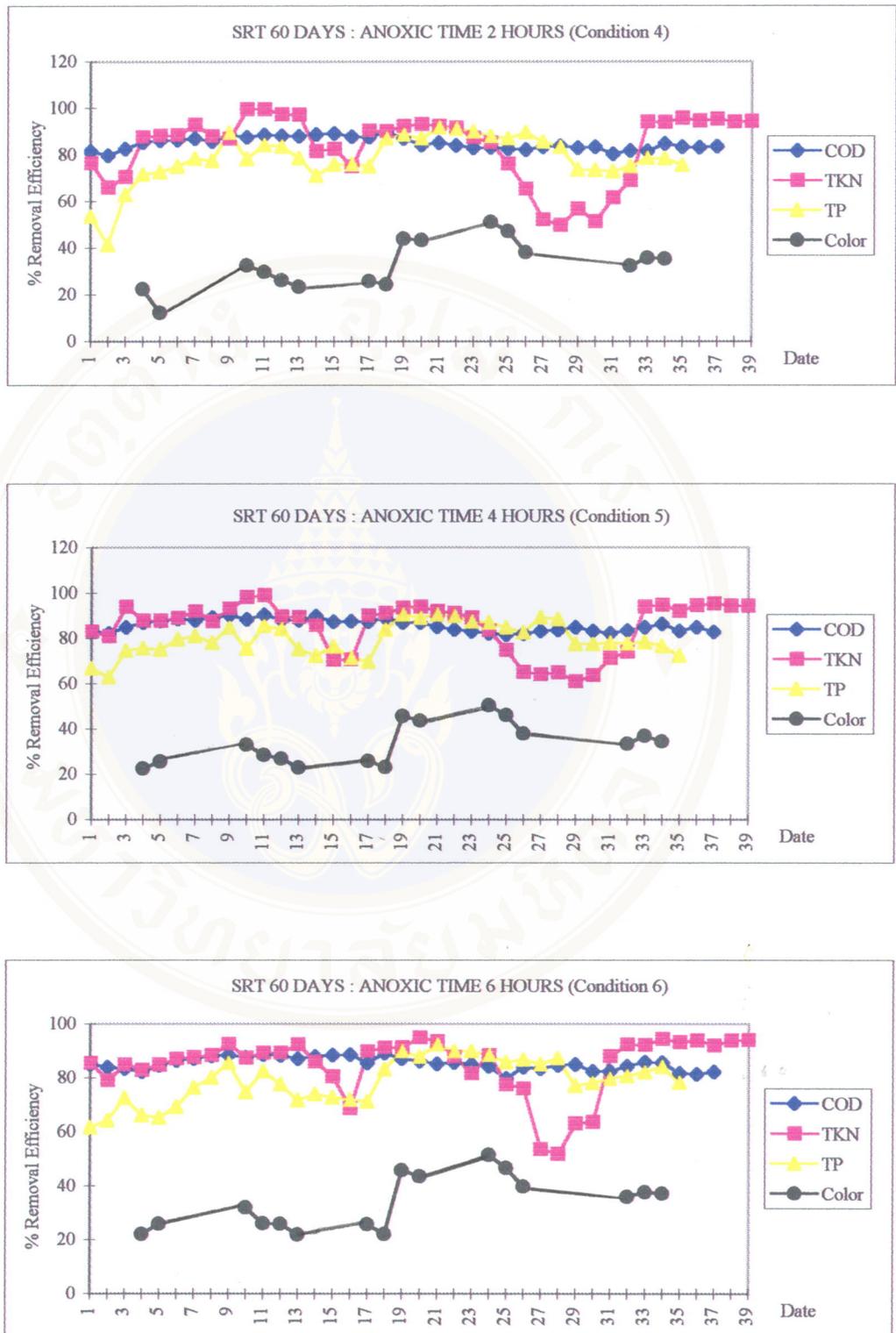


Figure 4.4 The average removal efficiencies of COD, TKN, TP and color under condition 4, 5 and 6 (SRT of 60 days, Anoxic time of 2, 4 and 6 hrs)

Experimental condition 4: AnA²/O² SBRs were performed with 60 days SRT and 2 hours anoxic time. The removal efficiencies of COD,TKN,TP and color were in the range of 79.8% - 89.9% (average 84.9%), 49.9% - 99.6% (average 82.9%), 41.5% - 91.8% (average 78.3%) and 12.1% - 51.1% (average 32.8%) respectively.

Experimental condition 5: AnA²/O² SBRs were performed with 60 days SRT and 4 hours anoxic time. The removal efficiencies of COD, TKN, TP and color were in the range of 81.7% - 90.5% (average 85.8%), 45.0% - 99.2% (average 84.3%), 62.9% - 90.5% (average 79.7%) and 22.5% - 50.6% (average 33.6%) respectively.

Experimental condition 6: AnA²/O² SBRs were performed with 60 days SRT and 6 hours anoxic time. The removal efficiencies of COD, TKN, TP and color were in the range of 79.8% - 89.0% (average 85.3%), 45.0% - 100% (average 83.7%), 44.7% - 92.4% (average 78.0%) and 21.9% - 51.6% (average 33.8%) respectively.

4.3.1.3 Group 3: Solid retention time of 80 days and Anoxic time of 2 , 4 and 6 hours

AnA²/O² SBRs were performed with 80 days SRT and anoxic time in reactor 1, 2 and 3 of about 2 hours, 4 hours and 6 hours, respectively. The experiment was operated from 22 January to 25 February 2000. The removal efficiencies of SBRs obtained during the experiment of group 3 were presented in Table 4.5 and the average removal efficiencies of these pollutants were shown in Figure 4.5.

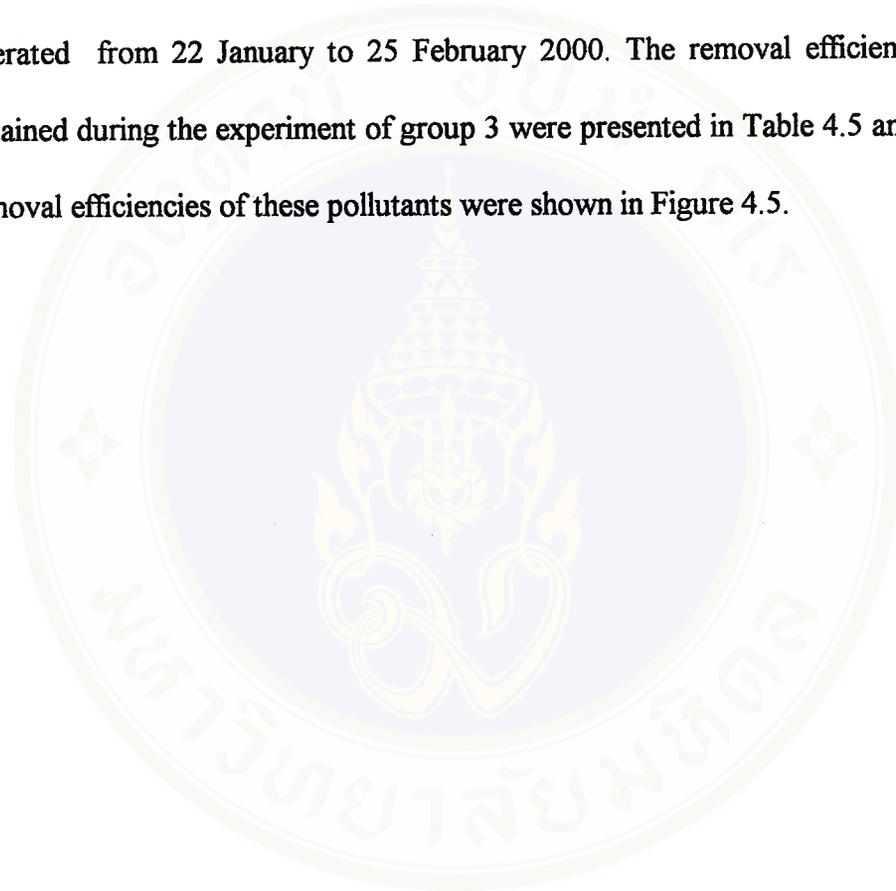


Table 4.5 The COD, TKN, TP, and color removal efficiencies of AnA²/O² SBRs in group 3 (SRT of 80 days, Anoxic time of 2, 4 and 6 hrs)

| <i>Parameters</i> | | <i>Condition 7</i> | <i>Condition 8</i> | <i>Condition 9</i> |
|-------------------------------|-------|-------------------------|-------------------------|-------------------------|
| | | <i>(Anoxic 2 hours)</i> | <i>(Anoxic 4 hours)</i> | <i>(Anoxic 6 hours)</i> |
| <i>COD</i> <i>(n=35)</i> | Min. | 75.2 | 73.8 | 71.0 |
| | Max. | 91.5 | 91.0 | 91.7 |
| | Mean. | 83.2 | 82.1 | 80.6 |
| | SD. | 5.4 | 4.8 | 6.0 |
| <i>TKN</i> <i>(n=35)</i> | Min. | 76.9 | 79.2 | 77.2 |
| | Max. | 90.1 | 90.3 | 91.1 |
| | Mean. | 84.3 | 84.3 | 83.2 |
| | SD. | 3.6 | 3.2 | 3.4 |
| <i>TP</i> <i>(n=35)</i> | Min. | 53.6 | 56.0 | 56.0 |
| | Max. | 88.0 | 91.0 | 90.4 |
| | Mean. | 73.0 | 76.4 | 73.6 |
| | SD. | 11.3 | 10.6 | 10.4 |
| <i>Color</i> <i>(n=20)</i> | Min. | 33.6 | 32.2 | 32.7 |
| | Max. | 59.2 | 60.8 | 60.7 |
| | Mean. | 43.6 | 43.9 | 43.9 |
| | SD. | 8.4 | 8.7 | 8.7 |

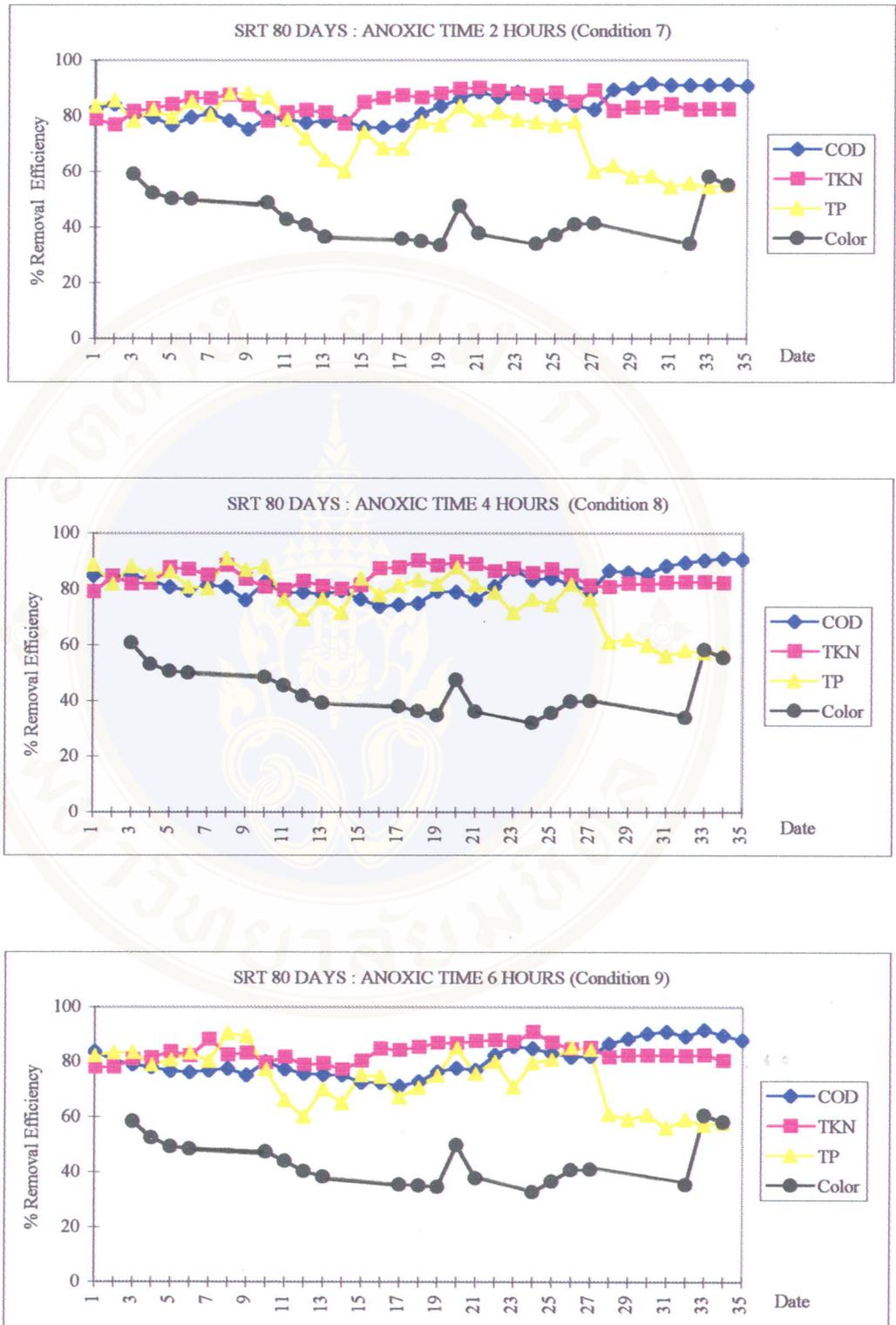


Figure 4.5 The average removal efficiencies of COD, TKN, TP and color under condition 7, 8 and 9 (SRT of 80 days, Anoxic time of 2, 4 and 6 hrs)

Experimental condition 7: AnA²/O² SBRs were performed with 80 days SRT and 2 hours anoxic time. The removal efficiencies of COD, TKN, TP and color were in the range of 75.2% - 91.5% (average 83.2%), 76.9% -90.1% (average 84.3%), 53.6% - 88.0% (average 73.0%) and 33.6% - 59.2% (average 43.6%), respectively.

Experimental condition 8: AnA²/O² SBRs were performed with 80 days SRT and 4 hours anoxic time. The removal efficiencies of COD, TKN, TP and color were in the range of 73.8% - 91.0% (average 82.1%), 79.2% - 90.3% (average 84.4%), 56.0% - 91.0% (average 76.4%) and 32.2% - 60.8% (average 43.9%), respectively.

Experimental condition 9: AnA²/O² SBRs were performed with 80 days SRT and 6 hours anoxic time. The removal efficiencies of COD, TKN, TP and color were in the range of 71.0% - 91.7% (average 80.6%), 77.2% - 91.1% (average 83.2%), 56.0%-90.4%(average 73.6%) and 32.7%-60.7%(average 43.9%), respectively.

4.3.2 Steady State Running Period

4.3.2.1 Group 1: Solid retention time of 40 days and Anoxic time of 2 , 4 and 6 hours

The removal efficiencies of AnA²/O² SBRs at the steady state running period in group 1 as shown in Table 4.6 and Figure 4.6 as described following.

Table 4.6 The COD, TKN ,TP and color removal efficiencies of AnA²/O² SBRs under steady state condition in group 1(SRT of 40 days, Anoxic time of 2, 4 and 6 hrs)

| <i>Parameter</i> | | <i>Condition 1</i> | <i>Condition 2</i> | <i>Condition 3</i> |
|------------------|----------------|-------------------------|-------------------------|-------------------------|
| | | <i>(Anoxic 2 hours)</i> | <i>(Anoxic 4 hours)</i> | <i>(Anoxic 6 hours)</i> |
| <i>COD</i> | Influent(mg/l) | 908 | 908 | 908 |
| | Effluent(mg/l) | 176 | 171 | 168 |
| | Removal(%) | 80.7 | 81.2 | 81.5 |
| <i>TKN</i> | Influent(mg/l) | 117 | 117 | 117 |
| | Effluent(mg/l) | 11.0 | 11.6 | 14.5 |
| | Removal(%) | 90.7 | 90.3 | 87.8 |
| <i>TP</i> | Influent(mg/l) | 17.7 | 17.7 | 17.7 |
| | Effluent(mg/l) | 4.4 | 4.40 | 4.50 |
| | Removal(%) | 75.2 | 74.7 | 74.3 |
| <i>Color</i> | Influent(ADMI) | 502 | 502 | 502 |
| | Effluent(ADMI) | 355 | 348 | 332 |
| | Removal(%) | 29.1 | 30.5 | 33.6 |

Experimental condition 1 : the percentage of COD, TKN, TP and color removal efficiencies were 80.7, 90.7, 75.2 and 29.1, respectively. The average of COD, TKN, TP and color in the effluent after treatment were 176 mg/l, 11.0 mg/l, 4.4 mg/l and 355 ADMI, respectively.

Experimental condition 2 : the percentage of COD, TKN, TP and color removal efficiencies were 81.2, 90.3, 74.7 and 30.5, respectively. The average of COD, TKN, TP and color in the effluent after treatment were 171 mg/l, 11.6 mg/l, 4.4 mg/l and 348 ADMI, respectively.

Experimental condition 3 : the percentage of COD, TKN, TP and color removal efficiencies were 81.5, 87.8, 74.3 and 33.6, respectively. The average of COD, TKN, TP and color in the effluent after treatment were 168 mg/l, 14.5 mg/l, 4.5 mg/l and 332 ADMI, respectively.



4.3.2.2 Group 2: Solid retention time of 60 days and Anoxic time of 2, 4 and 6 hours

The removal efficiencies of AnA²/O² SBRs at the steady state running period in group 2 as shown in Table 4.7 and Figure 4.6 as described below.

Experimental condition 4 : the percentage of COD, TKN, TP and color removal efficiencies were 82.8, 94.6, 75.3 and 34.5, respectively. The average of COD, TKN, TP and color in the effluent after treatment were 163 mg/l, 7.8 mg/l, 5.9 mg/l and 323 ADMI respectively.

Experimental condition 5 : the percentage of COD, TKN, TP and color removal efficiencies were 84.0, 94.3, 77.0 and 34.9, respectively. The average of COD, TKN, TP and color in the effluent after treatment were 152 mg/l, 8.3 mg/l, 5.4 mg/l and 321 ADMI respectively.

Experimental condition 6 : the percentage of COD, TKN, TP and color removal efficiencies were 83.2, 93.4, 79.9 and 37.0, respectively. The average of COD, TKN, TP and color in the effluent after treatment were 158 mg/l, 9.7 mg/l, 4.8 mg/l and 311 ADMI respectively.

Table 4.7 The COD, TKN ,TP and color removal efficiencies of AnA²/O² SBRs under steady state condition in group 2(SRT of 60 days, Anoxic time of 2, 4 and 6 hrs).

| <i>Parameter</i> | | <i>Condition 4</i> | <i>Condition 5</i> | <i>Condition 6</i> |
|------------------|----------------|-------------------------|-------------------------|-------------------------|
| | | <i>(Anoxic 2 hours)</i> | <i>(Anoxic 4 hours)</i> | <i>(Anoxic 6 hours)</i> |
| <i>COD</i> | Influent(mg/l) | 944 | 944 | 944 |
| | Effluent(mg/l) | 163 | 152 | 158 |
| | Removal(%) | 82.8 | 84.0 | 83.2 |
| <i>TKN</i> | Influent(mg/l) | 146 | 146 | 146 |
| | Effluent(mg/l) | 7.8 | 8.3 | 9.7 |
| | Removal(%) | 94.6 | 94.3 | 93.4 |
| <i>TP</i> | Influent(mg/l) | 23.6 | 23.6 | 23.6 |
| | Effluent(mg/l) | 5.9 | 5.4 | 4.8 |
| | Removal(%) | 75.3 | 77.0 | 79.9 |
| <i>Color</i> | Influent(ADMI) | 493 | 493 | 493 |
| | Effluent(ADMI) | 323 | 321 | 311 |
| | Removal(%) | 34.5 | 34.9 | 37.0 |

4.3.2.3 Group 3: Solid retention time of 80 days and Anoxic time of 2 , 4 and 6 hours

The removal efficiency of AnA²/O² SBRs at the steady state running period in group 3 as shown in Table 4.8 and Figure 4.6 as described below.

Experimental condition 7 : the percentage of COD, TKN, TP and color removal efficiencies were 90.7, 82.6, 56.8 and 49.1, respectively. The average of COD, TKN, TP and color in the effluent after treatment were 105 mg/l, 7.6 mg/l, 4.8 mg/l and 449 ADMI, respectively.

Experimental condition 8 : the percentage of COD, TKN, TP and color removal efficiencies were 88.50, 82.0, 58.7 and 49.3, respectively. The average of COD, TKN, TP and color in the effluent after treatment were 130 mg/l, 7.8 mg/l, 4.8 mg/l and 447 ADMI, respectively.

Experimental condition 9 : the percentage of COD, TKN, TP and color removal efficiencies were 89.4, 82.1, 58.7 and 51.5, respectively. The average of COD, TKN, TP and color in the effluent after treatment were 119 mg/l, 7.8 mg/l, 4.5 mg/l and 426 ADMI, respectively.

