SEQUENCING BATCH REACTOR DEMONSTRATION PROJECT
HAMILTON HARBOUR
SEDIMENT SUPERNATANT TREATMENT

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Site Remediation Division
Wastewater Technology Centre
operated by Rockcliffe Research Management

Abstract

The efficacy of treating supernatant derived from sediment dredged from Hamilton Harbour with a sequencing batch reactor, SBR, and ultra-filtration independently and in series was investigated. Based on the results of a treatability study performed in 4 L biological reactors it was concluded that use of a SBR, ultra-filtration unit or a combination of the two was not an appropriate treatment system for the sediment supernatant. The combination of SBR and ultra-filtration unit (in any order) could achieve effluent characterized by a five day biochemical oxygen demand, BOD_5, of less than 15 mg/L, total suspended solids, TSS, concentration of less than 15 mg/L, total ammonia nitrogen concentration of less than 1 mg/L and total phosphorous concentration of less than 1 mg/L. Untreated supernatant was characterized by BOD_5 marginally greater than 15 mg/L, TSS greater than 100 mg/L (up to 1 000 mg/L), NH_3 approximately 10 mg/L and TP less than 1 mg/L. Unless nitrification was a major goal it was recommended that biological processes are not required, and conventional flocculation or sand filtration would be more suited to solid/liquid separation than ultra-filtration units. One option that is worthwhile exploring is the removal of solids and free oil and grease by application of inorganic ultra-filtration units.

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1.0 AN OVERVIEW - GREAT LAKES CLEANUP FUND CONTAMINATED SEDIMENT REMOVAL AND TREATMENT TECHNOLOGY PROGRAMS

Environment Canada's Great Lakes Cleanup Fund, initiated in 1991, is one component of the federal Great Lakes Action Plan. The program focuses on Canada's 17 Areas of Concern identified by the International Joint Commission. The Cleanup Fund, administered by the Great Lakes Environment Office, is designed to help meet federal commitments in the development and implementation of cleanup options. To evaluate and foster the development of innovative sediment removal and treatment technologies the Contaminated Sediment Removal Technology Program (CSRTP) and Contaminated Sediment Treatment Technology Program (CoSTTeP) were initiated.

Approximately one-third of the Cleanup Fund budget is being directed towards contaminated sediment remediation. There are two reasons why the cleaning of sediments has been given such a high priority. The first is that pollutants in the sediment are absorbed into or ingested by organisms and plants which live in or on sediment. These benthic organisms are either directly impaired (killed by toxic effects, deformed at birth, caused to develop cancer) or pass the toxins up through the food chain (bio-accumulation, bio-magnification) where toxic effects can show up at the higher trophic levels including humans. The second reason sediment remediation is a priority is that sediments have now been identified as a major source of pollution to the water column above. During past years of heavy industrial and municipal pollution, sediments absorbed a great deal of pollution from the water column. Now, however, industrial and municipal discharges have been greatly reduced so that the water is generally cleaner than the sediment in a relative sense. Thus the pollutants stored in the sediments are now diffusing back into the water. This is a major obstacle to improving Great Lakes water quality since it could take hundreds of years for all of the pollutants to diffuse out of the sediment.

The Wastewater Technology Centre's (WTC) Site Remediation Division submitted an unsolicited proposal to the Great Lakes Environment Office to perform bench-scale and pilot-scale treatability studies on the excess water often associated with contaminated sediment removal and treatment operations. The key technology to be evaluated was the sequencing batch reactor (SBR) a relatively compact and hence mobile biological process. The proposal was accepted and the study commenced in October 1992. A two phase approach was adopted whereby it was proposed to perform bench-scale screening experiments in the laboratory to establish the process potential and operating conditions for the second phase of the study using a trailer mounted 1350 L SBR. The work described in this report was performed primarily by WTC's Site Remediation Division, assisted by WTC's

Physical/Chemical Processes Division and WTC's Biological Process Division. Analyses were performed by the Site Remediation Division, the Laboratory Division and the Civil Engineering Department of McMaster University.

2.0 PROJECT BACKGROUND AND OBJECTIVES

One approach to sediment remediation involves the removal of contaminated sediment using mechanical or hydraulic dredging technologies. The sediment may then be disposed of in a landfill or preferably treated to (potentially) recover a useful product. In either scenario - dredge and dispose or dredge and treat - it will usually be beneficial to minimize the volume of dredged material requiring further processing. An exception may be where treatment requires a sediment slurry such as a bioslurry treatment process.

Fundamental to volume reduction is the separation of the highly contaminated sediment solids from the comparatively clean water. This separation may be practically achieved by simple methods such as allowing the dredged sediment to consolidate and pumping off the free water (supernatant) or by more sophisticated means such as filter presses. In any operation the recovered "clean" water will still be characterized by a degree of suspended solid and soluble chemical compound contamination. It is a reasonable first approximation to assume that most of the contamination will be sorbed to the solids. Before this water may be discharged, to the sewers or directly to a receiving water, it must meet the discharge guidelines or regulations.

The objective of this study was principally to evaluate the potential to use a simple biological system either alone or coupled with a membrane filtration system to treat sediment process water. Specifically a system comprised of a SBR and ultra-filtration unit in series was evaluated to achieve the following effluent characteristics (the Ontario Ministry of the Environment's industrial effluent discharge guidelines):

1) A five day biochemical oxygen demand, BOD_5, of less than 15 mg/L
2) A total suspended solids, TSS, concentration of less than 15 mg/L
3) A total ammonia nitrogen concentration of less than 1 mg/L
4) A total phosphorous concentration of less than 1 mg/L.

The first two objectives took precedence over the second two objectives.

The feed stream was supernatant derived from sediment dredged during a pilot-scale removal project conducted under the auspices of the CSRTP in Hamilton Harbour, October 1992. The dredged sediment is being treated using a landfarming technology under the auspices of CoSTTeP. The landfarming technology required a dewatered sediment, primarily due to handleability constraints. Water was separated from the bulk sediment by allowing the sediment to consolidate on the barge and then at the treatment site. After a period of consolidation the water was pumped off the top of the sediment.

3.0 TECHNOLOGY DESCRIPTION

Two possible treatment technologies were investigated. A SBR was the core technology and, for operational reasons, an ultra-filtration unit was also investigated. Both the SBR and ultra-filtration unit are illustrated schematically in figure 1. To accomplish the study objectives the following treatment scenarios were investigated:

- A SBR alone
- An ultra-filtration unit alone
- A SBR followed by an ultra-filtration unit
- An ultra-filtration unit followed by an SBR

3.1 SEQUENCING BATCH REACTORS

The SBR is one form of the activated sludge process, well summarized by a number of papers (co)authored by Robert L. Irvine, University of Notre Dame, Indiana (ie. Irvine & Busch [1979] and Irvine & Ketchum [1989]). In contrast to the conventional continuous flow municipal systems in which biological processes and solid-liquid separation occur in separate containers the SBR is characterized by a single reactor.

In principle, operation of a single reactor SBR may simply be described by the following steps, illustrated schematically in figure 2: Wastewater is fed to a reactor already containing activated sludge, the reactor is filled to capacity (FILL); the mixed liquor is aerated and mixed allowing the biomass to biodegrade the organic contamination in the waste (REACT); all activity is stopped and the mixed liquor suspended solids (MLSS) are allowed to settle (SETTLE); finally the treated (biologically and clarified) water is decanted (DRAW) after which the cycle begins again.

