FILAMENTOUS GROWTH IN ENTRAPPED MICROBIAL CELL REACTOR TREATING WASTEWATER

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

Date

Signature

ABSTRACT

Sathyaseelan, Vinodgnanadeepan, M.S., Department of Civil Engineering, College of Engineering and Architecture, North Dakota State University, May 2010. Filamentous Growth in Entrapped Microbial Cell Reactor Treating Wastewater. Major Professor: Dr. Eakalak Khan.

The overgrowth of filamentous microorganisms in wastewater treatment systems is a common adversary condition leading to foaming, poor sludge settling problems, and reduction in organic removal efficiency. Entrapped microbial cell reactors have been investigated for their uses in wastewater treatment. However, their susceptibility to filamentous growth is not known. The objective of this study is to investigate the filamentous growth and its effect on the treatment performance of an entrapped microbial cell system treating wastewater. A typical activated sludge wastewater treatment system was included for comparative purpose. Both systems were operated at the same operating conditions using synthetic wastewater. Four different hydraulic retention times (HRT) (9, 6, 3, 1.5 hours), three different dissolved oxygen (DO) concentrations (2, 4.5 and 5.7 mg/l), and three different influent chemical oxygen demand (COD) concentrations (120, 206 and 300 mg/l) were investigated. Results showed that DO and organic loading rate (COD/HRT) did not have any effect on the organic (soluble COD and soluble biochemical oxygen demand at 5 days) removal efficiencies at high and medium HRT (9 and 6 hours), even when there was excessive filamentous growth in the entrapped microbial cell reactor. The organic removal efficiencies of the activated sludge system dropped for some cases at high and medium HRT because of excessive filamentous overgrowth. At low HRT (3 hours), there was abundant filamentous growth and a drop in the organic removal efficiencies in the entrapped microbial cell reactor. To determine the reason (between HRT

and filamentous abundance) for the decreases in organic removal efficiencies by the entrapped microbial cell system at the low HRT, a very low HRT of 1.5 hours was applied. DO and organic loading rate did not affect organic removal efficiencies of the entrapped cell reactor. Reduction of the filamentous microorganisms was attempted by chlorination using sodium hypochlorite. Three different chlorine dosages, 1, 0.25 and 0.50 g NaOCl/d, were applied. The dosage of 0.25 g NaOCl/d was found to be very effective in controlling the filamentous overgrowth in the entrapped microbial cell reactor. The reduction of filamentous organisms by chlorination did not result in improved organic removal efficiencies, suggesting that the very low HRT rather than the abundance of filamentous organisms was responsible for the poorer performance of the reactor. A cell morphology and organelle analysis indicated *Sphaerotilus natans* as the most frequently observed filamentous microorganism in the entrapped microbial cell reactor. A thick layer of biofilm was also observed on the entrapment matrix. The biofilm did not affect the performances of the reactor. These results suggested that the entrapped microbial cell reactor is subjected to filamentous overgrowth, but it has no effect on the performances of the reactor.

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CHAPTER 1

INTRODUCTION

1.1. Background

Filamentous overgrowth is a common problem in activated sludge wastewater treatment plants. Filamentous microorganisms form a backbone to which floc forming bacteria adhere (Sezgin et al., 1978). When filamentous microorganisms grow abundantly, sludge flocs are bound together by the filaments in a web like structure resulting in a condition in which sludge settling rates decrease and the thickening characteristics of the settled sludge are poor (Lau et al., 1984a,b). In addition, the overabundance of filamentous microorganisms causes foaming. Filamentous microorganisms make the floc hydrophobic and amenable to attachment by air bubbles. The floc with air bubbles is less dense than the water and therefore floats. Certain environmental conditions favor the overgrowth of filamentous microorganisms. Low dissolved oxygen (DO) levels in the aeration basin, high amounts of readily biodegradable substrate, low pH, and low nutrient concentrations are among them.

A microscopic examination of the types and abundance of the filamentous microorganisms provides the most valuable information about the nature and cause of the problem (Jenkins et al., 1993). The phenomenon of filamentous bulking has been recognized for a long time and is known to be caused by at least 14 types of filamentous microorganisms (Eikelboom et al., 1988). It is very rare to see only one filamentous organism type in bulking sludge. Usually three or more types are seen with one type present in a dominant quantity. Environmental conditions and the dominant filamentous types have been related. For example, at low organic loadings, *Sphaerotilus natans* and

Nocardia spp. are typically the dominant filamentous organisms. As a result, the information on the causative filament is helpful in finding a remedy for sludge bulking.

Two major methods are used to control the filamentous bulking and foaming problems: (1) providing suitable operating conditions that can suppress the overgrowth of filamentous microorganisms such as changing to a plug flow reactor mode from a complete mixing reactor mode (Chambers et al., 1982) and (2) using nonspecific methods such as the addition of toxicants to selectively kill the filaments (Jenkins et al., 1993 and Kim et al., 1994). Killing the filaments with chlorine or hydrogen peroxide is a very effective and economical method to control filamentous bulking.

As described above, filamentous overgrowth in activated sludge has been well studied. The overgrowth of filamentous microorganisms in any other wastewater treatment processes is undesirable. Filamentous overgrowth in nontraditional wastewater treatment processes has been rarely investigated. Lin et al. (2004a,b) studied the filamentous growth and control in an ultra compact biofilm reactor. The overgrowth caused a decrease in the density of the biofilm media leading to the loss of media from the reactor and increased the sludge volume. In addition, chlorination was an effective method for remediating and controlling the filamentous overgrowth in the reactor.

Entrapped microbial cell systems have been investigated for their uses in wastewater treatment. The entrapped microbial cell process has many advantages over free cells such as short start-up period, high cell density, easy cell separation, elimination of washout possibility, ease of restarting the operation, low effluent suspended solids, and life expectancy of more than 10 years. Because of the high cell density, it is possible to obtain high solids retention time (SRT) of about 200 to 300 days (Yang et al., 2002). Entrapped microbial cell systems have been tested for the removal of organic carbon (Yang et al., 1988), removal of nitrogen (van Ginkel et al., 1983), simultaneous removal of carbon and nitrogen (Yang et al., 2002), removal of heavy metals (Macaskie et al., 1984) and specific toxic organics, such as phenol (Yang et al., 1991) from wastewater.

1.2. Research Problem Statement

Biological treatment process is the most cost effective treatment process in treating wastewater. Previous studies on the cell entrapment systems for wastewater treatment focused mainly on the contaminant removal performances. The susceptibility of the systems to filamentous overgrowth is not known. Most of the biological treatment processes treating domestic wastewater encounter filamentous bulking problems. Since the entrapped microbial cell system is a biological treatment process, major aspects of filamentous overgrowth in the system should be studied.

1.3. Objectives

The objective of this study is to investigate the filamentous growth and its effect on the treatment performances of an entrapped microbial cell reactor treating synthetic wastewater. An activated sludge system was studied in parallel for comparison purpose. The filamentous growth was examined microscopically to identify and quantify responsible species at different operational conditions. The specific objectives of the study are:

1. To examine the effects of operating conditions, specifically DO level and organic loading rate (OLR), on filamentous growth and in turn the performance of the entrapped cell reactor, and

2. To investigate the effectiveness of chlorination in controlling filamentous growth in the entrapped cell reactor.

CHAPTER 2

LITERATURE REVIEW

2.1. Filamentous Microorganisms in Wastewater Treatment Systems

Filamentous bacteria are a group of bacteria that are mostly found in wastewater treatment systems. They grow in long thread-like strands or colonies. They can add stability and backbone or rigid support to the floc structure that keeps the floc from breaking up or shearing due to turbulence from pumps, aeration or transfer of the wastewater. Filamentous bacteria contribute to positive aspects in wastewater treatment. They are very good biochemical oxygen demand (BOD) removers, help the floc structure to filter out fine particulate matter that will improve clarifier efficiency, and reduce the amount of pin floc. They are also a major group of microorganisms helping in the oxidation of sulfides (Chung et al., 1997).

The negative aspects of filamentous overgrowth overrule the positive aspects. They interfere with separation and compaction of activated sludge leading to bulking, increase the sludge volume index (SVI) causing poor settling, increase polymer consumption needed for settling enhancement, and increase solids production resulting in high solids handling costs (Jenkins et al., 1993). Filamentous overgrowth also causes foaming. When filamentous microorganisms grow abundantly, they render hydrophobic flocs to which air bubbles can easily attach to. The floc-air bubble matrix floats to the surface due to less density. The matrix tends to stay there and forms a thick layer of scum which does not settle well and get carried to the clarifier.

2.1.1. Physical characteristics and staining properties of filamentous bacteria

Filamentous microorganisms can be identified by the physical characteristics of the filaments. The following are the characteristics found in filamentous microorganisms.

1. Branching.

A few types of the filamentous microorganisms have branching. Sometimes false branching can be observed. True branching is where there is contiguous cytoplasm between branched trichomes. The cells at both ends of some filamentous microorganisms have an elongated hair-like structure called a trichome.

2. Motility.

Very few filamentous types are motile. Few of them may display limited twitching or swaying motion.

3. Shape.

Filament cells are usually square, rectangular, oval, barrel, discoid, straight, smoothly curved, bent, and irregularly shaped chains of cells or coiled. Cell shape is usually very important to identify the type of filamentous microorganism.

4. Sheath.

Sheath is one of the most difficult characteristics to find. Sheath is a clear structure exterior to the cell wall which is very difficult to observe. Few types of filamentous organisms have a clear sheath.

5. Cross-wall (Cell septa).

The detection of the cell septa depends on the quality of the microscope. Few types of filamentous microorganisms have clear cell septa. Figure 2.1 shows *Nostocoida limicola* II which has cell septa.

Figure 2.1 *Nostocoida limicola* II filamentous microorganism showing clear cell septa (Environmental Leverage Inc.)

6. Filament diameter.

It is important to note if the diameter of filamentous microorganisms is greater or less than 1 μm. For example *Nostocodia limicola* I is 0.6-0.8 μm in diameter, whereas *Nocardia spp.* are usually greater than 1 μm in diameter.

7. Filament length.

Filament length is very important to identify the type of filamentous microorganism. For example, *S. natans* is 100-1000 μm long and *Flexibacter spp.* is 20-40 μm long.

8. Sulfur granules.

Presence or absence of sulfur granules in the cells is vital information in identifying the type of filamentous microorganism. Sulfur granules are present in only certain types of filamentous microorganisms. Presence of the sulfur granules can be identified using a phase contrast microscope. Sulfur granules appear as bright, refractive yellow colored pigments.

9. Staining reaction.

Depending on the reaction with stains (Gram stain and Neisser stain), the filamentous microorganisms can be identified. More on staining reaction is described in section 2.1.4.

2.1.2. Types of filamentous bacteria

There are about 29 types of filamentous microorganisms (Jenkins et al., 1993). The types of filamentous organisms observed in wastewater treatment systems have been investigated in a systematic fashion by several researchers (Cyrus et al., 1970, Eikelboom et al., 1998, Blackbeard et al., 1986). Only 12 to 14 types account for the majority of the bulking and foaming in wastewater treatment systems.

1. *S. natans* (Figure 2.2) are relatively long (100-1000 μm), straight or smoothly curved, rod-shaped cells and the filaments are round-ended. They contain a clear sheath and cell septa. False branching or no branching is mostly observed under a microscope. They are Gram negative, Nessier negative and have no sulfur granules.
2. *Thiothrix I.* They are straight or smoothly curved 100-500 μm long rectangular cells with prominent and heavy sheath and clear cell septa (Figure 2.3). They are Gram negative (sometimes showing false Gram positive), Nessier negative and have no sulfur granules.
3. *Thiothrix II. Thiothrix II* chains are straight or smoothly curved 0.7 to 1.4 μm in width and 50 – 200 μm in length. Their cells are rectangular. A sheath is usually present, but

very difficult to observe. They are Gram and Nessier negative. They normally contain spherical sulfur granules. Figure 2.3 shows *Thiothrix II* chains.

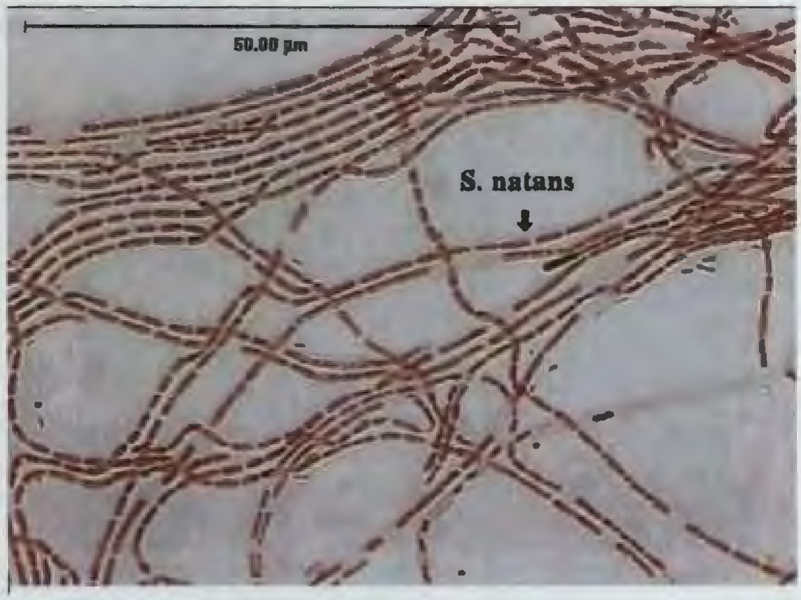

Figure 2.2 *S. natans* (Environmental Leverage Inc.).

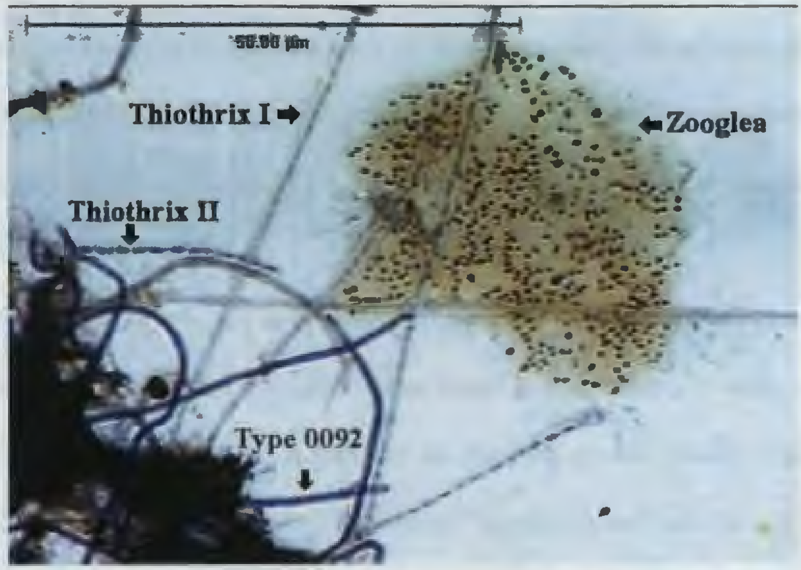

Figure 2.3 *Thiothrix I* and *Thiothrix II* (Environmental Leverage Inc.).

4. *Beggiatoa* spp. Usually *Beggiatoa* spp. form large, straight filaments, 1.0 to 3.0 µm in width and 100- 500 µm in length. They are actively motile by gliding and flexing the

bulking solution. They have cell septa, which are not very visible, but have no sheath. They generally contain substantial spherical sulfur granules. They are Gram and Nessier negative. *Beggiatoa* spp. is shown in Figure 2.4.

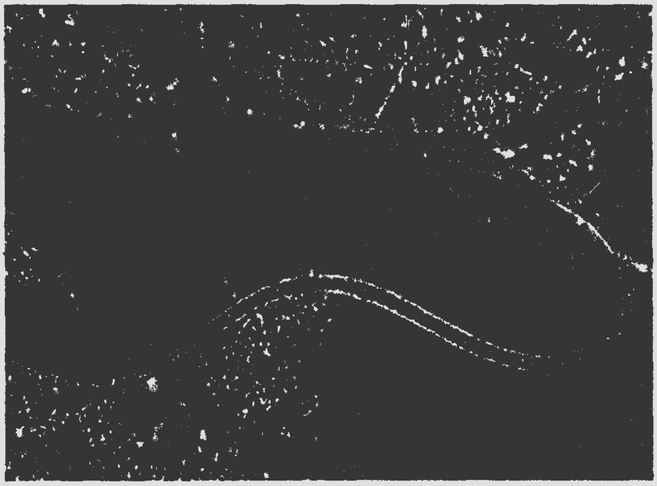

Figure 2.4 *Beggiatoa* spp. (Environmental Leverage Inc.).

5. *Microthrix parvicella. M. parvicella* form irregularly coiled filaments, 0.6-0.8 µm in diameter and 50-200 µm in length (Figure 2.5). They are usually found in tangles in the floc or as loose patches in bulking solutions. Sheath is absent in this organism. There are no branching and no cell septa. They stain Gram positive and Neisser negative, and have no sulfur granules.
6. *Nocardia* spp. *Nocardia* spp. are irregularly bent, and have short filaments, usually 1.0 µm in diameter and 5–30 µm in length. True branching is observed when observed under a microscope. There are no sheath and no attached growth for this filamentous microorganism. Cell septa are normally observed. They are Gram and Neisser positive. They do not contain sulfur granules. *Nocardia* spp. is shown in Figure 2.6.
7. *Nostocoida limicola* I. *N. limicola* I are bent and irregularly-coiled filaments, 0.6 – 0.8 µm in diameter and 100-200 µm in length. Cell septa are difficult to be observed and

have no sheath. On staining, they are Gram and Neisser positive. Figure 2.7 shows *N. limicola I*.

Figure 2.5 *M. parvicella* (Environmental Leverage Inc.).

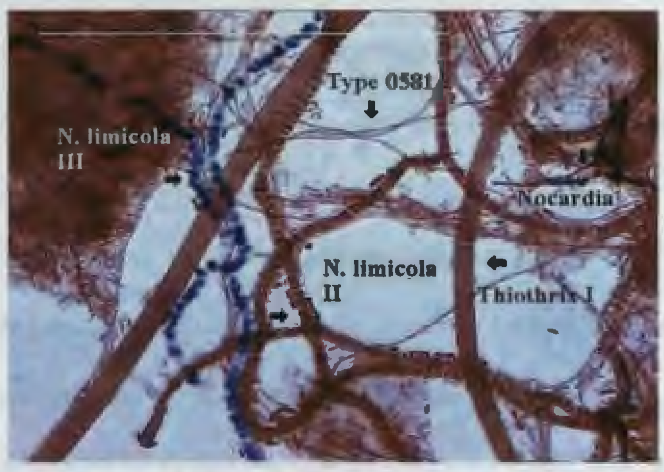

Figure 2.6 *Nocardia spp., Nostocoida limicola* II *and Nostocoida limicola* III (Environmental Leverage Inc.).

8. *Nostocoida limicola* II. *N. limicola* II are oval cells with septa but no cell sheath. Their filamentous chains are usually bent and irregularly-coiled, 1.2-1.4 μm in diameter and 100-200 μm in length. Their Neisser staining reaction is variable. They are mostly Gram negative with a possibility of false Gram positive. Figure 2.6 shows *N. limicola II*.

Figure 2.7 *Nostocoida limicola* I (Environmental Leverage Inc.).

9. *Nostocoida limicola* III. Their bent and irregularly coiled filaments are usually 1.6-2.0 μm in diameter and 200-300 μm in length. There is no sheath in this oval cell microorganism, which has cell septa. Usually both Gram and Neisser reactions are positive for *N. limicola* III but sometimes can be negative. They have no sulfur granules. Figure 2.6 shows *N. limicola* III.
10. *Haliscomenobacter hydrossis*. *H. hydrossis* form straight or bent, thin filaments with 0.5 μm in diameter and 10-100 μm length. A sheath is present but there are no cell septa in this microorganism, which is Gram and Neisser negative, and have no sulfur granules. Figure 2.8 shows *H. hydrossis*.
11. *Flexibacter* spp. These short, straight or smoothly curved filaments are usually 1.0 μm in diameter and 20-40 μm in length. They are motile by slow gliding and flexing. No sheath and no cell septa are present. Gram and Neisser stains are both negative. Sulfur granules are present.

12. *Bacillus* spp. They are rounded rod shaped cells and form filaments, 0.8-1.0 μm in diameter and 20-50 μm in length. Gram and Neisser stains are both negative. Sulfur granules are not present.

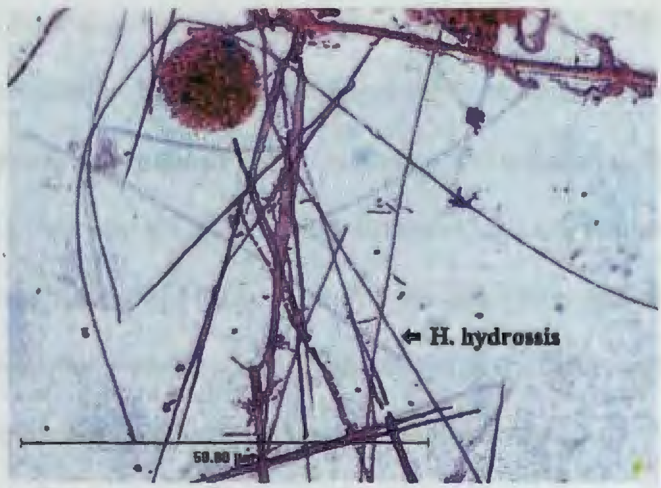

Figure 2.8 *H. hydrossis* (Environmental Leverage Inc.).

13. *Cyanophycae*. Their filaments are straight and 2.0-5.0 μm in diameter and 100-500 μm in length. Their cells are square or rectangular and have septa. No sheath is detected in *Cyanophycae*. Gram stain is usually negative with a possibility of false positive. Neisser stain is negative and no sulfur granules are normally observed.

14. *Fungi*. *Fungi* have very large trichomes, 3-8 μm in width and 300-1000 μm in length. Cells are rectangular and have no sheath but a heavy cell wall is present. True branching occurs. Gram and Neisser stains are both negative. They do not have sulfur granules.

2.1.3. Conditions causing filamentous overgrowth

There are several factors influencing the filamentous growth in a treatment process. They are DO concentration, nutrient (Nitrogen and Phosphorus) concentrations, pH, sulfide concentration (septicity), nature of the substrate, and amount of grease or oil (Richard et al., 1989).

The required DO concentration to prevent filamentous overgrowth is not a constant but a function of the food to microorganism (F/M) ratio (Palm et al., 1980). Higher DO concentrations are required to prevent the filamentous overgrowth, as the F/M ratio increases, due to faster oxygen consumption. In general, a DO concentration of 2.0 mg/l is recommended for F/M values up to 0.5. Some industrial and high rate domestic wastewater treatment plants operated at higher F/M ratios may need DO values higher than 2.0 mg/l due to oxygen diffusion limitations. Control of filamentous overgrowth due to low DO can be achieved by raising the aeration to increase the DO concentration.

Nitrogen (N) and phosphorus (P) can influence the filamentous overgrowth if not present in sufficient amounts in the wastewater influent. It is a common problem with industrial wastewater and not domestic wastewater. In general, a 5-day BOD (BOD_5): N: P weight ratio of 100:5:1 is needed in the influent wastewater for complete BOD removal (Richard et al., 1989). Micronutrients such as iron or sulfur have been reported not to influence the filamentous overgrowth.

The pH should be maintained in a range of 6.5 to 8.5. Low pH of < 6.5 may cause overgrowth of filamentous microorganisms. Wastewater septicity is usually indicated by odors and dark color caused by precipitated ferric sulfide (Mudrack et al., 1986). Septic wastewater contains elevated amounts of sulfides and low molecular weight organic acids (such as acetic and butyric acids), both of which encourage the growth of certain filaments. Observation of these filaments with intracellular sulfur granules is an indication of a septicity problem. Septicity is more common in systems in warmer climates and in those with large wastewater collection systems that have lift stations and force mains. Wastewater septicity can be treated by preaeration (which releases odors), chemical oxidation (chlorine, hydrogen peroxide), or chemical precipitation (ferric chloride).

Septicity can also originate within the plant processes (Richard et al., 1989). Common sources of septicity include equalization basins, primary and secondary clarifiers. These can be tested for sulfide or organic acid concentrations to determine whether they are significant sources of septicity. A sulfide concentration of >1-2 mg/l and an organic acid concentration > 100 mg/l favors filamentous growth.

Nature of the substrate has a direct effect on the filamentous growth. Richard et al. (1989) conducted pure culture experiments on filamentous microorganisms and found that they grow very well on fairly simple, soluble and readily metabolizable organic substrates. However, this does not mean that filamentous microorganisms grow only on these types of substrates. In biological nutrient removal wastewater treatment plants, slowly metabolizing substrate and particulate organic matter for which degradation rates are very slow in anaerobic and anoxic zones are returned to aerobic zones where they and/or their hydrolysis products could support the growth of certain filamentous microorganisms. The filamentous organisms favored by soluble and readily metabolizable organic substrates are *S. natans*, *Thiothrix* spp., *H. hydrossis*, *N. limicola*, and *M. parvicella*. The following filamentous organisms can grow on slowly metabolizable substrates *M. parvicella*, *Nocardia* spp., *Beggiatoa* spp., and *type 021N*. High amounts of grease or oil also affect the filamentous growth in the plant. Table 2.1 shows dominant types of filamentous microorganisms associated with different environmental conditions.

Table 2.1 Dominant types of filamentous microorganisms associated with different environmental conditions

Causative Condition	Filament Types
Low dissolved oxygen	*S. natans*, Type 1701 and *H. hydrossis*
Low organic loading rate (low F/M)	*M. parvicella*, *Nocardia* spp., and *Types 0041, 0675, 1851* and *0803*
Septic wastes/Sulfides (high organic acids)	*Thiothrix I* and *II*, *Beggiatoa* spp., *N. limicola II*, and *Types 021N, 0092, 0914, 0581, 0961* and *0411*
Nutrient deficiency	*Thiothrix I* and *II* and *Type 021N* (N deficient) *N. limicola III* (P deficient)
Low pH (< 6.0)	*Fungi*
High grease/oil	*Nocardia* spp., *M. parvicella* and *Type 1863*

2.1.4. Staining techniques

There are different staining techniques available to determine the characteristics of the filamentous microorganisms which can be used to identify them.

2.1.4.1. Gram staining technique

The Gram stain is a well known and widely used microbiological technique for classifying and identifying bacteria. This technique divides the bacteria into Gram positive or negative. Separation into these two classes is based on differences in the structure of the bacterial cell walls.

The conventional and most commonly used method of the Gram staining technique requires the use of four separate reagents. The reagents consist of a primary staining solution-crystal violet, a mordant solution-iodine and potassium iodide solution, a decolorizing agent (95% alcohol), and a counter staining solution-safranin. This technique involves the following steps.

1. Prepare a thin smear of cells on a microscopic slide and air dry it thoroughly,

2. Stain one minute with the primary staining solution-crystal violet dye and rinse for a few seconds with distilled water,
3. Stain one minute with the mordant solution and rinse well with distilled water,
4. Then, decolorize the slide with the 95% alcohol solution for 30 seconds and rinse well with distilled water,
5. Stain one minute with the counter stain-safranin solution,
6. Rinse the slide well with distilled water,
7. Examine the slide under oil immersion at 1000X magnification with direct illumination.

Typically, Gram positive bacteria will appear purple in color, while Gram negative bacteria will appear reddish, pink in color (Jenkins et al., 1993).

2.1.4.2. Neisser staining technique

Among different staining techniques available, the Neisser staining is one of the most useful techniques to identify microorganisms in wastewater. This technique is used to identify the polyphosphate granules in the microorganisms. The Neisser staining technique requires the use of two separate reagents, a primary staining solution of methylene blue and crystal violet and a second staining solution made of bismark brown. The following steps are adapted from Eikelboom and Van Buijsen (1981).

1. Prepare a thin smear of cells on a microscopic slide and air dry it thoroughly,
2. Stain the slide with the primary staining solution for 30 seconds and rinse with distilled water,
3. Then, stain it with the bismarck brown solution for one minute and rinsed with distilled water,

4. Examine the slide under oil immersion at 1000X magnification with direct illumination.

The Neisser positive bacteria will appear blue-violet in color, while the Neisser negative bacteria will appear yellow-brown in color.

2.1.4.3. Sulfur granule staining

This staining technique helps to identify sulfur granules in microorganisms. This staining technique requires a sodium thiosulfate solution and involves the following steps, which is modified from Nielsen (1985).

1. Mix 20 ml of a clear supernatant with 1 to 2 ml of a sludge sample in a 100 ml flask,
2. Add 1 ml of the sodium thiosulfate solution to the flask,
3. Provide mixing to the flask overnight at room temperature,
4. Prepare a thin smear of the mixture on a microscopic slide and observe it at 1000X magnification with a phase contrast microscope.

A positive test is based on the presence of highly refractive, yellow colored intercellular sulfur granules inside the filaments.

2.1.5. Filamentous counting techniques

There are different filament counting techniques available to determine the abundance or the quantity of filamentous bacteria present. A simplified filament counting technique used by the San Jose/Santa Clara Pollution Control Agency (Jenkins et al., 1993), which is widely used, is as follows. A 50 μl mixed liquor sample is placed in a glass slide and covered completely with a 22 x 30 mm cover slip. A microscope capable of 1000x total magnification is used. The observation starts at the edge of the cover slip and then consecutive fields across the entire 30 mm length of the cover slip. The eyepiece is fitted with a single hairline. The number of times that any filamentous organism intersects with the hairline is counted. The number of intersection for all the fields examined is summed and it is called the filament count. If a unit count is desired, the filament count must be multiplied by the number of fields in the 22 mm width of the slide.

Filament count/μl = (Filament count in one field/50 μl) x Number of fields

Even though the simplified filament counting technique quantifies the presence of filamentous microorganisms more accurately, it does not categorize the presence of filamentous microorganisms into an abundance scale. The "Subjective Scoring of Filament Abundance" (Jenkins et al., 1993) has been used to determine the abundance of filaments. It is a counting technique based on a microscopic observation under a phase contrast microscope at 1000 times magnification. Table 2.2 shows the scoring scale for abundance.

2.1.6. Filamentous identification

A simplified dichotomous key can be used to identify the type of filamentous microorganisms. It is a morphological based method (Eikelboom et al., 1975) which depends on the size and shape of the filaments, presence of sulfur granules, presence of sheath following the staining of 0.1% crystal violet, and Gram and Neisser staining. A simplified version of the dichotomous key is shown in Figure 2.9.

2.1.7. Filamentous control

There is no best approach for controlling the filamentous overgrowth and ensuring long term operation to be free from it. However, there are few techniques or steps available to correct the filamentous overgrowth problem (Jenkins et al., 1993).

A simplified key for identification of filamentous microorganisms by Eikelboom et al. (1975) can identify the causative filamentous organisms. Table 2.1 shows dominant

Table 2.2 Subjective scoring for filamentous abundance

Abundance Scale	Abundance	Description	No. of Filaments
0	None	No Filaments present	-
1	Few	Filaments present but occasionally observed	-
2	Some	Filaments observed at low density	-
3	Common	Filaments observed commonly	1 to 5
4	Very common	Filaments observed at medium density	5 to 20
5	Abundant	Filaments observed at high density	>20 but countable
6	Excessive	Filaments present at extremely high density	Not countable

types of filamentous microorganisms associated with different environmental conditions. Knowledge on the plant operation and the characteristics of the wastewater to be treated will help to determine the possible cause of the filamentous overgrowth. Most of the time, the cause of the problem can be rectified without major changes to the system and just by changing the operational parameters. For example, if the probable cause of the overgrowth is because of inadequate nutrient, adding the deficient nutrient to the wastewater will solve the problem. If the overgrowth is because of the septic nature of the wastewater, chemical oxidation by wastewater prechlorination or hydrogen peroxide addition should be initiated. Sometimes providing suitable operating conditions can suppress the overgrowth of filamentous microorganisms, such as changing to a plug flow reactor mode from a complete mixing reactor mode (Chambers et al., 1982).

Sometimes the overgrowth problems may require a major wastewater treatment plant design change. In some cases, non specific methods, such as the addition of chemicals to enhance the settling rate without attempting to kill the filamentous organisms, can be used to eliminate the filamentous overgrowth problems. Alum is one of the common chemicals used for this purpose.