Table 4.8 The COD, TKN ,TP and color removal efficiencies of AnA²/O² SBR under steady state condition in group 3(SRT of 80 days, Anoxic time of 2, 4 and 6 hrs).

| <i>Parameters</i> | | <i>Condition 7</i> | <i>Condition 8</i> | <i>Condition 9</i> |
|-------------------|----------------|-------------------------|-------------------------|-------------------------|
| | | <i>(Anoxic 2 hours)</i> | <i>(Anoxic 4 hours)</i> | <i>(Anoxic 6 hours)</i> |
| <i>COD</i> | Influent(mg/l) | 1,122 | 1,122 | 1,122 |
| | Effluent(mg/l) | 105 | 130 | 119 |
| | Removal(%) | 90.7 | 88.5 | 89.4 |
| <i>TKN</i> | Influent(mg/l) | 43.8 | 43.8 | 43.8 |
| | Effluent(mg/l) | 7.6 | 7.8 | 7.8 |
| | Removal(%) | 82.6 | 82.0 | 82.1 |
| <i>TP</i> | Influent(mg/l) | 11.0 | 11.0 | 11.0 |
| | Effluent(mg/l) | 4.8 | 4.6 | 4.5 |
| | Removal(%) | 56.8 | 58.7 | 58.8 |
| <i>Color</i> | Influent(ADMI) | 931 | 931 | 931 |
| | Effluent(ADMI) | 449 | 447 | 426 |
| | Removal(%) | 49.1 | 49.3 | 51.5 |

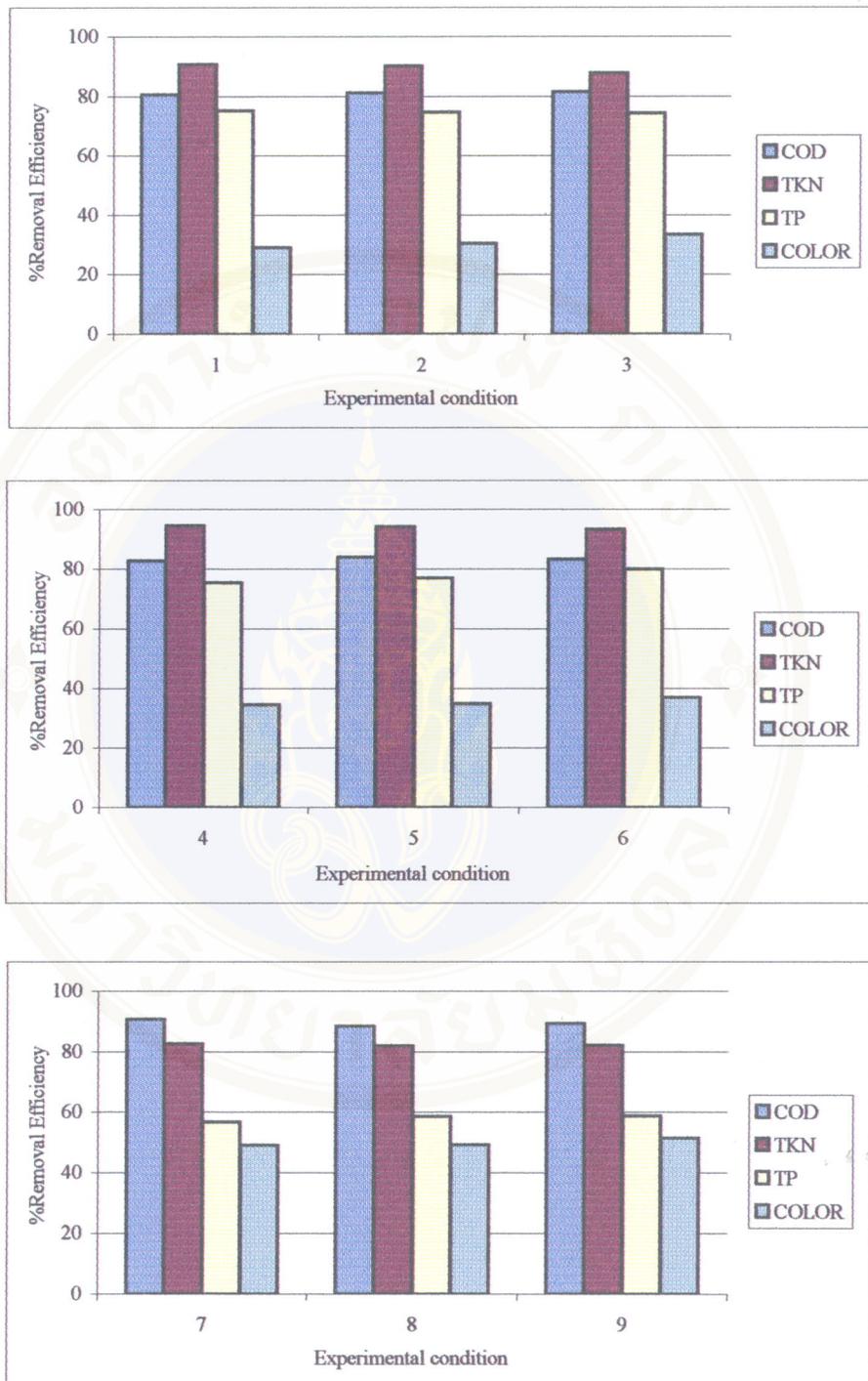


Figure 4.6 The COD, TKN, TP and color removal efficiencies of AnA²/O² SBRs under steady state condition

4.4 Statistical Analysis

4.4.1 Statistical Analysis for SRT

The results of statistical analysis of COD, TKN, TP and color removal efficiencies in percentage of AnA²/O² SBRs at SRT 40,60 and 80 days were summarized in Table 4.9 to 4.10 and Figure 4.7.

The average of COD removal efficiencies at SRT 40,60 and 80 days were 81.1% (SD=1.7), 83.3% (SD=1.5) and 89.5%(SD=1.8), respectively, and found that the efficiency of COD at SRT 80 days was significantly higher than those at 60 and 40 days ($p<0.05$) whereas the efficiency of COD removal at SRT 60 days was significantly higher than that at 40 days ($p<0.05$).

The average of TKN removal efficiencies at SRT 40,60 and 80 days were 89.6% (SD=3.3), 94.1% (SD=1.0) and 85.3%(SD=0.7), respectively, and found that the efficiency of TKN removal at SRT 60 days was significantly higher than those at 40 and 80 days ($p<0.05$), whereas the efficiency of TKN removal at SRT 40 days was significantly higher than that at 80 days ($p<0.05$).

The average of TP removal efficiencies at SRT 40,60 and 80 days were 74.7% (SD=2.5), 77.4% (SD=2.9) and 58.1%(SD=2.4), respectively, and found that the efficiency of TP removal at SRT 60 days was significantly higher than those at 40 and 80 days ($p<0.05$), whereas the efficiency of TP removal at SRT 40 days was significantly higher than that at 80 days ($p<0.05$).

The average of color removal efficiency at SRT 40,60 and 80 days were 31.1% (SD=4.2), 35.5% (SD=1.8) and 50.0%(SD=11.7), respectively, and found that

the efficiency of color removal at SRT 80 days was significantly higher than those at 60 and 40 days ($p < 0.05$), however; significantly differences of color removal efficiencies were found for the 40-days and 60-days SRT ($p < 0.05$).

Table 4.9 The results of COD,TKN,TP and color removal efficiencies under SRT of 40,60 and 80 days(%)

| <i>SRT</i> | <i>COD</i> | | <i>TKN</i> | | <i>TP</i> | | <i>Color</i> | |
|--|-------------|-----------|-------------|-----------|-------------|-----------|--------------|-----------|
| | <i>Mean</i> | <i>SD</i> | <i>Mean</i> | <i>SD</i> | <i>Mean</i> | <i>SD</i> | <i>Mean</i> | <i>SD</i> |
| <i>40 days</i> <i>(Condition 1,2,3)</i> | 81.1 | 1.7 | 89.6 | 3.3 | 74.7 | 2.5 | 31.1 | 4.2 |
| <i>60 days</i> <i>(Condition 4,5,6)</i> | 83.3 | 1.5 | 94.1 | 1.0 | 77.4 | 2.9 | 35.5 | 1.8 |
| <i>80 days</i> <i>(Condition 7,8,9)</i> | 89.5 | 1.8 | 85.3 | 0.7 | 58.1 | 2.4 | 50.0 | 11.7 |

Table 4.10 The results of statistical analysis of COD, TKN, TP and color removal efficiencies.

| <i>Parameters</i> | <i>Variables</i> | <i>ANOVA test</i> | <i>Multiple Comparison</i> |
|-------------------|-------------------|-------------------|----------------------------|
| COD | Anoxic time | NS | - |
| | SRT | DS | 80 > 60 > 40 |
| | SRT X Anoxic time | DS | 80X2 > 80X4 > 80X6 |
| TKN | Anoxic time | DS | 2>6, 2=4, 4=6 |
| | SRT | DS | 60 > 40 > 80 |
| | SRT X Anoxic time | NS | - |
| TP | Anoxic time | NS | - |
| | SRT | DS | 60 > 40 > 80 |
| | SRT X Anoxic time | NS | - |
| Color | Anoxic time | NS | - |
| | SRT | DS | 80 > 60 , 60 = 40 |
| | SRT X Anoxic time | NS | - |

Remark : NS means non significant different among the levels, $\alpha = 0.05$

DS means difference significantly among the levels, $\alpha = 0.05$

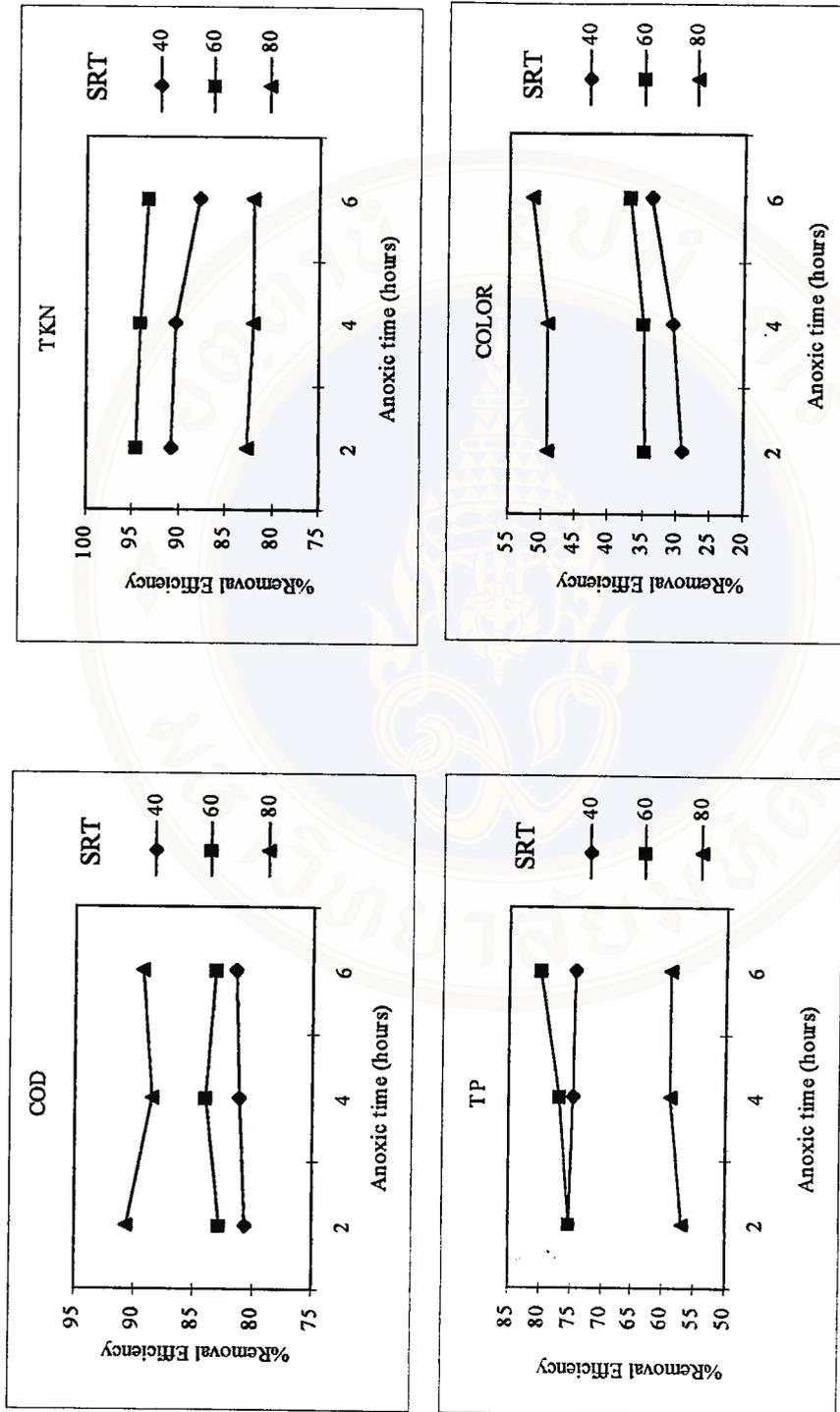


Figure 4.7 The relationship between SRT and COD, TKN, TP an color removal efficiencies

4.4.2 Statistical Analysis for Anoxic time

The results of statistical analysis of COD, TKN, TP and color removal efficiencies of AnA²/O² SBRs at anoxic time of 2, 4 and 6 hours were summarized in Table 4.10 to 4.11 and Figure 4.8.

The average of COD removal efficiencies at anoxic time of 2, 4 and 6 hours were 84.7%(SD=4.6) 84.6%(SD=3.6) and 84.7% (SD=3.8), respectively, no significantly differences of COD removal efficiencies were found for the 2, 4 and 6-hours anoxic times ($p<0.05$).

The average of TKN removal efficiencies at anoxic time of 2, 4 and 6 hours were 89.3%(SD=5.3), 88.9 %(SD=5.6) and 87.8% (SD=5.2), respectively, and found that the TKN removal efficiency at anoxic time 2 hours was significantly higher than that of 6 hours ($p< 0.05$) whereas no significantly differences of TKN removal efficiencies were found for 4-hours and 6 hours anoxic times ($p<0.05$).

The average of TP removal efficiencies at anoxic time of 2, 4 and 6 hours were 69.1 % (SD = 9.2), 70.1 % (SD = 8.7), 71.0 (SD = 9.5), respectively whereas no significantly differences of TP removal efficiencies were found for the 2, 4 and 6- hours anoxic times($p<0.05$).

The average of color removal efficiencies were 37.6% (SD = 11.3), 38.3% (SD = 11.0) and 40.7% (SD = 11.1), respectively whereas no significant differences of color removal efficiencies were found for the 2,4 and 6-hours anoxic times($p<0.05$).

Table 4.11 The results of COD, TKN, TP and color removal efficiencies under anoxic time of 2, 4 and 6 hours(%).

| Anoxic time | COD | | TKN | | TP | | Color | |
|------------------------------|------|-----|------|-----|------|-----|-------|------|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 2 hours (Condition 1,4,7) | 84.7 | 4.6 | 89.3 | 5.3 | 69.1 | 9.2 | 37.6 | 11.3 |
| 4 hours (Condition 2,5,8) | 84.6 | 3.6 | 88.9 | 5.6 | 70.1 | 8.7 | 38.3 | 11.0 |
| 6 hours (Condition 3,6,9) | 84.7 | 3.8 | 87.8 | 5.2 | 71.0 | 9.5 | 40.7 | 11.1 |

4.4.3 Statistical Analysis for Combination Effect of SRT and Anoxic time

The results of statistical analysis of the combination effect of SRT and anoxic time were found as shown in Table 4.10.

The combination effect of 80-days SRT and 2-hours anoxic time on the COD removal efficiency was significantly higher than those of 80 days SRT and 4 hours anoxic time and 80-days SRT and 6-hours anoxic time ($p < 0.05$). Whereas, the combination effect of 80-days SRT and 4-hours anoxic time on the COD removal efficiency was significantly higher than that of 80-days SRT and 6-hours anoxic time ($p < 0.05$).

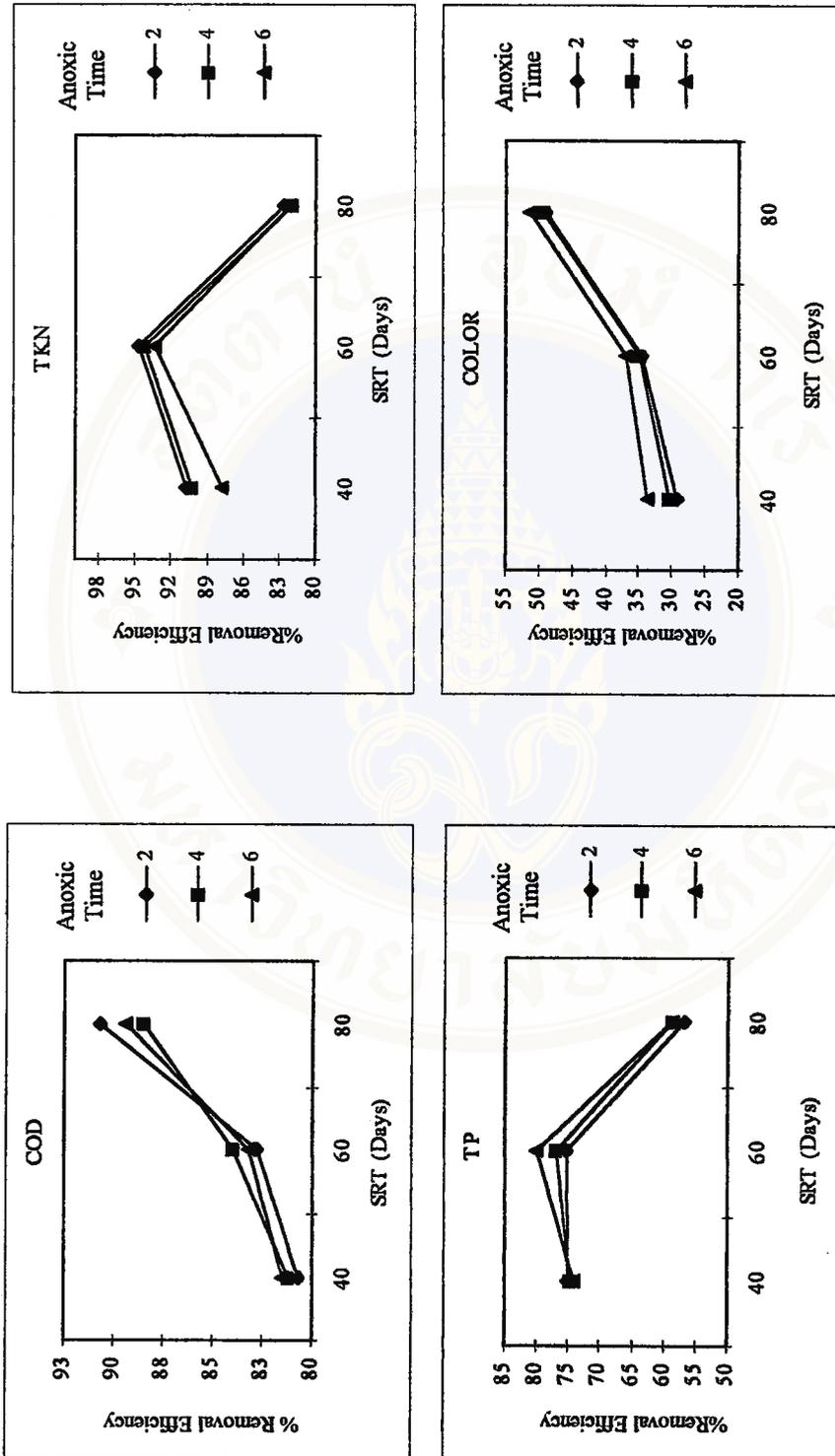


Figure 4.8 The relationship between Anoxic time and COD, TKN, TP and color removal efficiencies

Regression Analysis

Regression analysis was performed to decide whether SRT or anoxic time affecting the removal of pollutants by using forward stepwise regression and predict them by using polynomial regression.

From the results of the forward stepwise regression analysis, it was found that removal efficiencies(%) of each pollutant can be predicted from a linear combination of the SRT ($p < 0.001$), however, anoxic time did not significantly add to the ability of the equation to predict those.