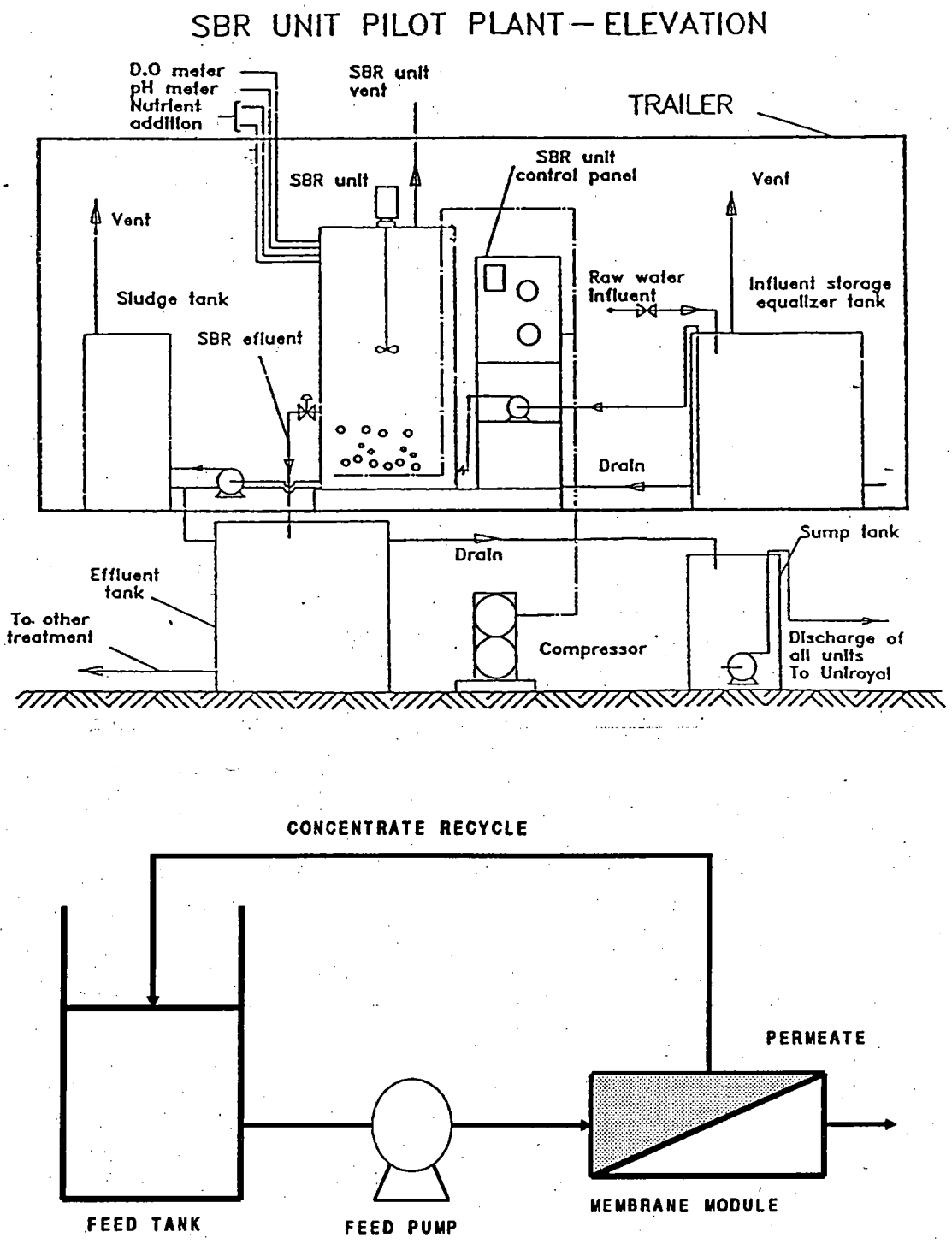


FIGURE 1. Schematic of WTC's pilot-scale SBR (top, adapted from Aziz, 1992) and ultra-filtration unit (bottom).

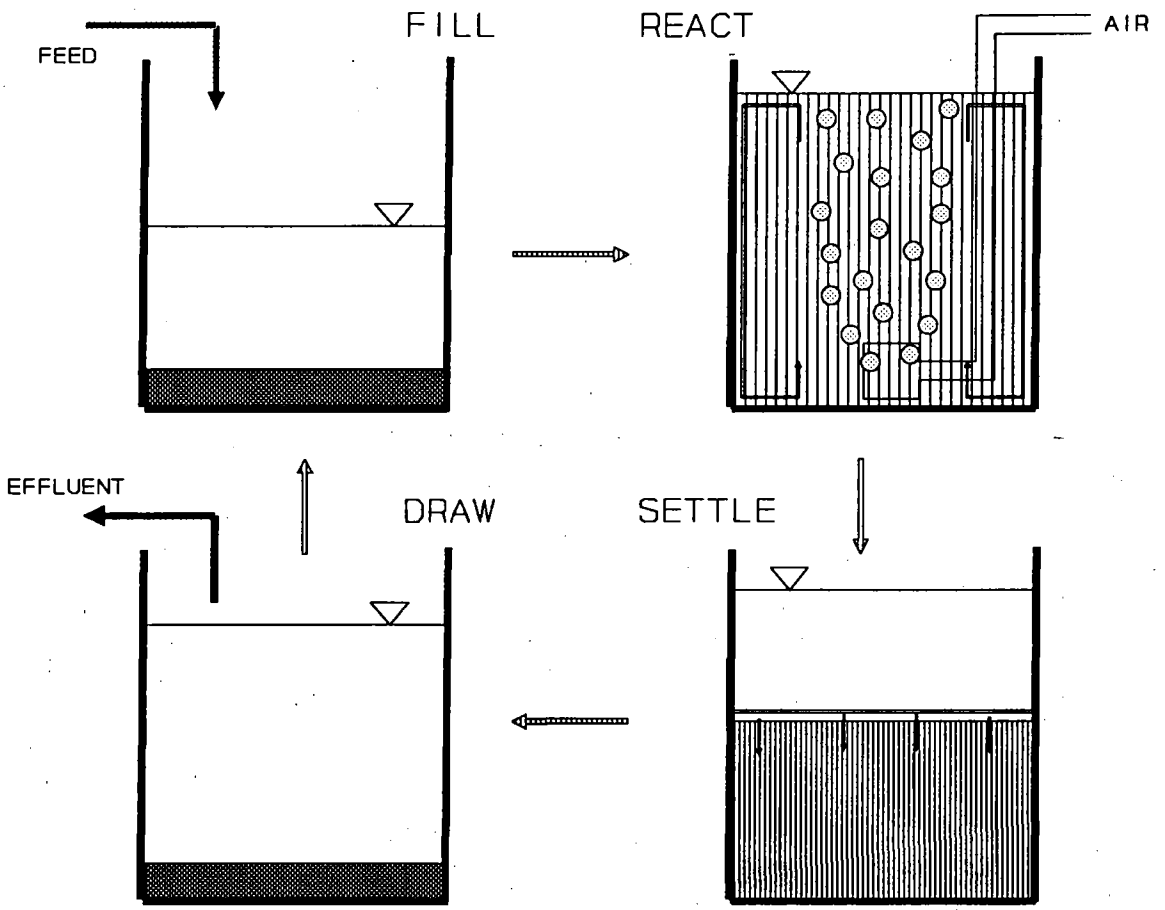


FIGURE 2. The sequence followed in the operation of a simple SBR.

The SBR is ideally suited to operations such as sediment remediation projects as it is compact and hence portable, it is not a continuous flow process and so the effluent may be held until proven to meet discharge criteria.

In the simplest form the only aeration and mixing occurs during the REACT period. Actual operation may be more complicated with aeration and mix strategies being applied through the FILL and REACT cycles. The strategies applied will generally result in varying degrees of one or a combination of BOD removal, suspended solids removal, nitrification, denitrification and phosphorous removal. Guidelines for a number of objectives, such as optimal removal of BOD and TSS, have been suggested by Arora et. al., 1985.

Generally SBRs outperform continuous flow reactors. The feasibility of SBRs is usually dependent on the performance during the settling period. If a settleable sludge does not develop then the reactor will wash out during the DRAW period (viable microorganisms will be drawn off with the supernatant). To increase the potential for developing a settleable biomass the following controls can be applied:

• An anoxic FILL period. This inhibits the growth of filamentous organisms (which are typical of poorly settling biomass) and ensures a high "initial" substrate concentration. A high substrate concentration enables microorganisms with good settling properties to out-compete filamentous organisms.