Sometimes addition of toxicants to selectively kill the extended filamentous organisms may solve the problem (Jenkins et al., 1993 and Kim et al., 1994). The addition of toxicants is the most popular method used to control the filamentous overgrowth and it is a cost effective method. Chlorine and hydrogen peroxide are two commonly used toxicants (Anon et al., 1979). Chlorine has been used in the form of sodium hypochlorite or calcium hypochlorite solution. Chlorine is a preferred toxicant because it is more economical, readily available and the amount required to control the filamentous control is quite small compared to hydrogen peroxide. A proper use of chlorine for bulking control will not affect or interfere with BOD and suspended solids removal. Several criteria have to be followed for successful bulking control by chlorination. A target value of SVI must be established (Beebe et al., 1981), chlorination should be used only when the targeted SVI is significantly and consistently exceeded and always a known and controlled chlorine dosage must be used.

High chlorine dosages will kill all or most of the required microorganisms needed for the treatment. Therefore, the chlorine dose and frequency of application are the two very important parameters. The usual chlorine dosage is 2 to 8 kg of Cl_2/1000 kg of mixed liquor suspended solids (MLSS) (Beebe et al., 1981, Jenkins et al., 1984, Chudoba et al., 1987).

Daigger et al. (1988) conducted a pilot study for bulking control in an enhanced biological phosphorous wastewater treatment system using the Virginia Initiative Process. Chlorine was used as a toxicant to control filamentous bulking. Return activated sludge

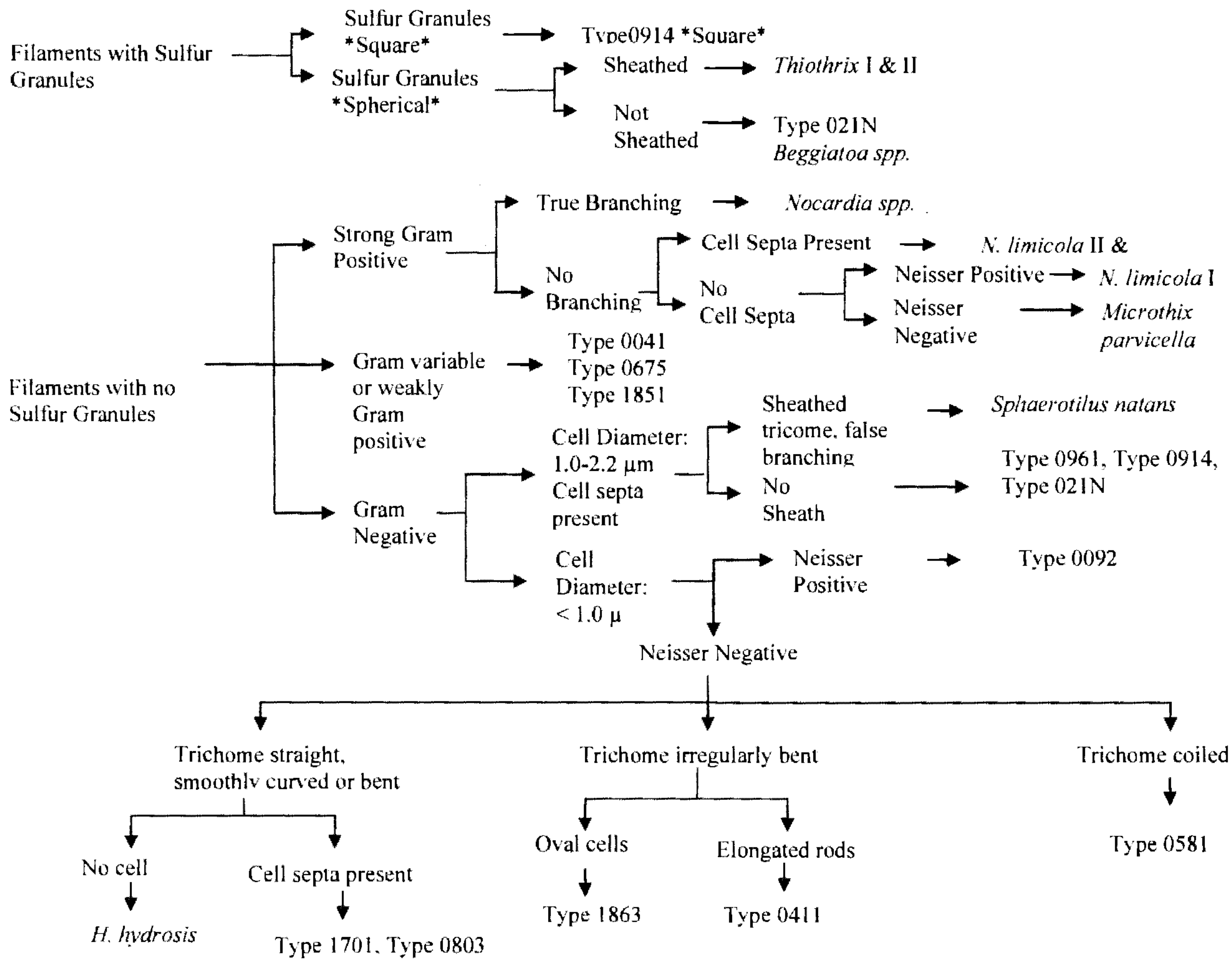

Figure 2.9 A simplified key for identification of filamentous microorganisms (adapted from Jenkins et al., 1984).

was chlorinated. Sodium hypochlorite was used as the chlorine source. They tested different chlorine dosages and found that a dosage of 2 kg of Cl_2/1000 kg of MLSS can get rid of the bulking problem without affecting the phosphorus removal efficiency and the settling rate.

Lin et al. (2004a) investigated the filamentous growth and control in an ultracompact biofilm reactor. They found that the filamentous microorganism overgrowth problem started on the tenth day of operation. Sodium hypochlorite was used as the chlorine source and its solution was pumped directly into the system. A dose of 5-10 g Cl/kg biomass day was found to be effective in controlling the filamentous growth and maintaining good biofilm morphology.

Lin et al. (2004b) studied the performance of a biofilm airlift suspension reactor using ethanol as a substrate. The reactor experienced filamentous overgrowth problems and chlorination was started after 12 days of operation by introducing a sodium hypochlorite solution directly into the reactor. Chlorine dosages of 5-15 g Cl/kg biomass day were applied. Even though these dosages were effective in controlling the filamentous overgrowth, the organic removal efficiency of the reactor was affected. A chlorine dose of 20 g Cl/kg biomass day was found to be excessive.

Hydrogen peroxide (H_2O_2) has also been used to control sludge bulking. A study from Keller and Cole (1973) showed that the required H_2O_2 doses are greater than the chlorine dose. Both continuous and batch applications of H_2O_2 were successful in controlling the bulking. Excellent mixing between H_2O_2 and the activated sludge was necessary for effective destruction of filamentous microorganisms.

2.2. Cell Entrapment for Wastewater Treatment

2.2.1. Introduction to entrapment

Entrapment of cells is very similar to adsorption of cells to solid surface. Cell entrapment is a technique that limits the free movement of cells. The mobility of cell is restricted by confining the cells into a porous or fibrous material. By polymerization or cross-linking of the gel material, the organisms are entrapped within the gel matrices. The enclosure of cell with a gel structure is unlikely to change the function of the cell (Tyagi et al., 1990). There are several advantages associated with the uses of entrapped cells for wastewater treatment including short start-up period, high cell density, elimination of washout possibility, high solids retention time, low sludge production, and life expectancy of more than 10 years.

2.2.2. Types of entrapment

There are different entrapment techniques. Different types of gel polymers such as alginate, carrageenan, cellulose triacetate, polyacrylamide, collagen, gelatin, agar, resins, polyester, polyvinyl alcohol, polystyrene and polyurethane have been used as cell carriers. Among these gel polymers, alginate, carrageenan, cellulose triacetate, polyvinyl alcohol and polyacrylamide are the most commonly used. Cellulose triacetate as a cell carrier is known to have the following advantages: non-biodegradable, highly porous, high mechanical strength, high stability, high durability, and inexpensive.

2.2.3. Application of entrapped microbial cells in wastewater treatment

Entrapped microbial cells have been used for treating collective contaminants in wastewater including carbonaceous organics, nitrogen, and heavy metals.

2.2.3.1. Removal of carbonaceous organics

Yang et al. (1988) used cellulose triacetate entrapped microbial cells for the removal of organic compounds in wastewater. Entrapped microbial cells were prepared with a carrier size of $10\times10\times10$ mm^3 and packed in a laboratory scale upflow reactor which was operated at hydraulic retention times (HRTs) of 6, 9 and 12 h. At HRT of 9 h, the system removed 94.5% of soluble organics in the wastewater.

2.2.3.2. Simultaneous removal of carbonaceous organics and nitrogen

Yang et al. (1997) studied an entrapped-mixed-microbial cell process for simultaneous removal of carbon and nitrogen in a single reactor which was operated on alternate schedules of aerobic, anoxic and anaerobic conditions for treating synthetic wastewater. They studied two different cubical sizes of cellulose triacetate carriers, 20 mm (large) and 10 mm (medium). The medium carrier operated at an HRT of 9 h and the ratio of aeration to non-aeration of 1:2, removed 96% soluble chemical oxygen demand (SCOD) and 84% total nitrogen (TN). The large carrier at the same conditions removed 96% SCOD and 74% TN.

Yang et al. (2002) investigated the use of cellulose triacetate entrapped microbial cells to simultaneously remove organic carbon and nitrogen in a single bioreactor treating synthetic wastewater. The influent had a SCOD/nitrogen ratio of 4:15. The reactor was operated at an aeration/nonaeration ratio of 0.5:2 h. The system removed 92% of SCOD and 92% of TN.

2.2.3.3. Removal of heavy metals in wastewater

Macaskie et al. (1984a,b) and Michel et al. (1986) investigated the removal of cadmium in synthetic wastewater by entrapped *Citrobacter sp.*. The polyacrylamide entrapped *Citrobactor sp.* scavenged cadmium and there by effectively removed it. Glycerol 2-phosphate used in the entrapment process serves as a phosphate donor. Metal uptake by the cells mediated by the cell bound phosphates liberates inorganic phosphate from an organic phosphate to precipitate cadmium as cell-bound metal phosphate. The application of this system to wastewater effluent control was very successful. Of additional note was the finding that the metal can be recovered from the column as concentrated slurry, with only 14.5% loss in activity of the entrapped cells retained within the gel. If the column is not loaded to saturation, recovery of most of the loaded metal is possible, but the maximum numbers of cadmium load and unload cycles, consistent with the retention of acceptable activity of the immobilized c ells remains to be established.

2.2.3.4. Removal of nitrogen

Nitrifying (*Nitrosomonas europaea*) and denitrifying bacteria (*Pseudomonas aeruginosa*) were separately entrapped in calcium alginate and used for treating N in wastewater (van Ginkel et al., 1983). Two separate reactors were used. One of the reactors was aerated for nitrification and the other reactor was not aerated to achieve denitrification. The result showed the potential of immobilized *N. europaea* for nitrification.

Chen et al. (1998) investigated simultaneous removal of carbon and nitrogen in wastewater using a phosphorylated polyvinyl alcohol (PVA)-immobilized cell reactor They used a 12 l continuous aeration vessel for the immobilized-cell reactor and synthetic municipal wastewater as a feed. The reactor was operated at an HRT of 2–10 h in which the chemical oxygen demand (COD) loading rate ranged from 0.855– 4.223 g COD/l.h. At a COD loading rate lower than 2.0 g COD/l.h, COD removal efficiency exceeded 90% accompanied by TN removal efficiency of 45%. The immobilized cell process yielded promising results particularly in terms of maintaining a high biomass concentration to attain high organic removal efficiency and reducing production of excess sludge to decrease operational cost. Denitrification in this immobilized-cell system was verified experimentally by measuring the nitrate reduction activity of the entrapped cells in the form of gel beads. The morphological observation was performed using a scanning electron microscope. These observations reveal that the aerobic heterotrophs (BOD-oxidizers) grew dominantly on the surface of the beads. The nitrifiers grew in the peripheral layer of the beads while the denitrifiers grew in the inner interior which was assumed to be an anoxic zone.

Cao et al. (2002) coimmobilized nitrifying and denitrifying bacteria by repeated freezing and thawing using PVA as a gel matrix. They investigated the factors affecting single-stage biodenitrification process (simultaneously occurring nitrification and denitrification in a reactor) such as nitrifying bacteria and denitrifying bacteria ratio, organic carbon sources, pH, alkalinity, temperature, DO and the operational stability of the coimmobilized cells. The experimental results showed that the nitrogen removal rate of the process increased with an increase in the percentage of nitrifying cells. The nitrogen removal rate by the co-immobilized cells was faster when nitrifying to denitrifying cells ratio was between 1.5:1 and 3.6:1. The nitrogen removal rate decreased if the percentage of nitrifying cells was too high. The nitrogen removal rate increased as the ratio of alkalinity and ammonia nitrogen increased. The nitrogen removal rate using ethanol as a carbon source was the fastest followed by methanol, acetic acid and glucose, respectively. The optimal values of pH, temperature and DO were 8.2, 30°C and 2.6 mg/l, respectively.

Cao et al. (2004) developed a new bioreactor (shell-and-tube co-immobilized cell bioreactor) for nitrogen removal from wastewater. It consisted of four parallel tubes made up of PVA gels containing nitrifying and denitrifying bacteria. The tubes were inside a cylindrical plexiglass shell and had two channels, one at each end. Synthetic wastewater was introduced into the shell-side space surrounding the tubes and the treated wastewater overflowed from the top of the shell. An ethanol solution was pumped into one channel which flows through the tubes into the other channel and then collected into an ethanol solution tank for recycling. The experiment was very successful. Oxygen and organic carbon source could be saved by the process.

Hill and Khan (2008) conducted a bench scale kinetic experiment to investigate the ability of calcium alginate entrapped cells to remove ammonia in anaerobic sludge digester supernatant. Entrapped nitrifiers and co-entrapped nitrifiers and denitrifiers (two separate systems) were studied with and without the addition of methanol. The co-immobilized reactor did not exhibit the extent of nitrite accumulation seen in the nitrifier reactor. The nitrifying reactor was unable to buffer the hydrogen ion production, during the nitrification process, to the level the co-entrapped cell reactors achieved. These results suggested the occurrence of denitrification in the co-entrapped reactors. Scanning electron microscopic images of different parts of the alginate spherical beads also supported the kinetic results. When methanol was added as a carbon source for denitrification, it barely affected the removal of ammonia or the accumulation of nitrite. It was found that the alginate itself was leaching carbon and that carbon supply could not be controlled. The study concluded that regardless of the methanol addition, the microorganisms had a carbon source and the effect of methanol addition could not be justified.

CHAPTER 3

MATERIAL AND METHODS

3.1. Wastewater Source and Preparation

Synthetic domestic wastewater was used as the influent for both entrapped cell reactor and activated sludge systems. Its composition (adapted from Yang et al., 1998) and characteristics are shown in Tables 3.1 and 3.2. Synthetic wastewater was prepared three times a week, in the Environmental Engineering Laboratory, North Dakota State University, Fargo, North Dakota, and stored in a refrigerator at 4°C. Stored synthetic wastewater was used within two days.

Table 3.1 Composition of synthetic wastewater

Constituent	Concentration (mg/l)
Sucrose, $C_{12}H_{22}O_{11}$	106, 185, 270
Ammonium sulfate, $(NH_4)_2SO_4$	125
Magnesium sulfate, $MgSO_4.7H_2O$	20
Ferric chloride, $FeCl_3.6H_2O$	0.125
Monobasic potassium phosphate, KH_2PO_4	131.75
Dibasic potassium phosphate, K_2HPO_4	267.55
Manganous sulfate, $MnSO_4.H_2O$	2.5
Calcium chloride, $CaCl_2$	1.87

Table 3.2 Characteristics of synthetic wastewater

Parameters	Concentration
Theoretical SCOD (mg/l)	120/207/303
Measured soluble carbonaceous biochemical oxygen demand at 5 days (mg/l)	121/195/302
Theoretical soluble ammonia nitrogen (mg/l)	26.5
pH	6.8-7.2

3.2. Cell Entrapment

The entrapment of cells in cellulose triacetate was performed according to the procedure described by Yang and See (1990). MLSS from the Moorhead Wastewater Treatment Plant was used as a source of mixed microbial cells for the entrapment. The entrapment was performed within 48 h after MLSS collection. The MLSS was aerated until the entrapment process was performed. Cellulose triacetate was chosen as an entrapment medium because of high stability and mechanical strength (Yang et al., 1988, See, 1990, Yang et al., 1990a,b).

A brief procedure of the cell entrapment is as follows. The collected MLSS was centrifuged at 10,000 rpm for 20 minutes to obtain 20% (w/v) of wet cell suspension. Cellulose triacetate was dissolved in methylene chloride at a concentration of 10% (w/v). Twenty grams of the 20% (w/v) wet cells (after centrifuging at 10,000 rpm for 20 minutes) were mixed with 100 ml of the cellulose triacetate-methylene chloride solution, and 20 ml of distilled water was added. Then, the solution was completely mixed to emulsion. Methylene chloride was added to make up for its loss due to volatilization during mixing. The emulsion was poured into a tray containing toluene for hardening purpose. The methylene chloride-MLSS mixture hardened and formed fiber after 30 minutes in toluene. Then, the fiber was cut into cubical shape approximately 5×5×5 mm. All the cell entrapment steps including cutting were performed in a fume hood.

The cubical matrices were continuously flushed with tap water for 12 h to rinse residual toluene and then packed in a reactor. Previous studies on these types of entrapped microbial cells under an electron microscope showed that the internal structure is porous and the pore sizes are within a range that allows free diffusion of substrates but does not permit the escape of microorganisms (Yang et al., 1990).

3.3. Experimental Setup

3.3.1. Entrapped microbial cell system

An up-flow entrapped microbial cell reactor used in the study had a total volume of 2.5 liters. The reactor was made of a plexiglass tube with an inside diameter of 3.5 inches and a height of 18 inches. The entrapped cells occupied a volume of 1.2 liters of the reactor while the void volume was 1.3 liters including feed and outlet zones. The feed and outlet zones occupied 0.65 and 0.1 liters respectively. The entrapped microbial cell reactor was placed on a wooden stand. To minimize the change in quality, the influent wastewater was stored in a refrigerator at 4°C before it was fed at the bottom of the bioreactor by a peristaltic pump (Master flex model 7520-35). The effluent was discharged through a 0.5 inch outlet located at the top of the reactor. Air was provided at the bottom of the column through four stone diffusers and the flow rate was 1.0 l/min. A diagram of the entrapped mixed microbial cell reactor setup is shown in Figure 3.1.

3.3.2. Activated sludge system

A glass apparatus was used as an activated sludge system. It had a larger outer cone, a smaller inner cone and a clarifying tube hanger. The total volume of the reactor was 6 liters. The larger outer cone rested on a three leg support. The smaller inner cone had six thread supports to fit into the outer cone. The inner cone rested concentrically inside the outer cone by adjusting the six threads. The inner cone was lowered so that the top ridge of the inner cone was below the top ridge of the outer cone. A rectangular plexiglass plate held the clarifying tube inside the top ridge of the inner smaller cone. The effluent removal tube simply rested on the top of the clarifying tube hanger.

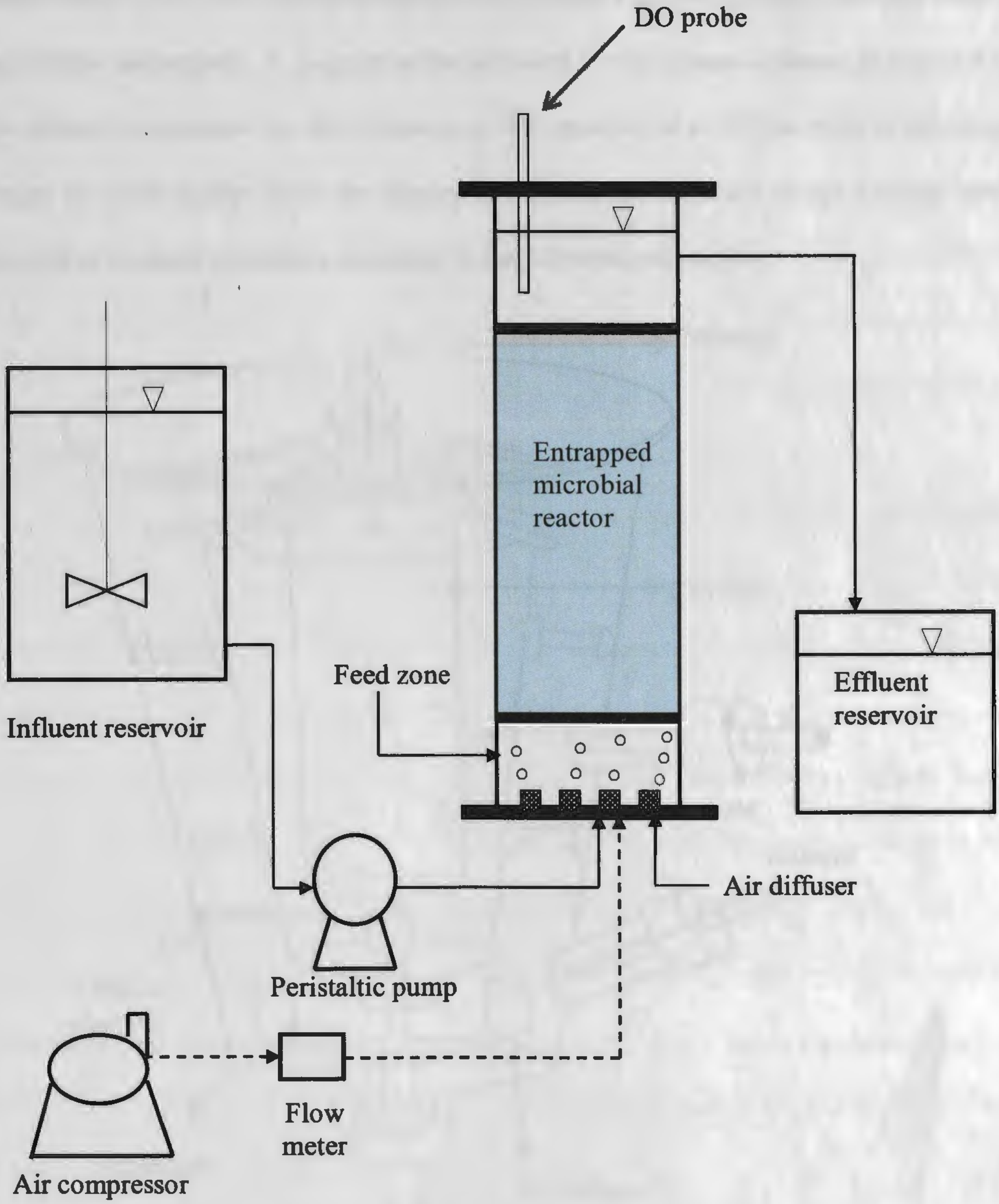

Figure 3.1 A diagram of entrapped microbial cell reactor system.

The influent was fed from the lower side of the outer cone. Three glass diffusers fitted at the bottom of the outer cone provided air between the larger outer cone and the smaller inner cone. The volumes of the aeration chamber and clarification chamber were 4 and 2 liters, respectively. A diagram of the activated sludge system is shown in Figure 3.2. The influent temperature for the system was also maintained at 4°C in order to minimize change in water quality. Both the entrapped cell and the activated sludge systems were operated at identical conditions described in the following subsection.

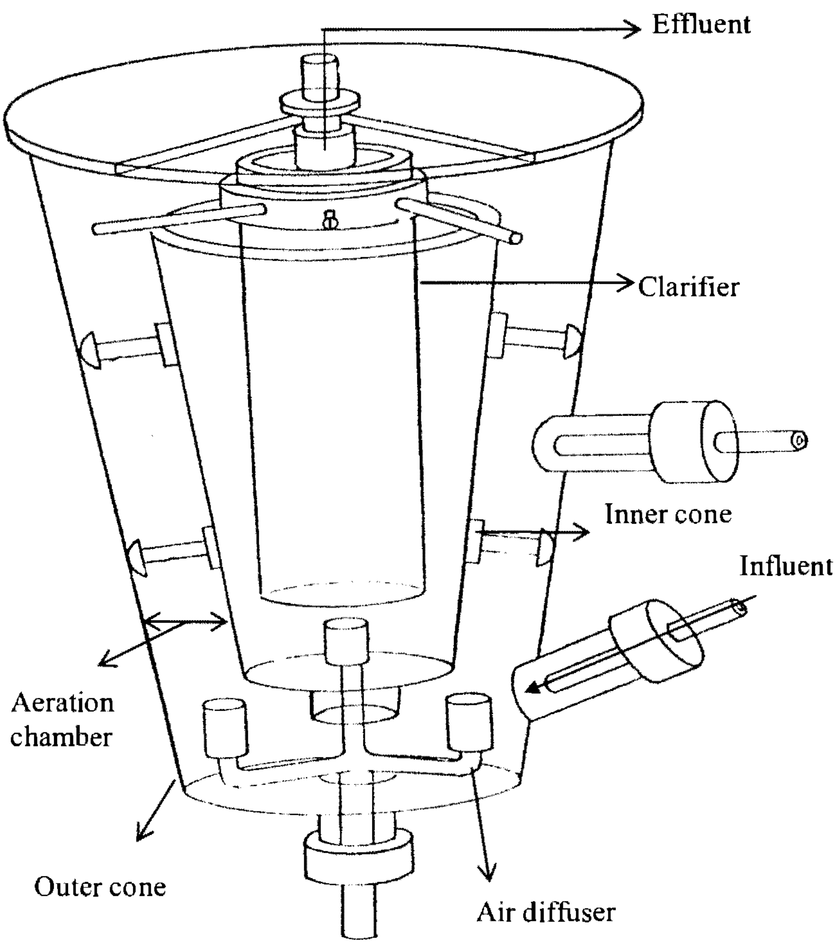

Figure 3.2 A diagram of activated sludge system.

3.4. Experimental Design and Procedure

The entrapped microbial cell reactor and activated sludge systems were operated simultaneously at a room temperature of 25 ± 2°C and the influent pH was monitored and found to be between 6.5 and 7.2. The solids retention time of the activated sludge system was maintained between 10 and 15 days by wasting 300 ml/d of the mixed liquor. The research was divided into four parts: 1. Effects of DO and OLR at a high HRT (9 h), 2. Effects of DO and OLR at a medium HRT (6 h), 3. Effects of DO and OLR at a low HRT (3 h), 4. Effect of filamentous overgrowth at a very low HRT (1.5 h) and chlorination to control the filamentous overgrowth in the entrapped microbial cell reactor. The durations for these four experiments were 50, 72, 72 and 20 days, respectively.

The first three experimental parts were conducted at three SCOD concentrations and three DO concentrations (3×3×3 experimental design) in the following order of HRTs, 6, 3 and 9 h while the last part (HRT of 1.5 h) was operated at three different SCOD concentrations and two different DO concentrations. It was not possible to operate the activated sludge system at an HRT of 1.5 h (last part) due to severe sludge bulking. Table 3.3 shows the detailed experimental design. From the start of each experiment, it took 2 days to achieve a steady state condition for the entrapped cell system. In the activated sludge system, 2-3 days were required to reach steady state. Effluent SCOD and soluble ammonia nitrogen (SNH_3-N) concentrations were used to determine the steady state. A steady state condition is achieved when there was minimal change (±10%) in the effluent SCOD and SNH_3-N concentrations.

One liter of the effluent was collected daily form both systems and analyzed for soluble carbonaceous BOD_5 ($SBOD_5$) SCOD, SNH_3-N, soluble nitrate-nitrogen (SNO_3-N), soluble nitrite-nitrogen (SNO_2-N), total suspended solids (TSS), MLSS, mixed liquor volatile suspended solids (MLVSS) and pH. It should be noted that MLSS and MLVSS are measured only for the activated sludge system.

Sodium hypochlorite (NaOCl) was used as a source of chlorine to find the effect of chlorination on the filamentous growth and performances of the entrapped cell system. Chlorination was conducted for only the worst condition (High filamentous microorganism abundance and low SCOD and $SBOD_5$ removal) which occurred in the last experimental part (very low HRT, low DO concentration and high OLR). Chlorine was directly introduced into the feeding zone on the third day of operation (one day after steady state was confirmed). Three different feeding chlorine concentrations of 100, 25 and 50 mg NaOCl/l were tested. When mixed with the synthetic wastewater in the feed zone, the feeding chlorine concentrations of 100, 25 and 50 mg NaOCl/l correspond to 60.60, 15.15 and 30.30 mg NaOCl/l in the synthetic wastewater. The chlorination was continuous for 6 h per day. Table 3.4 shows the chlorination parameters.

3.5. Analyses

Ammonia-nitrogen was analyzed using an ion selective electrode (Thermo Orion 250A+, VWR Symphony NH_3 Combination Electrode Cat. # 14002-794). Nitrate-nitrogen was analyzed using a VWR Symphony nitrate ion selective electrode in accordance with Standard Methods (APHA et al., 1998). Nitrite was analyzed colorimetrically using standard HACH NitriVer®2 reagents according to the method specified by the reagent manufacturer (HACH). TSS, MLVSS, $SBOD_5$, SCOD (HACH HR COD reagent), pH (Thermo Orion 250A+, pH Electrode 9107BN) and DO (Thermo Orion 850A+, 083005D) were all determined in accordance with Standard Methods (APHA et al., 1998).

Filamentous microorganisms were identified according to the simplified dichotomous key (Jenkins et al., 1984). The "Subjective Scoring of Filament Abundance" (Jenkins et al. 1993.) method was used to determine the abundance of filaments.

Table 3.3 Experimental design

Experiment No.	No. of Days Operated	HRT (h)	Design Values		
			DO (mg/l)	COD (mg/l)	OLR (mg COD/l.h)
1	6	6	5.7	300	50
2	4	6	5.7	206	34
3	4	6	5.7	120	20
4	4	6	4.5	300	50
5	4	6	4.5	206	34
6	4	6	4.5	120	20
7	8	6	2.0	300	50
8	8	6	2.0	206	34
9	8	6	2.0	120	20
10	8	3	5.7	300	100
11	8	3	5.7	206	69
12	8	3	5.7	120	40
13	8	3	4.5	300	100
14	8	3	4.5	206	69
15	8	3	4.5	120	40
16	8	3	2.0	300	100
17	8	3	2.0	206	69
18	8	3	2.0	120	40
19	8	9	5.7	300	33
20	8	9	5.7	206	23
21	8	9	5.7	120	13
22	8	9	4.5	300	33
23	8	9	4.5	206	23
24	8	9	4.5	120	13
25	8	9	2.0	300	33
26	8	9	2.0	206	23
27	8	9	2.0	120	13
28	5	1.5	2.0	300	200
29	5	1.5	2.0	206	137
30	5	1.5	2.0	120	80
31	5	1.5	4.5	300	200

Table 3.4 Chlorination parameters

Parameters	Values		
Chlorine concentration (mg/l)	100	25	50
HRT for chlorination (h)	6	6	6
Chlorination flow rate (l/d)	10	10	10
Chlorination loading rate (g/d)	1.00	0.25	0.50

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Design Values versus Experimental Values for DO, COD, and OLR

Table 4.1 shows the experimental values of DO, COD, and OLR. They are very close to the design values. The experimental values of DO were within ±0.3mg/l of the design values while the actual COD and corresponding OLR were within ±9 mg/l and ± 3 mg COD/l.h of the design values. Table 4.2 presents total number of days that the systems were operated and number of days which the systems were in steady-state and the data were collected. The entrapped cell system reached steady-state on the second day of operation for all conditions studied. The activated sludge system took longer to reach steady state at low HRT. It reached steady state on the third or fourth day of the operation because in the entrapped cell system, the number of cell matrix was constant for all experiments and there was no intentional cell wasting. In the activated sludge system, to maintain a SRT of 12 days, cells were wasted and therefore it took longer to achieve steady state. The activated sludge system was not operated at an HRT of 1.5 h (experiment no. 28, 29, 30 and 31) because the system started to experience bulking on the second day and therefore a steady state was impossible to achieve.