The equations of each pollutants removal efficiencies were shown as following :

- COD removal efficiency in this experiment can be predicted from the equation :

$$\text{COD Removal Efficiency (\%)} = 88.82 - (0.39 * \text{SRT}) + (0.005 * \text{SRT}^2)$$

$$(\text{Rsqr} = 0.82, \text{N} = 72)$$

- TKN removal efficiency in this experiment can be predicted from the equation :

$$\text{TKN Removal Efficiency (\%)} = 31.52 + (2.27 * \text{SRT}) - (0.02 * \text{SRT}^2)$$

$$(\text{Rsqr} = 0.86, \text{N} = 63)$$

- TP removal efficiency in this experiment can be predicted from the equation :

$$\text{TP Removal Efficiency(\%)} = 3.40 + (2.88 * \text{SRT}) - (0.028 * \text{SRT}^2)$$

$$(\text{Rsqr} = 0.92, \text{N} = 63)$$

- Color removal efficiency in this experiment can be predicted from the equation

$$\text{Color Removal Efficiency (\%)} = 52.67 - (1.05 * \text{SRT}) + (0.013 * \text{SRT}^2)$$

$$(\text{Rsqr} = 0.58, \text{N} = 27)$$

CHAPTER V

DISCUSSION

5.1 Wastewater Characteristics

According to Manual of textile processing industry, US.EPA, the textile factory used in this experiment was identified as the woven fabric finishing textile industry. The BOD, COD, TKN, TP and color of raw processing wastewater were in the average of 444, 1,047, 89.9, 18.4 mg/l and 544 ADMI, respectively. BOD or COD of raw wastewater were relatively high and the BOD/COD ratio was 0.42 and slightly lower than 0.54 reported by US.EPA (51). It means that the wastewater was composed of major portions of refractory organic in which was resistant to biodegradation by a conventional treatment system. The BOD:TKN:TP ratio was 100:20:4 indicating the excessive amount of nitrogen and phosphorus for BOD or COD removal. Therefore the residuals could be treated by nutrient removal system. Color value was higher than 325 ADMI reporting by US.EPA due to the high usage of reactive dyes in dyeing and printing process. COD/TKN ratio was about 11.6 (over 7.5) which was sufficient to remove total phosphorus.

5.2 Seeding and Acclimatization

Seeding sludge concentration was initially started with 6,000 mg/l. This value was greater than 2,000-3,000 mg/l for P-removal in SBR as reported by Tchobanoglous (3). Moreover, Ganesh (52) indicated that color removal can be enhanced under aerobic condition by increasing the biomass concentration in the reactor.

In acclimatization period, the textile wastewater was gradually increased step-by-step starting from 10% to 100% by volume. Each increasing step was made after the COD removal efficiency achieved 80% at least 3 days consecutively. Such acclimatization procedures were different from that of food processing wastewater as studied by Karcharnubarn (48). During acclimatization period, it was observed that COD removal efficiencies were gradually decreased from 88.3% to 80.8% at 10% to 40% increase by volume and from 92.2% to 81.0% at 50% to 100% increase by volume. The period of 40%-50% increase during acclimatization period was further extended due to the low COD removal efficiency at 40% increase. As the results, it appeared that the high-strength wastewater concentration as textile wastewater needed the longer acclimatization period by gradual increasing loading capacity step-by-step to achieve a high treatment performance.

Moreover, it also observed that MLSS values slightly decreased during acclimatization period, but it gradually increased to be 5,470, 5,560 and 5,280 mg/l in reactor 1, 2 and 3 respectively at the end of acclimatization period. These results are in substantial agreement with those of Martin A.M.(8) indicating that the population of microorganisms may not be able to biodegrade the material initially. As time passes, however, the biomass may become active towards the material.

5.3 The Efficiency of Anaerobic Sequencing Batch Reactors (AnA²/O² SBRs) in the Treatment of Textile Wastewater

AnA²/O² SBRs were operated for 5 months with the actual textile wastewater. During the entire experimental period, an experimental running conditions were performed by varying anoxic time and SRT simultaneously.

At the steady state condition, under the entire experimental conditions, COD, TKN, TP and color removal efficiencies were in the range of 80.7%-90.7%, 82.0%-94.6%, 56.8%-79.9% and 29.1%-51.5%, respectively.

Moreover, it could be observed that the COD and TKN removal efficiencies were closely consistent with the results of Bortone (38) indicating that the efficiency of an anoxic-aerobic treatment system in the treatment of combined textile and domestic wastewater in terms of COD, NH₄-N and TP removal were 80.5%-81.2%, 86.7%-93.7% and 38.2%-43.6%, respectively. Similarly, as shown in the results of Pansuwan (40), it was also found that TP and color removal were 33.5%-41.9% and 16.4%-19.0%, respectively. Therefore, TP and color removal efficiencies in this experiment

were greatly higher than those reported by Bortone and Pansuwan. The reason for the difference may be due to the operational pattern used in this experiment.

5.4 Removal Efficiency of Anaerobic Sequencing Batch Reactors

(AnA²/O² SBRs)

The sequential operation of AnA²/O² SBRs has been used to investigate simultaneous removal of COD, TKN, TP and color in textile wastewater. The comparison of removal efficiencies at an overall performances was illustrated in Table 5.1.

Table 5.1 The overall removal efficiencies of AnA²/O² SBRs under the steady state condition

| Group | SRT (day) | Anoxic time(hr) | Removal Efficiency (%) | | | | | | | |
|-------|--------------|--------------------|------------------------|-----|------|-----|------|-----|-------|------|
| | | | COD | | TKN | | TP | | Color | |
| | | | Ave. | SD. | Ave. | SD. | Ave. | SD. | Ave. | SD. |
| 1 | 40 | 2 | 80.7 | 1.7 | 90.7 | 2.2 | 75.2 | 1.9 | 29.1 | 3.3 |
| | | 4 | 81.2 | 2.3 | 90.3 | 3.3 | 74.7 | 2.8 | 30.5 | 3.4 |
| | | 6 | 81.5 | 1.2 | 87.8 | 3.8 | 74.3 | 3.1 | 33.6 | 5.6 |
| 2 | 60 | 2 | 82.8 | 1.4 | 94.6 | 0.7 | 75.3 | 2.4 | 34.5 | 1.8 |
| | | 4 | 84.0 | 1.3 | 94.3 | 1.0 | 77.0 | 2.1 | 34.9 | 1.8 |
| | | 6 | 83.2 | 1.8 | 93.4 | 1.0 | 79.9 | 2.5 | 37.0 | 0.9 |
| 3 | 80 | 2 | 90.7 | 0.7 | 82.6 | 0.8 | 56.8 | 2.8 | 49.1 | 13.1 |
| | | 4 | 88.5 | 2.2 | 82.0 | 0.6 | 58.7 | 2.3 | 49.3 | 13.3 |
| | | 6 | 89.4 | 1.6 | 82.1 | 0.7 | 58.8 | 1.9 | 51.5 | 13.9 |

From the overall performance of AnA²/O² SBR during steady state running, it indicated that the COD removal efficiency of AnA²/O² SBRs at SRT 40, 60 and 80 days were in the average of 81.1%, 83.3%, and 89.5%, respectively. The comparative analysis of COD removal efficiency among the three SRTs indicated that the COD removal efficiency at SRT 80 days was significantly higher than those of 40 and 60 days SRTs ($p < 0.05$). In addition, the COD removal efficiency at SRT 60 days also slightly higher than 40 days SRT ($p < 0.05$). One possible explanation is that the growth of bacteria at higher SRT undergo the endogenous phase resulting in lower organic substrate residues. The results seem to be consistent with our hypothesis that longer SRT would have higher COD removal efficiency than that of shorter one.

The average COD removal efficiency of AnA²/O² SBRs at the anoxic time of 2, 4 and 6 hours were 84.7%, 84.6% and 84.7%, respectively. The statistical analysis showed that the COD removal efficiency was insignificantly differed by the varying anoxic time ($p < 0.05$). One reason could be explain that the aeration periods, resulting in better influence on COD removal efficiency.

Considering the combination effect of SRT and anoxic time, it was found that the combination effect of 80 days SRT and anoxic time of 2 hours was slightly higher than that of 80 days SRT and anoxic time of 4 and 6 hours. These results showed that at higher SRT, it is not necessary to provide longer time in the first anoxic period, because it may reduce anoxic time in the second anoxic period. The longer time of the second anoxic period may be essential for denitrifying bacteria to use BOD as a carbon source for energy synthesis.

From the overall performance of AnA²/O² SBR during steady state running, it was found that the TKN removal efficiency of 40, 60 and 80 day SRT were in the average of 89.6%, 94.1% and 85.3%, respectively. The comparative analysis of TKN removal efficiency among the three SRTs indicated that the TKN removal efficiency at SRT 60 days was significantly higher than SRT 40 and 80 days ($p < 0.05$). In addition, the TKN removal efficiency at 40 days SRT was significantly higher than that of 80 days one. One possible explanation is that, the growth rate of nitrifiers is very slow at too shorter SRT. Hence, there are not adequate population of nitrifying organisms to remove TKN. Also, the growth rate of heterotrophic bacteria is greater than that of autotrophic nitrifying bacteria at too long SRT. The slower growing nitrifiers will gradually diminish in proportion to the total population, and washed out of the system (13). The results seem inconsistent with our hypothesis that longer SRT would have higher TKN removal efficiency than that of the shorter one.

TKN removal efficiency of An A²/O² SBR under the anoxic time of 2, 4 and 6 hours were in the average of 89.3%, 88.9% and 87.8%, respectively. The statistical analysis showed that the TKN removal efficiency at anoxic time of 2 hours was significantly higher than that of 6 hours, but the statistical analysis between anoxic time of 2 and 4 hours or 4 and 6 hours were insignificantly different ($p < 0.05$).

Referring to Reife A and Freeman HS(18), it was found that aromatic amine generated by anaerobic reduction of dyes that are generally more toxic than dye itself and sensitivity of nitrifier to toxicants or inhibition effect, consequently it possible

explains that at higher anoxic time, more color was reduced gave higher aromatic amines. Nitrifier bacteria may be suppressed leading to lower TKN removal efficiency. The results seem inconsistent with our hypothesis that longer anoxic time would have higher TKN removal efficiency than the shorter anoxic time.

From the overall performance of AnA²/O² SBR during steady state running, it was found that the TP removal efficiency of AnA²/O² SBR at SRT of 40, 60 and 80 days were in the average of 74.7%, 77.4% and 58.1%, respectively. The comparative analysis of TP removal efficiency among the three SRT indicated that the TP removal efficiency at SRT 60 days was significantly higher than those of 40 and 80 days SRTs ($p < 0.05$). In addition, 40 days SRT was significantly higher than that of 80 days SRT ($p < 0.05$). The possible explanation is that the simultaneous nitrification and denitrification may incompletely take place at too shorter SRT(40 days), causing high nitrate-nitrogen entering the anaerobic zone of biological phosphorus removal system. This could reduce the phosphorus removal capacity of the system. Under substrate limiting conditions, phosphorus uptake and nitrate reduction occurred simultaneously in anoxic reactor. Apparently nitrate influences the metabolism of the phosphorus accumulating bacteria so that no polyphosphate is being stored (53).

In addition, another reason, for too long SRT(80 days), is that the phosphate accumulating organisms can only dominate under low sludge age conditions, and their fractions decrease with an increase in sludge age (29). The results seem to be consistent

with our hypothesis that longer SRT would have higher TP removal efficiency than that of the shorter one.

TP removal efficiency of AnA²/O² SBR under anoxic time of 2 , 4 and 6 hours were in the average of 69.1%, 70.1% and 71.0%, respectively. The statistical analysis of TP removal efficiency among the three anoxic times indicated that the TP removal efficiency at all levels of anoxic time were insignificantly difference. This indicates that these varied anoxic time could not affect on TP removal efficiency. This findings are in accordance with Demuynck (32) who studied the sequence of short aerobic/anoxic phase SBR indicating that the biological-P removal was not affected by this alternative time sequence.

Color removal efficiency of AnA²/O² SBR under 40, 60 and 80 days SRT were in the average of 31.1%, 35.5% and 50.0%, respectively. The comparative analysis of color removal efficiency among the three SRTs indicated that the color removal efficiency at SRT 80 days was significantly higher than those of 40 and 60 days SRT($p < 0.05$), however; color removal efficiencies at 40 and 60 days SRT were insignificantly different ($p < 0.05$). Because color values of influent during running in group 3(SRT 80 days) was very high to 931 ADMI and more differ from group 1 and 2 that can be leaded to misinterpret the results. According to the report of Rahman RA (38) that one of the most influential variables for the growth of the biodecolorisation culture was dye concentration and changing this variable would significantly affect the growth rates of

the culture. The results seem to be consistent with our hypothesis that longer SRT would have higher color removal efficiency than that of shorter one.

Color removal efficiency of AnA²/O² SBR under anoxic time of 2, 4 and 6 hours were in the average of 37.6%, 38.3% and 40.7% respectively. The statistical analysis of differences among those were not found. It was noticed that the longer anoxic time gave the higher color removal efficiency. It was possible that the color removal may be occurred again after NO₃-N have already been depleted, consequently; the anoxic period, after NO₃-N was depleted, can help remove color. In addition, decolorization process also depends on organic substrate as electron donors. So, the longer of the first anoxic time, could yield better color removal due to more organic substrate availability. The results seem to be inconsistent with our hypothesis that longer anoxic time would have higher color removal efficiency than that of the shorter one.

5.5 The Optimum Running Condition

Comparison of COD, TKN, TP and color removal efficiencies among 9 experimental conditions, found that the optimum running condition of anoxic time at 2 hours and SRT 60 days, giving the COD, TKN, TP and color removal of 82.8%, 94.6%, 75.3% and 34.5%, respectively.

The contour graphs in Figures 5.1 to 5.4 showed the relationship between SRT and anoxic time on the COD, TKN, TP and color removal efficiencies. These indicated that SRT was more influence variable on the performance of the AnA²/O²

SBRs than anoxic time was. This finding seems to accord with the results generating from the comparative analysis using forward step-wise regression technique. As shown in Figure 5.1 and 5.2, it can be noticed that COD and color removal efficiencies increased as the SRT increased and the 80-days SRT gave significant difference in the removal efficiencies than those of the others. According to Figures 5.3 and 5.4, it can be observed that the TKN and TP removal efficiencies were the best at 60-days SRT, however; at 80-day SRT, TP removal efficiency was significantly dropped. In the other hand, it was illustrated that anoxic time affected slightly on COD and TKN removal efficiencies as shown in Figures 5.1 and 5.3, however; 2-hours anoxic time seem to be better than those of the others. In contrast, color and TP removal efficiencies seem to be no effect contributed by anoxic time as depicted in Figures 5.2 and 5.4.

As considering the results of contour graphs and statistical analysis seriously, SRT at 60 days and anoxic time of 2 hours are finally recommended as the optimum running condition for COD, nutrient and color removals of textile wastewater using an Anaerobic SBR (AnA²/O² SBR). In addition, a longer SRT of 80 days is necessary for COD and color removals, but it causes a major adverse effect on nutrient removal, especially TP removal. In contrast, at a shorter SRT of 40 days, COD, color and nutrient removal efficiencies were slightly lower than of that 60 days SRT. Rodrigo MA et. al (54) reported that the phosphate accumulating organisms can only dominate under low sludge age conditions, and their fractions decreased with an increase in sludge age. In addition, "G bacteria", a bacteria believed to cause the decline of the

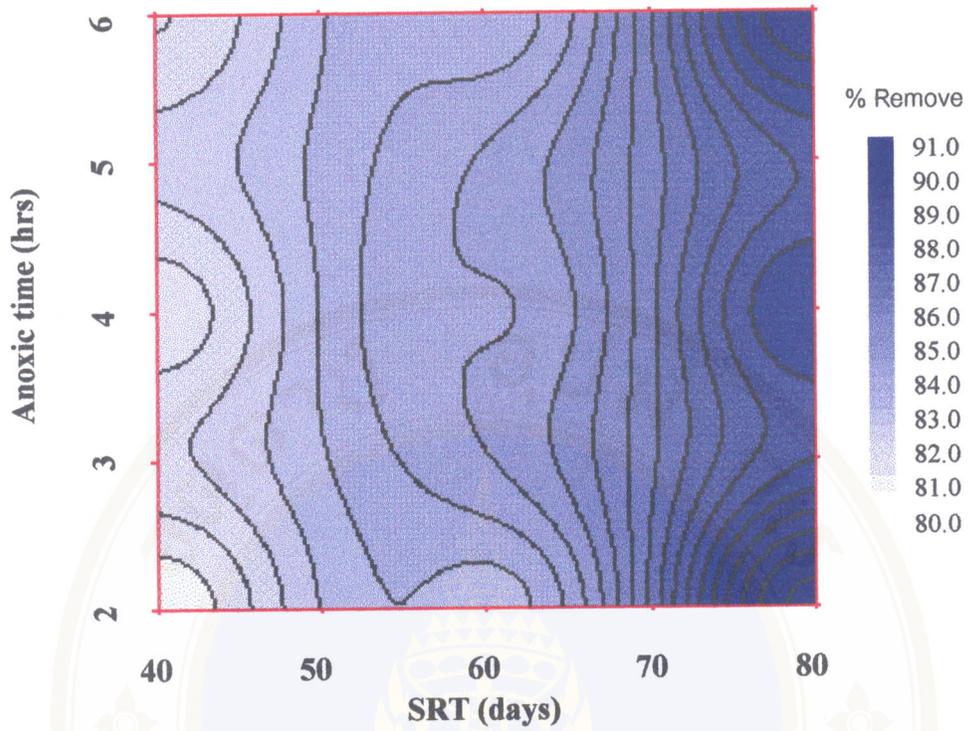


Figure 5.1 Contour graph for COD removal efficiency

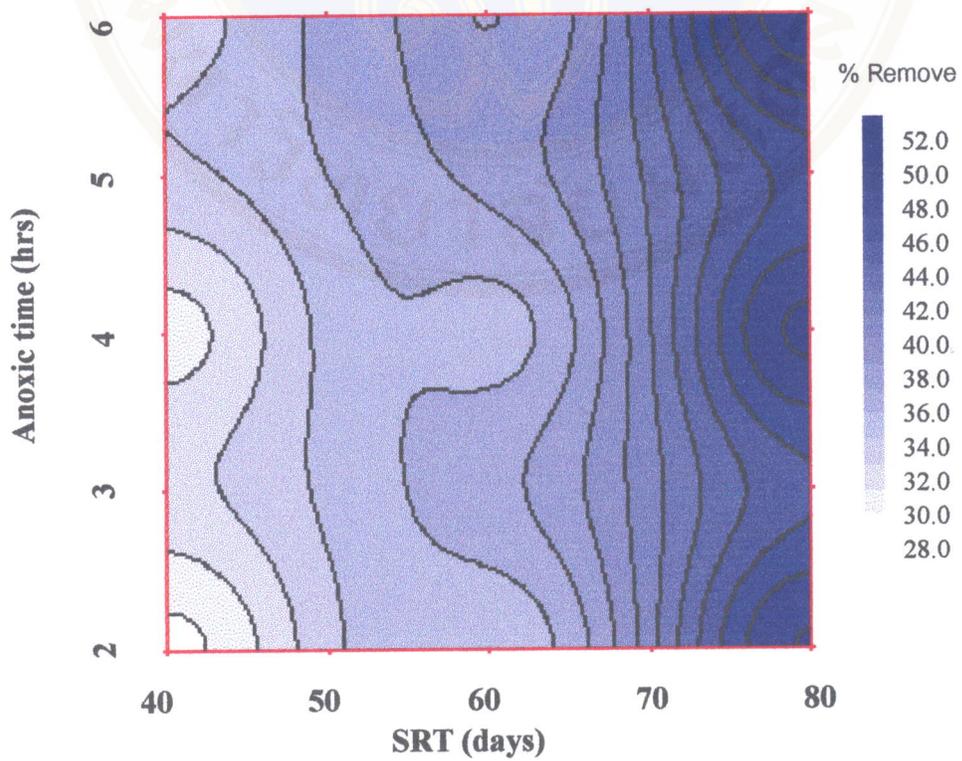


Figure 5.2 Contour graph for color removal efficiency

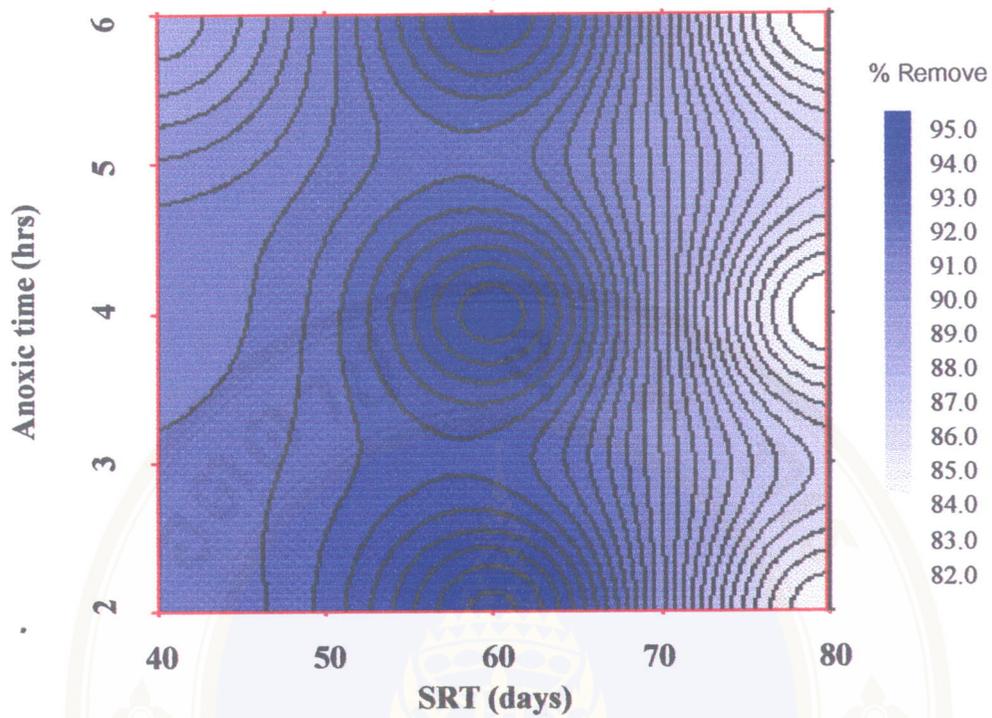


Figure 5.3 Contour graph for TKN removal efficiency

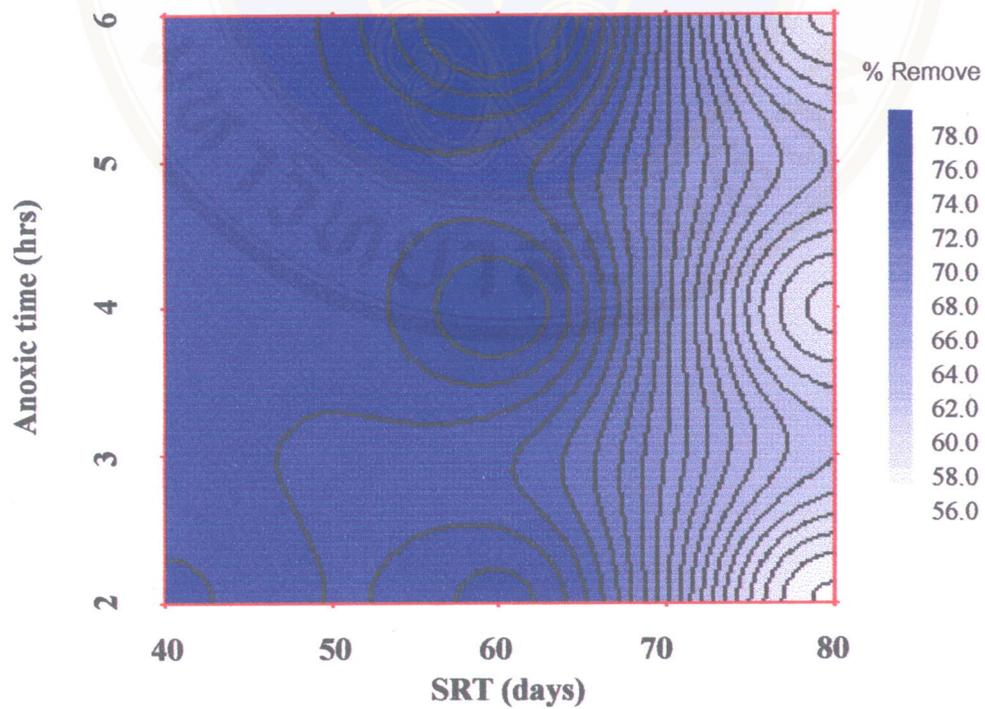


Figure 5.4 Contour graph for TP removal efficiency

phosphorus removal, are able to dominate in the biological culture if the sludge age is high. In conclusion, neither too long nor short SRT are suitable for AnA²/O² SBR in the removal of phosphate from textile wastewater.