• A short FILL period and long REACT period promote a better settling biomass when aerating through both. This is due to the high "initial" substrate concentration. A high substrate concentration enables microorganisms with good settling properties to out-compete filamentous organisms.

3.2 ULTRA-FILTRATION UNITS

As this study is to focus on the biological treatment of sediment supernatant, a detailed discussion of ultra-filtration units is not attempted. Two texts offer excellent summaries of the technology - Weber [1972] and Cheryan [1986]. The following is a brief note on some practical aspects of ultra-filtration units.

Ultra-filtration is a technology which acts as a positive block to particles or large organic molecules in a manner very similar to conventional paper filters. The filtration media is generally an organic polymer membrane supported by a rigid frame. The structural form may be a traditional plate and frame, spiral wound, tubular or hollow fibre. For all structural forms, the principles remain the same, the different designs generally impact the compactness and portability of the large scale units. The driving force for the filtration is a pressure differential from the dirty to clean side of the membrane.

As the ultra-filtration membranes present a positive block to contaminants (whether solids or molecules) the quality of effluent generated cannot be disputed. The principal concern in the use of ultra-filtration units is maintaining the flux of treated liquid through the membrane. Oils and very fine solids tend to clog the membrane units. To reduce membrane failure due to solids or oils a high

liquid shear must be applied to the membrane surface. In addition, temperature tends to have large affect on the flux; higher temperatures usually are associated with higher fluxes.

4.0 EXPERIMENTAL DESIGN

The overall approach taken was bound by time constraints imposed by the schedules for the sediment removal and treatment projects. The sediment was dredged beginning October 7, 1992. The supernatant was delivered on site (Pier 26) October 9. To reduce problems resulting from cold weather, such as freezing and temperature inhibition of microbial activity, the pilot-scale supernatant treatment demonstration was to be run as soon as possible. Prior to any pilot-scale activity a set of bench-scale treatability studies were to be performed, as screening tests, to indicate which of the four treatment scenarios listed above were practical and judged worthy of further investigation. The pilot-scale demonstration was to establish best effluent characteristics based on operating conditions derived from the bench-scale tests. Sample characterization and bench-scale studies were initiated concurrently. Complete analytical results were not completely available until completion of the bench-scale studies. The analytical methods used for this study are presented in Appendix A. The raw data is included as Appendix B.

The conceptual approach to the bench-scale studies is shown in figure 3. In the following discussion, sample points S1 to S5 refer to those shown in the figure 3.

4.1 SAMPLE CHARACTERIZATION

The supernatant (S1) was sampled and submitted for analysis of **BOD_5, COD, TOC, NH_3, NO_3, TKN, TP, pH, TSS and VSS.** BOD_5 is the parameter specified by regulations governing discharge requirements. However, due to the length of the analysis - 5 day test - COD was analyzed for as a rapid indicator. It was expected that a relationship between BOD_5 and COD would be established after approximately 10 samples had been analyzed. Once this relationship was established only COD was to be analyzed for except for at the end of bench- and pilot-scale test runs.

Analyses for trace organic contaminants (notably polynuclear aromatic hydrocarbons) was only to be performed on limited pilot-scale samples.

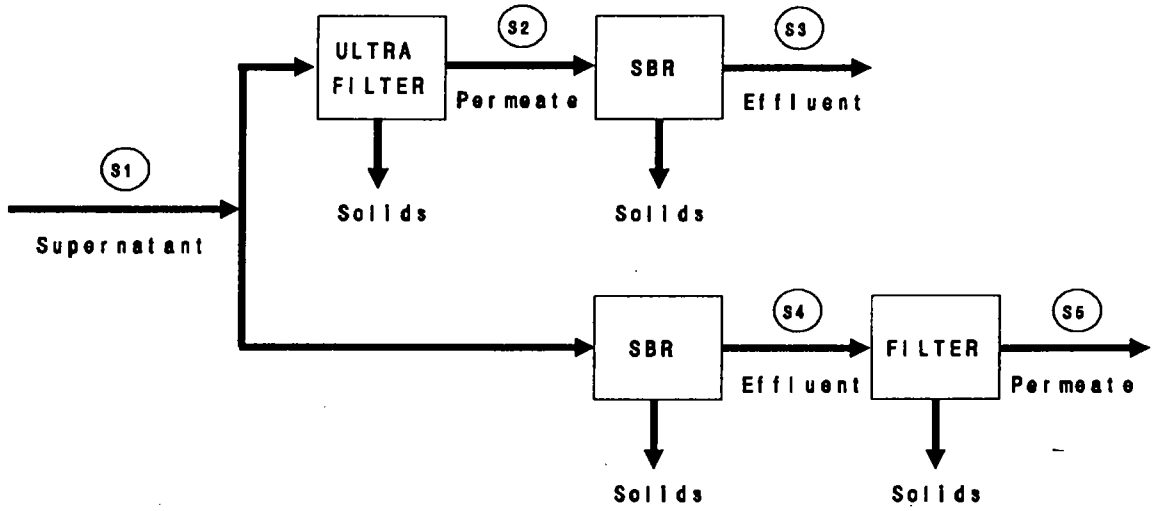


FIGURE 3. Conceptual approach and sampling points for bench-scale study.

4.2 SCREENING TESTS

4.2.1 ULTRA-FILTRATION

Sample filtration was required to prepare a large quantity (200 L) of feed for the SBRs. In addition filtration was required on a small quantity of SBR effluent to evaluate the applicability of the SBR/filtration scenarios. Two approaches were taken to achieve these requirements.

The SBR feed was prepared by passing the sediment supernatant over a "DESAL" G-50 flat sheet membrane with a 15,000 molecular weight cut-off. The membrane was mounted in a continuous flow apparatus operated to maintain a high shear across the membrane surface (preventing fouling by solids accumulation). Operation of the membrane was conducted by WTC's Physical/Chemical Processes Division using an existing unit.

The permeate was collected (S2) and then submitted for analysis of **BOD_5, COD, TOC, NH_3, NO_3, TKN, TP, pH and TSS.** In addition operational data (ie. flux and temperature) was recorded over a period of time. The data obtained from this test allowed the effectiveness of ultra-filtration alone to be evaluated. Also the suitability of filtrate from a filtration unit could be assessed as a feed to a biological process (ie. C:N:P).

The effluent from the SBRs treating initially unfiltered feed was filtered in small quantities (approximately 50 mL) through conventional 0.45 μm filter paper under vacuum and the filtrate (S5)

submitted for the same analyses as listed above. This allowed the effectiveness of a SBR followed by an ultra-filtration unit to be assessed.

4.2.2 SEQUENCING BATCH REACTORS

A sludge with good settling characteristics is required for the efficient use of an SBR. Samples of return activated sludge from two municipal sewage treatment plants (STP) were tested for their settleability characteristics in the non-acclimated form. Sludge from Woodward STP was tested as it would probably have been exposed to the contaminants expected in the sediment water (or sorbed to the solids). However past observations have found the Woodward sludge to contain a significant filamentous (bulking) microbial population (Aziz, 1992). Dundas STP sludge was also tested as it was known to have excellent settling properties even though it was unlikely to be acclimated to the contaminants in the supernatant. Either sludge should acclimate to the substrate type and concentrations in the supernatant.

Two distinct sets of reactors were set up. One set was run on the permeate from the ultra-filtration tests, a second set was fed the "raw" supernatant. As the phosphorous and organic nitrogen contents of the sediment was known to be high (RAP, 1989) it was assumed that the same would be true of the soluble forms and that no nutrient addition would be required.

