Membrane Biofilm Analysis Testbed

ME 450: Team 12

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ABSTRACT

The problems of domestic wastewater "sewage" treatment and the need to remove stress from freshwater resources are ubiquitous and fundamental to freshwater sustainability. Our sponsors are developing a test rig to explore the idea of using an Anaerobic Membrane Bioreactor (AnMBR) system as a solution. Our project is to design and build a membrane biofilm analysis testbed to allow for the analysis of membrane fouling and the biofilm formation. Success of this project will assist in research towards an AnMBR system for water purification.

EXECUTIVE SUMMARY

An Anaerobic Membrane Bioreactor (AnMBR) system can be used in the purification process of domestic wastewater sewage treatment. However, there are still many unknowns in this process and ongoing research is needed to better understand the integration of the anaerobic microbial treatment process, the stresses on the membrane, as well as resulting formation of the biofilm. Our goal is to aid in this research by creating a Membrane Biofilm Analysis Testbed, MBAT, to better understand the membrane fouling and the biofilm that forms as a result.

The development for this was done in multiple phases. The first phase was to establish engineering specifications that were determined by analyzing the requirements of our sponsors, Professor Skerlos, and PhD student, Kate Adams. Once these specifications were determined and fine tuned, a functional decomposition was developed consisting of several functions and sub functions that our system needed to perform. These were organized together for concept generation, and then to a final design.

Five main ideas that were focused on in creating our Final Design were the ability to securely house the membrane, allow for varying pressure differentials across the membrane, measure and record the required parameters, incorporate membrane cleaning methods, and be easy to operate via a combined interface. Our final design incorporated the best aspects of our concept generation process and meets the requirements outlined by the engineering specifications.

Our Final Design consists of: the membrane housing that is currently used in the AnMBR system (with attached sparging system), an inlet pump and a peristaltic pump connected to a series of pipes, and a LabVIEW setup. The use of the original membrane housing was decided for easy transfer of the membranes from the AnMBR system to the MBAT. A sparging system is already incorporated so the technician/researcher would simply be required to install the original membrane housing to begin testing. The flow system will be able to provide negative pressure as well as backflushing capabilities. A LabVIEW setup along with digital transducers is incorporated for a “one-stop” solution for data measurement and processing.

We have completed fabrication of our design. We have also completed testing of the MBAT for water and air tightness and flow validation and determined that our system is both air and water tight and is able to accommodate fluid flow. We were unable to complete testing of the LabView setup before the deadline. Our critiques of the design are focused on the overall design process with a section on the selection of a thicker head plate material to avoid warping during welding, and accuracy with regards to hand machining to avoid misaligned connections.

There is still some work to be done on the system. We have provided recommendations on how to complete tasks that we began but were unable to complete. Upon completion of these few tasks, the MBAT system will be complete and analysis of biofilm growth and its effects on membrane filtration may begin.

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PROBLEM STATEMENT

Sustainability of our freshwater resources is a global concern. There is currently a proposal for an Anaerobic Membrane Bioreactor system that is being researched that would help the treatment of our freshwater resources. This system works via an anaerobic microbial treatment that features removal of suspended solids and oxygen demanding wastes while an integrated membrane system removes pathogens and retains the anaerobic microbes so they do not enter the effluent water. Anaerobic digestion has been used for decades, but their integration with a membrane system is still unclear. Our sponsors have created this Anaerobic Membrane Bioreactor (AnMBR) system but it does not currently allow observation of membrane fouling or have the ability to analyze the biofilm and the effects of different flow types. Our project is to design a membrane biofilm analysis testbed to allow for the analysis of membrane fouling and the biofilm that forms as a result. This analysis includes measuring the pressure difference across the membranes, and measuring the flow rates before and after the membranes.

NOMENCLATURE

Term	Definition
Aerobic	With oxygen
Anaerobic	Without oxygen
Auto-claving	Process of sterilization by introducing heat into system
Backflushing	Reversing flow of fluid through a given substance
Biofilm	Thin resistant layer of microorganisms that form on various surfaces
Effluent	Flowing out
HRT	Hydraulic retention time; time for microbes interact with system
Membrane	Material which serves as a selective barrier
Sparging	To spray; introduce air or gas into a liquid

INFORMATION

Our preliminary task was to understand the working of the existing reactor and determine what, if any, previous work has been conducted in order to understand the formation and effect of biofilms on a membrane. We then conducted research to determine alternative methods of membrane cleaning and also attempted to do some competitive benchmarking in order to find if test beds have been built for similar purposes. We accomplished this task in several ways, the most important of which were our meetings with our sponsor Dr. Steven Skerlos and Mrs. Katrina Adams, a PhD student, who would also be using the reactor for research purposes. These meetings helped clarify and increase our understanding of the system and they also helped us finalize the various requirements from our project that would prove beneficial to the research.

Sponsor Resources

Initially, to help us to understand the working of the AnMBR system and its overall goals, our team utilized the resources provided by our sponsor related to this project. The first of which was the Funding Proposal that was submitted in 2008 to the Water Environment Research Foundation which laid down the details of the AnMBR and what the sponsor's research team expected to achieve using the device. The proposal was useful in providing us with information about the motivation behind creating the AnMBR. The proposal also proved invaluable to our overall literary search as it included an extensive set of external references that we could use to understand the system better.

Our sponsor also provided reports detailing the work done by student design teams prior to our own. The work done by team 21 during the fall semester of 2006 was beneficial to us as they had conducted a benchmarking comparison of both lab scale and industrial AnMBRs and this was helpful in understanding the real world applicability of the process. The work done by YingYi Lim for ME490 in the winter semester of 2009 was also extremely useful as it provided us with detailed information about several aspects of the existing lab setup. This information included a schematic of the existing membrane housing, an explanation and a visual description of the biofilm formation on a membrane and a detailed method to implement gas sparging to clean the membrane.

To supplement the information provided by our sponsor, our team conducted an extensive search of various literary sources in order to determine several pieces of information. The main goals of our search were to further understand the process of an AnMBR, the process of membrane fouling and to find alternative membrane cleaning methods and benchmark similar test stands. Our literature searches were guided in part by the extensive list of references that we obtained from the resources provided by our sponsor.

Patent Search

One of our major resources was results found from searching for patents for processes or test stands that were similar to the AnMBR and/or needed to perform similar functions to our test bed. After an extensive search we found the following patents that provided us with useful information for our project. The first page of these patents can be found in Appendices F-J.

US'262 and US'524 Patents: An analysis of these two patents relating to the treatment of water proved beneficial toward understanding the motivation behind the need to study biofilms and determine their effects on membrane performance and on the filtration process. Both of these patents dealt with water treatment apparatus that relied on biofilms for the filtration process rather than a membrane. The most important information gathered from these sources was that the biofilms can act as effective filters and that further study was required in order to achieve an optimum biofilm level that would achieve a good tradeoff between flow rate performance and water treatment.

US'790 Patent: This patent deals entirely with the filtration using a membrane and a way to continuously monitor membrane fouling. This includes ways to observe the streaming potential difference across the pores, the pressure differential on either side of the membrane and a difference in concentration of the contents in the feed and the filtered permeate in the membrane.

This patent is extremely useful to our team as there are several similarities between what was accomplished here and what we need to achieve with respect to data measurement.

US’401 and US’083 Patents: Both of these patents dealt with methods for controlling membrane fouling. The first patent deals with controlling membrane fouling by increasing the pressure differential across the surface of the membrane and includes various measurements that are performed to analyze this pressure. The second patent describes an air scouring process to clean the membrane that dynamically varies the scouring as a function of the membrane pressure differential. Both of these patents helped our team look at alternative methods for membrane cleaning that we had not considered.

Literary Search

Our literary searches provided us with extensive information that we could use to both further our understanding of the concepts involved and to find ways to achieve the various requirements from our project. These searches were performed using online journal databases and search engines such as Google Scholar and were done for a range of topics that concerned our project

Membrane Fouling and Biofilms: Our research led us to verify the claim that membrane fouling is a major issue in an anaerobic membrane bioreactor. The fouling of the membrane usually involves the formation of biofilm which is essentially a layer of microbes that are growing on the membrane surface. This builds up over time thus affecting the performance of the membrane. We were able to obtain information about the biofilm composition [1] and also about real world situations where biofilms affected the system performance such as treatment of municipal waste water [2]. Our research into biofilms led us to a few interesting results. One research paper concentrated on debunking the need for a membrane by claiming that the biofilm itself was sufficient for the filtration process and the only thing that was needed was a framework for the biofilm to grow on [3]. To some extent this served as added evidence to the researchers’ idea that biofilms are beneficial to the filtration process.

Membrane Cleaning: There were several research papers that suggested methods for cleaning a fouled membrane. One interesting suggestion was the use of a spring-damper system that would be connected to the membrane mount in order to make the membrane vibrate. The vibrating membrane was found to effectively retard biofilm growth and keep the membrane clean over the course of operation [4].

PROJECT REQUIREMENTS

In order to create our engineering specification we first had to meet with key stakeholders in the project to determine their needs and wants. We then refined these requirements into detailed engineering quantities. The customer requirements were grouped into three categories: operating conditions, experimental capability, and ease of use. These customer requirements were a major input into the development of the Engineering Specifications table and our engineering specifications.

Analysis of Customer Requirements

After reviewing the project description and relevant literature sources we created a list of issues around the membrane testing system that needed to be addressed. Upon meeting with our primary sponsors we made the following refinements to the original customer requirements:

- System should enable study of the effects of biofilm growth on membrane performance.
- House Membrane/Hold Membrane Housing: System should hold the membrane or hold a system used to house the membrane.
- System should maintain anaerobic operating conditions with the option for allowing for aerobic operation
- Fluid flow should be contained within the system and should be able to be controlled during operation.
- Operating parameters (temperature, trans-membrane pressure flow-rate) will need to be controlled during operation. It is desired that these operating parameters be recorded as well.
- There should be a system for data handling that allows the user to interface with the system
- Some of the system will use existing equipment and configurations in place. We should be able to incorporate current testing equipment into our design.
- The system must have the ability to self clean (backflushing, sparging, auto-claving, etc.)
- The system should be designed with the focus of lab testing in mind. Considerations should be made for in lab performance with regard to durability, safety, repeatability, precision and accuracy of experiments.

ENGINEERING SPECIFICATIONS

We created our engineering specifications by basing them off our customer requirements listed above. Table 1 on the next page displays our engineering specifications. As you can see below, each requirement has been quantified into a target engineering specification that our design will seek to incorporate.

Table 1: Engineering Specifications

Category	Customer	Specifications	Units	Target
Operating Conditions	Control operating temperature	Minimum operating temperature	°C	10°C
	Withstand operating pressure	Maximum pressure	psi	5
	Temperature variance should be low during operation	Temperature variation during operation	°C	± 3°C
	Membrane should be held securely during operation	No vertical/horizontal movement of membrane	Yes/No	Yes
	Should operate aerobically and anaerobically	Anaerobic operation	Yes/No	Both
Experimental Capability	Should allow for membrane cleaning methods	Back flushing	Yes/No	Yes
		Ability to Gas Sparge	Yes/No	Yes
		Variable flow rate while sparging	Yes/No	Yes
		Ability to Auto-Clave at 150°C	Yes/No	Yes
	Should accommodate adequate flow rates	Flow rate through system	mL/min	3.5
	System should filter water adequately	Effective membrane area	in^2	60
		# of membranes accommodated		2
		Membrane size supported (flat sheet)	in^2	15
	Would like ability to investigate pressure direction effects	Ability to apply positive and negative pressure	Yes/No	Yes
	System should operate for duration of experiment	Operating duration	Weeks	4
Measurement Capability	System should be able to measure/record relevant Parameters during operation	Ability to measure trans-membrane pressure	Yes/No	Yes
		Ability to measure flow rate constantly	Yes/No	Yes
		Ability to record data	Yes/No	Yes
		Interface with user	Yes/No	Yes
		Ability to measure differential/system temp	Yes/No	Yes
Ease of Use	System should be easy to control tests and read data	Unified One Stop Control + ReadOut Interface	Yes/No	Yes

		Quick membrane transfer		<3min
Budget Limits	Cost of system should be within $1000	Maximum Budget	$	1000*

*This was the value of the first maximum budget for the project as expressed by Professor Skerlos. However, it was found that a single peristaltic pump that would be adequate for our needs was approximately $2000. Due to this, our monetary constraint relies on Professor Skerlos and each part will be carefully considered during our meetings to prevent unnecessary purchases.

CONCEPT GENERATION

Concept generation was performed in a multi-step process. First, our customer/sponsor requirements were translated into detailed design specifications. These specifications were then translated into functions and sub functions that our system needed to provide. This break down of functions established a functional decomposition table as seen in Appendix E.

Function Level

After the functional decomposition was established, we generated concept ideas to achieve each of the sub functions. These concepts were then analyzed and compared in order to determine their positive and negative aspects. The best aspects of these concepts were combined together as a final concept for the sub function. This process was repeated for each sub function and the final concepts for the sub functions were then integrated as a whole to satisfy the overarching function while ensuring that no two concepts were in conflict.

Membrane Housing: The membrane housing was required to achieve three different aspects determined after consulting with our sponsors. First, it needed to incorporate the same functions as the membrane housing used in the AnMBR which was primarily to hold two membranes securely with an internal wireframe for the membranes to rest on for stress relief. Also, the membrane housing needed to incorporate an internal tube for the filtered permeate to leave the system via an effluent pipe. Another requirement was that the membrane housing needed to enable the membrane to be transferred from the bioreactor to the test bed in a short amount of time with a minimal tool requirement in order to preserve the biofilm layer. The last requirement was the membrane housing should be made of a material that could withstand extended periods of submersion and be a water tight external frame so that the membrane was the only location for water to flow through the system.

We considered several concepts for housing the membrane, one of which is described below in Figure 1. This concept had its share of positive and negative aspects and eventually was not considered for the alpha prototype. It was found to hold the membrane securely as desired but the concept failed an important requirement that indicated that minimum testing requirement was for two membranes as this only allowed for testing of one. Our analysis of the various design considered for this function led us to consider the possibility of using the existing membrane housing as it met all the requirements.

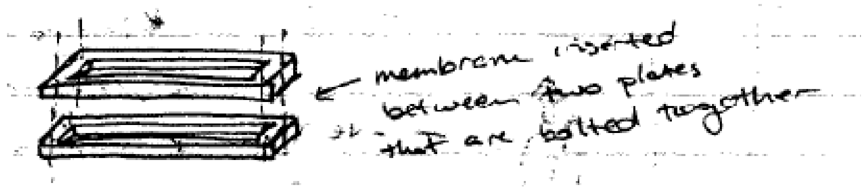


Figure 1: Concept Generation for Membrane Housing

Containment of Membrane Housing: Once we had a few ideas for the membrane housing, the next logical step was to determine how this would be held in place in the reactor during testing. This aspect of the design was required to securely mount the membrane housing while also allowing for quick mounting and dismounting of the housing. The other requirement of the quick mounting was that the connection to the effluent pipe be easy and quick as well. Lastly, this housing mount had to play a major role in maintaining submersion of the membrane housing for the duration of testing thus the material needed to be able to withstand extensive periods of submersion and be corrosion resistant as well.

Several concepts were generated to achieve this function and of these the following design was particularly significant as it had an impact on the design of our alpha prototype because of its many positive aspects. The design, seen in Figure 2 below, was basically a frame that allowed the membrane to be slid into it. The unique aspect of this frame was that it included a sparging system incorporated into the membrane housing holder. This is extremely useful as this would have the sparging system permanently incorporated into the frame. This in turn would mean that the mounting of the membrane housing could be achieved easily and quickly in two steps – connect the effluent pipe and mount the membrane.

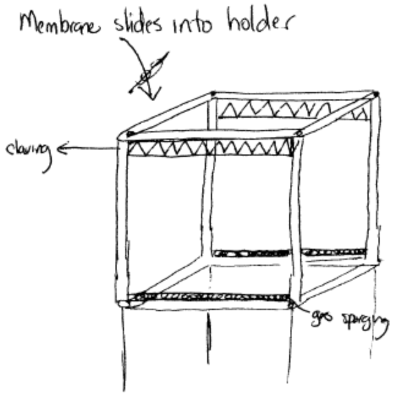


Figure 2: Concept Generation for Containment of Membrane Housing

Fluid Flow Containment: One of the most important requirements of our system was that it be both watertight and airtight in order to maintain anaerobic operation conditions. This requirement was established based on discussions with our sponsors who indicated that the majority of operation would occur in the absence of oxygen. Also, the domestic wastewater (DWW) flowing through the system could be deemed hazardous due to its composition that includes chlorides and sulfates (see Appendix G for composition of DWW). Several concepts were considered for the containment of the overall system including the use of a fish tank as the main container. We rejected this as a possibility due to the brittle nature of the fish tank material and finally determined that the system needed to be manufactured from a material that was corrosion resistant, water tight, able to withstand the operating pressure ranges of up to 5 psi, while at the same time, being easy to clean.

The containment required from the system also meant that the pipe connections had to be secured in order to prevent any leakage. The concepts considered for achieving secure pipe connections include having a screw on pipe connection system, a set of fixed pipes that would not be removed or reconnected during the operating duration and quick connects. For containment, the system enclosure lid also needed to incorporate aspects to provide an effective seal. Our team considered O-rings around the enclosure lid and having a fixed lid with just a small pull out segment for mounting the membrane housing that could be sealed.

Our sponsors also informed us that they would require the capability to test the system in aerobic conditions as well and this meant exposing the system to oxygen. In order to achieve this we considered having a sort of aeration tube entering the system. When aerobic operation is required, it could be used to send air into the system or send nitrogen into the system if anaerobic operation was needed instead. This method was established to be unnecessary for our needs. We also considered having a vent that can be opened and closed depending on the type of operation required but this led us to consider issues regarding creating new seals for this vent. Our last option that we considered was to simply have our hinged system lid act as one large ventilation system that could be sealed when operating anaerobically and left unsealed when aerobic operation was required.

Fluid Flow Control: Through extensive conversations with our sponsors, it was determined that the system required both positive and negative pressure as well as backflushing capabilities to displace the water through the membrane. We brainstormed various methods of achieving this level of control over the fluid flow paths. One of the concepts that we considered was to have quick connects on the pipe connections that could be switched around when the flow direction needed to be changed. We understood that this was not a good solution as this would seriously affect the integrity of the system with respect to containment and we believed that having multiple removable connections increased the chances of failure and thus containment breach. The other option that we considered was the use of a reversible pump to simplify backflushing but this would prove disadvantageous since it would not help us achieve the variation in the pressure gradient across the membrane.

One of our better design concepts included the reversible pump combined with a system of directional valves and piping that would redirect the flow along the specified fluid path. A diagram of the design concept for this solution is seen in Figure 3 and was found to be a great solution since it would only require the use of one pump via a system of pipes and 3-position valves. This subsystem increases the ease-of-use for the technician while still achieving the necessary capabilities.

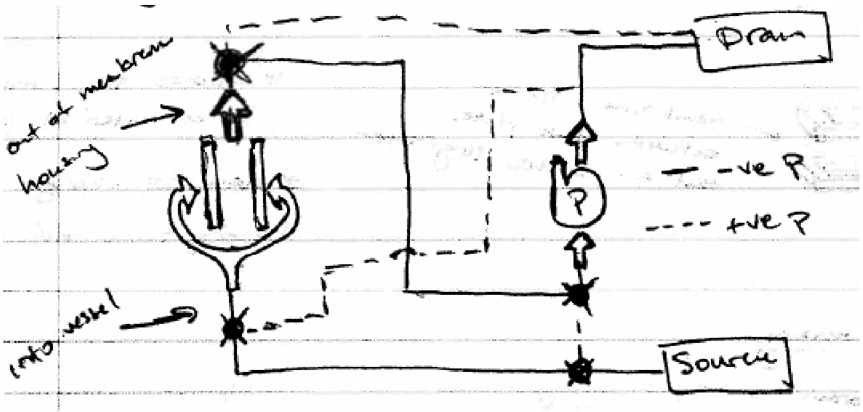


Figure 3: Concept Generation to Control Fluid Flow

Control Operating Conditions: The sensitivity to operating conditions of the processes involved in testing biofilms implied that there had to be an accurate and effective method of controlling these connections and maintaining them. Maintaining a constant system temperature and constant system pressure was the first important aspect in the design considerations. The second important factor to consider was the hydraulic retention time (HRT) selected for the process. A longer retention time implies that the anaerobic bacteria have a longer duration to clean the wastewater and a critical output of that cleaning process is heat. Thus, the greater the HRT, the greater the heat that is generated and our temperature control needs to adapt to this varying HRT and maintain the operating temperature accordingly.

Two major concepts were discussed to achieve this. The first was the idea of simply placing the entire system into a refrigerator as it would keep a constant temperature throughout the entire system. However, using a refrigerator would limit the ability to view the system under testing conditions and we are yet to evaluate the accuracy of a refrigerator in maintaining a desired temperature. A second concept to address the problem was a system that would use a radiator type cooling system to cool the water inside the vessel via a heat exchanging process. This is shown below in Figure 4 but we believe that this concept would pose other problems. The installation of the radiator system would prove to be difficult. Maintaining a contained heat exchanger flow would also prove to be difficult and would give the system a greater chance of failure. Depending on the HRT, the radiator cooling system may not be able to keep the required constant temperature throughout the process. Also, incorporating the radiator into the system would drastically increase our costs and manufacturing requirements and require us to conduct further research into effective coolants and containment methods for this system as well.

