The Application of a Membrane Bioreactor for Wastewater Treatment on a Northern Manitoban Aboriginal Community

By

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ABSTRACT

Water infrastructure on Aboriginal communities in Canada, and specifically Northern Manitoba is in sub-standard condition. A recent Government of Canada study indicated that an estimated $1.5 billion would need to be spent to improve this infrastructure.

September 2003 through July 2004, an examination of the effectiveness of a membrane bioreactor (MBR) in a Northern Manitoban Aboriginal community took place. This study was intended to identify and test an appropriate and effective solution for the lack of adequate wastewater treatment in these communities. The MBR system, employing a Zenon ZW-10 ultrafiltration membrane, was designed and constructed at the University of Manitoba. It was installed and tested in two phases at the Opaskwayak Cree Nation Reserve in Northern Manitoba.

Phase I was a direct comparison between the pilot-scale MBR and the community's existing Sequencing Batch Reactor (SBR) with sand filter. This phase occurred from September 2003 until December 2003. The MBR, with an SRT of 20-days and an HRT of 10 hours, outperformed the SBR in every category despite 2 mechanical/electrical failures that resulted in the loss of biomass from the MBR. The SBR/Sand filter combination had BOD, TSS, and TKN concentrations of 30.3 mg/L, 27.5 mg/L, and 8.4 mg/L, respectively. By comparison, the BOD, TSS, and TKN concentrations in the MBR effluent were <6 mg/L, <5 mg/L, and 1.3 mg/L respectively.

Phase II, from March 2004 through July 2004, tested the overall MBR efficacy and intended to assess a novel remote control and monitoring system. The MBR SRT was adjusted to 40-days and, as expected, the MBR MLVSS concentration increased to a relatively stable 5000 mg/L. The MBR continued to provide high quality effluent with some exceptions. Despite the 0.034 μm pore size, the total coliforms and TSS measured in the effluent were higher than in Phase I. This indicates a compromised membrane, faulty sampling procedures, or biological regrowth downstream of the membrane. This failure could point to the need for some form of tertiary disinfection.

Also in Phase II, a remote control and monitoring program was implemented. The controlling PC was controlled via the internet using pcAnywhere software. The software allowed for real-time monitoring and complete control of the pilot system.

In conclusion, the pilot-scale MBR yielded consistent, high quality wastewater effluent and this would benefit the pristine environments existing in Manitoba's north. The potential hands-free operation could be utilized to provide support to communities lacking sufficient wastewater treatment know-how.

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1 INTRODUCTION

First Nation's communities in Canada are experiencing severe water and wastewater infrastructure problems. A federal report indicated that approximately 60% of all wastewater treatment systems were ranked either medium or high risk for failure and required immediate attention (INAC, 2003). Drinking and wastewater treatment falls under the jurisdiction of the local band government with capital costs covered by Indian and Northern Affairs Canada (INAC, 2004). It was estimated that approximately $1.6 billion would be required to address the wastewater treatment deficiencies.

Although unclear in the federal report, Manitoban First Nations wastewater systems were not better off than the national average. In a previous study, it was discovered that about 75% of wastewater treatment systems on Manitoba's First Nations communities were substandard (Frederickson, 2002). More alarming is that 35% of those systems posed an immediate environmental and/or health risk. Such problems exist with a wide range of wastewater treatment systems; from septic fields to sequencing batch reactors. For example, on some First Nations communities, leaky septic tanks and improperly designed septic fields contaminated drinking water cisterns used for public consumption. Sequencing batch reactors with effluent contaminant levels well above the federal environmental limits were found placed upstream of drinking water intakes. The communities were plagued with broken valves, leaky sewage pipes, old equipment, and poorly designed and overly complex systems. Lack of operator training and attention coupled with deficient equipment currently pose a crisis in wastewater treatment on many Manitoban reserves.

This study was undertaken to explore the effectiveness of membrane bioreactors (MBR) in addressing the unique suite of problems encountered on many of Canada's First Nations communities. The following sections outline the problems, the current wastewater treatment systems in place on Manitoban reserves, and the operation of a pilot-scale MBR on the Opaskwayak Cree Nation. This thesis is both a way to raise awareness on the infrastructure deficit experienced in Canada's Aboriginal population and to explore the novel technology of membrane bioreactors.

2 LITERATURE REVIEW

2.1 First Nations Health

Food and waterborne illnesses have a higher rate of incidence in the First Nations population relative to the Canadian population (Health Canada, 2003). The rates among First Nations' children under the age of 15 are appallingly high. For example, shigellosis, a gastrointestinal disease related with poor water treatment, occurs over 22 times more frequently in First Nations children. Figure 1 outlines the rate of incidence of food and waterborne illnesses. These unacceptable statistics prompted an INAC study on water and wastewater systems in First Nations communities.

2.2 National First Nations Wastewater Treatment Assessment

In 2003, INAC released a report entitled "National Assessment of Water and Wastewater Systems in First Nations Communities". The INAC study had several objectives including an assessment of on-reserve systems, identification of deficiencies, and recommendation for improvements. Local regions contracted the study to engineering firms. The study had some limitations; notably that all water samples were based on databases owned by Health Canada and INAC. Furthermore, the study was limited to larger systems and:

"*Individual systems and those serving fewer than 5 homes were not assessed*"

The national results of the study are highlighted in Table 1.

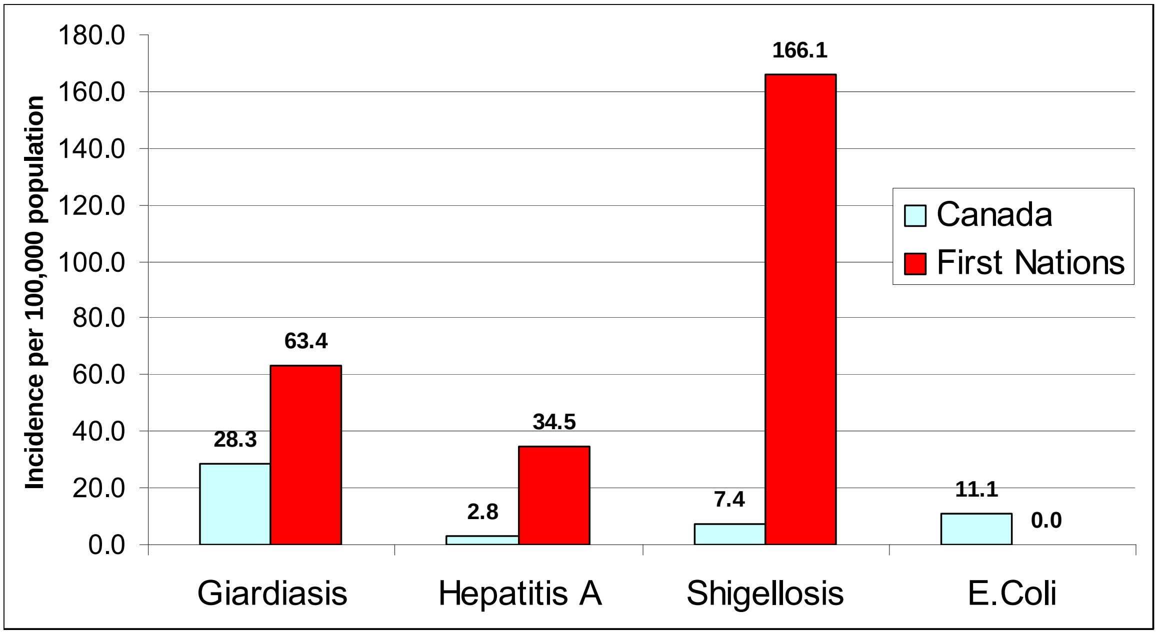


Figure 1: Enteric food and waterborne diseases among children aged 0 to 14, in First Nations versus Canada in 2003 (Health Canada, 2003).

Table 1: Assessment of Water and Wastewater Treatment Systems in First Nations communities (INAC, 2003).

Name of Region	Number of Assessed Wastewater Systems	Category A	Category B	Category C
Atlantic	16	**1** (6%)	**9** (56%)	**6** (38%)
Quebec and Cree	37	**23** (62%)	**11** (30%)	**3** (8%)
Ontario	58	**21** (36%)	**15** (26%)	**22** (38%)
Manitoba	67	**37** (55%)	**25** (37%)	**5** (7%)
Saskatchewan	97	**33** (34%)	**59** (61%)	**5** (5%)
Alberta	64	**40** (63%)	**12** (19%)	**12** (19%)
British Columbia	112	**25** (22%)	**68** (61%)	**19** (17%)
Yukon	11	**7** (64%)	**2** (18%)	**2** (18%)
Total	462	187	201	74
% of Total	100%	40%	44%	16%

Category A - Wastewater systems experiencing minimal problems or no problems.
Category B - Wastewater systems requiring some repairs.
Category C - Wastewater systems with potential health and safety concerns.

National averages indicate that approximately 60% of all wastewater treatment systems require some form of upgrade. The 2003 INAC report estimates upwards of 1.5 billion dollars are required for corrective action and improvement to wastewater treatment plants. This has significant importance to First Nations communities, environmental engineering firms, and taxpayers across Canada.

2.3 Manitoban First Nations Communities

There are 62 First Nations communities in Manitoba. They are scattered across the length and width of the province. Typical communities are isolated and relatively low in population. Many communities are situated next to the lakes and rivers from which they draw their drinking water and discharge their wastewater. Commercial and subsistence fishing and hunting are also very important to the First Nations living in these communities. Furthermore, the pristine quality of the water in northern Manitoba warrants a higher level of environmental protection. Damage will occur to these delicate ecosystems in the event of inadequate wastewater treatment. Nutrients such as nitrogen and phosphorous can suffocate the marine life in a lake. Gastrointestinal bacteria can contaminate the drinking water supply. Adequate and sustainable wastewater treatment and handling is necessary to protect both humans and wildlife in the area.

2.4 Manitoban Assessment of First Nations Wastewater Treatment

Manitoban First Nations communities fared relatively well in the national assessment of wastewater treatment systems. They ranked above the national average in all three categories. However, a closer inspection of the data collected for INAC in Manitoba revealed significant anomalies with the national report. A complete record of the data is included on a data compact disc in the Appendix. The wastewater treatment systems were ranked on a scale from 1 to 10. Table 2 outlines the Manitoba data and for convenience purposes the systems ranked 1-3, 4-6, and 7-10 were marked Category A, B, and C respectively. Furthermore, the systems are separated according to size as well as level of complexity. Individual systems are exclusively septic fields. Simple systems include septic fields and lagoons while sequencing batch reactors (SBR) and extended aeration (EA) systems were considered complex.

Table 2: Wastewater Treatment Systems in Manitoban First Nations Communities (INAC, 2004).

System Type	Number	Category **A** (1-3)	Category **B** (4-6)	Category **C** (7-10)	Average Ranking
Lagoons	**26**	**12** (46%)	**13** (50%)	**1** (4%)	4.04
Extended Aeration	**5**	**1** (20%)	**1** (20%)	**3** (60%)	6
SBR	**21**	**5** (24%)	**8** (38%)	**8** (38%)	5.29
Other	**3**	**1** (33%)	**0** (0%)	**2** (67%)	5.33
Individual Systems	**12**	**6** (50%)	**1** (8%)	**5** (42%)	4.58
Large Systems	**55**	**19** (35%)	**22** (40%)	**14** (25%)	4.76
Simple Systems	**41**	**19** (46%)	**14** (34%)	**8** (20%)	4.29
Complex Systems	**26**	**6** (23%)	**14** (54%)	**11** (42%)	5.42
Total	**67**	**25** (37%)	**23** (34%)	**19** (28%)	4.73

The inclusion of individual systems in the Manitoba data listed on the national assessment contravenes the above quoted limitation and is misleading to the reader. Table 2 indicates that once septic fields are removed from the data, the Manitoba averages drop significantly from the national assessment report. It cannot be assumed that all provinces were equally in error. However, should this be the case, the actual condition of wastewater treatment on Canadian First Nations communities is worse than reported and the upgrading costs involved would be substantially higher.

Table 3 includes a listing of typical problems for each category. It is important to note that even Category A, considered a minimal risk, still includes plant failures and safety concerns. The problems become increasingly worse with the categories. It is apparent from this data that First Nations communities are in extreme need of wastewater infrastructure improvement and training (Frederickson, 2002).

Table 3: Common problems associated with the 3 categories (INAC, 2004)

Category A - One or more of the following	**Category B** – One of more of the following (Category A inclusive)	**Category C** – One of more of the following (Categories A & B inclusive)
odour lack of community service spare parts required emergency power requirements lack of functional disinfection minimal operator training existing or potential ground water contamination electrical control problems infiltration and inflow plugging of septic fields high coliform levels lagoon berm erosion pump clogging plant ventilation lagoon sludge buildup occasionally exceeding discharge limi instrumentation malfunction lack of safety equipment lack of backup operator	poorly maintained records ponding of septic fields little regular maintenance extreme odour problems zero operator training sludge washout approaching or exceeding design capacity high water table limits use of septic fields lagoon discharge upstream of schoo water intake regularly exceeding discharge limit hydraulic under-loading no sludge management zero effluent testing building too small uncertified lagoon design lagoon berm breeched frequent raw sewage bypasses	system vandalized discharge of lagoon into wetlands septic tank and field problems throughout community discharge ditches next to school yar completely inoperational system (tot bypass) poor system design leads to safety hazards plant fails to meet discharge requirements for BOD, TSS, TC, an FC lagoon consists of sand or gravel wit no liner collapsed or cracked septic tanks frozen septic fields broken and cracked piping noxious gases that limit operator exposure to 30 minutes or less PLC failure children have become ill due to ponding septic fields sewage directly entering water cister

2.5 Roles and Responsibilities of INAC and First Nations

Indian and Northern Affairs Canada released a document in January of 2004 entitled "First Nations Water Management Strategy: Water and Wastewater Services on First Nations Reserves". The strategy allocates $600 million over five years to improve water and wastewater services. Although this is a large sum of money, it is still only about one-third of the amount estimated for wastewater alone. The strategy was developed jointly between Health Canada and INAC. A multi-barrier approach was proposed to reduce the risk to First Nations water resources. The barriers included: national standards and protocols, infrastructure upgrades, enhanced operator training and stronger inspection reporting and compliance. In order for this strategy to succeed, different roles and responsibilities of all stakeholders must be clearly defined. The roles and responsibilities are classified below. Table 4 provides an overview of the strategy developed by INAC and Health Canada.

2.5.1 Indian Northern Affairs Canada

Indian and Northern Affairs Canada provide funds and advice to First Nations on water and wastewater services. If funds are available and approved, financial support is provided to First Nations for physical infrastructure upgrades, enhancement of operation and maintenance, as well as improved operator training and certification.

2.5.2 First Nations

Under this water strategy, First Nations must ensure that all on-reserve water and wastewater systems meet funding agreement conditions. These conditions include planning, design, construction, operation and maintenance. The First Nation must also report all pertinent data agreed upon in the funding agreement in a comprehensive and transparent manner.

Table 4: First Nations Water Management Strategy (adapted from INAC, 2004).

1. Facilities Upgrade	Upgrade and build water and wastewater facilities to meet established design, construction and water quality standards with a priority on identified facilities.
2. Monitoring	Effective water quality monitoring program combined with a comprehensive and coordinated compliance and reporting regime that will detect problems faster and reduce risk to health
3. Operation & Maintenance	Effective and sustainable operation and maintenance program designed to ensure safety of the residents and the protection of infrastructure with a priority on high-risk facilities.
4. Training Programs	Plan for the continued expansion and enhancement of training programs, to ensure that all operators have the skills, knowledge and experience to fulfill their responsibilities.
5. Protocol Development	Integrated water quality management protocols and emergency response procedures with clearly defined roles and responsibilities consistent with national performance standards.
6. Public Awareness	Campaign aimed at informing First Nation decision-makers and individual households of their roles and responsibilities in ensuring the safety of water supplies within their communities and homes.
7. Standards	Comprehensive set of clearly defined standards, protocols and policies, using a multi-barrier approach.

2.6 Current Wastewater Effluent Guidelines

The current wastewater effluent guidelines are based solely on BOD, Suspended Solids and coliform concentrations and are summarized in Table 5.

Table 5: Comparison of the federal and provincial guidelines for wastewater effluent disposal

Parameter	Federal Guidelines	Manitoba Provincial Guidelines
BOD_5	20 mg/L	30 mg/L
Suspended Solids	25 mg/L	30 mg/L
Faecal Coliforms	400/100 mL	200/100 mL

2.7 Future Wastewater Effluent Guidelines

The Canadian Council of Ministers of the Environment (CCME) is currently working towards a new strategy for water protection. New standards are scheduled to be developed by November 2006. The new regulations will play a significant role in determining suitable treatment practices. Therefore any future, wastewater treatment system should be flexible enough to meet the new standards with a minimum of alteration.

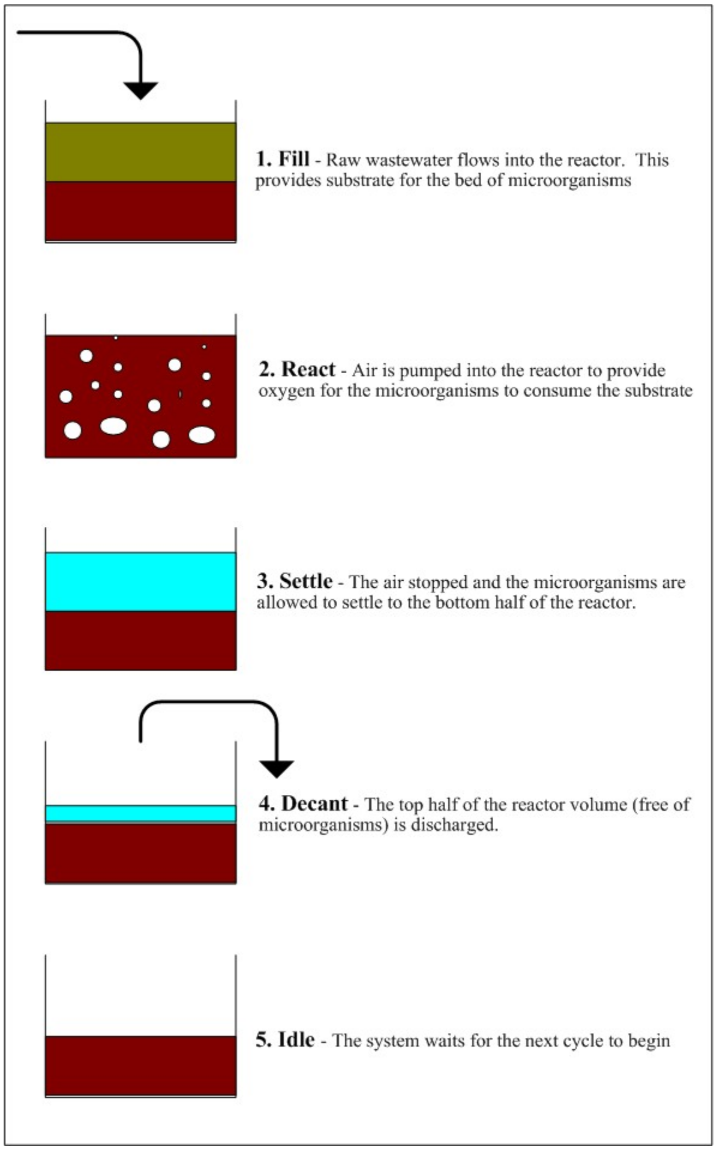
2.8 Wastewater Treatment Systems

There are several wastewater treatment systems currently employed on Manitoba First Nations communities. The following sections outline these systems and provide an alternative technology, the membrane bioreactor (MBR), for wastewater treatment.

2.8.1 Sequencing Batch Reactors

Sequencing batch reactors consist of a single reactor that functions on a sequence of steps (Metcalf & Eddy, 2003). The primary advantage of an SBR is realized in reduced capital expense. Given that clarification occurs in the reactor, there is no requirement for a separate clarification basin. The simplified operational steps for wastewater treatment in an SBR are illustrated in Figure 2. Twenty-one communities in northern Manitoba employ Sequencing Batch Reactors (SBRs) to treat their municipal wastewater. The average score, as per Table 2, for the SBRs in Manitoba was 5.29. This poor rating is almost certainly due to the complex nature of the system resulting in operational difficulty. Poor sludge settling in the SBR, failure of the controlling PLC, and mechanical problems with blower motors and pumps all combined to increase operational complexity. The appropriateness of the system under such characteristics is questionable. Sequencing Batch Reactors are often of concrete construction. Their time-stepped operation lends a smaller footprint due to aeration and clarification occurring in the same vessel. However, SBRs are typically built in pairs to allow for cycled flow. In other words, vessel #1 would be in its aeration cycle while vessel #2 is filling; thus limiting the need for equalization tanks and excess storage.

Figure 2: Sequence of wastewater treatment in a typical SBR



2.8.2 Rotating Biological Contactors

Rotating biological contactors (RBC) utilize attached microorganisms to achieve wastewater biodegradation. An RBC consists of a series of lightweight disks, usually polystyrene or PVC, closely spaced along a mechanically driven, horizontal shaft. The disks are usually about 40% submerged in water and rotate at 1.0 – 1.6 rpm (Metcalf & Eddy, 2003). The disks provide a medium for biomass to accumulate. As the RBC turns, the biomass is subjected to atmosphere and effluent, where it obtains oxygen and nutrients respectively. Three First Nations communities in Manitoba use rotating biological contactors for wastewater treatment. Their average ranking was 5.33. Excessive biomass sloughing is an operational issue with RBCs and downstream screens need to be used to prevent high TDS in the effluent. Additionally, the biomass growth on RBCs does not always accumulate evenly on the disks. This is especially true in areas with frequent power outages. Unbalanced growth on the submerged portion of the RBC has led to damaged motors and in the worst case, shearing of the drive shaft upon restart of the system.

2.8.3 Extended Aeration

A conventional extended aeration (EA) system consists of a large, aerated reactor tank with secondary clarification. It is similar to conventional plug-flow system in process flow however, the EA systems are sized for long solids-residence (SRT) and hydraulic retention times (HRT). Typical solids residence time (SRT) and hydraulic retention time (HRT) values are 20-30 days and 24 hours respectively (Metcalf & Eddy, 2003). The reactor design volume is larger in order handle the high HRT values and can deal with fluctuating community flows well. Extended aeration is often employed in pre-designed package plants for small communities with highly variable flow and low organic loading. Five First Nations communities in Manitoba use EA systems with an average score of 6. This is the worst average score of the systems employed.