The reactors were simple 4 L glass beakers, run under a fume hood. Aeration and mixing was provided by a single aeration stone. If necessary, low intensity mechanical mixing was to be applied to keep the solids suspended without disrupting the bioflocs. The reactors were seeded and run until 1 sludge retention time (SRT) to establish quasi-stable conditions prior to comprehensive sampling. It was recognized that at least 3 SRTs are usually required for stable operation of activated sludge processes, but in the interests of time, and accepting the screening nature of these tests, a single SRT was judged to be acceptable.

The following initial conditions were targeted (actual conditions varied somewhat) so that the two test variables were reactor feed and REACT time:

	REACTOR 1 & 3	REACTOR 2 & 4
Feed	Raw (R 1) Permeate (R 3)	Raw (R 2) Permeate (R 4)
MLVSS	3000 mg/L	3000 mg/L
SRT	10 days	10 days
HRT	16 hours	24 hours
FILL	30 minutes	30 minutes
REACT	6 hours	10 hours
SETTLE	1 hour	1 hour
DRAW	30 minutes	30 minutes
Aerate	REACT	REACT
Mix	FILL/REACT	FILL/REACT
Draw Volume	50% reactor volume	50% reactor volume

All operating conditions were chosen somewhat arbitrarily.

The mixed liquor volatile suspended solids (MLVSS) targeted is at the high end of literature values (Metcalf & Eddy). MLVSS was specified rather than MLSS as the non-organic particulate component in the unfiltered feed was expected to be high. The actual MLVSS value attained was expected to depend on the operating conditions and adjust to some "equilibrium" value with time. It was expected that the MLVSS would decline with time in the reactors treating unfiltered feed. If this decrease was excessive, the HRT was to be increased and the SRT was to be decreased or the reactor was to be considered to have failed and operation ceased.

From a limited literature review, SRT does not appear to greatly impact the efficiency of the biodegradation process in SBRs. Ten days was chosen as it appeared to be close to the minimum used in past operations, which was desirable given the time constraints imposed on the project. The low SRT should also promote biomass growth which will be important for the reactors treating unfiltered water ie. in maintaining a viable population in the MLSS. Beginning on the second day of operation, mixed liquor was wasted at the end of the last REACT period of each day, prior to beginning the SETTLE. The volume of mixed liquor wasted was calculated daily based on the MLVSS of the reactor and VSS of the reactor effluent (so 1/10th of the volatile mass was wasted each day).

The hydraulic residence time (HRT) depends on the cycle times and exchange volume each cycle. It was assumed that half of the reactor volume would be withdrawn (and then refilled with raw feed) each cycle although if the MLSS did not settle well this was to have been reduced to prevent reactor washout. If half the reactor volume is replaced each cycle then the HRT equals twice the total

cycle time (FILL+REACT+SETTLE+DRAW). The FILL time was short as the literature suggests that a high initial concentration of substrate results in the auto-selection of non-filamentous microorganisms. It is recommended in the literature (Irvine & Ketchum [1989]) that the sum of the SETTLE and DRAW time should be less than 3 hours to prevent gas formation due to denitrification (if nitrification has occurred previously). SETTLE time was finalized once the experiments had begun (noting that it would be highly dependent upon the MLSS settleability). The REACT time was selected to provide a "high" (reactors 2 and 4) and a "low" (reactors 1 and 3) reaction period during which aerobic biodegradation could occur. The practicality of running the bench-scale units was also considered, to limit "off-hours" management of the system.

Daily composites of the reactor effluent were created for each reactor (S3 and S4). For the reactors with two cycles each day 1 600 mL of the DRAW volume was added to the appropriate composite. For the reactors with three cycles each day 1 000 mL of the DRAW volume was added to the appropriate composite. Samples of the daily composites were submitted for **COD (total and soluble), TSS and VSS.** Feed was stored in 15 to 25 L containers. As each batch was begun a sample was taken and submitted for **COD (total and soluble), TSS and VSS.**

Samples of MLSS were taken daily from each reactor at the end of the first REACT period for the day, prior to the SETTLE period beginning. These samples were submitted for **COD (total and soluble), MLSS and MLVSS.** Sludge volume index (SVI) was qualitatively estimated from the MLSS during the REACT period and the settled volume after the SETTLE period.

Sampling to test the efficacy of the treatment occurred after 10 days of SBR operation. Samples of the reactor effluent (S3) and (S4) were submitted for analysis of **BOD_5, COD, NH_3, NO_3, TKN, TP, pH, TSS and VSS.**

5.0 RESULTS & DISCUSSION

5.1 SUPERNATANT CHARACTERIZATION

The supernatant characterization was conducted on an ongoing basis. Supernatant derived from a sample of Hamilton Harbour sediment had been analyzed in a previous study (ARC, 1992). ARC found that the supernatant had a high concentration of solids (1.01%) of which 10% was organic. The solid fraction was analyzed for the U.S. EPA list of priority polynuclear aromatic hydrocarbons

(PAHs) and a suite of metals. The total PAH concentration was approximately 111 mg/L, 90.9 mg/L of which was attributed to Naphthalene. As noted in the report (ARC), the actual concentrations were probably significantly lower and the elevated levels of Naphthalene only an analytical anomaly. The total water soluble organic concentration was determined as 50 mg/L. Given the low solubilities of the contaminants of concern, the PAHs, this low level is expected. Iron, lead, sulfur and zinc were present in concentrations of approximately 1919 mg/L, 20.2 mg/L, 191.9 mg/L and 202 mg/L respectively (on a dry weight basis).

During this study, an initial sample and final sample of supernatant was subjected to extensive analyses while samples taken periodically during the management of the SBRs were subjected to a reduced analyses. These data are shown in table 1.

The organic contaminants associated with the supernatant (as characterized by BOD_5, soluble TOC and soluble COD) was low. The relatively high total COD values were probably a reflection of the inorganic matter associated with the particulates - notably sulfides which oxidize to sulfates. The ARC data supports this conclusion.

Given the inherent variability in BOD_5 measurements ie. due to seed selection and as the trace levels of BOD were reported as 6 mg/L the values in table 1 are not considered above the objective of 15 mg/L.

The solids concentration was lower than the 1% determined in the ARC study, but approached 1 000 mg/L.

Grady & Lim [1980] report that biomass may be characterized by carbon, nitrogen and phosphorous compositions of 50%, 10-15% and 1-3% on a dry weight basis. Only a fraction (typically 40%) of substrate will be synthesized to biomass. Hence based on the data from table 1, the most probable limiting nutrient for biological growth was bio-available carbon.

Another note of interest is that both nitrogen and phosphorous are predominantly in the aqueous phase, as opposed to sorb onto the suspended solids. This is useful as only the aqueous forms of nutrients are easily biodegradable.

Date	Batch Number	BOD_5 Total	BOD_5 Soluble	TSS	VSS	COD Total	COD Soluble
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Oct 17	1			154		113	37
Oct 17	2			952			
Oct 18	3			760			
Oct 19	4	20	20	208		280	54.9
Oct 21	5	14	12	180		126.4	49.6
Oct 22	6			952	96		
Oct 23	7			198	62	110	37
Oct 24	8			100	36	107	24.3
Oct 27	9			152	68	94.4	25.8
Oct 28	10			144	68	110.8	24.2
Oct 29	11			252	94	125.2	26
Oct 31	12			86	44	117.2	28.3

Date	Batch Num.	pH	TOC Soluble	NH_3 Total	NO_3 Total	TKN Total	TKN Soluble	TP Total	TP Soluble
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Oct 17	1	7.88	30.6	13.3	0.005	15.75	14.9	-[1]	
Oct 31	12	7.4		7.21	0.18	8.24	7.71	0.59	0.11

Blanks indicate that no analysis was requested

1. This result was below the detection limit, however the detection limit was approximately 1 mg/L due to sample dilution

TABLE 1. Characteristics of supernatant derived from Hamilton Harbour sediment. Each day for which data is reported characterizes a 15 L to 25 L feed batch.