4.2. DO and OLR Effects at High HRT

4.2.1. Effects on SCOD and $SBOD_5$ removal

Figures 4.1(a) and 4.2(a) show the steady-state removal efficiency of SCOD and $SBOD_5$ of the entrapped microbial cell reactor while Figures 4.1(b) and 4.2(b) show the

Table 4.1 Design and experimental values of DO, COD, and OLR

Ex. No	HRT (h)	Design Values DO (mg/l)	COD (mg/l)	OLR (mg COD/l.h)	Experimental Values DO (mg/l)	COD (mg/l)	$SBOD_5$ (mg/l)	OLR (mg COD/l.h)
1	6	5.7	300	50	5.7	303	300	51
2	6	5.7	206	34	5.7	209	208	35
3	6	5.7	120	20	5.7	126	124	21
4	6	4.5	300	50	4.5	302	297	50
5	6	4.5	206	34	4.5	208	195	35
6	6	4.5	120	20	4.5	119	116	20
7	6	2.0	300	50	2.0	305	303	51
8	6	2.0	206	34	2.0	208	205	35
9	6	2.0	120	20	2.0	124	122	21
10	3	5.7	300	100	5.8	303	301	101
11	3	5.7	206	69	5.8	205	202	68
12	3	5.7	120	40	5.8	125	121	42
13	3	4.5	300	100	4.4	306	301	102
14	3	4.5	206	69	4.4	209	208	70
15	3	4.5	120	40	4.4	121	118	40
16	3	2.0	300	100	2.0	309	307	103
17	3	2.0	206	69	2.0	207	205	69
18	3	2.0	120	40	2.0	123	121	41
19	9	5.7	300	33	5.7	307	304	34
20	9	5.7	206	23	5.7	208	204	23
21	9	5.7	120	13	5.7	124	121	14
22	9	4.5	300	33	4.3	307	304	34
23	9	4.5	206	23	4.3	208	204	23
24	9	4.5	120	13	4.3	126	124	14
25	9	2.0	300	33	2.3	303	304	34
26	9	2.0	206	23	2.3	204	201	23
27	9	2.0	120	13	2.3	127	123	14
28	1.5	2.0	300	200	2.1	303	297	202
29	1.5	2.0	206	137	2.1	206	199	137
30	1.5	2.0	120	80	2.1	124	121	83
31	1.5	4.5	300	200	4.5	306	302	204

Table 4.2 Total number of days operated and number of days in steady-state

Experiment No.	Total No. of Days Operated	No. of Days in Steady-State	
		Entrapped Cell	Entrapped Cell
1	4	3	3
2	4	3	3
3	4	3	3
4	6	5	5
5	4	3	3
6	4	3	3
7	8	7	7
8	8	7	7
9	8	7	7
10	8	7	6
11	8	7	6
12	8	7	6
13	8	7	5
14	8	7	5
15	8	7	6
16	8	7	5
17	8	7	6
18	8	7	6
19	8	7	7
20	8	7	7
21	8	7	7
22	8	7	7
23	8	7	7
24	8	7	7
25	8	7	7
26	8	7	7
27	8	7	7
28	5	4	-*
29	5	4	-*
30	5	4	-*
31	5	4	-*

* Experiment was not operated

removal efficiency of SCOD and $SBOD_5$ in the activated sludge system. The analysis of variance (ANOVA) F-test was conducted to identify the significant difference in the average removal efficiencies of the entrapped microbial cell reactor and activated sludge system at different DOs and OLRs. For the activated sludge system, the average removal efficiency after bulking was used in the ANOVA F-test. When there was no bulking, the average removal efficiency after steady state was used in the ANOVA F-test. A criterion of p value greater than or equal to 0.7 was applied.

Based on the ANOVA F-test, DO and OLR did not affect SCOD and $SBOD_5$ removal in the Entrapped microbial reactor and the activated sludge systems ($p = 0.89$ and $p = 0.81$ respectively). The SCOD and $SBOD_5$ removal efficiencies in the entrapped microbial cell reactor were much higher than those in the activated sludge systems. Because of the high cell density in the entrapped cells (Nedovi et al., 2005), there was more need for and consumption of substrate (organic in the synthetic wastewater) resulting in higher removal efficiency. For both the entrapped microbial cell reactor and the activated sludge systems, the SCOD and $SBOD_5$ removal efficiencies were quite similar. This is because synthetic wastewater was used as the influent. The data reported for all the experiments is the average after steady state is achieved. The numbers on the bar graphs shows the standard deviation after a steady state condition is achieved.

4.2.2. Effects on nitrogen removal

Figures 4.3(a) and 4.3(b) show the soluble total nitrogen (STN) removal efficiency of the entrapped microbial cell reactor and activated sludge system, respectively. STN was based on the summation of SNH_3-N and SNO_3-N; there was no organic N in the synthetic wastewater and SNO_2-N was below the detection limit (0.1 mg N/L). The entrapped cell

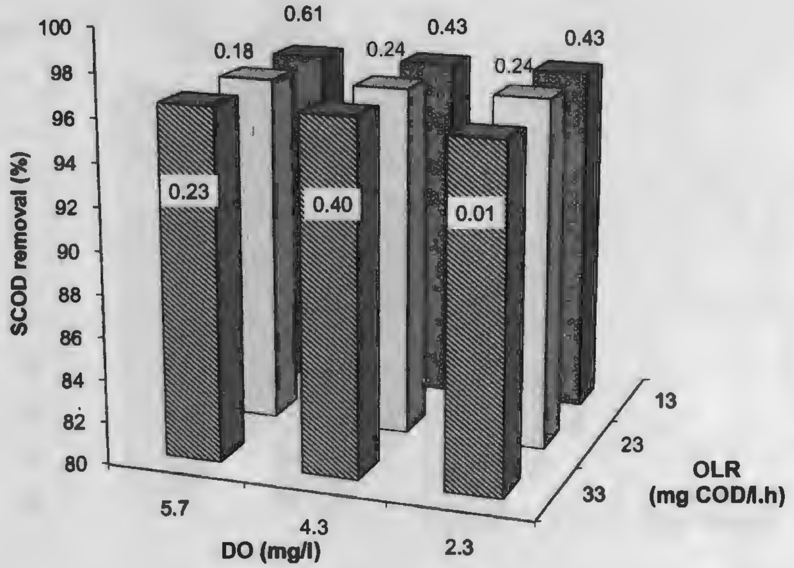

Figure 4.1(a) Percent SCOD removal at different DOs and OLRs for entrapped microbial cell reactor at high HRT (Standard deviation listed on or above the bars).

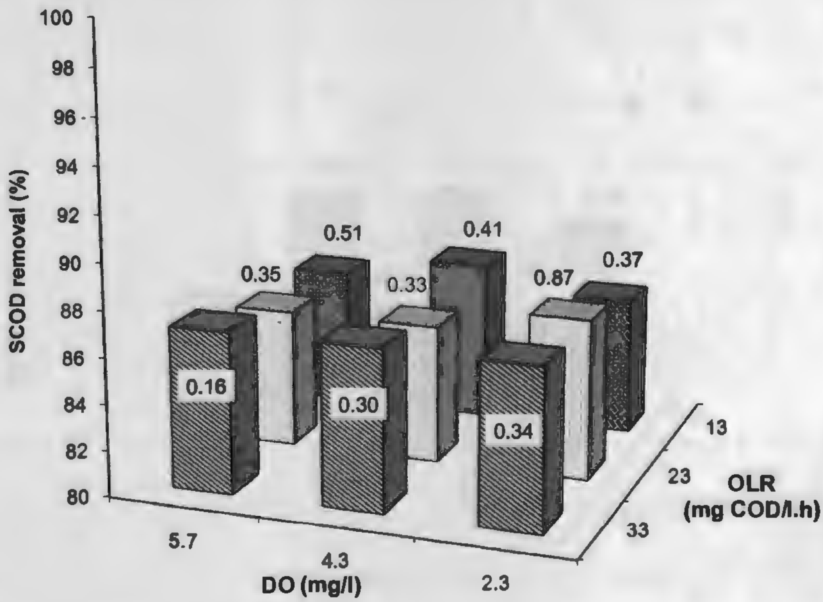

Figure 4.1 (b) Percent SCOD removal at different DOs and OLRs for activated sludge system at high HRT (Standard deviation listed on or above the bars).

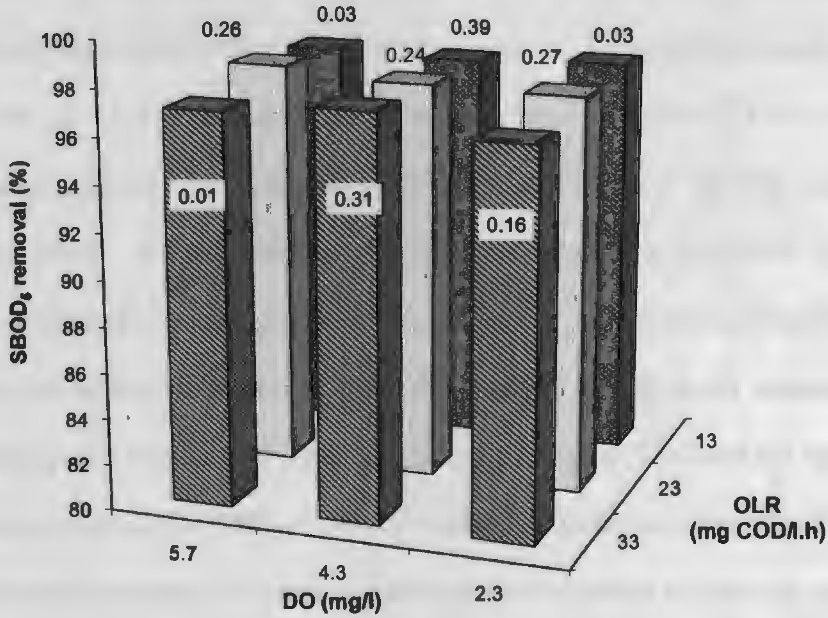

Figure 4.2(a) Percent $SBOD_5$ removal at different DOs and OLRs for entrapped microbial cell reactor at high HRT (Standard deviation listed on or above the bars).

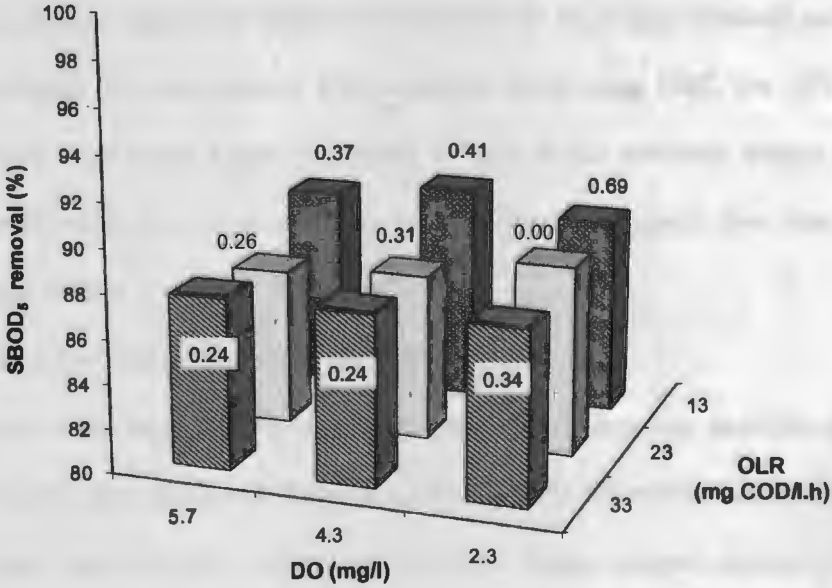

Figure 4.2(b) Percent $SBOD_5$ removal at different DOs and OLRs for activated sludge system at high HRT (Standard deviation listed on or above the bars).

system removed 37 to 39% of STN while the activated sludge system removed 26 to 30% of STN. DO and OLR had no effect on STN removal in the Entrapped microbial reactor (ANOVA F-Test, p = 0.85) and the activated sludge system (ANOVA F-Test, p = 0.8). Table 4.3 shows effluent concentrations of SNH_3-N and SNO_3-N in both entrapped microbial cell reactor and activated sludge systems. Based on the initial SNH_3-N concentration of synthetic wastewater of 26.5 mg N/L and N mass balance, N used for cell synthesis was calculated as presented in Table 4.3. The cell density in the entrapped cell system is much greater than that of the activated sludge system. Therefore the entrapped microbial system uptakes more SNH_3-N for cell synthesis than the activated sludge system. That was the reason for higher STN removal in entrapped microbial cell reactor compared to the activated sludge system.

Bacteria responsible for nitrification grow very slowly. Therefore to get better nitrification, hydraulic and solids retention times have to be longer (Metcalf and Eddy, 2003). Even though both the reactors were operated at the same HRT, the SRT of the entrapped system was much higher compared to that of the activated sludge system. Therefore, nitrification was more efficient in the entrapped system than that of the activated sludge system.

4.2.3. Effects on filamentous bulking and solids

Effluents from both the reactors were used for filamentous identification and abundance quantification. Figures 4.4(a) and 4.4(b) show the filamentous abundance scale in the entrapped microbial cell reactor and activated sludge system, respectively. The abundance scale shown in both figures was based on the highest value observed after

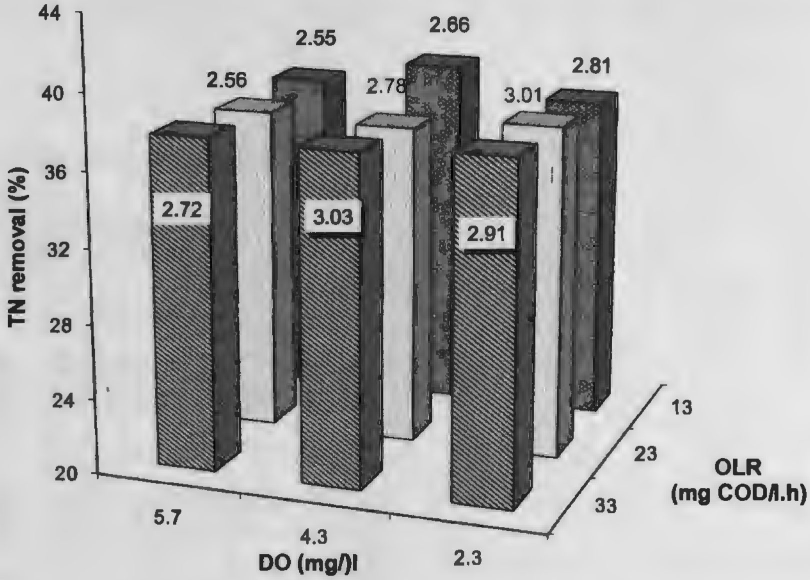

Figure 4.3(a) Percent STN removal at different DOs and OLRs for entrapped microbial cell reactor at high HRT(Standard deviation listed on or above the bars).

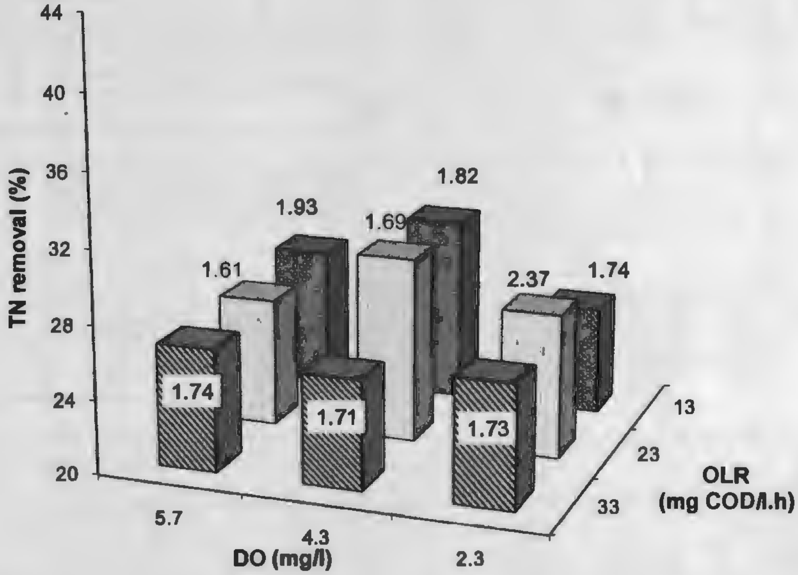

Figure 4.3(b) Percent STN removals at different DOs and OLRs for activated sludge system at high HRT (Standard deviation listed on or above the bars).

Table 4.3 Nitrogen concentrations at high HRT

Experiment No.	DO (mg/L)	Loading Rate (mg/l.h)	Entrapped Microbial Cell Reactor			Activated Sludge System		
			Effluent SNH_3-N (mg/l)	Effluent SNO_3-N (mg/l)	N Used for Cell Synthesis (mg/l)	Effluent SNH_3-N (mg/l)	Effluent SNO_3-N (mg/l)	N Used for Cell Synthesis (mg/l)
19	5.7	33	2.49	13.93	10.08	6.57	12.77	7.16
22	4.3	33	2.67	13.77	10.06	6.87	12.67	6.96
25	2.3	33	2.53	13.81	10.16	6.81	12.53	7.16
20	5.7	23	2.73	13.76	10.01	6.66	12.60	7.24
23	4.3	23	2.57	13.99	9.94	6.07	12.37	8.06
26	2.3	23	2.37	14.01	10.12	6.26	12.77	7.47
21	5.7	13	2.49	13.93	10.08	6.50	12.59	7.41
24	4.3	13	2.49	13.59	10.42	6.56	11.87	8.07
27	2.3	13	2.79	13.67	10.04	7.27	12.27	6.96

steady state. Once the abundance scale reached the highest value, it never decreased. The filamentous abundance scales in both the reactors were common or higher (scale of ≥ 3) from the second day of operation. This is likely because of the readily biodegradable substrate, sucrose which could have triggered this growth.

DO and OLR had some effects on the filamentous abundance in both reactors. In the entrapped cell reactor, at the lowest DO concentration, the filamentous abundance increased by one scale, common to very common. Low DO concentration led to the increase in the filamentous abundance scale by several filaments. However, the filamentous abundance did not substantially affect SCOD and $SBOD_5$ removal efficiencies and effluent TSS as shown in Table 4.4. OLR had less effect on the filamentous abundance compared to DO.

S. natans was identified as the dominant filamentous microorganism in the entrapped microbial cell system. This organism usually occurs at low DO concentrations. Figure 4.5 shows *S. natans* found in the effluent of entrapped microbial cell reactor. Figure 4.6 shows the biofilm formation on the entrapped cell matrix. A thin to thick layer of biofilm was observed on the entrapped matrix. The biofilm existence was not uniform throughout the cell matrix. It was patchy and therefore oxygen diffusion inside the matrix was not affected, minimizing the chance for denitrification. The biofilm did not affect the performance of the reactor. Cell matrices were washed thoroughly with tap water and distilled water at the end of each experiment to avoid the biofilm carry over. Steady state in the reactor was achieved on the second day of operation while the biofilm on the surface of the media was growing everyday and a thick layer of biofilm was observed after day 6. If the biofilm affected the performance of the reactor, the steady-state condition should not be achieved and maintainable after a short start-up period (1 day). At the end of each experiment, few cell matrices were taken from the reactor and the biofilm was washed and collected in a 50 ml beaker and stirred well. A slide was prepared and examined for filamentous organisms. Filamentous microorganisms grown on the biofilm were found. Figure 4.7 shows the filamentous microorganisms in the biofilm wash from the surface of entrapment media.

At the lowest DO and lowest and medium OLR, the filamentous scale of the activated sludge system was abundant and excessive (scales of 5 and 6). The abundance of 6 did not affect SCOD and $SBOD_5$ removal efficiency of the system but the bulking occurred as evidenced by an increase in the effluent TSS concentration from 28 to 105 mg/l. Foaming was not observed in the system. *M. parvicella* was identified as the dominant filamentous microorganism. This organism occurs at low loading rate and with a long SRT (10-40 days) and/or high grease/oil concentration. Figure 4.8 shows the *M. parvicella* found in the activated sludge system.

4.3. DO and OLR Effects at Medium HRT

4.3.1. Effects on SCOD and $SBOD_5$ removal

Figures 4.9(a) and 4.10(a) show the removal of SCOD and SBOD5 in the entrapped microbial cell reactor. DO and OLR did not affect SCOD and SBOD5 removal efficiencies in the Entrapped microbial reactor (ANOVA F-test, $p = 0.83$). There was no difference in the average SCOD and SBOD5 removal efficiencies between high and medium HRTs [Figures 4.9(a) and 4.10(a) versus Figures 4.1(a) and 4.2(a)]. For the activated sludge system (ANOVA F-test, $p = 0.43$), SCOD and SBOD5 removal efficiencies dropped at the low and medium DO concentrations when the OLR was the

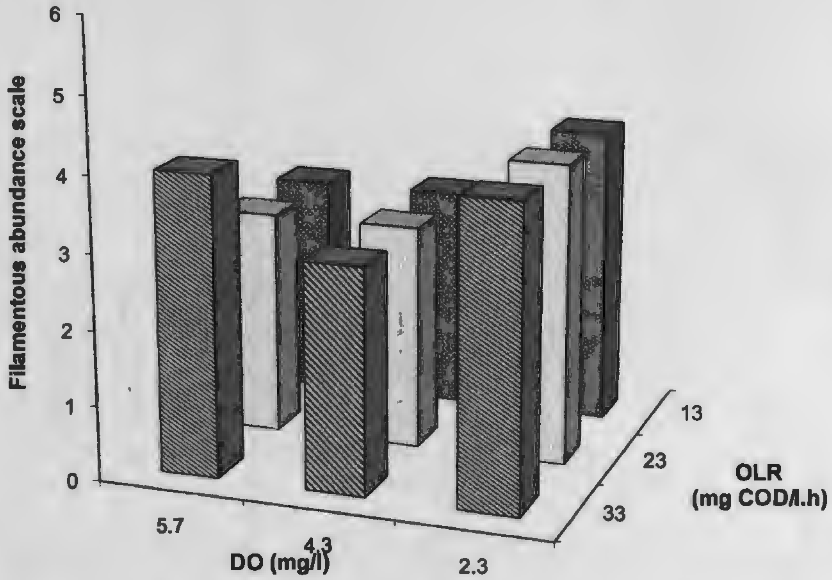

Figure 4.4(a) Filamentous abundance count at different DOs and OLRs for entrapped microbial cell reactor at high HRT.

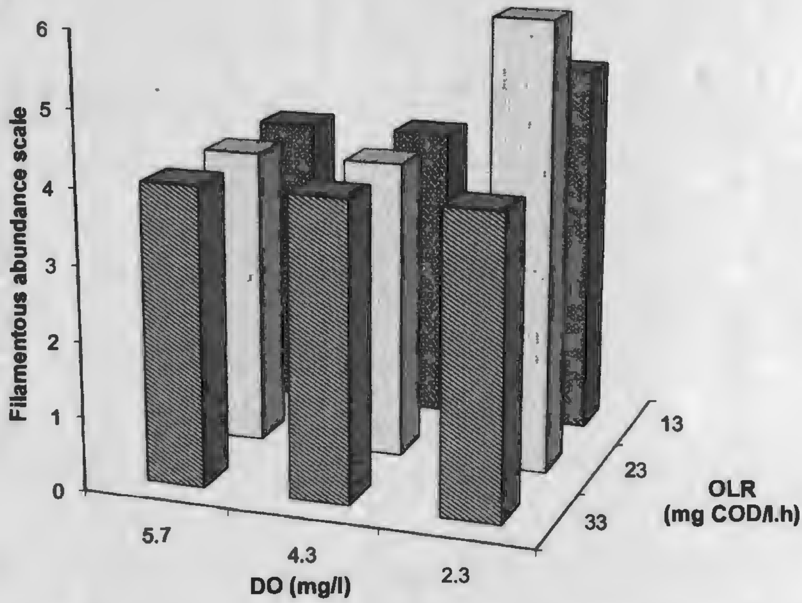

Figure 4.4(b) Filamentous abundance count at different DOs and OLRs for activated sludge system at high HRT.

Table 4.4 TSS and filamentous organism type in the reactors at high HRT

Experiment No.	DO (mg/L)	OLR (mg COD/l.h)	Entrapped Cell Reactor		Activated Sludge System	
			Effluent TSS (mg/l)	Filamentous Type	Effluent TSS (mg/l)	Filamentous Type
19	5.7	33	26	*S. natans*	21	*M. parvicella*
22	4.3	33	18	*S. natans*	20	*M. parvicella*
25	2.3	33	22	*S. natans*	15	*M. parvicella*
20	5.7	23	27	*S. natans*	22	*M. parvicella*
23	4.3	23	19	*S. natans*	19	*M. parvicella*
26	2.3	23	23	*S. natans*	28-105	*M. parvicella*
21	5.7	13	25	*S. natans*	21	*M. parvicella*
24	4.3	13	16	*S. natans*	19	*M. parvicella*
27	2.3	13	19	*S. natans*	26	*M. parvicella*

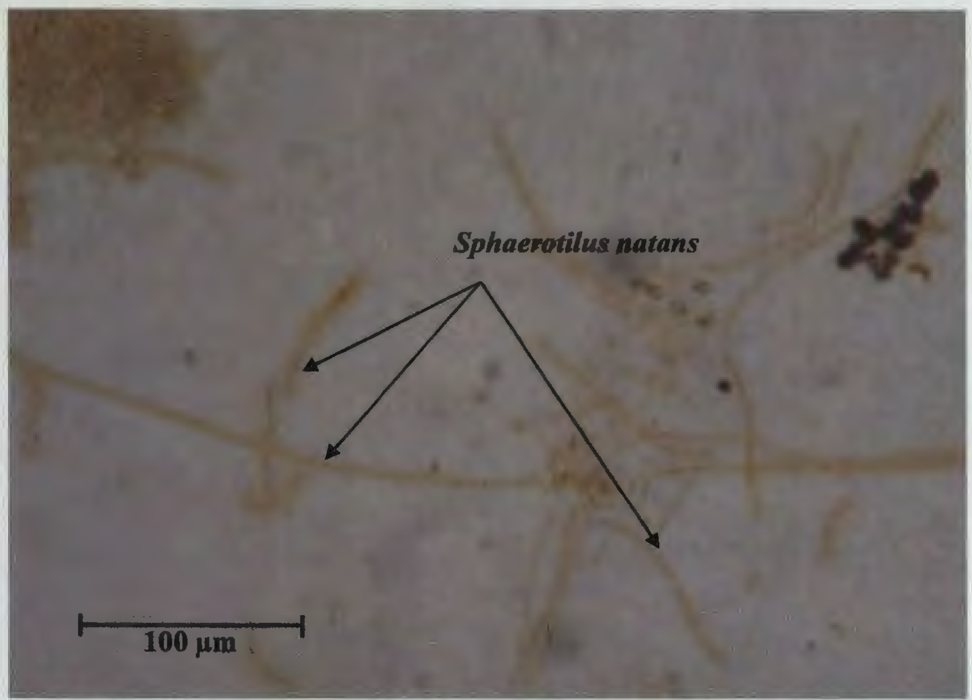

Figure 4.5 Dominant filamentous microorganism in entrapped microbial cell reactor at high HRT.

Figure 4.6 Biofilm formation on the surface of entrapment media at high HRT.

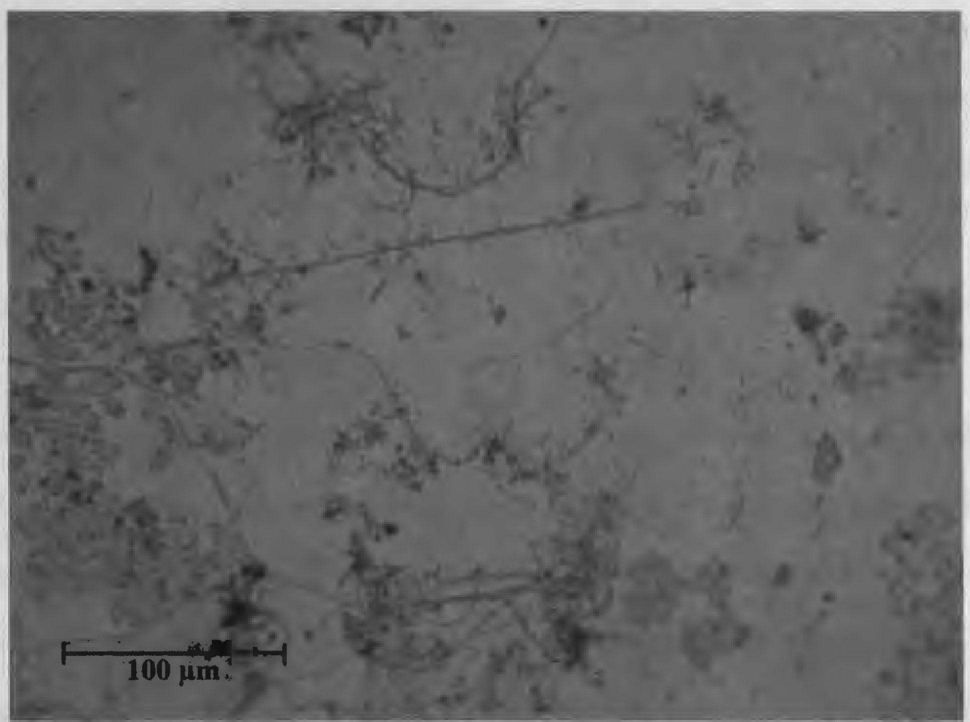

Figure 4.7 Filamentous microorganisms in the biofilm wash from the surface of entrapment media at high HRT.

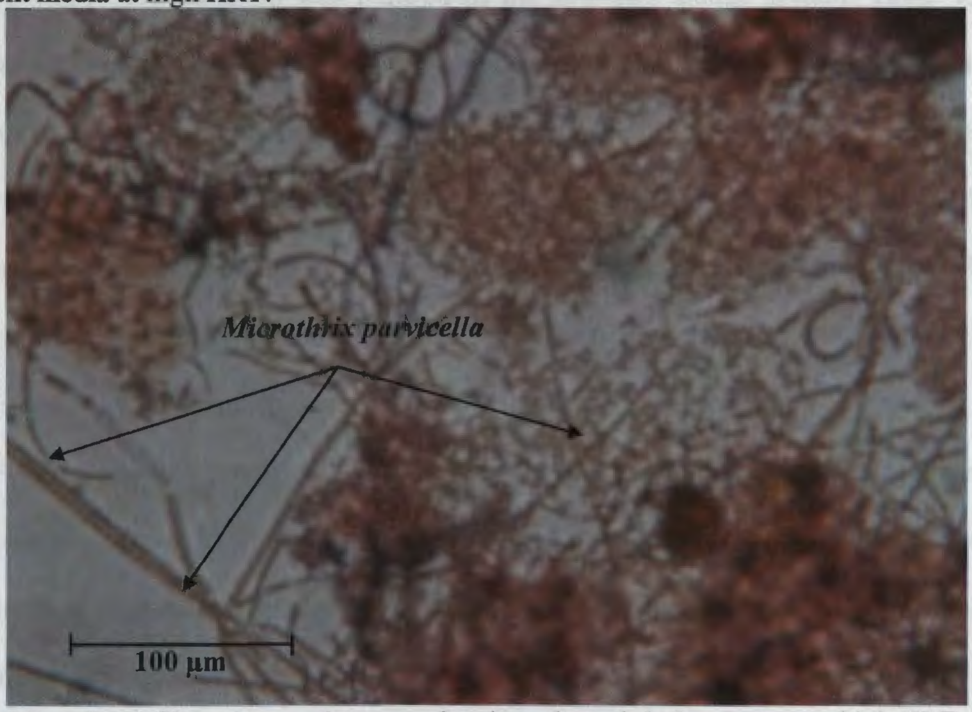

Figure 4.8 Dominant filamentous microorganism in activated sludge system at high HRT.

highest [Figure 4.9(b) and 4.10(b)]. These efficiency decreases were due to the loss of MLSS due to bulking (discussed in section 4.3.3). The entrapped microbial cell reactor was much more efficient than the activated sludge systems in removing SCOD and $SBOD_5$.