From the regression equations, it was also found that at the 74-days SRT, the COD and TKN removal efficiencies were 87.3 % and color removal efficiency was 44.8 % as shown in Figure 5.5.

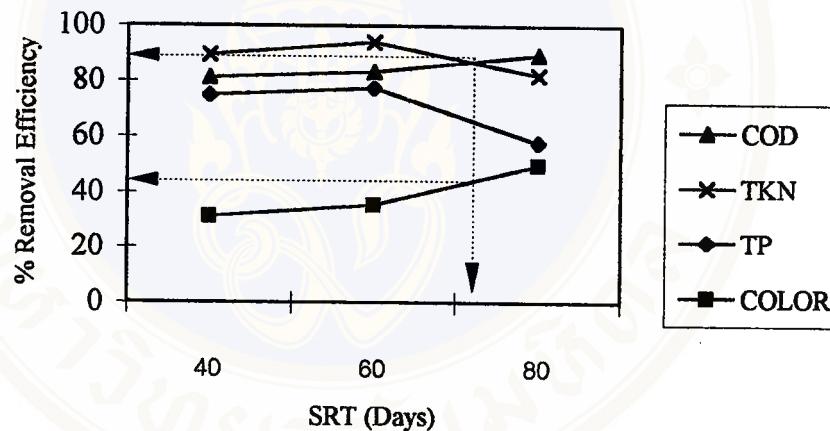


Figure 5.5 Prediction of SRT for COD, TKN, TP and color removal efficiencies.

At the optimum running condition, the average responses are summarized in Table 5.2.

Table 5.2 Summary of average responses at the recommend optimal system operating condition

| <i>Average Responses Process</i> | <i>Experimental Running Conditions</i> |
|---|--|
| • Running period (days) | 38 |
| • Influent flow (l/day) | 5 |
| • HRT (days) | 2 |
| • Volumetric Loading rate (kgCOD/m ³ /day) | 0.5 |
| • Mixed Liquor Suspended Solids(mg/l) | 5,800 |
| • F/M ratio (/day) | 0.08 |
| • SRT (days) | 60 |
| • Cycle time per day (hours) | 24 |
| • Reaction Period | 21 |
| • Anaerobic time fill (hours) | 4 |
| • Anoxic time1:Anoxic time2 (hours) | 2:7 |
| • Oxic time 1 : Oxic time 2 (hours) | 4:4 |
| • Setting Period (hours) | 1.5 |
| • Drawing Period (hour) | 0.5 |
| • Idle Period (hour) | 1 |
| • Sludge Wastage (kg dried solids/d) | 0.95 |
| • Effluent Quality | |
| • COD (mg/l) | 163 |
| • TKN (mg/l) | 7.8 |
| • TP (mg/l) | 5.9 |
| • Color (ADMI) | 323 |
| • System Removal Efficiency (%) | |
| • COD | 82.8 |
| • TKN | 94.6 |
| • TP | 75.3 |
| • Color | 34.5 |

5.6 Comparison of Effluent Qualities with Standards

It was found that the pH, COD, TKN of the effluent under the steady state condition met with the effluent standard for woven finishing and printing of textile industry proposed by The Ministry of Industry and The Ministry of Science Technology and Environment of Thailand. However, no effluent standard of total phosphorous is required, while the effluent color is considered to be objective.

Table 5.3 Comparison of Textile effluent qualities with standards

| <i>Parameters</i> | <i>In Experiment</i> | | <i>MOI</i> | <i>MOSTE</i> |
|--------------------------------|----------------------|--------------------------|-----------------|-----------------|
| | <i>range</i> | <i>optimum condition</i> | <i>Standard</i> | <i>Standard</i> |
| <i>pH</i> | 7.8-8.0 | 7.8 | 5.5-9.0 | 5.5-9.0 |
| <i>BOD (mg/l)</i> | - | - | ≤60 | ≤60 |
| <i>COD (mg/l)</i> | 105-176 | 163 | ≤400 | ≤400 |
| <i>Suspended solids (mg/l)</i> | - | - | ≤50 | ≤50 |
| <i>TKN (mg/l)</i> | 7.6-14.5 | 7.8 | ≤100 | ≤100 |
| <i>Oil and Grease (mg/l)</i> | - | - | ≤5 | ≤5 |
| <i>Color (ADMI)</i> | 311-449 | 323 | not objective | not objective |
| | | (greenish-yellow) | | |
| <i>TP (mg/l)</i> | 4.4-5.9 | 5.8 | - | - |

Note MOI : Ministry of Industry

MOSTE : Ministry of Science Technology and Environment

CHAPTER VI

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The experiment was designed to study the efficiency of an Anaerobic-Anoxic-Oxic-Anoxic-Oxic sequencing batch reactor (AnA²/O² SBR) in the treatment of textile wastewater. The two important independent variables (SRTs and Anoxic times) were varied 40, 60 and 80 days and 2, 4 and 6 hours, respectively. The following conclusions have been drawn from the results of this experimental research.

6.1.1 The Characteristics of Textile Wastewater

The characteristics of textile wastewater used in this experiment were pH 7.2, BOD 444 mg/l, COD 1,047 mg/l, TKN 89.93 mg/l, TP 18.38 mg/l and color 544 ADMI.

6.1.2 Seeding and Acclimatization

The concentration of the initial seeding sludge was about 6,000 mg/l. The acclimatization step was performed by gradually increase the raw wastewater from 10% to 100 % of volume in the step of 10% by volume. Each step was operated to achieved the COD removal efficiency of 80% at least 3 days consecutively. It took almost 2 months for seeding and acclimatization.

6.1.3 The Performance of Overall Experimental Conditions

The overall COD, TKN, TP and color removal efficiencies under steady state running condition were in the range of 80.67%- 90.68%, 82.03%-94.64%, 56.79%-79.92% and 29.14%-51.47%, respectively.

6.1.4 The Comparison of the Removal Efficiency with Research Hypotheses

The longer SRT is , the more COD and color are and vis versa with that of TKN and TP. For anoxic time, there was no relationship between anoxic time and the removal efficiency of TKN and color.

6.1.5 The Optimum Running Condition

The optimum running condition of the AnA²/O² SBR was at the anoxic time of 2 hours and the SRT of 60 days which yielded COD, TKN , TP and color removal efficiencies of 82.77%, 94.64%, 75.34% and 34.50% , respectively.

6.1.6 The Comparison of Effluent Qualities with Standards

The effluent COD and TKN values were met with those of the Thai regulation effluent standards. However, no effluent standard to total phosphorus is required, while the effluent color value was considered to be objectionable.

6.2 Recommendations

6.2.1 Pilot scale study in the actual An A²/O² SBRs system is recommend for further investigation and validation.

6.2.2 The possibility of chemical treatment before and/or after the An A²/O² SBR operating for efficient color removal need to be further investigated.

6.2.3 Application of the An A²/O² SBR to treat other high strength wastewater concentration in a combination with toxic or nonbiodegradable organics should be further enhanced.

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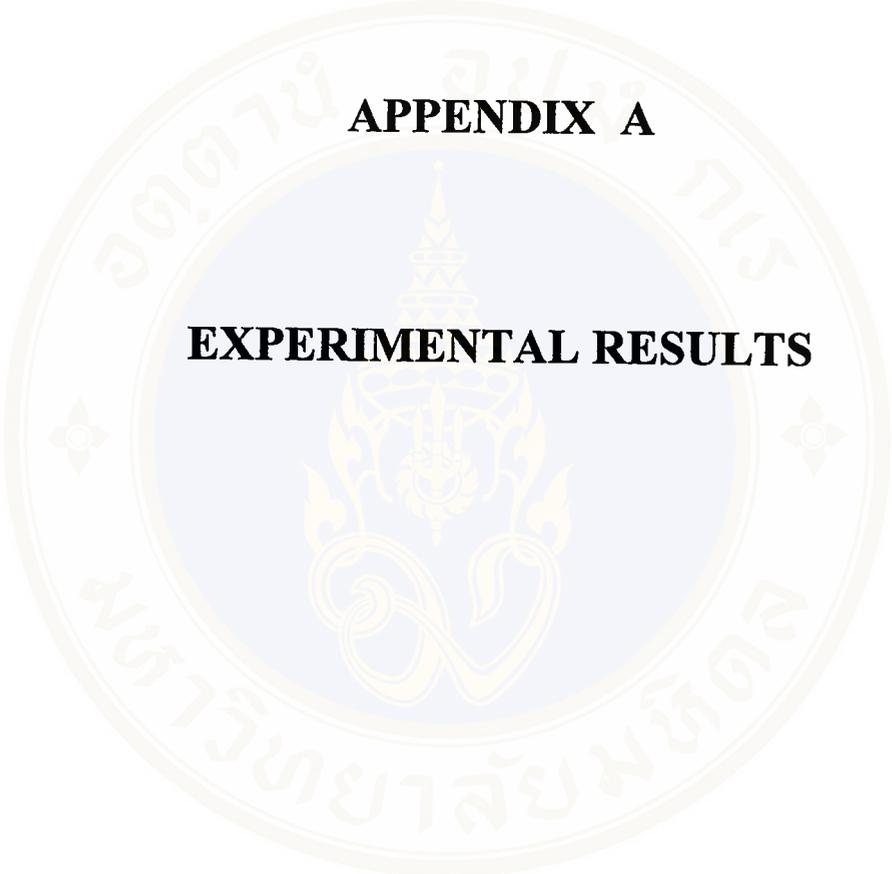
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The image features a large, faint watermark of the Mahidol University logo in the background. The logo is circular, with a blue center containing a golden emblem of a traditional Thai stupa. The outer ring of the logo contains the university's name in Thai script: "มหาวิทยาลัยมหิดล" at the bottom and "จุฬาลงกรณ์มหาวิทยาลัย" at the top.

APPENDIX A

EXPERIMENTAL RESULTS

Table A-1 COD removal efficiency of SBRs in group 1 (Condition 1, 2 and 3).

| <i>Date</i> | <i>Influent</i> | <i>Condition 1</i> | | <i>Condition 2</i> | | <i>Condition 3</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 1 | 1292 | 286 | 77.89 | 210 | 83.78 | 190 | 85.26 |
| 2 | 1105 | 305 | 72.41 | 229 | 79.31 | 248 | 77.59 |
| 3 | 1067 | 300 | 71.88 | 263 | 75.39 | 225 | 78.91 |
| 4 | 1125 | 298 | 73.54 | 242 | 78.50 | 279 | 75.19 |
| 5 | 1005 | 205 | 79.63 | 205 | 79.63 | 242 | 75.93 |
| 6 | 930 | 130 | 86.00 | 205 | 78.00 | 167 | 82.00 |
| 7 | 856 | 149 | 82.61 | 205 | 76.09 | 205 | 76.09 |
| 8 | 1005 | 124 | 87.70 | 212 | 78.92 | 247 | 75.41 |
| 9 | 988 | 159 | 83.93 | 194 | 80.36 | 265 | 73.21 |
| 10 | 1094 | 176 | 83.87 | 247 | 77.42 | 247 | 77.42 |
| 11 | 1094 | 176 | 83.87 | 212 | 80.65 | 282 | 74.19 |
| 12 | 1200 | 176 | 85.29 | 247 | 79.41 | 282 | 76.47 |
| 13 | 1129 | 194 | 82.81 | 176 | 84.38 | 212 | 81.25 |
| 14 | 1024 | 176 | 82.76 | 229 | 77.59 | 194 | 81.03 |
| 15 | 1129 | 212 | 81.25 | 212 | 81.25 | 194 | 82.81 |
| 16 | 1165 | 260 | 77.68 | 200 | 82.83 | 240 | 79.39 |
| 17 | 1200 | 220 | 81.67 | 240 | 80.00 | 260 | 78.33 |
| 18 | 1160 | 240 | 79.31 | 220 | 81.03 | 220 | 81.03 |
| 19 | 1160 | 236 | 79.65 | 216 | 81.35 | 256 | 77.95 |
| 20 | 1023 | 216 | 78.85 | 236 | 76.92 | 236 | 76.92 |
| 21 | 984 | 216 | 78.00 | 256 | 74.00 | 216 | 78.00 |
| 22 | 1023 | 236 | 76.92 | 236 | 76.92 | 216 | 78.85 |
| 23 | 1102 | 193 | 82.46 | 193 | 82.46 | 183 | 83.38 |
| 24 | 956 | 203 | 78.72 | 203 | 78.72 | 183 | 80.85 |
| 25 | 936 | 203 | 78.26 | 203 | 78.26 | 183 | 80.43 |
| 26 | 895 | 173 | 80.68 | 183 | 79.55 | 183 | 79.55 |
| 27 | 890 | 174 | 80.44 | 155 | 82.61 | 155 | 82.61 |
| 28 | 890 | 174 | 80.44 | 155 | 82.61 | 155 | 82.61 |

Table A-1 COD removal efficiency of SBRs in group 1 (Condition 1, 2 and 3)
(continued).

| <i>Date</i> | <i>Influent</i> | <i>Condition 1</i> | | <i>Condition 2</i> | | <i>Condition 3</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 29 | 890 | 155 | 82.61 | 165 | 81.52 | 155 | 82.61 |
| 30 | 910 | 155 | 82.98 | 135 | 85.11 | 165 | 81.91 |
| 31 | 900 | 169 | 81.25 | 169 | 81.25 | 169 | 81.25 |
| <i>Min.</i> | 856 | 124 | 71.88 | 135 | 74.00 | 155 | 73.21 |
| <i>Max.</i> | 1292 | 305 | 87.70 | 263 | 85.11 | 282 | 85.26 |
| <i>Mean</i> | 1036 | 203 | 80.50 | 208 | 79.86 | 215 | 79.30 |
| <i>SD.</i> | 115 | 49 | 3.68 | 31 | 2.66 | 40 | 3.00 |

Remark Influent and effluent present as mg/l.

Efficiency present as percent(%).



Table A-2 TKN removal efficiency of SBRs in group 1 (Condition 1, 2 and 3).

| <i>Date</i> | <i>Influent</i> | <i>Condition 1</i> | | <i>Condition 2</i> | | <i>Condition 3</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 1 | 106 | 41.13 | 61.19 | 12.66 | 88.06 | 11.47 | 89.18 |
| 2 | 99 | 46.67 | 52.99 | 10.68 | 89.24 | 13.84 | 86.06 |
| 3 | 100 | 48.25 | 51.78 | 8.31 | 91.70 | 7.51 | 92.49 |
| 4 | 98 | 30.85 | 68.55 | 7.51 | 92.34 | 7.91 | 91.94 |
| 5 | 91 | 14.24 | 84.28 | 7.91 | 91.27 | 7.91 | 91.27 |
| 6 | 88 | 8.70 | 90.13 | 8.70 | 90.13 | 9.49 | 89.24 |
| 7 | 89 | 9.49 | 89.38 | 10.68 | 88.05 | 10.68 | 88.05 |
| 8 | 92 | 10.28 | 88.79 | 10.55 | 88.50 | 11.07 | 87.93 |
| 9 | 91 | 10.01 | 89.02 | 10.55 | 88.43 | 9.49 | 89.60 |
| 10 | 88 | 12.13 | 86.26 | 13.18 | 85.08 | 13.72 | 84.47 |
| 11 | 88 | 13.72 | 84.43 | 14.76 | 83.24 | 15.82 | 82.04 |
| 12 | 83 | 13.72 | 83.54 | 17.40 | 79.12 | 23.21 | 72.15 |
| 13 | 74 | 15.30 | 79.35 | 16.61 | 77.58 | 22.97 | 69.00 |
| 14 | 86 | 13.72 | 84.04 | 14.51 | 83.12 | 27.16 | 68.40 |
| 15 | 74 | 14.76 | 80.01 | 14.76 | 80.01 | 18.46 | 75.00 |
| 16 | 73 | 13.18 | 82.02 | 13.45 | 81.65 | 13.45 | 81.65 |
| 17 | 73 | 13.18 | 82.02 | 13.45 | 81.65 | 13.18 | 82.02 |
| 18 | 71 | 13.72 | 80.69 | 14.76 | 79.22 | 13.45 | 81.07 |
| 19 | 56 | 18.19 | 67.51 | 12.86 | 77.03 | 12.54 | 77.60 |
| 20 | 112 | 34.50 | 69.31 | 26.97 | 76.01 | 17.88 | 84.10 |
| 21 | 110 | 27.05 | 75.48 | 22.34 | 79.75 | 9.53 | 91.36 |
| 22 | 109 | 16.93 | 84.42 | 14.53 | 86.63 | 9.41 | 91.34 |
| 23 | 111 | 5.55 | 95.00 | 11.29 | 89.83 | 1.88 | 98.31 |
| 24 | 121 | 18.11 | 85.08 | 12.70 | 89.54 | 13.41 | 88.95 |
| 25 | 122 | 10.82 | 91.15 | 12.70 | 89.62 | 13.41 | 89.04 |
| 26 | 114 | 9.17 | 91.94 | 8.70 | 92.36 | 12.00 | 89.46 |
| 27 | 130 | 18.11 | 86.05 | 21.05 | 83.79 | 24.00 | 81.51 |
| 28 | 123 | 12.47 | 89.84 | 13.52 | 88.99 | 20.27 | 83.49 |

Table A-2 TKN removal efficiency of SBRs in group 1 (Condition 1, 2 and 3)

(continued).

| <i>Date</i> | <i>Influent</i> | <i>Condition 1</i> | | <i>Condition 2</i> | | <i>Condition 3</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 29 | 110 | 8.47 | 92.30 | 8.47 | 92.30 | 9.41 | 91.45 |
| 30 | 111 | 8.47 | 92.37 | 8.94 | 91.95 | 10.35 | 90.68 |
| 31 | 110 | 9.41 | 91.45 | 7.53 | 93.16 | 12.35 | 88.78 |
| <i>Min.</i> | <i>55.98</i> | <i>5.55</i> | <i>51.78</i> | <i>7.51</i> | <i>76.01</i> | <i>1.88</i> | <i>68.40</i> |
| <i>Max.</i> | <i>130</i> | <i>48.25</i> | <i>95.00</i> | <i>26.97</i> | <i>93.16</i> | <i>27.16</i> | <i>98.31</i> |
| <i>Mean</i> | <i>96.95</i> | <i>17.43</i> | <i>81.63</i> | <i>12.97</i> | <i>86.11</i> | <i>13.46</i> | <i>85.41</i> |
| <i>SD.</i> | <i>18.15</i> | <i>11.29</i> | <i>11.24</i> | <i>4.48</i> | <i>5.30</i> | <i>5.55</i> | <i>7.13</i> |

Remarks Influent and effluent present as mg/l.