2.8.4 Facultative Lagoons

A facultative lagoon is an engineered containment pond in which biological degradation occurs naturally over time (Metcalf & Eddy, 2002). The bacteria inherent to these ponds are facultative meaning that they have the flexibility to exist in aerobic or anaerobic conditions. This is essential since aeration is atmospheric and not mechanically induced. Lagoons are typically constructed in pairs and are capable of holding 365 days of municipal wastewater flow. After a given HRT, the first (primary) lagoon decants to the second (secondary) lagoon for polishing. From the secondary lagoon, the effluent is discharged to the environment. Lagoons are usually lined with a layer of low permeability clay (e.g. $1x10^{-8}$ m/d) to contain the wastewater and prevent groundwater contamination. New lagoons and lagoons in high permeability areas require a synthetic liner in addition to the clay liner. The synthetic liner is commonly constructed of flat sheets of 8-mil (0.2mm) high density polyethylene (HDPE). A lagoon is the simplest of wastewater treatment systems available to small communities however it requires a large amount of space and due to its poor aesthetics, requires significant planning to avoid community resistance. Also, great care needs to be taken to ensure liner viability to prevent contaminated ground water and potentially the local drinking water supply.

Lagoons are the most abundant wastewater treatment system utilized on Manitoban First Nations communities and they faired the best with an average ranking of about 4. It is speculated that this relatively high ranking can be attributed to the simplicity and low-tech nature of the system.

2.8.5 Membrane Bioreactors

2.8.5.1 Introduction

A membrane bioreactor (MBR) combines the biological degradation of waste compounds and the physical separation of the biomass and treated water by employing membranes. The operational advantages of membrane bioreactors have been well-documented (Manem and Sanderson, 1996; Ueda *et al*., 1996; Cicek *et al*., 1998; Rosenberger *et al*., 2002). Of key importance is the MBR's ability to produce high quality effluent while providing an integral pathogen barrier. Furthermore, MBRs exhibit good resistance to variations in hydraulic and organic loadings (Cicek et al., 1999; Jefferson et al. 2000; Donn & Dimitriou, 2005). Replacing gravity settling used in conventional systems with membrane filtration in MBRs allows for extensive automation and presents possibilities for remote controlled monitoring and operation, thereby reducing the need for on-site expertise. These features could address most treatment problems experienced on Aboriginal communities in Manitoba by reliably producing high quality water and significantly reducing operator dependence (Buisson *et al*., 1998). In addition to the operational benefits, economic benefits could also be realized in a small, remote community setting. The complete retention of biomass in the reactor allows smaller reactors to treat equivalent flows of wastewater. Furthermore, studies demonstrated that membranes could be incorporated into existing treatment plants for enhanced effluent quality (Engelhardt et al. 1998; Ahn et al., 1999). Integrating membranes into existing systems could possibly reduce expansion costs in communities whose treatment plants are being outpaced by population growth.

2.8.5.2 Configuration

The wide array of membrane types allow MBRs to exist in two primary configurations; submerged and external. In the submerged arrangement, the membrane separation unit is immersed in the bioreactor vessel. Biological degradation occurs around the membrane keeping all of the biomass within the reactor (Figure 3). Plate and frame and hollow fibre membranes are capable of this configuration. In the external or recirculated MBR, the membrane separation unit is outside the main reactor. The biomass is separated externally, and returned to the reactor (Figure 4). A high-flow recirculation pump is required for external configuration utilizing a tubular or spiral-wound membrane. Thus the power requirement is much higher for these membranes than in submerged systems. However, external P&F or hollow fibre membranes show promise to reduce operational costs for aeration and membrane cleaning. This is based on the principal that air diffusers with efficient oxygen transfer coefficients are not suitable for cross-flow cleaning of membranes. By separating the types of air diffusers for oxygen transfer and membrane cleaning into different tanks, the power requirement could be reduced. In 1989, a study by Yamamoto et al. was the first to introduce a submerged MBR. Prior to this fundamental shift, membranes were primarily used in the external configuration. Reduction of the power requirement was the impetus behind submerged MBRs. In recent years, the focus of research and development has been primarily on submerged MBRs for municipal wastewater treatment.

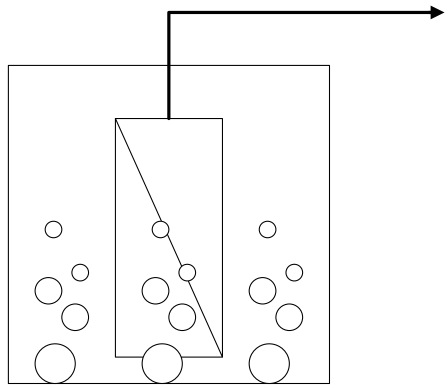


Figure 3: Submerged MBR Configuration - the membrane is situated inside the reaction vessel.

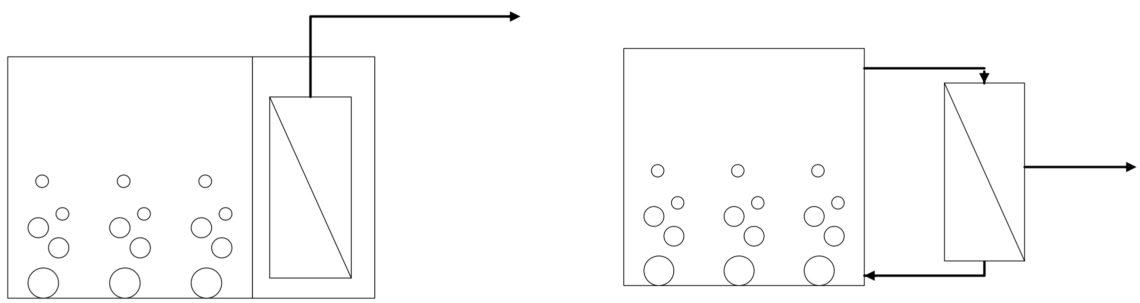


Figure 4: External MBR Configuration: In both of the above iterations of the external MBR, the membrane is placed outside of the main reaction vessel..

2.8.5.3 Membrane Types

Membranes have evolved with new materials and applications. The membranes primarily used in wastewater treatment are as follows

- **Plate and Frame –** The plate and frame membranes consist of two flat sheets of membrane material, usually an organic polymer, stretched across a thin frame. The space between the membrane sheets is placed under vacuum in order to provide the driving force for filtration. Several plates are arranged in a cassette to allow for increased surface area and convenient modular design. The membrane cassette is immersed in the mixed liquor and the separation flow is from outside-in. For example, Kubota membranes have air induced liquid cross-flow along the plates. This creates turbulence and hinders cake formation and subsequent fouling. The organic polymer, polyethylene for example, has the required flexibility to move slightly in the cross-flow to allow three-dimensional dynamic forces to reduce cake formation. The cross-flow of air also acts to dissolve oxygen to and mix the contents of the reactor.

- **Hollow fibre –** Hollow fibre membranes consist of long strands, or fibres, of hollow extruded membrane. They are most often of organic polymer construction and are applied much the same as plate and frame membranes. The fibres are mounted to a supporting structure that serves as a manifold for permeate transport as well as an air delivery system. Similar to the plate and frame modules, air induced liquid cross-flow prevents excessive cake formation and increases the lifespan of the membrane.

The fibres are most often employed in the outside-in arrangement. A vacuum is applied to the permeate manifold and this draws water from the reactor-side to the inside of the fibre and out of the system. As with the plate and frame membrane, hollow fibre membranes are also constructed in a cassette format to allow for the convenience of modular design. The Zenon Zeeweed membrane cassette is shown in Figure 6. The name refers to the similarity of action for the hollow fibres to seaweed waving in the ocean's current.

- **Tubular –** As the name implies, tubular membranes are hollow tubes with the membrane placed on the surface of the tube. Below the membrane surface is a supporting structure with high porosity. In most cases, tubular membranes are made of inorganic material such as ceramic and have a metal oxide membrane surface to provide a small nominal pore size. Tubular membranes have a different separation driving force than the previous two. Rather than vacuum pressure, the material to be separated flows along the membrane at high velocity under pressure. The velocity provides a transverse force to drive the water through the membrane while leaving the larger diameter particles behind. A tubular membrane could be used in the outside-in arrangement with the feed water flowing along the centre of the tube and the permeate passing to the outside walls, or the inside-out arrangement where the influent travels along the centre of the tube and travels axially outward.

Figure 5: An example of Zenon Zeeweed Cassette

2.8.5.4 Effluent Quality

The robustness of the MBR is exemplified in its ability to handle many different types and qualities of incoming waste yet maintain a high quality effluent. For example, a study performed on the biological degradation of landfill leachate showed that in a recent retrofit, the MBR/RO coupled system achieved acceptable effluent quality where biological oxidation alone failed (Ahn et al., 2002). Prior to the retrofit, the BOD and COD removal efficiencies were 79% and 66% respectively. After the retrofit was implemented, the MBR BOD and COD removal efficiencies both increased to 97%.

Simulated groundwater with high nitrate concentrations was treated using a sequencing membrane bioreactor (Rezania et al., 2005). The two-membrane system utilized one membrane to diffuse hydrogen into the mixed liquor and the second to separate water from the biomass. This novel approach completely denitrified the groundwater while retaining 95% of soluble microbial products.

Membrane bioreactors have been used for agricultural wastewater treatment as well. A report by Cicek in 2003 highlighted the potential uses of the MBR for agricultural waste management and treatment. This report was corroborated by a 2005 study in Korea that showed rates of removal for BOD and TSS around 99.9% (Kim et al., 2005). Only slightly less effective, the study showed that COD, TN, and TP were removed by 92.0%, 98.3% and 82.7%, respectively.

In 2002, Fane and Chang reviewed the design and operational options of membrane bioreactors. The study outlined the various types of membranes and configurations available to the design engineer. In particular, the study indicated that ultrafiltration membranes retain all biomass in the reactor and as such act as an integral pathogen barrier.

There have been several installations of MBRs to treat varying wastewater (Enegess et al., 2003). The report highlighted several systems across North America that treated wastewaters containing food ingredients, automotive factory waste, or pharmaceutical products. The broad range of wastes treated is a good indication of the flexibility of the MBR.

2.8.5.5 Effectiveness

The effectiveness of membrane bioreactors has been well documented. The effectiveness of membranes actually increases with time. In 2003, Klatt and LaPara saw increased bioreactor performance due to the bacterial community in the MBR adapting its physiology. In the laboratory setting, the complete retention of the membrane separation unit allowed faster and more complete adaptation to influent wastewater. This may or may not be valid for real world application however, it was also stated that these rapid physiological adaptations occurred within the first few days of operation. This has implications for rapid and efficient system startup. It can also be used to explain system resilience to changing or adverse conditions. The ability of a microbial community to rapidly adapt to upset conditions would be extremely valuable in systems that have less supervisory support and operated with less technical knowledge.

Along with biological degradation, the membrane itself physically removes some of the contaminants (Klatt and LaPara, 2003; Yoon et al. 2003). This retention increases residence time and allows the biomass to have the opportunity to degrade these recalcitrant compounds. Unfortunately, it is these same compounds that are thought to lead to membrane fouling.

2.8.5.6 Sustainability

Sustainability implies that operation of an MBR wastewater treatment system could carry-on into perpetuity. Sustainable operation is measured by the external actions (i.e. to be sustainable the effluent must not damage the environment). Conversely, the MBR must be intrinsically adaptive to changing operational conditions. This includes a resistance to fluctuating influent wastewater quality as well as resilient to various mechanical failures.

2.8.5.7 Wastewater Reuse

Several studies have been performed on the applicability of membrane bioreactors to treat wastewater for reuse (Durham et al., 2001; Xing et al., 2001; Liberti et al., 2003; Coté et al., 2004). Fresh water supplies are dwindling in areas where population density is climbing or has peaked. Industry is also under greater pressure to increase internal recycle rates and tap into previously discounted brackish and saline water sources. For example, the Water for Life strategy in Alberta has prompted a province-wide watershed study (Alberta Environment, 2003). This strategy has also driven Athabasca oil sands producers to before unseen levels of water treatment and reuse. In fact, some petroleum producers have mandated a “zero liquid discharge” level in which all contaminants in the process water are crystallized out of solution and stored as a dry solid (Petro-Canada, 2005).

The obligation to sustain our water resources has also driven research and development in many technologies, including membranes. Water reuse can be used to mitigate water shortages and provide a measure of certainty to long term water forecasts. The excellent effluent quality and integral pathogen barrier provided by MBRs makes it an ideal candidate for water reuse schemes. A 2001 report by Schaefer highlighted several water reuse success stories in Australia, Mexico and the US. Industrial and municipal wastewater was used to recharge aquifers and reused in industrial processes. However, the vast majority of MBRs are employed as one unit operation of a wastewater reuse scheme. In many cases, micro- and ultrafiltration membranes are used for the pre-treatment of feed water to reverse osmosis units (Madwar & Tarazi, 2002; Redondo, 2001).

The integrated membrane system (IMS) detailed by Redondo (2001), has been favoured in the Mediterranean. In essence, IMS uses continuous filtration by micro- or ultrafiltration elements prior to an RO desalination system. This integration has better microbiological control, reduces inherent foulants and minimizes the silt density index of the feed water entering the more sensitive, and more expensive, reverse osmosis elements.

Several installations around the world have demonstrated the technical and economic feasibility of treating municipal wastewater for reuse. There have been successful pilot and full-scale operations in the Canary Islands, Korea, Hungary, and the US, most notably in California and Arizona (del Pino & Durham, 1999).

2.8.5.8 Economics

The economics of any major project are the final arbiter of success. To be viable, the new technology must meet or reduce the overall costs of conventional treatment. While scientific studies may be in abundance, membrane technology can still be considered in its infancy with respect to wide-spread, full-scale operations. This is likely due to three primary factors. Firstly, membranes have the distinct reputation of increasing capital expense (CAPEX) of any water and wastewater treatment project. This can likely be attributed to lack of competition in the marketplace. Secondly, the cost of operation (OPEX) of a membrane system is considered high. Reverse osmosis systems which are most widespread and understood, use large, high-power pumps to circulate the feed water. It is expected that the so-called rule of thumb that membranes require large quantities of power have been applied to all membrane systems, including MBRs. Thirdly, there is a fundamental reluctance to spend large sums of money on technology that does not have a long history. People in general are conservative in their approach to problem solving. Governments, the primary developer of water treatment infrastructure, are exponentially more conservative.

Studies have confirmed that, in many instances, the use of membranes in wastewater treatment systems is more costly (Yoon et al., 2004). An MBR system was compared to a combined biological and chemical process (CBCP) in South Korea. As expected, it was found that the MBR process required less land and construction costs compared to the CBCP. However, the CAPEX of the membranes themselves outstripped these savings. The MBR's operational costs were also much lower than the CBCP for chemicals, energy and sludge disposal. Unfortunately, the replacement of membranes negated these savings. In the end, it was found that the MBR was $204/m^3 and $0.048/m^3 higher than the CBCP for CAPEX and OPEX respectively (Yoon et al., 2004). It should be noted that the one over-riding cost factor in this study turned out to be the direct cost of membranes. Thus it can be assumed that in the future the cost-effective production of more durable membranes will tip the scales in favour of MBRs. Furthermore, viewed in the context of a remote site, the construction savings could itself show MBRs to be more economically viable upfront.

Municipal wastewater reuse has undergone limited economic comparison and not all studies have pointed to poor MBR economics (del Pino & Durham, 1999). To be accurate, the economic study must look both at the cost of wastewater treatment and drinking water purification. The costs can vary depending on the ultimate end-use of the purified wastewater effluent. The West Basin Water District in El Segundo, California has two water reuse projects underway. The first project utilizes high quality, treated effluent injection into the fresh water aquifer to prevent saline water ingress. This could be considered indirect potable water reuse. The second project was to provide the nearby Mobil and Chevron refineries with boiler feed water. The operating costs for the continuous membrane filtration and reverse osmosis system were $0.122/m^3 less than conventional treatment (del Pino & Durham, 1999). In the same study, the impact of economies of scale are shown. An increase in production capacity from 1,000 m^3/d to 10,000 m^3/d yielded a reduction in investment cost of 41%.

Sludge production in most MBRs is reduced by virtue of the longer SRT and therefore sludge handling costs are minimized. In general, there is an inverse relationship between aeration and sludge handling costs. Thus, there exists an optimum point between aeration and sludge reduction. One study showed that sludge treatment costs were much greater than MBR aeration costs (Yoon et al., 2004). The study went on to conclude that for a fixed bioreactor size, the most economical operation is achieved at the highest possible MLSS. The cost reduction of sludge minimization exceeds the cost increase due to reduced oxygen transfer efficiency. However, this assumption only holds true until the physical limitation associated with delivering oxygen to microorganisms is reached. It should be noted that the economic conclusions drawn in this study may be incomplete since the reduction in membrane efficiency due to higher MLSS was not factored into the costs.

2.8.5.9 Retrofit Capabilities

The modular nature of most commercial-ready micro- and ultrafiltration membranes makes retrofitting of existing wastewater treatment plants relatively simple. Thus, when a conventional system is reaching its maximum flow rates, retrofitting to an MBR can increase its capacity to treat wastewater. Some of the other advantages of an MBR retrofit are the reduced cost of construction, the ability to increase the MLSS concentration and reduce sludge handling, and the quick turn-around time for startup (Ahn et al., 1999; Buisson et al., 1998). Furthermore, future requirements for increasing flow through the system can be satisfied by simply adding more membrane modules. It is specifically this flexibility that can extend the lifespan of the current wastewater treatment facilities beyond their respective communities' ability to outgrow them.

In other instances, the design of the conventional system may be inefficient. In South Korea, many systems were designed for an average BOD loading of 400 mg/L (Ahn et al., 1999). In reality, these systems were seeing much lower BOD loadings and were experiencing biomass instability and failed to reach effluent guidelines. One system was retrofitted with membranes and operated at higher MLSS concentrations to improve efficiency and meet guidelines. It was found that the MBR system achieved very stable effluent quality consistently below guideline limits and was more effective than direct filtration of the sewage. The low organic loading of the Korean wastewater treatments plants is very similar to some of the systems operated in northern Manitoba.

2.8.5.10 Remote Control and Monitoring

Very little work has been done on the remote control and monitoring of membrane bioreactors. The lack of study may be due to the prevalence of standard Supervisory Control and Data Acquisition (SCADA) systems currently in place in most large-scale wastewater treatment plants. The large area associated with conventional plants dictates the use of SCADA for adequate and timely monitoring and control of all unit operations in the system. However, SCADA is seldom if ever employed to control more than one wastewater treatment plant. Furthermore, most SCADA installations require supervision on-site and are not meant to be controlled from any significant distance.

A study performed at the University of Guelph developed a device and software to control a remote membrane system (Li et al., 2002). A control system was developed using the Java and CORBA internet-based architecture. Thus, the experimental membrane system could be controlled via a desktop PC connected to the internet. Java was used due to its universal and widely-used nature. The CORBA architecture has the flexibility to integrate components from several vendors. The system was capable of monitoring and controlling up to three experimental units with operational data stored on the local controlling PC.

There has been limited study in the computer control of membrane operation. A neural network was established for the control of ultrafiltration membrane backwashing (Teodosiu et al., 2000). Two neural networks were developed and trained to accurately predict the non-linear behaviour of the membrane flux-time relationship. The industrial application of these neural networks is currently limited due to the very specific nature of the program. However, the study lays the ground work for future operator-free control of non-critical systems.

If SCADA is assumed as the latest quantum leap in system control, it is predicted that the usage of neural networks and the control of systems via the Internet will be following. Operator-free and remote control will be implemented on a wide scale in the next generation of control systems.

3 RESEARCH OBJECTIVES

Overall Objective:

Investigate the technical and economical feasibility of membrane bioreactors (MBRs) for wastewater treatment in Northern Manitoba aboriginal communities and other secluded sites. Evaluate stability and reliability of such systems in response to shock loadings and operational failures and explore remote control and monitoring possibilities.

Specific Goals:

- Establish a site for the installation of a pilot-scale MBR unit for long-term experimentation and evaluation by identifying communities that have failing secondary wastewater treatment systems or are in need for an alternative to existing primary treatment.

• Develop a pilot-scale submerged MBR system, which incorporates remote control and monitoring capabilities. Ship the system to selected location and install it in existing wastewater treatment facility.

• Demonstrate the effectiveness of the MBR unit in the treatment of real wastewater under varying operational conditions over a sustained period of time by evaluating organic matter, nitrogen, phosphorus, and coliform/pathogen removal efficiencies.

• Expose system to shock hydraulic, organic, and nutrient loadings, determine its response to mechanical and electrical failures and evaluate its resilience during emergency situations.

• Explore remote control and monitoring strategies with the use of internet-based communication software, Symantec pcAnywhere, and a high-speed DSL network connection.

• Recommend and elaborate on other possible areas of application for remote controlled MBRs, such as large-scale remote northern construction sites, mining and oil exploration sites and communities located on pristine lakes or protected water bodies.

4 MATERIALS AND METHODS

4.1 Site Selection

For the present study, the Opaskwayak Cree Nation (OCN) reserve in Manitoba, Canada (See Figure 3), was chosen as the research site. There were several factors that lead to selection of OCN from a pool of candidate sites in Manitoba. Firstly, there was a wastewater treatment building with available room in OCN. This was essential to the successful implementation of the pilot-scale MBR. Secondly, there was local support for the project. The operator, Harold Young, and his assistant, John McKenzie, have shown keen interest and enthusiasm for the project. They have also offered space in the wastewater treatment building for the MBR and support in the installation and operation of the MBR. In addition, OCN was equipped with high-speed Internet access. This was essential for the execution of the remote control testing of the system via the Internet. Another determining factor was the highway accessibility of the reserve and the implications regarding installation and travel costs. Finally, one of the sponsors of this study, Manitoba Hydro, had a presence in The Pas and has offered support for the project in the way of travel and accommodations.

The community's existing wastewater treatment plant consisted of a sequencing batch reactor with sand filtration and a UV disinfection system (which was generally non-functional).

Figure 6: Location of the Opaskwayak Cree Nation and pilot-scale MBR.