4.3.2. Effects on nitrogen removal

The entrapped cell system removed 36 to 37% of STN [Figure 4.11(a)] while the activated sludge system removed 29 to 31% [Figure 4.11(b)]. DO and OLR had no effect on STN removal in the Entrapped microbial reactor and the activated sludge system. Table 4.5 shows the concentrations of SNH_3-N and SNO_3-N in both entrapped microbial cell reactor and activated sludge systems. For the same reason as explained in section 4.2.2, the entrapped microbial cell reactor reduced SNH_3-N concentration by 90%, whereas only 75% of SNH_3-N concentration was reduced in the activated sludge system. Table 4.5 shows the nitrogen concentration (based on the mass balance for nitrogen). Nitrification in the entrapped system was much higher than that of the activated sludge system. Similar to the previous experiment (high HRT), the entrapped microbial system used more SNH_3-N for cell synthesis than the activated sludge system. That was the reason for higher STN removal in the entrapped microbial cell reactor compared to the activated sludge system.

4.3.3. Effects on filamentous bulking and solids

Filamentous abundance scale in the entrapped microbial cell reactor and activated sludge system is shown in Figures 4.12(a) and 4.12(b). DO and OLR had some effects on the filamentous abundance in both reactors. At the low DO concentration, the filamentous organisms were found excessive in the entrapped cell reactor (for the same reasons stated

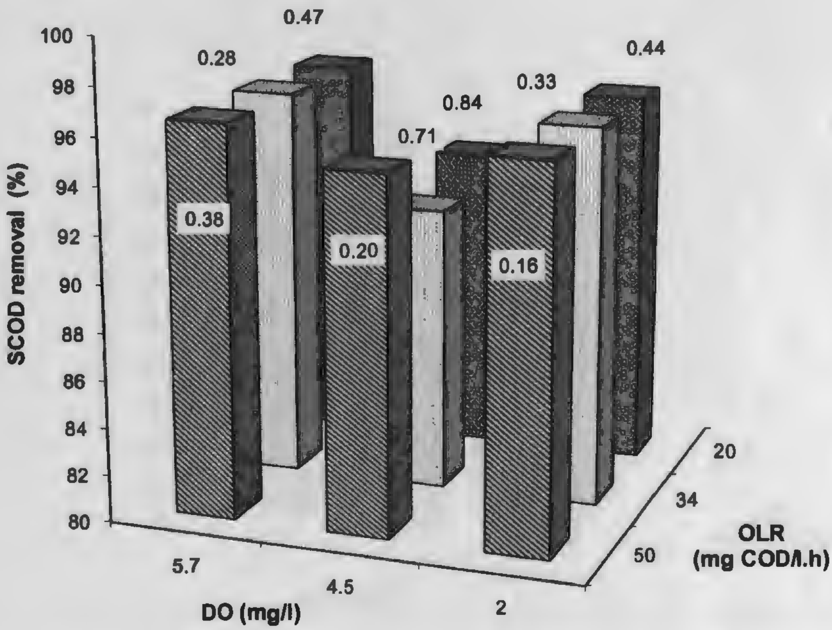

Figure 4.9(a) Percent SCOD removal at different DOs and OLRs for entrapped microbial cell reactor at medium HRT (Standard deviation listed on or above the bars).

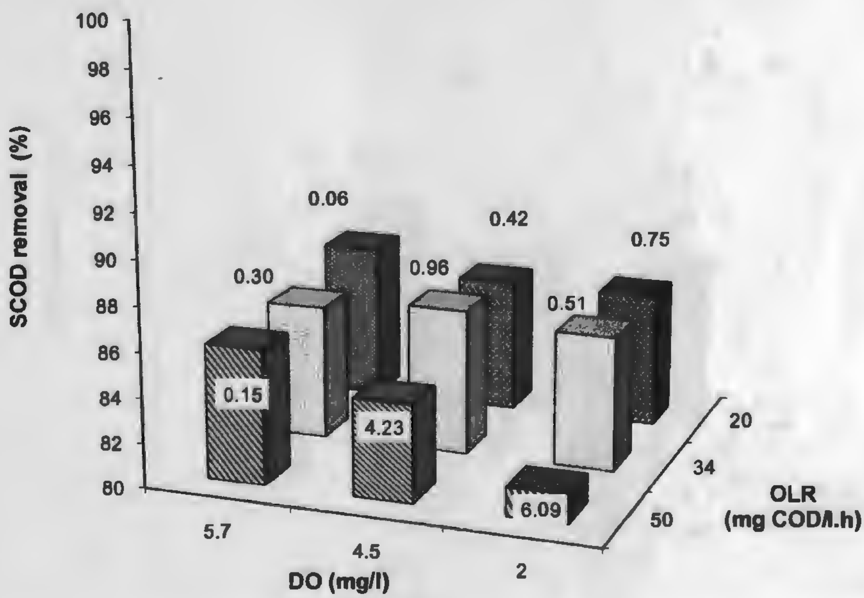

Figure 4.9(b) Percent SCOD removal at different DOs and OLRs for activated sludge system at medium HRT (Standard deviation listed on or above the bars).

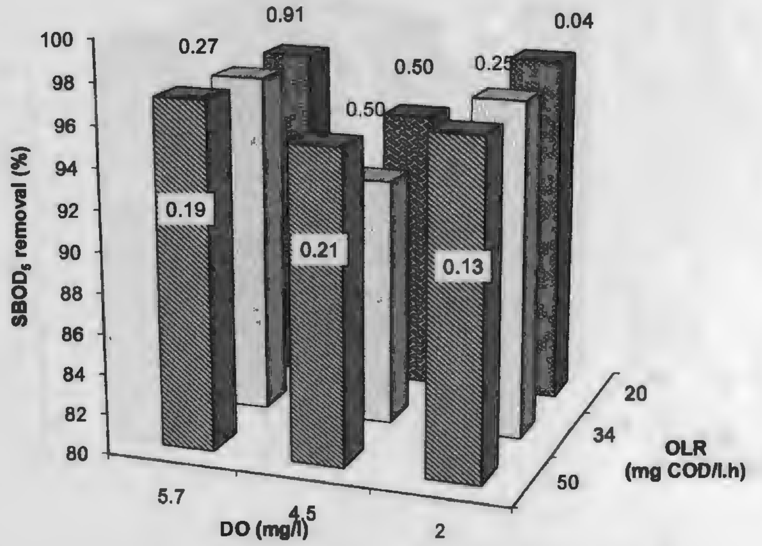

Figure 4.10(a) Percent $SBOD_5$ removal at different DOs and OLRs for entrapped microbial cell reactor at medium HRT (Standard deviation listed on or above the bars).

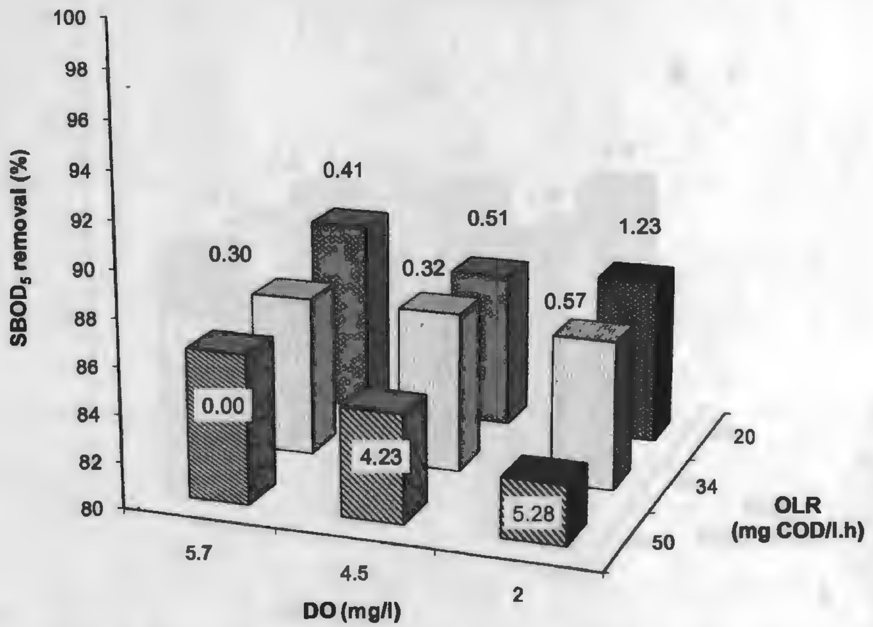

Figure 4.10(b) Percent $SBOD_5$ removal at different DOs and OLRs for activated sludge system at medium HR (Standard deviation listed on or above the bars).

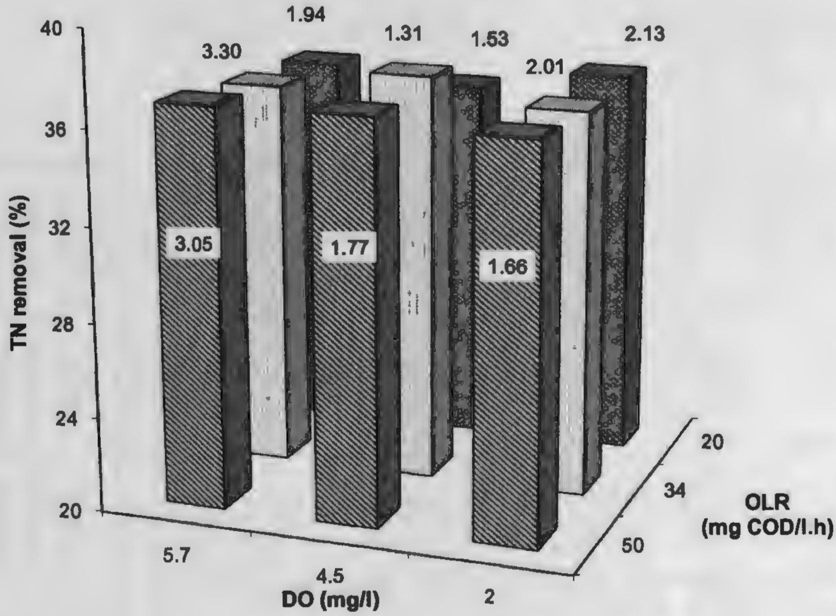

Figure 4.11(a) Percent STN removal at different DOs and OLRs for entrapped microbial cell reactor at medium HRT (Standard deviation listed on or above the bars).

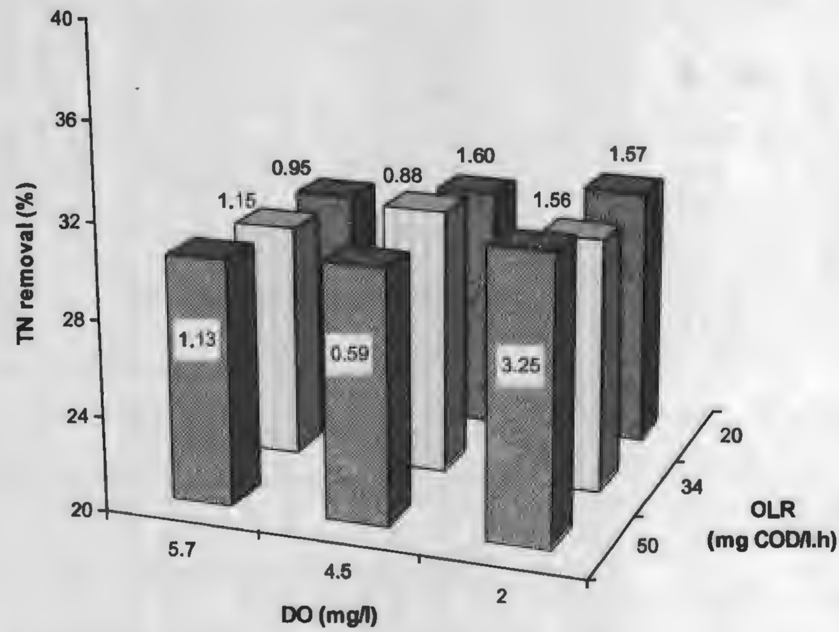

Figure 4.11(b) Percent STN removal at different DOs and OLRs for activated sludge system at medium HRT (Standard deviation listed on or above the bars).

Table 4.5 Nitrogen concentrations at medium HRT

Experiment No.	DO (mg/L)	Loading Rate (mg/l.h)	Entrapped Microbial Cell Reactor			Activated Sludge System		
			Effluent SNH_3-N (mg/l)	Effluent SNO_3-N (mg/l)	N Used for Cell Synthesis (mg/l)	Effluent SNH_3-N (mg/l)	Effluent SNO_3-N (mg/l)	N Used for Cell Synthesis (mg/l)
1	5.7	50	2.60	14.03	9.87	5.69	12.68	8.13
4	4.3	50	2.33	14.29	9.88	5.67	12.62	8.21
7	2.3	50	2.46	14.27	9.77	6.23	11.71	8.56
2	5.7	34	2.63	14.10	9.77	5.77	12.70	8.03
5	4.3	34	2.36	14.14	10.00	5.50	12.64	8.36
8	2.3	34	2.47	14.30	9.73	5.43	12.84	8.23
3	5.7	20	2.70	14.30	9.50	5.77	12.77	7.96
6	4.3	20	2.50	14.43	9.57	5.68	12.66	8.16
9	2.3	20	2.67	14.03	9.80	5.53	12.64	8.33

in section 4.2.3). Excessive filamentous growth did not affect the removal efficiency of the reactor. *S. natans* was identified as the dominant filamentous microorganism in the entrapped microbial cell system, same as in the previous experiment. Figure 4.13 shows *S. natans* found in the effluent of the entrapped microbial cell reactor. Figure 4.14 shows the biofilm formation on the entrapment matrix. A thick layer of biofilm was observed on the entrapment matrix. The biofilm did not affect the performance of the reactor.

At the low DO concentration, the filamentous scale of the activated sludge system was abundant and excessive (scales of 5 and 6). At the high OLR and the medium and low DO concentrations (4.5 and 2 mg/l), the activated sludge system had a severe bulking problem. TSS concentration and filamentous type in both the reactors at medium HRT is shown in Table 4.6. The TSS concentration in the effluent increased from 15 to 117 mg/l and the SCOD removal efficiency dropped from 86% (after steady state) to 75% (fourth day of operation). Bulking was observed from the fourth day of operation. Foaming was also observed in the system. For activated sludge systems, it is known that the DO concentration to prevent "low DO bulking" is a function of the organic loading rate. Higher DO is required to prevent the growth of the filaments as the OLR increases, due to faster oxygen consumption (Palm et al., 1980). *M. parvicella* was identified as the dominant filamentous microorganism in the activated sludge system. *M. parvicella* is a foam producing microorganism (Blackbeard et al., 1986, Blackall et al., 1991). Figure 4.15 shows *M. parvicella* found in the activated sludge system.

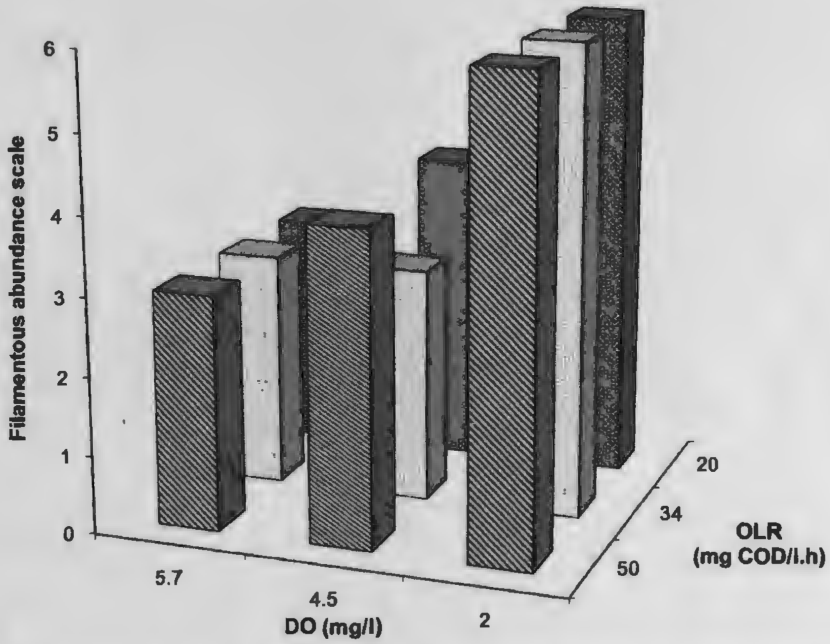

Figure 4.12(a) Filamentous abundance count at different DOs and OLRs for entrapped microbial cell reactor at medium HRT.

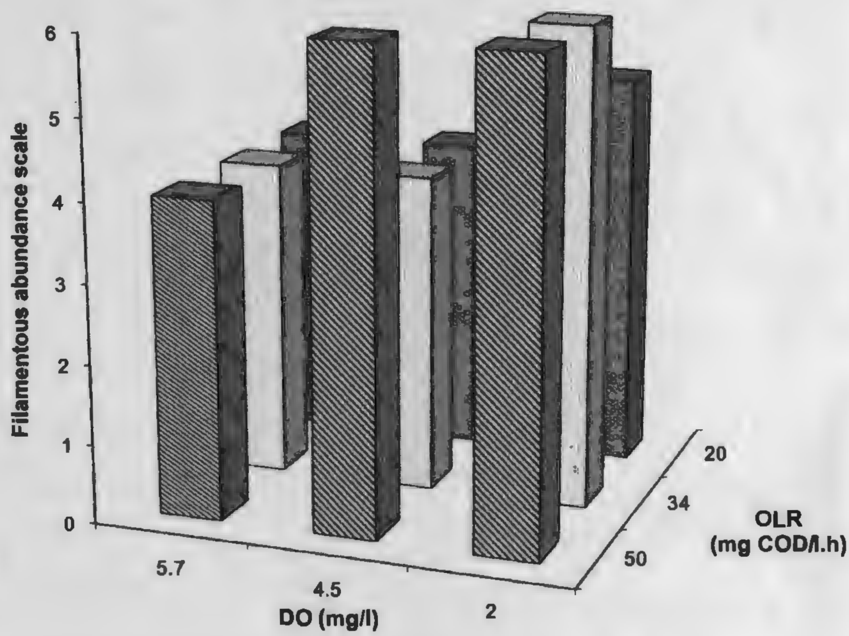

Figure 4.12(b) Filamentous abundance count at different DOs and OLRs for activated sludge system at medium HRT.

Table 4.6 TSS and filamentous organism type in the reactors at medium HRT

Experiment No.	DO (mg/L)	OLR (mg COD/l.h)	Entrapped Cell Reactor		Activated Sludge System	
			Effluent TSS (mg/l)	Filamentous Type	Effluent TSS (mg/l)	Filamentous Type
1	5.7	50	22	*S. natans*	17	*M. parvicella*
4	4.3	50	22	*S. natans*	15-105	*M. parvicella*
7	2.3	50	28	*S. natans*	16-117	*M. parvicella*
2	5.7	34	22	*S. natans*	16	*M. parvicella*
5	4.3	34	23	*S. natans*	15	*M. parvicella*
8	2.3	34	27	*S. natans*	17	*M. parvicella*
3	5.7	20	22	*S. natans*	16	*M. parvicella*
6	4.3	20	21	*S. natans*	16	*M. parvicella*
9	2.3	20	26	*S. natans*	19	*M. parvicella*

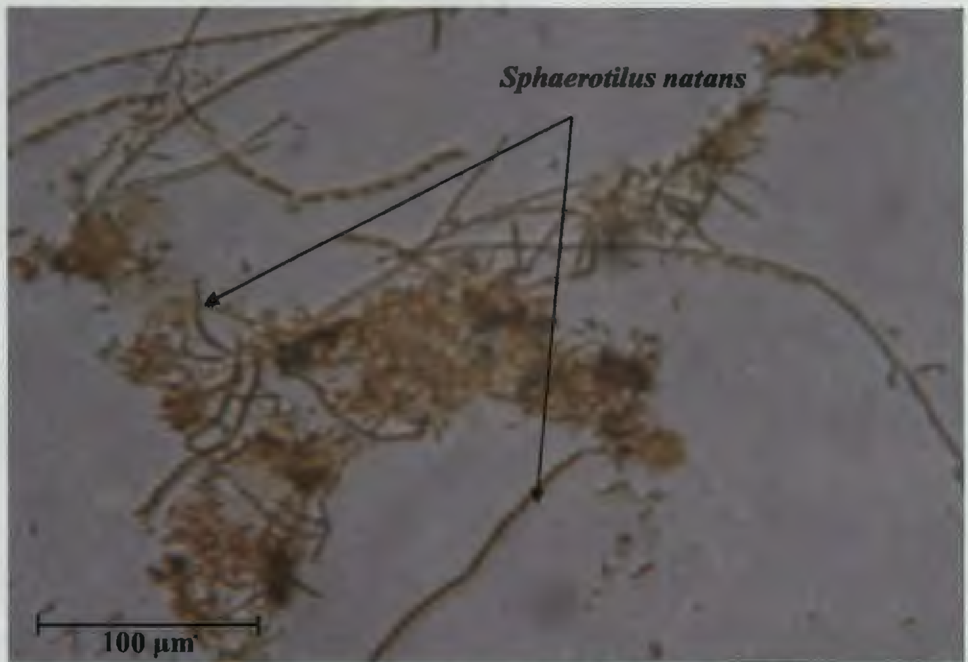

Figure 4.13 Dominant filamentous microorganism in entrapped microbial cell reactor at medium HRT.

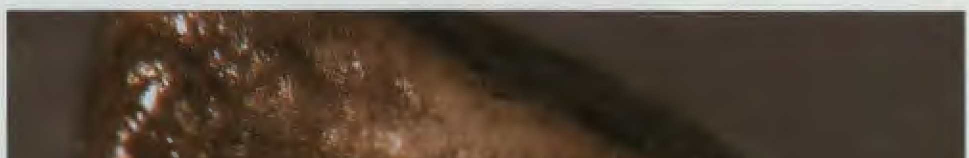

Figure 4.14 Biofilm formation on the surface of entrapment media at medium HRT.

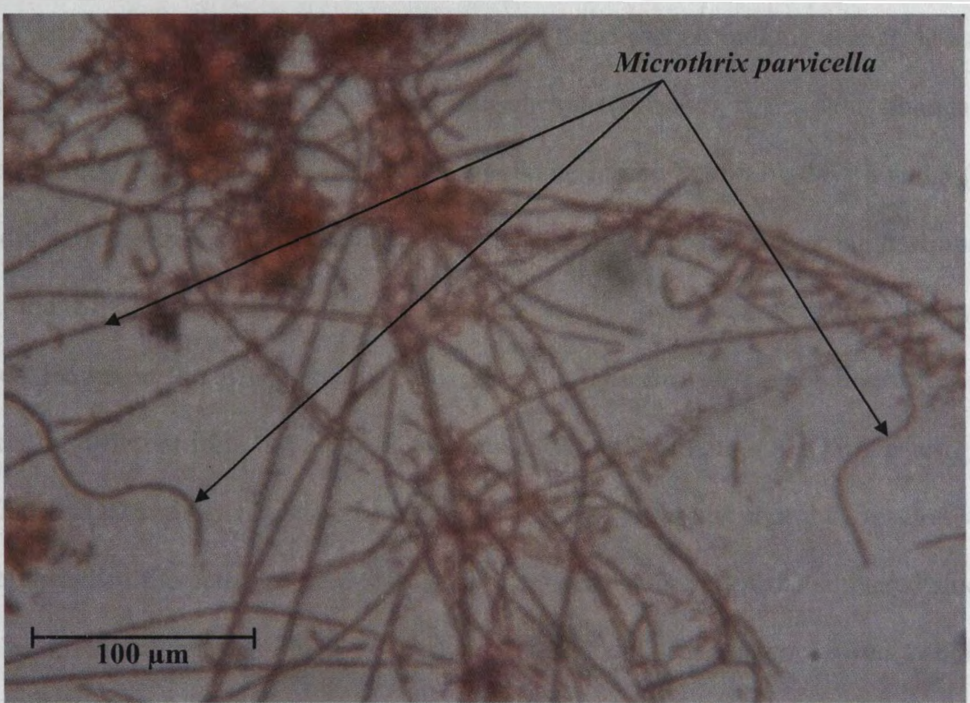

Figure 4.15 Dominant filamentous microorganism in activated sludge system at medium HRT.

4.4. DO and OLR Effects at Low HRT

4.4.1. Effects on SCOD and $SBOD_5$ removal

Figures 4.16(a) and 4.17(a) show the SCOD and $SBOD_5$ removal efficiencies in the entrapped cell system. The ANOVA F-test showed no significant difference in the SCOD and $SBOD_5$ removal efficiencies in the Entrapped microbial reactor at different DOs and OLRs ($p = 0.81$). The SCOD and $SBOD_5$ removal efficiencies at low HRT were lower than those at high and medium HRTs [Figures 4.16(a), 4.17(a) versus Figures 4.1(a), 4.2(a), 4.9(a), and 4.10(a)].

For the activated sludge system, the lowest SCOD and $SBOD_5$ removal occurred at the following three conditions: low DO and high OLR, low DO and medium OLR, and high DO and low OLR [Figure 4.16(b) and 4.17(b)]. The loss of MLSS due to severe bulking (discussed in section 4.4.3) was the cause for these drops in the efficiencies for the first two scenarios (see section 4.4.3). Even though there was no bulking at high DO and low OLR, because of the readily biodegradable substrate (sucrose), filamentous abundance count at this condition was excessive. There was some loss in MLSS on days 4 and 5 (see Appendix A, Experiment 12, Activated Sludge System). As a consequence, slight drops in SCOD and SBOD removal (6% drop after the steady state was first reached) were observed. However, the SCOD and $SBOD_5$ removal efficiencies at this condition were not significantly different from the other six conditions with no bulking (ANOVA F-test, p = 0.85). The SCOD and $SBOD_5$ removal efficiencies in the Entrapped microbial reactor were much higher than the activated sludge system. The BOD removal of the activated sludge system at all conditions was much lower than 85%, which is the criterion used to define secondary wastewater treatment.

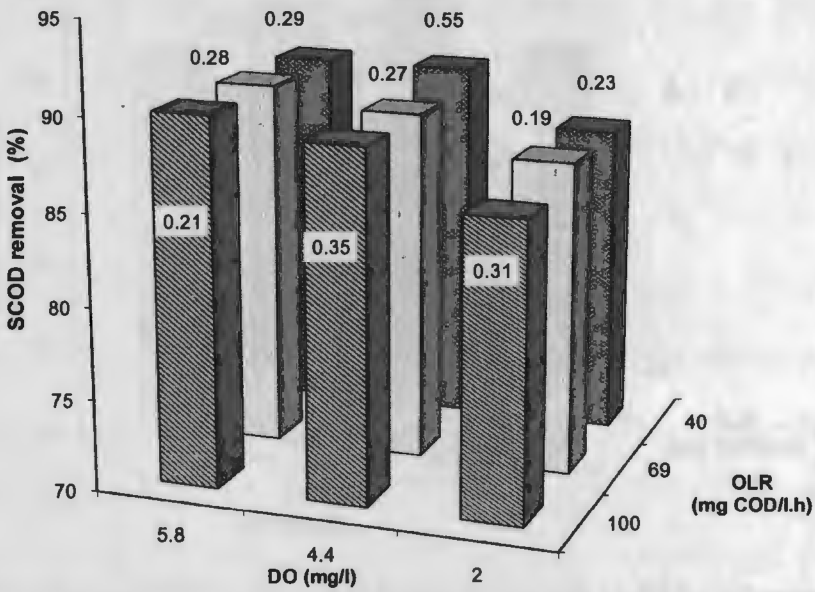

Figure 4.16(a) Percent SCOD removal at different DOs and OLRs for entrapped microbial cell reactor at low HRT (Standard deviation listed on or above the bars).

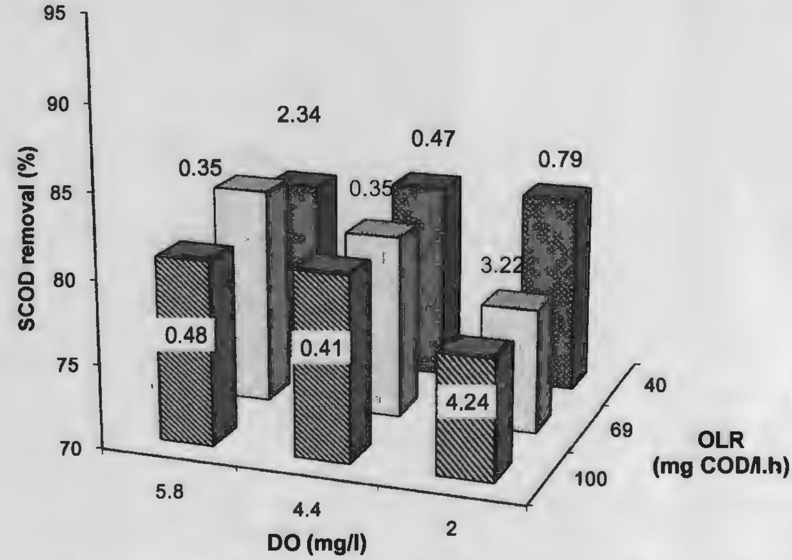

Figure 4.16(b) Percent SCOD removal at different DOs and OLRs for activated sludge system low HRT (Standard deviation listed on or above the bars).

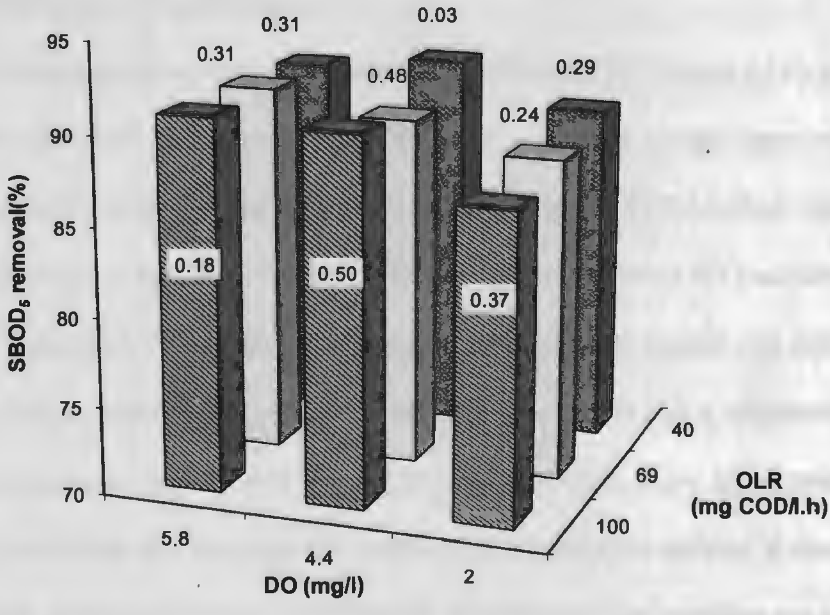

Figure 4.17(a) Percent $SBOD_5$ removal at different DOs and OLRs for entrapped microbial cell reactor at low HRT (Standard deviation listed on or above the bars).

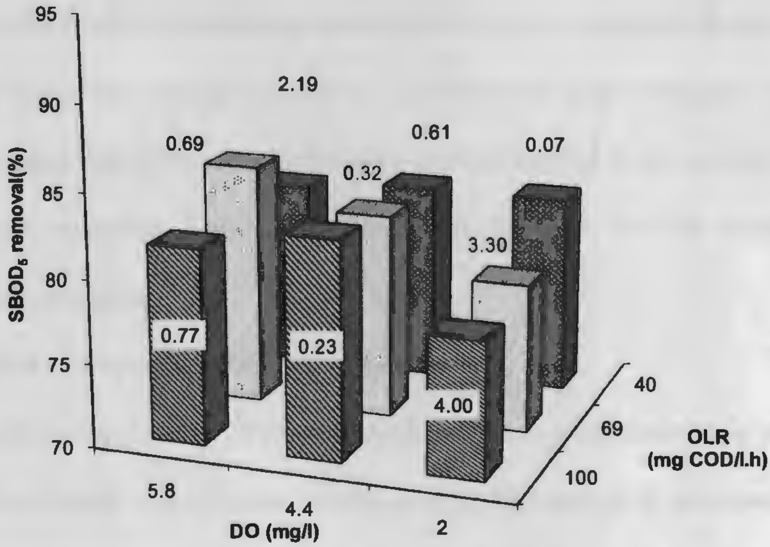

Figure 4.17(b) Percent $SBOD_5$ removal at different DOs and OLRs for activated sludge system low HRT(Standard deviation listed on or above the bars).