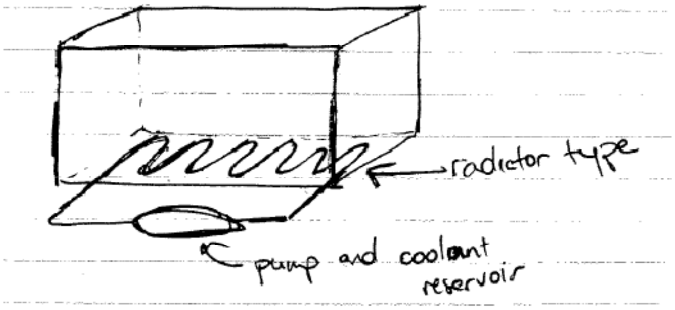


Figure 4: Concept Generation to Control System Temperature

Incorporates Membrane Cleaning Methods: Another important aspect of the design was to incorporate various ways to control the growth of the biofilm and clean the membrane surface. Specifically, sparging was the most important cleaning method that needed to be incorporated as this was being used in the current reactor in a periodic operating mode to successfully maintain the membrane performance. We considered two possibilities to integrate sparging into the system, the first being to use the existing sparging system and just mount the sparging tube in a method similar to that used in the AnMBR. The second option we considered was to integrate the sparging apparatus into the membrane housing frame in order to make the process of mounting the membrane housing quicker and hassle free.

One of our requirements also indicated that backflushing was a desired process and we considered two ways to incorporate this. The first method involved the use of a reversible pump to simply reverse the direction of the fluid flow to accomplish backflushing while the second method involved using the previously discussed valve system to redirect the flow in the reverse direction thus requiring the use of an existing unidirectional pump. We also considered incorporating other membrane cleaning methods into our system such as sonication and the use of a vibrating membrane. Both of these have been proven to work in effectively keeping the membrane biofilm free [4].

Other Aspects: There were several other aspects that needed to be incorporated into our system. One of the most important was for a way to measure various conditions such as pressure differential at the membrane surface and the temperature of the reactor. Through our discussions with our sponsors we determined that while this measurement was possible through manual gauges they did not satisfy the requirement that this data needed to be recorded as well. In order to incorporate adequate data recording functions we decided to go with digital transducers for the measurements purposes so that these could be hooked up to a DAQ and recorded on a computer system.

The other aspect that needed to be incorporated was a way to process the measured/stored data and display meaningful results such as plots that indicate the change in flow rate over time and a calculation of the membrane resistance using the flow rate and pressure differential across the membrane. We determined that this could best be achieved using a LabVIEW interface that could be used to both record the data and process it in order display the information. The LabVIEW interface could also serve as a “one-stop” solution for the entire system. Through this, the system operation can be controlled while storing the measured data over time and processing the data and displaying it as required.

System Level

Once the function level concepts were generated these were then combined together again to generate system level concepts. Again, conflicts among different conceptual solutions were anticipated and accounted for so that the system integration was smooth. Our system level solutions were then discussed in detail and the positive and negative aspects of each one were identified. The positive aspects of multiple solutions were then combined and this was the source of our alpha prototype. This section lists some of our combined subsystem concepts as well as the complete system concepts that led to our alpha prototype.

Combined Subsystem Concept #1: The first design concept that was generated was one which incorporated the system where the membrane housing would only secure one membrane between two plates. This membrane housing would then be contained in a frame that would be attached to a funnel system that would completely cover the membrane and the water would flow to the drain. This housing attachment would then be placed inside a vessel with a source pipe coming into the vessel and a drain pipe going out. The housing attachment would already be installed inside the vessel so the technician would only have to simply place the membrane housing into the system to begin testing. Figure 5 shows a sketch of this concept generation.

This first design concept had some good ideas within the overall system. The idea of simply placing the membrane housing into a system that was ready for testing was an important factor for the ease-of-use for the technician. Also, the source and drain pipes connected directly to the vessel allowed for complete submersion of the system at all times. The vessel would be airtight and watertight by using o-rings to secure the seal. These were important ideas that aided in the final concept generation of the alpha concept.

Although the first design concept had good ideas within the system itself but also many problems. The first problem is that the membrane would have to be taken out of the original membrane housing from the bioreactor and placed carefully in the new membrane housing. This would expose the membrane to the atmosphere for a longer period of time and could potentially jeopardize the entire experiment itself. Furthermore, the proposed membrane housing could only test one membrane at a time, although there is the possibility of running two membrane housings in parallel to solve this problem. However, the long exposure to the atmosphere trumps all other problems and thus, this solution was not used.

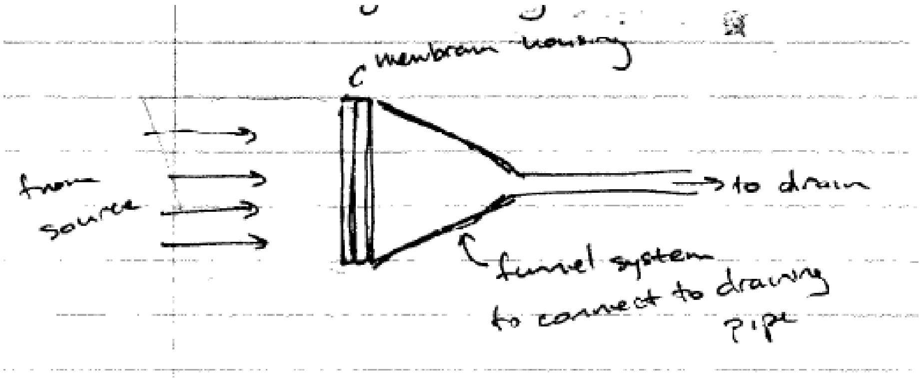


Figure 5: Concept Generation of Funnel System to Effluent Pipe

Combined Subsystem Concept #2: This concept for a membrane housing holder within the system secures the membrane housing from shifting during operation. The holder will be mounted on the vessel which will allow the technician to easily insert and remove the system for use. This holder system is compatible with the current membrane design. Membrane cleaning methods such as sparging can be integrated with the holder system instead of being attached to the membrane housing itself. With this concept the technician will be able to remove the housing from the reactor and directly insert and secure the housing into the holder for experimentation. Challenges associated with this concept are primarily associated with material selection of the holder and determining the least invasive method of attaching the holder to the vessel. Figure 2 on page 9 shows this.

Complete System Concept #1: One of our preliminary concepts for the entire system was developed with compatibility as quick transfer of the membrane housing as the core design goal. The underlying idea behind this was that the test stand and the bioreactor shared several functions and flow paths and thus to minimize costs it could be possible to use the same set up to perform the test functions in the test stand. To achieve this, a design was formulated where the test stand was a vessel that was identical to the reactor vessel so that the existing head plate/lid of the reactor could be transferred over to the test bed. Once the transfer was complete, the only operation necessary would be a minor reconfiguration of the pipe systems to achieve some of the test bed functions. Figure 6 shows this design concept.

This concept had its share of positive and negative aspects. The concept definitely satisfied the requirement of a quick transfer of the membrane from the reactor to the test bed. A compatible design such as this enabled the system to be ready for testing very quickly and increased the ease-of-use overall. Also, using a similar set up to the existing reactor would mean that costs were kept low since the entire head plate did not be remanufactured for the sake of the test stand and existing pumps and pipe connections could be directly used to achieve the test bed goals.

On the downside, the concept would have proven to be inefficient overall. Using the same head plate for both the reactor and the test bed would mean that only one could be used at any particular time and this would be detrimental to the researchers who would need to provide results in a timely manner. Another major issue with the design is that the existing system has no way to measure the required data such as pressure differential and this is a major requirement that isn't met. Another issue with this design is that the existing system does not have the capability for backflushing which is one of our requirements and it would require extensive reconfiguration of the pipe system to achieve this and the other flow control requirements.

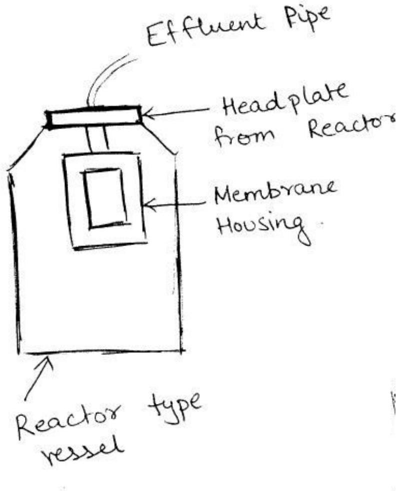


Figure 6: Concept Generation of Concept #3

ALPHA DESIGN

After developing concepts at both the system and the functional level, we selected the best aspects of each concept to incorporate them into our final design being sure to ensure compatibility of each of the individual functions during the process. Our Alpha Design is shown in Figure 7 below. It integrates the best ideas from our design concepts in a functional manner that satisfies all the customer requirements delineated in Appendix E.

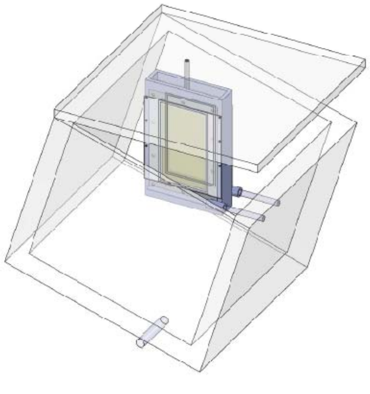


Figure 7: Alpha Prototype

Membrane Housing: Our membrane housing successfully prohibits the membrane from shifting during operation. The membrane fits between a metal plate and the larger rectangular section as shown in Figure 8. The plate will be secured onto the membrane using screws and the membrane will be secured in place between the two components.

Figure 8: Membrane Housing

Containment of Membrane Housing: The membrane housing will be placed into the opening of the housing holder and will be secured from horizontal and vertical movement by a series of notches that will slide over the front of the membrane once it is secured in place. Depending on the type of material selected for the housing holder it will be welded to the top of the vessel or secured used screws. An exploded view is shown below in Figure 9.

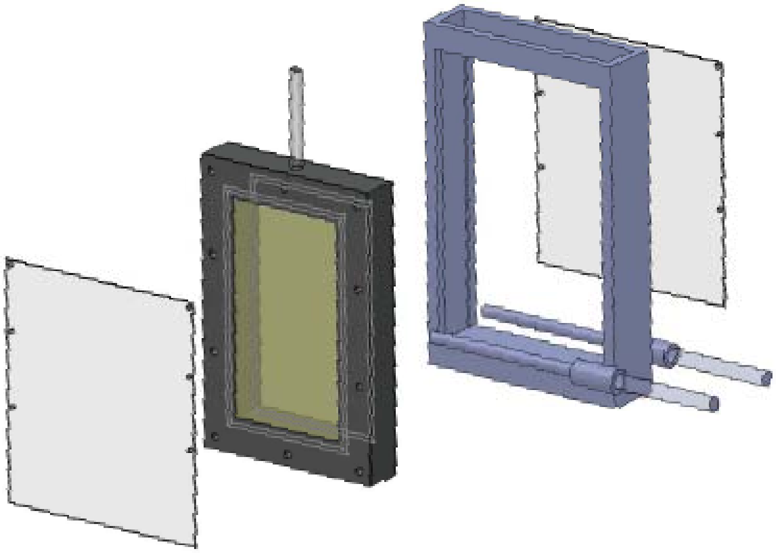


Figure 9: Membrane System Assembly

Fluid Flow Containment and Control: The main aspects contributing to the containment and control of our system are the test bed container shown in Figure 8 and the System Flow Diagram in Figure 10. The container itself will house the membrane system assembly. Filtration will take place inside the test bed container. We will ensure that this vessel is both air and water tight by integrating o-rings during assembly of the vessel and also by testing the vessel for air and water tightness under pressures relevant to operation.

We will control the fluid flow using our flow system. This system will transport fluid between the MBAT and the drain and the source respectively. This system incorporates one bi-directional pump and a series of valve connections. These valve connections will allow us to apply both positive and negative pressure to the MBAT system by moving the valves to flow along the path shown by the solid (negative pressure) and dashed (positive pressure) lines. The pumps being considered will be similar to the peristaltic pumps used in the existing AnMBR system. Our sponsors informed us that great thought had been put into selection of these pumps and the motivations for use in the AnMBR matched those of the MBAT. The peristaltic pump has the advantage of providing accurate and precise flows while preventing direct contact of the pump motor with corrosive material. The valves used will be three way solenoid valves that can be controlled via electrical inputs.

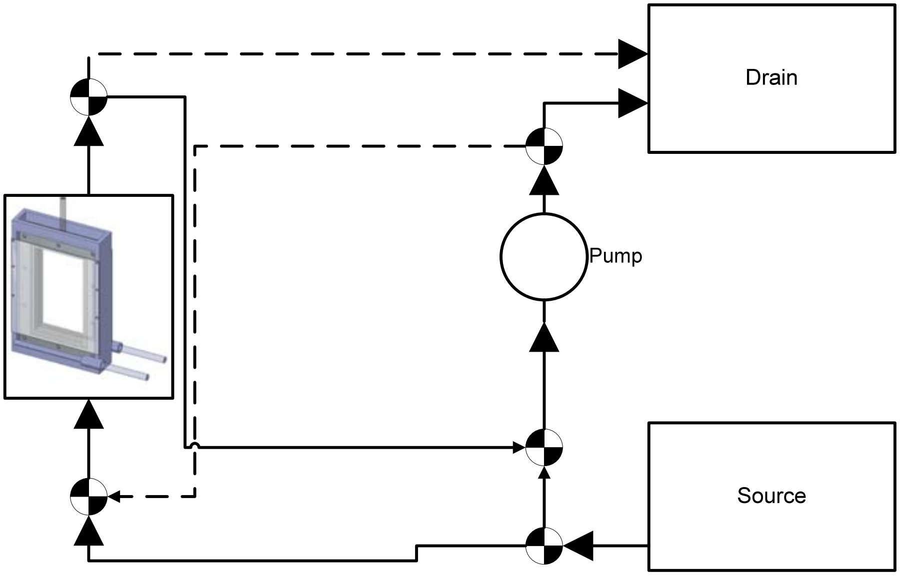


Figure 10: System Flow Diagram

Control Operating Conditions: We will control the pressure within the system by controlling the flow rate to limit the amount of fluid in the system at one time.

To achieve our target control from a temperature aspect of operation around 15°C with a variation of no greater than ±3℃ we plan to use a dorm size refrigerator. Our entire system will fit inside the refrigerator during operation. The refrigerator will allow the system to maintain a constant system temperature without constant interaction from the operator.

To control the level of oxygen in the system we will integrate a ventilation system on the test bed container that will be able to be adjusted depending on whether aerobic or anaerobic operation is desired.

Incorporate Membrane Cleaning Methods: Sparging will be incorporated into our system via two sparging tubes attached to each face of the membrane housing holder. Figure 11 shows the two sparging tubes as they will be attached at the bottom of the housing holder. A thin plate will be placed at the top of each side of the housing holder to direct the flow of the sparging gas vertically across the membrane. Our valve system in Figure 10 is constructed in such a way that back flushing can be performed during application of negative pressure by reversing the pump direction.

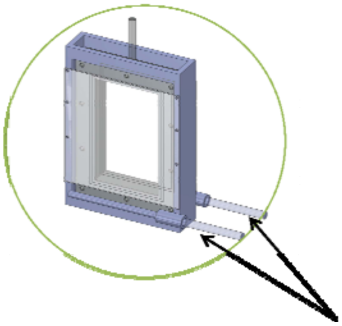


Figure 11: Sparging System (Arrows point to Sparging Tubes)

Measure Operating Parameters: We will use digital transducers to take measurements of operating conditions at varying points throughout the system. This data will be recorded via a DAQ system and will be integrated into our user interface.

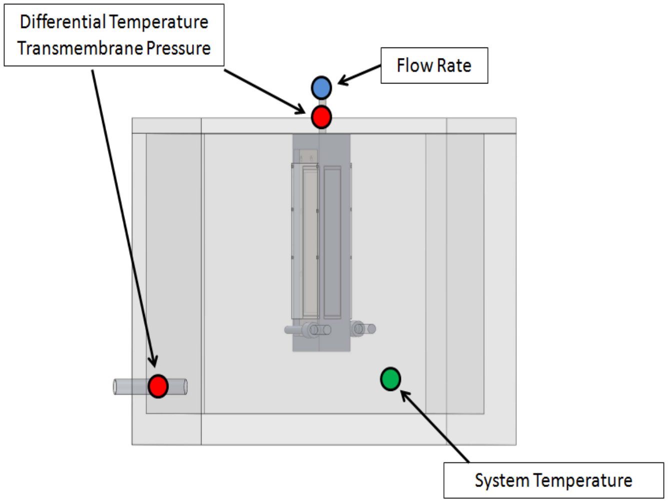


Figure 12: System Measurement Points

Interface with User: Realizing that our apparatus will be used in a laboratory system we plan to incorporate a system that takes recorded data from our measurements points and displays data and operating parameters to the technician in a real time format and also stores it for analysis at a later date. A sample user interface is shown in Figure 13. We are planning to use LabVIEW to create this user interface system.

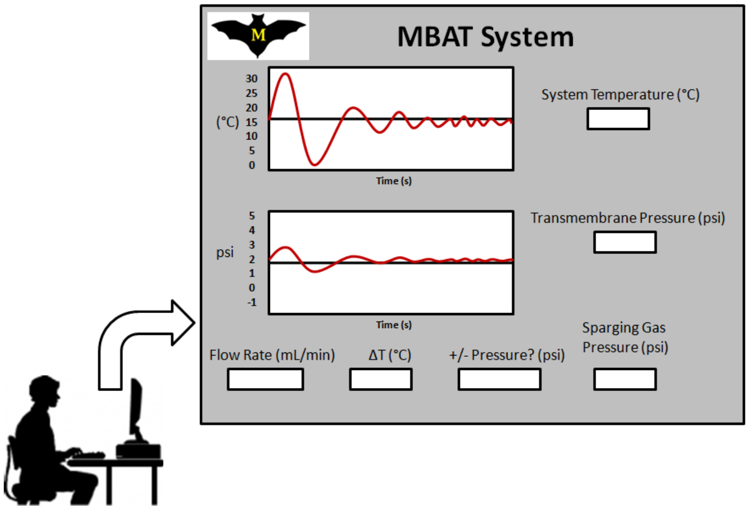


Figure 13: Sample MBAT Interface

BETA DESIGN

After a thorough analysis of our alpha design with Professor Skerlos and PhD student Kate Adams, our design has changed for the better. Furthermore, a necessary membrane change in the AnMBR system allowed us to view the process to improve our system. Although our team was on the correct path with our alpha prototype, components of our alpha design were deemed unnecessary. For example, the containment of the membrane housing is not needed. The membrane housing was directly connected to the head plate of the AnMBR system and was simply unscrewed and placed in a bucket to be examined when it was detached. This led us to the conclusion that an attachment of the membrane housing to the head plate of our MBAT system could be simplified. Additionally, sparging tubes were already in place and never had to be taken out of the membrane housing. A picture of the detached membrane housing can be seen in Figure 14 below.

Figure 14: The membrane housing with the sparging tubes and bolt attachment

Another change between the Beta Design and the Alpha Design is the change in the vessel. The Alpha Design comprised of a cube like shape with five walls and a hinged head plate. A hinged head plate required the vessel to be large enough to account for the sweeping angle of the membrane housing. Our sponsors indicated that they wanted to see a design that would minimize the volume. With this request, we saw that a cylindrical vessel with a head plate that would be bolted would be a better fit to decrease the volume. A cylindrical vessel would also decrease the chances of leaks compared to that of a cube shaped vessel; a cube shaped vessel requires the joining of the five walls, where the cylindrical vessel joins only at the top and the bottom. A base plate will be welded to the bottom of the cylinder, and a ring to the top of the cylinder. A head plate with all the necessary components attached would then be bolted to the ring using four hex thumbscrews. An O-ring would be used to ensure that the vessel remains air and water tight. The weight of our vessel was also considered and contributed to the Final Design.

FINAL DESIGN

The alpha prototype consisted of placing the MBAT inside a refrigerator to cool the fluid inside the system. An unused, large refrigerator was found in our sponsor's lab and is sufficient to house the MBAT system. Prior to ordering our materials, we calculated that the weight of the vessel and found it to be approximately **31 lbs**. After conversation with our sponsor, both parties agreed that this weight would be too much; the shelf's ability to hold the vessel inside the refrigerator had to be considered. Our sponsors also expressed the concern that the circular vessel may be vulnerable to instability.

Originally, only ½” circular stainless steel discs were found for the base plate, ring, and head plate. However, there was no necessary reason for these three components to be circular. Instead, we were able to find ¼” rectangular plates as well as a cylindrical pipe with a thinner wall; the new weight was calculated to be approximately **18 lbs**, reducing the weight by **13 lbs**. The new design with the square plates and new cylindrical pipe can be seen below in Figure 15. The only difference between the Beta Design and the Final Design is the reduction in weight with the new plate and pipe dimensions.