5.2 ULTRA-FILTRATION RESULTS

Two distinct batches of supernatant were processed at the beginning of the study and at the mid-way point. The performance data for the ultra-filtration unit is summarized in table 2. As with most membrane systems, the flux through the membrane used in this study increased with temperature and decreased with time. The flux during the second batch appears to be slightly higher than during the first batch at lower temperatures. The reason for this was not examined. Observation (visual and smell) suggested that the second batch had a higher free oil and grease content.

In a similar fashion to the "raw" supernatant, the ultra-filtration permeate was analyzed extensively for an initial and final sample while samples taken periodically during the management of the SBRs were subjected to a reduced analyses. These data are shown in table 3.

Batch	Feed Temperature	Pressure	Flux
	°C	bar	$L/m^2/hr$
Oct 15/16	22	3	22.15
	27	3	26.15
	28	3	25.80
	28	3	21.45
Oct 21/22	7	3	17.8
	23	3	28.2

TABLE 2. Membrane operating parameters and physical performance data.

With the exception of the suspended solids, total COD and BOD_5 the permeate characteristics were very similar to the "raw" supernatant. Comparison of the permeate data with the supernatant data shows that suspended solids removal was excellent. The values of 24 and 20 mg/L obtained for October 27 and 28 could well be due to analytical error - each value was from a single determination of accumulated solids from filtering 50 mL of permeate. Actual values were probably as low as for the other samples, especially since the permeate was from the same overall batch.

Date	Batch Number	BOD_5 Total	BOD_5 Soluble	TSS	COD Total
		mg/L	mg/L	mg/L	mg/L
Oct 17	1			6	36
Oct 17	2			8	
Oct 18	3			8	
Oct 19	4	6		6	
Oct 21	5			0[2]	
Oct 22	6			6	
Oct 23	7			6	18.1
Oct 24	8			4	15
Oct 27	9			24	20.4
Oct 28	10			20	22.7
Oct 29	11			2	19.5
Oct 31	12			2	27.2

Date	Batch Num.	pH	TOC Soluble	NH_3 Total	NO_3 Total	TKN Total	TKN Soluble	TP Total	TP Soluble
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Oct 17	1	8.47	20.2	11.8	0.13	14.79	11.69	-[1]	
Oct 31	12	7.72		5.86	0.25	6.20	5.95	0.68	0.74

Blanks indicate that no analysis was requested

1. This result was below the detection limit, however the detection limit was approximately 1 mg/L due to sample dilution

2 A negative value was obtained for TSS and has been equated to 0 mg/L

TABLE 3. Characteristics of permeate derived by passing the Hamilton Harbour sediment supernatant through the ultra-filtration membrane. Each day for which data is reported characterizes a 15 L to 25 L feed batch.

Based on the TSS, COD and BOD_5 data it appears as though the TSS and BOD_5 objectives would be easily met using an ultra-filtration unit alone. However the nitrogen and phosphorous species were essentially unchanged.

With respect to the suitability of the permeate as a feed source for the SBRs the limiting nutrient is likely carbon.

5.3 SBR SEED SELECTION

Return activated sludge (RAS) from the Woodward and Dundas STPs were tested for their settling characteristics. The Dundas STP RAS was selected for the SBR seed as it settled faster, produced a more concentrated settled sludge and lower supernatant suspended solids than the Woodward STP RAS. The reason that the Woodward STP RAS settled so poorly can be attributed to the biomass being stressed due to a change in the STP operating conditions just before the RAS was collected.

5.4 SBR PERFORMANCE

Operation of all four reactors commenced on October 16, 1992. The ultimate operating conditions are listed below. Throughout the period of operation the mixed liquor maintained excellent settleability although a relatively low concentration of colloidal material formed a stable suspension in the two reactors receiving the supernatant. In all four reactors some build-up of biomass occurred on the reactor walls. The most severe effect was seen in reactors 3 and 4 where an oily scum was apparent.

	REACTOR 1 & 3	REACTOR 2 & 4
Feed	Raw (R 1) Permeate (R 3)	Raw (R 2) Permeate (R 4)
MLVSS	200-800 mg/L	200-800 mg/L
SRT	10 days	10 days
HRT	16 hours	24 hours
FILL	0 minutes	0 minutes
REACT	7 hours	11 hours
SETTLE	1 hour	1 hour
DRAW	0 minutes	0 minutes
Aerate	REACT	REACT
Mix	REACT	REACT
Draw Volume	50% reactor volume	50% reactor volume

Figure 4 shows the relative errors derived from a reactor mass balance of non-volatile solids. The data was calculated using the following model:

MASS BALANCE ON NON-VOLATILE SOLIDS

$MI(i) - MO(i) - W(i) - \xi(i) = \Delta MR(i)$

where MI is the mass of solids added to the reactor with the feed (three two litre volumes for reactors 1 and 3 and two two litre volumes for reactors 2 and 4 each day)

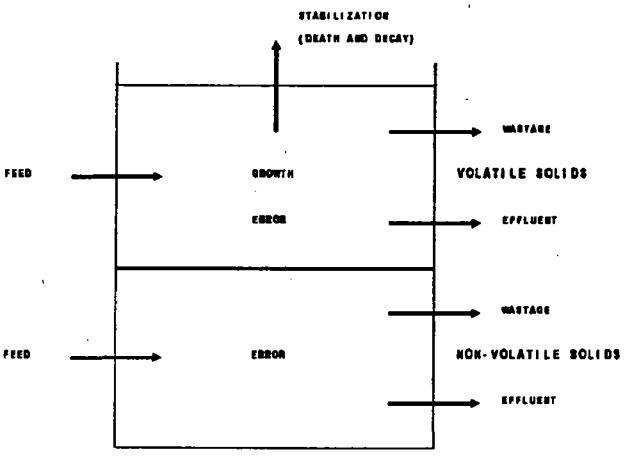
MO is the mass of solids removed from the reactor with the draw (as for MI)

W is the mass of solids removed from the reactor as waste (approximately 400 mL each day)

ξ is the error (or the mass of solids unaccounted for in the reactor mass balance)

ΔMR is the change in suspended solids mass in the reactor from day $i-1$ to day i

Non-volatile solids (total solids less volatile solids) are used for the mass balance as they should be conservative. In comparison, volatile solids include losses such as biological stabilization of solids (forming CO_2 and other gases) which cannot be quantified with the data from this study. The unaccounted mass, ξ, is that required to close a mass balance. This quantity represents the cumulative errors in the measurements of the MLSS, MLVSS, feed and draw suspended solids (volatile and total). Confidence in the data is reduced as the absolute value of the relative error increases.



MODEL OF SOURCES AND SINKS FOR SOLIDS IN AN SBR

In reactors 3 and 4, the reactor mass had higher levels of total solids and non-volatile solids (due to the unfiltered nature of the feed) than reactors 1 and 2. As shown, there appears to be greater variability and error associated with these systems. The suggestion is that the reactor volume was not completely mixed and hence the samples taken for MLSS and MLVSS were not representative of the reactor volume. This may have been a result of non-volatile solids settling out of the reactor volume on some occasions if the aeration was not sufficiently vigorous. Figure 5 support this hypothesis and also suggest that the volatile solids were probably better represented (as they would