4.4.2. Effects on nitrogen removal

The entrapped cell system removed 32 to 36% of STN [Figure 4.18(a)] and DO and OLR had no effect on STN removal. The activated sludge system removed 12 to 30% [Figure 4.18(b)] and DO and OLR had some effects on STN removal. Bulking in the activated sludge system affected STN removal. Table 4.7 shows the concentrations of the SNH_3-N and SNO_3-N in both the entrapped microbial cell reactor and activated sludge system. Due to severe bulking, the activated sludge system lost a substantial amount of MLSS. Because of that, N used for cell synthesis reduced. More nitrification at the two bulking conditions was not expected. pH increases during the bulking at these conditions support the occurrence of more nitrification. It is possible that nitrifiers are more immune to bulking than non-nitrifiers. Also, the ability of filamentous microorganisms such as *M. parvicella* to nitrify has been reported (Simona et al., 2006). As explained in section 4.2.2, the entrapped microbial cell reactor reduced the SNH_3-N concentration by 90%, whereas only 75% of the SNH_3-N concentration was reduced in the activated sludge system. Based on the mass balance for nitrogen (Table 4.7), nitrification in the entrapped cell system was much higher than that of the activated sludge system. Similar to the previous experiments, the entrapped microbial system consumed more SNH_3-N for cell synthesis than the activated sludge system.

4.4.3. Effects on filamentous bulking and solids

Figures 4.19(a) and 4.19(b) show the filamentous abundance scale in the entrapped microbial cell reactor and activated sludge system. DO and OLR had some effect on the filamentous abundance in both the reactors. For the same reasons stated in section 4.2.3, the filamentous organisms were found excessive in the entrapped cell reactor at the low DO concentration. The excessive filamentous abundance scale did not affect the removal efficiency of the reactor. Similar to the other experiments for entrapped microbial cell reactor, *S. natans* [Figure 4.20] was identified as the dominant filamentous microorganism. Figure 4.21 shows a thick layer of biofilm observed in the entrapment matrix. The biofilm did not affect the performance of the reactor.

At the low DO concentration and at the low OLR, the filamentous scale of the activated sludge system was excessive. At the low DO concentration and high and medium OLR (100 and 69 mg/l.h), activated sludge system had a severe bulking problem. TSS concentration and filamentous type in both the reactors at low HRT is shown in Table 4.8. The effluent TSS concentration increased from 26 to 180 mg/l and the SCOD removal efficiency decreased from 82% to 71%. Bulking in activated sludge system started after four days of operation. Severe foaming was also observed in the

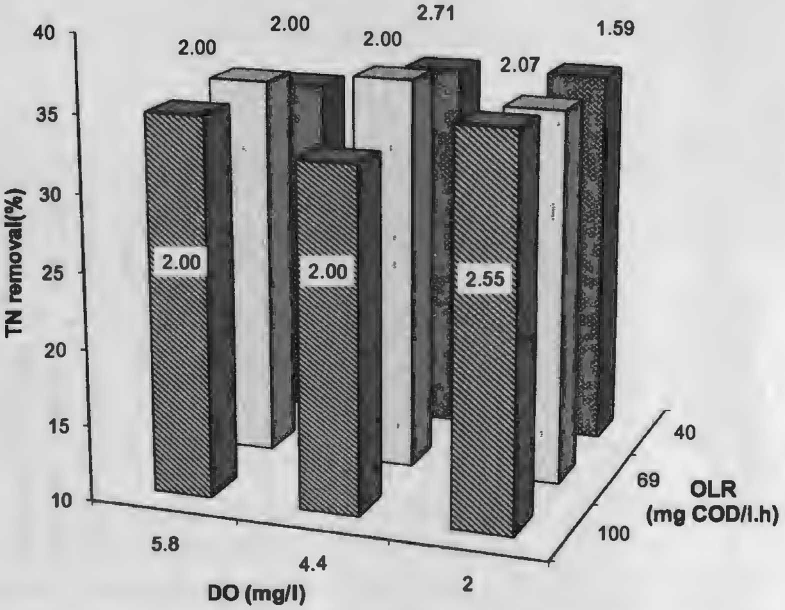

Figure 4.18(a) Percent STN removal at different DOs and OLRs for entrapped microbial cell reactor at low HRT (Standard deviation listed on or above the bars).

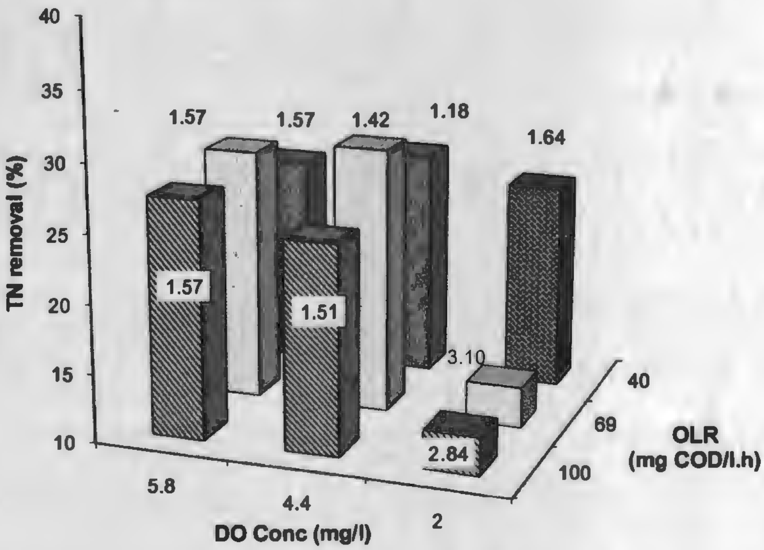

Figure 4.18(b) Percent STN removal at different DOs and OLRs for activated sludge system low HRT (Standard deviation listed on or above the bars).

Table 4.7 Nitrogen concentrations at low HRT

Experiment No.	DO (mg/L)	Loading Rate (mg/l.h)	Entrapped Microbial Cell Reactor			Activated Sludge System		
			Effluent SNH_3-N (mg/l)	Effluent SNO_3-N (mg/l)	N Used for Cell Synthesis (mg/l)	Effluent SNH_3-N (mg/l)	Effluent SNO_3-N (mg/l)	N Used for Cell Synthesis (mg/l)
10	5.8	100	2.97	14.20	9.33	6.13	13.04	7.33
13	4.4	100	3.37	14.40	8.73	6.73	13.01	6.76
16	2	100	3.00	14.00	9.50	6.57	16.44	3.49
11	5.8	69	2.77	14.30	9.43	6.03	12.84	7.63
14	4.4	69	2.87	14.00	9.63	5.81	12.81	7.88
17	2	69	3.17	14.04	9.29	6.60	16.37	3.53
12	5.8	40	3.27	14.30	8.93	6.33	13.34	6.83
15	4.4	40	2.99	14.16	9.35	5.97	13.34	7.19
18	2	40	3.00	14.10	9.40	6.49	13.26	6.75

system. *M. parvicella* and *N. limicola I* were identified as the dominant filamentous microorganisms in the activated sludge system. Figure 4.22 shows *M. parvicella* and *N. limicola I* observed in the activated sludge system.

4.5. Effect of Filamentous Overgrowth at Very Low HRT

At the low HRT, slight decreases in SCOD and $SBOD_5$ removal and more filaments were observed compared to at the medium and high HRTs. However, there was no clear evidence to indicate what caused the drop in the removal efficiencies (between HRT and filamentous abundance). To elucidate this issue, both entrapped cell and activated sludge systems were operated at a very low HRT (1.5 hours) and chlorination was performed to control filamentous overgrowth. Only low and medium DO concentrations were tested. The activated sludge system started to experience severe bulking and complete cell wash-out from the second day of operation at both DO concentrations occurred. The operation of the system was discontinued.

The SCOD, $SBOD_5$, and STN removal efficiencies in the entrapped microbial cell reactor at the applied DO and OLR are shown in Table 4.9. The SCOD, $SBOD_5$, and STN removal efficiencies were considerably low compared to the other HRTs. Table 4.10 shows the effluent SNH_3-N concentration, effluent SNO_3-N and the nitrogen concentration used for cell synthesis based on the mass balance for nitrogen. Nitrogen used for cell synthesis was much lower than the other experiments. Filamentous microorganisms were found excessive for all four experiments.

Experiment no. 28 (low DO and high OLR) had very low organic removal efficiencies and excessive filamentous abundance scale. Therefore, it was repeated with chlorination. The chlorination parameters and program are explained in Chapter 3.

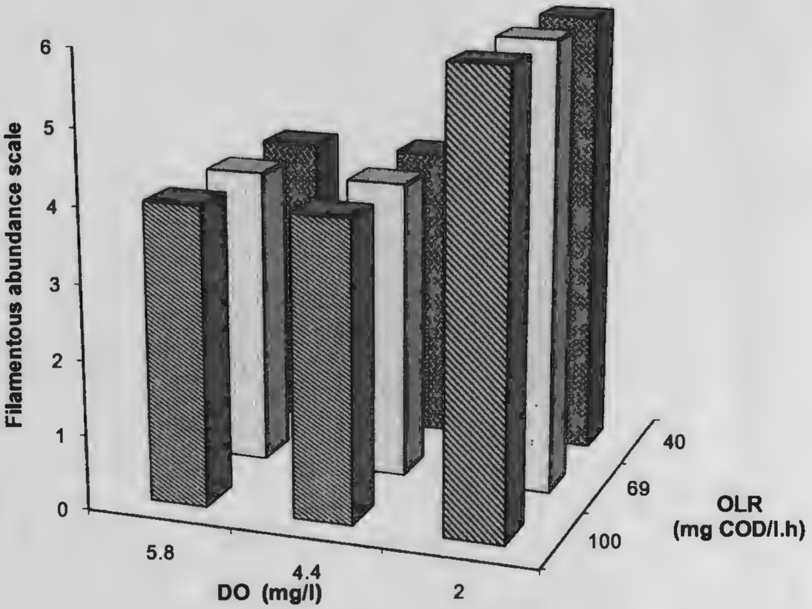

Figure 4.19(a) Filamentous abundance count at different DOs and OLRs for entrapped microbial cell reactor at low HRT.

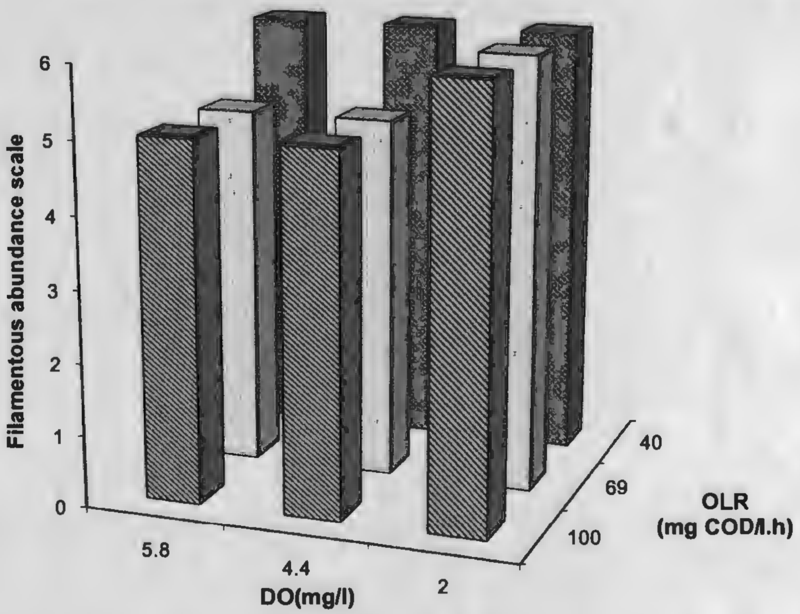

Figure 4.19(b) Filamentous abundance count at different DOs and OLRs for activated sludge system low HRT.

Table 4.8 TSS and filamentous organism type in the reactors low HRT

Experiment No.	DO (mg/L)	OLR (mg COD/l.h)	Entrapped Cell Reactor		Activated Sludge System	
			Effluent TSS (mg/l)	Filamentous Type	Effluent TSS (mg/l)	Filamentous Type
10	5.8	100	24	*S. natans*	24	*N. limicola I*
13	4.4	100	25	*S. natans*	24	*N. limicola I*
16	2.0	100	28	*S. natans*	28-180	*N. limicola I*
11	5.8	69	24	*S. natans*	24	*M. parvicella*
14	4.4	69	24	*S. natans*	23	*M. parvicella*
17	2.0	69	28	*S. natans*	26-164	*M. parvicella*
12	5.8	40	24	*S. natans*	24	*M. parvicella*
15	4.4	40	25	*S. natans*	23	*M. parvicella/ N. limicola I*
18	2.0	40	28	*S. natans*	22	*M. parvicella/ N. limicola I*

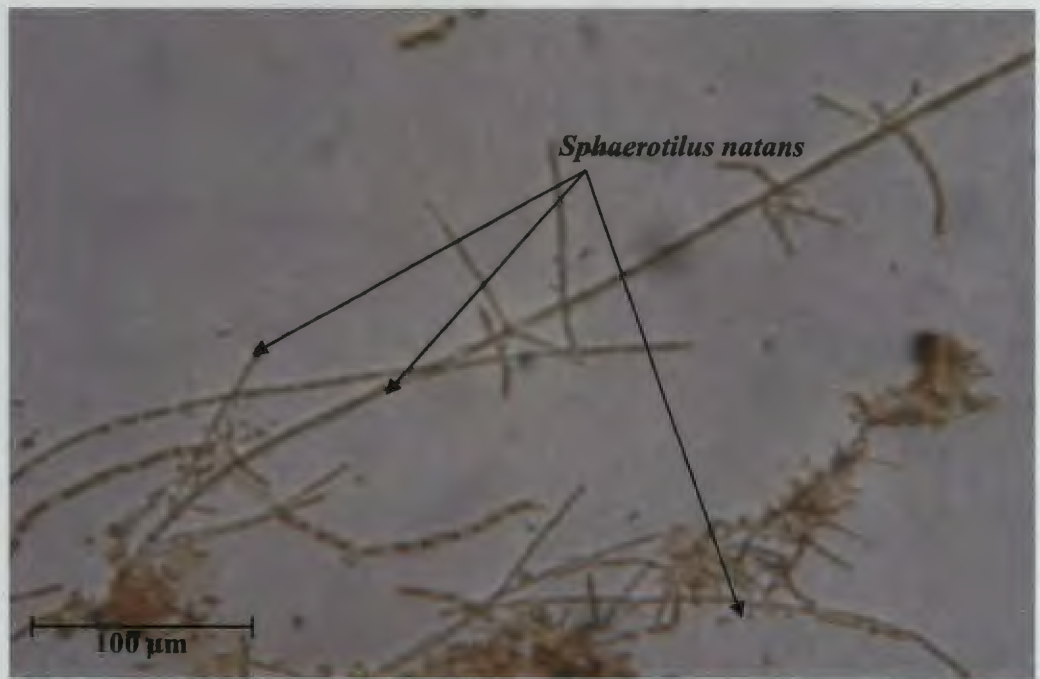

Figure 4.20 Dominant filamentous microorganism in entrapped microbial cell reactor at low HRT.

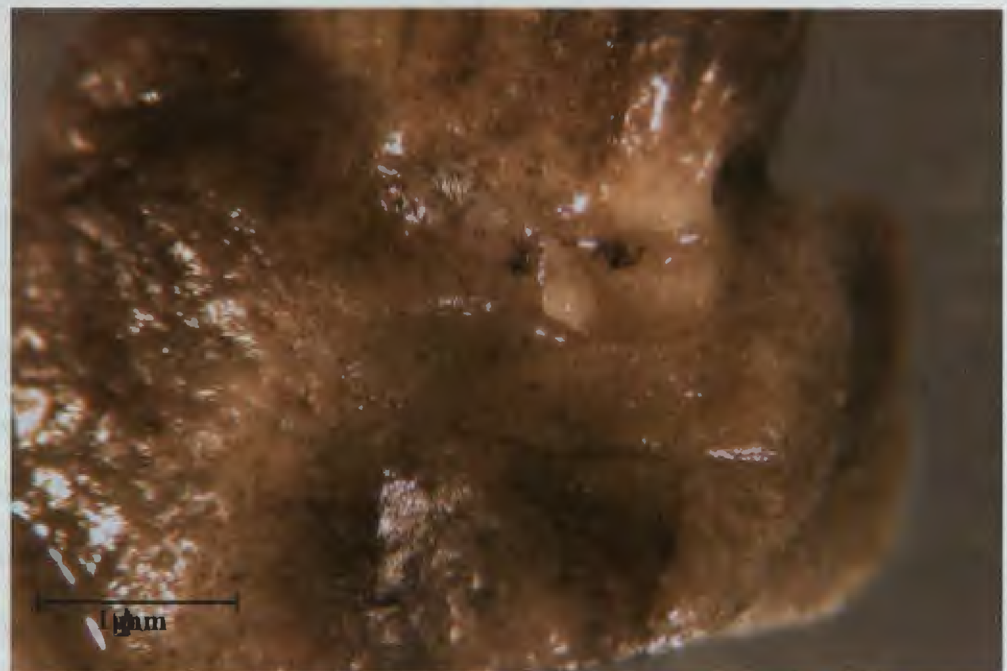
Figure 4.21 Biofilm formation on the surface of entrapment media at low HRT.

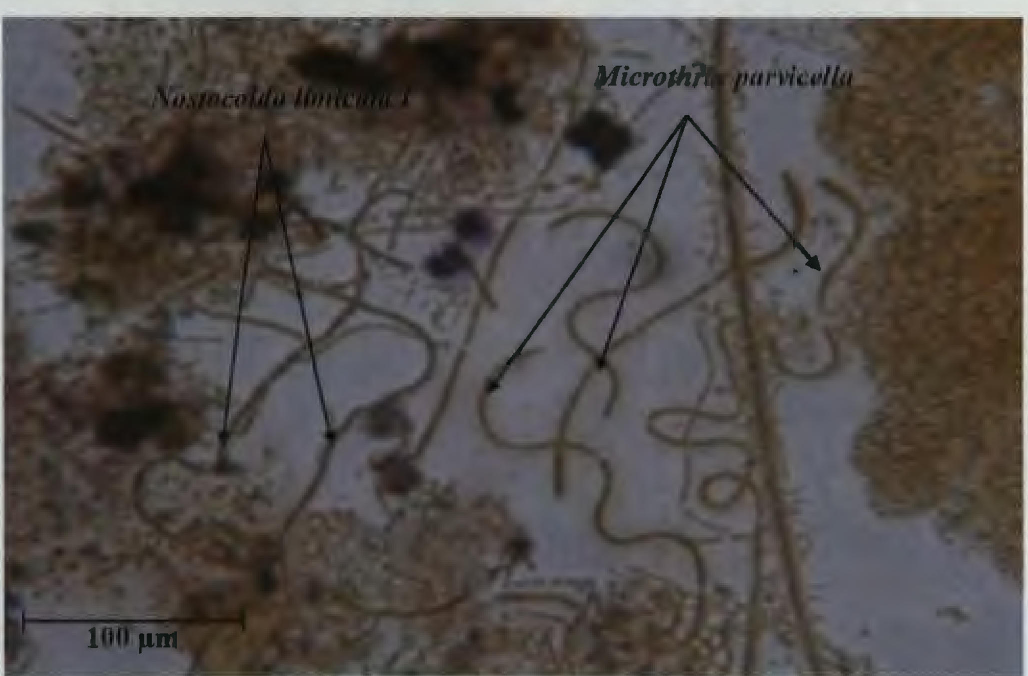

Figure 4.22 Dominant filamentous microorganism in activated sludge system low HRT.

Three different chlorine concentrations of 100, 25, 50 mg NaOCl/l were used. Chlorine was introduced directly into the feeding zone on the third day of operation (one day after steady state was confirmed). Figure 4.23(a), 4.23(b), 4.23(c), 4.23(d) and 4.23(e) show the percent removal of SCOD, $SBOD_5$, STN, the filamentous abundance count and effluent TSS concentration respectively at different chlorine concentrations and at different days. When a chlorine concentration of 100 mg NaOCl/l was applied, SCOD, $SBOD_5$ and STN removal efficiencies dropped drastically (SCOD removal efficiency dropped from 69% to 56%) because of the over-killing of microbial cells. Effluent TSS concentration increased on day 4 likely due to the detachment of biofilm and filament from the matrix. Therefore, the chlorine concentration of 100 mg/l was an overdose. Figure 4.23(d) shows the filamentous abundance scale drop from a scale of 6 to 2 or

Table 4.9 Overall performance of entrapped microbial cell reactor at very low HRT

Experiment No.	DO (mg/l)	HRT (hrs)	Influent SCOD (mg/l)	OLR (mg/l.h)	Entrapped Microbial Cell Reactor				
					SCOD Removal (%)	$SBOD_5$ Removal (%)	STN Removal (%)	Effluent TSS (mg/l)	Filamentous Abundance
28	2.1	1.5	300	200	68	69.1	20.1	23	6
31	4.5	1.5	300	200	70	71.6	20.1	27	6
29	2.1	1.5	206	137	69	69.6	18.6	27	6
30	2.1	1.5	120	80	72	73.8	16.8	28	6

Table 4.10 Nitrogen concentrations at very low HRT

Experiment No.	DO (mg/l)	Influent SCOD (mg/l)	OLR (mg/l.h)	Entrapped Microbial Cell Reactor		
				Effluent SNH_3-N (mg/l)	Effluent SNO_3-N (mg/l)	N Used for Cell Synthesis (mg/l)
28	2.1	300	200	11.98	9.10	5.42
31	4.5	300	200	11.90	9.18	5.42
29	2.1	206	137	12.28	9.20	5.02
30	2.1	120	80	12.70	9.25	4.55

excessive to some. Chlorination was stopped on the sixth day and the experiment was continued without chlorination. Once the steady state was achieved again (SCOD removal efficiency returned to normal within 5 days after the chlorination was stopped), the media was taken out of the bioreactor, washed and repacked.

Since chlorine concentration of 100 mg NaOCl/l was very high, a chlorine concentration of 25 mg NaOCl/l was tested. There was no substantial increase in SCOD, $SBOD_5$, and STN removal efficiencies after the filamentous abundance was suppressed from excessive to common (four days of operation after steady state condition). Therefore, the drop in the removal efficiencies compared to the low HRT was not due to the filamentous overgrowth but the operating condition (very low HRT). There was a slight increase in the effluent TSS concentration. To make sure the chlorine dosage of 25 mg/l was sufficient to kill the filamentous overgrowth, a chlorine concentration of 50 mg NaOCl/l was tested. There was no increase in the removal efficiencies of the reactor. Filamentous abundance scale dropped within one day from excessive to common. Therefore, the chlorine dosage of 25 mg/l was sufficient. These observations confirm that the operating condition (very low HRT) not the filamentous overgrowth in the reactor was the cause of decreases in organic removal efficiencies.

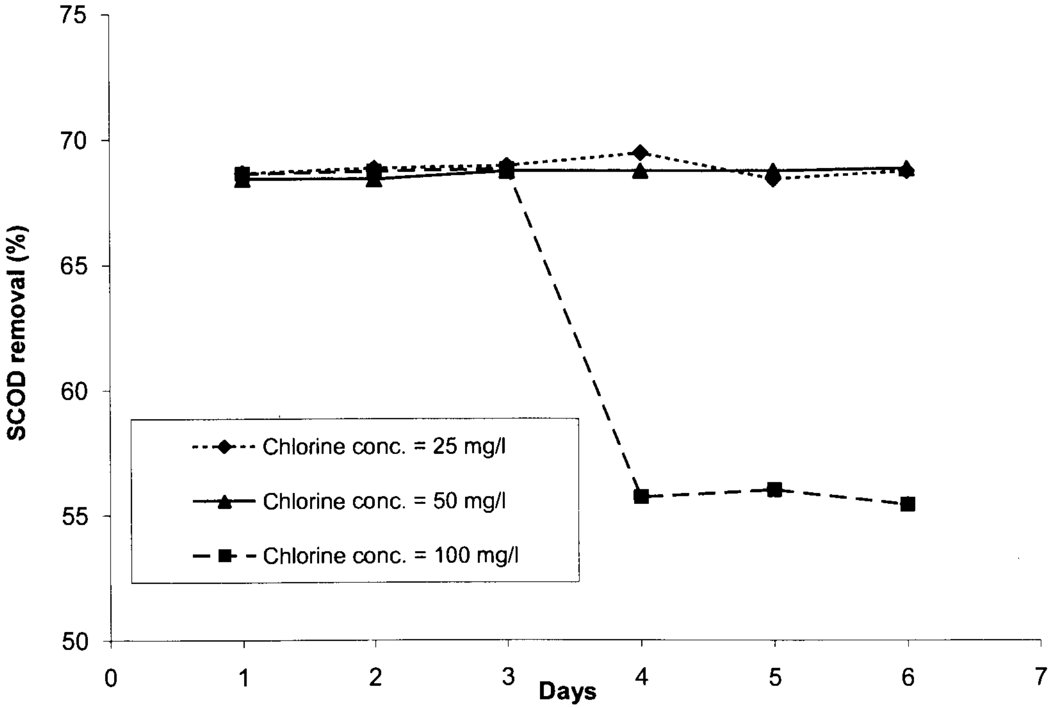

Figure 4.23(a) Percent SCOD removal at different chlorine concentrations.

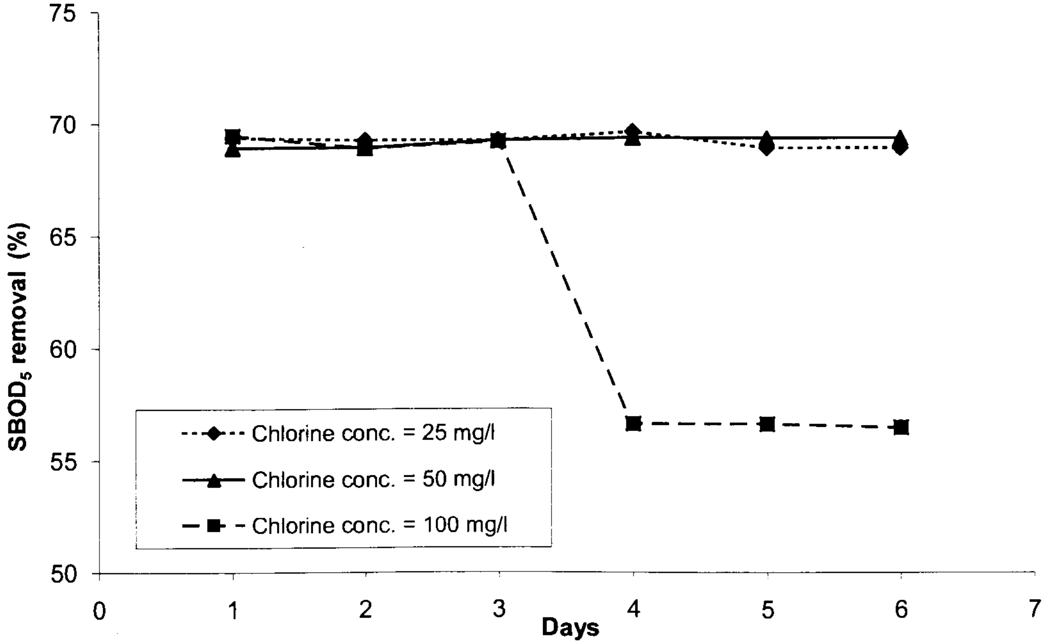

Figure 4.23(b) Percent $SBOD_5$ removal at different chlorine concentrations.

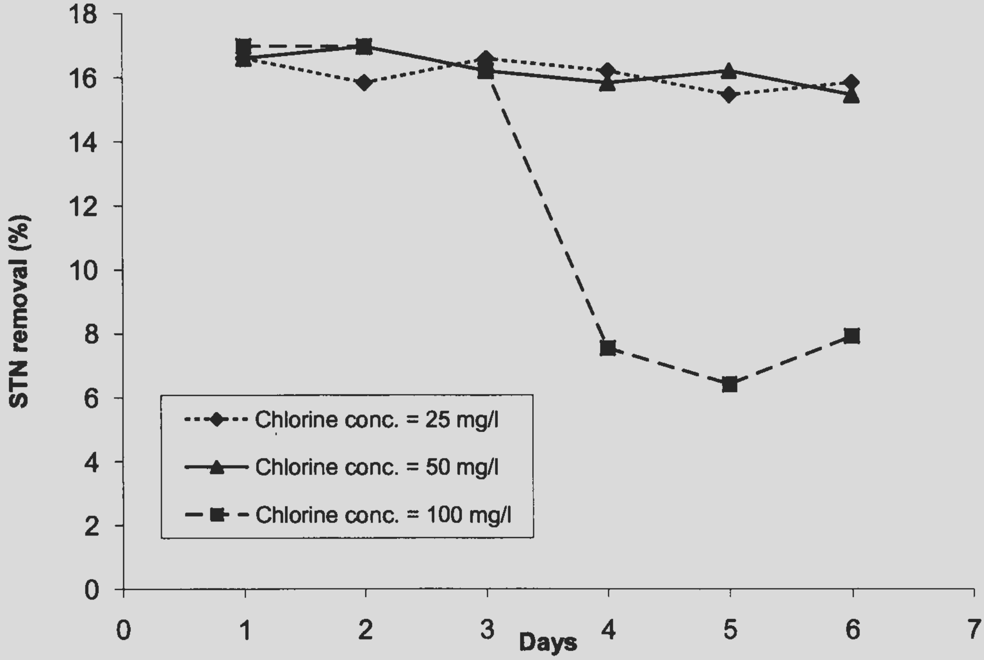

Figure 4.23(c) Percent STN removal at different chlorine concentrations.

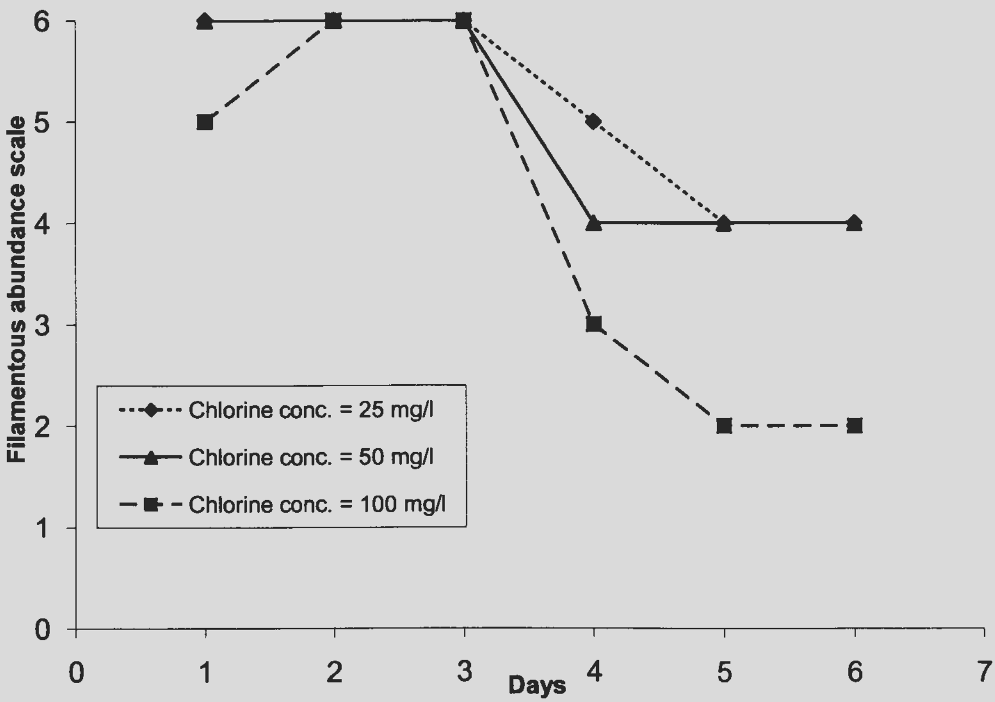

Figure 4.23(d) Filamentous abundance scale at different chlorine concentrations.