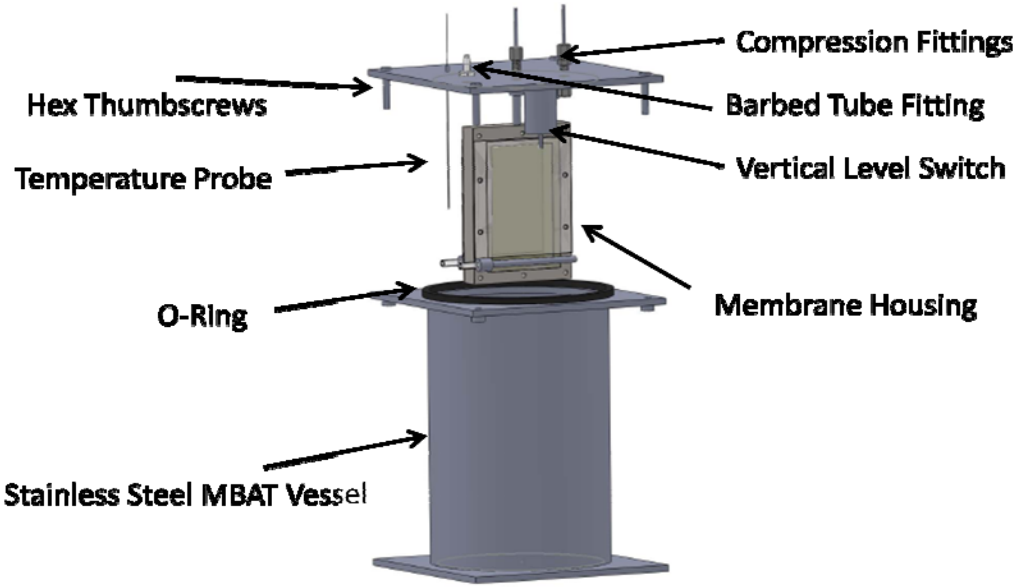


Figure 15: Final design can be seen here with the cylindrical vessel along with the square shaped head plate, ring, and base plate.

The base plate can also be used to secure the vessel to the shelving unit inside the refrigerator with the use of clamps.

ENGINEERING ANALYSIS

O-ring Necessities

We have decided to use an FEP-Encapsulated O-ring because according to McMaster Carr, it has the most resistance to corrosive fluids. The O-ring that was chosen has an inside diameter of 6-½” and an outside diameter of 6-¾”.

O-rings have been used for decades for creating seals and will be used in our design to keep our vessel air and water tight. They are designed to be seated in a groove, determined by the parameters of the O-ring. R.T. Dygert International, a company that specializes in seals, was found to have a table for dimensions of groove designs based on the type of O-ring for automotive sealing applications. These dimensions would be adequate since automotive sealing is designed for high temperature and high pressure applications. The O-ring specification chart requires that the depth of the groove be between 0.112” and 0.118” while the width of the groove is between 0.180” and 0.190” **[5]**.

Thumbscrews

Thumbscrews are currently used to secure the head plate of the AnMBR system and, according to Kate Adams, this is adequate. Hex thumbscrews were chosen for the option of tightening the bolts with a wrench if higher pressures required it.

Material Selection and Dimensions

The synthetic wastewater (See Appendix G) contains many organic and inorganic compounds that require all our material to be corrosion resistant. Furthermore, we will need to do a pressure vessel analysis to ensure that it will be able to withstand at least 5psi of pressure since this will be the proposed maximum pressure within the container. We were also given a requirement that the system needs to withstand a pH range of 2-12. Strength was considered, but not a critical component because of the low pressures the system would encounter.

All these parameters were entered into the Cambridge Engineering Selector as tests for acid/base resistance and yield strength. The three results that proved to be suitable for our use were Brass, Copper and Stainless Steel (SS). Our team selected stainless steel as the material of choice based on availability and price from our vendor McMaster Carr. Essentially, any one of the three would have been usable but the prices and masses of brass and copper were higher as they were only offered as high thickness options.

Our vessel dimensions were determined by three factors. The most important factor was the consideration that the membrane housing which has dimensions of 4” by 6”. We determined that we needed an inch clearance on either side in the horizontal direction in order to provide sufficient space for the sparging tubes and thus selected an MBAT diameter of 6”. We also determined that the current system has the membrane housing extend approximately 3.5” from the head plate and in order to maintain compatibility it was necessary that this be incorporated hence the minimum height requirement translated to 10”. The second factor considered was the availability of pipe sizes, and this made us choose an MBAT height of 12” as there were SS pipes of this size readily available with an internal diameter of 6.065”. The last factor considered was that of weight and this determined the thickness of the MBAT. Our sponsors indicated that weight reduction would be beneficial hence the outer diameter of 6.357” was selected.

Component Selection and LabVIEW

One of the major sections of our Final Design was our component selection. These ranged from pumps with corresponding tubing all the way to measurement transducers and the corresponding LabVIEW connector modules. All of our selected components and the reasons behind their selection are given below. More details of this information can be found in the Bill of Materials in Appendix A.

Pump: The pump selection process was a simple one. The current AnMBR system had pumps that were perfect for the required functions and this implied their applicability for our MBAT system which performed them same function in terms of fluid flows. Thus we selected Masterflex L/S Computer Compatible Digital Peristaltic Pump Systems. These pumps came with included pump heads and were perfect to be controlled via LabVIEW as they were configurable using a RS232 serial port.

Tubing: Selection of tubes was a simple process as well. The selected pumps were compatible with Masterflex L/S 25 tubes that had an inner diameter of 0.19”. We selected the Tygon food type for the inlet pipes as these have excellent non wetting properties and can be flush cleaned easily. This is important as our domestic wastewater will be flowing through these pipes. The Viton FDA pipes were selected for the effluent pipes as they have a higher resistance to acids and a tolerance to sulfuric acid was one of the requirements for the effluent tubes.

One major motivation behind the selection of pumps and tubing that were similar to the existing system was to simplify things for researchers. The AnMBR and MBAT are related systems and it does not make sense to reinvent the wheel to perform the same functions on the MBAT. Using similar components ensures that parts are interchangeable thus the need for specialized spares for the MBAT is reduced since the researchers could just use the parts available for the AnMBR.

LabVIEW with DAQ: Our team was clear that we needed a LabVIEW system integrated with a DAQ in order to successfully implement the one central control/analysis station. The selection of the DAQ was made easy by the fact that one was provided to us by the sponsor with sufficient capabilities to measure from all our components. The provided DAQ is a DAQcard-6036E and it is connected to an SC2345 Signal Conditioning Board. All of these components can be purchased from National Instruments if necessary.

Pressure Transducers: Two of our sensors needed to record pressure data but each of them had a completely different purpose. To measure the pressure across the membrane we required a differential pressure transducer. We selected the Omega PX26 model for this purpose due to several reasons. First, the silicon sensor would be able to withstand the corrosive materials found in the synthetic wastewater. Second, the MBAT internal pressure had a maximum rating of 5psi, and this model was available in row differential pressure ranges of ±1 psig or ±15 psig (the selected model). Lastly, the compact size and inexpensive nature of this model aids us in staying within the prescribed budget. Along with this transducer, we also selected a corresponding connector plug as well as wiring to connect from the sensor to the DAQ

The second transducer was required in order to measure the sparging gas pressure. We were informed that the sparging gas (Nitrogen) was available in cylinders at pressure levels of about 2000psi. To sufficiently accommodate this pressure level, we picked a sensor that could measure about 10000psi. We were aided by the fact that this sensor was readily available to us from our sponsor. Both these transducers output their sensor data as voltage signals. This implied that we needed two voltage modules in order to connect the sensor to the DAQ signal conditioning board. One was provided by our sponsor, thus just one extra needs to be purchased.

Thermocouples: Our system needed to compute a temperature differential between the inlet and the outlet while also keeping track of internal system temperature. For this purpose, two types of thermocouples were selected on the basis of their required use. The first that was selected was a pipe fitting probe for the MBAT system temperature. This was a K type thermocouple that would simply be a probe into the MBAT container and constantly measure temperature.

For the temperature differential we selected a K type flow through probe. This was perfect for our needs as this connected very easily to our inlet and outlet pipes as it is designed to accommodate pipes of o.25” outer diameters. Both thermocouples need dedicated thermocouple modules to interface with the DAQ and once again, they were provided by our sponsors.

Sparging Gas Valve: One need was to be able to control the sparging gas and set up a periodic interval for it to operate. This interval and duration of operation needed to be changeable to arrive at an optimum level. Our team selected a high pressure normally closed solenoid valve from Clark Cooper. This valve has a pressure rating of 5000Psi and is more than sufficient for our sparging cylinders which are rated at approximately 2000psi.

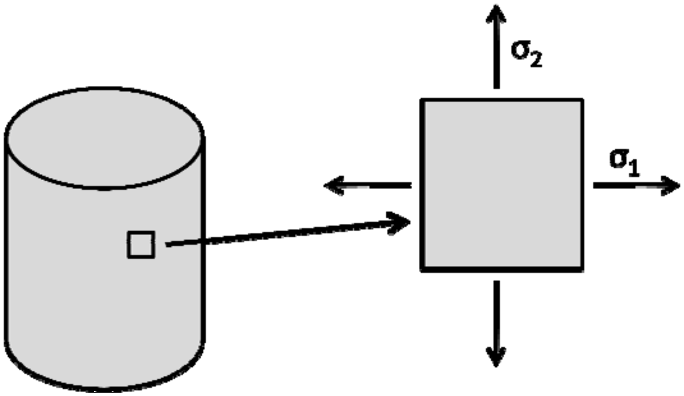
Vertical Level Switch: One major requirement of the filtration process is that there should be a constant level of fluid. This is to ensure that the membrane is always submerged. We selected a vertical level switch that can be set up to turn on or off when the water level hits a certain depth. This switch can then be used to control the inlet pump in order to ensure that the MBAT remains filled.

Temperature Control Analysis

We will be using a refrigerator to keep the fluid at the specific temperature outlined in our engineering specifications stated previously. We will need to test the refrigerators functions to make certain the ability to keep a consistent temperature within our desired temperature differential between the influent and effluent pipes. Furthermore, a conductive heat transfer analysis will be needed with respect to the HRT and to determine the thickness of insulation (if any) required for temperature sensitive components of our system such as digital transducers and devices used for data acquisition (wires, etc.) At the same time, our team needed to generate a heat transfer model in order to determine the changes in temperature and this has been discussed in the engineering analysis section below.

Failure Analysis

Material: ASTM 316 Stainless Steel
Properties: 0.2% Offset Yield Strength = 290 MPa = 42060.9 psi
Shape: Hollow Cylinder
Dimensions: Height = 10 in, Outer Diameter = 6.625 in, Inner Diameter = 6.357 in, Wall Thickness = .134 in
Free Body Diagram:



$$\boldsymbol{\sigma_1 = \frac{pr}{t}}$$
$$\boldsymbol{\sigma_2 = \frac{pr}{2t} - \frac{F}{A}}$$

Where p is the pressure, r is the internal radius, and t is the wall thickness. From the equations from σ_1 and σ_2 and the assumption that F is a compressive force one can deduce that $\sigma_1 > \sigma_2$. Using this deduction we used σ_1 for our failure analysis.

Failure Criterion: $\sigma_1 > \sigma_{YS}$

Assuming a maximum operating pressure of 5 psig,

$$\sigma_1 = \frac{pr}{t} = \frac{19.7\,psi * \left(\frac{6.357}{2}\right) in}{0.134\,in} = 467.2\,psi$$

Does vessel fail in tension? **<u>No, $\sigma_1 < \sigma_{YS}$</u>**

Safety Factor:

Thickness for $\sigma_1 = \sigma_{YS} = 42060.9$ psi

$$\sigma_1 = \frac{pr}{t} \rightarrow t\sigma_1 = pr \rightarrow t = \frac{pr}{\sigma_1} = \frac{19.7\,psi * \left(\frac{6.357}{2}\right) in}{42060.9\,psi} = .001489\,in$$

$$S_f = \frac{.134}{.001489} = \mathbf{90}$$

From our analysis we were able to determine that our vessel exhibits a safety factor of 90 against failure of combined loading during maximum operating pressure.

Drop from Height: The biggest risk associated with the MBAT is that it is dropped from a height. At a weight of 18 pounds the MBAT system has a potential energy of 73.2 Joules when resting on a laboratory counter of 3 feet.

$$Energy_{Potential} = mg\Delta h = 73.2\,Joules$$

This level of energy is equivalent to that of a baseball traveling at 71 miles per hour. The force exerted if the MBAT were to drop on one's foot is comparable to dropping a bowling ball on a foot. This force is high enough to break bones in the foot.

Heat Transfer Model

A customer requirement is that the temperature vary by no more than ±3°C during operation. We performed a heat transfer analysis on the system to determine the rate at which heat leaves the MBAT system. We assumed a steady state model and no heat generation from the anaerobic digestion (according to our sponsor, Kate Adams, this phenomena was negligible in the heat transfer model). Our results are shown below.

Heat Loss Through Side:

Material: ASTM 316 Stainless Steel
Properties: Thermal Conductivity (k) = 16.3 W/m*K
Shape: Hollow Cylinder
Dimensions: Height (H) = 0.2032 m, Outer Radius (r_2) = 0.0841 m, Inner Radius (r_1) = 0.0807 m
Wall Thickness = .003404 m
Assumption: Influent and effluent flow rates small relative to volume of container, assume steady state model and no heat generation from anaerobic digestion.

$$\frac{q}{A} = -k * \frac{dT}{dr}$$
$$A = 2\pi r H$$

$$\frac{q}{2\pi r H}\int_{r_1}^{r_2}\frac{dr}{r} = -k\int_{T_1}^{T_2} dT$$

$$q = k * \frac{2\pi H}{\ln\left(\frac{r_2}{r_1}\right)} = 16.3 * \frac{2\pi * 0.2032}{\ln\left(\frac{r_2}{r_1}\right)} * (T_1 - T_2) = \mathbf{504.287\ (T_1 - T_2)}$$

For a completely filled MBAT, the heat required to increase the temperature of the fluid in the system by 3°C is approximately 65kJ. Assuming a temperature variation between the MBAT interior and the outer environment of 5°C, the fluid inside the MBAT will take 43.2 seconds to heat by 3°C. This result proves that some type of temperature control is necessary to meet the required customer specifications.

Heat Loss Through Bottom:

Material: 410 Stainless Steel
Properties: Thermal Conductivity (k) = 24.9 W/m*K
Shape: Flat Plate
Dimensions: Thickness (ΔX) = 0.00635 m, Length = 0.2032 m, Width = 0.2032 m, Area exposed to fluid = 0.018 m^2

$$\frac{q}{A} = \frac{k}{x_2 - x_1} * (T_1 - T_2) \rightarrow q = \frac{T_1 - T_2}{\frac{\Delta x}{kA}} = \frac{T_1 - T_2}{\frac{.00635}{24.9 * .018}} = 0.014(T_1 - T_2)$$

Pump Sizing

To determine the power requirement for the inlet pump an energy balance was performed on the system.

Energy Balance: $W = \Delta U + \Delta KE + \Delta P/\rho + g\Delta z$

After simplifying and canceling terms:

$$W_s = g * (z_1 - z_2) + \frac{P_1 - P_2}{\rho}$$

$$W_s = g * (0m - 0.5m) + \frac{1atm - (1atm + TMP)}{1\frac{kg}{m^3}}$$

$$W_s = g * (0m - 0.5m) + \frac{1atm - (1.068atm)}{1\frac{kg}{m^3}}$$

$$W_s = -4.803\frac{m^2}{s^2} \pm 6890\frac{m^2}{s^2} = 6895\ \frac{J}{kg}$$

To determine the mass flow rate assume a volumetric flow rate of 5mL/min

$$5\frac{mL}{min} = 8.33 * 10^{-8}\frac{m^3}{s} * 1\frac{kg}{m^3} = 8.33 * 10^{-8}\frac{kg}{s}$$

$$-6895\ \frac{J}{kg} * 8.33 * 10^{-8}\frac{kg}{s} = -.000575\ W \rightarrow \boldsymbol{.575\ mW\ Required}$$

Mass Calculations

Table 2: Mass Savings from Re-Design

	B design	**Γ design**
Component	Mass (kg)	Mass (kg)
Tube	5.85	2.87
Top Plate	3.29	2.03
Bottom Plate	3.29	2.03
Ring	1.44	1.132
Total Mass	**13.87 (30.57lb)**	**8.062 (17.75lb)**

Bolt Analysis

The AnMBR system's head plate uses thumb screws to secure it to the vessel. After consulting with our sponsors, they expressed that the pressure within the vessel will not be over 5psi as seen in our list of engineering specifications on Page 10 and the thumb screws were preferred because of the ease of use. Using the specified pressure of 5psi, pressure vessel and force calculations were done using equations from Hibbeler's *Statics and Mechanics of Materials* **[6]** and the equations can be seen below where *F* is the force on the head plate from the pressure of the vessel, *p* is the gauge pressure, and *r* is the radius of the vessel. In the second equation, *N* is the number of bolts required given the tensile strength of the bolt material, *σ*, and the area, *a*, of the bolt. The force that the bolts would combat was determined to be **158.69lbf**.

$$F = p\pi r^2$$
$$N = \frac{F}{\sigma\pi a^2}$$

We decided on four 18-8 Stainless Steel, ¼”-20 hex thumb screws that were 1-¼” in length. These thumbscrews had a rating of 80,000 psi. This gave us a safety factor of 2000%. This very high safety factor is expected since the tensile strength of the bolt is so large and the pressure inside the vessel is small.

The ultimate shear strength in the bolt is approximately 75% of its ultimate tensile strength [6]. The ultimate shear strength is then 60,000psi. However, the bolts under normal operating conditions will experience a negligible amount of shear since the bolts will only be used to hold down the head plate to the head plate mount.

SAFETY

The plan for safe manufacture, assembly, and testing of the MBAT is outlined in this section. A detailed safety report is provided in Appendix M.

Component Design: Consideration was made to the nature of the influent fluid to our system when designing components. Components needed to resistant to acids and bases so as not to cause corrosion and vessel failure. Each component was checked for both temperature and pressure rating to ensure that it was suitable for our system. Components of the system were analyzed using FMEA which is provided in the safety report in Appendix M.

System Design: The combination of our system design and the low operating pressure that the system will encounter result in a safety factor of 90 from burst, and a safety factor of 2000 against yield for the bolts when operating at its proposed maximum operating pressure. The O-ring and its groove are designed for high pressure, high temperature in automotive applications and will be more than adequate for our design. Bolt shear stress will not be an issue since its main purpose is to be used in tension.

Manufacturing: To manufacture our parts, the processes include: Sawing, CNC milling, drilling, and tapping, and TIG welding. There are hazards associated with these operations that include sharp edges, flying debris, fast moving equipment, and extremely high heat. Our entire team has been safety trained to work in the machine shop and John Song enrolled in welding training earlier in the semester. He will be responsible for the welding portion of our operation. We will use proper protective equipment and we will be under supervision of shop supervisors during manufacturing. We have attempted to order parts that are as close to the size we require as possible to minimize the need for machining.

Assembly: Assembly does not pose a high risk. Components will be attached using screws, bolts, and screw in connections. Some components of our system are heavy (25lb) so we will be sure to employ proper lifting techniques and ensure that the system is stable so that it does not tip over at any point.

Testing: Testing is a key aspect of this project as the key customer requirements are that the system contain water securely and be able to operate anaerobically. Fluid must be able to circulate through the system with no leakages at any point within the system. All testing will be conducted at pressures < 10 psi.

Design Safe Analysis: Design Safe was utilized to assess the risk associated with the manufacturing, assembly, and operation of the MBAT system. There are some inherent risks associated with the leakage of toxic chemicals listed in Appendix G from the vessel during operation. The MBAT system will be tested before in lab operation to ensure that the system and airtight but it is important that all connection are made securely to avoid any leaks. Hazards from chemicals and biological material can be reduces by wearing proper personal protective equipment, PPE (lab coat, gloves, eyewear) when handing components of the system. We have designed the system to maintain integrity well beyond the stresses that they system will experience so failure by explosion is practically negligible.

Furthermore, necessary precautions should be taken to avoid any chances at spills which could cause slippery conditions for the user. As stated above, dropping the MBAT alone is similar to dropping a bowling ball and with water into the system, the weight of the MBAT will only further increase.

Electronic exposure to liquids was also an important risk that was also derived. The pumps, level sensor, thermocouple, and differential pressure gauge all need electricity to function and precautions must be taken to avoid exposure to the liquids that will be used and to avoid risk of electric shock.

The system weight should be considered when moving the system. Proper lifting techniques should be applied to avoid any injuries during this process. The square base plates add stability to the system so that it will not tip during operation but we recommend that the system by clamped to a flat surface during operation to ensure that this risk is minimized.

Material and Manufacturing Process Selection (Using CES Software)

One of the primary tasks performed during the design process was the selection of materials that were suitable for use with the MBAT system. Our material selection for tubing was determined by the selected effluent pump and this limited us to the Masterflex L/S series of tubing. From among these we determined that the Tygon Food and the Viton FDA will be the most suitable for the inlet and outlet respectively. This was based on criteria of corrosion resistance, acid resistance for the effluent tubing and non wetting properties for the inlet tubing.

Our remaining material selection was conducted for primarily the MBAT Vessel and the various barbed connectors that would be used. Both of these were determined by taking into consideration corrosion resistance for a pH range from 2 to 12 and a maximum service temperature of above 150°C to allow for autoclaving. The vessel also had considerations of yield strength, machinability and weldability in order to ensure the performance as a pressure vessel and enable easier manufacturing. Using these criteria we determined material indices and via CES we determined suitable materials for both these functions. For the MBAT Vessel we selected stainless steel and for the barbed connections we had the choice of polypropylene or polyethylene as both met our requirements. For a more detailed material selection process see Appendix C.