4.2 Demographics of OCN

The Opaskwayak Cree Nation is situated on the northern bank of the Saskatchewan River near the 54^{th} parallel on the western side of Manitoba. The geographic area is the Canadian Shield. A pulp-and-paper operation is located to the east of the community and employs a large portion of the population of OCN and the neighbouring community of The Pas.

As of September 2005, the population of OCN was approximately 3000 on-reserve residents (INAC, 2005). Most of the community is serviced with running water and central sewage collection and treatment. There is a large hockey arena and shopping centre located in the town site. The hockey arena in particular could be a source for the highly variable wastewater. Further study on the raw wastewater quality would be required to quantify the impact of major sporting events (i.e. where the majority of the community is in attendance) on ammonia-N and BOD levels.

4.3 Sequencing Batch Reactor

The pilot-scale MBR was compared with the existing wastewater treatment system at the OCN reserve, which consisted of two sequencing batch reactors (SBR) and three sand filtration units. The original treatment system incorporated a UV disinfection trough after the sand filters. However, the ballast for the UV system malfunctioned early in the start-up phase of the plant's commissioning. Furthermore, the high turbidity of the effluent leaving the filters was such that, even when the UV system was operational, it was ineffective. Each reactor went through the treatment cycle once per day. The decanted effluent was pumped to the sand filtration units. The filtered water passed down the UV trough and into the neighboring river. The SRT was maintained at around nine days while the HRT ranged from 16-24 hours depending on influent flow. Pictures of the OCN wastewater treatment plant are located in the Appendix.

Table 6: OCN Sequencing Batch Reactor operational parameters

	Spring	Winter
Total System Flow Rate (Imp GPD)	**250,000**	**150,000**
I cycle/reactor/day		

Parameter	SBR #1	SBR #2	Total
Volume (Imp gallons) @ 100%	212000	122200	334200
Volume (L) @ 100%	954000	549900	1503900
Reactor Volume After Decant	50%	50%	
Volume (L) @ 50%	477000	274950	751950
# of Sludge Pumps	4	4	8
Sludge Pump Q (US GPM)	150	150	300
Sludge Pump Q (Imp GPM)	127	127	253.3333
Sludge Waste Time (min)	5	4	9
Sludge Waste Volume/cycle (Imp Gal)	2533	2027	4560
Sludge Waste Volume/cycle (L)	45600	36480	82080
Average MLVSS @ 100% (mg/L)	580	580	580
Average MLVSS @ 50% (mg/L)	1160	1160	1160
Total Sludge Mass (g)	553320	318942	872262
Sludge Mass Wasted (g)	52896	42316.8	95212.8
HRT (winter) (d)			**2.23**
HRT (spring) (d)			**1.34**
SRT (d)			**9.2**

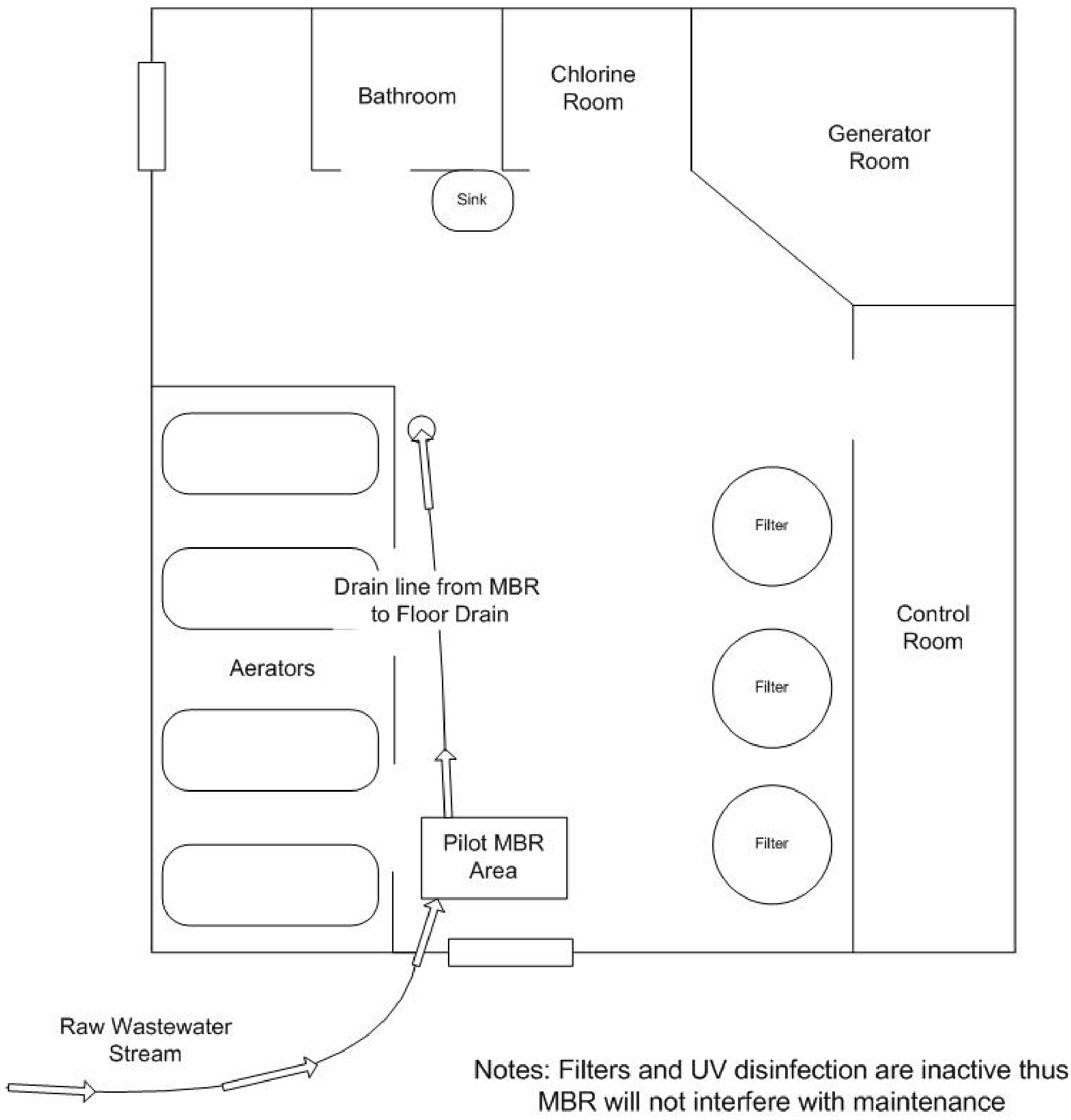


Figure 7: Location of the MBR within the existing plant

4.4 MBR Design

The pilot-scale MBR, shown in Figures 9 through 14, consisted of a Zenon ZW-10 hollow-fibre ultrafiltration membrane submerged in a 200-L reactor. The membrane had a nominal pore size of 0.035μm and a surface area of $0.93m^2$. The MBR was fed a continuous flow of wastewater diverted from the Opaskwayak Cree Nation wastewater collection system. The system hydraulic retention time (HRT) and solids residence time (SRT) were 10 hours and 20 days, respectively for the first phase. The SRT was increase to 40 days for the second phase of testing. The process pump operated on a 10-minute cycle. The pump drew water through the membrane for 570 seconds and backwashed the membrane with clean permeate from a backwash tank for 30 seconds. Air channeled through the membrane module's central support structure provided membrane surface scouring and oxygen delivery. Mixed liquor was automatically wasted from the bioreactor in regular intervals using a computer controlled solenoid valve, 5-litre cylinder and electronic level switches. At a user-specified time interval, the solenoid valve would open and mixed liquor would fill the cylinder. The level switches were triggered once the required five litres were obtained. A computer-controlled pump then emptied the cylinder to the sewer. Through this method, it was possible to establish a given SRT by specifying the frequency of sludge wasting. The unit was equipped with online sensors for measurement of trans-membrane pressure, mixed liquor dissolved oxygen, mixed liquor pH and temperature. A computer controlled data acquisition system read the sensors and directed the system via a Visual Basic program. The experimental system incorporated the internet-based communication software, Symantec pcAnywhere, and a high-speed DSL network connection to enable research on remote monitoring and control. The software allowed access, via the Internet, for complete control of the operational system as well as current data logged from the online sensors. In addition, the software allowed for electronic communication between the onsite operator and the researcher. A dedicated internet protocol address allowed for seamless reconnection in case of power outages.

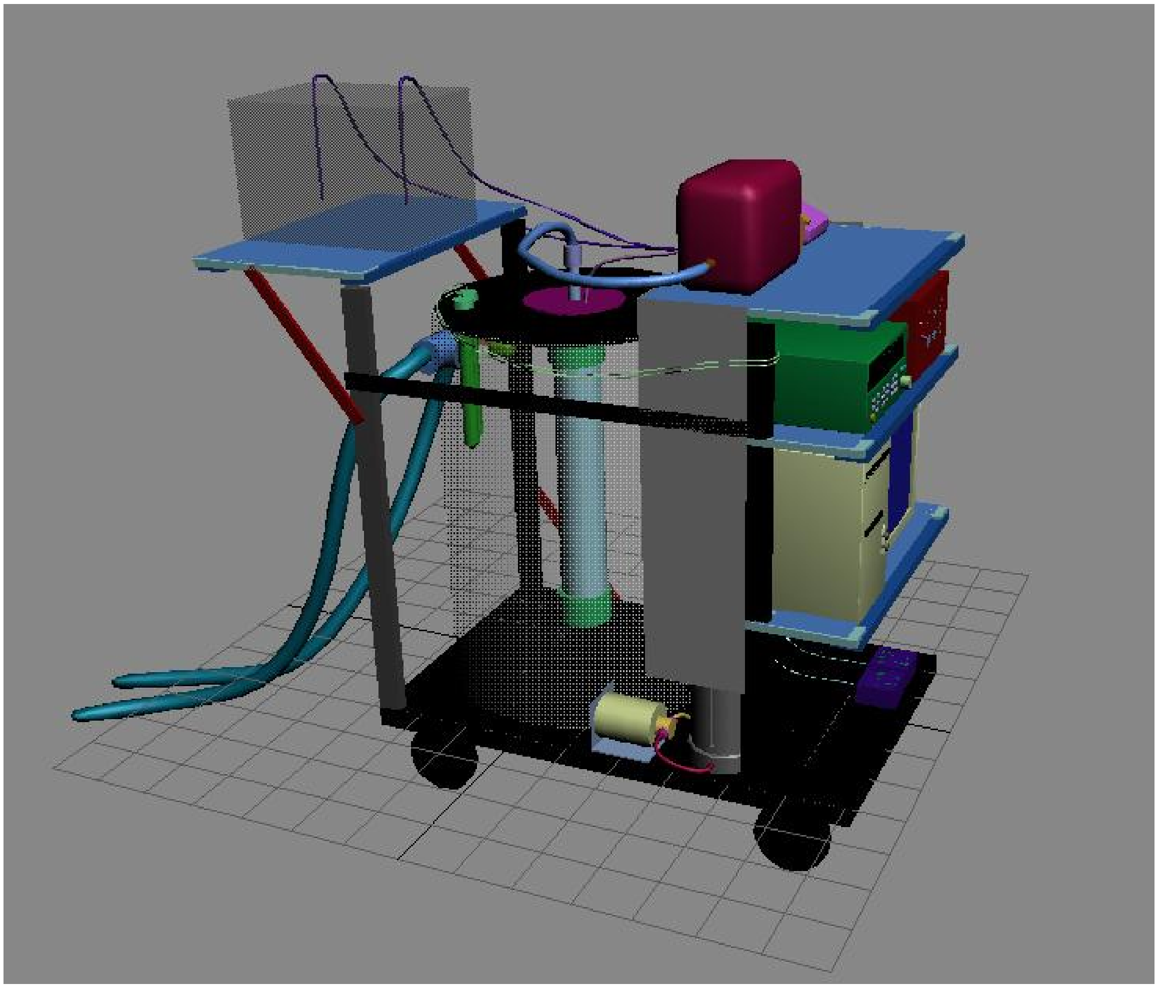


Figure 8: Pilot-scale membrane bioreactor (Left)

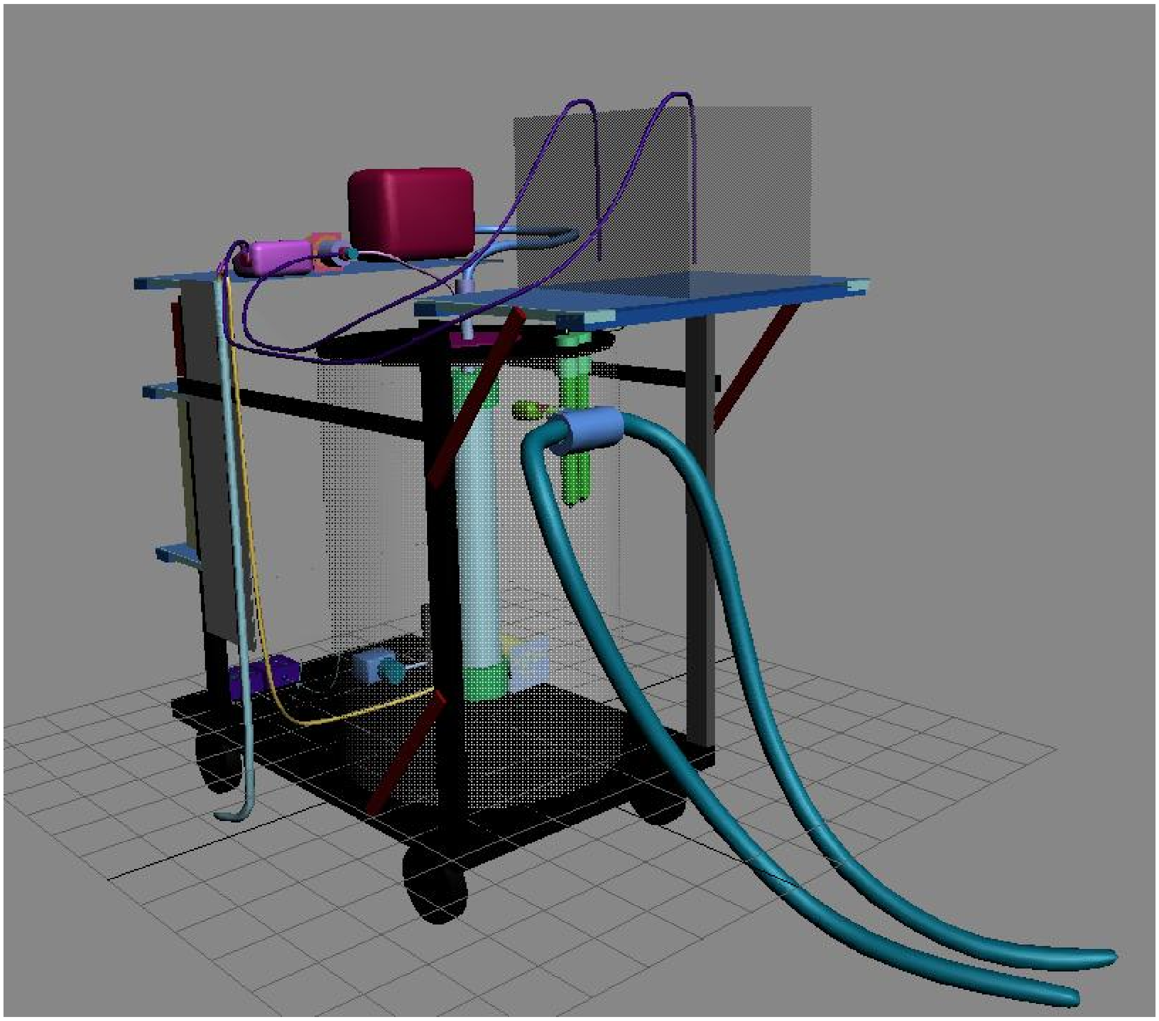


Figure 9: Pilot-scale membrane bioreactor (Rear)

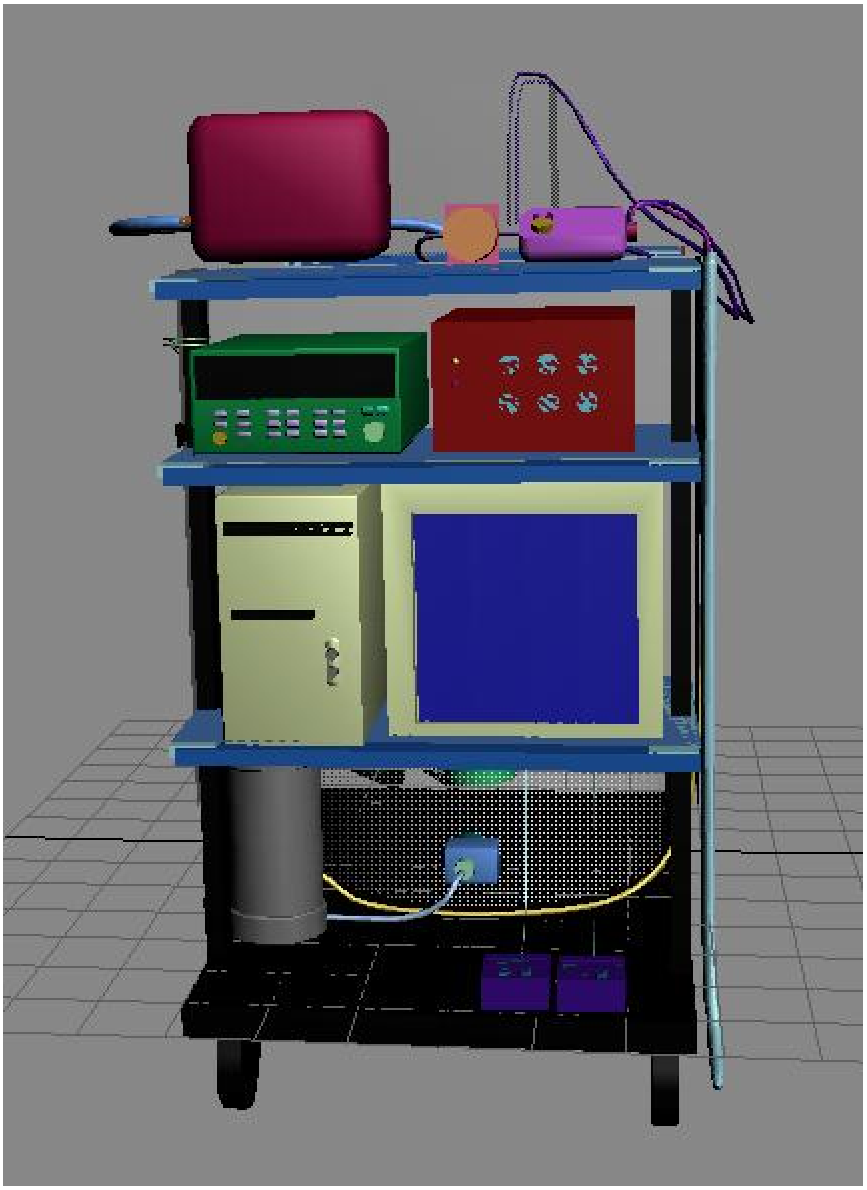


Figure 10: Pilot-scale membrane bioreactor (Front)

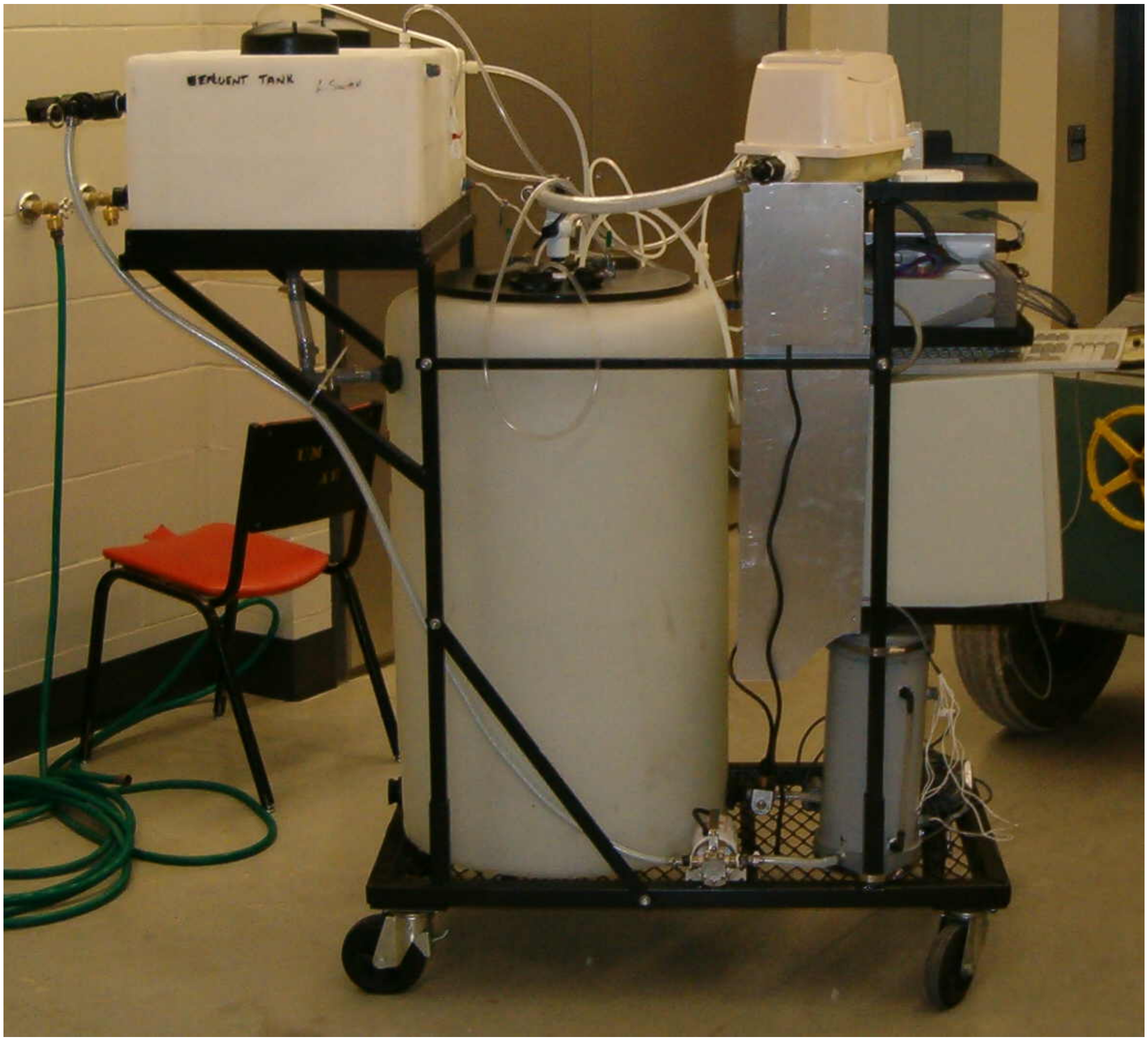


Figure 11: MBR Pilot System (left side)