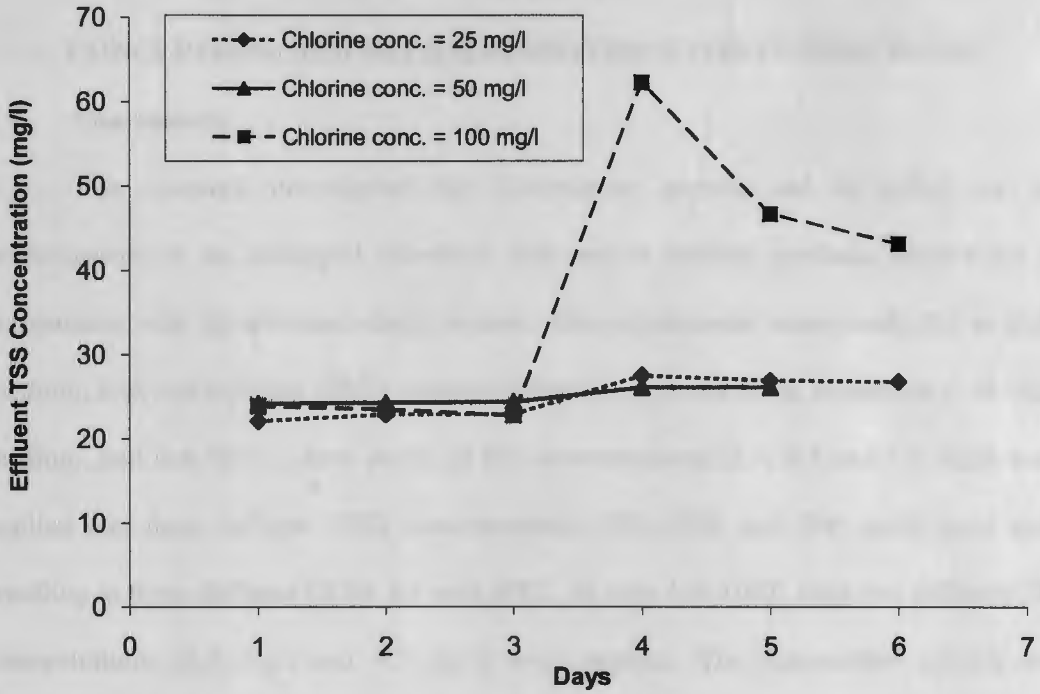

Figure 4.23(e) Effluent TSS concentration at different chlorine concentrations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

5.1. Conclusions

This research investigated the filamentous growth and its effect on the performances of an entrapped microbial cell reactor treating synthetic wastewater in comparison with an activated sludge system. The experiments were conducted at high, medium, low, and very low HRTs corresponding to 9, 6, 3 and 1.5 h, respectively. At high, medium, and low HRTs, three levels of DO concentrations (2.0, 4.5 and 5.7 mg/l) were applied and three influent COD concentrations (100, 200, and 306 mg/l) were used resulting in three different OLRs for each HRT. At very low HRT, only two different DO concentrations (2.0 mg/l and 4.5 mg/l) were applied. The filamentous growth was examined microscopically to quantify and identify responsible species at different operating conditions. SCOD, $SBOD_5$, SNH_3-N, SNO_2-N and SNO_3-N were the parameters measured to determine the performances of the reactor, which were determined after both systems achieved steady state conditions.

At all operating conditions, the entrapped microbial cell reactor was more effective compared to the activated sludge system. Entrapped cell reactors are known to have higher cell densities and longer solids retention time than activated sludge systems and therefore render better performances. At high HRT, the entrapped microbial cell reactor removed 96.5% of SCOD, 97% of $SBOD_5$ and 37-39% STN, whereas the activated sludge system removed 87% SCOD, 89% $SBOD_5$ and 25-30% STN. At medium and low HRTs, the entrapped microbial cell reactor was at least 10% more efficient in SCOD, $SBOD_5$, and

STN removal than the activated sludge system. Because of the higher cell density in the entrapped cell system, N uptake was greater resulting in more STN removal.

At high HRT, the three OLRs studied were 33, 23, 13 mg COD/l.h. DO and OLR did not have any effects on the SCOD, $SBOD_5$ and STN removal efficiencies of the entrapped cell reactor. *S. natans* was the dominant filamentous microorganism and was very common at low DO. However, the organism did not affect the SCOD, $SBOD_5$ and STN removal efficiencies of the reactor. In the activated sludge system, at low DO, filamentous microorganisms were found excessive and very common at medium and low OLRs, respectively. At low DO and medium OLR, the system experienced severe bulking. *M. parvicella* was identified as the dominant filamentous microorganism.

The values of OLRs at medium HRT were 50, 34 and 21 mg COD/l.h. Similar to the results at high HRT, DO and OLR did not affect the SCOD, $SBOD_5$ and STN removal efficiencies of the entrapped cell reactor and *S. natans* was the dominant filamentous microorganism. At low DO, regardless of OLR *S. natans* was excessive but had no negative impact on the performances of the reactor. SCOD and $SBOD_5$ removal efficiencies at medium HRT were not much different from those at high HRT. In the activated sludge system, at high OLR and medium and low DO concentrations, severe bulking was observed. *M. parvicella* was the responsible filamentous microorganism. Foaming was also observed in the system. *M. parvicella* is commonly known for causing it.

The results at low HRT, in terms of the effects of DO and OLR (100, 69 and 40 mg COD/l.h) on SCOD, $SBOD_5$, STN removal was not different from those at medium HRT. However, there were slight decreases in SCOD and $SBOD_5$ removal efficiencies when compared to those at high and medium HRTs. At low DO concentration, the filamentous abundance scale for the entrapped microbial cell reactor was excessive. Similar to the other experiments for the entrapped microbial cell reactor, *S. natans* was identified as the dominant filamentous microorganism. A thick layer of biofilm was also observed on the entrapment matrix. The biofilm did not affect the performances of the reactor. The activated sludge system experienced severe bulking at low DO and high OLR, and low DO and medium OLR. *N. limicola I* was the dominant filamentous microorganism along with *M. parvicella*.

To determine the reason (between HRT and filamentous abundance) for the decreases in SCOD and $SBOD_5$ removal by the entrapped microbial cell system at low HRT, a very low HRT of 1.5 h was applied. At very low HRT, the activated sludge system had severe bulking that made it impossible to function. Again, DO and OLR (200, 137 and 80 mg COD/l.h) did not affect SCOD and $SBOD_5$ removal efficiencies of the entrapped cell reactor. Filamentous microorganisms were found excessive with *S. natans* being the dominant species. Reduction of the filamentous microorganisms was attempted by chlorination using sodium hypochlorite. Three different chlorine dosages, 1, 0.25 and 0.50 g NaOCl/d were applied. The dosage of 0.25 g NaOCl/d was found to be very effective in controlling the filamentous overgrowth in the entrapped microbial cell reactor. The reduction of filamentous organisms by chlorination did not result in improved $SBOD_5$ and SCOD removal suggesting that very low HRT rather than the abundance of filamentous organisms was responsible for the lower performances of the reactor. The results in this study led to conclusions that the entrapped microbial cell reactor is subjected to filamentous overgrowth but it has no effect on the performances of the reactor and chlorination was very effective in controlling the filamentous overgrowth in the reactor but it is not required.

5.2. Recommendations for Future Work

In this study, the entrapped microbial cell reactor was not tested with real domestic wastewater. A study investigating the filamentous overgrowth should be conducted with real domestic wastewater. Real domestic wastewater may cause a different filamentous microorganism to be dominant in the system and may have different effects than the synthetic wastewater. This study was conducted using a packed bed reactor. Investigating the filamentous overgrowth in a fluidized bed entrapped cell reactor is recommended. In a fluidized bed reactor, oxygen and substrate diffusions into the entrapment matrix could be greater than that of the packed bed reactor, which may induce the growth of a different filamentous microorganism in the reactor. In addition, cellulose triacetate was the cell entrapment matrix in this study. Similar studies using other common cell entrapment matrices such as alginate, k-carrageenan, polyacrylamide, and polyvinyl alcohol are recommended. A different entrapment matrix could change the performances of the reactor and also the filamentous microorganism associated with it. A future study on different matrices should include electron microscopic analysis of the inside of the matrix to record the presence of filamentous growth inside the matrix.

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APPENDIX A

Table A.1 Entrapped microbial reactor - Experiment 1

Parameter	Entrapped microbial system				
Influent	Day 1	Day 2	Day 3	Day 4	Average
pH	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00
DO	5.60	5.70	5.90	5.70	5.73
SCOD (mg/l)	303	303	304	302	303.00
$SBOD_5$ (mg/l)	300	301	301	301	300.75
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50
Effluent					
pH	6.10	6.10	6.15	6.20	6.14
TSS (mg/l)	28.70	20.60	21.80	23.40	21.93
SCOD (mg/l)	17.00	9.00	11.00	11.00	10.33
$SBOD_5$ (mg/l)	16.00	8.00	9.00	9.00	8.67
NH_3-N (mg/l)	2.70	2.90	2.60	2.30	2.60
NO_3-N (mg/l)	14.80	14.60	13.90	13.60	14.03
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.60	17.60	16.60	16.00	16.73
SCOD removal efficiency (%)	94.39	97.03	96.38	96.36	96.59
$SBOD_5$ removal efficiency (%)	94.67	97.34	97.01	97.01	97.12
TN removal efficiency (%)	33.58	33.58	37.36	39.62	36.86
Abundance scale		3.00	3.00	3.00	3.00
Filamentous type	*S. natans*				

Table A.2 Activated sludge system- Experiment 1

Parameter	Entrapped microbial system				
Influent	Day 1	Day 2	Day 3	Day 4	Average
pH	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00
DO	5.60	5.70	5.90	5.70	5.73
SCOD (mg/l)	303	303	304	302	303
$SBOD_5$ (mg/l)	300	301	301	301	300
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50
Effluent					
MLSS (mg/l)	1587	1586	1580	1572	1581
MLVSS (mg/l)	1345	1346	1349	1343	1346
F/M ratio	0.22				
pH	6.70	6.80	6.70	6.60	6.70
TSS (mg/l)	25.70	17.80	16.30	16.50	16.87
SCOD (mg/l)	56.00	42.00	43.00	42.00	42.33
$SBOD_5$ (mg/l)	54.00	41.00	41.00	41.00	41.00
NH_3-N (mg/l)	4.36	5.75	5.73	5.59	5.69
NO_3-N (mg/l)	13.56	12.87	12.73	12.45	12.68
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.02	18.72	18.56	18.14	18.47
SCOD removal efficiency (%)	81.52	86.14	85.86	86.09	86.03
$SBOD_5$ removal efficiency (%)	82.00	86.38	86.38	86.38	86.38
TN removal efficiency (%)	32.00	29.36	29.96	31.55	30.29
Abundance scale		4	4	4	4
Filamentous type	*M. parvicella*				

Table A.3 Entrapped microbial reactor - Experiment 2

Parameter	Entrapped microbial system				
Influent	Day 1	Day 2	Day 3	Day 4	Average
pH	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00
DO	5.90	5.70	5.60	5.70	5.73
SCOD (mg/l)	210	210	209	209	209.50
$SBOD_5$ (mg/l)	208	209	208	208	208.25
NH3-N (mg/l)	26.50	26.50	26.50	26.50	26.50
Effluent					
pH	6.20	6.10	6.10	6.10	6.13
TSS (mg/l)	26.00	21.89	22.59	22.16	22.21
SCOD (mg/l)	14.00	7.00	8.00	7.00	7.33
$SBOD_5$ (mg/l)	12.00	7.00	6.00	6.00	6.33
NH_3-N (mg/l)	2.35	2.80	2.70	2.40	2.63
NO_3-N (mg/l)	14.80	14.90	13.80	13.60	14.10
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.25	17.80	16.60	16.10	16.83
SCOD removal efficiency (%)	93.33	96.67	96.17	96.65	96.50
$SBOD_5$ removal efficiency (%)	94.23	96.65	97.12	97.12	96.96
TN removal efficiency (%)	34.91	32.83	37.36	39.25	36.48
Abundance scale		3.00	3.00	3.00	3.00
Filamentous type	*S. natans*				

Table A.4 Activated sludge system- Experiment 2

Parameter	Activated sludge system				
Influent	Day 1	Day 2	Day 3	Day 4	Average
pH	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00
DO	5.90	5.70	5.60	5.70	5.73
SCOD (mg/l)	210	210	209	209	209.50
$SBOD_5$ (mg/l)	208	209	208	208	208.25
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50
Effluent					
MLSS (mg/l)	1598	1586	1587	1572	1586
MLVSS (mg/l)	1368	1361	1363	1358	1363
F/M ratio	0.2				
pH	6.80	6.60	6.60	6.60	6.65
TSS (mg/l)	26.60	16.65	15.80	15.30	15.92
SCOD (mg/l)	39.00	28.00	29.00	28.00	28.33
$SBOD_5$ (mg/l)	36.00	27.00	28.00	27.00	27.33
NH_3-N (mg/l)	4.36	5.90	5.80	5.60	5.77
NO_3-N (mg/l)	13.70	12.90	12.60	12.60	12.70
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.16	18.90	18.50	18.30	18.57
SCOD removal efficiency (%)	81.43	86.67	86.12	86.60	86.46
$SBOD_5$ removal efficiency (%)	82.69	87.08	86.54	87.02	86.88
TN removal efficiency (%)	31.47	28.68	30.19	30.94	29.94
Abundance scale		4.00	4.00	4.00	4.00
Filamentous type	*M. parvicella*				

Table A.5 Entrapped microbial reactor - Experiment 3

Parameter	Entrapped microbial system				
Influent	Day 1	Day 2	Day 3	Day 4	Average
pH	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00
DO	5.80	5.60	5.80	5.70	5.73
SCOD (mg/l)	127	126	126	127	126.50
$SBOD_5$ (mg/l)	125	125	124	124	124.50
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50
Effluent					
pH	6.10	6.20	6.20	6.20	6.18
TSS (mg/l)	28.90	22.10	22.30	21.60	22.00
SCOD (mg/l)	15.00	5.00	4.00	4.00	4.33
$SBOD_5$ (mg/l)	12.00	5.00	3.00	3.00	3.67
NH_3-N (mg/l)	2.70	2.80	2.30	2.30	2.47
NO_3-N (mg/l)	14.70	14.40	14.60	13.90	14.30
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.50	17.30	17.00	16.30	16.87
SCOD removal efficiency (%)	88.19	96.03	96.83	96.85	96.57
$SBOD_5$ removal efficiency (%)	90.40	96.00	97.58	97.58	97.05
TN removal efficiency (%)	33.96	34.72	35.85	38.49	36.35
Abundance scale		3.00	3.00	3.00	3.00
Filamentous type	*S. natans*				

Table A.6 Activated sludge system- Experiment 3

Parameter	Activated sludge system				
Influent	Day 1	Day 2	Day 3	Day 4	Average
pH	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00
DO	5.80	5.60	5.80	5.70	5.73
SCOD (mg/l)	127	126	126	127	126.50
$SBOD_5$ (mg/l)	125	125	124	124	124.50
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50
Effluent					
MLSS (mg/l)	1585	1586	1590	1579	1585
MLVSS (mg/l)	1370	1378.00	1365	1367	1370
F/M ratio	0.19				
pH	6.90	6.60	6.70	6.70	6.73
TSS (mg/l)	26.96	16.30	16.40	16.10	16.27
SCOD (mg/l)	25.00	16.00	16.00	16.00	16.00
$SBOD_5$ (mg/l)	23.00	15.00	14.00	14.00	14.33
NH_3-N (mg/l)	4.70	5.80	5.90	5.60	5.77
NO_3-N (mg/l)	13.30	12.70	12.90	12.70	12.77
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.10	18.60	18.90	18.40	18.63
SCOD removal efficiency (%)	80.31	87.30	87.30	87.40	87.33
$SBOD_5$ removal efficiency (%)	81.60	88.00	88.71	88.71	88.47
TN removal efficiency (%)	31.70	29.81	28.68	30.57	29.69
Abundance scale		4.00	4.00	4.00	4.00
Filamentous type	*M. parvicella*				

Table A.7 Entrapped microbial reactor - Experiment 4

Parameter	Entrapped microbial system				
Influent	Day 1	Day 2	Day 3	Day 4	Average
pH	7.22	7.22	7.22	7.22	
HRT (h)	6.00	6.00	6.00	6.00	
DO	4.44	4.55	4.30	4.50	4.45
SCOD (mg/l)	301	303	302	302	302.00
$SBOD_5$ (mg/l)	295	298	297	296	296.50
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50
Effluent					
pH	6.22	6.22	6.22	6.20	6.22
TSS (mg/l)	36.00	22.30	21.70	24.50	22.83
SCOD (mg/l)	39.00	14.00	15.00	15.00	14.67
$SBOD_5$ (mg/l)	37.00	13.00	14.00	14.00	13.67
NH_3-N (mg/l)	2.80	2.50	2.10	2.40	2.33
NO_3-N (mg/l)	14.10	14.60	14.50	13.76	14.29
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.00	17.20	16.70	16.26	16.72
SCOD removal efficiency (%)	87.04	95.38	95.03	95.03	95.15
$SBOD_5$ removal efficiency (%)	87.46	95.64	95.29	95.27	95.40
TN removal efficiency (%)	35.85	35.09	36.98	38.64	36.91
Abundance scale		4.00	4.00	4.00	4.00
Filamentous type	*S. natans*				

Table A.8 Activated sludge system- Experiment 4

Parameter	Activated sludge system				
Influent	Day 1	Day 2	Day 3	Day 4	Average
pH	7.22	7.22	7.22	7.22	
HRT (h)	6.00	6.00	6.00	6.00	
DO	4.44	4.55	4.30	4.50	4.45
SCOD (mg/l)	301	303	302	302	302.00
$SBOD_5$ (mg/l)	295	298	297	296	296.50
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50
Effluent					
MLSS (mg/l)	1580	1578	1587	1586	1583
MLVSS (mg/l)	1338	1336	1339	1339	1338
F/M ratio	0.23				
pH	6.75	6.62	6.80	6.90	6.77
TSS (mg/l)	26.00	14.45	15.58	105.80	45.28
SCOD (mg/l)	43.00	39.00	41.00	62.00	47.33
$SBOD_5$ (mg/l)	41.00	38.00	39.00	60.00	45.67
NH_3-N (mg/l)	4.64	5.54	5.67	5.80	5.67
NO_3-N (mg/l)	13.66	12.78	12.76	12.32	12.62
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.40	18.42	18.53	18.22	18.39
SCOD removal efficiency (%)	85.71	87.13	86.42	79.47	84.34
$SBOD_5$ removal efficiency (%)	86.10	87.25	86.87	79.73	84.62
TN removal efficiency (%)	30.57	30.49	30.08	31.23	30.60
Abundance scale		6.00	6.00	6.00	6.00
Filamentous type	*M. parvicella*				

Table A.9 Entrapped microbial reactor - Experiment 5

Parameter	Entrapped microbial system						
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00	6.00	6.00
DO	4.55	4.40	4.20	4.51	4.50	4.80	4.49
SCOD (mg/l)	207	209	209	207	208	208.00	208.00
$SBOD_5$ (mg/l)	195	196	195	194	193	197.00	195.00
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent							
pH	6.30	6.30	6.20	6.20	6.30	6.30	6.27
TSS (mg/l)	31.35	23.45	26.67	21.33	22.45	21.36	23.05
SCOD (mg/l)	29.00	17.00	17.00	16.00	19.00	15.00	16.80
$SBOD_5$ (mg/l)	28.00	15.00	16.00	14.00	16.00	14.00	15.00
NH_3-N (mg/l)	2.60	2.30	2.00	2.20	2.90	2.40	2.36
NO_3-N (mg/l)	14.10	14.56	14.40	13.76	13.80	14.20	14.14
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	16.80	16.96	16.50	16.06	16.80	16.70	16.60
SCOD removal efficiency (%)	85.99	91.87	91.87	92.27	90.87	92.79	91.93
$SBOD_5$ removal efficiency (%)	85.64	92.35	91.79	92.78	91.71	92.89	92.31
TN removal efficiency (%)	36.60	36.00	37.74	39.40	36.60	36.98	37.34
Abundance scale		3	3	3	3	3	3
Filamentous type	*S. natans*						

Table A.10 Activated sludge system- Experiment 5

Parameter	Activated sludge system						
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00	6.00	6.00
DO	4.55	4.40	4.20	4.51	4.50	4.80	4.49
SCOD (mg/l)	207.00	209.00	209.00	207.00	208.00	208.00	208.00
$SBOD_5$ (mg/l)	195.00	196.00	195.00	194.00	193.00	197.00	195.00
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent							
MLSS (mg/l)	1603	1540	1538	1542	1543	1538	1551
MLVSS (mg/l)	1330	1323	1322	1323	1324	1321	1324
F/M ratio	0.19						
pH	6.70	6.60	6.80	6.90	6.50	6.60	6.68
TSS (mg/l)	25.45	14.45	13.55	14.55	16.62	15.38	14.91
SCOD (mg/l)	39.00	26.00	29.00	31.00	28.00	27.00	28.20
$SBOD_5$ (mg/l)	37.00	25.00	25.00	26.00	26.00	26.00	25.60
NH_3-N (mg/l)	5.74	5.45	5.67	5.70	5.60	5.50	5.58
NO_3-N (mg/l)	12.56	12.37	12.45	12.33	12.87	12.64	12.53
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.40	17.92	18.22	18.13	18.57	18.24	18.22
SCOD removal efficiency (%)	81.16	87.56	86.12	85.02	86.54	87.02	86.45
$SBOD_5$ removal efficiency (%)	81.03	87.24	87.18	86.60	86.53	86.80	86.87
TN removal efficiency (%)	30.57	32.38	31.25	31.58	29.92	31.17	31.26
Abundance scale		4	4	4	4	4	4
Filamentous type	*M. parvicella*						

Table A.11 Entrapped microbial reactor - Experiment 6

Parameter	Entrapped microbial system				
Influent	Day 1	Day 2	Day 3	Day 4	Average
pH	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00
DO	4.44	4.55	4.30	4.50	4.45
SCOD (mg/l)	120	118	119	119	119.00
$SBOD_5$ (mg/l)	117	115	117	116	116.25
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50
Effluent					
pH	6.20	6.20	6.10	6.20	6.18
TSS (mg/l)	29.50	20.67	21.33	21.00	21.00
SCOD (mg/l)	19.00	8.00	9.00	7.00	8.00
$SBOD_5$ (mg/l)	16.00	7.00	7.00	6.00	6.67
NH_3-N (mg/l)	2.60	2.60	2.50	2.40	2.50
NO_3-N (mg/l)	14.40	14.70	14.50	14.10	14.43
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.10	17.40	17.10	16.60	17.03
SCOD removal efficiency (%)	84.17	93.22	92.44	94.12	93.26
$SBOD_5$ removal efficiency (%)	86.32	93.91	94.02	94.83	94.25
TN removal efficiency (%)	35.47	34.34	35.47	37.36	35.72
Abundance scale		4	4	4	4
Filamentous type	*S. natans*				

Table A12 Activated sludge system- Experiment 6

Parameter	Activated sludge system				
Influent	Day 1	Day 2	Day 3	Day 4	Average
pH	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00
DO	4.44	4.55	4.30	4.50	4.45
SCOD (mg/l)	120	118	119	119	119.00
$SBOD_5$ (mg/l)	117	115	117	116	116.25
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50
Effluent					
MLSS (mg/l)	1585	1578	1572	1580	1579
MLVSS (mg/l)	1360	1359	1365	1340	1356
F/M ratio	0.16				
pH	6.60	6.70	6.70	6.70	6.68
TSS (mg/l)	25.45	15.45	15.58	17.00	16.01
SCOD (mg/l)	25.00	16.00	17.00	17.00	16.67
$SBOD_5$ (mg/l)	23.00	15.00	15.00	16.00	15.33
NH_3-N (mg/l)	4.37	5.77	5.70	5.56	5.68
NO_3-N (mg/l)	13.26	12.89	12.79	12.30	12.66
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.73	18.76	18.59	17.96	18.44
SCOD removal efficiency (%)	79.17	86.44	85.71	85.71	85.96
$SBOD_5$ removal efficiency (%)	80.34	86.96	87.18	86.21	86.78
TN removal efficiency (%)	33.09	29.21	29.85	32.23	30.43
Abundance scale		4	4	4	4
Filamentous type	*M. parvicella*				

Table A.13 Entrapped microbial reactor - Experiment 7

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
DO	2.10	2.0	2.1	2.0	2.1	2.00	2.0	2.0	2.04
SCOD (mg/l)	304	304	306	305	305	306.00	305	305	305.00
$SBOD_5$ (mg/l)	302	303	303	304	304.00	303.00	304	304	303.38
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.20	6.20	6.20	6.20	6.20	6.20	6.2	6.2	6.20
TSS (mg/l)	28.90	28.30	27.40	26.95	28.90	28.30	27.9	28.1	27.98
SCOD (mg/l)	22.00	12.00	12.00	12.00	13.00	12.00	12.00	13.00	12.29
$SBOD_5$ (mg/l)	21.00	11.00	11.00	10.00	11.00	11.00	11.00	11.00	10.86
NH_3-N (mg/l)	2.80	2.70	2.20	2.40	2.60	2.70	2.3	2.3	2.46
NO_3-N (mg/l)	14.60	14.50	14.70	13.90	13.80	14.70	14.1	14.2	14.27
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.50	17.30	17.00	16.40	16.50	17.50	16.50	16.60	16.83
SCOD removal efficiency (%)	92.76	96.05	96.08	96.07	95.74	96.08	96.07	95.74	95.97
$SBOD_5$ removal efficiency (%)	93.05	96.37	96.37	96.71	96.38	96.37	96.38	96.38	96.42
TN removal efficiency (%)	33.96	34.72	35.85	38.11	37.74	33.96	37.74	37.36	36.50
Abundance scale		6	6	6	6	6.00	6	6	6
Filamentous type	*S. natans*								

Table A.14 Activated sludge system- Experiment 7

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
DO	2.10	2.2	2.1	2.3	2.1	2.0	2.0	2.0	2.10
SCOD (mg/l)	304	304	306	305	305	306	305	305	305.00
$SBOD_5$ (mg/l)	302	303	303	304	304.00	303	304	304	303.38
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1610	1590	1587	1585	1289	1210	1075	989	1367
MLVSS (mg/l)	1390	1380	1378	1345	1376	1073	890	780	1202
F/M ratio	0.25								
pH	6.90	6.80	6.90	6.90	6.90	6.80	6.90	6.90	6.87
TSS (mg/l)	31.58	14.98	16.15	17.10	16.00	84.95	111	117.98	54.02
SCOD (mg/l)	59	42	43	42	42	79	77	75	57.14
$SBOD_5$ (mg/l)	57.00	40.00	41.00	41.00	39.00	71	73	66	53.00
NH_3-N (mg/l)	4.60	5.80	5.70	5.90	5.80	6.8	6.9	6.7	6.23
NO_3-N (mg/l)	13.40	12.70	12.90	12.80	12.90	10.3	10.3	10.1	11.71
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.10	18.60	18.70	18.80	18.80	17.20	17.30	16.90	18.04
SCOD removal efficiency (%)	80.59	86.18	85.95	86.23	86.23	74.18	74.75	75.41	81.28
$SBOD_5$ removal efficiency (%)	81.13	86.80	86.47	86.51	87.17	76.57	75.99	78.29	82.54
TN removal efficiency (%)	31.70	29.81	29.43	29.06	29.06	35.09	34.72	36.23	31.91
Abundance scale		4	5	5	6	6	6	6	6.00
Filamentous type	*M. parvicella*								

Table A.15 Entrapped microbial reactor - Experiment 8

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
DO	2.10	2.0	2.1	2.0	2.1	2.00	2.0	2.0	2.04
SCOD (mg/l)	208	209	206	208	209	208.00	206	209	207.88
$SBOD_5$ (mg/l)	205	204	202	206	207.00	207.00	205	207	205.38
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.20	6.20	6.30	6.00	6.10	6.2	6.1	6.15
TSS (mg/l)	35.60	28.30	27.30	26.90	25.00	26.70	26.9	27.9	27.00
SCOD (mg/l)	14.00	9.00	8.00	9.00	7.00	8.00	8.00	8.00	8.14
$SBOD_5$ (mg/l)	13.00	7.00	7.00	7.00	6.00	7.00	6.00	7.00	6.71
NH_3-N (mg/l)	3.10	2.80	2.30	2.40	2.50	2.70	2.4	2.2	2.47
NO_3-N (mg/l)	14.60	14.70	14.80	13.80	13.80	14.60	14.3	14.1	14.30
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.80	17.60	17.20	16.30	16.40	17.40	16.80	16.40	16.87
SCOD removal efficiency (%)	93.27	95.69	96.12	95.67	96.65	96.15	96.12	96.17	96.08
$SBOD_5$ removal efficiency (%)	93.66	96.57	96.53	96.60	97.10	96.62	97.07	96.62	96.73
TN removal efficiency (%)	32.83	33.58	35.09	38.49	38.11	34.34	36.60	38.11	36.33
Abundance scale		4	6	6	6	6	6	6	6
Filamentous type	*S. natans*								

Table A.16 Activated sludge system- Experiment 8

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
DO	2.10	2.0	2.3	2.2	2.1	2.0	2.0	2.0	2.09
SCOD (mg/l)	208	209	206	208	209	208	206	209	207.88
$SBOD_5$ (mg/l)	205	204	202	206	207.00	207	205	207	205.38
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1660	1610	1590	1595	1598	1594	1589	1570	1601
MLVSS (mg/l)	1418	1389	1387	1398	1367	1387	1388	1388	1390
pH	6.80	6.90	6.90	6.90	6.90	6.80	6.90	6.90	6.89
TSS (mg/l)	28.00	16.90	16.90	17.20	17.40	16.8	16.8	16.9	16.99
SCOD (mg/l)	39	30	31	28	30	30	29	31	29.86
$SBOD_5$ (mg/l)	35.00	28.00	28.00	26.00	27.00	29	29	29	28.00
NH_3-N (mg/l)	3.70	5.70	5.90	5.50	5.30	5.30	5.10	5.20	5.43
NO_3-N (mg/l)	15.90	12.30	13.10	13.20	12.90	12.7	12.8	12.9	12.84
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	19.70	18.10	19.10	18.80	18.30	18.10	18.00	18.20	18.37
SCOD removal efficiency (%)	81.25	85.65	84.95	86.54	85.65	85.58	85.92	85.17	85.64
$SBOD_5$ removal efficiency (%)	82.93	86.27	86.14	87.38	86.96	85.99	85.85	85.99	86.37
TN removal efficiency (%)	25.66	31.70	27.92	29.06	30.94	31.70	32.08	31.32	30.67
Abundance scale		5	6	6	6	6	6	6	6
Filamentous type	*M. parvicella*								

Table A.17 Entrapped microbial reactor - Experiment 9

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
DO	2.00	2.0	2.0	2.1	2.0	2.00	2.0	2.0	2.01
SCOD (mg/l)	125	124	123	126	127	123.00	125	121	124.25
$SBOD_5$ (mg/l)	122	123	122	124	125.00	121.00	122	119	122.25
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.20	6.20	6.20	6.20	6.20	6.20	6.2	6.2	6.20
TSS (mg/l)	36.90	27.90	25.00	25.90	26.30	25.90	26.7	25.1	26.11
SCOD (mg/l)	16.00	5.00	5.00	4.00	4.00	4.00	5.00	4.00	4.43
$SBOD_5$ (mg/l)	13.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
NH_3-N (mg/l)	3.30	3.00	2.50	2.60	2.70	2.90	2.6	2.4	2.67
NO_3-N (mg/l)	14.40	14.50	14.60	13.50	13.50	14.30	14	13.8	14.03
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.80	17.60	17.20	16.20	16.30	17.30	16.70	16.30	16.80
SCOD removal efficiency (%)	87.20	95.97	95.93	96.83	96.85	96.75	96.00	96.69	96.43
$SBOD_5$ removal efficiency (%)	89.34	97.56	97.54	97.58	97.60	97.52	97.54	97.48	97.55
TN removal efficiency (%)	32.83	33.58	35.09	38.87	38.49	34.72	36.98	38.49	36.60
Abundance scale		6	6	6	6	6	6	6	6
Filamentous type	*S. natans*								