Once the materials were determined we also attempted to determine manufacturing processes for these parts in the event that other lab researchers required the use of a similar MBAT system and needed to manufacture one. We assumed batch sizes of 1000 for both the parts and based on that used the CES Process selector. We determined that for these small batch sizes we would use electric discharge wire cutting to manufacture the stainless steel and polymer extrusion for the thermoplastics. We did consider however that the actual batch sizes for these components would be a lot higher as their use extends beyond just the realm of MBAT systems and we considered larger scale mass production processes which would be powder injection molding for the stainless steel and thermoplastic injection molding for the polypropylene/polyethylene.

Design for Environmental Sustainability (Using SimaPro Software)

Two materials were selected using CES; 2.67kg of 316 stainless steel for our vessel, and 5g of polyethylene for the tubing. It was determined that the 316 stainless steel has a bigger impact on the environment than the polyethylene and requires a higher mineral requirement and a higher energy input according to EcoIndicator 99 damage classifications. However, stainless steel is 100% recyclable where as polyethylene is not and takes several centuries until it is sufficiently degraded. Since we are using small amounts of polyethylene in comparison to 316 stainless steel, stainless steel was determined to be the primary contributor to the negative environmental impact of the MBAT. A more detailed analysis can be seen in Appendix C.

FABRICATION PLAN

The plan for the fabrication of our MBAT system is outline in this section. The first priority is the development of the vessel of our system, and then to add the necessary components to measure temperatures, pressures, and flow rates.

Vessel Construction

Four components will be used to construct the vessel; the head plate, ring, base plate, and cylindrical tube. The vessel will be constructed after machining a 12” 316 Stainless Steel pipe with an outside diameter of 6.625” and an inside diameter of 6.357”. The pipe will be cut down to 10” using the lathe machine with a lathe spindle speed of 40.6 rotations per minute with a high speed steel tool bit **[7]**. The 8”x24”x¼” 410 stainless steel plate will be will be cut into thirds, lengthwise, producing roughly three 8”x8”x¼” plates. The stainless steel plate will be cut using the band saw with the tool speed at 50 feet per minute as indicated on the band saw machine in the machine shop. It is important to note that these will not be the exact measurements since cutting the material will inevitably remove some as well, but this will not be a problem. Two out of the three plates will also have to be further machined to produce the ring and the head plate.

Ring: One plate will be CNC machined to include a 6.357” diameter centered hole, the same size as the inner diameter of the cylindrical pipe. Four holes will be drilled and tapped to allow for the ¼”-20 bolts that will be used to secure the head plate to the ring. Additionally, a groove with a width of 0.185” and a depth of 0.115” needs to be machined into the ring for the O-ring.

Again, these are the dimensions found from the R.T. Dygert International website based on high temperature and high pressure applications, adequate for our use. A drawing of the ring can be seen in Figure 17 below. CNC machining will be required because of the accuracy needed to machine the circles.

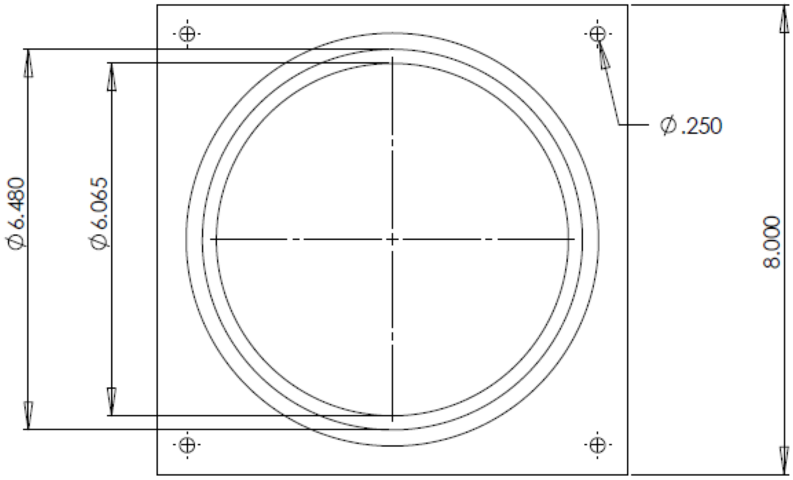


Figure 17: Drawing of the ring component showing the O-ring groove, hole, and four holes for the bolts.

Head Plate: The second plate will be machined to include holes to allow for the following:

- Membrane housing to effluent flow tube
- Influent flow tube
- Reactor temperature probe
- Aeration tube
- Sparging gas tube

A drawing can be seen for the head plate below in Figure 18:

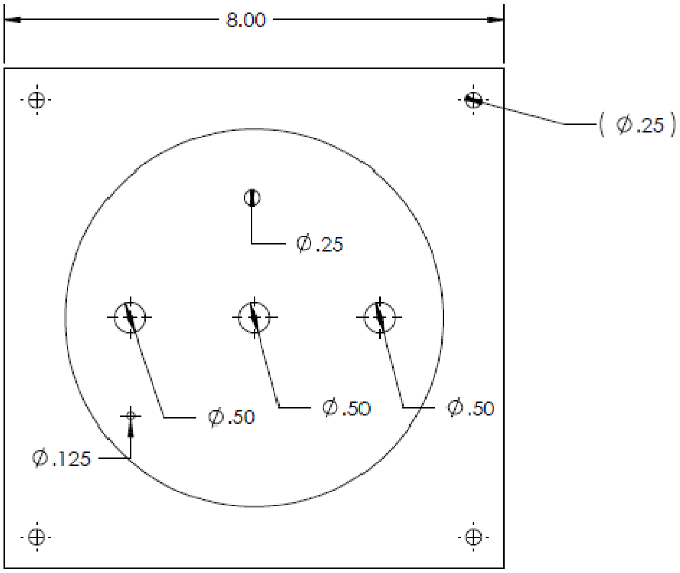


Figure 18: Drawing for the head plate component showing the holes allowing connections for the influent and effluent tube, reactor temperature probe, aeration and sparging tube.

Welding

The base plate and the ring will be welded to the ends of the cylindrical pipe via tungsten inert gas (TIG) welding. The TIG welding process is commonly used in applications for thin sections of stainless steel and is the best way to weld our components to minimize the metal warping from the heat.

Welding Safety[8]: TIG welding, like any other type of welding, can be dangerous if the proper precautions are not taken. The TIG welding process produces intense ultraviolet radiation which can cause a form of sunburn and trigger the development of skin cancer in the most extreme form. Flying sparks and droplets of molten metal can also be present which can cause severe burns and start a fire if flammable material is nearby. However, if done properly, very few sparks or metal droplets are produced. It is essential that the welder wear protective clothing, which includes leather gloves, a closed collar shirt to protect the neck and throat area, a protective long sleeve jacket and a welding helmet to prevent retinal damage and ultraviolet burns to the cornea. The ultraviolet burn to the cornea is also known as Arc eye and is very painful if adequate eye protection is not worn.

Welders are also exposed to dangerous gases and particulate matter. The arc produced in TIG welding produces short wavelength ultraviolet light, which causes surrounding air to break down and form ozone, a molecule comprising of three oxygen atoms; heavy metals can be inhaled into the lungs. Proper ventilation will be required during the welding process.

ASSEMBLY PLAN

Pressure Vessel Sub-Assembly

The pressure vessel sub assembly is the portion of the system that will house the membrane Figure 19 below shows a CAD model of the pressure vessel sub assembly.

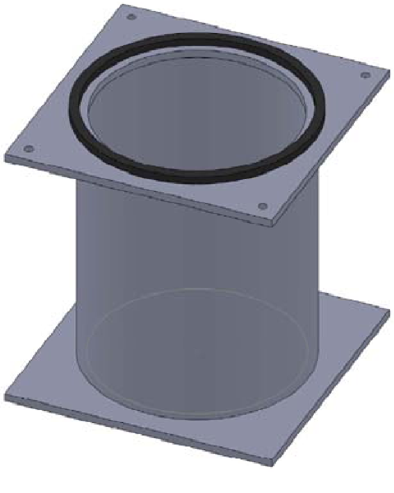


Figure 19: Pressure Vessel Sub Assembly

This sub assembly was assembled using the following components:

- Bottom Plate

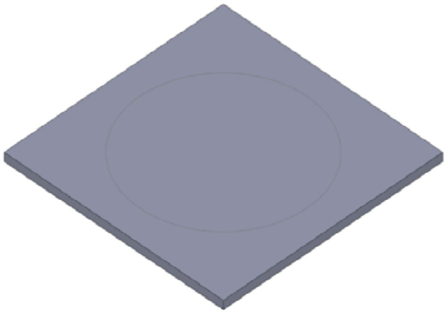


Figure 20: Bottom Plate

- Vessel Tube

Figure 21: Vessel Tube

- Head Plate Mount

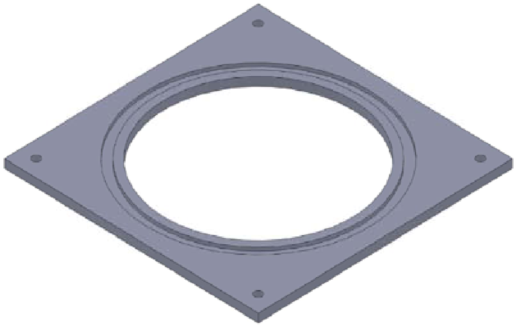


Figure 22: Head Plate Mount

- O-Ring

Figure 23: O-Ring

This sub assembly was assembled using the following steps:

1. Attach the bottom plate and the head plate mount to each end of the vessel tube using Tungsten inert gas welding, creating the object shown in Figure 24. The complete fabrication is also explained in the Fabrication Section previously in the report.

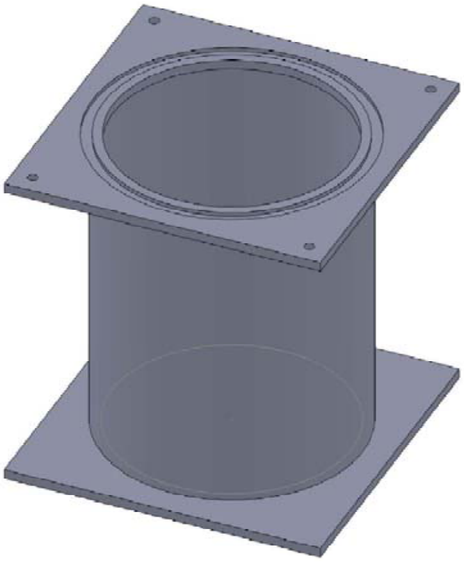


Figure 24: Pressure Vessel

2. Affix the O-Ring to the head plate mount using epoxy. Ensure that the O-Ring is connected securely to the head plate mount.

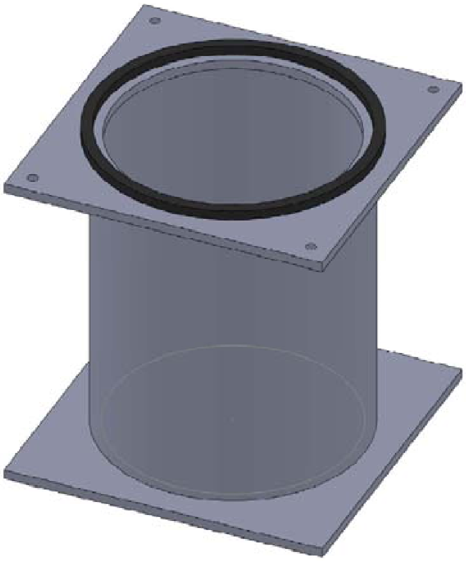


Figure 25: Pressure Vessel Sub Assembly

Head Plate Sub Assembly

The Head Plate Sub Assembly consists of the connections for the inlet, outlet, and sparging tubes. It is also the mount location for the system temperature sensor and the vertical level sensor. The final head plate sub assembly is shown in Figure 26.

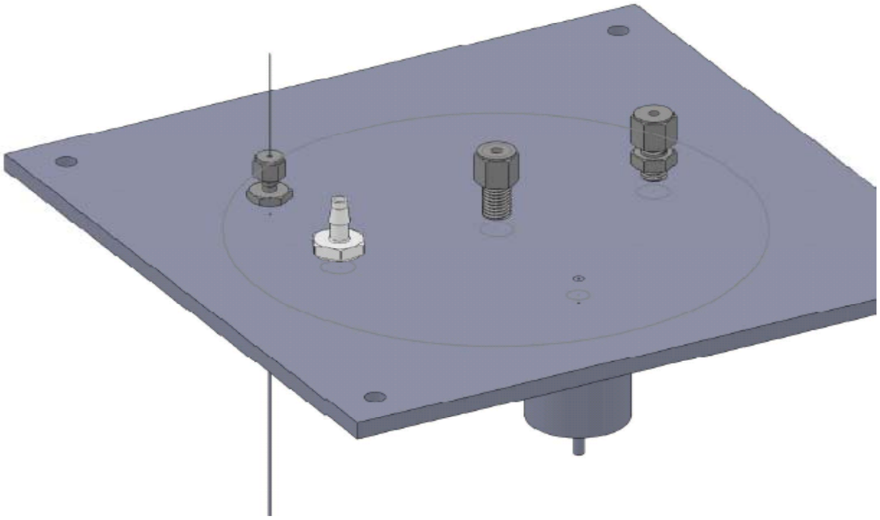


Figure 26: Final Head Plate Sub Assembly

The Head Plate assembly was constructed using the following steps:

1. Connect the barbed pipe fitting and the compression fitting to the head plate. The barbed pipe fitting should be screwed into the ¼"hole while the compression tube fittings should be screwed into the 3/10" holes. Ensure that each fitting is tightened securely to ensure that air and water tight conditions are maintained.

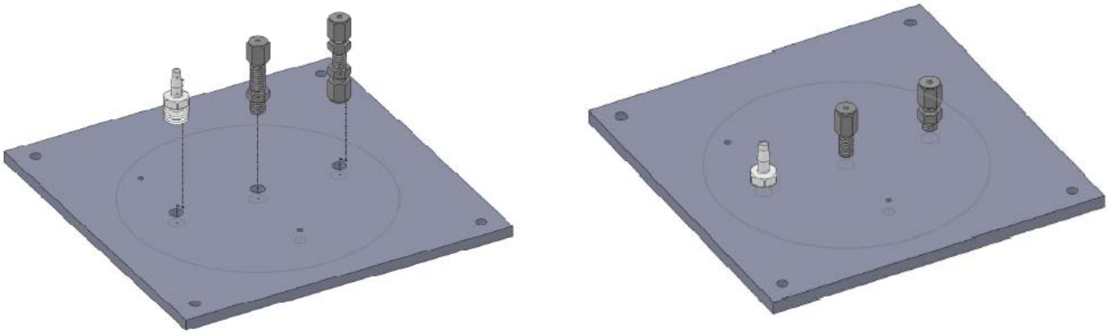


Figure 27: Head Plate Assembly Before (left) and after (right) installation of Barbed Fittings

2. Screw the vertical level sensor into the 1/8" threaded hole that directly adjacent to the center compression fitting Afterwards, insert the temperature probe into the head plate by inserting the probe through the compression fitting and tightening the fitting around the probe. This step is illustrated in Figure 28. Once again, insure that each component is screwed tightly into each hole to ensure that the system is water-tight and air-tight.

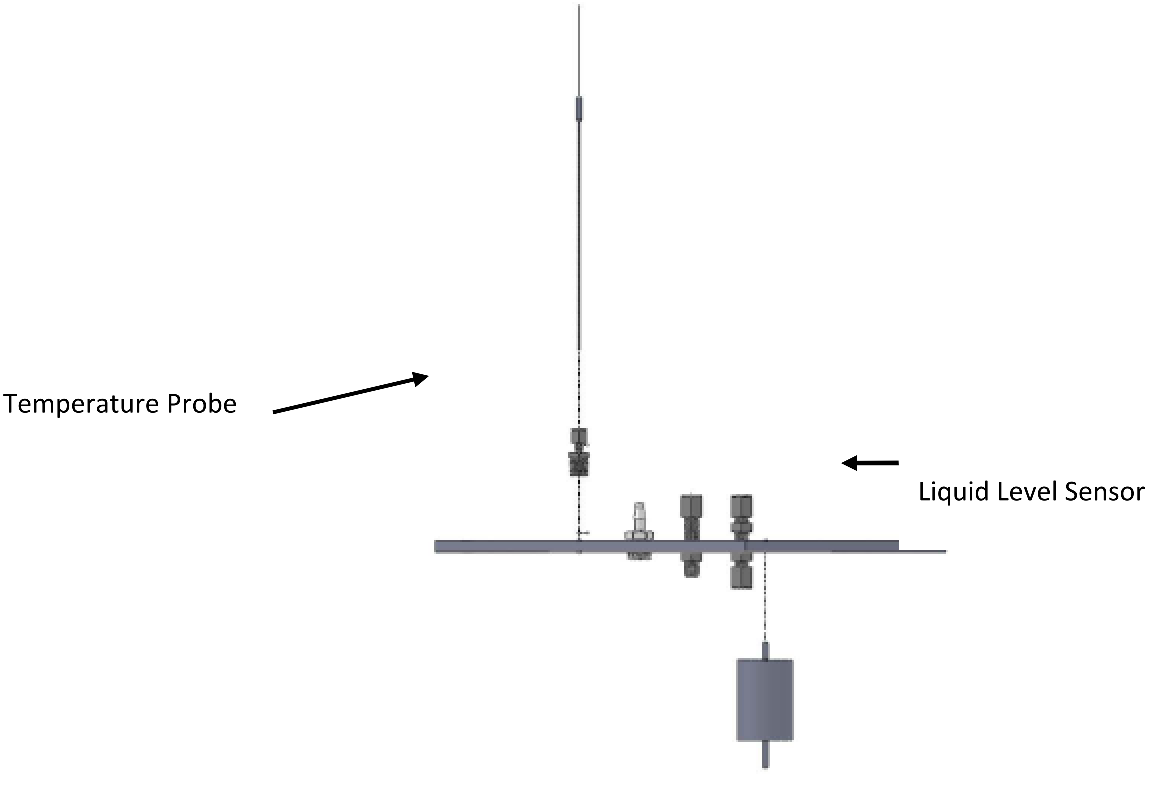


Figure 28: Incorporation of Temperature and Level Sensor Probes

3. Upon removal of the membrane from the AnMBR (instructions for that process are in a separate document), the membrane housing should look as shown in Figure 10.

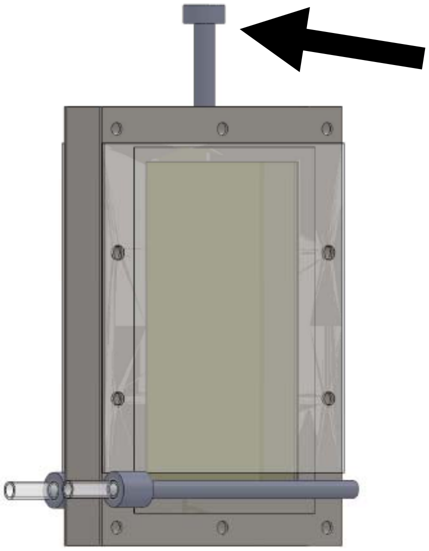


Figure 29: Membrane Housing

Figure 30: Membrane Housing Connector

Notice the connector rising from the top of the membrane housing (denoted by the arrow). The top of this connector features a threaded end connection. To connect the membrane housing to the head plate, screw this threaded connection over the threaded end of the middle compression fitting. Ensure that this is a tight connection. This step is shown in Figure 12. The temperature probe and the level sensor which were installed in previous steps are omitted for clarity.

Figure 31: Connection of Membrane Housing to Head Plate

To connect the influent tube to the head plate slide the tubing onto the fitting as shown in Figure 13 and 14. Press the tubing down onto the fitting so that there is a tight fit. Clamps may be needed to ensure a tight fit between the tube and the fitting. The same process shown to the right can be repeated for the sparging tube inside the vessel.

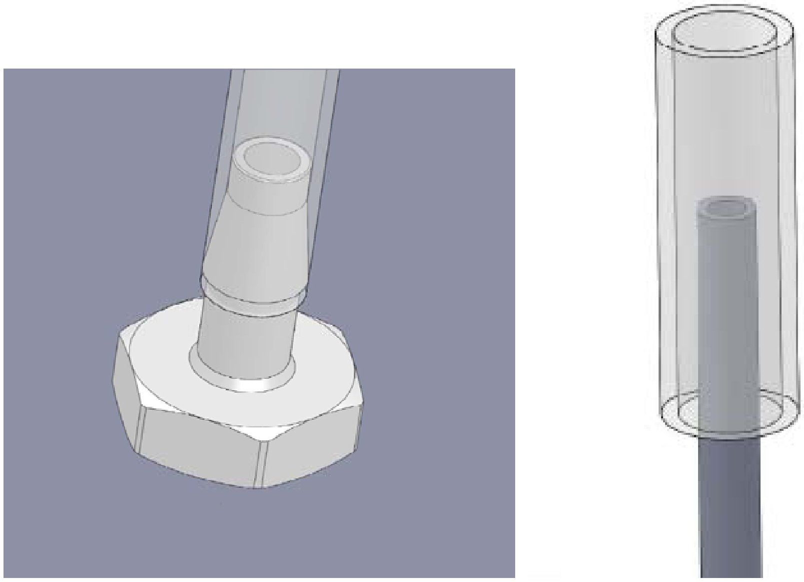


Figure 32: Connection of Tubing to Fittings

4. The Head Plate Sub Assembly can be connected to the vessel itself by inserting bolts through each of the 4 holes in each corner of the head plate. Each of these bolts should be tightened securely by hand to maintain airtight conditions.