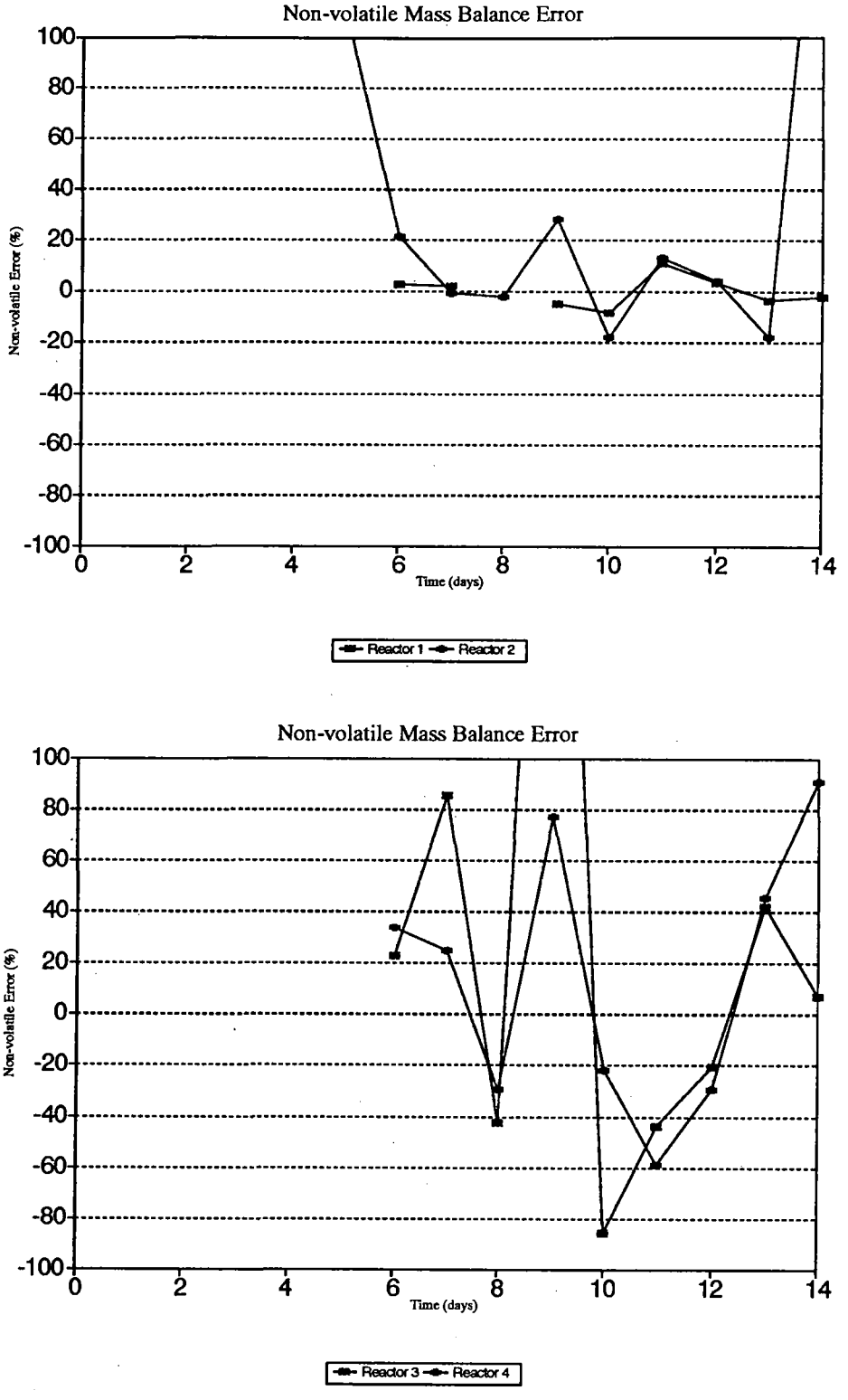


FIGURE 4. Relative errors calculated through a mass balance of reactor non-volatile solids. Reactors 1 and 2 (top) were fed permeate. Reactors 3 and 4 (bottom) were fed supernatant.

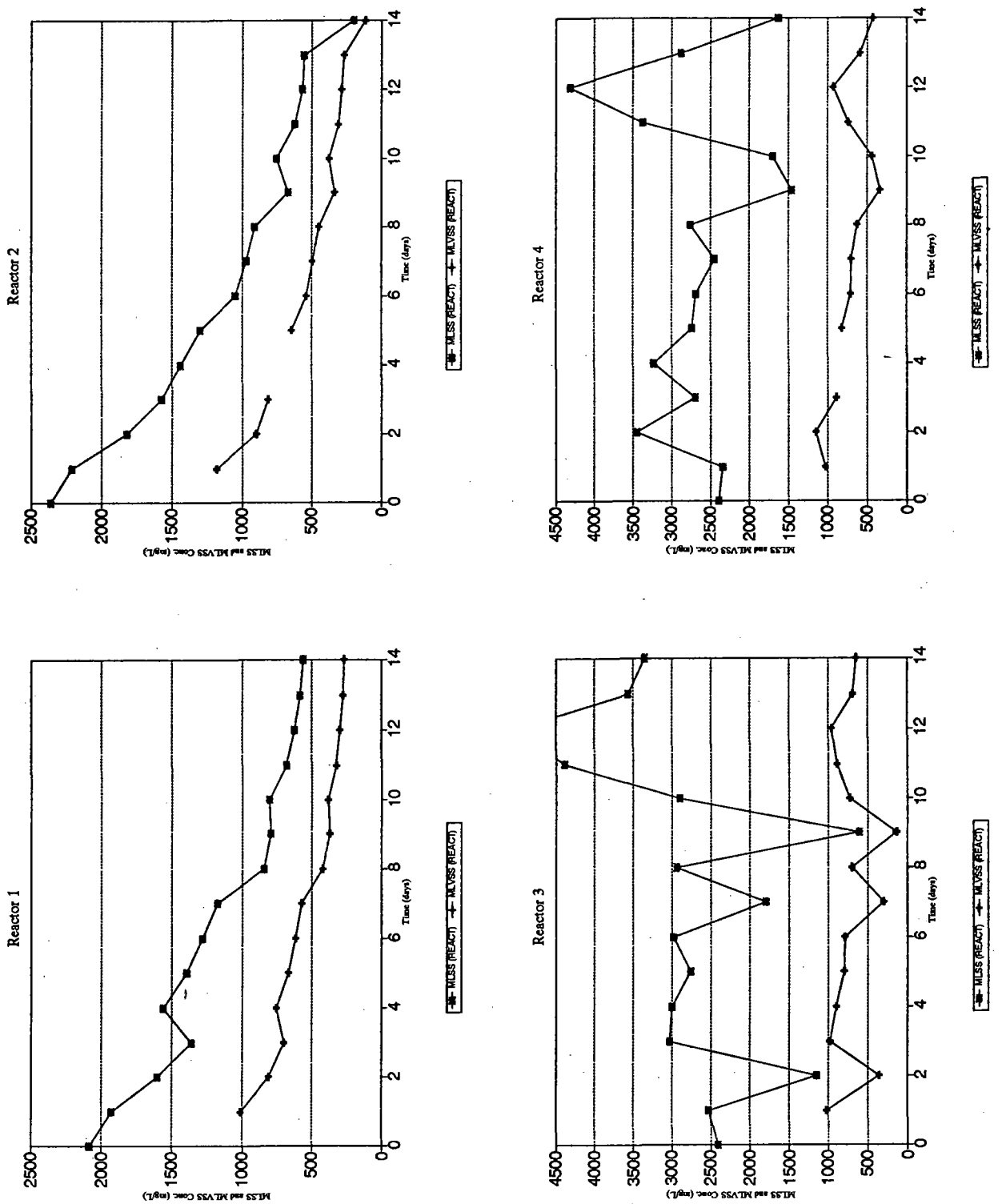


FIGURE 5. Reactor mixed liquor suspended solids and mixed liquor volatile suspended solids (Reactors 1 to 4) for the period of the testing.

tend to remain in suspension more readily). Note that the relative fluctuations in MLSS are much greater than for MLVSS.

The MLVSS data for all reactors, figure 5, suggest the microbial population adjusted downwards and was relatively stable after approximately 8 days of operation. At this point it is likely that the bio-available organic matter entering with the feed supported biological growth at a rate sufficient to offset death and decay of the biomass. This was most pronounced for reactors 1 and 2, for which there was no interference resulting from volatile solids in the feed.

The MLVSS concentration for reactors 1 and 2 appeared to stabilize at approximately 200 to 300 mg/L, while the MLVSS concentration for reactors 3 and 4 appeared to stabilize at 500 to 750 mg/L. The higher concentration could be due to the feed volatile solids and/or the bioavailability of soluble organics through desorption sustaining a higher active biomass.