Efficiency present as percent(%).

Table A-3 TP removal efficiency of SBRs in group 1 (Condition 1, 2 and 3).

| <i>Date</i> | <i>Influent</i> | <i>Condition 1</i> | | <i>Condition 2</i> | | <i>Condition 3</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 1 | 24.49 | 6.91 | 71.76 | 2.35 | 90.41 | 2.35 | 90.41 |
| 2 | 18.78 | 5.14 | 72.64 | 1.71 | 90.88 | 2.09 | 88.85 |
| 3 | 20.68 | 3.43 | 83.43 | 1.27 | 93.86 | 0.70 | 96.62 |
| 4 | 21.95 | 2.28 | 89.59 | 2.16 | 90.17 | 1.14 | 94.80 |
| 5 | 17.64 | 1.90 | 89.21 | 2.16 | 87.77 | 2.16 | 87.77 |
| 6 | 18.90 | 2.41 | 87.25 | 1.97 | 89.59 | 3.30 | 82.55 |
| 7 | 20.93 | 2.28 | 89.09 | 1.59 | 92.42 | 2.41 | 88.48 |
| 8 | 20.93 | 2.16 | 89.70 | 3.17 | 84.85 | 2.41 | 88.48 |
| 9 | 20.93 | 1.33 | 93.64 | 1.78 | 91.52 | 1.78 | 91.52 |
| 10 | 21.57 | 2.03 | 90.59 | 2.79 | 87.06 | 1.52 | 92.94 |
| 11 | 23.47 | 2.54 | 89.19 | 3.43 | 85.40 | 2.66 | 88.65 |
| 12 | 22.20 | 2.66 | 88.00 | 2.66 | 88.00 | 3.43 | 84.57 |
| 13 | 11.29 | 3.05 | 73.03 | 3.43 | 69.66 | 2.82 | 75.03 |
| 14 | 14.08 | 2.03 | 85.59 | 3.17 | 77.48 | 3.25 | 76.92 |
| 15 | 15.35 | 2.41 | 84.29 | 3.05 | 80.16 | 3.05 | 80.16 |
| 16 | 13.07 | 2.41 | 81.55 | 3.05 | 76.70 | 2.79 | 78.64 |
| 17 | 13.07 | 2.54 | 80.59 | 3.17 | 75.73 | 2.16 | 83.49 |
| 18 | 13.07 | 2.54 | 80.59 | 3.05 | 76.70 | 2.41 | 81.55 |
| 19 | 10.91 | 3.43 | 68.60 | 2.79 | 74.42 | 2.54 | 76.75 |
| 20 | 18.90 | 3.81 | 79.87 | 4.31 | 77.18 | 3.74 | 80.20 |
| 21 | 17.64 | 4.44 | 74.82 | 3.43 | 80.57 | 3.81 | 78.42 |
| 22 | 17.64 | 4.31 | 75.54 | 5.46 | 69.07 | 2.92 | 83.45 |
| 23 | 18.90 | 3.68 | 80.54 | 4.95 | 73.83 | 2.41 | 87.25 |
| 24 | 17.64 | 4.19 | 76.26 | 4.76 | 73.00 | 4.76 | 73.00 |
| 25 | 18.27 | 4.57 | 75.00 | 4.57 | 75.00 | 4.75 | 74.00 |
| 26 | 20.17 | 4.57 | 77.35 | 4.64 | 77.00 | 5.45 | 73.00 |
| 27 | 20.17 | 4.57 | 77.35 | 4.31 | 78.61 | 4.69 | 76.73 |
| 28 | 18.97 | 4.95 | 73.91 | 4.44 | 76.59 | 3.81 | 79.93 |

Table A-3 TP removal efficiency of SBRs in group 1 (Condition 1, 2 and 3)

(continued).

| <i>Date</i> | <i>Influent</i> | <i>Condition 1</i> | | <i>Condition 2</i> | | <i>Condition 3</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 29 | 14.59 | 3.79 | 74.00 | 4.23 | 71.00 | 4.06 | 72.17 |
| 30 | 13.83 | 3.81 | 72.48 | 3.87 | 72.00 | 4.01 | 71.00 |
| <i>Min.</i> | <i>10.91</i> | <i>1.33</i> | <i>68.60</i> | <i>1.27</i> | <i>69.07</i> | <i>0.70</i> | <i>71.00</i> |
| <i>Max.</i> | <i>24.49</i> | <i>6.91</i> | <i>93.64</i> | <i>5.46</i> | <i>93.86</i> | <i>5.45</i> | <i>96.62</i> |
| <i>Mean</i> | <i>18.00</i> | <i>3.34</i> | <i>80.85</i> | <i>3.26</i> | <i>80.89</i> | <i>2.98</i> | <i>82.58</i> |
| <i>SD.</i> | <i>3.64</i> | <i>1.25</i> | <i>7.01</i> | <i>1.11</i> | <i>7.65</i> | <i>1.12</i> | <i>7.20</i> |

Remarks Influent and effluent present as mg/l.

Efficiency present as percent(%).

Table A-4 Color removal efficiency of SBRs in group 1 (Condition 1, 2 and 3).

| <i>Date</i> | <i>Influent</i> | <i>Condition 1</i> | | <i>Condition 2</i> | | <i>Condition 3</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 1 | 610 | 501 | 17.79 | 503 | 17.57 | 517 | 15.22 |
| 2 | 587 | 497 | 15.37 | 482 | 17.90 | 487 | 17.02 |
| 3 | 626 | 497 | 20.64 | 484 | 22.58 | 485 | 22.43 |
| 4 | 579 | 359 | 38.05 | 371 | 35.95 | 372 | 35.78 |
| 8 | 415 | 294 | 29.18 | 300 | 27.81 | 296 | 28.63 |
| 9 | 412 | 290 | 29.73 | 288 | 30.21 | 287 | 30.32 |
| 10 | 463 | 289 | 37.58 | 290 | 37.40 | 292 | 37.01 |
| 11 | 425 | 268 | 36.99 | 272 | 35.86 | 267 | 37.05 |
| 16 | 896 | 648 | 27.61 | 639 | 28.67 | 634 | 29.18 |
| 17 | 755 | 611 | 18.98 | 606 | 19.73 | 607 | 19.52 |
| 18 | 776 | 607 | 21.80 | 610 | 21.46 | 612 | 21.10 |
| 22 | 600 | 417 | 30.57 | 410 | 31.63 | 419 | 30.16 |
| 23 | 676 | 393 | 41.84 | 387 | 42.76 | 382 | 43.50 |
| 24 | 937 | 394 | 57.93 | 381 | 59.40 | 374 | 60.15 |
| 25 | 586 | 356 | 39.31 | 347 | 40.87 | 345 | 41.20 |
| 29 | 481 | 348 | 27.64 | 342 | 28.77 | 314 | 34.76 |
| 30 | 551 | 369 | 32.96 | 361 | 34.47 | 339 | 38.51 |
| 31 | 474 | 347 | 26.83 | 340 | 28.34 | 344 | 27.51 |
| <i>Min.</i> | <i>412</i> | <i>268</i> | <i>15.37</i> | <i>272</i> | <i>17.57</i> | <i>267</i> | <i>15.22</i> |
| <i>Max.</i> | <i>937</i> | <i>648</i> | <i>57.93</i> | <i>639</i> | <i>59.40</i> | <i>634</i> | <i>60.15</i> |
| <i>Mean</i> | <i>603</i> | <i>416</i> | <i>30.60</i> | <i>412</i> | <i>31.19</i> | <i>410</i> | <i>31.61</i> |
| <i>SD.</i> | <i>156</i> | <i>118</i> | <i>10.41</i> | <i>116</i> | <i>10.33</i> | <i>119</i> | <i>10.95</i> |

Remarks Influent and effluent present as ADMI.

Efficiency present as percent(%).

Table A-5 Mixed Liqour Suspended Solids(MLSS) in experimental group 1
(Condition 1, 2 and 3)(mg/l).

| <i>Date</i> | <i>Condition 1</i> | <i>Condition 2</i> | <i>Condition 3</i> |
|-------------|--------------------|--------------------|--------------------|
| 1 | 5860 | 6060 | 5760 |
| 3 | 5960 | 6040 | 5740 |
| 5 | 6040 | 6320 | 6040 |
| 7 | 5760 | 5720 | 5540 |
| 9 | 5840 | 5700 | 5440 |
| 11 | 5380 | 5320 | 5300 |
| 13 | 5100 | 5380 | 5060 |
| 15 | 5220 | 5100 | 5180 |
| 17 | 5080 | 5260 | 5000 |
| 19 | 5080 | 5120 | 5000 |
| 21 | 4720 | 4760 | 4760 |
| 23 | 4740 | 4780 | 4620 |
| 25 | 4560 | 4620 | 4680 |
| 27 | 4580 | 4700 | 4640 |
| 29 | 4260 | 4420 | 4220 |
| 31 | 4520 | 4500 | 4320 |
| 33 | 4360 | 4360 | 4480 |
| 35 | 4140 | 4080 | 4140 |
| 37 | 4220 | 4080 | 4140 |
| 39 | 3980 | 3940 | 4040 |
| <i>Min.</i> | <i>3980</i> | <i>3940</i> | <i>4040</i> |
| <i>Max.</i> | <i>6040</i> | <i>6320</i> | <i>6040</i> |
| <i>Mean</i> | <i>4970</i> | <i>5013</i> | <i>4905</i> |
| <i>SD.</i> | <i>662</i> | <i>705</i> | <i>599</i> |

Table A-6 pH value in experimental group 1 (condition 1, 2 and 3).

| <i>Date</i> | <i>Influent</i> | <i>Effluent</i> | | |
|-------------|-----------------|--------------------|--------------------|--------------------|
| | | <i>Condition 1</i> | <i>Condition 2</i> | <i>Condition 3</i> |
| 1 | 7.2 | 7.7 | 7.5 | 7.5 |
| 2 | 7.2 | – | – | 7.7 |
| 3 | 7.2 | 7.9 | 7.7 | 7.7 |
| 4 | 7.2 | 7.6 | 7.6 | 7.8 |
| 5 | 7.2 | 7.7 | 7.8 | 7.8 |
| 6 | 7.2 | 8.1 | 7.8 | 7.9 |
| 7 | 7.2 | 7.9 | 7.8 | 7.8 |
| 8 | 7.2 | 7.7 | 7.6 | 7.6 |
| 9 | 7.2 | 7.8 | 7.8 | 7.8 |
| 10 | 7.2 | 7.8 | 7.8 | 7.8 |
| 11 | 7.2 | 7.8 | 7.9 | 7.9 |
| 12 | 7.2 | 7.7 | 7.6 | 7.6 |
| 13 | 7.0 | 7.7 | 7.6 | 7.6 |
| 14 | 7.1 | 7.8 | 7.6 | 7.6 |
| 15 | 7.1 | 7.7 | 7.6 | 7.5 |
| 16 | 7.1 | 8.0 | 7.9 | 8.0 |
| 17 | 7.2 | 7.5 | 7.6 | 7.7 |
| 18 | 7.2 | 7.9 | 7.9 | 8.1 |
| 19 | 7.2 | 8.0 | 8.0 | 8.2 |
| 20 | 7.2 | 7.8 | 7.7 | 7.6 |
| 21 | 7.2 | 7.8 | 7.7 | 7.7 |
| 22 | – | 7.5 | 7.5 | 7.8 |
| 23 | 7.1 | 7.6 | 7.6 | 7.6 |
| 24 | 7.1 | 7.6 | 7.6 | 7.5 |
| 25 | 7.1 | 7.5 | 7.5 | 7.5 |
| 26 | 7.1 | 8.4 | 8.0 | 7.5 |
| 27 | 7.1 | 7.6 | 7.5 | 7.5 |
| 28 | 7.1 | 7.4 | 7.4 | 7.4 |

Table A-6 pH value in experimental group 1 (condition 1, 2 and 3)

(continued).

| <i>Date</i> | <i>Influent</i> | <i>Effluent</i> | | |
|-------------|-----------------|--------------------|--------------------|--------------------|
| | | <i>Condition 1</i> | <i>Condition 2</i> | <i>Condition 3</i> |
| 29 | 7.1 | 7.5 | 7.5 | 7.4 |
| 30 | 7.2 | 7.6 | 7.5 | 7.4 |
| 31 | 7.1 | 7.4 | 7.4 | 7.3 |
| 32 | 7.1 | – | – | – |
| 33 | 7.2 | 7.6 | 7.4 | 7.2 |
| 34 | 7.2 | 7.6 | 7.6 | 7.8 |
| 35 | 7.2 | 7.4 | 7.5 | 7.5 |
| 36 | 7.2 | 7.6 | 7.6 | 7.5 |
| 38 | 7.2 | 7.8 | 7.7 | 7.7 |
| 39 | 7.2 | 7.7 | 7.4 | 7.9 |
| 40 | 7.2 | 7.8 | 7.6 | 7.8 |
| <i>Min.</i> | 7.0 | 7.4 | 7.4 | 7.2 |
| <i>Max.</i> | 7.2 | 8.4 | 8.0 | 8.2 |
| <i>Mean</i> | 7.2 | 7.7 | 7.6 | 7.7 |
| <i>SD.</i> | 0.1 | 0.2 | 0.2 | 0.2 |

Table A-7 COD removal efficiency of SBRs in group 2 (Condition 4, 5 and 6).

| <i>Date</i> | <i>Influent</i> | <i>Condition 4</i> | | <i>Condition 5</i> | | <i>Condition 6</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 1 | 1091 | 200 | 81.67 | 182 | 83.33 | 164 | 85.00 |
| 2 | 1091 | 221 | 79.78 | 194 | 82.21 | 176 | 83.82 |
| 3 | 1059 | 185 | 82.50 | 159 | 85.00 | 176 | 83.33 |
| 4 | 1094 | 159 | 85.48 | 141 | 87.10 | 194 | 82.26 |
| 5 | 1024 | 141 | 86.21 | 124 | 87.93 | 158 | 84.53 |
| 6 | 1165 | 159 | 86.36 | 132 | 88.64 | 158 | 86.41 |
| 7 | 986 | 129 | 86.96 | 118 | 88.04 | 129 | 86.96 |
| 8 | 900 | 129 | 85.71 | 96 | 89.29 | 107 | 88.10 |
| 9 | 1114 | 129 | 88.46 | 107 | 90.38 | 129 | 88.46 |
| 10 | 1029 | 129 | 87.50 | 118 | 88.54 | 129 | 87.50 |
| 11 | 1071 | 122 | 88.61 | 102 | 90.51 | 122 | 88.61 |
| 12 | 1037 | 122 | 88.24 | 122 | 88.24 | 122 | 88.24 |
| 13 | 1017 | 122 | 88.00 | 122 | 88.00 | 132 | 87.00 |
| 14 | 1098 | 122 | 88.89 | 112 | 89.82 | 132 | 87.96 |
| 15 | 1139 | 122 | 89.29 | 142 | 87.50 | 132 | 88.39 |
| 16 | 1159 | 142 | 87.72 | 142 | 87.72 | 132 | 88.60 |
| 17 | 976 | 122 | 87.50 | 122 | 87.50 | 142 | 85.42 |
| 18 | 1139 | 115 | 89.89 | 125 | 89.04 | 125 | 89.04 |
| 19 | 1037 | 134 | 87.04 | 134 | 87.04 | 134 | 87.04 |
| 20 | 1037 | 163 | 84.26 | 134 | 87.04 | 144 | 86.11 |
| 21 | 1037 | 154 | 85.19 | 154 | 85.19 | 154 | 85.19 |
| 22 | 1075 | 173 | 83.93 | 173 | 83.93 | 154 | 85.71 |
| 23 | 1018 | 173 | 83.02 | 173 | 83.02 | 154 | 84.91 |
| 24 | 998 | 167 | 83.25 | 177 | 82.27 | 157 | 84.24 |
| 25 | 1023 | 177 | 82.69 | 187 | 81.73 | 207 | 79.81 |
| 26 | 1102 | 197 | 82.14 | 197 | 82.14 | 177 | 83.93 |
| 27 | 1180 | 197 | 83.33 | 197 | 83.33 | 197 | 83.33 |

Table A-7 COD removal efficiency of SBRs in group 2 (Condition 4, 5 and 6)

(continued).

| <i>Date</i> | <i>Influent</i> | <i>Condition 4</i> | | <i>Condition 5</i> | | <i>Condition 6</i> | |
|--------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 28 | 1062 | 173 | 83.73 | 173 | 83.73 | 163 | 84.64 |
| 29 | 1020 | 173 | 83.07 | 154 | 84.95 | 154 | 84.95 |
| 30 | 1037 | 173 | 83.33 | 173 | 83.33 | 182 | 82.41 |
| 31 | 979 | 192 | 80.39 | 173 | 82.35 | 173 | 82.35 |
| 32 | 960 | 174 | 81.89 | 159 | 83.46 | 151 | 84.25 |
| 33 | 907 | 166 | 81.67 | 136 | 85.00 | 129 | 85.83 |
| 34 | 945 | 144 | 84.80 | 129 | 86.40 | 136 | 85.60 |
| 35 | 907 | 151 | 83.33 | 151 | 83.33 | 166 | 81.67 |
| 36 | 850 | 144 | 83.11 | 129 | 84.89 | 159 | 81.33 |
| 37 | 964 | 158 | 83.65 | 165 | 82.90 | 172 | 82.16 |
| <i>Min.</i> | <i>850</i> | <i>115</i> | <i>79.78</i> | <i>96</i> | <i>81.73</i> | <i>107</i> | <i>79.81</i> |
| <i>Max.</i> | <i>1180</i> | <i>221</i> | <i>89.89</i> | <i>197</i> | <i>90.51</i> | <i>207</i> | <i>89.04</i> |
| <i>Mean.</i> | <i>1036</i> | <i>155</i> | <i>84.93</i> | <i>147</i> | <i>85.81</i> | <i>152</i> | <i>85.27</i> |
| <i>SD.</i> | <i>78.01</i> | <i>27.31</i> | <i>2.70</i> | <i>28.06</i> | <i>2.67</i> | <i>23.57</i> | <i>2.39</i> |

Remarks : Influent and effluent present as mg/l.
Efficiency present as percent(%).