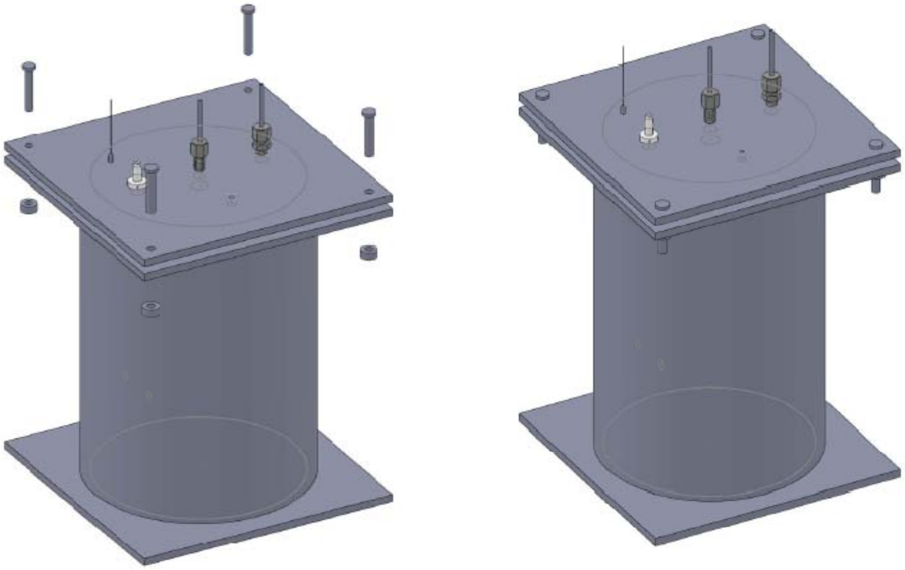


Figure 33: MBAT System before and after Installation of Screws and Bolts

EXPERIMENTAL VALIDATION PLAN

During operation the system will be required to hold water and operate anaerobically under pressure. The goal of our experimental testing will be to determine if the system is both water and air tight under the maximum operating pressure of 5psi. If testing proves that our system is both airtight and watertight we will conclude that the integrity of our vessel is sufficient for in lab use.

Procedure

Two experimental trials will be performed on our system: the first to ensure that the system is airtight and the second to prove that the system is water tight. Protective eyewear will be worn at all times during our testing. A third test will be conducted to ensure that our vertical level sensors will work.

Air Tight Testing: The vessel will be assembled and all openings of the vessel will be sealed. A small length of tubing will be attached to each barbed pipe fitting. Two of the lengths of tubing will be sealed with rubber stoppers. The third will be left open. Attached to this open length of pipe will be a small bicycle pump. The vessel will then be completely submerged vertically in water. Using the pressure reading on the pump as a guide, the vessel will pressured up to 10 psi in increments of 1 psi. During the entire length of testing, we will check to ensure that no air bubbles are rising to the surface as this would show that the system is not completely airtight. We will use our data and observation to complete Table 3 below.

Table 3: Table to determine air tightness testing

Pressure Reading (psi)	Leakage (Air Bubbles Observed)
1	Y/N
2	Y/N
3	Y/N
4	Y/N
5	Y/N
6	Y/N
7	Y/N
8	Y/N
9	Y/N
10	Y/N

Water Tight Testing: Water Tight Testing will occur in a manner similar to Air Tight testing. The vessel will be filled with water before testing. All openings of the vessel will be sealed except for one and a bicycle pump will be utilized in the same way as the previous testing. The vessel will but be submerged in water but placed a large bucket to ensure no large spills if leaking does occur. Using the pressure reading on the pump as a guide, the vessel will pressured up to 5psi in increments of one psi. During the entire length of testing, we will check to ensure that no moisture is seen on the outside of the vessel as this would show that the system is not completely watertight. We will use our data to complete Table 4 below.

Table 4: Table to determine water tightness testing

Pressure Reading (psi)	Leakage (Water Observed)
1	Y/N
2	Y/N
3	Y/N
4	Y/N
5	Y/N
6	Y/N
7	Y/N
8	Y/N
9	Y/N
10	Y/N

Flow Validation Testing: During this test we will attach pumps and tubing to the vessel. Specifically, we will attach the influent and effluent pumps and then circulate clear water to the assembled system to ensure that fluid does indeed flow. During this test we will check for leaks in the system (especially at the tubing connections) and we will also check for the presence of air bubbles in the flow lines.

Level Sensor Testing: A simple test with the level sensor will also be completed. An inlet pump will be attached to the vessel as well as a peristaltic pump for the effluent. The level sensor works by having resistance to turn off the pump when the sensor is in the low position, and having no resistance when the sensor is in the high position. The system will be run for at least 10 minutes using clean water to see that the sensor works for a number of cycles.

Temperature and Differential Pressure Sensor Validation: After completion of our LabVIEW interface, we will attach the thermocouple, differential pressure gauge, and effluent pump to the DAQ. With the LabVIEW system up and running on our computer, we will repeat the flow validation test. During this test we will verify that our data acquisition is receiving data from the MBAT system and that these readings are representative of the actual system conditions.

Refrigerator Calibration: The refrigerator that will be used for lab operation will also need to be calibrated for our researchers. We will simply place a digital thermometer into the refrigerator and measure the temperatures at each setting given by the refrigerator.

Interpreting Results: Using our observations and recorded data from our pressure, flow, and sensor validation tests we will analyze the data. If each of these tests proves to be successful it can be said that our system is viable and will operate as planned during in lab operations.

VALIDATION RESULTS

Air and water tightness testing was completed as well as the flow validation and level sensor tests. Temperature and differential pressure sensor and their incorporation into the system with LabVIEW were not calibrated. The refrigerator was also tested. These are all outline in this section below.

Air and Water Tightness Testing: We were able to successfully test our vessel for air tightness by pressurizing our vessel to 20psi while submerged in water without any signs of air leaks from the seals and connections. A snapshot was taken during the testing and can be seen in Figure 34.

Figure 34: Air tightness testing was completed successfully while the vessel was submerged in water.

Flow Validation and Level Sensor Testing: We conducted a flow validation test for ten minutes in the laboratory. During our test we did not see any signs of leakage or observed the presence of air in our flow lines. The level sensor also worked as it should by turning the influent pump on as more water was needed, and turning it off when enough water was in the vessel. A snapshot of the flow validation and level sensor testing setup can be seen in Figure 35 below. Both the influent and effluent pumps are not the pumps that will be used in the system but are simply to demonstrate and validate that the proposed flow method and the level sensor will work.

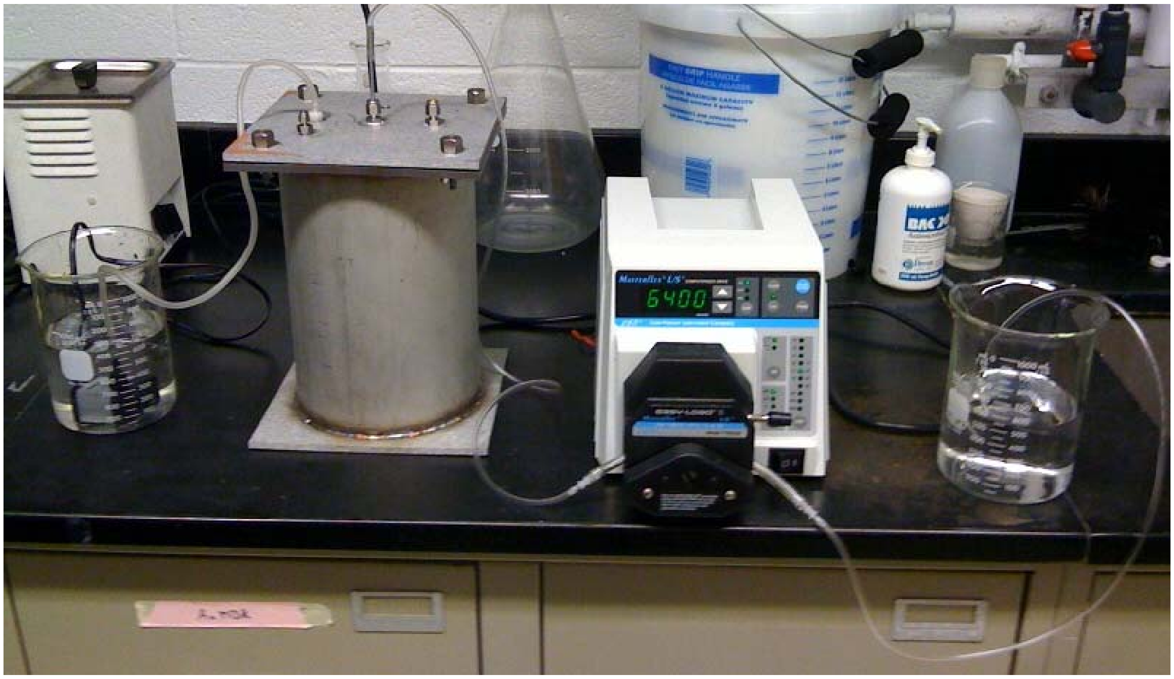


Figure 35: The setup for the flow validation and level sensor testing was completed successfully and is shown above. From left to right: source with example influent pump, MBAT vessel, example effluent peristaltic pump and drain.

Validation Testing: To determine if our device is suitable for operation we performed several validation tests. We performed a water-tightness validation test in which we used a bicycle pump to pressurize the MBAT to 20 psi while filled with water and checked for water leaks. We also performed an air tightness validation test in which we submerged the MBAT in water and pumped air into the vessel while continuously checking for the presence of air bubbles. The MBAT passed both of these validation tests proving to be both water and air tight. We also developed a procedure to calibrate the refrigerator that the MBAT would operate in but we found it unnecessary to complete the calibration as the lowest power setting of the refrigerator corresponded to 10°C. We developed a procedure to validate our sensors but we were unable to complete the validation before the project submission date.

Refrigerator Validation: We began our calibration according to the procedure outlined in the Testing Validation section and determined that a refrigerator setting of "1" corresponds to a temperature of 10°C. As the lowest setting is within the desired temperature range expressed by our sponsor we did not calibrate the refrigerator any further.

DISCUSSION

We have confidence that our MBAT system will be suitable for its purposes in assisting Kate Adams in her doctoral studies, but there were a few things that we would have done differently if the design process could be repeated and are outlined in this section. Different challenges that emerged are also discussed in this section.

Sensor Validation Critique

Due to a variety of reasons our team ended up being short of time to perform several tasks for the MBAT with regards to sensor validation and the set up of the LabVIEW, the latter of which has been discussed earlier. Our sensor validation was delayed and eventually not completed partly because our sensors were finalized very late in the design process. Our team started off with a long list of required sensors and as the requirements of the project became clearer, we determined the most streamlined sensor system with a finalized list of three sensors for temperature, differential pressure and mass flow rate. Furthermore, we waited for the completion of our LabVIEW setup in order to perform all of our complete system validation at one go and this proved to be an inefficient use of available time and resources. Looking back, given the chance to go over our design process again we would have validated our sensors according to our validation plan using the LabVIEW Signal Express soon after fabrication of our system was completed rather than waiting for the MBAT interface completion.

Another aspect of our validation that was left undone was the validation of flow rate measurement using the Ohaus weighing scale. Our team intended to use this using a serial interface to the LabVIEW and validate this with the rest of the system. We did not anticipate the lack of documentation relating to the serial control of this device and left it until too late. Given the change to do this project again, we would contact O-Haus, the manufacturer of the scale, and request for detailed documentation for the serial control aspect of their scales early on in the semester and incorporate this into our system better.

Flow Direction

Between our final design and fabrication of the prototype, we have been questioning how to establish positive pressure across the membrane. Initially the thought was that as long as the pressure inside the vessel was greater than the pressure outside the vessel, the system would allow for positive pressure. The proposed plan is to disable the level sensor so the influent pump could then build up pressure inside the vessel. However, this theory has yet to be tested and a number of calculations and analysis must be done prior to this. It is unknown whether the pump is capable of building up the pressure using the proposed solution and further investigation needs to be completed.

Another proposed solution is to switch the tubing connections so that the effluent pipe experiences atmospheric pressure and only goes to the volume flow rate sensor (scale and bucket system). That way, the peristaltic pump can be used to pump the synthetic wastewater into the vessel creating a pressure difference to push the wastewater across the membrane.

Benchmarking

The current AnMBR system was benchmarked and proved beneficial to our design. By attending a disassembly session of the AnMBR we were able to redesign the MBAT and modify our component selection to be more compatible with the overall system. Additionally we were able to utilize many of the extra parts and components not used in the AnMBR system in our design. It would have been beneficial to have performed a more thorough benchmarking of the AnMBR system earlier and to have taken complete inventory of the extra parts in the laboratory. This information would have reduced cost and material selection time throughout our design process.

Design Critique

Although the design and fabrication of our product was successful, there were a few things that we would change. The head plate mount and our base plate were warped after the welding process. The base plate is not as critical of an issue, but the warping in the head plate requires the user of our system to tighten the bolts that connect the head plate to the mount more than expected. Luckily, the integrity of the design is still intact and the O-ring seal performs as it should. Upon review of the warping, there is a 1/16” difference. If the fabrication process could be redone, the original ¼” plates would be replaced with plates of at least, 3/8” and then machined down to its final size after the welding process.

Furthermore, threading the holes for all the connections on the head plate could have been more accurate. The through-wall couple connection for the effluent pipe and the 1/8” NPT for the level sensor are off center and could have been prevented with more work. A tapping guide was used but did not have the correct size for our needs. If redone, we would have created our own guide using a scrap piece of aluminum found in the machine shop, and drilling a hole to fit the size of the tap.

During the final design and fabrication process a discussion on the need for a pressure relief valve was questioned for safety. We were ensured that the maximum operating pressure at any given time would be no more than 5psi. Initial investigation into burst discs showed prices of just under $100 but were for pressures ranging intermittently from 100 to 750psi, greater than the pressures that may be encountered in the MBAT system. Further investigation into a suitable burst disc or a pressure relief valve would be completed if this project was redone.

Pump Control Critique: One of the major problem areas in the MBAT final system relates to the Masterflex L/S Computer Compatible Peristaltic Pump that needed to be incorporated into the system. First, this interfaced with the LabVIEW via an RS232 serial connection and our team had little experience dealing with this aspect of the LabVIEW system. Furthermore, the pump was finalized merely two weeks prior to the expo and we suffered a setback when it went out of stock from all known vendors with a 45 day down time. Given the chance to work on this project again, we would like to begin work much earlier with regards to setting up the serial VI on LabVIEW. We would also consider the possibility of parts going out of stock at the last minute and attempt to order parts early in order to compensate for potentially prolonged down times.

RECOMMENDATIONS

There are a number of recommendations we would like to make in regards to the MBAT system. These include an effluent pump recommendation as well as recommendations to our vessel. Both are outlined in this section.

Pump Recommendations

There are a number of recommendations we would like to make in regards to the MBAT system. First, we were not able to secure the peristaltic pump; the pump has been out of stock but as of Monday, December 14, 2009, they are back in stock. The peristaltic pump that will fit the need of the MBAT system is the Masterflex L/S (laboratory standard) Computer Peristaltic Pump Drive, part number HV-07551-10 by Cole Parmer and a Masterflex Easy Load II pump head. The pump head was chosen because it was compatible with the AnMBR system and can be interchanged if needed. The reason for a peristaltic pump is not only because of its accuracy, but also because a peristaltic pump does not have to come into contact with the corrosive and toxic synthetic wastewater material found in Appendix G. Furthermore, a computer controlled pump will also allow the user to control the flow and direction of the pump to allow for backflushing. An extensive study needs to be performed in order to comprehend the syntax for pump control using the serial interface before this can be incorporated and we recommend that someone who is well versed with the LabVIEW interface address this when incorporating the pump into the system.

Another recommendation we'd like to make is the cleaning of the inlet pump. We have purchased a freshwater/saltwater aquarium pump from Aqua Clear. Although the aquarium pump will suffice as an inlet pump, it is strongly recommended that it be cleaned using a bleach solution (as opposed to auto-claving at 150°C) according to the manufacturer's manual.

Vessel Recommendations

We also recommend purchasing four hex nuts for the top plate assembly. We purchased a pack of 18-8 Stainless Steel ¼"-20 thumb nuts (Part Number 94365A390) from McMaster-Carr but failed to recognize that a pack only contains one nut. Three more can be purchased, but since the bolt must be tightened down completely due to the warping in the head plate mount, any ¼"-20 nuts will work.

The head plate contains some manufacturing errors as well. The tapped thread for the Yor-Lok Through-Wall Compression Tube Coupling is not straight and thus the membrane housing is not centered either. Furthermore, the threading for the 1/8" NPT for the level sensor is not centered either, although this is not as big of a problem since it worked well during our level sensor validation testing.

Sensor Validation Plan and Recommendation

We recommend that a sensor validation be performed prior to the complete implementation of the MBAT system. The validation of the thermocouple can be performed by connecting the thermocouple to the LabVIEW signal express and observing the measurement of the ambient air temperature i.e. room temperature of approximately 23°C inside campus buildings. The validation can be made conclusive by verifying the change in temperature by gripping the thermocouple in one's hand or placing it in a temperature controlled environment to verify the change from room temperature.

Validation for the differential pressure transducer is a little more complicated as there is no differential pressure gauge to test against. The only validation we can recommend is to test under multiple conditions. The first step would be to set up the system at atmospheric pressure with no filtration taking place. Under this condition the transducer should produce a voltage output that translates to 0 psi pressure across the membrane. The second test would be to use a bicycle pump in the sealed MBAT system to generate positive pressure. Under this condition, the transducer should produce a voltage output that translates to the positive psi range. Similarly, a test can be performed by using the effluent pump to pull fluid through the membrane to verify for negative pressure. The differential pressure readings can be further validated by using standard pressure gauges at the inlet and outlet and computing the difference and comparing results with the differential gauge.

Our validation for the flow rate measurement via a weighing scale could not be performed as there was no documentation regarding the serial port control and measurement. We would like to recommend that OHaus be contacted in order to obtain a detailed instructions manual for the serial port operation of their weighing scale model AV2102 before it can be incorporated into the LabVIEW and validated. Once this documentation is obtained, the system can be set up to measure mass for fixed time duration via LabVIEW. This mass can then be converted to volume using the density and a volumetric flow rate can be calculated this way. This sensor system can be validated by utilizing a pre-determined volume of a substance and verifying if the calculations match this volume.

Lastly, we would like to recommend the incorporation of the serial LabVIEW interface in order to incorporate the pump control and the weighing scale. Our team was unable to complete this due to limitations of time and experience with the serial interface but we have some recommendations and instructions for the overall LabVIEW setup and these are covered in Appendix N.

Refrigerator Calibration

If operation below 10°C is required we recommend that the refrigerator be calibrated to determine the refrigerator settings corresponding to the desired operating temperature of the MBAT. Though we did not complete the refrigerator validation we have written a procedure to perform this task that can be seen in the validation plan.

Positive Flow Recommendations

As previously outlined in the discussion section, a positive pressure flow needs to be further investigated. Two proposed solutions exist so far, to continuously pump water into the vessel using the influent pump, or to change the tubing connections and use the effluent pump as an influent pump and have the effluent tube connected directly to the volume flow rate subsystem (scale and bucket combination). Both these solutions require that the level sensor be disabled. We recommend using these two proposals to begin the design of a positive flow MBAT system.

CONCLUSION

Our main goal in this project is to help our sponsors gain information about the interaction between the anaerobic microbes and membranes. The project requires that the membranes be transferred from the previous Anaerobic Microbial Bioreactor (AnMBR) system to the Membrane Analysis Testbed (MBAT) system. Furthermore, the testbed needs to hold the membrane securely and fluid flow through the membranes needs to accommodate a number of specifications outlined by our sponsors. For instance, the system also needs to incorporate various membrane cleaning methods such as sparging and backflushing. Throughout the entire process, it is also required that we measure and record data on the temperature, trans-membrane pressure, and flow rate of influent and effluent water. It is also required that the temperature of the fluid throughout the process be between 10°C - 15°C with a deviation no more than 3°C throughout the process.

The main challenges that we faced with this project was the cost of the parts that needed to be selected. Initial investigation into the cost of the pumps was approximately $2000 so we wanted to be sure to finalize the correct pump. Furthermore, all parts needed to be corrosion resistance since all parts will come into contact with the synthetic wastewater (details of the synthetic wastewater can be found in Appendix G).

Our final design consists of a vessel, thermocouple, differential pressure gauge, and a system that can measure the effluent flow rate using a simple scale and bucket system. An aquarium pump will be used as an influent pump to transport the synthetic wastewater into the vessel, while a peristaltic pump will be used to pull the effluent water out of the system. A vertical level sensor was also integrated into the vessel to control the influent pump. Our design also incorporated LabVIEW to measure, display, and store the temperature of the system and the differential pressure to measure the trans-membrane pressure. Furthermore, the peristaltic pump that was chosen is computer programmable, allowing for automated backflushing should the need arise. Sparging gas will be incorporated into the system via a nitrogen tank and a regulator. The system will be housed in a refrigerator to allow for operation in the desired temperature range. Additionally, we have created the MBAT to be compatible with the AnMBR system in terms of the tubing requirements. This allows for a reduction of cost for running both systems (alternative tubing and fittings are not needed for the MBAT).