Table A18 Activated sludge system- Experiment 9

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
DO	2.10	2.0	2.1	2.0	2.1	2.0	2.0	2.0	2.04
SCOD (mg/l)	125	124	123	126	127	123	125	121	124.25
$SBOD_5$ (mg/l)	122	123	122	124	125.00	121	122	119	122.25
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1580	1588	1575	1576	1579	1560	1545	1570	1572
MLVSS (mg/l)	1388	1345	1387	1349	1371	1363	1345	1388	1367
F/M ratio	0.11								
pH	6.60	6.90	6.70	6.80	6.90	6.90	6.80	6.90	6.84
TSS (mg/l)	33.80	17.90	18.90	21.10	20.20	19.8	19.2	18.9	19.43
SCOD (mg/l)	27	18	17	18	19	17	16	18	17.57
$SBOD_5$ (mg/l)	24.00	17.00	15.00	16.00	18.00	15	13	16	15.71
NH_3-N (mg/l)	3.80	5.80	6.00	5.60	5.40	5.4	5.2	5.3	5.53
NO_3-N (mg/l)	15.70	12.10	12.90	13.00	12.70	12.5	12.6	12.7	12.64
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	19.60	18.00	19.00	18.70	18.20	18.00	17.90	18.10	18.27
SCOD removal efficiency (%)	78.40	85.48	86.18	85.71	85.04	86.18	87.20	85.12	85.85
$SBOD_5$ removal efficiency (%)	80.33	86.18	87.70	87.10	85.60	87.60	89.34	86.55	87.15
TN removal efficiency (%)	26.04	32.08	28.30	29.43	31.32	32.08	32.45	31.70	31.05
Abundance scale		3	4	5	5	5	5	5	5
Filamentous type	*M. parvicella*								

Table A.19 Entrapped microbial reactor - Experiment 10

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	5.70	5.8	5.9	5.8	5.8	5.8	5.8	5.8	5.80
SCOD (mg/l)	301	300	305	304	303	304	303	303	302.88
$SBOD_5$ (mg/l)	300	298	304	303	302.00	301	300	300	301.00
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.20	6.10	6.20	6.30	6.2	6.2	6.2	6.19
TSS (mg/l)	35.70	24.50	22.30	25.90	25.00	24.2	23.9	23.9	24.24
SCOD (mg/l)	45.00	31.00	30.00	30.00	31.00	31.00	30.00	31.00	30.57
$SBOD_5$ (mg/l)	42.00	28.00	28.00	27.00	28.00	28.00	27.00	27.00	27.57
NH_3-N (mg/l)	3.60	3.30	2.80	2.90	3.00	3.2	2.9	2.7	2.97
NO_3-N (mg/l)	14.50	14.60	14.70	13.70	13.70	14.5	14.2	14	14.20
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.20	18.00	17.60	16.70	16.80	17.80	17.20	16.80	17.27
SCOD removal efficiency (%)	85.05	89.67	90.16	90.13	89.77	89.80	90.10	89.77	89.91
$SBOD_5$ removal efficiency (%)	86.00	90.60	90.79	91.09	90.73	90.70	91.00	91.00	90.84
TN removal efficiency (%)	31.32	32.08	33.58	36.98	36.60	32.83	35.09	36.60	34.82
Abundance scale		4	4	4	4	4	4	4	4
Filamentous type	*S. natans*								

Table A.20 Activated sludge system- Experiment 10

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	5.70	5.6	5.8	5.9	5.7	5.7	5.9	5.8	5.76
SCOD (mg/l)	301	300	305	304	303	304	303	303	302.88
$SBOD_5$ (mg/l)	300	298	304	303	302.00	301	300	300	301.00
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1655	1598	1585	1586	1589	1570	1555	1580	1590
MLVSS (mg/l)	1430	1358	1400	1362	1384	1376	1358	1401	1384
F/M ratio	0.81								
pH	6.70	6.80	6.90	6.90	6.90	6.90	6.80	6.90	6.87
TSS (mg/l)	37.90	22.40	23.90	25.75	23.80	24.4	24.8	23.1	24.02
SCOD (mg/l)	84	60	57	57	58	57	57	57	57.57
$SBOD_5$ (mg/l)	80.00	59.00	55.00	54.00	56.00	55	52	55	55.14
NH_3-N (mg/l)	4.40	6.40	6.60	6.20	6.00	6	5.8	5.9	6.13
NO_3-N (mg/l)	16.10	12.50	13.30	13.40	13.10	12.9	13	13.1	13.04
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	20.60	19.00	20.00	19.70	19.20	19.00	18.90	19.10	19.27
SCOD removal efficiency (%)	72.09	80.00	81.31	81.25	80.86	81.25	81.19	81.19	81.01
$SBOD_5$ removal efficiency (%)	73.33	80.20	81.91	82.18	81.46	81.73	82.67	81.67	81.69
TN removal efficiency (%)	22.26	28.30	24.53	25.66	27.55	28.30	28.68	27.92	27.28
Abundance scale		4	4	5	5	5	5	5	5.0
Filamentous type	*N. limicola I*								

Table A.21 Entrapped microbial reactor - Experiment 11

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	5.60	5.7	5.8	5.7	5.7	5.7	5.7	5.7	5.70
SCOD (mg/l)	201	209	206	205	206	207	207	208	206.13
$SBOD_5$ (mg/l)	198	198	197	199	203.00	206	206	207	201.75
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.20	6.20	6.20	6.20	6.30	6.2	6.2	6.2	6.21
TSS (mg/l)	40.40	24.30	24.70	23.90	24.10	23.8	23.9	24.1	24.11
SCOD (mg/l)	35.00	20.00	21.00	21.00	20.00	20.00	20.00	20.00	20.29
$SBOD_5$ (mg/l)	31.00	18.00	18.00	19.00	19.00	18.00	19.00	18.00	18.43
NH_3-N (mg/l)	3.40	3.10	2.60	2.70	2.80	3	2.7	2.5	2.77
NO_3-N (mg/l)	14.60	14.70	14.80	13.80	13.80	14.6	14.3	14.1	14.30
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.10	17.90	17.50	16.60	16.70	17.70	17.10	16.70	17.17
SCOD removal efficiency (%)	82.59	90.43	89.81	89.76	90.29	90.34	90.34	90.38	90.19
$SBOD_5$ removal efficiency (%)	84.34	90.91	90.86	90.45	90.64	91.26	90.78	91.30	90.89
TN removal efficiency (%)	31.70	32.45	33.96	37.36	36.98	33.21	35.47	36.98	35.20
Abundance scale		4	4	4	4	4	4	4	4
Filamentous type	*S. natans*								

Table A.22 Activated sludge system- Experiment 11

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	5.90	5.5	5.9	5.9	5.9	5.8	5.8	5.8	5.81
SCOD (mg/l)	201	209	206	205	206	207	207	208	206.13
$SBOD_5$ (mg/l)	198	198	197	199	203.00	206	206	207	201.75
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1590	1598	1586	1586	1555	1570	1555	1580	1578
MLVSS (mg/l)	1362	1322	1379	1362	1384	1376	1358	1390	1367
F/M ratio	0.59								
pH	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90
TSS (mg/l)	41.90	23.40	24.90	24.60	23.40	24.2	23.9	24.1	24.07
SCOD (mg/l)	57	35	36	35	34	34	35	35	34.86
$SBOD_5$ (mg/l)	51.00	33.00	31.00	31.00	32.00	30	31	31	31.29
NH_3-N (mg/l)	4.30	6.30	6.50	6.10	5.90	5.9	5.7	5.8	6.03
NO_3-N (mg/l)	15.90	12.30	13.10	13.20	12.90	12.7	12.8	12.9	12.84
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	20.30	18.70	19.70	19.40	18.90	18.70	18.60	18.80	18.97
SCOD removal efficiency (%)	71.64	83.25	82.52	82.93	83.50	83.57	83.09	83.17	83.15
$SBOD_5$ removal efficiency (%)	74.24	83.33	84.26	84.42	84.24	85.44	84.95	85.02	84.52
TN removal efficiency (%)	23.40	29.43	25.66	26.79	28.68	29.43	29.81	29.06	28.41
Abundance scale		4	5	5	5	5	5	5	5.00
Filamentous type	*N. limicola I*								

Table A.23 Entrapped microbial reactor - Experiment 12

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	5.50	5.6	5.9	5.9	5.9	5.9	5.5	5.7	5.74
SCOD (mg/l)	124	126	125	125	125	124	124	122	124.38
$SBOD_5$ (mg/l)	120	122	122	122	121.00	121	123	118	121.13
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.20	6.20	6.10	6.20	6.10	6.2	6.2	6.2	6.18
TSS (mg/l)	38.10	23.90	24.10	24.30	23.80	24.5	23.8	23.9	24.04
SCOD (mg/l)	26.00	12.00	13.00	12.00	12.00	12.00	12.00	12.00	12.14
$SBOD_5$ (mg/l)	22.00	11.00	12.00	11.00	11.00	11.00	11.00	11.00	11.14
NH_3-N (mg/l)	3.90	3.60	3.10	3.20	3.30	3.5	3.2	3	3.27
NO_3-N (mg/l)	14.60	14.70	14.80	13.80	13.80	14.6	14.3	14.1	14.30
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.60	18.40	18.00	17.10	17.20	18.20	17.60	17.20	17.67
SCOD removal efficiency (%)	79.03	90.48	89.60	90.40	90.40	90.32	90.32	90.16	90.24
$SBOD_5$ removal efficiency (%)	81.67	90.98	90.16	90.98	90.91	90.91	91.06	90.68	90.81
TN removal efficiency (%)	29.81	30.57	32.08	35.47	35.09	31.32	33.58	35.09	33.32
Abundance scale		4	4	4	4	4	4	4	4
Filamentous type	*S. natans*								

Table A.24 Activated sludge system- Experiment 12

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	5.70	5.7	5.7	5.9	5.9	5.9	5.9	5.6	5.79
SCOD (mg/l)	124	126	125	125	125	124	124	122	124.38
$SBOD_5$ (mg/l)	120	122	122	122	121.00	121	123	118	121.13
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1655	1598	1585	1345	1367	1540	1510	1513	1514
MLVSS (mg/l)	1330	1340	1367	1367	1313	1378	1298	1367	1345
F/M ratio	0.36								
pH	6.80	6.70	6.90	6.90	6.90	6.90	6.80	6.90	6.86
TSS (mg/l)	44.78	19.90	19.70	29.67	29.75	25.3	24.90	19.10	24.05
SCOD (mg/l)	28	21	21	28	27	25	21	21	23.43
$SBOD_5$ (mg/l)	23.00	19.00	19.00	26.00	25.00	22	19	18	21.14
NH_3-N (mg/l)	4.60	6.60	6.80	6.40	6.20	6.2	6	6.1	6.33
NO_3-N (mg/l)	16.40	12.80	13.60	13.70	13.40	13.2	13.3	13.4	13.34
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	21.10	19.50	20.50	20.20	19.70	19.50	19.40	19.60	19.77
SCOD removal efficiency (%)	77.42	83.33	83.20	77.60	78.40	79.84	83.06	82.79	81.17
$SBOD_5$ removal efficiency (%)	80.83	84.43	84.43	78.69	79.34	81.82	84.55	84.75	82.57
TN removal efficiency (%)	20.38	26.42	22.64	23.77	25.66	26.42	26.79	26.04	25.39
Abundance scale		5	6	6	6	6	6	6	6.00
Filamentous type	*N. limicola I*								

Table A.25 Entrapped microbial reactor - Experiment 13

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	4.50	4.4	4.5	4.6	4.2	4.3	4.4	4.4	4.41
SCOD (mg/l)	305	306	307	310	306	302	306	306	306.00
$SBOD_5$ (mg/l)	300	303	303	303	301.00	298	300	303	301.38
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.26	6.20	6.20	6.30	6.30	6.20	6.20	6.20	6.23
TSS (mg/l)	36.90	24.80	25.10	24.90	25.10	24.9	24.9	24.9	24.94
SCOD (mg/l)	44.00	32.00	32.00	33.00	34.00	34.00	34.00	34.00	33.29
$SBOD_5$ (mg/l)	42.00	28.00	28.00	27.00	27.00	30.00	30.00	30.00	28.57
NH_3-N (mg/l)	4.00	3.70	3.20	3.30	3.40	3.6	3.3	3.1	3.37
NO_3-N (mg/l)	14.70	14.80	14.90	13.90	13.90	14.7	14.4	14.2	14.40
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.80	18.60	18.20	17.30	17.40	18.40	17.80	17.40	17.87
SCOD removal efficiency (%)	85.57	89.54	89.58	89.35	88.89	88.74	88.89	88.89	89.13
$SBOD_5$ removal efficiency (%)	86.00	90.76	90.76	91.09	91.03	89.93	90.00	90.10	90.52
TN removal efficiency (%)	29.06	29.81	31.32	34.72	34.34	30.57	32.83	34.34	32.56
Abundance scale	·	4	4	4	4	4	4	4	4
Filamentous type	*S. natans*								

Table A.26 Activated sludge system- Experiment 13

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	4.40	4.5	4.5	4.4	4.2	4.3	4.4	4.4	4.39
SCOD (mg/l)	305	306	307	310	306	302	306	306	306.00
$SBOD_5$ (mg/l)	300	303	303	303	301.00	298	300	303	301.38
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1658	1601	1588	1573	1568	1543	1513	1516	1570
MLVSS (mg/l)	1437	1365	1407	1369	1391	1383	1365	1408	1391
F/M ratio	0.80								
pH	6.80	6.80	6.90	6.90	6.90	6.90	6.80	6.90	6.87
TSS (mg/l)	38.20	22.70	24.20	26.05	24.10	24.7	25.1	23.4	24.32
SCOD (mg/l)	67	54	53	52	55	51	53	53	53.00
$SBOD_5$ (mg/l)	65.00	51.00	52.00	51.00	51.00	52	51	51	51.29
NH_3-N (mg/l)	5.00	7.00	7.20	6.80	6.60	6.6	6.4	6.5	6.73
NO_3-N (mg/l)	16.00	12.40	13.20	13.40	13.10	12.9	13	13.1	13.01
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	21.10	19.50	20.50	20.30	19.80	19.60	19.50	19.70	19.84
SCOD removal efficiency (%)	78.03	82.35	82.74	83.23	82.03	83.11	82.68	82.68	82.69
$SBOD_5$ removal efficiency (%)	78.33	83.17	82.84	83.17	83.06	82.55	83.00	83.17	82.99
TN removal efficiency (%)	20.38	26.42	22.64	23.40	25.28	26.04	26.42	25.66	25.12
Abundance scale		5	5	5	5	5	5	5	5
Filamentous type	*M. parvicella*								

Table A.27 Entrapped microbial reactor - Experiment 14

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
SCOD (mg/l)	209	208	208	207	209	209	210	210	208.75
$SBOD_5$ (mg/l)	207	206	206	207	207.00	206	208	208	206.88
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.10	6.10	6.10	6.10	6.10	6.10	6.20	6.11
TSS (mg/l)	31.70	24.20	22.00	25.60	24.70	23.9	23.6	23.6	23.94
SCOD (mg/l)	44.00	23.00	23.00	24.00	24.00	23.00	23.00	23.00	23.29
$SBOD_5$ (mg/l)	41.00	22.00	22.00	21.00	23.00	20.00	21.00	21.00	21.43
NH_3-N (mg/l)	3.50	3.20	2.70	2.80	2.90	3.1	2.8	2.6	2.87
NO_3-N (mg/l)	14.30	14.40	14.50	13.50	13.50	14.3	14	13.8	14.00
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.90	17.70	17.30	16.40	16.50	17.50	16.90	16.50	16.97
SCOD removal efficiency (%)	78.95	88.94	88.94	88.41	88.52	89.00	89.05	89.05	88.84
$SBOD_5$ removal efficiency (%)	80.19	89.32	89.32	89.86	88.89	90.29	89.90	89.90	89.64
TN removal efficiency (%)	32.45	33.21	34.72	38.11	37.74	33.96	36.23	37.74	35.96
Abundance scale		3	4	4	4	4	4	4	4
Filamentous type	*S. natans*								

Table A.28 Activated sludge system- Experiment 14

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	4.50	4.40	4.50	4.40	4.40	4.50	4.40	4.40	4.44
SCOD (mg/l)	209	208	208	207	209	209	210	210	208.75
$SBOD_5$ (mg/l)	207	206	206	207	207.00	206	208	208	206.88
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1560	1571	1567	1589	1563	1523	1561	1557	1561
MLVSS (mg/l)	1345	1367	1389	1369	1334	1367	1357	1316	1356
F/M ratio	0.61								
pH	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90
TSS (mg/l)	32.30	21.50	23.00	24.85	22.90	23.5	23.9	22.2	23.12
SCOD (mg/l)	49	38	39	40	40	40	40	40	39.57
$SBOD_5$ (mg/l)	47.00	36.00	36.00	36.00	37.00	37	37	38	36.71
NH_3-N (mg/l)	4.30	6.30	6.50	5.80	5.60	5.6	5.4	5.5	5.81
NO_3-N (mg/l)	15.70	12.10	12.90	13.00	13.00	12.8	12.9	13	12.81
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	20.10	18.50	19.50	18.90	18.70	18.50	18.40	18.60	18.73
SCOD removal efficiency (%)	76.56	81.73	81.25	80.68	80.86	80.86	80.95	80.95	81.04
$SBOD_5$ removal efficiency (%)	77.29	82.52	82.52	82.61	82.13	82.04	82.21	81.73	82.25
TN removal efficiency (%)	24.15	30.19	26.42	28.68	29.43	30.19	30.57	29.81	29.33
Abundance scale		3	3	5	5	5	5	5	5
Filamentous type	*M. parvicella*								

Table A29 Entrapped microbial reactor - Experiment 15

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	4.50	4.5	4.3	4.4	4.4	4.4	4.4	4.4	4.41
SCOD (mg/l)	121	120	120	120	120	122	121	121	120.63
$SBOD_5$ (mg/l)	118	118	119	118	118	118	119	118	118.25
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.10	6.10	6.10	6.10	6.1	6.2	6.2	6.13
TSS (mg/l)	44.70	24.40	24.60	25.80	25.10	24.9	24.8	25.1	24.96
SCOD (mg/l)	28.00	12.00	11.00	12.00	12.00	12.00	13.00	13.00	12.14
$SBOD_5$ (mg/l)	25.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
NH_3-N (mg/l)	3.70	3.40	3.00	3.10	2.90	3.1	2.8	2.6	2.99
NO_3-N (mg/l)	14.70	14.80	14.90	13.60	13.60	14.4	14	13.8	14.16
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.50	18.30	18.00	16.80	16.60	17.60	16.90	16.50	17.24
SCOD removal efficiency (%)	76.86	90.00	90.83	90.00	90.00	90.16	89.26	89.26	89.93
$SBOD_5$ removal efficiency (%)	78.81	91.53	91.60	91.53	91.53	91.53	91.60	91.53	91.55
TN removal efficiency (%)	30.19	30.94	32.08	36.60	37.36	33.58	36.23	37.74	34.93
Abundance scale		4	4	4	4	4	4	4	4
Filamentous type	*S. natans*								

Table A.30 Activated sludge system- Experiment 15

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	5.70	5.6	5.8	5.9	5.7	5.7	5.9	5.8	5.76
SCOD (mg/l)	121	120	120	120	120	122	121	121	120.63
$SBOD_5$ (mg/l)	118	118	119	118	118	118	119	118	118.25
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1548	1556	1554	1559	1561	1543	1542	1541	1551
MLVSS (mg/l)	1341	1345	1323	1376	1341	1362	1377	1341	1351
F/M ratio	0.35								
pH	6.90	6.20	6.90	6.90	6.90	6.90	6.90	6.90	6.80
TSS (mg/l)	39.10	22.70	23.10	23.70	23.10	23.1	23.3	22.6	23.09
SCOD (mg/l)	35	21	21	22	22	21	22	22	21.57
$SBOD_5$ (mg/l)	33	18	18	19	19	19	19	20	18.86
NH_3-N (mg/l)	3.90	5.90	6.10	5.70	6.30	6.3	5.7	5.8	5.97
NO_3-N (mg/l)	15.80	12.80	13.60	13.70	13.20	13	13.5	13.6	13.34
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	19.80	18.80	19.80	19.50	19.60	19.40	19.30	19.50	19.41
SCOD removal efficiency (%)	71.07	82.50	82.50	81.67	81.67	82.79	81.82	81.82	82.11
$SBOD_5$ removal efficiency (%)	72.03	84.75	84.87	83.90	83.90	83.90	84.03	83.05	84.06
TN removal efficiency (%)	25.28	29.06	25.28	26.42	26.04	26.79	27.17	26.42	26.74
Abundance scale		6	6	6	6	6	6	6	6
Filamentous type	*M. parvicella*								

Table A.31 Entrapped microbial reactor - Experiment 16

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	2.10	1.9	1.8	2.2	2.0	2.1	2.1	2.0	2.03
SCOD (mg/l)	310	309	308	309	309	308	309	309	308.88
$SBOD_5$ (mg/l)	308	307	306	308	307	307	307	307	307.13
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.20	6.20	6.20	6.00	6.10	6.2	6.2	6.1	6.15
TSS (mg/l)	27.80	27.90	28.90	26.80	28.10	27.6	27.9	28.3	27.93
SCOD (mg/l)	51.00	43.00	42.00	41.00	42.00	42.00	43.00	44.00	42.43
$SBOD_5$ (mg/l)	44.00	40.00	39.00	38.00	38.00	39.00	40.00	41.00	39.29
NH_3-N (mg/l)	3.90	3.60	3.10	2.70	2.80	3	3	2.8	3.00
NO_3-N (mg/l)	14.30	14.40	14.50	13.50	13.50	14.3	14	13.8	14.00
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.30	18.10	17.70	16.30	16.40	17.40	17.10	16.70	17.10
SCOD removal efficiency (%)	83.55	86.08	86.36	86.73	86.41	86.36	86.08	85.76	86.26
$SBOD_5$ removal efficiency (%)	85.71	86.97	87.25	87.66	87.62	87.30	86.97	86.64	87.20
TN removal efficiency (%)	30.94	31.70	33.21	38.49	38.11	34.34	35.47	36.98	35.47
Abundance scale		6	6	6	6	6	6	6	6
Filamentous type	*S. natans*								

Table A.32 Activated sludge system- Experiment 16

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	2.00	2.2	1.9	2.0	2.1	2.1	2.0	2.0	2.04
SCOD (mg/l)	310	309	308	309	309	308	309	309	308.88
$SBOD_5$ (mg/l)	308	307	306	308	307	307	307	307	307.13
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1546	1567	1573	1547	1501	1409	1267	1131	1443
MLVSS (mg/l)	1328	1361	1317	1343	1334	1216	1076	973	1244
F/M ratio	0.86								
pH	6.80	6.90	6.90	6.90	7.40	7.50	7.50	7.50	7.23
TSS (mg/l)	31.35	28.60	28.70	28.10	86.40	103.4	139.7	179.8	84.96
SCOD (mg/l)	61	58	57	56	77	78	81	87	70.57
$SBOD_5$ (mg/l)	58.00	55.00	55.00	55.00	71.00	71	78	85	67.14
NH_3-N (mg/l)	6.60	6.30	6.90	6.90	7.10	7.1	5.8	5.9	6.57
NO_3-N (mg/l)	16.30	16.60	16.50	16.70	16.70	16.3	16.4	15.9	16.44
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	23.00	23.00	23.50	23.70	23.90	23.50	22.30	21.90	23.11
SCOD removal efficiency (%)	80.32	81.23	81.49	81.88	75.08	74.68	73.79	71.84	77.14
$SBOD_5$ removal efficiency (%)	81.17	82.08	82.03	82.14	76.87	76.87	74.59	72.31	78.13
TN removal efficiency (%)	13.21	13.21	11.32	10.57	9.81	11.32	15.85	17.36	12.78
Abundance scale		5	5	6	6	6	6	6	6
Filamentous type	*M. parvicella*								

Table A.33 Entrapped microbial reactor - Experiment 17

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	2.00	2.0	2.0	2.1	2.1	2.0	2.0	2.0	2.03
SCOD (mg/l)	208	207	208	207	207	207	207	207	207.25
$SBOD_5$ (mg/l)	206	206	206	205	205	205	205	205	205.38
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.00	6.00	6.10	6.10	6.10	6.1	6.1	6.2	6.09
TSS (mg/l)	30.60	27.60	27.90	28.10	27.90	28.3	28.1	28.3	28.03
SCOD (mg/l)	28	27	27	27	28	27	27	27	27.14
$SBOD_5$ (mg/l)	25	25	25	24	25	24	24	24	24.43
NH_3-N (mg/l)	3.80	3.50	3.00	3.10	3.20	3.4	3.1	2.9	3.17
NO_3-N (mg/l)	14.40	14.50	14.60	13.60	13.50	14.3	14	13.8	14.04
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.30	18.10	17.70	16.80	16.80	17.80	17.20	16.80	17.31
SCOD removal efficiency (%)	86.54	86.96	87.02	86.96	86.47	86.96	86.96	86.96	86.90
$SBOD_5$ removal efficiency (%)	87.86	87.86	87.86	88.29	87.80	88.29	88.29	88.29	88.10
TN removal efficiency (%)	30.94	31.70	33.21	36.60	36.60	32.83	35.09	36.60	34.66
Abundance scale		5	6	6	6	6	6	6	6
Filamentous type	*S. natans*								

Table A.34 Activated sludge system- Experiment 17

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	2.10	2.1	2.1	2.0	2.0	2.0	2.0	2.0	2.04
SCOD (mg/l)	208	207	208	207	207	207	207	207	207.25
$SBOD_5$ (mg/l)	206	206	206	205	205	205	205	205	205.38
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1578	1567	1536	1543	1402	1207	1143	1043	1377
MLVSS (mg/l)	1321	1324	1329	1341	1236	1013	979	836	1172
F/M ratio	0.69								
pH	6.70	6.80	6.90	6.80	7.50	7.50	7.50	7.50	7.21
TSS (mg/l)	25.90	26.10	26.20	25.75	98.60	137.9	153.1	163.9	90.22
SCOD (mg/l)	47	40	40	40	48	51	53	55	46.71
$SBOD_5$ (mg/l)	45.00	37.00	37.00	37.00	42.00	48	49	53	43.29
NH_3-N (mg/l)	6.30	6.60	6.80	6.70	7.20	7.3	5.9	5.7	6.60
NO_3-N (mg/l)	16.20	16.30	16.40	16.70	16.80	16.2	16.3	15.9	16.37
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	22.60	23.00	23.30	23.50	24.10	23.60	22.30	21.70	23.07
SCOD removal efficiency (%)	77.40	80.68	80.77	80.68	76.81	75.36	74.40	73.43	77.45
$SBOD_5$ removal efficiency (%)	78.16	82.04	82.04	81.95	79.51	76.59	76.10	74.15	78.91
TN removal efficiency (%)	14.72	13.21	12.08	11.32	9.06	10.94	15.85	18.11	12.94
Abundance scale		5	6	6	6	6	6	6	6
Filamentous type	*M. parvicella and N. limicola*								

Table A.35 Entrapped microbial reactor - Experiment 18

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	2.10	2.1	1.9	2.0	2.0	2.0	2.0	2.0	2.01
SCOD (mg/l)	121	124	125	126	124	123	124	124	123.88
$SBOD_5$ (mg/l)	118	122	122	122	121	121	121	121	121.00
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.10	6.20	6.30	6.30	6.3	6.1	6.1	6.19
TSS (mg/l)	28.10	27.90	28.10	27.90	28.20	28.3	28.6	27.3	28.04
SCOD (mg/l)	21	16	16	17	16	16	16	16	16.14
$SBOD_5$ (mg/l)	18	13	13	14	13	13	13	13	13.14
NH_3-N (mg/l)	3.30	3.00	2.50	3.10	3.20	3.4	3	2.8	3.00
NO_3-N (mg/l)	14.40	14.50	14.60	13.60	13.60	14.4	14.1	13.9	14.10
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.80	17.60	17.20	16.80	16.90	17.90	17.20	16.80	17.20
SCOD removal efficiency (%)	82.64	87.10	87.20	86.51	87.10	86.99	87.10	87.10	87.01
$SBOD_5$ removal efficiency (%)	84.75	89.34	89.34	88.52	89.26	89.26	89.26	89.26	89.18
TN removal efficiency (%)	32.83	33.58	35.09	36.60	36.23	32.45	35.09	36.60	35.09
Abundance scale		6	6	6	6	6	6	6	6
Filamentous type	*S. natans*								

Table A.36 Activated sludge system- Experiment 18

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
DO	2.10	2.0	2.2	2.0	1.9	1.9	2.0	2.0	2.01
SCOD (mg/l)	121	124	125	126	124	123	124	124	123.88
$SBOD_5$ (mg/l)	118	122	122	122	121	121	121	121	121.00
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1589	1576	1567	1549	1586	1589	1593	1597	1581
MLVSS (mg/l)	1367	1378	1343	1355	1371	1332	1383	1359	1361
F/M ratio	0.35								
pH	6.90	6.80	6.90	6.70	6.70	6.90	6.80	6.90	6.81
TSS (mg/l)	36.70	20.70	22.30	23.60	22.10	21.9	22.2	21.9	22.10
SCOD (mg/l)	29	23	22	21	23	21	21	21	21.71
$SBOD_5$ (mg/l)	25	20	20	20	20	20	20	20	20
NH_3-N (mg/l)	4.30	6.30	6.70	6.30	6.60	6.6	6.4	6.5	6.49
NO_3-N (mg/l)	16.20	12.60	13.60	13.70	13.30	13.1	13.2	13.3	13.26
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	20.60	19.00	20.40	20.10	20.00	19.80	19.70	19.90	19.84
SCOD removal efficiency (%)	76.03	81.45	82.40	83.33	81.45	82.93	83.06	83.06	82.53
$SBOD_5$ removal efficiency (%)	78.81	83.61	83.61	83.61	83.47	83.47	83.47	83.47	83.53
TN removal efficiency (%)	22.26	28.30	23.02	24.15	24.53	25.28	25.66	24.91	25.12
Abundance scale		6	6	6	6	6	6	6	6.00
Filamentous type	*M. parvicella and N. limicola*								

Table A.37 Entrapped microbial reactor - Experiment19

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	5.60	5.8	5.7	5.7	5.7	5.8	5.7	5.7	5.71
SCOD (mg/l)	308	307	307	306	307	307	307	307	307.00
$SBOD_5$ (mg/l)	305	304	303	302	302	303	305	305	303.63
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.20	6.20	6.10	6.20	6.10	6.1	6.1	6.1	6.14
TSS (mg/l)	27.10	26.50	26.30	25.90	25.70	25.90	26.70	25.10	26.01
SCOD (mg/l)	12.00	11.00	11.00	11.00	11.00	12.00	10.00	10.00	10.86
$SBOD_5$ (mg/l)	10.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
NH_3-N (mg/l)	3.40	3.10	2.60	2.30	2.40	2.6	2.3	2.1	2.49
NO_3-N (mg/l)	14.30	14.40	14.50	13.40	13.40	14.2	13.9	13.7	13.93
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.80	17.60	17.20	15.80	15.90	16.90	16.30	15.90	16.51
SCOD removal efficiency (%)	96.10	96.42	96.42	96.41	96.42	96.09	96.74	96.74	96.46
$SBOD_5$ removal efficiency (%)	96.72	97.04	97.03	97.02	97.02	97.03	97.05	97.05	97.03
TN removal efficiency (%)	32.83	33.58	35.09	40.38	40.00	36.23	38.49	40.00	37.68
Abundance scale		4	4	4	4	4	4	4	4
Filamentous type	*S. natans*								