Table A-8 TKN removal efficiency of SBRs in group 2 (Condition 4, 5 and 6).

| <i>Date</i> | <i>Influent</i> | <i>Condition 4</i> | | <i>Condition 5</i> | | <i>Condition 6</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 1 | 161 | 37.51 | 76.68 | 27.28 | 83.04 | 23.28 | 85.53 |
| 2 | 152 | 51.74 | 66.05 | 28.93 | 81.02 | 31.99 | 79.01 |
| 3 | 62.09 | 18.20 | 70.69 | 1.18 | 98.10 | 9.41 | 84.84 |
| 4 | 65.86 | 8.23 | 87.50 | 8.00 | 87.85 | 11.29 | 82.86 |
| 5 | 62.09 | 7.29 | 88.26 | 7.53 | 87.87 | 9.41 | 84.84 |
| 6 | 68.68 | 8.00 | 88.35 | 7.53 | 89.04 | 8.94 | 86.98 |
| 7 | 60.21 | 4.21 | 93.01 | 4.80 | 92.03 | 7.53 | 87.49 |
| 8 | 60.59 | 7.29 | 87.97 | 7.53 | 87.57 | 7.06 | 88.35 |
| 9 | 67.08 | 8.70 | 87.03 | 4.59 | 93.16 | 4.94 | 92.64 |
| 10 | 64.37 | 0.27 | 99.58 | 1.08 | 98.32 | 8.11 | 87.40 |
| 11 | 66.00 | 0.27 | 99.59 | 0.54 | 99.18 | 7.03 | 89.35 |
| 12 | 10.82 | 0.29 | 97.32 | 5.95 | 45.01 | 5.95 | 45.01 |
| 13 | 64.92 | 1.76 | 97.29 | 6.76 | 89.59 | 4.89 | 92.47 |
| 14 | 66.00 | 12.17 | 81.56 | 9.20 | 86.06 | 9.20 | 86.06 |
| 15 | 69.78 | 12.17 | 82.56 | 20.56 | 70.54 | 13.66 | 80.42 |
| 16 | 70.87 | 17.70 | 75.02 | 20.69 | 70.81 | 22.18 | 68.70 |
| 17 | 65.46 | 6.22 | 90.50 | 6.49 | 90.09 | 6.63 | 89.87 |
| 18 | 63.83 | 6.22 | 90.26 | 5.68 | 91.10 | 5.68 | 91.10 |
| 19 | 99.54 | 7.57 | 92.40 | 6.36 | 93.61 | 8.66 | 91.30 |
| 20 | 103 | 7.03 | 93.16 | 6.22 | 93.95 | 5.14 | 95.00 |
| 21 | 101 | 7.71 | 92.34 | 7.84 | 92.21 | 6.49 | 93.55 |
| 22 | 101 | 8.38 | 91.67 | 8.93 | 91.13 | 12.44 | 87.64 |
| 23 | 103 | 12.85 | 87.50 | 11.09 | 89.21 | 18.93 | 81.58 |
| 24 | 102 | 15.01 | 85.24 | 16.77 | 83.51 | 11.77 | 88.43 |
| 25 | 137 | 32.73 | 76.18 | 34.62 | 74.80 | 30.83 | 77.56 |
| 26 | 135 | 46.66 | 65.50 | 47.06 | 65.20 | 32.46 | 76.00 |
| 27 | 136 | 64.78 | 52.29 | 48.82 | 64.04 | 63.02 | 53.59 |

Table A-8 TKN removal efficiency of SBRs in group 2 (Condition 4, 5 and 6)

(continued).

| <i>Date</i> | <i>Influent</i> | <i>Condition 4</i> | | <i>Condition 5</i> | | <i>Condition 6</i> | |
|--------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 28 | 136 | 68.30 | 49.90 | 47.74 | 64.98 | 65.46 | 51.98 |
| 29 | 159 | 68.57 | 56.89 | 62.08 | 60.97 | 58.69 | 63.10 |
| 30 | 158 | 76.82 | 51.37 | 57.34 | 63.70 | 57.34 | 63.70 |
| 31 | 155 | 59.51 | 61.53 | 44.36 | 71.33 | 18.39 | 88.11 |
| 32 | 156 | 48.15 | 69.09 | 40.57 | 73.96 | 11.90 | 92.36 |
| 33 | 151 | 8.93 | 94.10 | 8.93 | 94.10 | 11.90 | 92.14 |
| 34 | 145 | 8.66 | 94.03 | 7.57 | 94.78 | 8.11 | 94.41 |
| 35 | 151 | 6.49 | 95.72 | 11.90 | 92.14 | 10.28 | 93.21 |
| 36 | 153 | 8.11 | 94.68 | 8.11 | 94.68 | 9.20 | 93.97 |
| 37 | 146 | 6.76 | 95.37 | 6.76 | 95.37 | 11.63 | 92.04 |
| 38 | 138 | 7.98 | 94.24 | 7.57 | 94.53 | 8.38 | 93.95 |
| 39 | 138 | 7.84 | 94.34 | 7.71 | 94.43 | 8.25 | 94.04 |
| <i>Min.</i> | <i>10.82</i> | <i>0.27</i> | <i>49.90</i> | <i>0.54</i> | <i>45.01</i> | <i>4.89</i> | <i>45.01</i> |
| <i>Max.</i> | <i>161</i> | <i>76.82</i> | <i>100</i> | <i>62.08</i> | <i>99.18</i> | <i>65.46</i> | <i>95</i> |
| <i>Mean.</i> | <i>105</i> | <i>20.18</i> | <i>83.25</i> | <i>17.25</i> | <i>84.18</i> | <i>17.09</i> | <i>83.60</i> |
| <i>SD.</i> | <i>41.36</i> | <i>22.47</i> | <i>14.41</i> | <i>17.25</i> | <i>12.92</i> | <i>16.74</i> | <i>12.59</i> |

Remarks Influent and effluent present as mg/l.

Efficiency present as percent(%).

Table A-9 TP removal efficiency of SBRs in group 2 (Condition 4, 5 and 6).

| <i>Date</i> | <i>Influent</i> | <i>Condition 4</i> | | <i>Condition 5</i> | | <i>Condition 6</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 1 | 18.97 | 8.82 | 53.50 | 6.28 | 66.89 | 7.30 | 61.54 |
| 2 | 18.97 | 11.10 | 41.47 | 7.04 | 62.88 | 6.79 | 64.21 |
| 3 | 11.74 | 4.38 | 62.70 | 2.98 | 74.60 | 3.24 | 72.44 |
| 4 | 12.24 | 3.49 | 71.50 | 2.98 | 75.65 | 4.16 | 66.02 |
| 5 | 9.52 | 2.60 | 72.66 | 2.38 | 74.99 | 5.27 | 44.67 |
| 6 | 10.91 | 2.73 | 75.00 | 2.22 | 79.65 | 3.80 | 65.17 |
| 7 | 9.39 | 2.03 | 78.38 | 1.78 | 81.08 | 2.23 | 76.21 |
| 8 | 9.52 | 2.16 | 77.33 | 2.08 | 78.13 | 1.90 | 80.00 |
| 9 | 18.40 | 1.90 | 89.66 | 2.79 | 84.83 | 2.66 | 85.52 |
| 10 | 13.96 | 3.05 | 78.18 | 3.43 | 75.45 | 3.55 | 74.55 |
| 11 | 18.52 | 2.92 | 84.25 | 2.66 | 85.62 | 3.27 | 82.33 |
| 12 | 15.23 | 2.49 | 83.67 | 2.41 | 84.16 | 3.43 | 77.50 |
| 13 | 15.23 | 3.25 | 78.67 | 3.76 | 75.34 | 4.31 | 71.67 |
| 14 | 17.51 | 5.08 | 71.01 | 4.82 | 72.46 | 4.57 | 73.91 |
| 15 | 16.75 | 4.06 | 75.76 | 3.93 | 76.52 | 4.57 | 72.73 |
| 16 | 17.51 | 4.19 | 76.09 | 5.02 | 71.30 | 4.95 | 71.74 |
| 17 | 9.64 | 2.41 | 74.99 | 2.92 | 69.74 | 2.79 | 71.05 |
| 18 | 15.73 | 2.03 | 87.10 | 2.54 | 83.87 | 2.66 | 83.07 |
| 19 | 20.05 | 2.28 | 88.61 | 1.90 | 90.51 | 2.03 | 89.87 |
| 20 | 19.67 | 2.54 | 87.10 | 2.16 | 89.03 | 2.41 | 87.74 |
| 21 | 20.05 | 1.65 | 91.77 | 1.90 | 90.51 | 1.52 | 92.41 |
| 22 | 18.78 | 1.65 | 91.22 | 1.90 | 89.87 | 1.90 | 89.87 |
| 23 | 20.30 | 2.03 | 90.00 | 2.54 | 87.50 | 2.08 | 89.75 |
| 24 | 20.05 | 2.41 | 87.97 | 2.59 | 87.09 | 2.33 | 88.36 |
| 25 | 21.31 | 2.79 | 86.91 | 3.27 | 84.64 | 3.07 | 85.60 |
| 26 | 22.84 | 2.36 | 89.67 | 3.93 | 82.78 | 3.05 | 86.67 |
| 27 | 26.14 | 3.76 | 85.63 | 2.79 | 89.32 | 3.93 | 84.95 |

Table A-9 TP removal efficiency of SBRs in group 2 (Condition 4, 5 and 6)

(continued).

| <i>Date</i> | <i>Influent</i> | <i>Condition 4</i> | | <i>Condition 5</i> | | <i>Condition 6</i> | |
|--------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 30 | 26.64 | 7.11 | 73.33 | 5.96 | 77.62 | 5.84 | 78.10 |
| 28 | 26.64 | 4.44 | 83.34 | 3.10 | 88.38 | 3.43 | 87.14 |
| 29 | 23.09 | 6.09 | 73.63 | 5.20 | 77.47 | 5.33 | 76.92 |
| 31 | 27.91 | 7.61 | 72.73 | 6.09 | 78.18 | 5.71 | 79.55 |
| 32 | 22.84 | 5.71 | 75.00 | 5.08 | 77.78 | 4.44 | 80.56 |
| 33 | 22.58 | 4.82 | 78.65 | 4.87 | 78.43 | 4.06 | 82.02 |
| 34 | 22.33 | 4.82 | 78.41 | 5.20 | 76.70 | 3.55 | 84.09 |
| 35 | 19.79 | 4.82 | 75.64 | 5.46 | 72.44 | 4.31 | 78.20 |
| <i>Min.</i> | <i>9.39</i> | <i>1.65</i> | <i>41.47</i> | <i>1.78</i> | <i>62.88</i> | <i>1.52</i> | <i>44.67</i> |
| <i>Max.</i> | <i>27.91</i> | <i>11.10</i> | <i>91.77</i> | <i>7.04</i> | <i>90.51</i> | <i>7.30</i> | <i>92.41</i> |
| <i>Mean.</i> | <i>18.31</i> | <i>3.87</i> | <i>78.33</i> | <i>3.60</i> | <i>79.75</i> | <i>3.73</i> | <i>78.17</i> |
| <i>SD.</i> | <i>5.17</i> | <i>2.17</i> | <i>10.56</i> | <i>1.49</i> | <i>7.08</i> | <i>1.41</i> | <i>9.94</i> |

Remarks Influent and effluent present as mg/l.

Efficiency present as percent(%).

Table A-10 Color removal efficiency of SBRs in group 2 (Condition 4, 5 and 6).

| <i>Date</i> | <i>Influent</i> | <i>Condition 4</i> | | <i>Condition 5</i> | | <i>Condition 6</i> | |
|--------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 4 | 331 | 257 | 22.36 | 256 | 22.53 | 257 | 22.22 |
| 5 | 308 | 270 | 12.11 | 229 | 25.51 | 228 | 25.88 |
| 10 | 416 | 280 | 32.69 | 279 | 32.98 | 283 | 32.09 |
| 11 | 363 | 255 | 29.83 | 260 | 28.44 | 268 | 26.14 |
| 12 | 354 | 261 | 26.25 | 259 | 26.90 | 262 | 25.95 |
| 13 | 329 | 252 | 23.39 | 254 | 22.80 | 257 | 21.94 |
| 17 | 328 | 243 | 25.86 | 243 | 25.84 | 243 | 25.86 |
| 18 | 317 | 239 | 24.43 | 244 | 23.04 | 246 | 22.23 |
| 19 | 414 | 231 | 44.09 | 224 | 45.86 | 224 | 45.81 |
| 20 | 394 | 223 | 43.42 | 222 | 43.77 | 222 | 43.66 |
| 24 | 455 | 222 | 51.14 | 225 | 50.55 | 220 | 51.59 |
| 25 | 483 | 255 | 47.14 | 260 | 46.16 | 257 | 46.71 |
| 26 | 440 | 272 | 38.12 | 273 | 37.97 | 265 | 39.87 |
| 32 | 481 | 325 | 32.42 | 320 | 33.49 | 308 | 36.04 |
| 33 | 509 | 327 | 35.74 | 322 | 36.89 | 317 | 37.76 |
| 34 | 489 | 316 | 35.34 | 321 | 34.38 | 307 | 37.14 |
| <i>Min.</i> | 308 | 222 | 12.11 | 222 | 22.53 | 220 | 21.94 |
| <i>Max.</i> | 509 | 327 | 51.14 | 322 | 50.55 | 317 | 51.59 |
| <i>Mean.</i> | 401 | 264 | 32.77 | 262 | 33.57 | 260 | 33.81 |
| <i>SD.</i> | 69.46 | 33.37 | 10.40 | 33.74 | 9.23 | 30.75 | 9.83 |

Remarks Influent and effluent present as ADMI.

Efficiency present as percent(%).

Table A-11 Mixed Liquor Suspended Solids(MLSS)in experimental group 2
(Condition 4, 5 and 6) (mg/l).

| Date | Condition 4 | Condition 5 | Condition 6 |
|--------------|-------------|-------------|-------------|
| 3 | 6260 | 6240 | 6080 |
| 5 | 6360 | 6180 | 5980 |
| 7 | 6260 | 6260 | 6080 |
| 9 | 6460 | 6340 | 6140 |
| 11 | 6320 | 6300 | 6140 |
| 13 | 6160 | 6120 | 5860 |
| 15 | 6140 | 6140 | 5880 |
| 17 | 6080 | 6080 | 5800 |
| 19 | 6280 | 6100 | 5760 |
| 21 | 6260 | 6020 | 5660 |
| 23 | 6300 | 6220 | 5680 |
| 25 | 6160 | 6040 | 5720 |
| 27 | 6020 | 6000 | 5980 |
| 29 | 6160 | 6100 | 5920 |
| 31 | 5940 | 5980 | 5780 |
| 33 | 5940 | 5660 | 5760 |
| 35 | 5820 | 5700 | 5740 |
| 37 | 5700 | 5720 | 5580 |
| 39 | 5470 | 5490 | 5370 |
| <i>Min.</i> | <i>5470</i> | <i>5490</i> | <i>5370</i> |
| <i>Max.</i> | <i>6460</i> | <i>6340</i> | <i>6140</i> |
| <i>Mean.</i> | <i>6110</i> | <i>6036</i> | <i>5837</i> |
| <i>SD.</i> | <i>247</i> | <i>235</i> | <i>202</i> |

Table A-12 pH value in experimental group 2(condition 4, 5 and 6)

| <i>Date</i> | <i>Influent</i> | <i>Effluent</i> | | |
|-------------|-----------------|--------------------|--------------------|--------------------|
| | | <i>Condition 4</i> | <i>Condition 5</i> | <i>Condition 6</i> |
| 1 | 7.2 | 7.7 | 7.6 | 7.7 |
| 2 | 7.2 | 7.7 | 7.6 | 7.7 |
| 3 | 7.2 | 7.8 | 7.8 | 7.8 |
| 4 | 7.0 | 8.0 | 8.0 | 8.0 |
| 5 | 7.1 | 8.0 | 8.0 | 8.0 |
| 6 | 7.2 | 7.8 | 7.8 | 7.8 |
| 7 | 7.1 | 7.9 | 7.9 | 7.9 |
| 8 | 7.1 | 7.8 | 7.8 | 7.8 |
| 9 | 7.1 | 8.0 | 8.0 | 8.0 |
| 10 | 7.1 | 7.8 | 7.9 | 8.0 |
| 11 | 7.2 | 8.0 | 8.0 | 8.0 |
| 12 | 7.2 | 7.8 | 7.8 | 8.0 |
| 13 | 7.2 | 7.8 | 7.8 | 7.9 |
| 14 | 7.2 | 7.7 | 7.8 | 7.7 |
| 15 | 7.2 | 7.8 | 7.8 | 7.8 |
| 16 | 7.1 | 7.7 | 7.8 | 7.8 |
| 17 | 7.0 | 7.8 | 7.7 | 7.7 |
| 18 | 7.2 | 7.8 | 7.9 | 7.9 |
| 19 | 7.1 | 7.8 | 7.8 | 7.8 |
| 20 | 7.1 | 7.6 | 7.6 | 7.8 |
| 21 | 7.1 | 7.6 | 7.7 | 7.7 |
| 22 | 7.2 | 7.6 | 7.6 | 7.6 |
| 23 | 7.2 | 7.6 | 7.7 | 7.6 |
| 24 | 7.2 | 7.6 | 7.6 | 7.6 |
| 25 | 7.2 | – | – | – |
| 26 | 7.2 | 7.8 | 7.8 | 7.8 |
| 27 | 7.2 | 7.8 | 7.9 | 7.9 |

Table A-12 pH value in experimental group 2(condition 4, 5 and 6)

(continued).

| <i>Date</i> | <i>Influent</i> | <i>Effluent</i> | | |
|--------------|-----------------|--------------------|--------------------|--------------------|
| | | <i>Condition 4</i> | <i>Condition 5</i> | <i>Condition 6</i> |
| 28 | 7.2 | 7.9 | 7.8 | 7.9 |
| 29 | 7.2 | 8.0 | 7.9 | 7.9 |
| 30 | 7.1 | 8.0 | 7.8 | 7.9 |
| 31 | 7.2 | 7.8 | 7.7 | 7.6 |
| 32 | 7.2 | 7.8 | 7.7 | 7.8 |
| 33 | 7.2 | 7.7 | 7.8 | 7.9 |
| 34 | 7.2 | 7.8 | 8.0 | 8.0 |
| 35 | 7.2 | 7.6 | 7.8 | 7.7 |
| 36 | 7.2 | 7.8 | 7.9 | 7.7 |
| 37 | 7.2 | 7.8 | 7.8 | 7.6 |
| 38 | 7.2 | 7.8 | 7.8 | 7.4 |
| <i>Min.</i> | 7.0 | 7.6 | 7.6 | 7.4 |
| <i>Max.</i> | 7.2 | 8.0 | 8.0 | 8.0 |
| <i>Mean.</i> | 7.2 | 7.8 | 7.8 | 7.8 |
| <i>SD.</i> | 0.1 | 0.1 | 0.1 | 0.1 |

Table A-13 COD removal efficiency of SBRs in group 3 (Condition 7, 8 and 9)

| <i>Date</i> | <i>Influent</i> | <i>Condition 7</i> | | <i>Condition 8</i> | | <i>Condition 9</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 1 | 1164 | 204 | 82.50 | 175 | 85.00 | 189 | 83.75 |
| 2 | 1200 | 189 | 84.24 | 182 | 84.85 | 233 | 80.61 |
| 3 | 1109 | 218 | 80.33 | 167 | 84.92 | 233 | 79.02 |
| 4 | 1109 | 228 | 79.46 | 187 | 83.13 | 244 | 77.99 |
| 5 | 976 | 228 | 76.67 | 187 | 80.83 | 228 | 76.67 |
| 6 | 956 | 195 | 79.57 | 195 | 79.57 | 228 | 76.17 |
| 7 | 1058 | 203 | 80.77 | 195 | 81.54 | 244 | 76.92 |
| 8 | 976 | 212 | 78.33 | 187 | 80.83 | 220 | 77.50 |
| 9 | 773 | 192 | 75.16 | 184 | 76.19 | 192 | 75.16 |
| 10 | 1280 | 264 | 79.38 | 224 | 82.50 | 256 | 80.00 |
| 11 | 1200 | 256 | 78.67 | 256 | 78.67 | 272 | 77.33 |
| 12 | 1220 | 272 | 77.70 | 256 | 79.02 | 296 | 75.74 |
| 13 | 1100 | 240 | 78.18 | 240 | 78.18 | 272 | 75.27 |
| 14 | 1040 | 229 | 78.02 | 213 | 79.49 | 259 | 75.09 |
| 15 | 1105 | 267 | 75.86 | 259 | 76.55 | 305 | 72.41 |
| 16 | 1105 | 267 | 75.86 | 290 | 73.79 | 305 | 72.41 |
| 17 | 1105 | 259 | 76.55 | 282 | 74.48 | 320 | 71.03 |
| 18 | 1067 | 206 | 80.71 | 267 | 75.00 | 290 | 72.86 |
| 19 | 1067 | 175 | 83.57 | 221 | 79.29 | 251 | 76.43 |
| 20 | 1124 | 160 | 85.76 | 236 | 78.98 | 251 | 77.63 |
| 21 | 1124 | 130 | 88.47 | 267 | 76.27 | 259 | 76.95 |
| 22 | 1086 | 145 | 86.67 | 206 | 81.05 | 190 | 82.46 |
| 23 | 1048 | 120 | 88.55 | 135 | 87.11 | 150 | 85.68 |
| 24 | 900 | 120 | 86.67 | 150 | 83.33 | 135 | 85.00 |
| 25 | 844 | 135 | 84.00 | 135 | 84.00 | 143 | 83.11 |
| 26 | 825 | 135 | 83.64 | 150 | 81.82 | 150 | 81.82 |
| 27 | 825 | 148 | 82.10 | 170 | 79.41 | 148 | 82.10 |

Table A-13 COD removal efficiency of SBRs in group 3 (Condition 7, 8 and 9)
(continued).

| <i>Date</i> | <i>Influent</i> | <i>Condition 7</i> | | <i>Condition 8</i> | | <i>Condition 9</i> | |
|--------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 28 | 1108 | 118 | 89.33 | 148 | 86.67 | 148 | 86.67 |
| 29 | 1163 | 118 | 89.84 | 162 | 86.03 | 133 | 88.57 |
| 30 | 1218 | 103 | 91.52 | 177 | 85.45 | 118 | 90.30 |
| 31 | 1145 | 103 | 90.97 | 133 | 88.39 | 103 | 90.97 |
| 32 | 978 | 89 | 90.94 | 103 | 89.43 | 103 | 89.43 |
| 33 | 1071 | 96 | 91.03 | 103 | 90.35 | 89 | 91.72 |
| 34 | 1089 | 97 | 91.11 | 98 | 91.00 | 113 | 89.63 |
| 35 | 1210 | 113 | 90.67 | 113 | 90.67 | 145 | 88.00 |
| <i>Min.</i> | <i>773</i> | <i>89</i> | <i>75.16</i> | <i>98.00</i> | <i>73.79</i> | <i>88.62</i> | <i>71.03</i> |
| <i>Max.</i> | <i>1280</i> | <i>272</i> | <i>91.52</i> | <i>290</i> | <i>91.00</i> | <i>320</i> | <i>91.72</i> |
| <i>Mean.</i> | <i>1068</i> | <i>178</i> | <i>83.22</i> | <i>190</i> | <i>82.11</i> | <i>206</i> | <i>80.64</i> |
| <i>SD.</i> | <i>122</i> | <i>59</i> | <i>5.39</i> | <i>53.44</i> | <i>4.77</i> | <i>67.98</i> | <i>6.00</i> |

Remarks : Effluent present as mg/l

Efficiency present as percent(%).