A number of recommendations have also been outlined. The peristaltic pump was not able to be secured because it was out of stock, but it is recommended that a L/S (laboratory standard) Computer Peristaltic Pump Drive, part number HV-07551-10 by Cole Parmer be purchased as the effluent pump. The aquarium inlet pump needs to be cleaned using a bleach solution according to manufacturer's recommendation. Also, four hex nuts are recommended for the top plate assembly; four wing nuts were used for testing, but it is difficult to tighten the bolts securely and is not recommended. During the refrigerator calibration, the lowest setting outputted a temperature reading of 10°C; the lowest preferred range of temperature described by our sponsors. If operation is required below this temperature setting, further calibration is recommended and a procedure is outlined in the recommendation section. Additionally, the weigh scale to be incorporated for flow rate measurement could not be setup because the lack of documentation relating to the serial control and time constraints. Documentation needs to be acquired to integrate the scale into a LabVIEW setup.

A positive pressure flow was not able to be designed into the system but was deemed unnecessary by Professor Skerlos between the final design and fabrication phase. However, there are two proposed methods that can be investigated to achieve this. The influent pump can be used to continuously pump in wastewater to build up pressure, but a thorough investigation of the influent pump needs to be completed to ensure that it will not fail in this manner. Another suggestion is to use the more durable peristaltic pump used for the effluent pump, and use it as an influent pump and connect the effluent pipe straight to the scale used for flow measurement. Both suggestions are based on the idea that the pressure prior to membrane must be larger than after the membrane filtration process. In both cases, the vertical level switch needs to be disabled.

Given the scope of the project and the time constraints we had to address, our team believes that we have met the project goal in creating a system that can control and examine the growth of the biofilm and observe its characteristics on the wastewater filtration process. While there is still much work to be done, we have left Kate Adams with a product that will help her in her doctoral studies.

ACKNOWLEDGEMENTS

We would not have been able to complete what we have in this project if it were not for the help from a number of people. We would like to thank the following:

Professor Steven Skerlos, for his patience and understanding as well as his continuous support throughout the semester.

Kate Adams, for helping us with the engineering specifications. Adam Smith, for helping us understand the technical aspects of the AnMBR system. Dan Johnson, for his help with the testing validation phase as well as helping us address the associated safety issues. Bob Coury, for his help with the welding portion in the fabrication process. We'd also like to thank John Baker for his help and guidance with the integration of LabVIEW into our system.

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US6387262: Hollow-fiber membrane biofilm reactor for autohydrogenotrophic treatment of water

US5484524: Wastewater treatment apparatus

US5888401: Method and apparatus for reducing membrane fouling

US6463790: Membrane filtration method and apparatus for simultaneously and continuously monitoring time-based membrane fouling

US7459083: Method for controlling fouling of a membrane filter

BIOGRAPHIES

Deandre Reagins

I am a fifth year student double majoring in Chemical and Mechanical Engineering with a minor in Economics. I am originally from Carthage, Texas. As a child I had interests in science and math and I have pursued my interests up until this point. I see my degree path as being able to link to very important engineering fields and I feel it will be very useful in the energy industry which is where I hope to work.

I have had four previous internships as a collegiate student: one with the Chicago Transit Authority and the other three with Shell Exploration and Production. I have worked in the upstream division of Shell during my time there and I would like to function as a drilling or completion engineer within the company at some point. I am also considering graduate school programs in both Petroleum Engineering and Energy Resource Engineering at Stanford University and the University of Texas at Austin.

During this past summer at Shell I worked on a project focusing on the treatment of water used in oilfield operations for recycle and reuse. The experience was gratifying at the time as it allowed me to tie together many of the concepts I have learned in the Mechanical and Chemical Engineering Departments. I anticipate that the experience from that summer will also aid during this project.

John Song

I am currently a fifth year student mechanical engineering graduating with a concentration in energy. I am not yet certain what I want to do with the rest of my life as I'm sure many other students in the same situation are or should be. The world is big and there is a lot one can do with a University of Michigan education. I've always been good at science and math but have only recently begun to understand the meaning of being an engineer. This past summer, I've been working on a homemade jet engine that is built around a large truck turbocharger and hope to be able to make it run in the not so distant future.

I've chosen to have a concentration in energy because I enjoy learning about the field of fluid mechanics, thermodynamics and the idea of sustainability. Although my future is uncertain, I love experiencing new adventures and learning through every experience. I love spending time outdoors with my friends and enjoy the idea of living off the land.

I was drawn to this project because of the impact I believe it will have with its success and its feature of sustainability. Clean water is an important aspect in civilization and I believe in the ideas that the research team has outlined for the project. I hope this can be the start of my impact on saving the world.

Adithya Varadarajan

I am a 5th year student studying Mechanical Engineering. I am originally from the other side of the globe, New Delhi, India. Throughout my childhood, I was obsessed with making and building things and that passion led me to pursue engineering in my undergraduate education. Around the time of my application to Michigan there was an Industrial Design program on offer but when it was time for me to declare a major, the program was no longer available and I chose Mechanical Engineering as I felt it would give me a better foundation in engineering fundamentals that I could build upon in later studies. Over the course of my Mechanical Engineering education, I firmly established my love for Design and an unfortunate dislike for a couple of pure ME topics that I shall refrain from mentioning. Following the completion of my major in December, I intend on pursuing graduate studies in Product Design.

My past experience includes an internship with Chrysler where I primarily did data analysis and programming, the latter being one of my strengths. This past summer I worked for Maruti Suzuki, an Indian automobile company, where I worked on redesigning seating systems. I have also studied abroad in Germany where I carried out research and developed conceptual designs for a fluidized bed gasifier. In terms of my long term future, I have three dreams – study Product Design at Stanford, travel the world and start my own design company (the plans for which I am currently developing).

Appendix A: Bill of Materials

BILL OF MATERIALS
Updated – 14th December 2009

S. No	Vendor	Item	Part No.	Quantity	$/unit	Function	Total $	Note
1	Omega	Low Cost Wet/Wet Differential Pressure Sensor	PX26-015DV	1	$36.00	Measure Differential Pressure across Membrane	$36.00	Purchased
2	Omega	Pressure Sensor Connector (4 pin)	CX136-4	1	$3.00	Connector to LabVIEW module	$3.00	Purchased
3	Omega	Pressure Sensor Cable (4 conductor, 100 ft)	TX4-100	1	$35.00	Wire for Connector	$35.00	Purchased
4	Omega	Thermocouple	KQSS-116G-12	1	$22.00	Measure Reactor Temperature	$22.00	Purchased
5	Omega	Level Sensor Switch	LV-22	1	$61.00	Switch on inlet pump based on water level	$61.00	Purchased
6	Cole Parmer	Tygon Food Tubing, L/S 25, 0.19" ID, 25ft	HV-06429-25	1	$83.00	Inlet Tubing	$83.00	Available in Lab

7	Cole Parmer	Viton FDA Tubing, L/S 25, 0.19" ID, 25ft	HV-96412-25	1	$181.00	Effluent Tubing	$181.00	Available in Lab
8	Cole Parmer	L/S Computer Compatible Peristaltic Pump Drive	HV-07551-10	1	$1,980.00	Programmable Peristaltic Pump for Effluent	$1,980.00	Out of Stock
9	Cole Parmer	L/S Easy-Load II pump head, SS rotor	HV-77201-60	1	$300.00	Pump head for Peristaltic Pump	$300.00	Out of Stock
10	Cole Parmer	2-stage regulator, 2000 scfh, 580 CGA fitting	EW-98202-23	1	$370.00	Sparging Gas Regulator	$370.00	Purchased
11	Ohaus	Adventurer Pro 2102C, Weighing Scale	AV-2102C	1	$871.50	Weighing scale for mass flow rate (effluent)	$871.50	Available in Lab
12	National Instruments		NI PCI-6034E	1	$999.00	PCI DAQ Card	$999.00	Available in Lab
13	National Instruments	Connector Cable	SHC68-68-EP	1	$129.00	DAQ to Connector Block Cable	$129.00	Available in Lab
14	National Instruments	Connector Block	SC-2345	1	$359.00	Connector Block for LabVIEW Modules	$359.00	Available in Lab

15	National Instruments	LabVIEW Full		1	$2,599.00		$2,599.00	Available in Lab
16	National Instruments	Analog Thermocouple Module	SCC-TC01	1	$179.00	Thermocouple Input Module	$179.00	Available in Lab
17	National Instruments	Analog Voltage Module	SCC-AI02	1	$359.00	Voltage Input Module	$359.00	Available in Lab
18	McMaster Carr	Thin Wall 316SS Pipe, 6.357" ID, 12" Length	4378K611	1	$87.72	MBAT Vessel Container	$87.72	Purchased
19	McMaster Carr	Wear Resistant 410SS Sheet, 1/4" thick, 8" x 24"	9524K662	1	$223.73	Head Plate, Mount and Base Plate	$223.73	Purchased
20	McMaster Carr	FEP Encapsulated Viton O-Ring, 6.5" ID, 6.75" OD	93445K551	1	$13.68	O-ring	$13.68	Purchased
21	McMaster Carr	18-8 SS Hex Thumb Screw. 1/4"-20, 1.25" Length	90113A169	4	$5.67	Thumb Screws	$22.68	Purchased
22	McMaster Carr	316SS Yor-Lok Tube Thru Wall coupling, 1/8" OD	5182K723	2	$25.49	Compression Fittings	$50.98	Purchased

23	McMaster Carr	18-8 SS Hex Thumb Nut, 1/4"-20	94365A390	4	$5.46	Nuts	$21.84	Purchased
24	McMaster Carr	316SS Yor-Lok Tube Adapter, 1/16" OD, 1/8" NPT	5182K435	1	$13.11	Yor-Lok Compression Fitting for Thermocouple	$13.11	Purchased
25	McMaster Carr	PE Barb Tube Fitting Adapter, 3/16" ID, 1/8" NPT	2808K26	1	$5.39	Barbed Connectors (pack of 10)	$5.39	Purchased
26	KNF	Micro Diaphragm Gas Pump, 12V DC, 1 bar	NMP830KVDC	1	$130.00	For Aeration	$130.00	Out of Stock
27	Aqua Clear	Aquarium Pump	402	1	$44.99	Inlet Pump	$44.99	Purchased
						Total Expenditure	$1011.12	

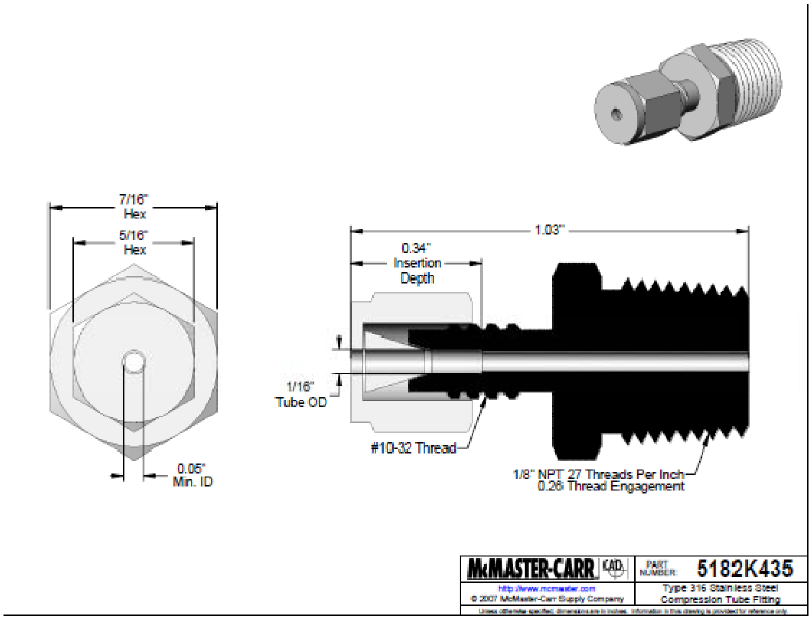
Appendix B: Engineering Change Notices from Final Design

There were three main engineering changes with regards to our system. These changes impacted our head plate assembly and our flow diagram.

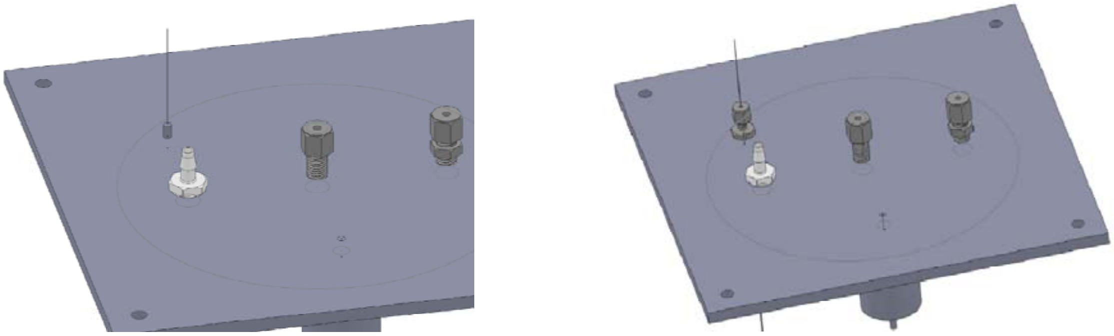
Thermocouple

To save on costs and assembly time, we changed thermocouple models. Both thermocouples are k type thermocouples. The thermocouple that we are now utilizing differs from the original thermocouple in the manner that it can be attached to the head plate mount. The thermocouple we were originally considering was able to be screwed directly into the head plate mount where as this thermocouple had to be attached using a fitting. This change did not affect our data acquisition system in any way. This change was made on November 10, 2009 and was approved by our sponsor.

Compression Tube Fitting



As we changed our thermocouple it became necessary to develop a way to attach the thermocouple probe to the head plate. We chose to attach the thermocouple to the head plate using a compression tube fitting. This fitting was chosen so that it would not require any additional machining to the head plate. The change was made on November 20, 2009 and was approved by our sponsor. This change is illustrated in the figure below.



Head Plate Assembly Before (Left) and After Design Change

Inlet Pump

Upon reanalyzing our flow system, we determined that a peristaltic pump is only needed for the effluent end of the MBAT system. The type of precision provided by the peristaltic pump is not required for the inlet pump as it will only be responsible for filling the MBAT to a desired level. We obtained an aquarium pump to use for the inlet flow. This change was made on November 20, 2009 and authorized by our sponsor.

Appendix C: (a) Material Selection

Our detailed material selection process has been covered for three major components of our final design.

TUBING

Our material for tubing in the entire MBAT system was selected based on several considerations. One of the requirements was that it needed to be compatible with the selected effluent pump which was a Masterflex L/S pump. We further added the requirement for compatibility with the existing AnMBR system in order to facilitate ease of interchangeable tubing. The requirement from the inlet tube was that it needed to have excellent non-wetting properties due to the suspended matter in the synthetic wastewater and this would enable ease of cleaning. The effluent tube needed to have strong acid resistance as the effluent contained a fair amount of sulfuric acid. Both the inlet and the effluent needed a pressure tolerance of at least 5psi which was the pressure rating of the MBAT system.

Based on these criteria, we selected the Tygon Food tubing for the inlet and Viton FDA tubing for the outlet. The Tygon tubing has good resistance to corrosion and has excellent non wetting properties, allowing for flush cleaning and complete drainage. The Viton FDA tubing has good corrosion resistance and is particularly good for acids. Both tubing types have a high service temperature and can be autoclaved. Both the tubing types also happen to be the same tubing used in the AnMBR system thus achieving the goal of compatibility and ensuring that the tubing is interchangeable with that system.

MBAT VESSEL

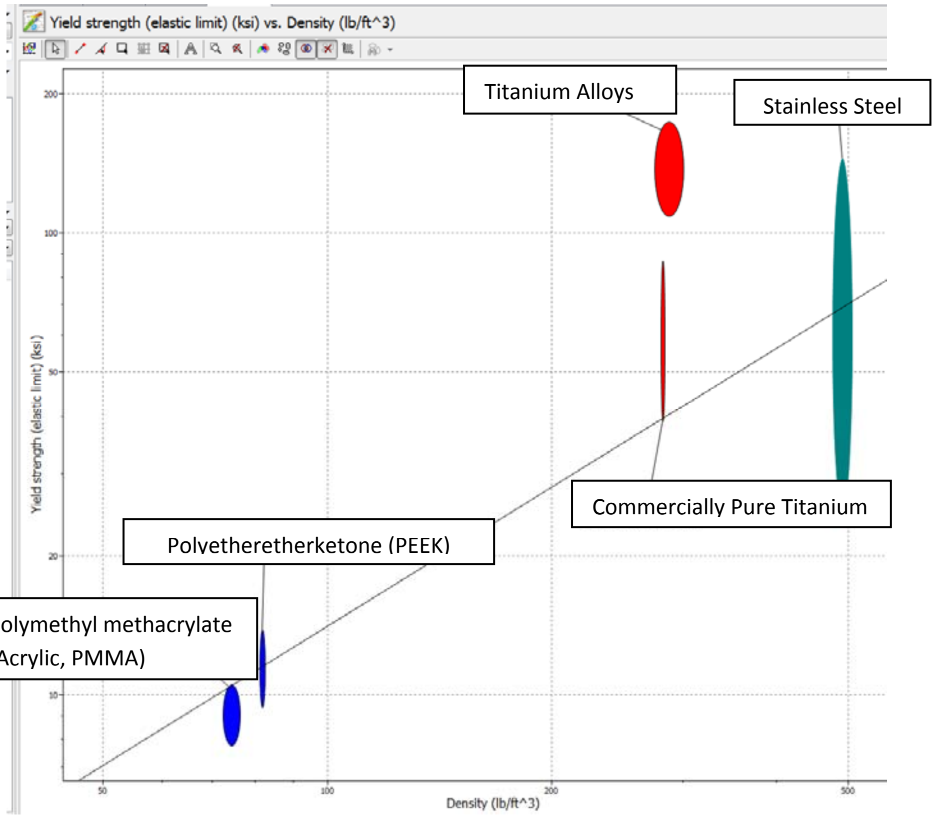
Our MBAT vessel was another part of the system for which material selection was a key aspect. The primary function of this component was to act as an airtight pressure vessel for the anaerobic digestion to take place. There were also several constraints on the selection of this material and these are listed below –

- Bear axial loads – the system would be placed vertically and this would mean that the material at the base needed to be able to withstand the axial loading of the material above it in the vessel including that of the headplate and the components attached to it.
- Corrosion resistance – this was an important constraint as the synthetic wastewater had a pH range between 2 and 12 both pre and post the treatment process and the vessel needed to withstand this for an extended duration.
- Service Temperature – one of the cleaning methods that will be employed for the system is autoclaving and this involves heating of the system to temperatures of about 150C. For this purpose, the vessel material needed to have a service temperature higher than this amount.
- Machinability and Weldability – both of these were important constraints with regards to the ease of manufacturing our vessel using our given resources. It was important to find a material that did not require any expensive, hazardous or specialized machining methods
- Radius – The decided shape was a cylinder and the radius needed to be a minimum of 6 inches when taking into consideration that the membrane housing was 4 inches wide with a clearance of an inch on either side.

Using all these constraints we determined the appropriate material index for a cylinder with internal pressure. For a strength limited design at minimum mass (cost, energy, eco-impact) -- the material index that needed to be maximized was

$$\boldsymbol{\sigma_f}/(\boldsymbol{\rho})$$

By using this material index with our various constraints in CES, we obtained 5 candidate materials for the MBAT vessel as



From these, the material selected was stainless steel due to several factors.

- Stainless Steel and PMMA are the lowest cost among these 5 materials. PMMA has poor sulfuric acid resistance so was rejected.
- Stainless steel is also the lowest for embodied energy and CO2 footprint in primary production.
- It meets all our criteria as it has successfully passed through all the stages of our CES material selection

BARBED CONNECTORS

The primary function of these fittings was to act as an airtight interface between the head plate of the MBAT Vessel and the tubing for the flow system. There were several constraints on these fittings –

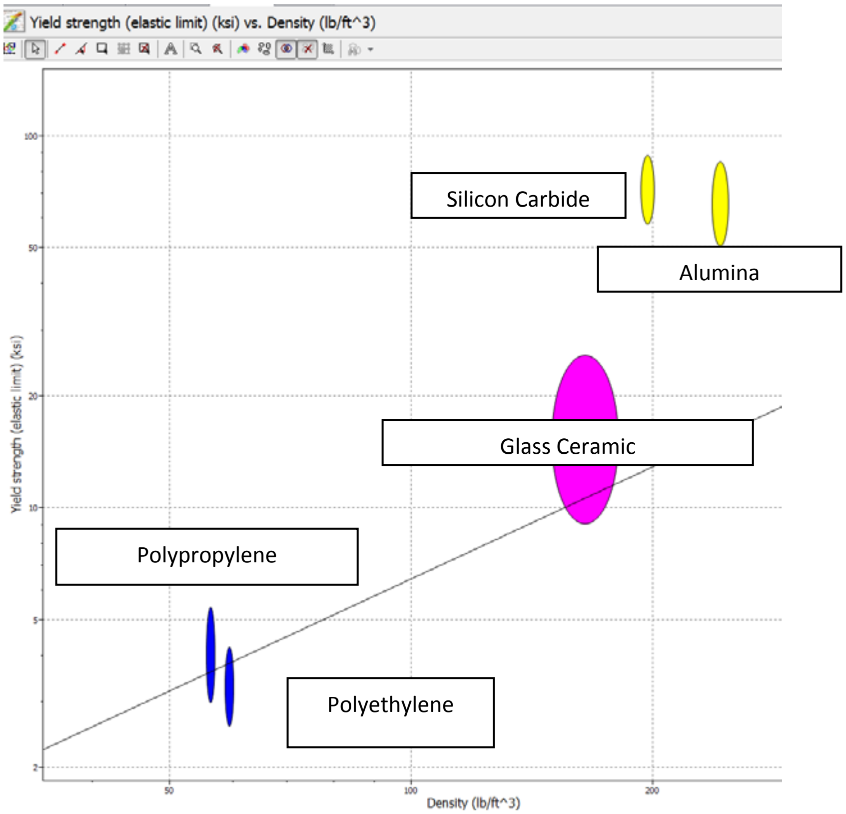
- Corrosion resistance – this was an important constraint as the synthetic wastewater had a pH range between 2 and 12 both pre and post the treatment process and the vessel needed to withstand this for an extended duration.