Figure 12: MBR Pilot System (right side)

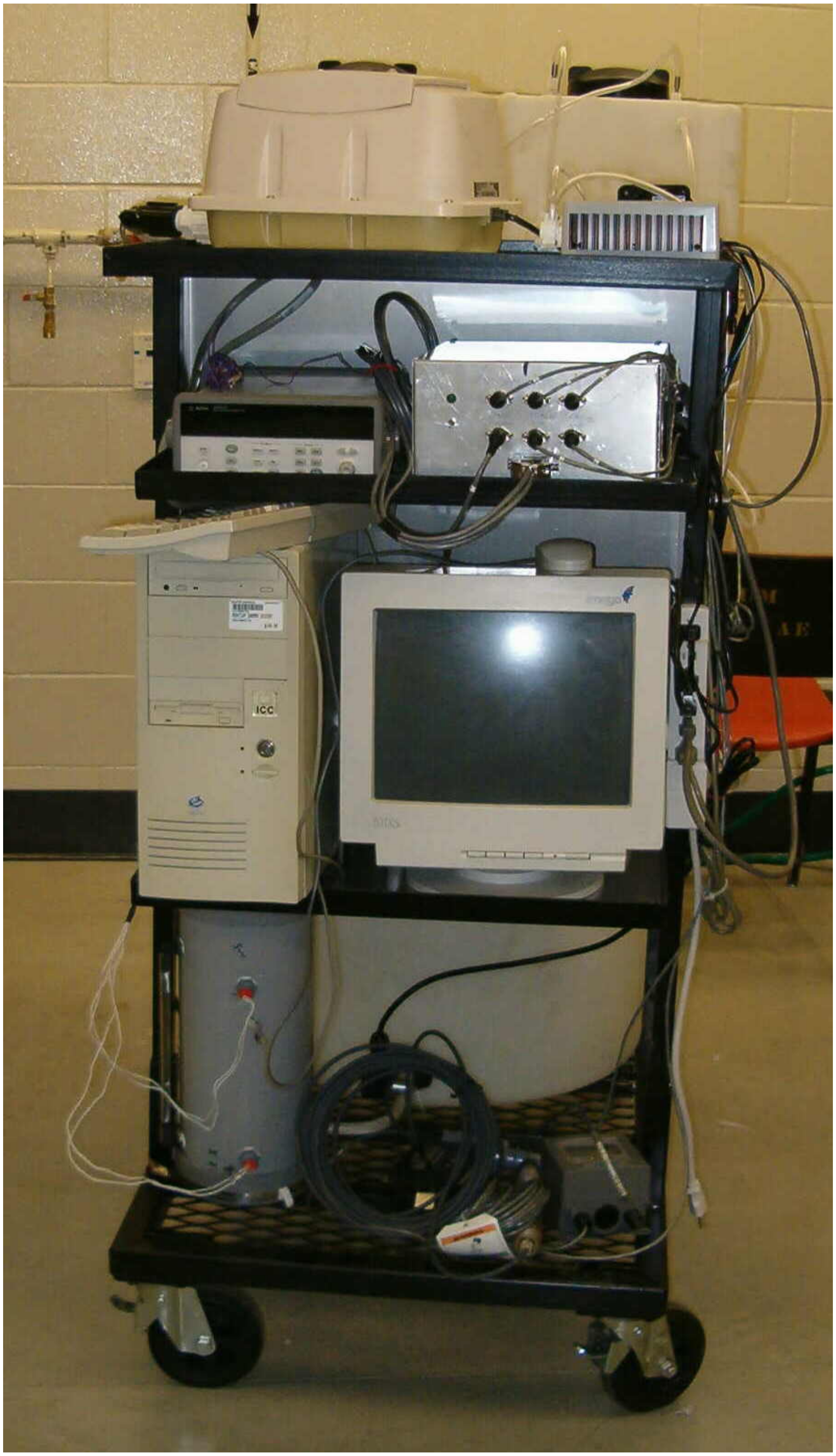


Figure 13: Pilot MBR (front)

4.5 Instrumentation

In order to adequately measure the operation of the pilot-scale MBR, online instrumentation was incorporated into the design. Figure 15 is a piping and instrumentation diagram outlining the process flow and electronic control. Online sensors for dissolved oxygen, pH, and a thermocouple for temperature were installed into the reactor vessel. A pressure transducer was placed inline on the membrane unit. Electro-magnetic level switches were installed in the reactor and backwash tank. An Agilent data acquisition system (DAS) was used to collect and store the data from each sensor and switch. The membrane process pump, effluent transfer pump, sludge waste pump and sludge waste solenoid valve were all hardwired to the DAS for analog or digital control. A desktop PC with an Intel Pentium 1 processor and 32 MB of RAM communicated with the DAS to store the data and manipulate the pumps and valve. The control algorithm is further described in the following section.

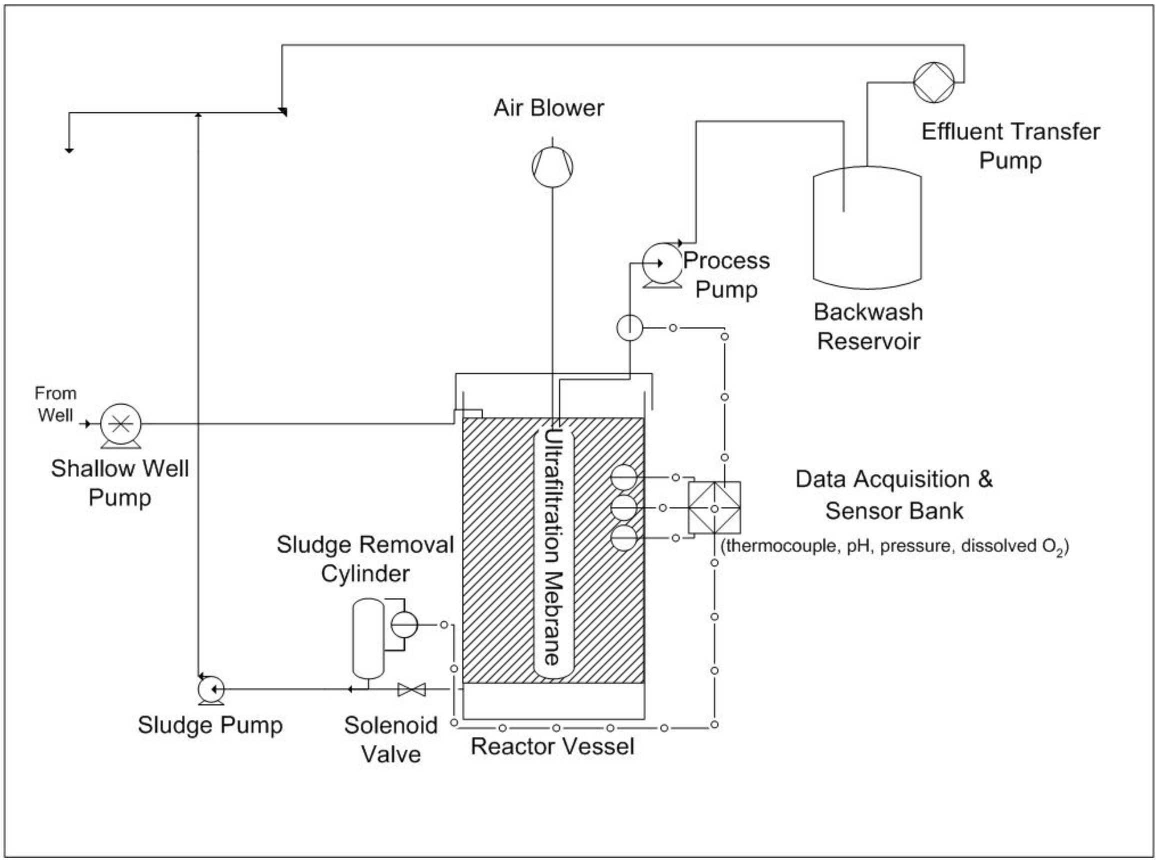


Figure 14: Pilot System Configuration

4.6 *Automated Control*

4.6.1 Visual Basic Program

The full Visual Basic Program code is included in the Appendix. The program accomplished three primary functions. Firstly, the program operated as a control system for the micropump suction and backwash intervals to effectively control the HRT. Secondly, the program controlled the sludge wasting interval to control the SRT. Thirdly, it acted as a data acquisition system by capturing the information from the online sensors. The online sensors also acted as control parameters for the pumps. For example, if the level sensors indicated low levels in the tank or excessive trans-membrane pressure, the system would be shut down. Algorithms outlining the process control parameters are shown in Figures 16 & 17.

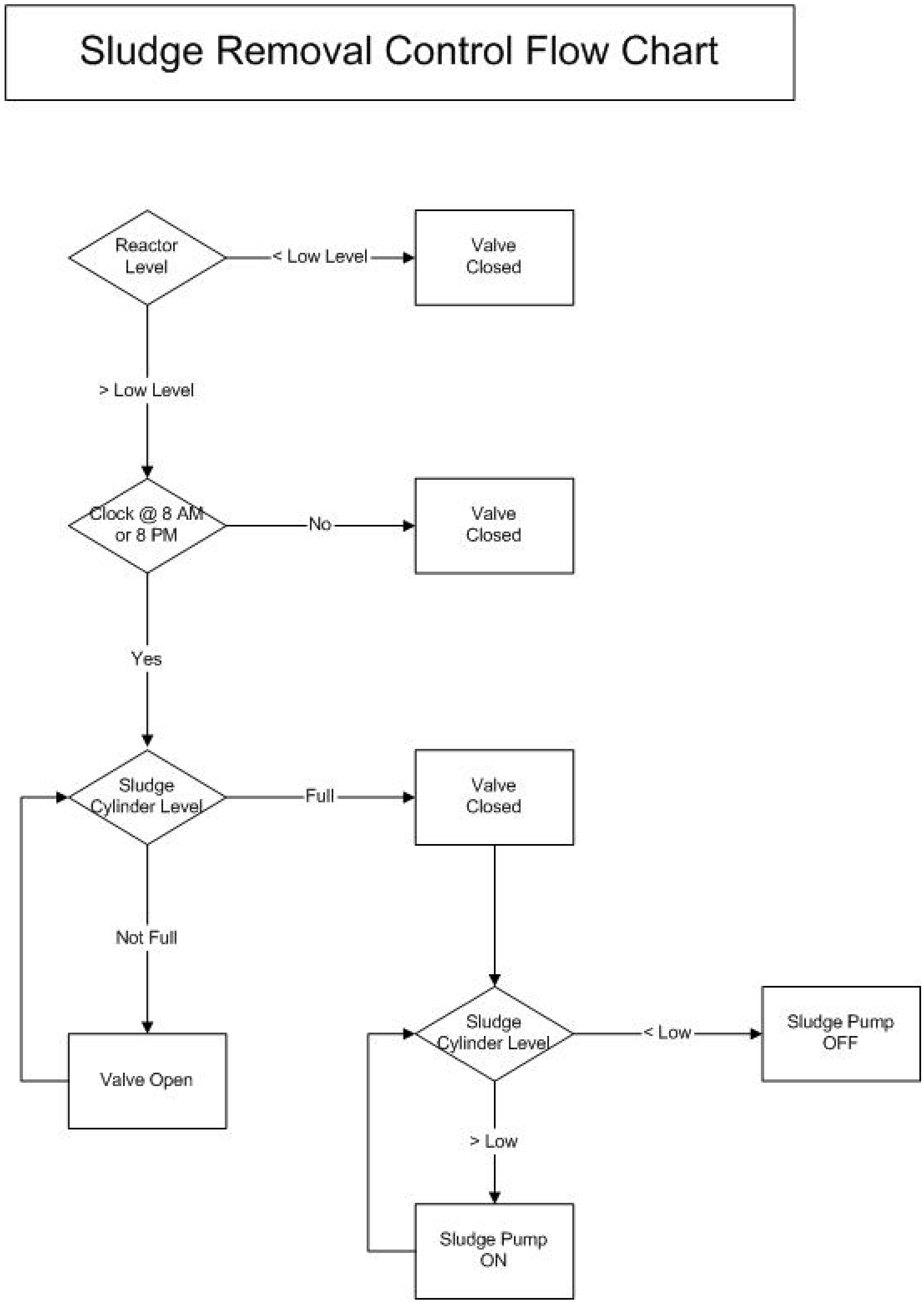


Figure 15: Algorithm for MBR sludge removal program

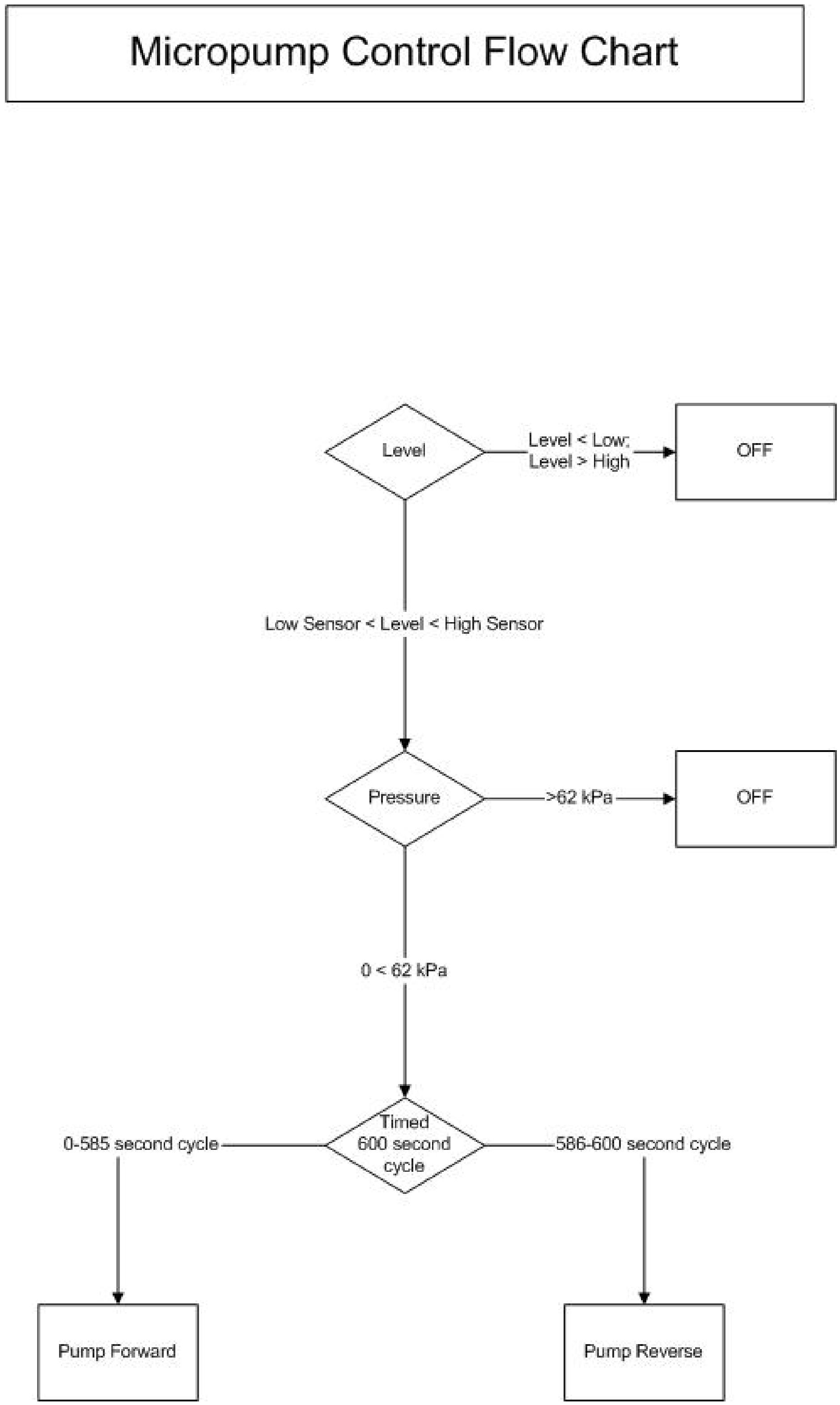


Figure 16: Algorithm for micro-pump operation

4.6.2 Remote Control and Monitoring

In the second phase of experimentation, the system was controlled remotely via the Internet. The Symantec's remote control program, pcAnywhere, was installed on the pilot system PC. The PC was programmed to serve as a web-host with a password protected login for "Super-User" control. A dedicated Internet Protocol (IP) address was assigned to the PC. A laptop was equipped with the pcAnywhere Remote Access software. Thus, through the Internet and the dedicated IP address, the laptop was capable of finding and assuming control over the pilot PC from any location in the world. The "Super-User" status of the controlling computer allows full access to all functions of the host computer. Essentially, the communications window on the laptop displayed the desktop of the host computer. A screen shot of the desktop is found in Figure 18 Through the host desktop, one is capable of viewing the current status of the pilot system including dissolved oxygen, pH, temperature and time of operation. It is also possible to control the flow rate of both the process and effluent transfer pumps as well as alter the duration of and frequency of backwashing and sludge wasting. Although not utilized, the program had the capability of using an Internet-capable digital video camera to view the system for any unusual characteristics such as excessive foaming or low reactor levels.

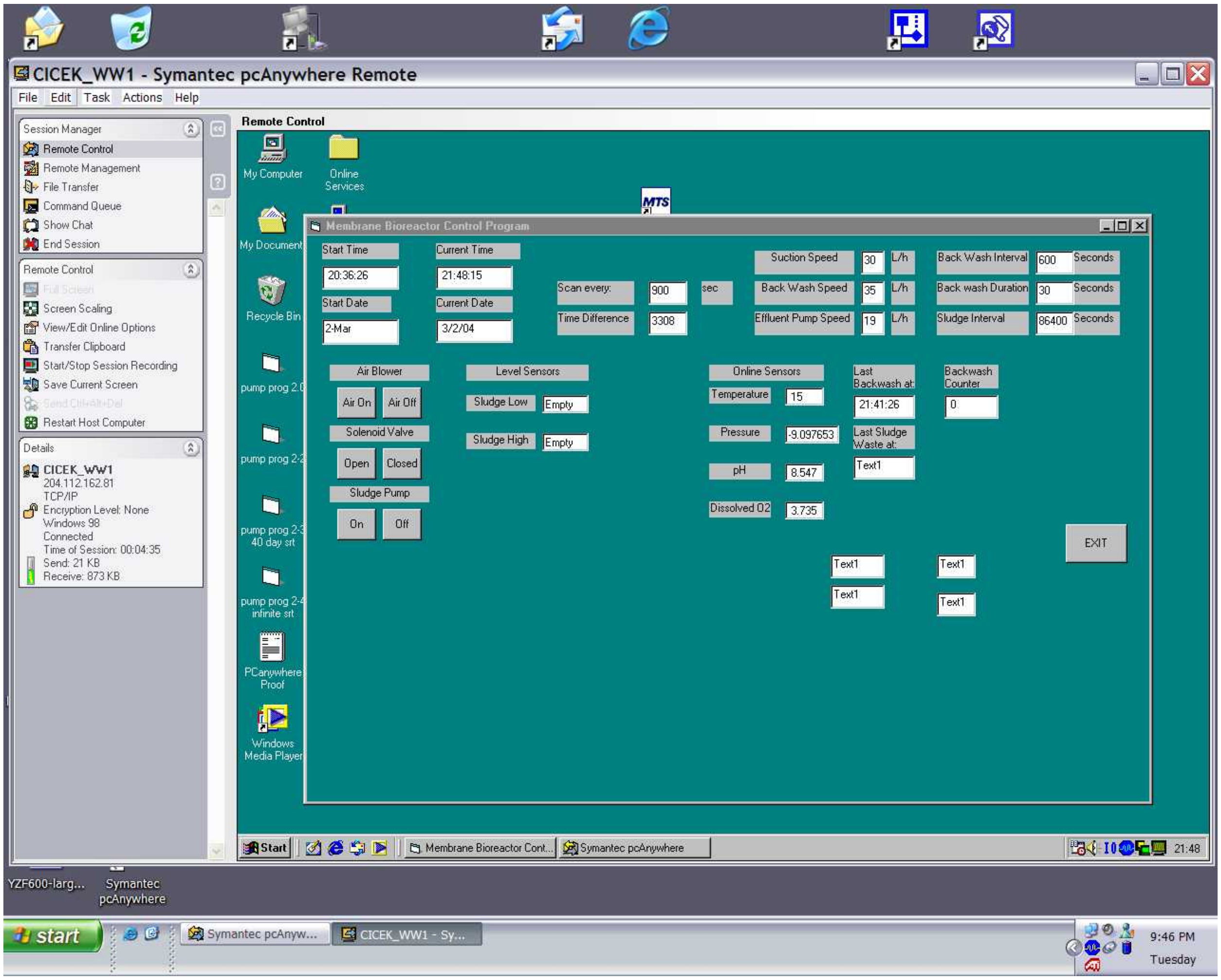


Figure 17: Screenshot from remote computer while controlling pilot system

4.7 Sampling and Operation Methodology

4.7.1 Data Collection and Analysis

The data collection was performed through a combination of online analyzers and lab testing. The lab testing was further broken down into in-house testing at the University of Manitoba and third-party lab testing. Due primarily to time and location constraints, in-house testing was used primarily in the second phase of MBR testing whereas a third-party was utilized primarily in first phase pilot testing. The third-party labs employed in this study were Envirotest Laboratories and Norwest Laboratories, both in Winnipeg, MB..

During Phase I, all material flows were sampled and analyzed weekly with the exception of the MBR effluent, which was sampled and analyzed twice weekly (i.e. every three or four days). Table 6 is a testing matrix that shows the sampling frequency and analyses for each material flow.