Effluent total and soluble COD data are presented in figure 6. The soluble COD for reactors 1 and 2 was below 20 mg/L by day 5 of operation. For reactors 3 and 4 the soluble COD was below 25 mg/L. In all cases it is probable that soluble BOD_5 was also below 15 mg/L. Total COD was below 30 mg/L for reactors 1 and 2 after day 5 of operation (except for day 14 for reactor 2) while the total COD for reactors 3 and 4 were significantly higher, up to 71 mg/L. Again it is likely that the BOD_5 was lower than 15 mg/L as the high total CODs are probably a result of inorganic oxygen demand (such as sulfides).

Effluent VSS and TSS data are presented in figure 7. The TSS in the effluent was below 15 mg/L during the period of the study for reactors 1 and 2 (except for a spike on days 12 and 13 for reactor 2). All of the solids were volatile which was to be expected given the low solids in the feed. Both reactors 3 and 4 failed to meet the TSS < 15 mg/L objective for the majority of the study. Reactor 3 peaked at approximately 200 mg/L. In both cases a significant fraction of the solids was non-volatile. The spike at day 6 corresponds to an increase in the feed solids to 952 mg/L through one batch of feed. The ensuing decrease is similar to the classic wash-out curves observed in continuous flow completely mixed reactors.

The composite collected during the DRAW periods from each reactor over the last day of operation was submitted for an expanded list of analyses. The data for this last day are presented in table 4. Feed data are also presented for ease of comparison.

Sample	Date	Batch Num.	NH_3 Total	NO_3 Total	TKN Total	TKN Soluble	TP Total	TP Soluble
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Super-natant (Influent)	Oct 17	1	13.3	0.005	15.75	14.9	-[1]	
	Oct 31	12	7.21	0.18	8.24	7.71	0.59	0.11
Reactor 3 Effluent	Oct 31		0.2	6.71	2.64	1.37	0.48	0.23
Reactor 4 Effluent	Oct 31		0.04	7.54	2.19	0.87	0.42	0.31

Sample	Date	Batch Num.	NH_3 Total	NO_3 Total	TKN Total	TKN Soluble	TP Total	TP Soluble
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Permeate (Influent)	Oct 17	1	11.8	0.13	14.79	11.69	-[1]	
	Oct 31	12	5.86	0.25	6.20	5.95	0.68	0.74
Reactor 1 Effluent	Oct 31		0.06	6.51	1.23	0.60	0.88	0.77
Reactor 2 Effluent	Oct 31		0.04	6.76	1.07	0.85	0.90	0.82

Blanks indicate that no analysis was requested

1. This result was below the detection limit, however the detection limit was approximately 1 mg/L due to sample dilution

TABLE 4. Characteristics of the influent (fill) to, and the effluent (draw) from, the four SBRs. (**TOP:** supernatant and **BOTTOM:** permeate).

Total and soluble BOD_5 data has been omitted from table 4 as only trace levels (1 to 2 mg/L) were measured in the reactor effluent.

It is immediately apparent that nitrification was occurring in all reactors. The change from feed to effluent was characterized by the NH_3 concentration decreasing and NO_3 concentration increasing by a comparable amount - typical of nitrification. The NH_3 concentration had decreased to at least 0.2 mg/L (reactor 3) which satisfies the nitrogen removal objective targeted in this study. The fourth objective, phosphorous removal, was not apparent (and was not expected as anoxic periods

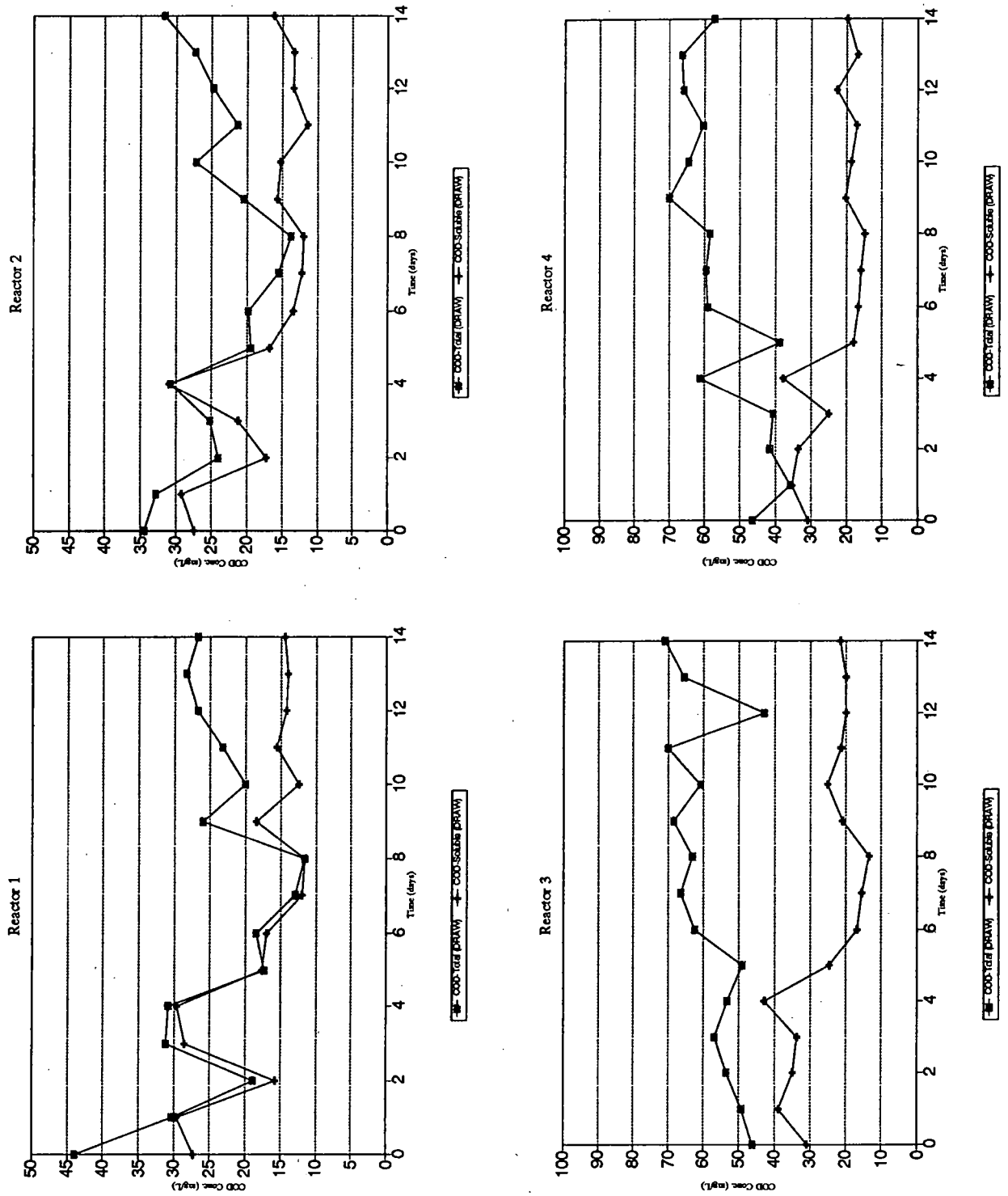


FIGURE 6. Total and soluble COD of the effluent (DRAW) from Reactors 1 to 4. Influent total COD was between 15 and 40 mg/L for Reactors 1 and 2, and between 100 and 300 mg/L for Reactors 3 and 4.