Table A-14 TKN removal efficiency of SBRs in group 3 (Condition 7, 8 and 9).

| <i>Date</i> | <i>Influent</i> | <i>Condition 7</i> | | <i>Condition 8</i> | | <i>Condition 9</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 1 | 76.75 | 16.29 | 78.78 | 15.93 | 79.24 | 16.83 | 78.07 |
| 2 | 76.75 | 17.74 | 76.89 | 11.59 | 84.90 | 16.83 | 78.07 |
| 3 | 81.82 | 15.02 | 81.64 | 14.66 | 82.08 | 15.57 | 80.97 |
| 4 | 79.65 | 13.76 | 82.72 | 14.12 | 82.27 | 14.66 | 81.59 |
| 5 | 91.23 | 14.48 | 84.13 | 11.04 | 87.90 | 14.84 | 83.73 |
| 6 | 89.79 | 12.13 | 86.49 | 11.59 | 87.09 | 15.93 | 82.26 |
| 7 | 95.58 | 13.03 | 86.37 | 14.12 | 85.23 | 11.22 | 88.26 |
| 8 | 89.79 | 11.22 | 87.50 | 10.14 | 88.71 | 15.57 | 82.66 |
| 9 | 85.44 | 13.76 | 83.90 | 13.94 | 83.68 | 14.30 | 83.26 |
| 10 | 62.27 | 13.58 | 78.19 | 11.95 | 80.81 | 12.67 | 79.65 |
| 11 | 59.37 | 11.22 | 81.10 | 11.95 | 79.87 | 10.86 | 81.71 |
| 12 | 61.55 | 11.04 | 82.06 | 10.50 | 82.94 | 13.03 | 78.83 |
| 13 | 58.65 | 11.04 | 81.18 | 11.04 | 81.18 | 12.13 | 79.32 |
| 14 | 49.24 | 11.22 | 77.21 | 9.78 | 80.14 | 11.22 | 77.21 |
| 15 | 66.62 | 10.14 | 84.78 | 12.31 | 81.52 | 13.03 | 80.44 |
| 16 | 66.62 | 9.05 | 86.42 | 8.33 | 87.50 | 10.14 | 84.78 |
| 17 | 68.79 | 8.69 | 87.37 | 8.33 | 87.89 | 10.86 | 84.21 |
| 18 | 67.34 | 9.05 | 86.56 | 6.52 | 90.32 | 9.78 | 85.48 |
| 19 | 69.51 | 8.33 | 88.02 | 7.96 | 88.55 | 9.05 | 86.98 |
| 20 | 76.75 | 7.96 | 89.63 | 7.78 | 89.86 | 10.14 | 86.79 |
| 21 | 67.34 | 6.70 | 90.05 | 7.42 | 88.98 | 8.33 | 87.63 |
| 22 | 72.41 | 7.96 | 89.01 | 9.78 | 86.49 | 8.69 | 88.00 |
| 23 | 72.41 | 8.69 | 88.00 | 9.05 | 87.50 | 9.23 | 87.25 |
| 24 | 68.79 | 8.69 | 87.37 | 9.78 | 85.78 | 6.15 | 91.06 |
| 25 | 68.06 | 7.96 | 88.30 | 8.69 | 87.23 | 8.69 | 87.23 |
| 26 | 56.48 | 8.51 | 84.93 | 8.51 | 84.93 | 8.69 | 84.61 |
| 27 | 56.48 | 6.15 | 89.11 | 10.50 | 81.41 | 8.33 | 85.25 |

Table A-14 TKN removal efficiency of SBRs in group 3 (Condition 7, 8 and 9)
(continued).

| <i>Date</i> | <i>Influent</i> | <i>Condition 7</i> | | <i>Condition 8</i> | | <i>Condition 9</i> | |
|--------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 28 | 43.44 | 7.96 | 81.68 | 8.33 | 80.82 | 7.96 | 81.68 |
| 29 | 43.44 | 7.42 | 82.92 | 7.78 | 82.09 | 7.60 | 82.50 |
| 30 | 43.44 | 7.42 | 82.92 | 7.96 | 81.68 | 7.60 | 82.50 |
| 31 | 43.44 | 6.88 | 84.16 | 7.60 | 82.50 | 7.60 | 82.50 |
| 32 | 42.72 | 7.60 | 82.21 | 7.42 | 82.63 | 7.60 | 82.21 |
| 33 | 44.89 | 7.96 | 82.27 | 7.80 | 82.62 | 7.78 | 82.67 |
| 34 | 44.89 | 7.96 | 82.27 | 7.96 | 82.27 | 8.69 | 80.64 |
| <i>Min.</i> | 42.72 | 6.15 | 76.89 | 6.52 | 79.24 | 6.15 | 77.21 |
| <i>Max.</i> | 95.58 | 17.74 | 90.05 | 15.93 | 90.32 | 16.83 | 91.06 |
| <i>Mean.</i> | 65.93 | 10.19 | 84.30 | 10.06 | 84.37 | 10.93 | 83.24 |
| <i>SD.</i> | 15.56 | 3.00 | 3.61 | 2.45 | 3.24 | 3.12 | 3.35 |

Remarks : Effluent present as mg/l

Efficiency present as percent(%).

Table A-15 TP removal efficiency of SBRs in group 3 (Condition 7, 8 and 9).

| <i>Date</i> | <i>Influent</i> | <i>Condition 7</i> | | <i>Condition 8</i> | | <i>Condition 9</i> | |
|-------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 1 | 20.05 | 3.30 | 83.54 | 2.28 | 88.61 | 3.55 | 82.28 |
| 2 | 18.27 | 2.66 | 85.42 | 3.30 | 81.94 | 3.05 | 83.33 |
| 3 | 20.30 | 4.44 | 78.13 | 2.41 | 88.12 | 3.38 | 83.37 |
| 4 | 18.02 | 3.17 | 82.39 | 2.66 | 85.21 | 3.81 | 78.87 |
| 5 | 18.52 | 3.81 | 79.45 | 2.51 | 86.44 | 3.55 | 80.82 |
| 6 | 20.55 | 3.05 | 85.18 | 3.93 | 80.86 | 3.43 | 83.33 |
| 7 | 19.28 | 3.81 | 80.26 | 3.81 | 80.26 | 3.81 | 80.26 |
| 8 | 21.06 | 2.54 | 87.95 | 1.90 | 90.96 | 2.03 | 90.36 |
| 9 | 15.48 | 1.85 | 88.03 | 2.03 | 86.88 | 1.65 | 89.35 |
| 10 | 27.91 | 3.76 | 86.55 | 3.30 | 88.18 | 6.34 | 77.27 |
| 11 | 24.61 | 5.20 | 78.86 | 5.84 | 76.29 | 8.37 | 65.98 |
| 12 | 19.79 | 5.58 | 71.80 | 6.09 | 69.23 | 7.90 | 60.08 |
| 13 | 21.57 | 7.74 | 64.12 | 5.02 | 76.71 | 6.47 | 70.00 |
| 14 | 17.76 | 7.10 | 60.03 | 5.08 | 71.43 | 6.22 | 65.00 |
| 15 | 23.55 | 6.09 | 74.14 | 3.81 | 83.84 | 5.84 | 75.22 |
| 16 | 22.89 | 7.23 | 68.41 | 5.08 | 77.83 | 5.84 | 74.51 |
| 17 | 23.09 | 7.36 | 68.13 | 4.31 | 81.32 | 7.61 | 67.03 |
| 18 | 22.84 | 5.08 | 77.78 | 3.81 | 83.33 | 6.72 | 70.56 |
| 19 | 22.84 | 5.33 | 76.67 | 4.19 | 81.67 | 5.71 | 75.00 |
| 20 | 24.87 | 4.11 | 83.47 | 3.05 | 87.75 | 3.68 | 85.21 |
| 21 | 21.31 | 4.57 | 78.57 | 3.93 | 81.55 | 5.20 | 75.59 |
| 22 | 22.84 | 4.31 | 81.11 | 4.82 | 78.89 | 4.57 | 80.00 |
| 23 | 16.49 | 3.55 | 78.46 | 4.69 | 71.54 | 4.82 | 70.77 |
| 24 | 19.28 | 4.31 | 77.63 | 4.57 | 76.32 | 3.93 | 79.60 |
| 25 | 17.26 | 4.06 | 76.47 | 4.44 | 74.27 | 3.30 | 80.88 |
| 26 | 22.33 | 4.95 | 77.84 | 4.06 | 81.82 | 3.30 | 85.23 |
| 27 | 19.28 | 7.74 | 59.87 | 4.57 | 76.32 | 2.99 | 84.47 |

Table A-15 TP removal efficiency of SBRs in group 3(Condition 7, 8 and 9)
(continued).

| <i>Date</i> | <i>Influent</i> | <i>Condition 7</i> | | <i>Condition 8</i> | | <i>Condition 9</i> | |
|--------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 28 | 9.90 | 3.76 | 61.99 | 3.86 | 61.00 | 3.86 | 61.00 |
| 29 | 12.13 | 5.09 | 58.00 | 4.62 | 61.93 | 4.95 | 59.21 |
| 30 | 11.67 | 4.87 | 58.26 | 4.69 | 59.78 | 4.57 | 60.87 |
| 31 | 10.66 | 4.87 | 54.28 | 4.69 | 55.95 | 4.69 | 56.00 |
| 32 | 11.17 | 4.95 | 55.68 | 4.69 | 57.96 | 4.57 | 59.10 |
| 33 | 10.66 | 4.87 | 54.28 | 4.57 | 57.15 | 4.57 | 57.15 |
| 34 | 10.91 | 4.91 | 55.00 | 4.69 | 57.00 | 4.58 | 58.00 |
| <i>Min.</i> | <i>9.90</i> | <i>1.85</i> | <i>54.28</i> | <i>1.90</i> | <i>55.95</i> | <i>1.65</i> | <i>56.00</i> |
| <i>Max.</i> | <i>27.91</i> | <i>7.74</i> | <i>88.03</i> | <i>6.09</i> | <i>90.96</i> | <i>8.37</i> | <i>90.36</i> |
| <i>Mean.</i> | <i>18.80</i> | <i>4.71</i> | <i>73.17</i> | <i>4.04</i> | <i>76.42</i> | <i>4.67</i> | <i>73.70</i> |
| <i>SD.</i> | <i>4.76</i> | <i>1.47</i> | <i>10.97</i> | <i>1.04</i> | <i>10.55</i> | <i>1.60</i> | <i>10.31</i> |

Remarks : Effluent present as mg/l

Efficiency present as percent(%).

Table A-16 Color removal efficiency of SBRs in group 3 (Condition 7, 8 and 9).

| <i>Date</i> | <i>Influent</i> | <i>Condition 7</i> | | <i>Condition 8</i> | | <i>Condition 9</i> | |
|--------------|-----------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|
| | | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> | <i>Effluent</i> | <i>Efficiency</i> |
| 3 | 568 | 232 | 59.20 | 223 | 60.76 | 237 | 58.36 |
| 4 | 494 | 235 | 52.32 | 231 | 53.15 | 234 | 52.59 |
| 5 | 516 | 256 | 50.40 | 255 | 50.65 | 262 | 49.29 |
| 6 | 528 | 263 | 50.13 | 264 | 49.99 | 273 | 48.41 |
| 10 | 598 | 306 | 48.77 | 308 | 48.44 | 315 | 47.40 |
| 11 | 603 | 345 | 42.81 | 328 | 45.58 | 338 | 44.03 |
| 12 | 601 | 356 | 40.77 | 350 | 41.85 | 359 | 40.37 |
| 13 | 592 | 376 | 36.49 | 359 | 39.33 | 365 | 38.35 |
| 17 | 613 | 393 | 35.88 | 380 | 37.97 | 395 | 35.52 |
| 18 | 580 | 376 | 35.08 | 369 | 36.32 | 376 | 35.17 |
| 19 | 551 | 366 | 33.57 | 359 | 34.79 | 361 | 34.57 |
| 20 | 591 | 310 | 47.48 | 310 | 47.49 | 296 | 49.85 |
| 21 | 479 | 297 | 37.88 | 305 | 36.23 | 298 | 37.78 |
| 24 | 451 | 298 | 34.00 | 306 | 32.18 | 304 | 32.69 |
| 25 | 472 | 296 | 37.20 | 304 | 35.64 | 299 | 36.64 |
| 26 | 532 | 313 | 41.05 | 320 | 39.80 | 314 | 40.95 |
| 27 | 553 | 325 | 41.30 | 332 | 40.01 | 326 | 41.07 |
| 32 | 613 | 404 | 34.07 | 405 | 34.02 | 395 | 35.53 |
| 33 | 1,128 | 472 | 58.15 | 469 | 58.39 | 444 | 60.65 |
| 34 | 1,050 | 471 | 55.11 | 468 | 55.48 | 439 | 58.24 |
| <i>Min.</i> | 451 | 232 | 33.57 | 223 | 32.18 | 234 | 32.69 |
| <i>Max.</i> | 1,128 | 472 | 59.20 | 469 | 60.76 | 444 | 60.65 |
| <i>Mean.</i> | 606 | 335 | 43.58 | 332 | 43.90 | 331 | 43.87 |
| <i>SD.</i> | 173 | 68 | 8.44 | 67 | 8.67 | 60 | 8.73 |

Remarks : Effluent present as ADMI.

Efficiency present as percent(%).

Table A-17 Mixed Liquor Suspended Solids(MLSS) in experimental group 3
(Condition 7, 8 and 9)(mg/l).

| <i>Date</i> | <i>Condition 7</i> | <i>Condition 8</i> | <i>Condition 9</i> |
|--------------|--------------------|--------------------|--------------------|
| 1 | 6380 | 6400 | 6170 |
| 3 | 6480 | 6430 | 6190 |
| 5 | 6160 | 6210 | 6130 |
| 7 | 6240 | 6390 | 6160 |
| 9 | 6310 | 6420 | 6130 |
| 11 | 6390 | 6440 | 6250 |
| 13 | 6310 | 6500 | 6180 |
| 15 | 6370 | 6440 | 6130 |
| 17 | 6370 | 6420 | 6090 |
| 19 | 6500 | 6530 | 6270 |
| 21 | 6350 | 6310 | 6050 |
| 23 | 6460 | 6450 | 6180 |
| 25 | 6240 | 6260 | 6080 |
| 27 | 6070 | 6160 | 5970 |
| 29 | 6180 | 6180 | 5900 |
| 31 | 6300 | 6310 | 6010 |
| 33 | 6200 | 6210 | 6000 |
| 35 | 6320 | 6450 | 6230 |
| 37 | 6250 | 6410 | 6010 |
| 39 | 6320 | 6390 | 6100 |
| <i>Min.</i> | 6070 | 6160 | 5900 |
| <i>Max.</i> | 6500 | 6530 | 6270 |
| <i>Mean.</i> | 6310 | 6366 | 6112 |
| <i>SD.</i> | 110 | 109 | 98 |

Table A-18 pH value in experimental group 3 (condition 7, 8 and 9).

| Date | Influent | Effluent | | |
|------|----------|-------------|-------------|-------------|
| | | Condition 7 | Condition 8 | Condition 9 |
| 1 | 7.2 | 8.1 | 8.2 | 8.1 |
| 2 | 7.2 | 7.8 | 7.8 | 7.8 |
| 3 | 7.1 | 7.8 | 7.8 | 7.8 |
| 4 | 7.2 | 7.8 | 7.8 | 7.8 |
| 5 | 7.2 | 8.0 | 8.0 | 7.9 |
| 6 | 7.2 | 7.9 | 8.0 | 8.0 |
| 7 | 7.2 | 7.7 | 7.8 | 7.8 |
| 8 | 7.2 | 7.8 | 7.8 | 7.8 |
| 9 | 7.2 | 8.0 | 8.1 | 8.1 |
| 10 | 7.2 | 7.8 | 7.8 | 7.9 |
| 11 | 7.2 | 7.8 | 7.8 | 7.9 |
| 12 | 7.1 | 7.8 | 7.9 | 8.0 |
| 13 | 7.2 | 8.0 | 8.0 | 8.0 |
| 14 | 7.1 | 7.8 | 7.8 | 7.9 |
| 15 | 7.1 | 7.8 | 7.8 | 7.8 |
| 16 | 7.0 | 7.8 | 7.8 | 7.8 |
| 17 | 7.2 | 7.8 | 7.8 | 7.8 |
| 18 | 7.1 | 7.9 | 7.9 | 7.9 |
| 19 | 7.2 | 7.8 | 7.9 | 7.9 |
| 20 | 7.2 | 7.8 | 7.8 | 7.8 |
| 21 | 7.2 | 7.8 | 7.8 | 7.8 |
| 22 | 7.1 | 8.2 | 8.1 | 8.0 |
| 23 | 7.1 | 8.6 | 8.4 | 8.3 |
| 24 | 7.1 | 8.3 | 8.2 | 8.2 |
| 25 | 7.1 | 8.2 | 8.1 | 8.1 |
| 26 | 7.2 | - | - | - |
| 27 | 7.2 | 8.0 | 8.0 | 8.1 |

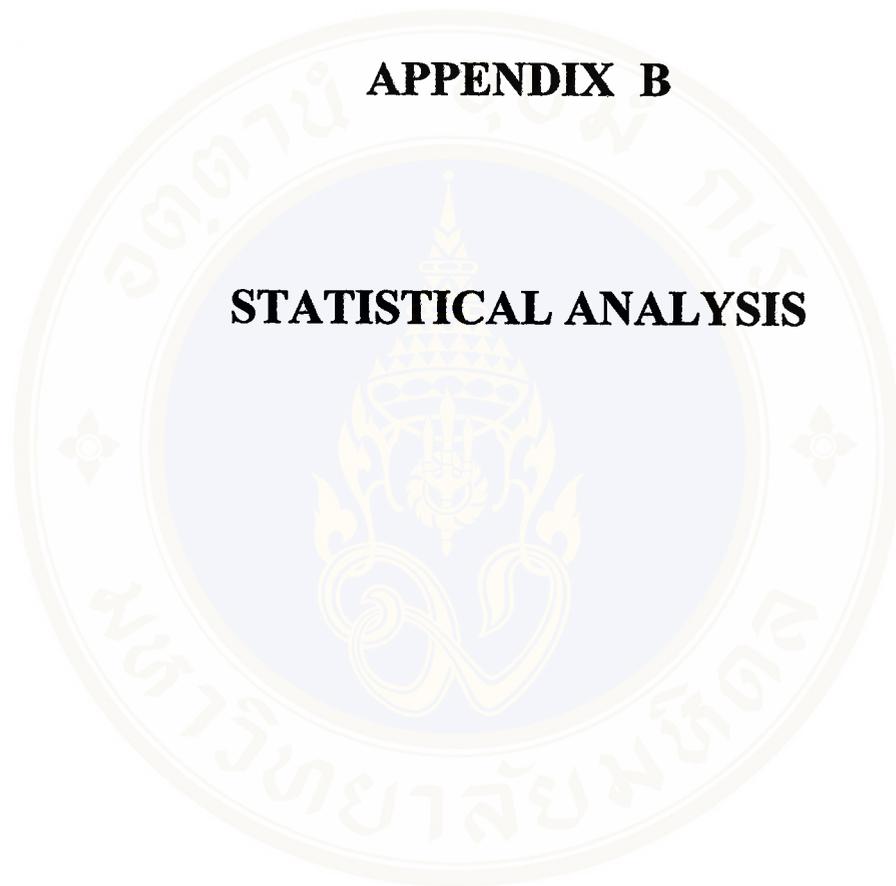
Table A-18 pH value in experimental group 3 (condition 7, 8 and 9)

(continued)

| Date | Influent | Effluent | | |
|--------------|----------|-------------|-------------|-------------|
| | | Condition 7 | Condition 8 | Condition 9 |
| 30 | 7.1 | 7.9 | 7.9 | 7.9 |
| 28 | 7.2 | 8.1 | 8.0 | 8.0 |
| 29 | 7.0 | 8.0 | 7.9 | 7.9 |
| 31 | 7.1 | 8.0 | 8.0 | 8.0 |
| 32 | 7.0 | 8.0 | 8.0 | 8.0 |
| 33 | 7.1 | 7.8 | 7.8 | 7.8 |
| 34 | 7.2 | 8.1 | 8.0 | 7.9 |
| 35 | 7.2 | 8.1 | 7.8 | 7.8 |
| 36 | 7.1 | 8.4 | 7.9 | 7.9 |
| 37 | 7.1 | – | – | – |
| 38 | 7.2 | 8.0 | 8.0 | 8.0 |
| 39 | 7.2 | 8.0 | 8.0 | 8.1 |
| <i>Min.</i> | 7.0 | 7.7 | 7.8 | 7.8 |
| <i>Max.</i> | 7.2 | 8.6 | 8.4 | 8.3 |
| <i>Mean.</i> | 7.1 | 8.0 | 7.9 | 7.9 |
| <i>SD.</i> | 0.06 | 0.20 | 0.15 | 0.13 |