Table 7: Testing Matrix for Pilot Testing

		Parameters											
Material Flow	**Frequency**	**TSS**	**VSS**	**COD**	**Soluble COD**	**BOD**	**DOC**	**TKN**	**TP**	**NH3**	**NO3**	**NO2**	**TC**
Wastewater (Influent)	Once/week	√	√	√		√		√	√				
MBR sludge	Once/week	√	√		√			√	√				
SBR sludge	Once/week	√	√		√			√	√				
MBR effluent	Twice/week	√	√	√		√	√	√	√	√	√	√	√
SBR effluent	Once/week	√	√	√		√		√	√	√	√	√	√
SBR/Filter Effluent	Once/week	√	√	√		√	√	√	√	√	√	√	√

LEGEND:

TSS – Total Suspended Solids; VSS – Volatile Suspended Solids

COD – Chemical Oxygen Demand; Soluble COD – Chemical Oxygen Demand on filtered sample

BOD – Biochemical Oxygen Demand; DOC – Dissolved Organic Carbon

TKN – Total Kjeldahl Nitrogen; TP – Total Phosphorous

NH3 – Ammonia; NO3 – Nitrate

NO2 – Nitrite; TC - Total Coliforms

4.7.1.1 In-House Lab Measurements

The University of Manitoba Environmental Engineering lab was used to perform the analysis from the period starting March 26 to July 27. The samples were collected in OCN and transported to Winnipeg where they were stored in a refrigerator at 4^{o}C until testing could occur. The lab measurements followed either the APHA Standard Methods for the Testing of Water and Wastewater or the equivalent Hach standard methods.

4.7.1.1.1 Hach DR/2500 Spectrophotometer

The bulk of the in-house analysis utilized a Hach DR/2500 Spectrophotometer. The parameters that were tested include: Chemical Oxygen Demand (COD), Nitrate (NO3), Ammonia (NH3) Total Nitrogen (TN), and Total Phosphorous (TP).

4.7.1.1.2 Other Analysis

Testing not using the Hach DR/2500 included: Total Solids (TS), Total Suspended Solids (TSS), Total Volatile Solids (TVS), and Volatile Suspended Solids (VSS). The methods for these simple analyses are according APHA, 1999.

4.7.1.2 Third-party Labs

Envirotest Laboratories was used exclusively for the first phase of MBR testing. During Phase II testing was performed primarily in-house with the Total Coliform and BOD testing awarded to Norwest Laboratories.

5 RESULTS

5.1 Pilot System Drawbacks

The first iterations of all pilot systems have room for improvement. The pilot-scale MBR in this project is no exception. The following table outlines the list of problems encountered with the system and possible recommendations.

Table 8: Drawbacks of the pilot-system and potential mitigation measures

Drawback	Explanation	Recommendation
Plugged foot valve	Solids in the wastewater plugged the screened foot valve and prevented flow of feed water to system.	Pre-screen wastewater to minimum 5 mm screen to prevent solids from negatively impacting operation.
Better Program	The Visual Basic program was prone to upset. This may have been due to poor programming or inappropriate selection of software.	Implement a system utilizing machine language to be more robust than the higher level languages such as Visual Basic.
Stronger Computer	Desktop PC was not powerful enough to manage all calculations quickly and efficiently and was prone to freezing or a delayed clock	Ideally, industry standard PLCs would be used to better emulate full-scale operation and provide a more robust operating framework
Aeration causing heating	As the blower ran it warmed up and thus heated the air entering the MBR.	The air temperature should be moderated to emulate working level conditions.
Sludge removal unreliable	Due to poor software performance some instances occurred where sludge wasting did not happen as scheduled. Furthermore, the solenoid valve froze and manual wasting was required for a portion of testing.	Ensure selection proper solenoid valve for wastewater service. Ensure reliable operating program.
Dissolved oxygen sensor fouled quickly	Biological growth occurred rapidly on the DO sensor. This yielded skewed and unreliable results	This is a common industry problem. Self-cleaning sensors have been developed and could reduce this problem.
Frozen feed water line	The feed water line became plugged and froze due to lack of circulation	Provide better screening to prevent plugging. Install heat tracing and insulation to eliminate freezing in the event of a failure
Damaged or moldy membranes	The membranes surface was spotted with mold growth and in one case the surface tore. The cause of the tear was unknown.	Proper cleaning and maintenance will reduce the occurrence of damaged membranes

Figure 18: Plugged screen on foot valve.

Figure 19: Guard screen for foot valve

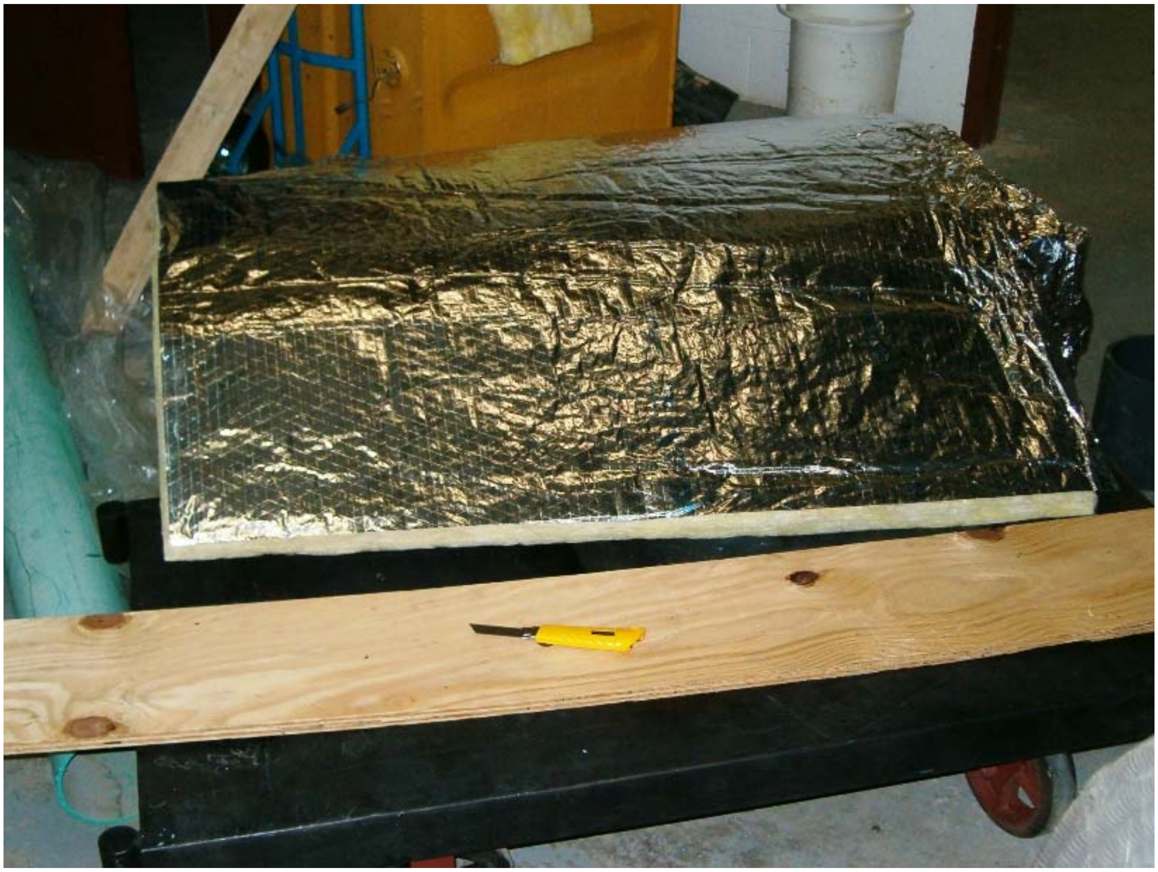


Figure 20: Reflective Insulation for Feed Water Piping.

Figure 21: Heat tracing for feed water piping

Figure 22: Heat tracing on raw wastewater cap

Figure 23: Membrane with mold growth. Transport packaging in back

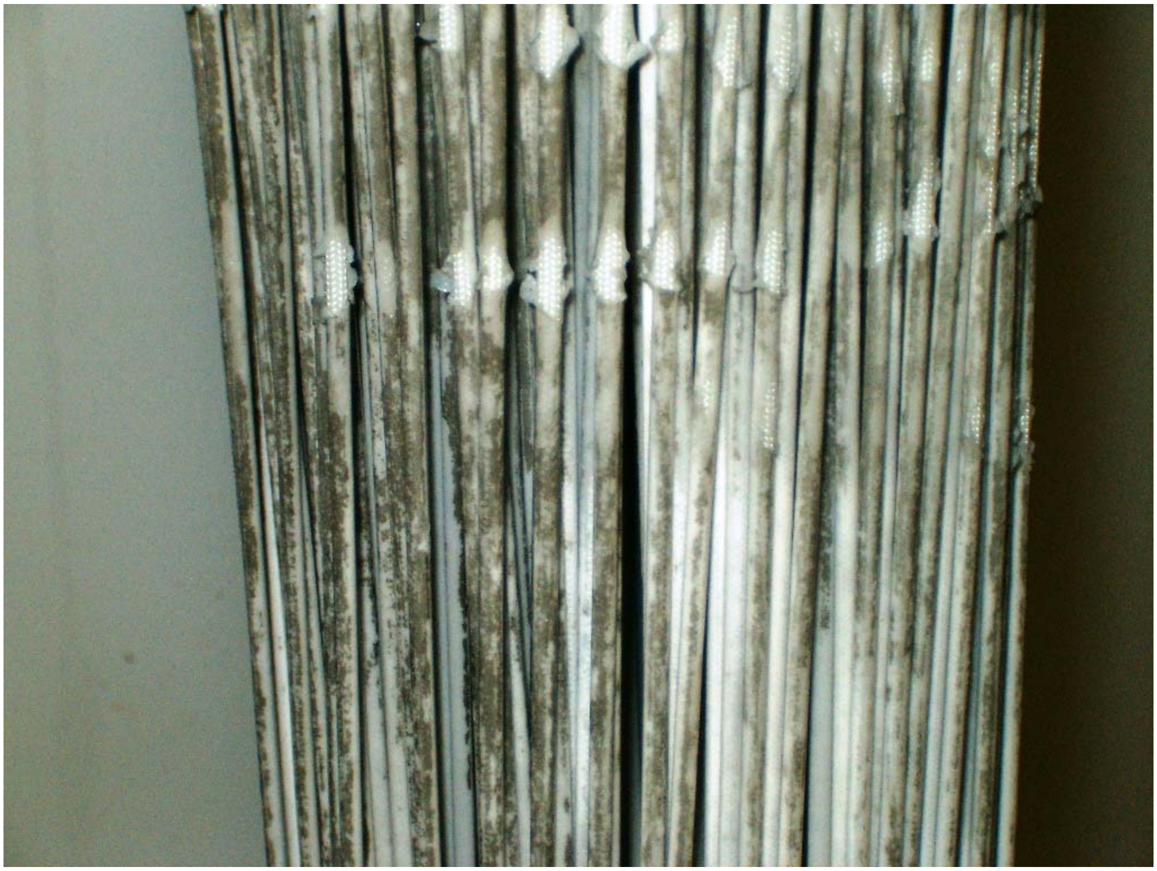


Figure 24: Torn and moldy membrane

5.2 MBR vs. SBR (Sep 03 - Dec 03)

Nitrification performance, effluent quality, and mixed liquor stability were examined for both systems, which received low strength, highly variable wastewater. The wastewater quality in OCN is relatively weak as outlined in Table 1. There is substantial infiltration and inflow in the community sewage collection system. The flow ranges from $600m^3/d$ in the winter to $1,000m^3/d$ in the spring.

Table 9: Opaskwayak Cree Nation raw wastewater characteristics

Parameter	Unit	Concentration	Std. Deviation
Biological Oxygen Demand (BOD)	mg/L	106	13.5
Total Suspended Solids (TSS)	mg/L	79	26.4
Volatile Suspended Solids (VSS)	mg/L	59	13.6
Total Kjeldahl Nitrogen (TKN)	mg-N/L	25	7.7
Total Phosphorus (TP)	mg-P/L	4	0.6

The SBR maintained an average mixed liquor volatile suspended solids (MLVSS) concentration of 580 mg/L. The performance of MBR, SBR, and SBR+Sand Filter systems were individually characterized by analyzing BOD, TSS, TKN, TP, ammonia, and nitrate in their respective effluents on a weekly basis. The mixed liquor in the MBR and SBR were analyzed for TSS, VSS, TKN, TP, and soluble COD. All analyses were performed in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 1997)

As membrane surface fouling occurred, the trans-membrane pressure increased slowly from 3 to 17 kPa, at which point the membrane was chemically cleaned. The membrane was rated to 50 kPa in suction; however, the process pump used could provide only 17 kPa of suction. Figure 27 illustrates the approximately symmetrical increase in pressure for both suction and backwash phases between two membrane cleaning events. The mixed liquor pH remained at approximately 8.3 without external augmentation. The mixed liquor temperature ranged from 11^{o}C to 18^{o}C and averaging around 14.5^{o}C. Table 10 highlights the effluent quality of the MBR, the SBR alone, and the combination of the SBR and sand filters for an operational period of 12 weeks. The pilot-scale MBR outperformed the SBR and Filter system by consistently achieving effluent BOD, TSS, and TKN concentrations of <6mg/L, <5mg/L and <1.5mg/L respectively.

Table 10: Comparison of effluent characteristics

Parameter (unit)	SBR only	SBR + Filters	MBR
BOD (mg/L)	16.1 ± 11.7	30.3 ± 18.8	<6
TSS (mg/L)	14.2 ± 9.8	27.5 ± 19.1	<5
TKN (mg/L)	6.8 ± 3.8	8.4 ± 3.7	1.3 ± 0.4
TP (mg/L)	1.7 ± 0.3	2.2 ± 0.6	1.9 ± 0.3
NH3 (mg/L)	3.8 ± 2.9	3.6 ± 2.6	0.2 ± 0.3
NO3 (mg/L)	6.4 ± 4.0	6.2 ± 3.2	16.1 ± 2.6

Figure 25: From left to right: Tap Water, MBR Effluent, SBR+Filter Effluent

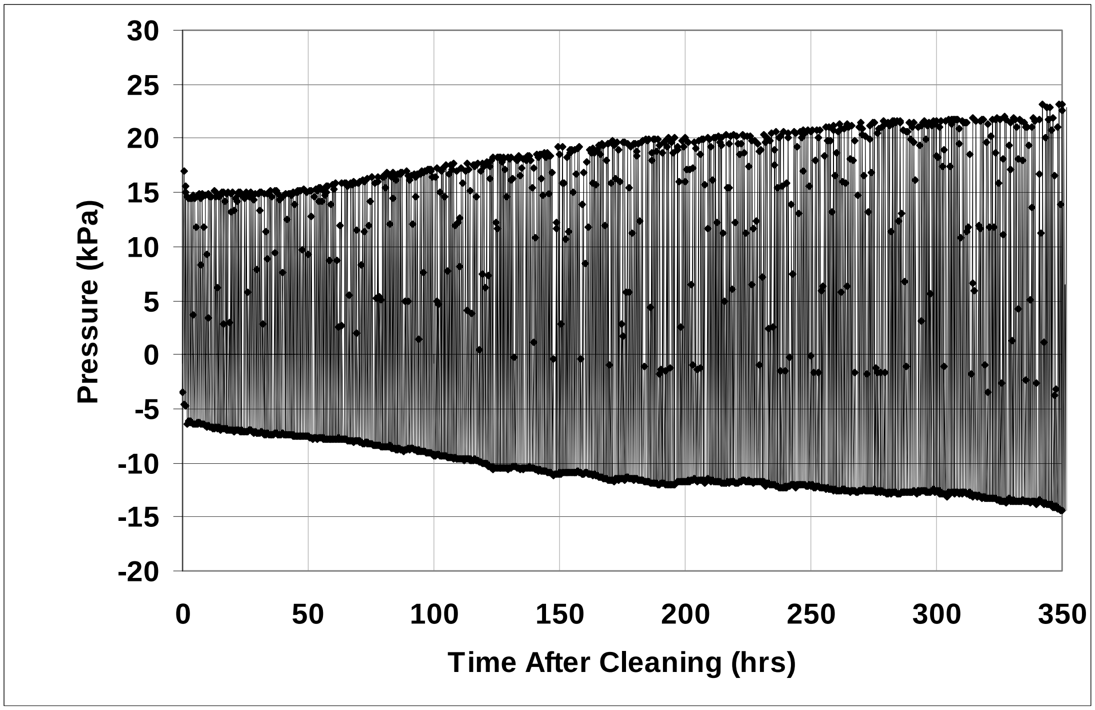


Figure 26: Increase in transmembrane pressure between two chemical cleaning events

Due to the relatively weak municipal wastewater, the MLVSS concentration in the MBR had an average around 1000 mg/L. This is low for typical MBRs with 20-day SRT. However, this can be explained by two mechanical and electrical failures that prevented the system reaching steady-state operation. A more realistic average MLVSS value would be approximately 2500 mg/L. When compared to an SBR MLVSS value of approximately 600 mg/L, a quadrupling of the MLVSS to 2500 mg/L implied that the MBR could treat the same volumetric flow rate as the SBR system with approximately one-quarter the reactor volume. Despite the relatively low mixed liquor temperature and variable wastewater loading, full nitrification was observed in the MBR (Table 10). The retention of all biomass within the MBR and the operation at higher SRTs allowed for the more sensitive nitrifying culture to sustain activity at these conventionally unfavorable conditions. Several mechanical and electrical problems have occasionally interrupted steady state operation of the pilot-scale MBR unit. This is evident in Figure 28. Previously mentioned, a mechanical failure in the automatic sludge wasting system resulted in loss of biomass twice; once in late October and the other in early November. The loss of biomass also triggered a temporary reduction in nitrification. In the same period corresponding to the washouts, the TKN in the MBR effluent spiked. Once the mechanical difficulties were remedied, the system rapidly re-established adequate MLVSS levels and nitrification performance.

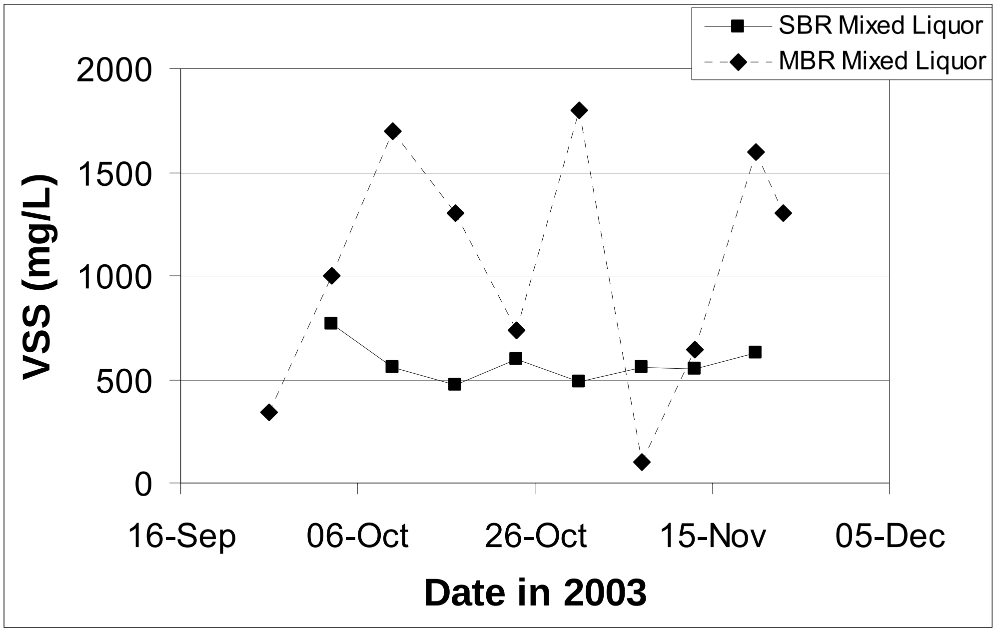


Figure 27: Mixed liquor volatile suspended solids concentrations in both the SBR and MBR

Figures 29 and 30 demonstrate the highly fluctuating nature of the incoming wastewater in terms of BOD and TSS, as well as the corresponding response of the existing SBR system and the pilot MBR. Despite the short term mechanical failures encountered during the operation of the pilot-scale MBR, effluent quality was not compromised and both BOD and TSS remained at or below detection limits. The SBR/filter system, on the other hand, which did not encounter any mechanical or electrical problems during the testing period, frequently produced effluent which did not meet general discharge guidelines (< 30 mg/l BOD and TSS).

The rapid re-growth of biomass and restoration of performance stands testament to the resiliency of the system to mechanical failures. This is particularly important for remote sites with limited operator attention where the potential for mechanical or electrical failures are increased. In addition, short-term power outages, which would interrupt filtration and aeration, are commonplace occurrences in remote, northern communities. A system that is resilient to such interruptions and is capable of quickly re-gaining operational effectiveness can be of great value.