Table A.38 Activated sludge system- Experiment 19

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	5.50	5.8	5.7	5.9	5.7	5.7	5.7	5.7	5.71
SCOD (mg/l)	308	307	307	306	307	307	307	307	307.00
$SBOD_5$ (mg/l)	305	304	303	302	302	303	305	305	303.63
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1583	1588	1577	1579	1568	1589	1571	1576	1579
MLVSS (mg/l)	1343	1354	1361	1367	1317	1334	1321	1317	1339
F/M ratio	0.22								
pH	6.70	6.90	6.90	6.90	6.80	6.90	6.90	6.90	6.89
TSS (mg/l)	51.80	20.80	21.10	20.70	21.30	21.1	20.7	21.3	21.00
SCOD (mg/l)	57	41	40	40	41	40	40	40	40.29
$SBOD_5$ (mg/l)	53.00	39.00	37.00	37.00	37.00	37.00	37.00	37.00	37.29
NH_3-N (mg/l)	4.90	6.90	7.10	6.70	6.40	6.4	6.2	6.3	6.57
NO_3-N (mg/l)	15.80	12.20	13.00	13.10	12.60	12.4	13	13.1	12.77
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	20.80	19.20	20.20	19.90	19.10	18.90	19.30	19.50	19.44
SCOD removal efficiency (%)	81.49	86.64	86.97	86.93	86.64	86.97	86.97	86.97	86.87
$SBOD_5$ removal efficiency (%)	82.62	87.17	87.79	87.75	87.75	87.79	87.87	87.87	87.71
TN removal efficiency (%)	21.51	27.55	23.77	24.91	27.92	28.68	27.17	26.42	26.63
Abundance scale		3	4	4	4	4	4	4	4
Filamentous type	*M. parvicella*								

Table A.39 Entrapped microbial reactor - Experiment 20

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	5.70	5.8	5.7	5.7	5.6	5.8	5.7	5.7	5.71
SCOD (mg/l)	209	208	209	208	208	208	208	208	208.25
$SBOD_5$ (mg/l)	205	204	204	203	203	204	202	203	203.50
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.10	6.10	6.20	6.20	6.1	6.1	6.1	6.13
TSS (mg/l)	28.10	27.60	27.10	27.10	27.10	27.10	27.10	27.10	27.17
SCOD (mg/l)	8.00	8.00	7.00	7.00	7.00	7.00	7.00	7.00	7.14
$SBOD_5$ (mg/l)	5.00	5.00	4.00	5.00	5.00	4.00	4.00	4.00	4.43
NH_3-N (mg/l)	3.50	3.20	2.70	2.60	2.70	2.9	2.6	2.4	2.73
NO_3-N (mg/l)	14.20	14.30	14.40	13.20	13.20	14	13.7	13.5	13.76
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.80	17.60	17.20	15.90	16.00	17.00	16.40	16.00	16.59
SCOD removal efficiency (%)	96.17	96.15	96.65	96.63	96.63	96.63	96.63	96.63	96.57
$SBOD_5$ removal efficiency (%)	97.56	97.55	98.04	97.54	97.54	98.04	98.02	98.03	97.82
TN removal efficiency (%)	32.83	33.58	35.09	40.00	39.62	35.85	38.11	39.62	37.41
Abundance scale		3	3	3	3	3	3	3	3
Filamentous type	*S. natan*								

Table A.40 Activated sludge system- Experiment 20

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	5.60	5.7	5.8	5.9	5.8	5.7	5.7	5.7	5.74
SCOD (mg/l)	209	208	209	208	208	208	208	208	208.25
$SBOD_5$ (mg/l)	205	204	204	203	203	204	202	203	203.50
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1583	1588	1577	1579	1568	1589	1571	1576	1579
MLVSS (mg/l)	1343	1354	1361	1367	1317	1334	1321	1317	1339
F/M ratio	0.20								
pH	6.60	6.90	6.90	6.90	6.80	6.90	6.90	6.90	6.89
TSS (mg/l)	51.80	20.80	21.10	20.70	21.30	21.1	20.7	21.3	21.00
SCOD (mg/l)	53	29	28	29	29	29	30	30	29.14
$SBOD_5$ (mg/l)	53.00	26.00	27.00	26.00	26.00	26.00	27.00	26.00	26.29
NH_3-N (mg/l)	4.70	6.70	6.90	6.90	6.60	6.6	6.4	6.5	6.66
NO_3-N (mg/l)	15.70	12.10	12.90	12.90	12.40	12.2	12.8	12.9	12.60
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	20.50	18.90	19.90	19.90	19.10	18.90	19.30	19.50	19.36
SCOD removal efficiency (%)	74.64	86.06	86.60	86.06	86.06	86.06	85.58	85.58	86.00
$SBOD_5$ removal efficiency (%)	74.15	87.25	86.76	87.19	87.19	87.25	86.63	87.19	87.07
TN removal efficiency (%)	22.64	28.68	24.91	24.91	27.92	28.68	27.17	26.42	26.95
Abundance scale		3	4	4	4	4	4	4	4
Filamentous type	*M. parvicella*								

Table A.41 Entrapped microbial reactor - Experiment 21

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	5.70	5.7	5.7	5.5	5.8	5.7	5.8	5.8	5.71
SCOD (mg/l)	124	123	126	124	124	124	124	124	124
$SBOD_5$ (mg/l)	120	120	123	122	121	120	119	122	120.88
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.10	6.10	6.10	6.10	6.1	6.2	6.2	6.13
TSS (mg/l)	26.10	24.10	24.30	25.60	25.30	25.10	25.40	25.10	24.99
SCOD (mg/l)	3.00	3.00	4.00	4.00	4.00	5.00	5.00	5.00	4.29
$SBOD_5$ (mg/l)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
NH_3-N (mg/l)	3.40	3.10	2.60	2.30	2.40	2.6	2.3	2.1	2.49
NO_3-N (mg/l)	14.10	14.20	14.30	13.20	13.20	14.00	13.90	14.70	13.93
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.60	17.40	17.00	15.60	15.70	16.70	16.30	16.90	16.51
SCOD removal efficiency (%)	97.58	97.56	96.83	96.77	96.77	95.97	95.97	95.97	96.55
$SBOD_5$ removal efficiency (%)	97.50	97.50	97.56	97.54	97.52	97.50	97.48	97.54	97.52
TN removal efficiency (%)	33.58	34.34	35.85	41.13	40.75	36.98	38.49	36.23	37.68
Abundance scale		3	3	3	3	3	3	3	3
Filamentous type	*S. Natan*								

Table A.42 Activated sludge system- Experiment 21

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	5.70	5.7	5.6	5.8	5.8	5.6	5.6	5.8	5.70
SCOD (mg/l)	124	123	126	124	124	124	124	124	124.13
$SBOD_5$ (mg/l)	120	120	123	122	121	120	119	122	120.88
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1579	1583	1579	1587	1567	1589	1573	1547	1576
MLVSS (mg/l)	1323	1324	1328	1329	1331	1354	1341	1354	1336
F/M ratio	0.15								
pH	6.80	6.90	6.90	6.90	6.80	6.90	6.90	6.90	6.89
TSS (mg/l)	51.80	20.80	21.10	20.70	21.30	21.1	20.7	21.3	21.00
SCOD (mg/l)	27	18	17	16	17	17	17	17	17.00
$SBOD_5$ (mg/l)	24.00	14.00	13.00	13.00	13.00	13.00	13.00	13.00	13.14
NH_3-N (mg/l)	4.80	6.70	7.20	6.60	6.30	6.40	6.10	6.20	6.50
NO_3-N (mg/l)	15.60	12.00	12.80	13.00	12.50	12.3	12.7	12.8	12.59
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	20.50	18.80	20.10	19.70	18.90	18.80	18.90	19.10	19.19
SCOD removal efficiency (%)	78.23	85.37	86.51	87.10	86.29	86.29	86.29	86.29	86.30
$SBOD_5$ removal efficiency (%)	80.00	88.33	89.43	89.34	89.26	89.17	89.08	89.34	89.14
TN removal efficiency (%)	22.64	29.06	24.15	25.66	28.68	29.06	28.68	27.92	27.60
Abundance scale		4	4	4	4	4	4	4	4
Filamentous type	*M. parvicella*								

Table A.43 Entrapped microbial reactor - Experiment 22

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	4.30	4.2	4.2	4.4	4.5	4.3	4.3	4.3	4.31
SCOD (mg/l)	307	308	307	308	308	307	308	308	307.63
$SBOD_5$ (mg/l)	303	304	303	303	303	303	304	305	303.50
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.10	6.20	6.20	6.10	6.2	6.2	6.1	6.15
TSS (mg/l)	19.10	18.40	18.30	18.10	18.20	18.10	17.90	17.90	18.13
SCOD (mg/l)	11.00	10.00	11.00	12.00	12.00	12.00	10.00	9.00	10.86
$SBOD_5$ (mg/l)	9.00	9.00	8.00	7.00	7.00	9.00	7.00	7.00	7.71
NH_3-N (mg/l)	3.70	3.40	2.90	2.60	2.50	2.7	2.4	2.2	2.67
NO_3-N (mg/l)	14.10	14.20	14.30	13.20	13.20	14.3	13.7	13.5	13.77
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.90	17.70	17.30	15.90	15.80	17.10	16.20	15.80	16.54
SCOD removal efficiency (%)	96.42	96.75	96.42	96.10	96.10	96.09	96.75	97.08	96.47
$SBOD_5$ removal efficiency (%)	97.03	97.04	97.36	97.69	97.69	97.03	97.70	97.70	97.46
TN removal efficiency (%)	32.45	33.21	34.72	40.00	40.38	35.47	38.87	40.38	37.57
Abundance scale		3	3	3	3	3	3	3	3
Filamentous type	*S. natan*								

Table A.44 Activated sludge system- Experiment 22

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	4.40	4.2	4.3	4.4	4.4	4.5	4.5	4.4	4.39
SCOD (mg/l)	307	308	307	308	308	307	308	308	307.63
$SBOD_5$ (mg/l)	303	304	303	303	303	303	304	305	303.50
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1561	1563	1567	1561	1562	1559	1571	1573	1565
MLVSS (mg/l)	1356	1345	1345	1356	1367	1333	1323	1327	1344
F/M ratio	0.26								
pH	6.80	6.80	6.80	6.70	6.70	6.90	6.90	6.90	6.81
TSS (mg/l)	47.80	19.90	20.30	20.80	19.60	20.3	20.1	19.9	20.13
SCOD (mg/l)	61	40	39	41	42	40	40	40	40.29
$SBOD_5$ (mg/l)	53.00	38.00	37.00	37.00	36.00	38.00	38.00	38.00	37.43
NH_3-N (mg/l)	5.20	7.20	7.40	7.00	6.70	6.7	6.5	6.6	6.87
NO_3-N (mg/l)	15.70	12.10	12.90	13.00	12.50	12.3	12.9	13	12.67
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	21.00	19.40	20.40	20.10	19.30	19.10	19.50	19.70	19.64
SCOD removal efficiency (%)	80.13	87.01	87.30	86.69	86.36	86.97	87.01	87.01	86.91
$SBOD_5$ removal efficiency (%)	82.51	87.50	87.79	87.79	88.12	87.46	87.50	87.54	87.67
TN removal efficiency (%)	20.75	26.79	23.02	24.15	27.17	27.92	26.42	25.66	25.88
Abundance scale		4	4	4	4	4	4	4	4
Filamentous type	*M. parvicella*								

Table A.45 Entrapped microbial reactor - Experiment 23

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	4.40	4.6	4.4	4.4	4.3	4.4	4.4	4.3	4.40
SCOD (mg/l)	208	207	207	206	205	208	208	208	207.13
$SBOD_5$ (mg/l)	205	204	204	203	202	205	203	203	203.63
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.10	6.20	6.10	6.20	6.10	6.10	6.10	6.13
TSS (mg/l)	27.80	19.10	18.90	18.70	19.20	18.30	18.30	17.60	18.59
SCOD (mg/l)	7.00	7.00	7.00	8.00	7.00	7.00	8.00	7.00	7.29
$SBOD_5$ (mg/l)	5.00	5.00	5.00	6.00	5.00	5.00	6.00	5.00	5.29
NH_3-N (mg/l)	3.20	2.90	2.40	2.50	2.60	2.8	2.5	2.3	2.57
NO_3-N (mg/l)	14.70	14.80	14.90	13.80	13.20	14	13.7	13.5	13.99
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	18.00	17.80	17.40	16.40	15.90	16.90	16.30	15.90	16.66
SCOD removal efficiency (%)	96.63	96.62	96.62	96.12	96.59	96.63	96.15	96.63	96.48
$SBOD_5$ removal efficiency (%)	97.56	97.55	97.55	97.04	97.52	97.56	97.04	97.54	97.40
TN removal efficiency (%)	32.08	32.83	34.34	38.11	40.00	36.23	38.49	40.00	37.14
Abundance scale		3	3	3	3	3	3	3	3
Filamentous type	*S. natans*								

Table A.46 Activated sludge system- Experiment 23

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	4.60	4.6	4.4	4.4	4.4	4.3	4.3	4.3	4.41
SCOD (mg/l)	208	207	207	206	205	208	208	208	207.13
$SBOD_5$ (mg/l)	205	204	204	203	202	205	203	203	203.63
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1581	1587	1576	1567	1546	1549	1573	1577	1570
MLVSS (mg/l)	1341	1347	1348	1363	1317	1316	1323	1317	1334
F/M ratio	0.18								
pH	6.80	6.90	6.70	6.70	6.80	6.90	6.90	6.90	6.83
TSS (mg/l)	28.90	19.10	18.90	19.20	18.20	19.3	19.1	19.1	18.99
SCOD (mg/l)	31	27	28	29	27	28	28	28	27.86
$SBOD_5$ (mg/l)	28.00	25.00	25.00	25.00	26.00	25.00	26.00	26.00	25.43
NH_3-N (mg/l)	4.20	6.20	6.40	6.20	5.90	5.9	5.9	6	6.07
NO_3-N (mg/l)	15.40	11.80	12.60	12.70	12.20	12	12.6	12.7	12.37
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	19.70	18.10	19.10	19.00	18.20	18.00	18.60	18.80	18.54
SCOD removal efficiency (%)	85.10	86.96	86.47	85.92	86.83	86.54	86.54	86.54	86.54
$SBOD_5$ removal efficiency (%)	86.34	87.75	87.75	87.68	87.13	87.80	87.19	87.19	87.50
TN removal efficiency (%)	25.66	31.70	27.92	28.30	31.32	32.08	29.81	29.06	30.03
Abundance scale		3	4	4	4	4	4	4	4
Filamentous type	*M. parvicella*								

Table A.47 Entrapped microbial reactor - Experiment 24

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	4.40	4.5	4.4	4.6	4.4	4.4	4.4	4.4	4.44
SCOD (mg/l)	127	126	127	127	127	127	127	127	126.88
$SBOD_5$ (mg/l)	124	124	124	124	125	123	123	123	123.75
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.10	6.10	6.20	6.10	6.1	6.1	6.1	6.11
TSS (mg/l)	15.90	16.10	15.90	16.30	16.20	16.10	15.80	16.10	16.07
SCOD (mg/l)	7.00	5.00	5.00	5.00	4.00	4.00	4.00	5.00	4.57
$SBOD_5$ (mg/l)	5.00	3.00	4.00	4.00	3.00	3.00	3.00	3.00	3.29
NH_3-N (mg/l)	3.10	2.80	2.30	2.10	2.20	2.4	2.9	2.7	2.49
NO_3-N (mg/l)	14.10	14.20	14.30	13.00	13.00	13.8	13.5	13.3	13.59
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.30	17.10	16.70	15.20	15.30	16.30	16.50	16.10	16.17
SCOD removal efficiency (%)	94.49	96.03	96.06	96.06	96.85	96.85	96.85	96.06	96.40
$SBOD_5$ removal efficiency (%)	95.97	97.58	96.77	96.77	97.60	97.56	97.56	97.56	97.34
TN removal efficiency (%)	34.72	35.47	36.98	42.64	42.26	38.49	37.74	39.25	38.98
Abundance scale		3	3	3	3	3	3	3	3
Filamentous type	*S. natans*								

Table A.48 Activated sludge system- Experiment 24

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	4.40	4.4	4.4	4.5	4.6	4.4	4.5	4.4	4.44
SCOD (mg/l)	127	126	127	127	127	127	127	127	126.88
$SBOD_5$ (mg/l)	124	124	124	124	125	123	123	123	123.75
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1581	1583	1578	1567	1571	1563	1578	1577	1575
MLVSS (mg/l)	1347	1378	1378	1366	1312	1299	1381	1317	1347
F/M ratio	0.12								
pH	6.90	6.90	6.80	6.90	6.90	6.90	6.80	6.90	6.87
TSS (mg/l)	23.20	19.10	18.90	19.20	18.80	18.7	19.1	18.3	18.87
SCOD (mg/l)	47	16	16	16	17	17	17	16	16.43
$SBOD_5$ (mg/l)	43.00	13.00	12.00	13.00	13.00	13.00	12.00	12.00	12.57
NH_3-N (mg/l)	4.60	6.60	6.80	6.40	6.10	6.60	6.80	6.60	6.56
NO_3-N (mg/l)	14.90	11.30	12.10	12.20	11.70	11.5	12.1	12.2	11.87
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	19.60	18.00	19.00	18.70	17.90	18.20	19.00	18.90	18.53
SCOD removal efficiency (%)	63.23	87.30	87.40	87.40	86.61	86.61	86.61	87.40	87.05
$SBOD_5$ removal efficiency (%)	65.32	89.52	90.32	89.52	89.60	89.43	90.24	90.24	89.84
TN removal efficiency (%)	26.04	32.08	28.30	29.43	32.45	31.32	28.30	28.68	30.08
Abundance scale		4	4	4	4	4	4	4	4
Filamentous type	*M. parvicella*								

Table A.49 Entrapped microbial reactor - Experiment 25

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	2.30	2.3	2.2	2.2	2.3	2.3	2.3	2.3	2.28
SCOD (mg/l)	303	302	304	303	302	301	302	303	302.50
$SBOD_5$ (mg/l)	305	304	303	302	302	303	305	305	303.63
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.10	6.10	6.20	6.10	6.20	6.20	6.10	6.14
TSS (mg/l)	26.50	21.90	22.10	22.70	21.10	22.10	21.90	22.10	21.99
SCOD (mg/l)	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
$SBOD_5$ (mg/l)	10.00	11.00	10.00	11.00	10.00	10.00	10.00	10.00	10.29
NH_3-N (mg/l)	3.70	3.40	2.90	2.20	2.30	2.5	2.1	2.3	2.53
NO_3-N (mg/l)	14.00	14.10	14.20	13.20	13.20	14	14.1	13.9	13.81
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.80	17.60	17.20	15.50	15.60	16.60	16.30	16.30	16.44
SCOD removal efficiency (%)	96.04	96.03	96.05	96.04	96.03	96.01	96.03	96.04	96.03
$SBOD_5$ removal efficiency (%)	96.72	96.38	96.70	96.36	96.69	96.70	96.72	96.72	96.61
TN removal efficiency (%)	32.83	33.58	35.09	41.51	41.13	37.36	38.49	38.49	37.95
Abundance scale		4	4	4	4	4	4	4	4
Filamentous type	*S. natans*								

Table A.50 Activated sludge system- Experiment 25

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	2.20	2.4	2.3	2.3	2.1	2.3	2.3	2.2	2.26
SCOD (mg/l)	303	302	304	303	302	301	302	303	302.50
$SBOD_5$ (mg/l)	305	304	303	302	302	303	305	305	303.63
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1581	1587	1575	1573	1563	1583	1581	1571	1576
MLVSS (mg/l)	1341	1351	1353	1321	1319	1333	1327	1337	1335
F/M ratio	0.24								
pH	6.80	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90
TSS (mg/l)	36.70	23.20	14.90	14.70	15.10	14.8	15.2	14.9	14.93
SCOD (mg/l)	58	39	39	40	38	41	40	40	39.57
$SBOD_5$ (mg/l)	54.00	36.00	36.00	38.00	36.00	38.00	38.00	38.00	37.14
NH_3-N (mg/l)	4.50	6.50	6.70	7.20	6.90	6.9	6.7	6.8	6.81
NO_3-N (mg/l)	15.70	12.10	12.90	12.80	12.30	12.1	12.7	12.8	12.53
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	20.30	18.70	19.70	20.10	19.30	19.10	19.50	19.70	19.44
SCOD removal efficiency (%)	80.86	87.09	87.17	86.80	87.42	86.38	86.75	86.80	86.92
$SBOD_5$ removal efficiency (%)	82.30	88.16	88.12	87.42	88.08	87.46	87.54	87.54	87.76
TN removal efficiency (%)	23.40	29.43	25.66	24.15	27.17	27.92	26.42	25.66	26.63
Abundance scale		4	4	4	4	4	4	4	4
Filamentous type	*M. parvicella*								

Table A.51 Entrapped microbial reactor - Experiment 26

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	2.30	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.30
SCOD (mg/l)	204	203	204	204	204	204	204	204	203.88
$SBOD_5$ (mg/l)	200	201	201	201	201	201	201	201	200.88
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.30	6.20	6.20	6.20	6.10	6.20	6.20	6.10	6.19
TSS (mg/l)	34.60	22.90	22.80	22.70	23.30	23.70	23.10	23.20	23.10
SCOD (mg/l)	7.00	8.00	7.00	8.00	7.00	7.00	7.00	7.00	7.29
$SBOD_5$ (mg/l)	5.00	6.00	5.00	5.00	6.00	6.00	5.00	5.00	5.43
NH_3-N (mg/l)	3.60	3.30	2.80	2.10	2.20	2.40	2.00	1.80	2.37
NO_3-N (mg/l)	14.20	14.30	14.40	13.40	13.40	14.20	14.30	14.10	14.01
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.90	17.70	17.30	15.60	15.70	16.70	16.40	16.00	16.49
SCOD removal efficiency (%)	96.57	96.06	96.57	96.08	96.57	96.57	96.57	96.57	96.43
$SBOD_5$ removal efficiency (%)	97.50	97.01	97.51	97.51	97.01	97.01	97.51	97.51	97.30
TN removal efficiency (%)	32.45	33.21	34.72	41.13	40.75	36.98	38.11	39.62	37.79
Abundance scale		4.00	4.00	4.00	4.00	4	4	4	4
Filamentous type	*S. natans*								

Table A.52 Activated sludge system- Experiment 26

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	2.30	2.3	2.4	2.4	2.2	2.3	2.3	2.3	2.31
SCOD (mg/l)	204	203	204	204	204	204	204	204	203.88
$SBOD_5$ (mg/l)	200	201	201	201	201	201	201	201	200.88
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1557	1555	1567	1567	1561	1430	1410	1290	1492
MLVSS (mg/l)	1323	1339	1361	1316	1318	1210	1232	1067	1271
F/M ratio	0.19								
pH	6.70	6.80	6.90	6.90	6.90	6.90	6.90	6.90	6.89
TSS (mg/l)	41.70	27.90	28.10	27.90	28.20	99.8	95.7	104.9	58.93
SCOD (mg/l)	37	26	26	27	27	27	28	28	27.00
$SBOD_5$ (mg/l)	33.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
NH_3-N (mg/l)	4.70	6.70	6.90	6.50	6.00	6.00	5.80	5.90	6.26
NO_3-N (mg/l)	15.70	12.90	13.10	12.80	12.80	12.70	12.40	12.70	12.77
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	20.50	19.70	20.10	19.40	18.90	18.80	18.30	18.70	19.13
SCOD removal efficiency (%)	81.86	87.19	87.25	86.76	86.76	86.76	86.27	86.27	86.76
$SBOD_5$ removal efficiency (%)	83.50	88.56	88.56	88.56	88.56	88.56	88.56	88.56	88.56
TN removal efficiency (%)	22.64	25.66	24.15	26.79	28.68	29.06	30.94	29.43	27.82
Abundance scale		4	4	4	6	6	6	6	6
Filamentous type	*M. parvicella*								

Table A.53 Entrapped microbial reactor - Experiment 27

Parameter	Entrapped microbial system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	2.30	2.2	2.4	2.3	2.3	2.3	2.3	2.3	2.30
SCOD (mg/l)	127	125	127	127	128	126	127	127	126.75
$SBOD_5$ (mg/l)	122	122	123	122	125	122	121	124	122.63
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
pH	6.10	6.40	6.10	6.10	6.10	6.10	6.10	6.10	6.14
TSS (mg/l)	19.10	19.10	18.90	18.90	19.00	18.90	19.10	19.10	19.00
SCOD (mg/l)	5.00	5.00	5.00	5.00	4.00	4.00	4.00	4.00	4.43
$SBOD_5$ (mg/l)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
NH_3-N (mg/l)	3.70	3.40	2.90	2.60	2.70	2.9	2.6	2.4	2.79
NO_3-N (mg/l)	14.10	14.20	14.30	13.20	13.10	13.9	13.6	13.4	13.67
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	17.90	17.70	17.30	15.90	15.90	16.90	16.30	15.90	16.56
SCOD removal efficiency (%)	96.06	96.00	96.06	96.06	96.88	96.83	96.85	96.85	96.50
$SBOD_5$ removal efficiency (%)	97.54	97.54	97.56	97.54	97.60	97.54	97.52	97.58	97.56
TN removal efficiency (%)	32.45	33.21	34.72	40.00	40.00	36.23	38.49	40.00	37.52
Abundance scale		3	4	4	4	4	4	4	4
Filamentous type	*S. natans*								

Table A.54 Activated sludge system- Experiment 27

Parameter	Activated sludge system								
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Day6	Day 7	Day 8	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
DO	2.30	2.2	2.4	2.4	2.2	2.2	2.3	2.3	2.29
SCOD (mg/l)	127	125	127	127	128	126	127	127	126.75
$SBOD_5$ (mg/l)	122	122	123	122	125	122	121	124	122.63
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Effluent									
MLSS (mg/l)	1567	1586	1577	1568	1568	1562	1571	1576	1572
MLVSS (mg/l)	1342	1347	1367	1331	1311	1390	1371	1319	1347
F/M ratio	0.13								
pH	6.90	6.90	6.90	6.90	6.80	6.90	6.90	6.90	6.89
TSS (mg/l)	43.20	27.10	26.30	25.80	25.90	26.10	26.70	26.10	26.29
SCOD (mg/l)	29	17	18	18	18	17	17	17	17.43
$SBOD_5$ (mg/l)	25.00	15.00	14.00	14.00	13.00	13.00	13.00	13.00	13.57
NH_3-N (mg/l)	5.60	7.60	7.80	7.40	7.10	7.1	6.9	7	7.27
NO_3-N (mg/l)	15.30	11.70	12.50	12.60	12.10	11.9	12.5	12.6	12.27
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	21.00	19.40	20.40	20.10	19.30	19.10	19.50	19.70	19.64
SCOD removal efficiency (%)	77.17	86.40	85.83	85.83	85.94	86.51	86.61	86.61	86.25
$SBOD_5$ removal efficiency (%)	79.51	87.70	88.62	88.52	89.60	89.34	89.26	89.52	88.94
TN removal efficiency (%)	20.75	26.79	23.02	24.15	27.17	27.92	26.42	25.66	25.88
Abundance scale		4	5	5	5	5	5	5	5
Filamentous type	*M. parvicella*								

Table A.55 Entrapped microbial reactor - Experiment 28

Parameter	Entrapped microbial system					
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	1.50	1.50	1.50	1.50	1.50	1.50
DO	2.10	2.10	2.00	2.10	2.10	2.08
SCOD (mg/l)	301	303	304	302	304	302.80
$SBOD_5$ (mg/l)	298	297	296	298	298.00	297.40
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50
Effluent						
pH	6.10	6.20	6.10	6.10	6.10	6.13
TSS (mg/l)	24.10	23.50	22.90	22.30	22.70	22.85
SCOD (mg/l)	96.00	97.00	97.00	96.00	96.00	96.50
$SBOD_5$ (mg/l)	91.00	92.00	93.00	91.00	91.00	91.75
NH_3-N (mg/l)	8.90	8.80	9.10	9.20	9.30	9.10
NO_3-N (mg/l)	12.20	12.30	12.10	11.90	11.60	11.98
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	21.20	21.20	21.30	21.20	21.00	21.18
SCOD removal efficiency (%)	68.11	67.99	68.09	68.21	68.42	68.18
$SBOD_5$ removal efficiency (%)	69.46	69.02	68.58	69.46	69.46	69.13
TN removal efficiency (%)	20.00	20.00	19.62	20.00	20.75	20.09
Abundance scale		6	6	6	6	6
Filamentous type	*S. natans*					

Table A.56 Entrapped microbial reactor - Experiment 29

Parameter	Entrapped microbial system					
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	1.50	1.50	1.50	1.50	1.50	1.50
DO	2.20	2.20	2.10	2.10	2.10	2.14
SCOD (mg/l)	205	206	206	206	206	205.80
$SBOD_5$ (mg/l)	198	199	199	199	199.00	198.80
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50
Effluent						
pH	6.10	6.10	6.10	6.10	6.10	6.10
TSS (mg/l)	28.10	27.90	25.90	26.80	26.70	26.83
SCOD (mg/l)	65.00	65.00	63.00	64.00	64.00	64.00
$SBOD_5$ (mg/l)	62.00	61.00	60.00	61.00	60.00	60.50
NH_3-N (mg/l)	9.20	8.90	9.20	9.30	9.40	9.20
NO_3-N (mg/l)	12.70	12.60	12.30	12.10	12.10	12.28
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	22.00	21.60	21.60	21.50	21.60	21.58
SCOD removal efficiency (%)	68.29	68.45	69.42	68.93	68.93	68.93
$SBOD_5$ removal efficiency (%)	68.69	69.35	69.85	69.35	69.85	69.60
TN removal efficiency (%)	16.98	18.49	18.49	18.87	18.49	18.58
Abundance scale		6	6	6	6	6
Filamentous type	*S. natans*					

Table A.57 Entrapped microbial reactor - Experiment 30

Parameter	Entrapped microbial system					
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	1.50	1.50	1.50	1.50	1.50	1.50
DO	2.10	2.10	2.10	2.10	2.10	2.10
SCOD (mg/l)	125	124	124	124	124	124.20
$SBOD_5$ (mg/l)	122	121	120	120	120.00	120.60
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50
Effluent						
pH	6.10	6.10	6.10	6.10	6.10	6.10
TSS (mg/l)	27.90	28.10	28.10	27.90	27.80	27.98
SCOD (mg/l)	35.00	34.00	36.00	35.00	35.00	35.00
$SBOD_5$ (mg/l)	31.00	31.00	32.00	32.00	31.00	31.50
NH_3-N (mg/l)	8.80	9.10	9.20	9.30	9.40	9.25
NO_3-N (mg/l)	12.60	12.70	12.60	12.90	12.60	12.70
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	21.50	21.90	21.90	22.30	22.10	22.05
SCOD removal efficiency (%)	72.00	72.58	70.97	71.77	71.77	71.77
$SBOD_5$ removal efficiency (%)	74.59	74.38	73.33	73.33	74.17	73.80
TN removal efficiency (%)	18.87	17.36	17.36	15.85	16.60	16.79
Abundance scale		6	6	6	6	6
Filamentous type	*S. natans*					

Table A.58 Entrapped microbial reactor - Experiment 31

Parameter	Entrapped microbial system					
Influent	Day 1	Day 2	Day 3	Day 4	Day 5	Average
pH	7.22	7.22	7.22	7.22	7.22	7.22
HRT (h)	1.50	1.50	1.50	1.50	1.50	1.50
DO	4.40	4.50	4.50	4.50	4.50	4.48
SCOD (mg/l)	305	307	307	306	306	306.20
$SBOD_5$ (mg/l)	301	301	302	303	303.00	302.00
NH_3-N (mg/l)	26.50	26.50	26.50	26.50	26.50	26.50
Effluent						
pH	6.20	6.20	6.10	6.10	6.10	6.13
TSS (mg/l)	28.10	27.30	27.10	26.80	26.80	27.00
SCOD (mg/l)	95.00	91.00	91.00	91.00	91.00	91.00
$SBOD_5$ (mg/l)	91.00	86.00	87.00	85.00	85.00	85.75
NH_3-N (mg/l)	12.30	12.20	12.30	11.80	11.30	11.90
NO_3-N (mg/l)	9.20	9.10	9.10	9.20	9.30	9.18
NO_2-N (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10
TN (mg/l)	21.60	21.40	21.50	21.10	20.70	21.18
SCOD removal efficiency (%)	68.85	70.36	70.36	70.26	70.26	70.31
$SBOD_5$ removal efficiency (%)	69.77	71.43	71.19	71.95	71.95	71.63
TN removal efficiency (%)	18.49	19.25	18.87	20.38	21.89	20.09
Abundance scale		6	6	6	6	6
Filamentous type	*S. natans*					