- Service Temperature – one of the cleaning methods that will be employed for the system is autoclaving and this involves heating of the system to temperatures of about 150C. For this purpose, the vessel material needed to have a service temperature higher than this amount.
- Shape – The shape of these fittings is a 3D hollow prismatic solid

We approximated the shape of our fittings to be cylinders and using all the above constraints we determined the appropriate material index for a cylinder with internal pressure. For a strength limited design at minimum mass (cost, energy, eco-impact) -- the material index that needed to be maximized was

$$\boldsymbol{\sigma_f/(\rho)}$$

By using this material index with our various constraints in CES, we obtained 5 candidate materials for the barbed connectors as ---------



From these, the material selected was polyethylene.

- We could have used either polyethylene or polypropylene as both meet all the desired characteristics
- Both materials are low cost, and have low environmental impact compared to the others as they can be recycled.

Appendix C: (b) Environmental Performance

Material Selection Assignment

1. Material Selection Assignment (Environmental Performance)

1. *Start with the 2 materials that you selected using CES in the Material Selection assignment above.*

   Material #1: 316 Stainless Steel
   Material #2: Polyethylene

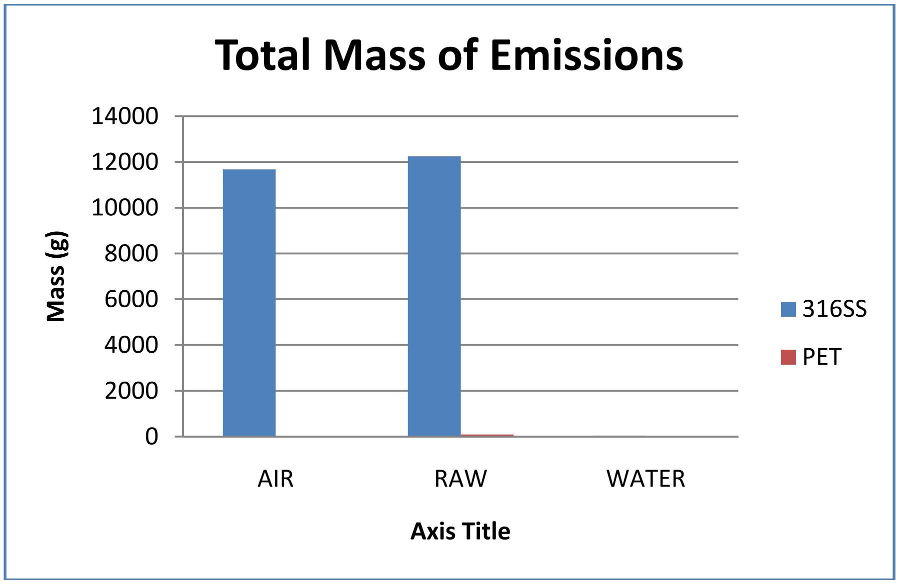
2. *Determine what mass of these materials you need in your final design.*

   Mass of Material 1: 2.67kg
   Mass of Material 2: 5g

3. *Look up closest materials available in SimaPro*

   316 Stainless Steel: X2CrNiMo1712 (316L)
   Polyethylene: PET ETH S

4. *Calculate total mass of air emissions, water emissions, use of raw materials, and (solid) waste*



	AIR	RAW	WATER
316 SS	11671	112247.39	43.95

Polyethylene	7.154	93.2166	0.255

5. *Determine which material choice has a bigger impact on the environment within each of the EcoIndicator 99 damage classifications.*

   316 stainless steel has a bigger impact on the environment within each of the EcoIndicator 99 damage classifications.

6. *Discuss which of the damage meta-categories ("human health", "ecotoxicity" and "resources") are most likely to be important based on the EI99 point values.*

   Based on the EI99 point values resources use (minerals) is the most important consideration. By observing values from the single score and normalized plots it is clear that mineral use is the highest contributor to environmental impact. Stainless steel has a high mineral requirement in comparison to PET, requiring nickel, nitrogen, and molybdenum in addition to other elements. Additionally the process of creating steel requires a higher energy input than does PET.

7. *Determine which material (on its own) has a higher EcoIndicator 99 "point value" and discuss which material is likely to have a bigger impact when the life cycle of the whole product is considered.*

   Stainless steel has the higher EcoIndicator 99 point value and appears to have the higher impact environmental impact. When considering the full life cycle of the material stainless steel is the more impactful material from a life cycle approach. Stainless steel has higher energy, labor, and material requirements to manufacture. Stainless steel is 100% recyclable and the recycling of stainless steel has a higher environmental impact that the recycling of PET. If the stainless steel is not recycled it may rust after time and release iron oxides into the environment. Both materials are important. PET can be recycled but is not considered biodegradable as it takes several centuries until it is sufficiently degraded. Since we are using such as small amount of PET in comparison to 316 stainless steel we determined that the primary contributor to the environmental impact of the MBAT.

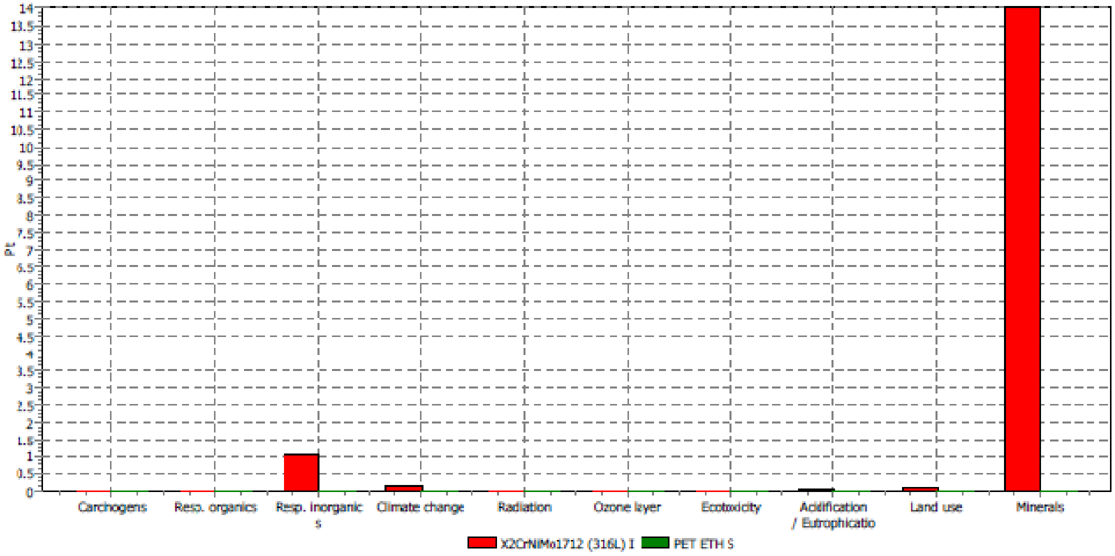
   We analyzed other materials such as brass in SimaPro and came to the conclusion that based on our material requirements (corrosion resistance and pH exposure) these materials are the materials that met our engineering requirements and have the most minimal environmental footprint.

SimaPro 7.1 Educational
Project: MBAT

Impact assessment

Date: 12/13/2009 Time: 3:41:26 PM

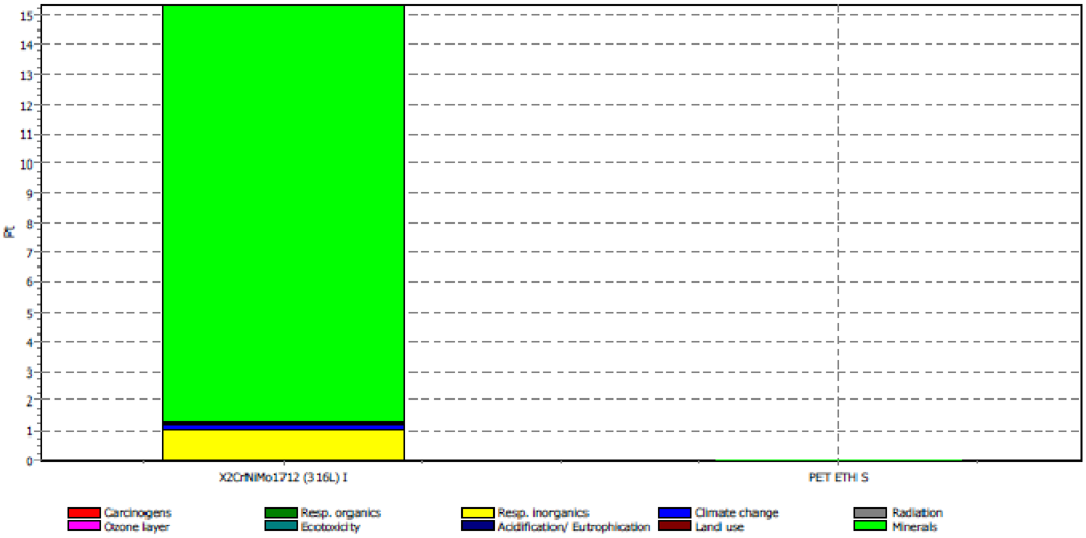
Title: Comparing 2.87 kg 'X2CrNiMo1712 (316L) I' with 0.002 kg 'PET ETH S'
Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I
Indicator: Weighting
Per impact category: Yes
Skip categories: Never
Relative mode: Non



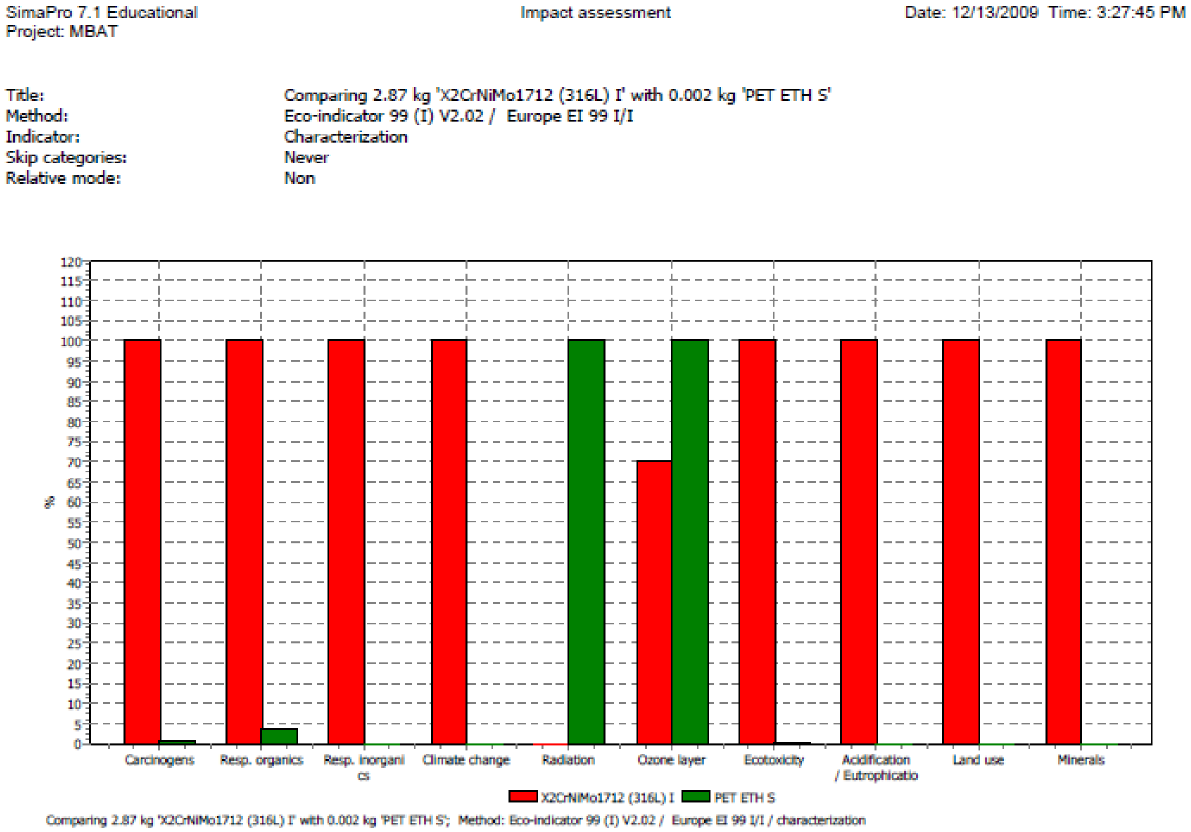
Comparing 2.87 kg 'X2CrNiMo1712 (316L) I' with 0.002 kg 'PET ETH S'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / weighting

SimaPro 7.1 Educational	Impact assessment	Date: 12/13/2009 Time: 3:41:48 PM
Project: MBAT

Title: Comparing 2.87 kg 'X2CrNiMo1712 (316L) I' with 0.002 kg 'PET ETH S'
Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I
Indicator: Single score
Per impact category: Yes
Skip categories: Never
Relative mode: Non



Comparing 2.87 kg 'X2CrNiMo1712 (316L) I' with 0.002 kg 'PET ETH S'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / single score



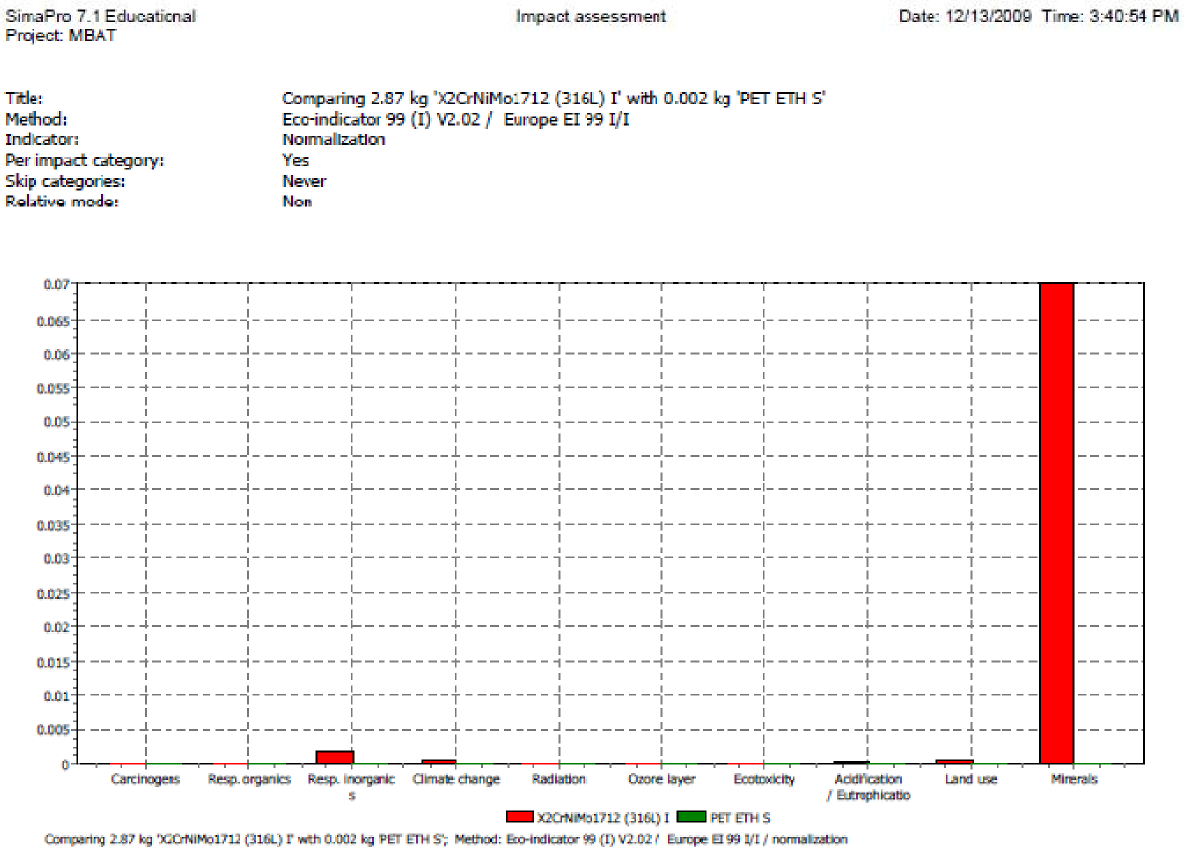
SimaPro 7.1 Educational
Project: MBAT

Impact assessment

Date: 12/13/2009 Time: 3:27:45 PM

Title:	Comparing 2.87 kg 'X2CrNiMo1712 (316L) I' with 0.002 kg 'PET ETH S'
Method:	Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I
Indicator:	Characterization
Skip categories:	Never
Relative mode:	Non

Comparing 2.87 kg 'X2CrNiMo1712 (316L) I' with 0.002 kg 'PET ETH S'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / characterization



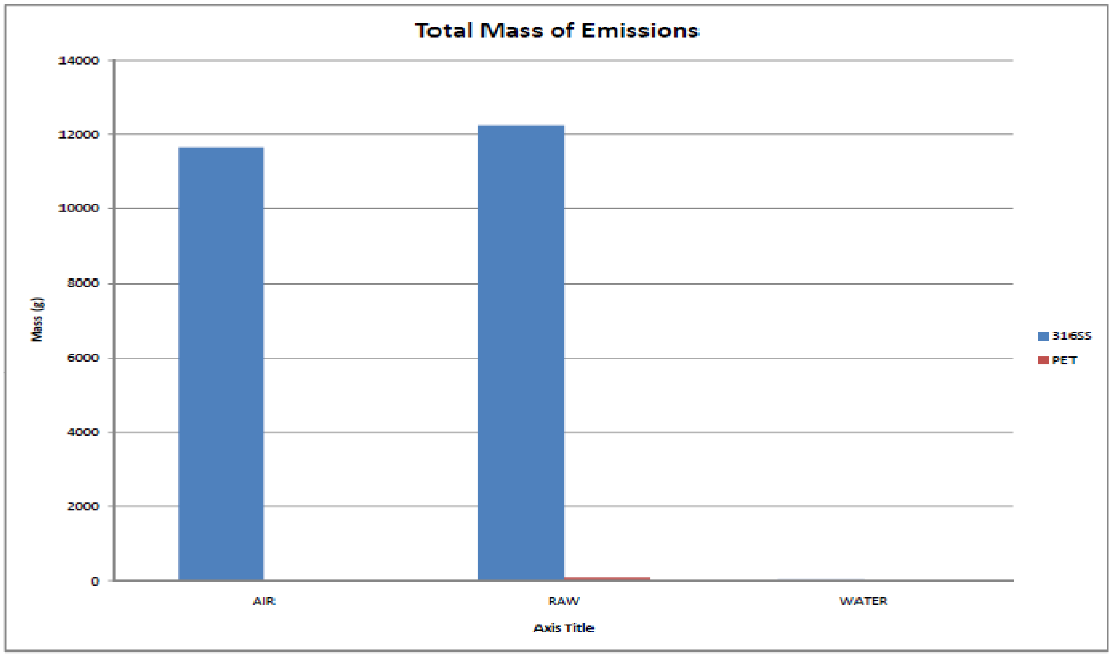
SimaPro 7.1 Educational
Project: MBAT

Impact assessment

Date: 12/13/2009 Time: 3:40:54 PM

Title:	Comparing 2.87 kg 'X2CrNiMo1712 (316L) I' with 0.002 kg 'PET ETH S'
Method:	Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I
Indicator:	Normalization
Per impact category:	Yes
Skip categories:	Never
Relative mode:	Non

Comparing 2.87 kg 'X2CrNiMo1712 (316L) I' with 0.002 kg 'PET ETH S'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / normalization



Appendix C: (c) Manufacturing Process Selection

While our project is a "one-off" laboratory instrument for the sake of research, we do anticipate other researchers needing to use the MBAT system to study the effect of biofilms. For this purpose we estimate a production volume of roughly 1000 for the MBAT. Our primary components and their engineering characteristics are described in the table below