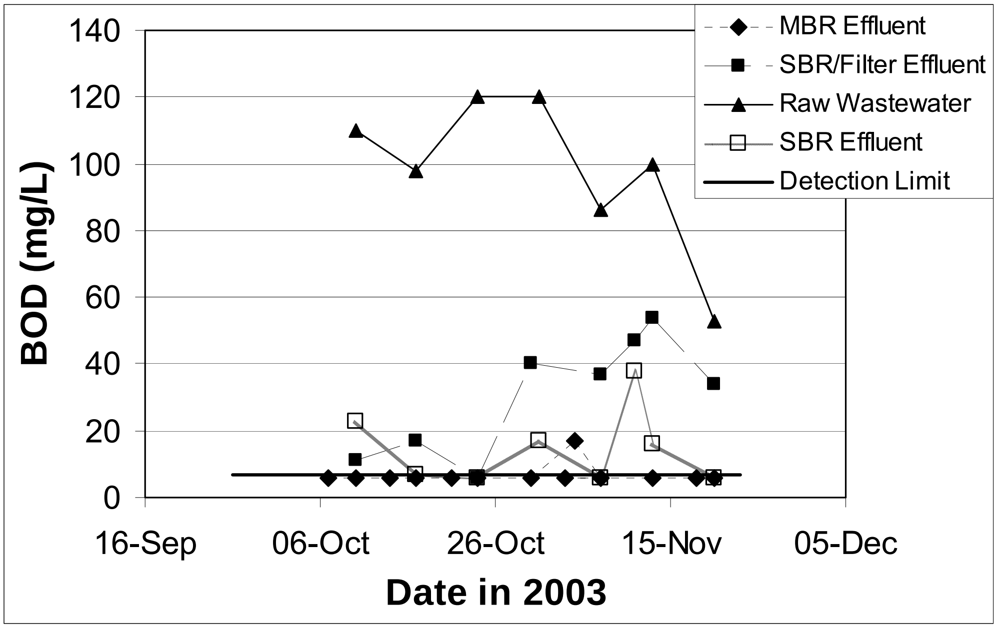


Figure 28: Effluent BOD comparison between MBR, SBR+Filters, and raw wastewater

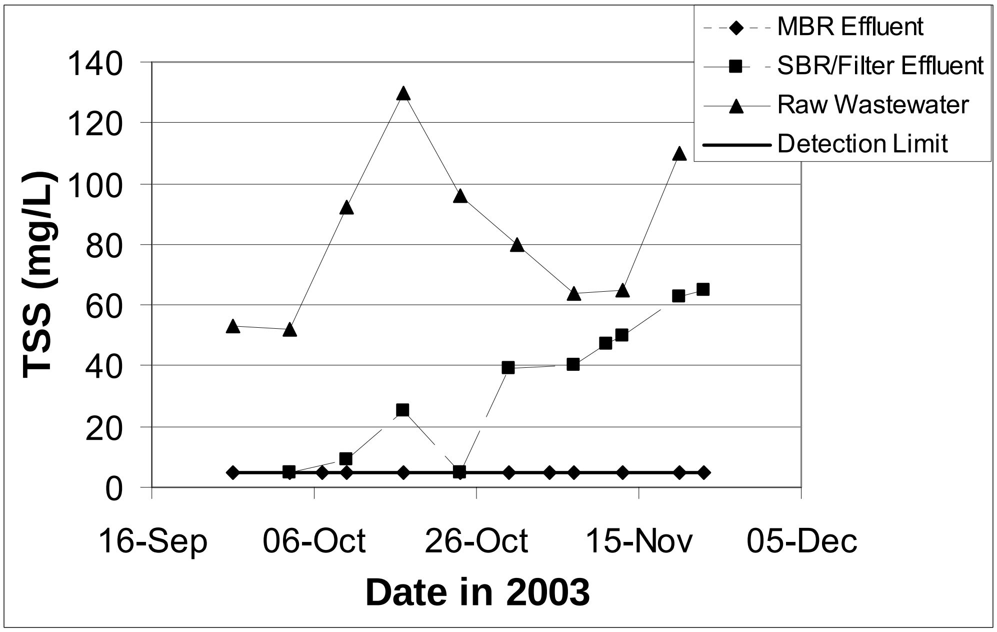


Figure 29: Effluent suspended solids comparison between MBR, SBR+Filters, and raw wastewater

5.3 MBR Efficacy (March 2004 - July 2004)

The period from March, 2004 through July, 2004 was used to determine the overall efficacy of the MBR. This was also the time where the Internet-based monitoring and control was implemented.

The MBR pilot was operated from March through July 2004. Analysis was performed as per the testing matrix previously shown. The system was monitored daily from Winnipeg via the Internet. Over the winter during a testing hiatus, the electric solenoid valve seized and the automatic sludge wasting system was no longer functional. Thus manual wasting was accomplished at every trip. During this period of testing, the SRT was doubled from 20 to 40 days. To achieve the 40-day SRT, a specified volume of sludge was wasted for each day between visits. For example, the 200-L vessel would normally waste about 5 L/day of mixed liquor. Therefore, if five days elapsed between visits, 5 x 5 L/d = 25 L was wasted. This irregular wasting of sludge was less than ideal but the MBR performed well under the circumstances. A more regular wastage of sludge would provide a less variable environment for the membrane and likely improve the performance even further. A second hiccup to the operation occurred once during this testing phase. The PC froze from memory overload. At 32 MB of RAM, the system was not well-equipped to deal with the data logging plus the internet operation. After troubleshooting the problem, the solution was to restart the computer every twelve hours to refresh the RAM and prevent further hang-ups. This worked well and no problems were encountered afterwards.

5.3.1 Mixed Liquor

The MBR mixed liquor volatile suspended solids concentrations for Phase II testing were approximately five times the MBR MLVSS concentrations witnessed in Phase I. Phase II MLVSS concentrations averaged to around 5000 mg/L where as the Phase I MLSVSS concentration averaged to around 1000 mg/K. However, the two washouts in phase one did not allow for a proper accumulation of biomass. The highest MLVSS concentration in Phase I was 1800 mg/L. This could be assumed to be near normal operation. Despite the differences in operational conditions, the concentration is roughly double as is expected with a doubling of SRT.

5.3.2 Effluent Quality

The MBR effluent quality was again well below the environmental discharge guidelines for BOD and TSS. The average effluent BOD and TSS concentrations were 5.8 mg/L and 6.5 mg/L respectively. The TSS concentration was surprising since the ultrafiltration membrane, at a nominal pore size of 0.034 µm should not allow any solids to pass through. However, when taking the effluent total coliform levels into account it becomes apparent that there is some form of breakthrough occurring. Three conditions could exist. First, the membrane may have developed a tear or hole in its surface over time and was allowing a small amount of solids and biomass through. This is a plausible argument since damage had been witnessed on one membrane prior to Phase II commencement. The second could be biological regrowth somewhere in the system downstream of the membrane. This is an indication of pilot-system dysfunction. This was not tested for but could have occurred over time. Finally, the sample may have been contaminated. As such the sampling procedure may have been faulty.

Regardless of the cause, this data indicates that the membrane system cannot be assumed to be fool-proof in regards to pathogen retention. The 0.034 µm pore size rating implies that all bacteria are retained. However, in a full-scale operation in a remote northern setting, membrane damage and system dysfunction are realities. Therefore, it would likely be prudent for some form of disinfection to occur downstream of the membrane.

The low ammonia concentrations indicated complete nitrification of the wastewater. Although highly fluctuating, the total nitrogen levels were very closely related to the nitrate levels. Figure 35 shows the highly fluctuating levels of total nitrogen and nitrate concentration while the ammonia levels remained relatively constant. There does not appear to be any correlation between the MLVSS and the nitrogen fluctuations. Therefore, one could assume that the influent ammonia concentration was fluctuating over time. If this is the case, this further identifies the MBR's ability to adapt to fluctuating influent characteristics.

Total phosphorous was measured but the Hach DR/2500 standard testing procedure was interfered with by the nitrogen levels. Upon inspection of Figures 32 and 34 it becomes apparent that the phosphorous mirrors the nitrogen testing. Thus, the Hach phosphorous testing was not considered reliable and was not reported.

Table 11: MBR Analysis for Mixed liquor and Effluent

Parameter (unit)	Membrane Bioreactor March – July 2005	
	Average	Standard Deviation
Mixed Liquor TSS (mg/L)	6511	822
Mixed Liquor VSS (mg/L)	5018	901
Mixed Liquor Soluble COD (mg/L)	241	130
Effluent COD (mg/L)	22.2	7.4
Effluent BOD (mg/L)	5.8	3.6
Effluent TSS (mg/L)	6.5	0.8
Effluent Total Nitrogen (mg/L)	34.8	26.1
Effluent NH3 (mg/L)	1.5	1.2
Effluent NO3 (mg/L)	28.7	25.8
Effluent Total Coliforms (MPN)	2552*	3843*

* The data for total coliforms was highly inconsistent. When removing the outlier of 9300 MPN/100 the actual average and standard deviation was 865 and 849 respectively.

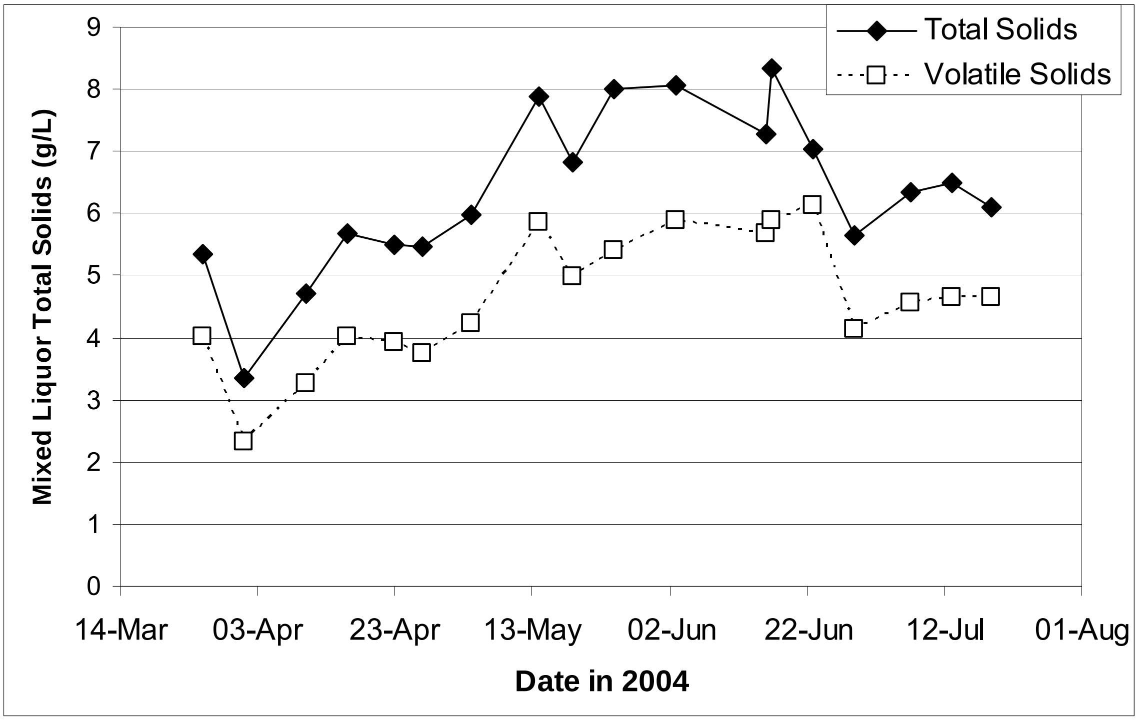


Figure 30: MBR Mixed Liquor Total and Volatile Solids concentrations from March through July 2004

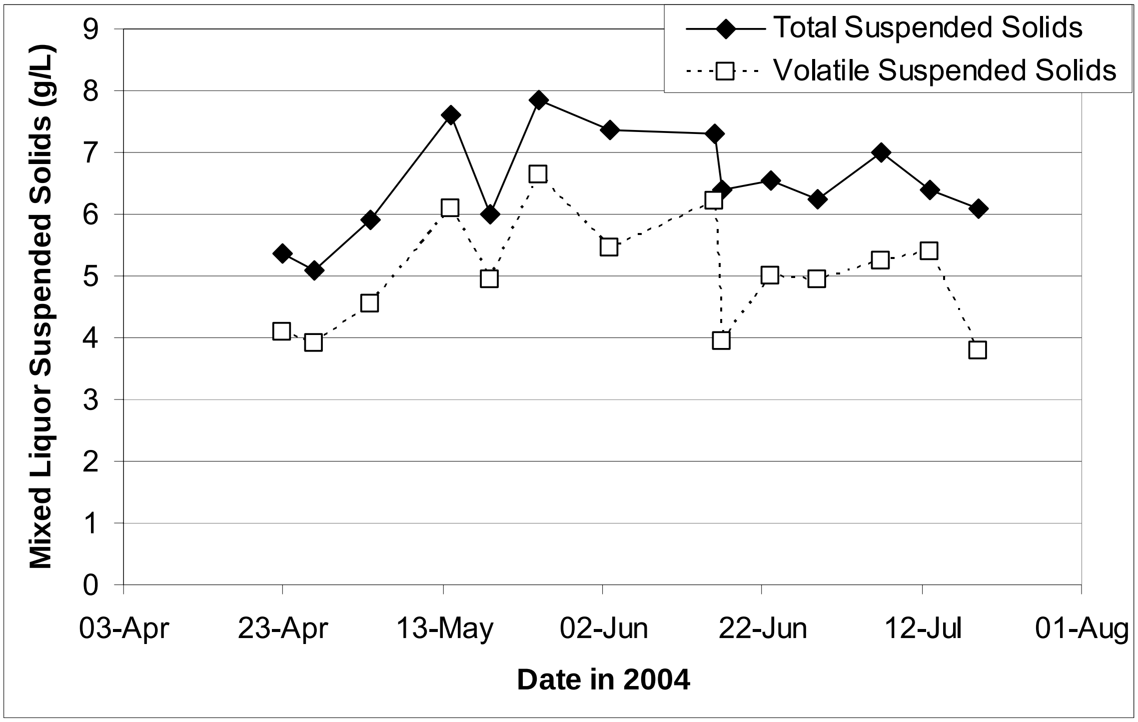


Figure 31: MBR Mixed Liquor Suspended Solids concentration from April through July 2004

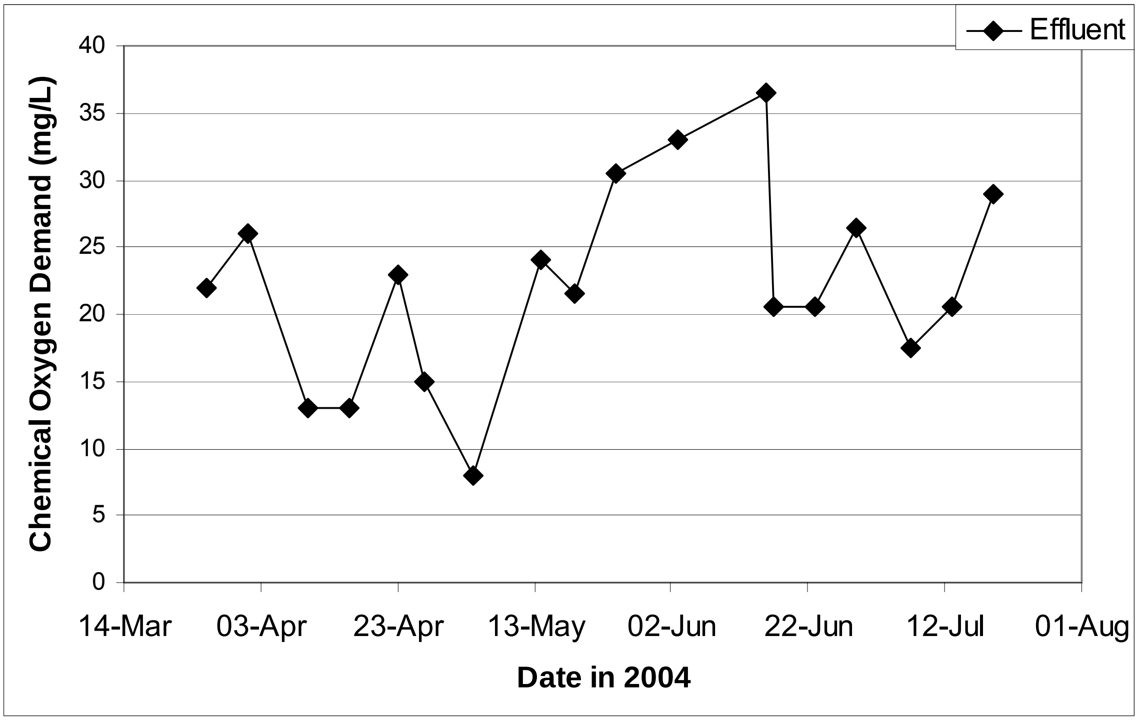


Figure 32: MBR Effluent Chemical Oxygen Demand from March through July 2004

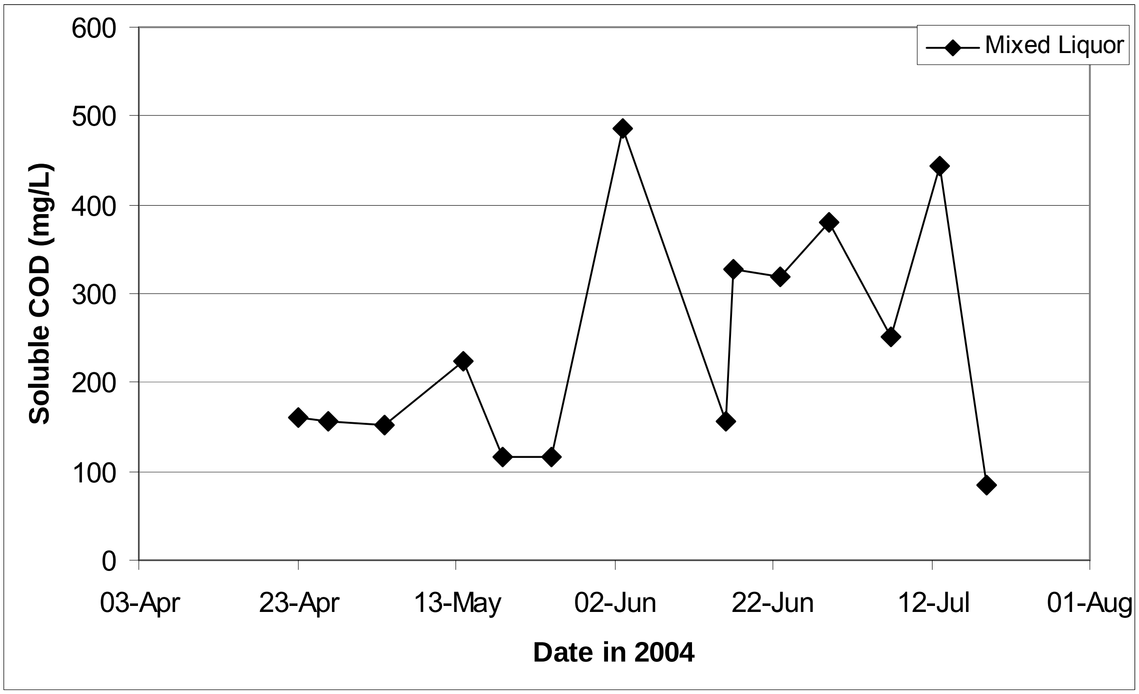


Figure 33: MBR Mixed Liquor Soluble COD from April through July 2004

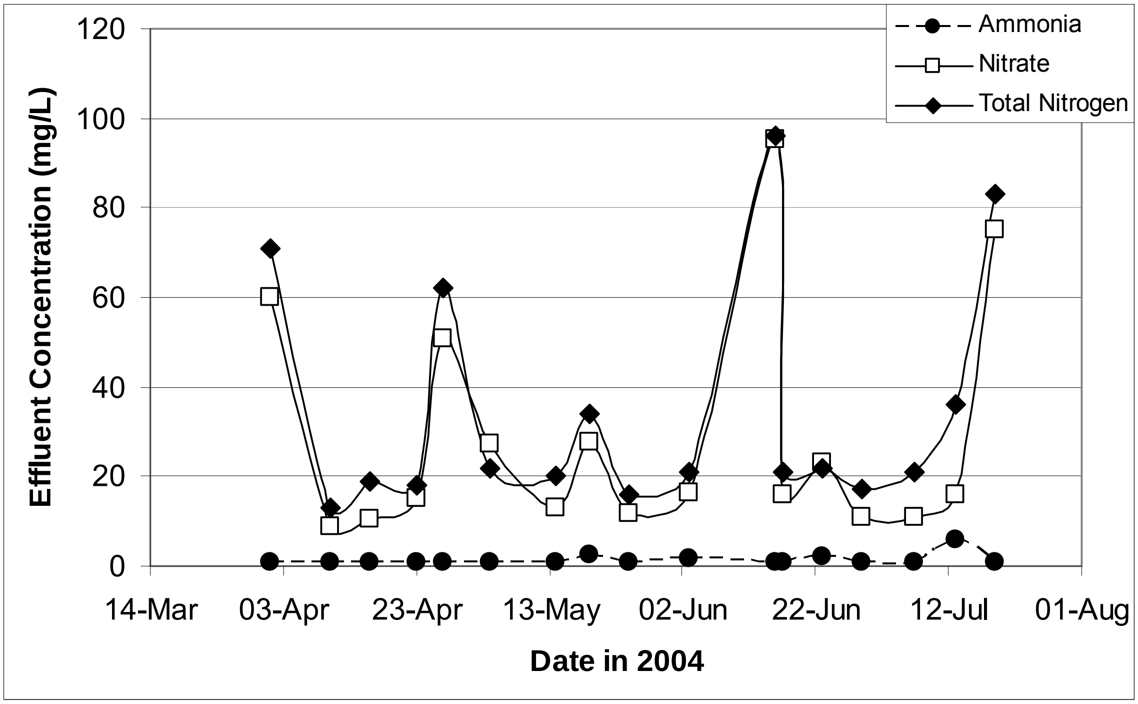


Figure 34: MBR Effluent Ammonia, Nitrate, and Total Nitrogen from March through July 2004

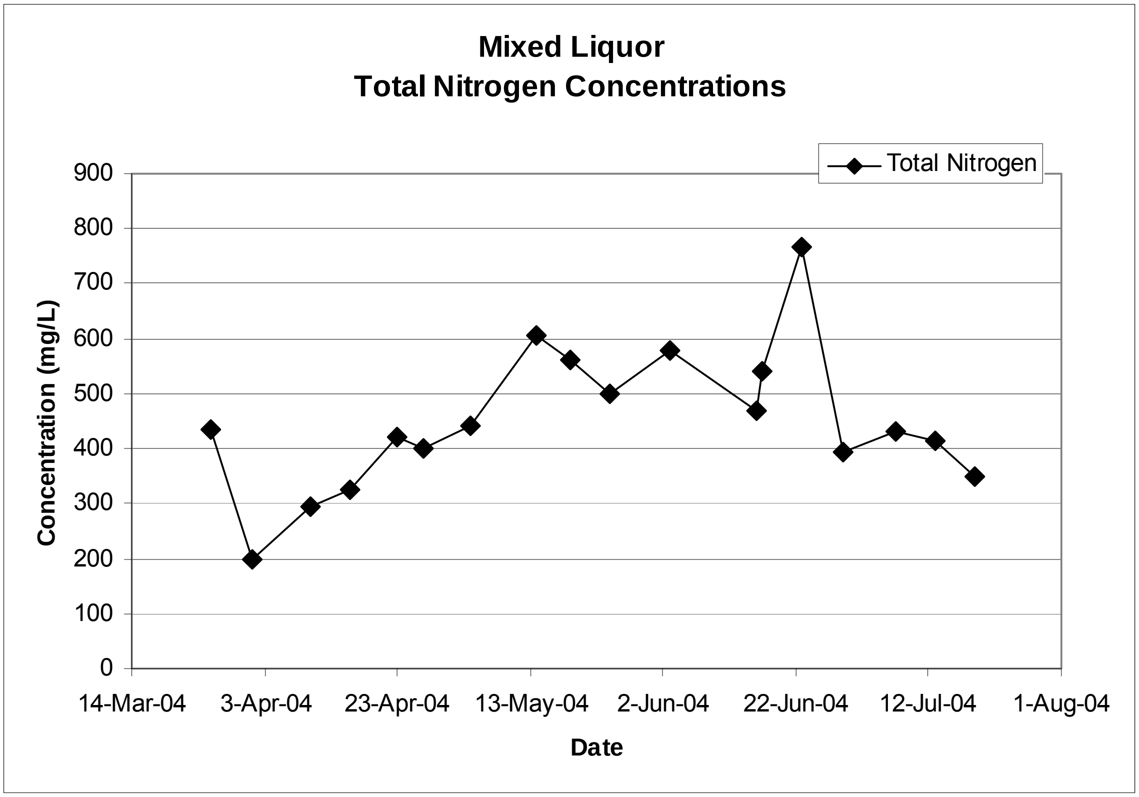


Figure 35: MBR Mixed Liquor Total Nitrogen concentrations from March through July 2004