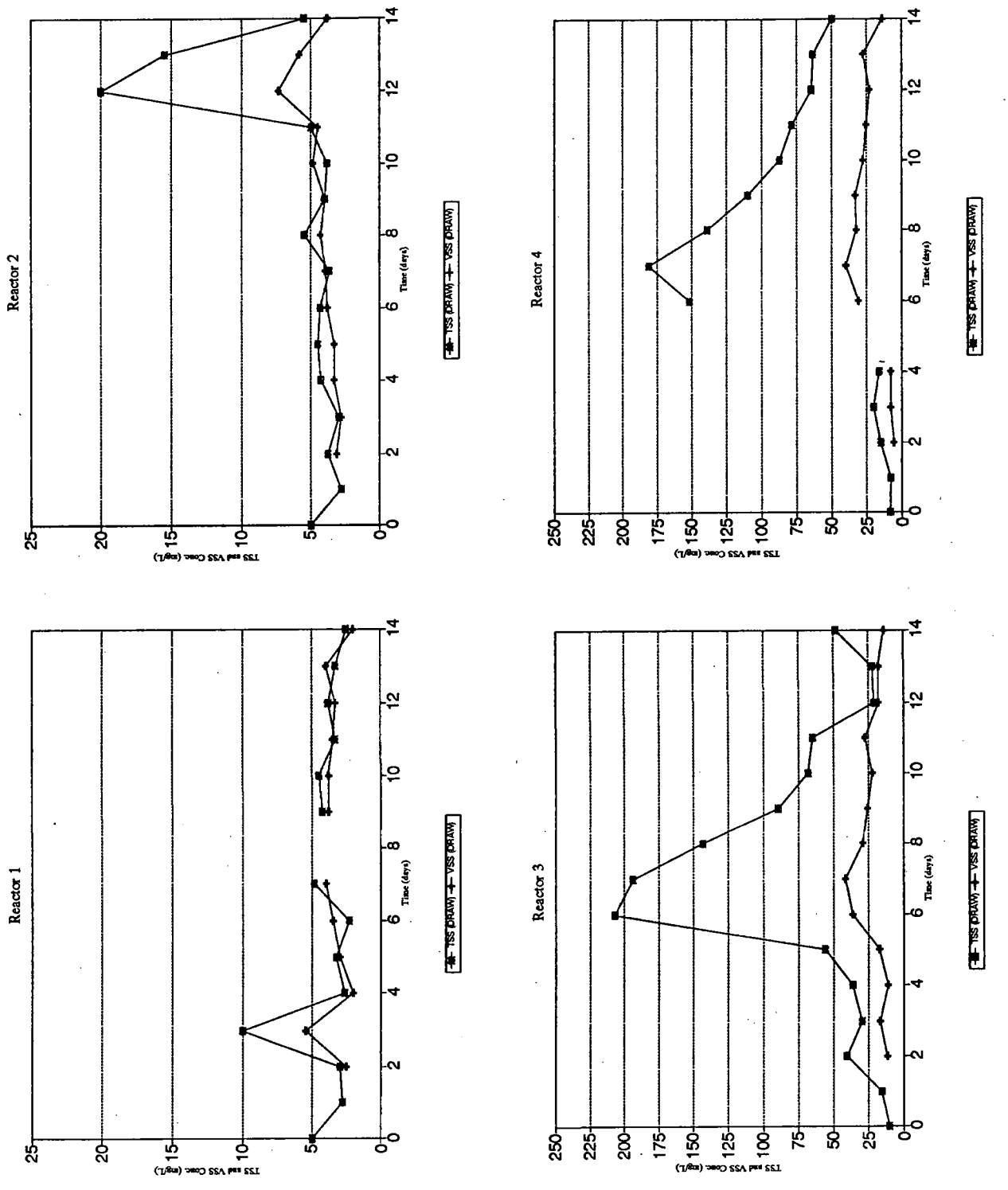


FIGURE 7. Total suspended solids and volatile suspended solids in the effluent (DRAW) from Reactors 1 to 4. Influent total suspended solids was essentially 0 mg/L for Reactors 1 and 2, and between 100 and 1,000 mg/L for Reactors 3 and 4.

were not included in the SBR operation). However, the phosphorous levels were initially (and remained) below the guideline of 1.0 mg/L.

5.5 SYNOPSIS OF RESULTS

- The supernatant was characterized by TSS of between 100 and 1 000 mg/L, total COD between 100 and 300 mg/L and total BOD_5 near to the 15 mg/L objective. Total phosphorous was below 1 mg/L;

- Effluent from the ultra-filtration unit fed supernatant easily met TSS objectives. However the ultra-filtration had little effect on the nitrogen and phosphorous concentrations. Membrane fluxes ranged from 20 to 30 $L/m^2/hr$;

- Bio-available carbon was hypothesized to be the growth limiting nutrient in both the supernatant and permeate;

- The SBRs reached steady state after approximately 8 days of operation;

- REACT time had no marked effect on SBR performance, although the effluent TSS appeared to be attenuated marginally at longer REACT times;

- An SBR alone could not meet the effluent objectives. BOD_5 was reduced to trace levels, soluble COD was marginally reduced, complete nitrification occurred in all cases. Phosphorous levels were <u>not</u> affected.

6.0 CONCLUSIONS

1) The supernatant BOD_5 will probably not require treatment to meet the objective (15 mg/L)

2) The SBR is not capable of treating the supernatant so that the TSS objective (15 mg/L) will be met. The ultra-filtration unit will easily treat the supernatant to meet the TSS discharge objective

3) Treatment of the supernatant with the SBR reduced NH_3 concentrations to below the discharge objective (1 mg/L). The ultra-filtration unit was ineffective as a means of reducing the NH_3

4) The supernatant met the phosphorous objective (1 mg/L) without treatment

5) A combination of ultra-filtration unit and SBR would be required to meet the four study objectives.

7.0 RECOMMENDATIONS

1) The SBR/filtration system should not be piloted. The combined system is not recommended for treatment of the supernatant.

2) Solids removal could be accomplished easily and at relatively high rates using conventional means such as flocculation/settling or sand filtration. The sludge could then be combined with the bulk sediment for treatment or disposal.

3) If free oil and grease was considered to be a problem an ultra-filtration system, utilizing an inorganic membrane (as opposed to the organic membrane used in this study), should be able to remove the oil and grease and suspended solids at a moderate rate. This option should be investigated as some sediment process waters have considerable oil content.

4) If NH_3 removal is considered a high priority it may be air stripped or biologically removed.

5) If an SBR is used for nitrification it should:

a) follow suspended solids removal as the reactors appear more stable with lower influent solids

b) operate with short fill and draw cycles and short react cycle (ie. 7 hours was found to be sufficient, shorter times may also suffice) to maximize throughput.

References:

Alberta Research Council [1992]
Bench Scale Studies Hamilton Harbour Sediments.
Contract No. 1-6021. Alberta Research Council. March, 1992.

Arora, M. L., Barth, E. F. and Umphres, M. B. [1985]
Technology Evaluation of Sequencing Batch Reactors.
Journal WPCF. 57(8): 867 - 875.

Aziz, C. [1992]
SBR Operation and Performance.
Wastewater Technology Centre Report. July 1992.

Ultrafiltration Handbook.
Cheryan, M.
Technomic Publishing Company, Inc., Pennsylvania, 1986.

Biological Wastewater Treatment - Theory and Applications.
Grady Jr., C. P. L. and Lim, H. C.
Marcel Dekker, Inc., New York, New York, 1980.

Irvine, R. L. and Busch, A. W. [1979]
Sequencing Batch Biological Reactors - An Overview.
Journal WPCF. 51(2): 235 - 243.

Irvine, R. L. and Ketchum Jr., L. H. [1989]
Sequencing Batch Reactors for Biological Wastewater Treatment.
CRC Critical Reviews in Environmental Control. 18(4): 255 - 294.

Hamilton Harbour Remedial Action Plan Writing Team [1989]
Remedial Action Plan for Hamilton Harbour. Stage 1 Report: Environmental Conditions and Problem Definitions.

Wastewater Engineering: Treatment/Disposal/Reuse. 2nd Edition.
Metcalf & Eddy, Inc.
McGraw-Hill Inc., 1979.

Physicochemical Processes For Water Quality Control.
Weber Jr., W. J.
John Wiley & Sons, Inc., 1972.