APPENDIX B

STATISTICAL ANALYSIS



Two Way Analysis of Variance

Dependent Variable: %CODrem

| Source of Variation | DF | SS | MS | F | P |
|---------------------|----|------------|------------|------------|--------|
| SRT | 2 | 9.138E+002 | 4.569E+002 | 1.695E+002 | <0.001 |
| Anoxic time | 2 | 3.524E-001 | 1.762E-001 | 6.535E-002 | 0.937 |
| SRT x Anoxic time | 4 | 2.723E+001 | 6.808E+000 | 2.525E+000 | 0.049 |
| Residual | 63 | 1.698E+002 | 2.696E+000 | | |
| Total | 71 | 1.111E+003 | 1.565E+001 | | |

Least square means for SRT

| Group | Mean | SEM |
|------------|------------|------------|
| 4.000E+001 | 8.112E+001 | 3.352E-001 |
| 6.000E+001 | 8.331E+001 | 3.352E-001 |
| 8.000E+001 | 8.953E+001 | 3.352E-001 |

Least square means for Anoxic time

| Group | Mean | SEM |
|------------|------------|------------|
| 2.000E+000 | 8.471E+001 | 3.352E-001 |
| 4.000E+000 | 8.455E+001 | 3.352E-001 |
| 6.000E+000 | 8.470E+001 | 3.352E-001 |

Least square means for SRT x Anoxic time

| Group | Mean | SEM |
|----------------|------------|------------|
| 40.000 x 2.000 | 8.067E+001 | 5.805E-001 |
| 40.000 x 4.000 | 8.120E+001 | 5.805E-001 |
| 40.000 x 6.000 | 8.148E+001 | 5.805E-001 |
| 60.000 x 2.000 | 8.277E+001 | 5.805E-001 |
| 60.000 x 4.000 | 8.396E+001 | 5.805E-001 |
| 60.000 x 6.000 | 8.320E+001 | 5.805E-001 |
| 80.000 x 2.000 | 9.068E+001 | 5.805E-001 |
| 80.000 x 4.000 | 8.850E+001 | 5.805E-001 |
| 80.000 x 6.000 | 8.941E+001 | 5.805E-001 |

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor: SRT

| Comparison | Diff of Means | p | q | P<0.05 |
|-------------------|---------------|---|------------|--------|
| 80.000 vs. 40.000 | 8.411E+000 | 3 | 2.510E+001 | Yes |
| 80.000 vs. 60.000 | 6.219E+000 | 3 | 1.856E+001 | Yes |
| 60.000 vs. 40.000 | 2.192E+000 | 3 | 6.539E+000 | Yes |

Comparisons for factor: Anoxic time

| Comparison | Diff of Means | p | q | P<0.05 |
|-----------------|---------------|---|------------|--------|
| 2.000 vs. 4.000 | 1.533E-001 | 3 | 4.575E-001 | No |
| 2.000 vs. 6.000 | 1.042E-002 | 3 | 3.108E-002 | No |
| 6.000 vs. 4.000 | 1.429E-001 | 3 | 4.264E-001 | No |

Forward Stepwise Regression: Dependent Variable:%CODrem
 F-to-Enter: 4.000 P = 0.049 F-to-Remove: 3.900 P = 0.052

Step 0:

Standard Error of Estimate = 3.956

Analysis of Variance:

| Group | DF | SS | MS | F | P |
|----------|----|----------|--------|---|---|
| Residual | 71 | 1111.212 | 15.651 | | |

Variables in Model

| Group | Coef. | Std. Coeff. | Std. Error | F-to-Remove | P |
|----------|--------|-------------|------------|-------------|---|
| Constant | 84.652 | | 0.466 | | |

Variables not in Model

| Group | F-to-Enter | P |
|-------------|------------|--------|
| SRT | 226.542 | <0.001 |
| Anoxic time | 0.000082 | 0.993 |

Step 1: SRT Entered

R = 0.874 Rsqr = 0.764 Adj Rsqr = 0.761

Standard Error of Estimate = 1.936

Analysis of Variance:

| Group | DF | SS | MS | F | P |
|------------|----|---------|---------|---------|--------|
| Regression | 1 | 848.905 | 848.905 | 226.542 | <0.001 |
| Residual | 70 | 262.306 | 3.747 | | |

Variables in Model

| Group | Coef. | Std. Coeff. | Std. Error | F-to-Remove | P |
|----------|--------|-------------|------------|-------------|--------|
| Constant | 72.036 | | 0.869 | | |
| SRT | 0.210 | 0.874 | 0.014 | 226.542 | <0.001 |

Variables not in Model

| Group | F-to-Enter | P |
|-------------|------------|-------|
| Anoxic time | 0.00034 | 0.985 |

Summary Table

| Step # | Vars. Entered | Vars. Removed | R | RSqr | Delta RSqr | Vars in Model |
|--------|---------------|---------------|-------|-------|------------|---------------|
| 1 | SRT | | 0.874 | 0.764 | 0.764 | 1 |

The dependent variable %CODrem can be predicted from a linear combination of the independent variables:

P
 SRT <0.001

The following variables did not significantly add to the ability of the equation to predict %CODrem and were not included in the final equation: Anoxic time

Polynomial Regression, Order Only:

$$\%CODrem = 8.882E+001 - (3.939E-001 * SRT) + (5.034E-003 * SRT^2)$$

N = 7.200E+001

R = 9.068E-001 Rsqr = 8.223E-001 Adj Rsqr = 8.172E-001

Analysis of Variance:

| | DF | SS | MS | F | P |
|------------|----|------------|------------|------------|--------|
| Regression | 2 | 9.138E+002 | 4.569E+002 | 1.597E+002 | <0.001 |
| Residual | 69 | 1.974E+002 | 2.861E+000 | | |
| Total | 71 | 1.111E+003 | 1.565E+001 | | |

Standard Error of Estimate = 1.692

Normality Test: Failed (P = 0.041)

Constant Variance Test: Passed (P = 0.631)

Power of performed test with alpha = 0.050: 1.000

Two Way Analysis of Variance

Dependent Variable: %TKNrem

| Source of Variation | DF | SS | MS | F | P |
|---------------------|----|------------|------------|------------|--------|
| SRT | 2 | 1.504E+003 | 7.520E+002 | 2.007E+002 | <0.001 |
| Anoxic time | 2 | 2.768E+001 | 1.384E+001 | 3.693E+000 | 0.031 |
| SRT x Anoxic time | 4 | 1.544E+001 | 3.860E+000 | 1.030E+000 | 0.400 |
| Residual | 54 | 2.024E+002 | 3.748E+000 | | |
| Total | 62 | 1.749E+003 | 2.822E+001 | | |

Least square means for SRT

| Group | Mean | SEM |
|------------|------------|------------|
| 4.000E+001 | 8.960E+001 | 4.224E-001 |
| 6.000E+001 | 9.411E+001 | 4.224E-001 |
| 8.000E+001 | 8.225E+001 | 4.224E-001 |

Least square means for Anoxic time

| Group | Mean | SEM |
|------------|------------|------------|
| 2.000E+000 | 8.933E+001 | 4.224E-001 |
| 4.000E+000 | 8.888E+001 | 4.224E-001 |
| 6.000E+000 | 8.776E+001 | 4.224E-001 |

Least square means for SRT x Anoxic time

| Group | Mean | SEM |
|----------------|------------|------------|
| 40.000 x 2.000 | 9.073E+001 | 7.317E-001 |
| 40.000 x 4.000 | 9.031E+001 | 7.317E-001 |
| 40.000 x 6.000 | 8.777E+001 | 7.317E-001 |
| 60.000 x 2.000 | 9.464E+001 | 7.317E-001 |
| 60.000 x 4.000 | 9.429E+001 | 7.317E-001 |
| 60.000 x 6.000 | 9.339E+001 | 7.317E-001 |
| 80.000 x 2.000 | 8.263E+001 | 7.317E-001 |
| 80.000 x 4.000 | 8.203E+001 | 7.317E-001 |
| 80.000 x 6.000 | 8.210E+001 | 7.317E-001 |

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor: SRT

| Comparison | Diff of Means | p | q | P<0.05 |
|-------------------|---------------|---|------------|--------|
| 60.000 vs. 80.000 | 1.185E+001 | 3 | 2.806E+001 | Yes |
| 60.000 vs. 40.000 | 4.504E+000 | 3 | 1.066E+001 | Yes |
| 40.000 vs. 80.000 | 7.350E+000 | 3 | 1.740E+001 | Yes |

Comparisons for factor: Anoxic time

| Comparison | Diff of Means | p | q | P<0.05 |
|-----------------|---------------|---|------------|--------|
| 2.000 vs. 6.000 | 1.578E+000 | 3 | 3.736E+000 | Yes |
| 2.000 vs. 4.000 | 4.581E-001 | 3 | 1.084E+000 | No |
| 4.000 vs. 6.000 | 1.120E+000 | 3 | 2.651E+000 | No |

Polynomial Regression, Order Only:

$$\%TKNrem = 3.152E+001 + (2.270E+000 * SRT) - (2.045E-002 * SRT^2)$$

N = 6.300E+001

R = 9.272E-001 Rsqr = 8.597E-001 Adj Rsqr = 8.550E-001

Analysis of Variance:

| | DF | SS | MS | F | P |
|------------|----|------------|------------|------------|--------|
| Regression | 2 | 1.504E+003 | 7.520E+002 | 1.838E+002 | <0.001 |
| Residual | 60 | 2.455E+002 | 4.092E+000 | | |
| Total | 62 | 1.749E+003 | 2.822E+001 | | |

Standard Error of Estimate = 2.023

Normality Test: Failed (P = <0.001)

Constant Variance Test: Passed (P = 0.293)

Power of performed test with alpha = 0.050: 1.000

Two Way Analysis of Variance

Dependent Variable: %TPrem

| Source of Variation | DF | SS | MS | F | P |
|---------------------|----|------------|------------|------------|--------|
| SRT | 2 | 4.606E+003 | 2.303E+003 | 3.867E+002 | <0.001 |
| Anoxic time | 2 | 3.697E+001 | 1.849E+001 | 3.104E+000 | 0.053 |
| SRT x Anoxic time | 4 | 5.913E+001 | 1.478E+001 | 2.482E+000 | 0.055 |
| Residual | 54 | 3.217E+002 | 5.957E+000 | | |
| Total | 62 | 5.024E+003 | 8.104E+001 | | |

Least square means for SRT

| Group | Mean | SEM |
|------------|------------|------------|
| 4.000E+001 | 7.473E+001 | 5.326E-001 |
| 6.000E+001 | 7.740E+001 | 5.326E-001 |
| 8.000E+001 | 5.808E+001 | 5.326E-001 |

Least square means for Anoxic time

| Group | Mean | SEM |
|------------|------------|------------|
| 2.000E+000 | 6.911E+001 | 5.326E-001 |
| 4.000E+000 | 7.012E+001 | 5.326E-001 |
| 6.000E+000 | 7.098E+001 | 5.326E-001 |

Least square means for SRT x Anoxic time

| Group | Mean | SEM |
|----------------|------------|------------|
| 40.000 x 2.000 | 7.519E+001 | 9.225E-001 |
| 40.000 x 4.000 | 7.474E+001 | 9.225E-001 |
| 40.000 x 6.000 | 7.426E+001 | 9.225E-001 |
| 60.000 x 2.000 | 7.534E+001 | 9.225E-001 |
| 60.000 x 4.000 | 7.695E+001 | 9.225E-001 |
| 60.000 x 6.000 | 7.992E+001 | 9.225E-001 |
| 80.000 x 2.000 | 5.679E+001 | 9.225E-001 |
| 80.000 x 4.000 | 5.868E+001 | 9.225E-001 |
| 80.000 x 6.000 | 5.876E+001 | 9.225E-001 |

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor: SRT

| Comparison | Diff of Means | p | q | P<0.05 |
|-------------------|---------------|---|------------|--------|
| 60.000 vs. 80.000 | 1.933E+001 | 3 | 3.629E+001 | Yes |
| 60.000 vs. 40.000 | 2.670E+000 | 3 | 5.013E+000 | Yes |
| 40.000 vs. 80.000 | 1.666E+001 | 3 | 3.127E+001 | Yes |

Comparisons for factor: Anoxic time

| Comparison | Diff of Means | p | q | P<0.05 |
|-----------------|---------------|---|------------|--------|
| 6.000 vs. 2.000 | 1.874E+000 | 3 | 3.519E+000 | No |
| 6.000 vs. 4.000 | 8.576E-001 | 3 | 1.610E+000 | No |
| 4.000 vs. 2.000 | 1.017E+000 | 3 | 1.909E+000 | No |

Forward Stepwise Regression: Dependent Variable: %TPrem
 F-to-Enter: 4.000 P = 0.050 F-to-Remove: 3.900 P = 0.053

Step 0:

Standard Error of Estimate = 9.002

Analysis of Variance:

| Group | DF | SS | MS | F | P |
|----------|----|----------|--------|---|---|
| Residual | 62 | 5024.181 | 81.035 | | |

Variables in Model

| Group | Coef. | Std. Coeff. | Std. Error | F-to-Remove | P |
|----------|--------|-------------|------------|-------------|---|
| Constant | 70.070 | | 1.134 | | |

Variables not in Model

| Group | F-to-Enter | P |
|-------------|------------|--------|
| SRT | 84.168 | <0.001 |
| Anoxic time | 0.451 | 0.504 |

Step 1: SRT Entered

R = 0.761 Rsqr = 0.580 Adj Rsqr = 0.573

Standard Error of Estimate = 5.883

Analysis of Variance:

| Group | DF | SS | MS | F | P |
|------------|----|----------|----------|--------|--------|
| Regression | 1 | 2913.001 | 2913.001 | 84.168 | <0.001 |
| Residual | 61 | 2111.180 | 34.610 | | |

Variables in Model

| Group | Coef. | Std. Coeff. | Std. Error | F-to-Remove | P |
|----------|--------|-------------|------------|-------------|--------|
| Constant | 95.055 | | 2.822 | | |
| SRT | -0.416 | -0.761 | 0.045 | 84.168 | <0.001 |

Variables not in Model

| Group | F-to-Enter | P |
|-------------|------------|-------|
| Anoxic time | 1.067 | 0.306 |

Summary Table

| Step # | Vars. Entered | Vars. Removed | R | RSqr | Delta RSqr | Vars in Model |
|--------|---------------|---------------|-------|-------|------------|---------------|
| 1 | SRT | | 0.761 | 0.580 | 0.580 | 1 |

The dependent variable %TPrem can be predicted from a linear combination of the independent variables:

P
 SRT <0.001

The following variables did not significantly add to the ability of the equation to predict %TPrem and were not included in the final equation: Anoxic time

Polynomial Regression, Order Only:

$$\%TPrem = 3.404E+000 + (2.883E+000 * SRT) - (2.750E-002 * SRT^2)$$

N = 6.300E+001

R = 9.575E-001 Rsqr = 9.168E-001 Adj Rsqr = 9.141E-001

Analysis of Variance:

| | DF | SS | MS | F | P |
|------------|----|------------|------------|------------|--------|
| Regression | 2 | 4.606E+003 | 2.303E+003 | 3.308E+002 | <0.001 |
| Residual | 60 | 4.178E+002 | 6.963E+000 | | |
| Total | 62 | 5.024E+003 | 8.104E+001 | | |

Standard Error of Estimate = 2.639

Normality Test: Passed (P = 0.668)

Constant Variance Test: Passed (P = 0.681)

Power of performed test with alpha = 0.050: 1.000

Two Way Analysis of Variance

Dependent Variable: %COLORrem

| Source of Variation | DF | SS | MS | F | P |
|---------------------|----|------------|------------|------------|--------|
| SRT | 2 | 1.756E+003 | 8.781E+002 | 1.312E+001 | <0.001 |
| Anoxic time | 2 | 4.791E+001 | 2.396E+001 | 3.579E-001 | 0.704 |
| SRT x Anoxic time | 4 | 4.158E+000 | 1.040E+000 | 1.553E-002 | 0.999 |
| Residual | 18 | 1.205E+003 | 6.694E+001 | | |
| Total | 26 | 3.013E+003 | 1.159E+002 | | |

Least square means for SRT

| Group | Mean | SEM |
|------------|------------|------------|
| 4.000E+001 | 3.109E+001 | 2.727E+000 |
| 6.000E+001 | 3.547E+001 | 2.727E+000 |
| 8.000E+001 | 4.996E+001 | 2.727E+000 |

Least square means for Anoxic time

| Group | Mean | SEM |
|------------|------------|------------|
| 2.000E+000 | 3.758E+001 | 2.727E+000 |
| 4.000E+000 | 3.825E+001 | 2.727E+000 |
| 6.000E+000 | 4.068E+001 | 2.727E+000 |

Least square means for SRT x Anoxic time

| Group | Mean | SEM |
|----------------|------------|------------|
| 40.000 x 2.000 | 2.914E+001 | 4.724E+000 |
| 40.000 x 4.000 | 3.053E+001 | 4.724E+000 |
| 40.000 x 6.000 | 3.359E+001 | 4.724E+000 |
| 60.000 x 2.000 | 3.450E+001 | 4.724E+000 |
| 60.000 x 4.000 | 3.492E+001 | 4.724E+000 |
| 60.000 x 6.000 | 3.698E+001 | 4.724E+000 |
| 80.000 x 2.000 | 4.911E+001 | 4.724E+000 |
| 80.000 x 4.000 | 4.929E+001 | 4.724E+000 |
| 80.000 x 6.000 | 5.148E+001 | 4.724E+000 |

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor: SRT

| Comparison | Diff of Means | p | q | P<0.05 |
|-------------------|---------------|---|------------|--------|
| 80.000 vs. 40.000 | 1.887E+001 | 3 | 6.920E+000 | Yes |
| 80.000 vs. 60.000 | 1.449E+001 | 3 | 5.314E+000 | Yes |
| 60.000 vs. 40.000 | 4.379E+000 | 3 | 1.606E+000 | No |

Comparisons for factor: Anoxic time

| Comparison | Diff of Means | p | q | P<0.05 |
|-----------------|---------------|---|------------|--------|
| 6.000 vs. 2.000 | 3.098E+000 | 3 | 1.136E+000 | No |
| 6.000 vs. 4.000 | 2.436E+000 | 3 | 8.930E-001 | No |
| 4.000 vs. 2.000 | 6.628E-001 | 3 | 2.430E-001 | No |

Forward Stepwise Regression: Dependent Variable:%COLORrem
 F-to-Enter: 4.000 P = 0.056 F-to-Remove: 3.900 P = 0.059

Step 0:

Standard Error of Estimate = 10.765

Analysis of Variance:

| Group | DF | SS | MS | F | P |
|----------|----|----------|---------|---|---|
| Residual | 26 | 3013.229 | 115.893 | | |

Variables in Model

| Group | Coef. | Std. Coeff. | Std. Error | F-to-Remove | P |
|----------|--------|-------------|------------|-------------|---|
| Constant | 38.838 | | 2.072 | | |

Variables not in Model

| Group | F-to-Enter | P |
|-------------|------------|--------|
| SRT | 28.407 | <0.001 |
| Anoxic time | 0.364 | 0.552 |

Step 1:SRT Entered

R = 0.729 Rsqr = 0.532 Adj Rsqr = 0.513

Standard Error of Estimate = 7.511

Analysis of Variance:

| Group | DF | SS | MS | F | P |
|------------|----|----------|----------|--------|--------|
| Regression | 1 | 1602.723 | 1602.723 | 28.407 | <0.001 |
| Residual | 25 | 1410.505 | 56.420 | | |

Variables in Model

| Group | Coef. | Std. Coeff. | Std. Error | F-to-Remove | P |
|----------|--------|-------------|------------|-------------|--------|
| Constant | 10.530 | | 5.505 | | |
| SRT | 0.472 | 0.729 | 0.089 | 28.407 | <0.001 |

Variables not in Model

| Group | F-to-Enter | P |
|-------------|------------|-------|
| Anoxic time | 0.758 | 0.392 |

Summary Table

| Step # | Vars. Entered | Vars. Removed | R | RSqr | Delta RSqr | Vars in Model |
|--------|---------------|---------------|-------|-------|------------|---------------|
| 1 | SRT | | 0.729 | 0.532 | 0.532 | 1 |

The dependent variable %COLORrem can be predicted from a linear combination of the independent variables:

 P
 SRT <0.001

The following variables did not significantly add to the ability of the equation to predict %COLORrem and were not included in the final equation: Anoxic time

Polynomial Regression, Order Only:

$$\%COLORrem = 5.267E+001 + (1.045E+000 * SRT) - (1.264E-002 * SRT^2)$$

N = 2.700E+001

R = 7.634E-001 Rsqr = 5.828E-001 Adj Rsqr = 5.481E-001

Analysis of Variance:

| | DF | SS | MS | F | P |
|------------|----|------------|------------|------------|--------|
| Regression | 2 | 1.756E+003 | 8.781E+002 | 1.676E+001 | <0.001 |
| Residual | 24 | 1.257E+003 | 5.238E+001 | | |
| Total | 26 | 3.013E+003 | 1.159E+002 | | |

Standard Error of Estimate = 7.237

Normality Test: Passed (P = 0.078)

Constant Variance Test: Passed (P = 0.007)

Power of performed test with alpha = 0.050: 0.998

BIOGRAPHY



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INSTITUTIONS ATTENDED Mahidol University, 1990-1993:
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