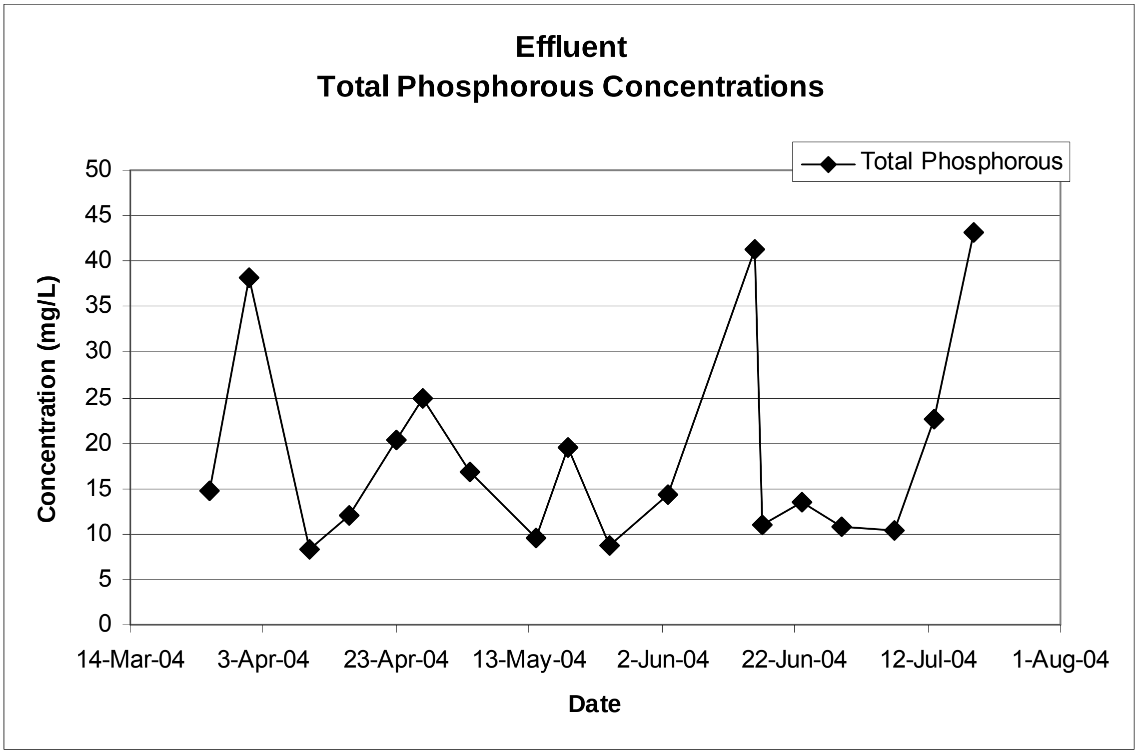


Figure 36: MBR Effluent Total Phosphorous concentrations from March through July 2004

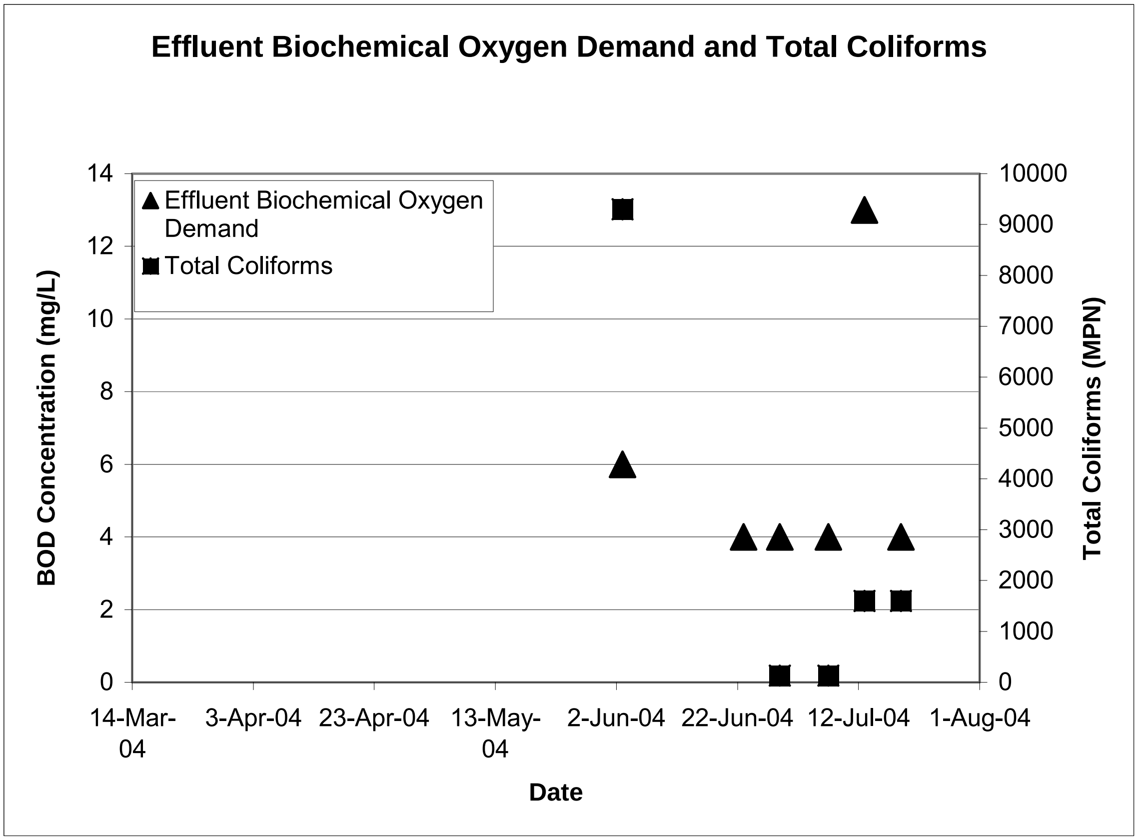


Figure 37: MBR Effluent Biochemical Oxygen Demand and Total Coliforms levels from May through July 2004

6 CONCLUSIONS

The objectives established at the outset of the project have mostly been achieved. The pilot-scale membrane bioreactor was designed, built and evaluated. The field work spanned 10 months in which the system was evaluated.

The Opaskwayak Cree Nation (OCN) was instrumental in establishing a site for the installation and long-term evaluation of the pilot-scale MBR. A slip-stream of municipal wastewater from OCN was used to accurately verify the system effectiveness in treating highly fluctuating, municipal wastewater. With the help of the onsite operators, a direct comparison between their current, problem-prone system, a sequencing batch reactor, and the pilot-scale MBR was made. The building, electricity and onsite support were thanks to Harold Young and John Mackenzie.

The design of the pilot-scale MBR was a modified Zenon system. The modifications were made to increase the flexibility of testing and incorporate remote control and monitoring functions. The system design was complete by August 2003 and installed by September of that year.

The pilot-scale MBR was not without operational difficulties. Despite two system failures, the evaluation went smoothly. The MBR proved to treat the effluent to an extremely high quality. In fact, the system failures served to highlight the resiliency of the MBR to adverse environmental condition. The system was evaluated through a number of parameters include biochemical oxygen demand, chemical oxygen demand, nutrient loading and pathogen levels. In all categories, save pathogen reduction, the MBR met or exceeded environmental guidelines.

Unfortunately, planned, scenario-based testing was not accomplished. Despite the lack of time to assess the system's performance under various shock loadings, a good representation of system resiliency was established. As was previously mentioned, system failures had occurred. An electrical failure and a mechanical failure both resulted in the extreme loss of mixed liquor biomass. However, once the problem was corrected, the effluent quality quickly returned to excellent levels.

In the second phase of testing, the MBR was controlled and monitored via the Internet. A dedicated internet protocol address and pcAnywhere, a remote control program, allowed real-time viewing and control of the system from anywhere on the planet. The MBR system was controlled with a program written in Visual Basic. The pH probe, dissolved oxygen sensor, and pressure transducer were hard wired into the system. These parameters were gathered every 15 minutes to ascertain the MBR function to a high resolution. The online sensors were also displayed on the monitor for both remote and hands-on control.

The effectiveness of the MBR was proven. It treats highly fluctuating, municipal wastewater to a high quality effluent. While the pilot-system was not without its defects, a commercial-scale system would be effective in most remote locations. The simple process flow and highly resilient nature of the system make it a good alternative for communities without 24-hour, 7 days-a-week supervision and limited technical support. The excellent effluent quality can help protect the pristine and fragile environment in northern Canada. The compact design of the system could be incorporated into portable domestic sewage facilities that could be used on isolated construction sites as well as oil and gas drilling rigs.

The research from this project has yielded one peer-reviewed paper in Water Science and Technology and three conferences proceedings. The information gathered is novel to northern Manitoban First Nations communities and will hopefully be used to improve the environmental infrastructure in these much deserving communities.

7 Recommendations for OCN Wastewater Treatment

The poor performance of the current wastewater treatment system is characterized by frequent excursions above provincial wastewater effluent limits. The Biochemical Oxygen Demand, Total Suspended Solids, and Total Coliforms levels often exceed the limits of 25 mg/L, 25 mg/L, and 100 MPN/100 mL respectively. The following recommendations are intended to provide insight into the process and help OCN achieve consist, high quality effluent suitable for environmental discharge.

7.1 Repair or Decommission Sand Filters

Interestingly, the water leaving the SBR actually degrades when passing through the sand filters. In fact, the SBR alone meets the environmental limits much more often than the combined SBR and sand filter. Therefore, the sand filters need to be assessed for design, media selection, and operating conditions. A properly implemented sand filter will help reduce TSS in the effluent and some thought should be given to fixing them. However, a simpler and much more cost-effective solution may be to take the filters offline and simply discharge the SBR effluent to the Saskatchewan River. According to data collected in this study environmental excursions would likely be reduced with this strategy

7.2 Repair Ultraviolet Light Disinfection

The UV disinfection system was offline shortly after initial commissioning of the plant. Troubleshooting and repairing the UV disinfection system would .help to ensure appropriate effluent coliform levels and reduce reliance on chlorine disinfection. However, the water quality passing down the UV trough should have minimal TSS to allow adequate transmissivity of UV light and thus microbial deactivation. Furthermore, the self-cleaning UV light bulbs could alleviate operator attention and help ensure proper function. If the SBR cannot achieve adequate TSS levels in its effluent, some form of filtration should be employed. Given the difficulties with the current sand filters, a micro- or ultrafiltration membrane implemented upstream of the UV trough may be more effective.

7.3 Retrofit a Full-Scale MBR in Second SBR Reaction Vessel

Currently OCN has two SBR vessels. For the short-term, one of the vessels can accommodate all of the wastewater treatment needs of the community. With a free vessel, the infrastructure exists for the opportunity to retrofit an MBR into the current system. This MBR could utilize submersed micro- or ultrafiltration membrane modules to achieve all of the benefits previously stated in this document. Specifically, the MBR would increase the quality of effluent and easily reach TSS targets for adequate UV disinfection. Several components would need to be addressed by an engineering consulting company such as the controlling PLC, the air blowers and diffusers for economical and adequate oxygen transfer, and sludge wasting capabilities. The combination of SBR and MBR in two different vessels allows the community gradually transition to the use of the new system. Furthermore, the MBR would allow for OCN to grow considerably without further significant upgrades to it wastewater treatment plant.

8 Engineering Significance and Future Work

- What use is this research to local engineering firms? World-wide use of research?

Given the large sums of money the federal government has identified for infrastructure upgrading on First Nations communities, it seems obvious that local engineering firms would want to be aware of the various treatment systems and their efficacy in the communities. Furthermore, the MBR technology is not limited to municipal systems. Portable systems for emergency water treatment and remote construction sites are opportunities for local firms to explore.

- What would need to be explored to achieve effective WWT on Aboriginal communities?

The application of MBRs may be limited to communities that have potential for retrofitting. This would indicate communities with extended aeration and SBRs as prime candidates for an MBR. However, further study should be identified to determine the appropriateness of the technology to the individual community. In other words, the community must have the people as well as the capital required to operate any type of advanced wastewater system. It is in the author's opinion that communities should always opt for the most simple system to achieve its desired goals.

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APPENDIX

1. Phase I Data
2. Phase II Data
3. Visual Basic Program Code

Phase I Data

RAW WASTEWATER						
Date	**COD**	**BOD**	**TSS**	**VSS**	**TKN**	**TP**
9/26/2003	120		53	42	17.2	2.31
10/3/2003	240		52	45	20.6	3,1
10/10/2003		110	92	68	24	3.38
10/17/2003		98	130	76	30.7	3.64
10/24/2003		120	96	74	26.6	3.75
10/31/2003		120	80	66	13.6	3.73
11/7/2003		86	64	48	34.4	3.91
11/13/2003		100	65	53	38.1	4.84
11/20/2003		53	110	53	33.4	4.02

MBR EFFLUENT											
Date	**TSS**	**VSS**	**COD**	**BOD**	**DOC**	**TKN**	**TP**	**NH3**	**NO3**	**NO2**	**Tcoli**
9/26/2003	5	5	29			4.6	1.36	4.39	6.15	1.43	9300
10/3/2003	5	5	20			1.1	1.36	0.02	12.3	0.1	430
10/7/2003	5	5		6		1.2	2.06	0.07	1.31	0.27	24000
10/10/2003	5	5		6		1	1.83	0.05	1.35	0.16	24000
10/14/2003				6				0.1	16.4	0.32	
10/17/2003	5	5		6		1.3	1.96	0.05	18.4	0.17	110000
10/21/2003				6	11	2	2.17	0.73	13.3	0.12	
10/24/2003	5			6	9			4.83	8.41	0.91	110000
10/30/2003	5			6	9	1.3	1.71	0.2	16.1	0.28	110000
11/4/2003	5			17	18	19.8	2.04	15.8	0.05	0.11	9300
11/7/2003	5			6	14	17	1.86	15.9	0.19	0.29	2300
11/3/2003				6	14				0.23	0.16	
11/13/2003	5			6	13	20.4	1.93	16.8	0.26	0.21	930
11/18/2003				6	12				3.69	1.17	
11/20/2003	5			6	12	11.3	2.11	8.62	8.79	1.41	230
11/23/2003	5		40		13	1.7	5.5	0.06	50.3	0.34	110000

Phase I Data (cont'd)

MBR Mixed Liquor					
Date	**TSS**	**VSS**	**TKN**	**TP**	**Soluble COD**
9/26/2003	420.0	340	31.1	6.99	200
10/3/2003	1200.0	1000	96.8	13	57
10/10/2003	2100.0	1700	152	18.8	68
10/17/2003	1800.0	1300	142	15	39
10/24/2003	900.0	740	53.1	9.75	64
10/31/2003	2200.0	1800	175	16.8	71
11/7/2003	140.0	97	50.4	7.88	130
11/13/2003	750.0	640	110	12.4	250
11/20/2003	1700.0	1600	179	17	240
11/23/2003	1500.0	1300	142	21	110

SBR EFFLUENT										
Date	**TSS**	**VSS**	**COD**	**BOD**	**TKN**	**TP**	**NH3**	**NO3**	**NO2**	**Tcoli**
10/3/2003	7	7	41		6.2	1.2	4.74	4.17	0.24	110000
10/10/2003	22	17		23	3.2	1.57	1.16	1.76	0.26	150000
10/17/2003	6			7	2.6	1.83	0.32	13	0.22	110000
10/24/2003	<5			6			0.05	13.3	0.06	110000
10/31/2003	7			17	7.6	1.69	6.54	4	0.2	110000
11/7/2003	<5			6	5.7	1.53	4.31	5.81	0.23	46000
11/11/2003	30			38	10.3	1.95	5.05	5.34	0.16	110000
11/13/2003	13			16	5.1	1.32	3.58	6.36	0.25	110000
11/20/2003	35			6	13.9	2.23	8.87	4.18	0.12	110000
11/23/2003	92		110		22.6	3.97	12.6	2.53	0.13	110000

Phase I Data (cont'd)

SBR+Filter EFFLUENT											
Date	TSS	VSS	COD	BOD	DOC	TKN	TP	NH3	NO3	NO2	Tcoli
10/3/2003	5	9	38			5.7	1.35	3.88	5.1	0.2	150000
10/10/2003	9	21		11		3.1	1.66	0.27	1.73	0.27	150000
10/17/2003	25			17		5	2.07	1.86	9.79	0.21	110000
10/24/2003	5			6				0.04	12.8	0.04	110000
10/30/2003	39			40		9.8	2.39	5.72	4.62	0.23	110000
11/7/2003	40			37	9	8.4	2.34	4.12	5.61	0.21	N/A
11/11/2003	47			47	12	11.8	2.21	4.73	5.63	0.14	110000
11/13/2003	50			54	10	9.2	2.3	3.51	6.38	0.19	46000
11/20/2003	63			34	12	14.5	3.23	8	4.3	0.13	110000
11/23/2003	65		84		15	21.1	3.64	14.5	1.51	0.12	110000

SBR Mixed Liquor					
Date	TSS	VSS	TKN	TP	Soluble COD
9/26/2003	610.0		63.6	11	81
10/3/2003	880.0	770	80.8	12	38
10/10/2003	690.0	560	62.8	10.5	22
10/17/2003	600.0	470	63.3	10.1	36
10/24/2003	720.0	600	63.6	9.64	33
10/31/2003	600.0	490	105	11.5	26
11/7/2003	670.0	560	76.9	13	32
11/13/2003	680.0	550	80	10.3	31
11/20/2003	750.0	630	80.6	11.2	34
11/23/2003					

Phase II Data

Effluent Biochemical Oxygen Demand	
Date	BOD (mg/L)
26-Mar-04	
1-Apr-04	
10-Apr-04	
16-Apr-04	
23-Apr-04	
27-Apr-04	
4-May-04	
14-May-04	
19-May-04	
25-May-04	
3-Jun-04	<6
16-Jun-04	0
17-Jun-04	0
23-Jun-04	<4
29-Jun-04	<4
7-Jul-04	<4
13-Jul-04	13
19-Jul-04	<4

		Effluent COD		Mixed Liquor Soluble COD
	Date	COD (mg/L)	Avg (mg/L	Soluble COD (mg/L)
Tested May 6th	**26-Mar**	22	22	NA
	1-Apr	26	26	
	10-Apr	13	13	
	16-Apr	13	13	
	23-Apr	23	23	160
	27-Apr	15	15	156
	4-May	8	8	153
Tested May 21	**14-May**	25	24	225
		23		
	19-May	24	21.5	117
		19		
Tested May 26	**25-May**	32	30.5	117
		29		
Tested July 27	**3-Jun**	23	33	486
		43		
Tested July 27	**16-Jun**	31	36.5	156
		42		
Tested July 27	**17-Jun**	19	20.5	327
		22		
Tested July 27	**23-Jun**	21	20.5	318
		20		
Tested July 27	**29-Jun**	25	26.5	381
		28		
Tested July 27	**7-Jul**	11	17.5	252
		24		
Tested July 27	**13-Jul**	28	20.5	444
		13		
Tested July 27	**19-Jul**	24	29	84
		34		

Effluent Total Coliforms	
Date	MPN
26-Mar-04	
1-Apr-04	
10-Apr-04	
16-Apr-04	
23-Apr-04	
27-Apr-04	
4-May-04	
14-May-04	
19-May-04	
25-May-04	
3-Jun-04	9300
16-Jun-04	
17-Jun-04	
23-Jun-04	
29-Jun-04	130
7-Jul-04	130
13-Jul-04	>1600
19-Jul-04	>1600

Phase II (cont'd)

Effluent Total Nitrogen Concentration			
Date	Effluent Total Nitrogen (mg/L)	Diluted* Mixed Liquor Total Nitrogen (mg/L)	Absolute Mixed Liquor Total Nitrogen (mg/L)
26-Mar-04		87	435
1-Apr-04	71	40	200
10-Apr-04	13	59	295
16-Apr-04	19	65	325
23-Apr-04	18	84	420
27-Apr-04	62	80	400
4-May-04	22	88	440
14-May-04	20	121	605
19-May-04	34	112	560
25-May-04	16	100	500
3-Jun-04	21	116	580
16-Jun-04	96	94	470
17-Jun-04	21	108	540
23-Jun-04	22	153	765
29-Jun-04	17	79	395
7-Jul-04	21	86	430
13-Jul-04	36	83	415
19-Jul-04	83	70	350

* Mixed liquor diluted 5 times (i.e. 4 mL H2O to 1 mL sample)

Effluent Ammonia Concentrations	
Date	Effluent Concentration (mg/L)
26-Mar-04	NA
1-Apr-04	<1
10-Apr-04	<1
16-Apr-04	<1
23-Apr-04	<1
27-Apr-04	<1
4-May-04	<1
14-May-04	<1
19-May-04	2.5
25-May-04	<1
3-Jun-04	1.5
16-Jun-04	<1
17-Jun-04	<1
23-Jun-04	2
29-Jun-04	<1
7-Jul-04	<1
13-Jul-04	6
19-Jul-04	<1

Effluent Nitrate Concentration			
Date	Graph Height	Concentration (mg/L)	
26-Mar-04	NA	NA	
1-Apr-04	88.0	59.85	
10-Apr-04	21.0	8.90	
16-Apr-04	23.0	10.42	
23-Apr-04	29.0	14.98	
27-Apr-04	76.0	50.72	
4-May-04	45.0	27.15	
14-May-04	26.5	13.08	
19-May-04	45.5	27.53	
25-May-04	25.0	11.94	
3-Jun-04	31.0	16.50	
16-Jun-04	81.0	95.42	7 times <-- dilution not 4
17-Jun-04	30.5	16.12	
23-Jun-04	39.5	22.97	
29-Jun-04	23.5	10.80	
7-Jul-04	23.5	10.80	
13-Jul-04	30.0	15.74	
19-Jul-04	108.0	75.06	

*** Samples diluted 4 times (i.e. 3 mL H2O to**

Visual Basic Program Code

```
Option Explicit
 Dim defrm As Long                'Session to Default Resource Manager
 Dim vi As Long                   'Session to instrument
 Dim Temp As Single
 Dim cmnd As String
 Dim TimeControl As Long
 Dim TimeControlFlag As Boolean
 Dim ForRevFlag As Boolean
 Dim Control As Byte
 Dim Switches As Integer
 Dim volts As Single
 Dim FirstOut As Integer
 Dim output As String * 100
 Dim processpumpspeed As Single
 Dim BackwashSpeed As Single
 Dim EffPumpSpeed As Single
 Dim backwashflag As Integer
 Dim backwashtime As Long
 Dim Rdgs(3) As Single
 Dim sludgeflag As Boolean
 Dim sludgepumpflag As Boolean
 Dim TimerButton As Boolean
 Dim ObExcelApp As Object
 Dim ObWorkSheet As Object



 'sets the byte so that the process pump is operated forward

 Private Sub Forward()
   Call viOpenDefaultRM(defrm)
   Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
   Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
   Call viVScanf(vi, Control, 0)
   Control = Control Or 1 'Boolean logic statement on the Control Byte --> xxxx xxxx OR 0000 0001 = 1111 1111 = 255 =
Bit#1 = off = forward
   Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0) 'sends value of control variable to DAS
channel 201

   'Call viClear(vi)  'Clear Device Session
   Call viClear(defrm) 'Clears session "defrm"
 End Sub

'sets the byte to backward process pump

Private Sub Reverse()
   Call viOpenDefaultRM(defrm)
   Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
   Call viVPrintf(vi, "sour:dig:data 254, (@201)" + Chr$(10), 0) ' Statement setting byte to 254 = 1111 1110 = bit#1 = 1 =
reverse
```

```
   'Call viClear(vi)  'Clear Device Session
   'Call viClear(defrm) 'Clears session "defrm"
   Call viClose(defrm)  'Closes Session "defrm"


End Sub


'every click changes the state of the blower.  each case has a unique code to allow for on, off or automatic
'the first case sets bit#4 on the control byte so the blower is on.  This is the default setting.

Private Sub CmdBlower_Click()
    Select Case OptAirBlower.Caption
    Case "Auto"
         Call viOpenDefaultRM(defrm)
         Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
      Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
      Call viVScanf(vi, Control, 0)
      If Control < 240 Then Control = 255
      Control = Control And 247  ' set only bit 3 to a '0'
      Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
      OptAirBlower.Caption = "On"
      OptAirBlower.BackColor = &H60E020

   'Call viClear(vi)  'Clear Device Session
   'Call viClear(defrm) 'Clears session "defrm"
   Call viClose(defrm)  'Closes Session "defrm"

'The case on sets the byte for bit 2 to be 1 which means off.

    Case "On"
      Call viOpenDefaultRM(defrm)
      Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
      Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
      Call viVScanf(vi, Control, 0)
      If Control < 240 Then Control = 255
      Control = Control Or 8  ' set only bit 2 to a '1'
      Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
      OptAirBlower.Caption = "Off"
      OptAirBlower.BackColor = &H6040FF


   ' Call viClear(vi)  'Clear Device Session
   'Call viClear(defrm) 'Clears session "defrm"
   Call viClose(defrm)  'Closes Session "defrm"


 'Case off sets the blower back to auto.

    Case "Off"
          Call viOpenDefaultRM(defrm)
   Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
       Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
       Call viVScanf(vi, Control, 0)
            If Control < 240 Then Control = 255
       Control = Control And 247  ' set only bit 2 to a '0'
```

```
      Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
      OptAirBlower.Caption = "Auto"
      OptAirBlower.BackColor = &HE0B0A0

   ' Call viClear(vi)  'Clear Device Session
   ' Call viClear(defrm) 'Clears session "defrm"
   Call viClose(defrm)  'Closes Session "defrm"

    End Select

End Sub

'performed on exiting the program

Private Sub CmdExit_Click()
  TimeControlFlag = False
   Call viVPrintf(vi, "sour:volt 0.0,(@204)" + Chr$(10), 0)
   Call viVPrintf(vi, "sour:volt 3.75,(@205)" + Chr$(10), 0)
   Call viVPrintf(vi, "sour:dig:data 255, (@201)" + Chr$(10), 0)
   Call viClose(vi)
   Call viClose(defrm)

   End
End Sub

'same as blower operations except performed on a different bit #0 in the control byte.

Private Sub CmdProcessPump_Click()
   Select Case OptProcessPump.Caption
   Case "Auto"

      Call viOpenDefaultRM(defrm)
      Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
      Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
      Call viVScanf(vi, Control, 0)
      OptProcessPump.Caption = "Forward"
      OptProcessPump.BackColor = &HE08020
      OptProcessPump.ForeColor = &H80000014
            If Control < 240 Then Control = 255

      Control = Control Or 1  ' set only bit 0 to a '1'
      Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
      Call viVPrintf(vi, "sour:volt" + Str$(processpumpspeed) + ", (@204)" + Chr$(10), 0) 'sets voltage for process pump

   '   Call viClear(vi)  'Clear Device Session
   'Call viClear(defrm) 'Clears session "defrm"
   Call viClose(defrm)  'Closes Session "defrm"


  Case "Forward"
      Call viOpenDefaultRM(defrm)
      Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
      Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
      Call viVScanf(vi, Control, 0)
      OptProcessPump.Caption = "Reverse"
      OptProcessPump.BackColor = &HA08020
```

```
          If Control < 240 Then Control = 255

      Control = Control And 254  'reset only bit 0 to a '0''Boolean logic statement on the Control Byte --> xxxx xxxx AND 1111 1110 = xxxx xxx0 -->Bit#0 = 0 = forward
      Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0) 'write value in Control variable to DAS system
      Call viVPrintf(vi, "sour:volt" + Str$(BackwashSpeed) + ", (@204)" + Chr$(10), 0) 'sets voltage for process pump

   '   Call viClear(vi)  'Clear Device Session
   'Call viClear(defrm) 'Clears session "defrm"
   Call viClose(defrm)  'Closes Session "defrm"

   Case "Reverse"
      Call viOpenDefaultRM(defrm)
      Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
      Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
      Call viVScanf(vi, Control, 0)
      OptProcessPump.Caption = "Auto"
      OptProcessPump.BackColor = &HE0B0A0
      OptProcessPump.ForeColor = &H80000012
      Control = Control Or 1  ' set only bit 0 to a '1''Boolean logic statement on the Control Byte --> xxxx xxxx OR 0000 0001 = xxxx xxx1 --> Bit#0 = 1 = reverse
      Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
      Call viVPrintf(vi, "sour:volt" + Str$(processpumpspeed) + ", (@204)" + Chr$(10), 0) 'sets voltage for process pump

   '   Call viClear(vi)  'Clear Device Session
   'Call viClear(defrm) 'Clears session "defrm"
   Call viClose(defrm)  'Closes Session "defrm"


   End Select
End Sub

'same as above except on bit #2

Private Sub CmdSludgePump_Click()
   Select Case OptSludgePump.Caption
   Case "Auto"

          If Control < 240 Then Control = 255
      Call viOpenDefaultRM(defrm)
      Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
      Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
      Call viVScanf(vi, Control, 0)
      Control = Control And 251  ' set only bit 2 to a '0'
      Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
      OptSludgePump.Caption = "On"
      OptSludgePump.BackColor = &H60E020

   '    Call viClear(vi)  'Clear Device Session
   'Call viClear(defrm) 'Clears session "defrm"
   Call viClose(defrm)  'Closes Session "defrm"

   Case "On"

          If Control < 240 Then Control = 255
```

```
    Call viOpenDefaultRM(defrm)
    Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
    Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
    Call viVScanf(vi, Control, 0)
    Control = Control Or 4  ' set only bit 2 to a '1'
    Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
    OptSludgePump.Caption = "Off"
    OptSludgePump.BackColor = &H6040FF

  '    Call viClear(vi)  'Clear Device Session
  'Call viClear(defrm) 'Clears session "defrm"
  Call viClose(defrm)  'Closes Session "defrm"

  Case "Off"
    OptSludgePump.Caption = "Auto"
    OptSludgePump.BackColor = &HE0B0A0
  End Select
End Sub

'same as other ops except it is performed on bit #1
Private Sub CmdSolenoid_Click()
  Select Case OptSolenoid.Caption
  Case "Auto"

    If Control < 240 Then Control = 255
    Call viOpenDefaultRM(defrm)
    Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
    Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
    Call viVScanf(vi, Control, 0)
    Control = Control And 253
    Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
    OptSolenoid.Caption = "Open"
    OptSolenoid.BackColor = &H60E020

  '    Call viClear(vi)  'Clear Device Session
  'Call viClear(defrm) 'Clears session "defrm"
  Call viClose(defrm)  'Closes Session "defrm"


  Case "Open"

    If Control < 240 Then Control = 255
    Call viOpenDefaultRM(defrm)
    Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
    Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
    Call viVScanf(vi, Control, 0)
    Control = Control Or 2  '
    Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
    OptSolenoid.Caption = "Closed"
    OptSolenoid.BackColor = &H6040FF

  '    Call viClear(vi)  'Clear Device Session
  'Call viClear(defrm) 'Clears session "defrm"
  Call viClose(defrm)  'Closes Session "defrm"

  Case "Closed"
```

```
        If Control < 240 Then Control = 255
    OptSolenoid.Caption = "Auto"
    OptSolenoid.BackColor = &HE0B0A0
    Call viOpenDefaultRM(defrm)
    Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
    Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
    Call viVScanf(vi, Control, 0)
    Control = Control Or 2  ' set only bit 1 to a '1'
    Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)

  '    Call viClear(vi)  'Clear Device Session
  'Call viClear(defrm) 'Clears session "defrm"
  Call viClose(defrm)  'Closes Session "defrm"

  End Select
End Sub

Private Sub PumpControl()

  Call viOpenDefaultRM(defrm)
  Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)

  Call viVPrintf(vi, "sour:volt 0.0,(@204)" + Chr$(10), 0)
  Call viVPrintf(vi, "sour:dig:data 255, (@201)" + Chr$(10), 0)
  volts = Val(TxtProcessPump.Text) / 4

 '  Call viClear(vi)  'Clear Device Session
  'Call viClear(defrm) 'Clears session "defrm"
  Call viClose(defrm)  'Closes Session "defrm"

End Sub



Private Sub CmdStart_Click()
TimerButton = True
End Sub

Private Sub Form_Initialize()
  Call viOpenDefaultRM(defrm)
  Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)

  Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
  Call viVScanf(vi, "%t", output)

  Call viVPrintf(vi, "sour:volt 0.0,(@204)" + Chr$(10), 0)
  Call viVPrintf(vi, "sour:volt 3.75,(@205)" + Chr$(10), 0)
  Call viVPrintf(vi, "sour:dig:data 255, (@201)" + Chr$(10), 0)
  TimerButton = True
  sludgeflag = False
  sludgepumpflag = False

'     Call viClear(vi)  'Clear Device Session
  'Call viClear(defrm) 'Clears session "defrm" "defrm"
  Call viClose(defrm)  'Closes Session "defrm"
```

```
End Sub



Private Sub timestop_Click()
TimerButton = False
End Sub

Private Sub SensingBackwashTimer_Timer()

    processpumpspeed = Val(TxtProcessPump.Text) * 0.0236 + 0.2161
    BackwashSpeed = Val(TxtBackwash.Text) * 0.023 + 0.2879
    EffPumpSpeed = Val(TxtEffPump.Text) * -0.0099 + 3.75
    controltime.Text = Str(TimeControl)
    bwtime.Text = Str$(backwashtime)

Call viOpenDefaultRM(defrm)
Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)

Call viVPrintf(vi, "sour:volt" + Str$(EffPumpSpeed) + ", (@205)" + Chr$(10), 0) 'sets voltage for effluent pump

'opening Excel and creating a worksheet to save data to


'If ((TimeControl \ 20) * 20) = TimeControl Then
'
'Set ObExcelApp = GetObject(, "Excel.Application")
'ObExcelApp.Workbooks.Add
'Set ObWorkSheet = ObExcelApp.activesheet
'ObWorkSheet.cells(1, 1).Value = "Date and Time"
'ObWorkSheet.cells(1, 2).Value = "Temperature"
'ObWorkSheet.cells(1, 3).Value = "Pressure"
'ObWorkSheet.cells(1, 4).Value = "pH"
'ObWorkSheet.cells(1, 5).Value = "DO"
'
'ObExcelApp.save ("c:\Datatest.xls")
'ObExcelApp.quit
'
'End If





TimeControl = TimeControl + 1
  'If ((TimeControl \ 10) * 10) = TimeControl Then
   '   Call viOpenDefaultRM(defrm)
   '   Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
   '   Call viVPrintf(vi, "Meas:Dig:Byte? (@202)" + Chr$(10), 0)
   '   Call viVScanf(vi, "%t", output)
   '   Switches = Val(output)

      'following instructions scan for values from sensors
```

```
' Call viVPrintf(vi, "meas:Temp? TC,T,(@101)" + Chr$(10), 0)
' Call viVScanf(vi, "%t", output)
' Temp = Val(output)
' TxtTemp.Text = Str$(Temp)

' Call viVPrintf(vi, "Meas:volt:Dc? (@102)" + Chr$(10), 0)
' Call viVScanf(vi, "%t", output)
' Rdgs(0) = Val(output)
' Rdgs(0) = ((Rdgs(0) - 1) * 7.5 - 15) * 101.325 / 14.7
' TxtPressure.Text = Str$(Rdgs(0))

' Call viVPrintf(vi, "Meas:volt:dc? (@103)" + Chr$(10), 0)
' Call viVScanf(vi, "%t", output)
' Rdgs(1) = Val(output)
' Rdgs(1) = (Rdgs(1) - 1) * 14 / 4
' TxtPh.Text = Str$(Rdgs(1))

' Call viVPrintf(vi, "Meas:volt:dc? (@104)" + Chr$(10), 0)
' Call viVScanf(vi, "%t", output)
' Rdgs(2) = Val(output)
' Rdgs(2) = (Rdgs(2) - 1) * 5
' TxtDO.Text = Str$(Rdgs(2))

' If (Switches And 1) = 0 Then
'   OptSludgeHiIP.Caption = "Open"
'   OptSludgeHiIP.BackColor = &H60E020
' Else
'   OptSludgeHiIP.Caption = "Closed"
'   OptSludgeHiIP.BackColor = &H6040FF
' End If

' If (Switches And 2) = 0 Then
'   OptSludgeLoIP.Caption = "Open"
'   OptSludgeLoIP.BackColor = &H60E020
' Else
'   OptSludgeLoIP.Caption = "Closed"
'   OptSludgeLoIP.BackColor = &H6040FF
' End If

' If (Switches And 4) = 0 Then
'   OptEffluentIP.Caption = "Open"
'   OptEffluentIP.BackColor = &H60E020
' Else
'   OptEffluentIP.Caption = "Closed"
'   OptEffluentIP.BackColor = &H6040FF
' End If

' If (Switches And 8) = 0 Then
'   OptReactorIP.Caption = "Open"
'   OptReactorIP.BackColor = &H60E020
' Else
'   OptReactorIP.Caption = "Closed"
'   OptReactorIP.BackColor = &H6040FF
' End If

'' 'Pump control
```

```
    ''' 'If processpumpspeed >= 0# And processpumpspeed < 1.5 Then
     ''' '  Call viVPrintf(vi, "sour:volt " + Str$(processpumpspeed) + ",(@204)" + Chr$(10), 0)
    ''' 'End If
  ' End If



'If TimerButton = False Then Exit Sub





'Initialize step sets the system to forward mode for the first interval
    If backwashflag = 0 Then
     backwashflag = 2
     Call viOpenDefaultRM(defrm)
     Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
     Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
     Call viVScanf(vi, "%t", output)
     If Control < 240 Then Control = 255
     Control = Control Or 1  ' set only bit 0 to a '1"Boolean logic statement on the Control Byte --> xxxx xxxx OR 0000 0001 =
xxxx xxx1 --> Bit#0 = 1 = reverse
     Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
     Call viVPrintf(vi, "sour:volt " + Str$(processpumpspeed) + ",(@204)" + Chr$(10), 0)

 '    Call viClear(vi)  'Clear Device Session
  'Call viClear(defrm) 'Clears session "defrm"
  Call viClose(defrm)  'Closes Session "defrm"

    End If


'The backwash flag has been set to 1, the direction of pump is changed and the speed is set to backwashspeed.
'This series of steps takes place every backwash interval time
    If ((TimeControl \ (Val(TxtBackwashInt) * 60)) * (Val(TxtBackwashInt) * 60)) = TimeControl Then
       backwashtime = 0
       backwashflag = 1
     Call viOpenDefaultRM(defrm)
     Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
     Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
     Call viVScanf(vi, "%t", output)
     Control = Control And 254  ' set only bit 0 to a '1"Boolean logic statement on the Control Byte --> xxxx xxxx OR 0000
0001 = xxxx xxx1 --> Bit#0 = 1 = reverse
     Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
     Call viVPrintf(vi, "sour:volt " + Str$(BackwashSpeed) + ",(@204)" + Chr$(10), 0)

 '    Call viClear(vi)  'Clear Device Session
  'Call viClear(defrm) 'Clears session "defrm"
  Call viClose(defrm)  'Closes Session "defrm"

'This checks to see whether the backwash flag is set to 1 and if so it performs the backwash for the specified
'duration.  It increments backwashtime until it reaches the value specified then it sets the flag to 2 and we
'start all over again.
    End If
```

```
    If backwashflag = 1 Then
      backwashtime = backwashtime + 1
      If backwashtime = Val(TxtBackwashDuration.Text) Then
         backwashflag = 2
         Call viOpenDefaultRM(defrm)
         Call viOpen(defrm, "GPIB0::9::INSTR", 0, 0, vi)
         Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
         Call viVScanf(vi, "%t", output)
         Control = Control Or 1  ' set only bit 0 to a '1"Boolean logic statement on the Control Byte --> xxxx xxxx OR 0000 0001
= xxxx xxx1 --> Bit#0 = 1 = reverse
         Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
         Call viVPrintf(vi, "sour:volt " + Str$(processpumpspeed) + ",(@204)" + Chr$(10), 0)

 '        Call viClear(vi)  'Clear Device Session
   'Call viClear(defrm) 'Clears session "defrm"
   Call viClose(defrm)  'Closes Session "defrm"

      End If
    End If


'This code controls the automatic sludge wasting.  The code checks to see whether the time interval
'and the level sensors have been satisfied.  The sequence of operation is as follows:
'   1.  The time sludgewaste time interval must occur before the operation is activated
'   2.  Once the time is true, the solenoid valve opens
'   3.  The solenoid valve runs until the sludge high level sensor is closed
'   4.  The pump turns on when the solenoid valve is closed
'   5.  The pump turns off when the sludge low level sensor is open.


    '  If ((TimeControl \ (Val(TxtSludgeWaste.Text) * 60)) * (Val(TxtSludgeWaste.Text) * 60)) = TimeControl Then
    '    sludgeflag = True
    '  End If
    '
    '  If sludgeflag = True Then
    '
    '       'open solenoid
    '
    '       Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
    '       Call viVScanf(vi, Control, 0)
    '       Control = Control And 253
    '       Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
    '       OptSolenoid.Caption = "Open"
    '       OptSolenoid.BackColor = &H60E020
    '
    '       'close solenoid
    '       If OptSludgeHiIP.Caption = "Closed" Then
    '           Call viVScanf(vi, Control, 0)
    '           Control = Control Or 2  '
    '           Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
    '           OptSolenoid.Caption = "Closed"
    '           OptSolenoid.BackColor = &H6040FF
    '           sludgeflag = False
    '           sludgepumpflag = True
    '       End If
    '    End If
```

```
    '
    '    If sludgepumpflag = True Then
    '
    '           'Turn on Pump
    '           Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
    '           Call viVScanf(vi, Control, 0)
    '           Control = Control And 251  ' set only bit 2 to a '0'
    '           Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
    '           OptSludgePump.Caption = "On"
    '           OptSludgePump.BackColor = &H60E020
    '
    '           'Turn off pump
    '           If (Switches And 2) = 0 Then
    '              OptSludgeLoIP.Caption = "Open"
    '              OptSludgeLoIP.BackColor = &H60E020
    '              Call viVPrintf(vi, "sour:dig:data:BYTE? (@201)" + Chr$(10), 0)
    '              Call viVScanf(vi, Control, 0)
    '              Control = Control Or 4  ' set only bit 2 to a '1'
    '              Call viVPrintf(vi, "sour:dig:data:BYTE " + Str$(Control) + ", (@201)" + Chr$(10), 0)
    '              OptSludgePump.Caption = "Off"
    '              OptSludgePump.BackColor = &H6040FF
    '              sludgeflag = False
    '
    '           End If
    '
    '     End If
    '

If TimerButton = False Then

Call viVPrintf(vi, "sour:volt " + Str$(EffPumpSpeed) + ",(@204)" + Chr$(10), 0)
Call viVPrintf(vi, "sour:volt " + Str$(processpumpspeed) + ",(@205)" + Chr$(10), 0)

'Call viClear(vi)  'Clear Device Session
   'Call viClear(defrm) 'Clears session "defrm"
   Call viClose(defrm)  'Closes Session "defrm"

End If



     'Pump control

       'If processpumpspeed >= 0# And processpumpspeed < 1.5 Then
        '  Call viVPrintf(vi, "sour:volt " + Str$(processpumpspeed) + ",(@204)" + Chr$(10), 0)
       'End If



End Sub
```