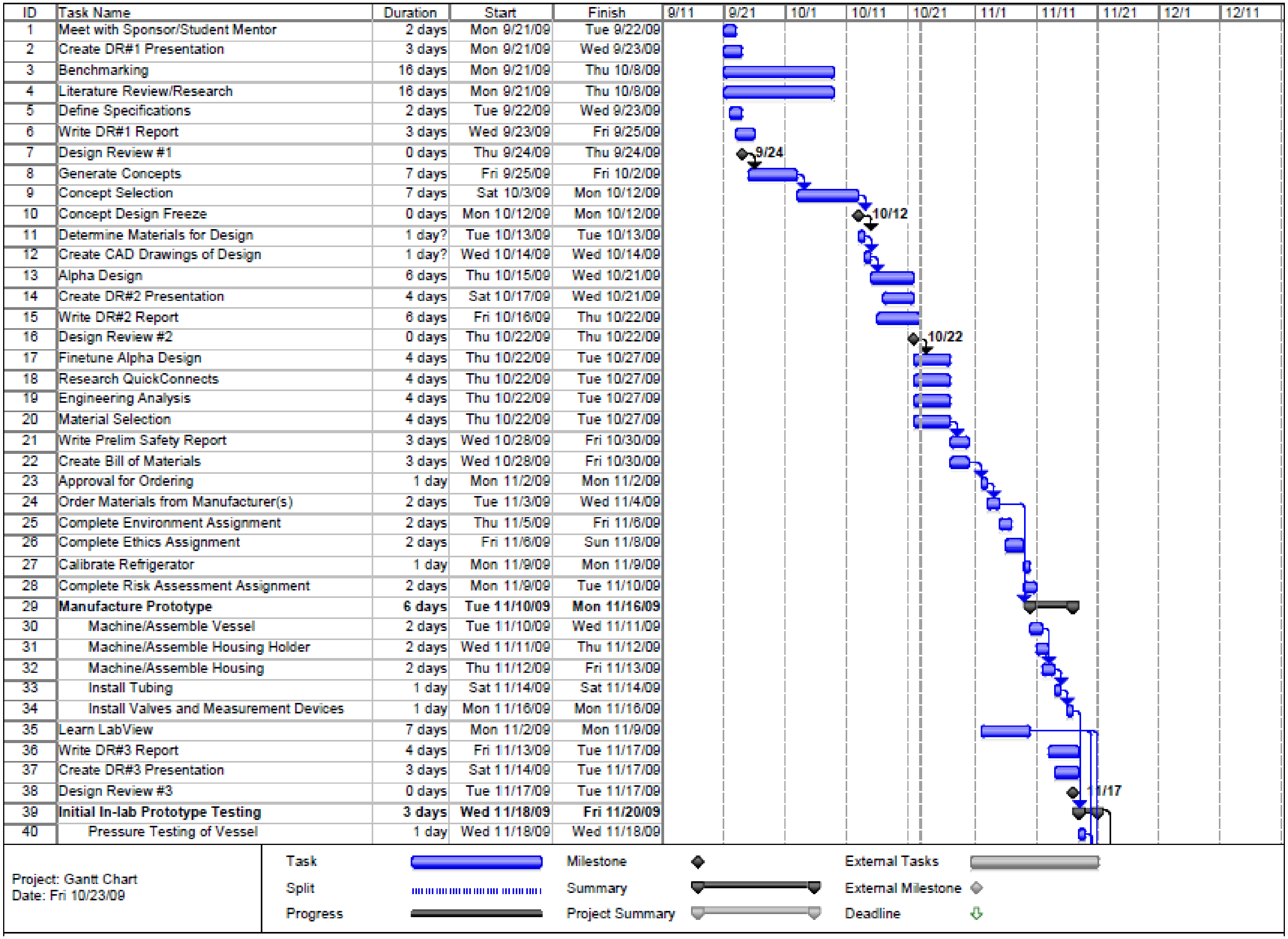
Table 1: Engineering Requirements

Specification	**Barbed Connector**	**MBAT Vessel**
Material	Thermoplastic	Ferrous Metal
shape	Circular prismatic	Circular prismatic
Mass (kg)	<0.1	< 15
section thickness (mm)	0.1	10
batch size (units)	1000	1000

Based on our analysis in the CES Process Selector we have determined that for the required batch sizes and feature sizes, the following processes are suitable

- MBAT Vessel – Electric Discharge Wire Cutting – This process has an economic batch size of 1 to 1000 units. Also, this is the only stainless steel process that provides us with a thin enough material thickness of 10mm. for our vessel
- Barbed Connector – Polymer Extrusion – this is the only remotely suitable process for manufacturing barbed connectors at such low production volumes. It meets the requirements for section thickness for the part but it cannot be used alone to make the barbed connectors, it needs to be utilized in combination with a cutting process.
- While these processes are highly specialized, it is safe to assume that these parts have applicability for other fields as well and their actual production numbers will be a lot higher than 1000. In this case we can look at powder injection molding for stainless steel batch sizes upto 10^7 and thermoplastic injection molding for the polypropylene/polyethylene for batch sizes upto 10^6.

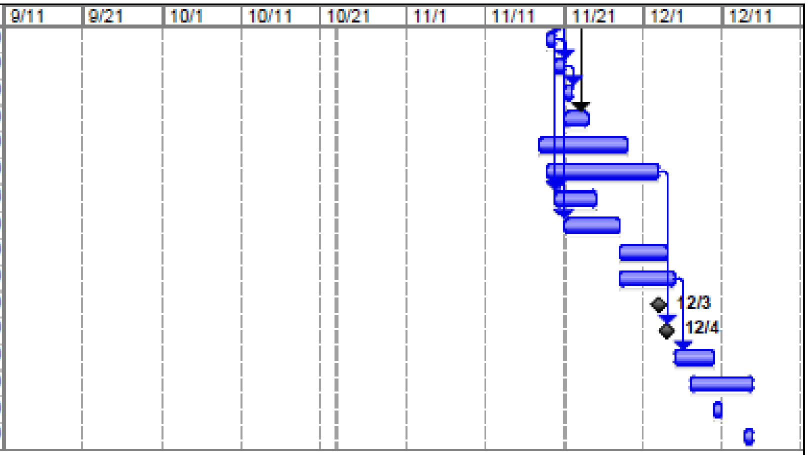
Appendix D: Gantt Chart



ID	Task Name	Duration	Start	Finish
1	Meet with Sponsor/Student Mentor	2 days	Mon 9/21/09	Tue 9/22/09
2	Create DR#1 Presentation	3 days	Mon 9/21/09	Wed 9/23/09
3	Benchmarking	16 days	Mon 9/21/09	Thu 10/8/09
4	Literature Review/Research	16 days	Mon 9/21/09	Thu 10/8/09
5	Define Specifications	2 days	Tue 9/22/09	Wed 9/23/09
6	Write DR#1 Report	3 days	Wed 9/23/09	Fri 9/25/09
7	Design Review #1	0 days	Thu 9/24/09	Thu 9/24/09
8	Generate Concepts	7 days	Fri 9/25/09	Fri 10/2/09
9	Concept Selection	7 days	Sat 10/3/09	Mon 10/12/09
10	Concept Design Freeze	0 days	Mon 10/12/09	Mon 10/12/09
11	Determine Materials for Design	1 day?	Tue 10/13/09	Tue 10/13/09
12	Create CAD Drawings of Design	1 day?	Wed 10/14/09	Wed 10/14/09
13	Alpha Design	6 days	Thu 10/15/09	Wed 10/21/09
14	Create DR#2 Presentation	4 days	Sat 10/17/09	Wed 10/21/09
15	Write DR#2 Report	6 days	Fri 10/16/09	Thu 10/22/09
16	Design Review #2	0 days	Thu 10/22/09	Thu 10/22/09
17	Finetune Alpha Design	4 days	Thu 10/22/09	Tue 10/27/09
18	Research QuickConnects	4 days	Thu 10/22/09	Tue 10/27/09
19	Engineering Analysis	4 days	Thu 10/22/09	Tue 10/27/09
20	Material Selection	4 days	Thu 10/22/09	Tue 10/27/09
21	Write Prelim Safety Report	3 days	Wed 10/28/09	Fri 10/30/09
22	Create Bill of Materials	3 days	Wed 10/28/09	Fri 10/30/09
23	Approval for Ordering	1 day	Mon 11/2/09	Mon 11/2/09
24	Order Materials from Manufacturer(s)	2 days	Tue 11/3/09	Wed 11/4/09
25	Complete Environment Assignment	2 days	Thu 11/5/09	Fri 11/6/09
26	Complete Ethics Assignment	2 days	Fri 11/6/09	Sun 11/8/09
27	Calibrate Refrigerator	1 day	Mon 11/9/09	Mon 11/9/09
28	Complete Risk Assessment Assignment	2 days	Mon 11/9/09	Tue 11/10/09
29	**Manufacture Prototype**	**6 days**	**Tue 11/10/09**	**Mon 11/16/09**
30	Machine/Assemble Vessel	2 days	Tue 11/10/09	Wed 11/11/09
31	Machine/Assemble Housing Holder	2 days	Wed 11/11/09	Thu 11/12/09
32	Machine/Assemble Housing	2 days	Thu 11/12/09	Fri 11/13/09
33	Install Tubing	1 day	Sat 11/14/09	Sat 11/14/09
34	Install Valves and Measurement Devices	1 day	Mon 11/16/09	Mon 11/16/09
35	Learn LabView	7 days	Mon 11/2/09	Mon 11/9/09
36	Write DR#3 Report	4 days	Fri 11/13/09	Tue 11/17/09
37	Create DR#3 Presentation	3 days	Sat 11/14/09	Tue 11/17/09
38	Design Review #3	0 days	Tue 11/17/09	Tue 11/17/09
39	**Initial In-lab Prototype Testing**	**3 days**	**Wed 11/18/09**	**Fri 11/20/09**
40	Pressure Testing of Vessel	1 day	Wed 11/18/09	Wed 11/18/09

Project: Gantt Chart
Date: Fri 10/23/09

ID	Task Name	Duration	Start	Finish
41	Testing for Water Tightness	1 day	Thu 11/19/09	Thu 11/19/09
42	Testing for Airtightness	1 day	Fri 11/20/09	Fri 11/20/09
43	Analyze Testing Results	1 day	Sat 11/21/09	Sat 11/21/09
44	Final Design	2 days	Sat 11/21/09	Mon 11/23/09
45	Refine and Build Final Prototype	10 days	Wed 11/18/09	Sat 11/28/09
46	Further In-Lab Testing	12 days	Thu 11/19/09	Wed 12/2/09
47	Implement Lab View Control System	4 days	Fri 11/20/09	Tue 11/24/09
48	Implement Lab View Data Collection System	6 days	Sat 11/21/09	Fri 11/27/09
49	Create DR#4 Presentation	5 days	Sat 11/28/09	Thu 12/3/09
50	Write DR#4 Report	6 days	Sat 11/28/09	Fri 12/4/09
51	Design Review #4	0 days	Thu 12/3/09	Thu 12/3/09
52	All testing complete	0 days	Fri 12/4/09	Fri 12/4/09
53	Create Design Expo Presentation	4 days	Sat 12/5/09	Wed 12/9/09
54	Write Final Report	6 days	Mon 12/7/09	Mon 12/14/09
55	Design Expo	1 day	Thu 12/10/09	Thu 12/10/09
56	Final Report Complete	1 day	Mon 12/14/09	Mon 12/14/09



Project: Gantt Chart
Date: Fri 10/23/09

Task	▬	Milestone	◆	External Tasks	▬
Split	┅	Summary	▬	External Milestone	◆
Progress	▬	Project Summary	▬	Deadline	⇩

Appendix E: Functional Decomposition

Functional Decomposition of MBAT

Design Problem – Create apparatus to analyze performance of membrane with or without biofilms under various conditions and flow types.

Functional Decomposition:

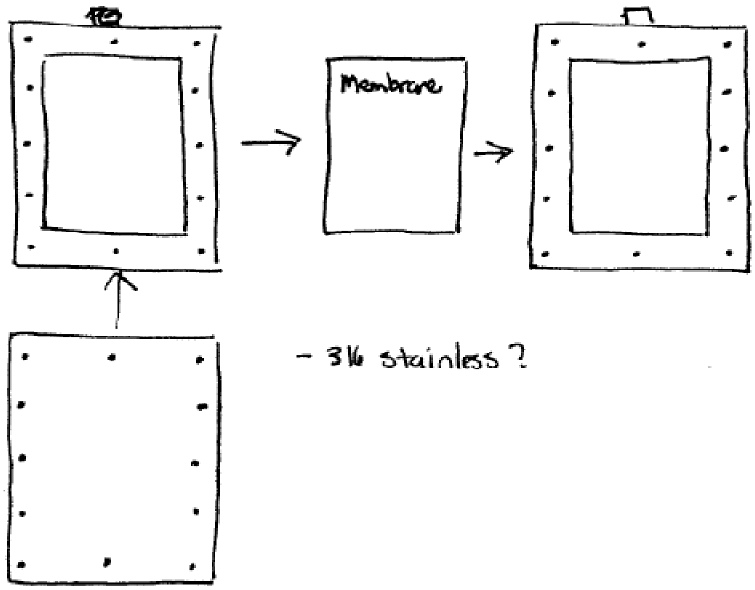
1. House Membrane
    1.1. Replicate functions of existing housing
    1.2. Easy and Fast Transfer from existing housing
    1.3. Withstands extended periods of submersion
2. Hold Membrane Housing
    2.1. Secure mount for membrane housing
    2.2. Ensure connection to effluent pipe
    2.3. Allow easy mount/dismount
    2.4. Maintain submersion
3. Contain Fluid Flow
    3.1. Secure Containment for System
        3.1.1. Watertight
        3.1.2. Airtight
        3.1.3. Ability to Allow Air into System (Ventilation)
    3.2. Secure Pipe Connections
        3.2.1. Watertight
4. Control Fluid Flow
    4.1. Move fluid
        4.1.1. From Source to Contaiment
        4.1.2. From Containment, through membrane to outlet
    4.2. Control Flow Rate
    4.3. Control Flow Direction (Forward/Reverse)
    4.4. Control Fluid Pathways (depending on positive/negative pressure requirement)
        4.4.1. Easy to alter flow pathways
5. Control Operating Conditions
    5.1. Maintain System Temperature at required level
        5.1.1. Allow adaptability for varying HRT
    5.2. Allows Aerobic Operation
    5.3. Allows Anaerobic Operation
6. Measure Required Parameters
    6.1. Measure Flow Rate
    6.2. Measure Pressure Differential Across Membrane
    6.3. Measure Temperature
        6.3.1. Temperature of System
        6.3.2. Temperature Differential between inlet, outlet
    6.4. Track Flow Direction
7. Incorporates membrane cleaning methods
    7.1. Sparging
        7.1.1. Allow for Observation of Sparging
            7.1.1.1. Measure Flow Rate (Pressure?)
        7.1.2. Control Sparging
            7.1.2.1. Control Gas flow rate
            7.1.2.2. Control pressure
            7.1.2.3. Control sparging duration
            7.1.2.4. Allow for intermittent, periodic operation
                7.1.2.4.1. Control interval

- 7.1.2.4.2. Control Duration
- 7.2. Back Flushing
  - 7.2.1. Allow for reversal of flow direction
  - 7.2.2. Safeguard membrane integrity
    - 7.2.2.1. Limit Flow rate?
- 7.3. Allow for alternative cleaning methods
  - 7.3.1. Auto-claving
  - 7.3.2. Sonication
  - 7.3.3. Vibrating Membrane

8. Data Handling
   - 8.1. Collect Data
     - 8.1.1. Collect flow rate data
     - 8.1.2. Collect pressure differential data
     - 8.1.3. Collect temperature and temperature differential data
     - 8.1.4. Store Collected Data
   - 8.2. Process Data
     - 8.2.1. Plot flow rate vs time
     - 8.2.2. Plot pressure differential vs time
     - 8.2.3. Real-time analysis
       - 8.2.3.1. Calculate Membrane Resistance R
       - 8.2.3.2. Plot R vs Time
       - 8.2.3.3. Plot R vs Pressure Differential
9. Interface with user
   - 9.1. Control Overall System
     - 9.1.1. Control Fluid Movement
       - 9.1.1.1. Control Flow Rate
     - 9.1.2. Fluid Pathway Control
     - 9.1.3. Cleaning Method Control
       - 9.1.3.1. Control Duration, Intervals of Operation
       - 9.1.3.2. Control Flow Rate/Amount of Sparging Gas.
     - 9.1.4. Control System Temperature
   - 9.2. Display Information
     - 9.2.1. Current Flow Rate
     - 9.2.2. Current Pressure Differential
     - 9.2.3. Current Temperature
     - 9.2.4. Real-time plots
       - 9.2.4.1. Flow Rate vs Time
       - 9.2.4.2. Pressure Differential vs Time
     - 9.2.5. Current Flow Pathway
   - 9.3. Appropriate Warnings
     - 9.3.1. Double Check Fluid Pathway
     - 9.3.2. Double Check Flow Rate

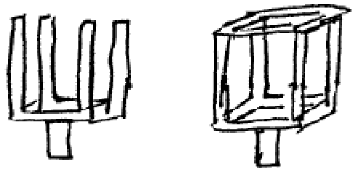
Appendix F: Concept Generation Sketches

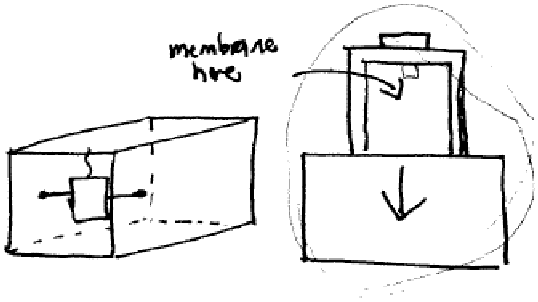
1. House Membrane



- 316 stainless ?

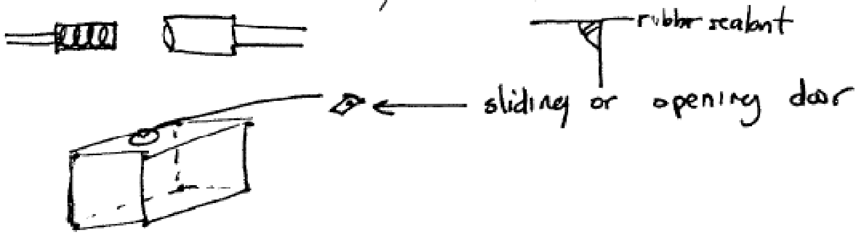
2. Hold Membrane Housing





3. Contain Fluid Flow

Pipe Connections (existing conditions)



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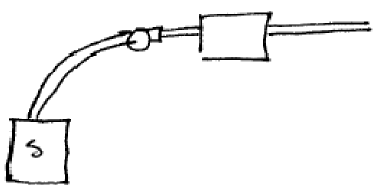
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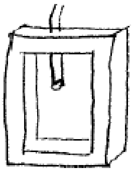

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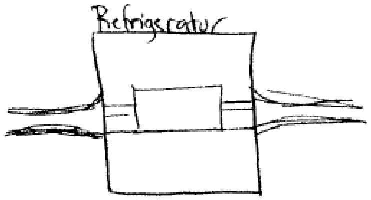
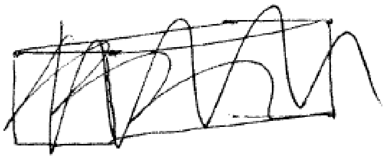
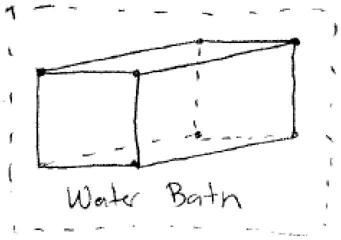
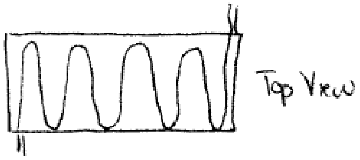

Refrigerator

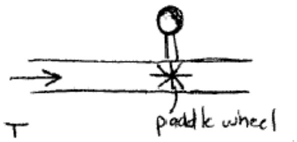


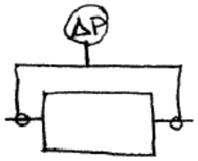

Water Bath

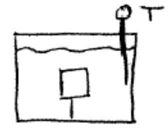

Top View

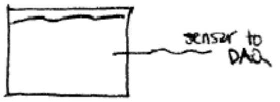

sliding door/vents/screw down plate

6.


paddle wheel

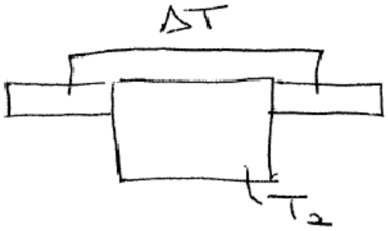

ΔP


T

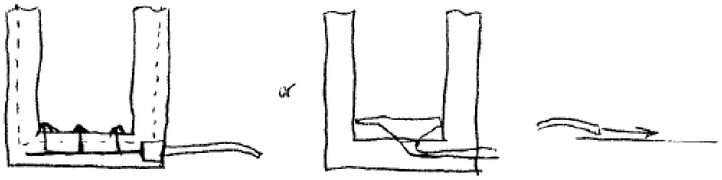

sensor to DAQ

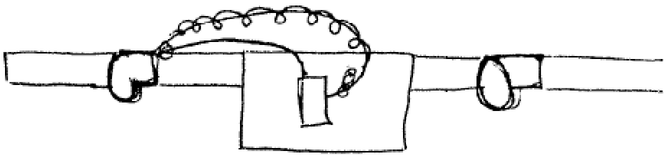

T1
T2
T3

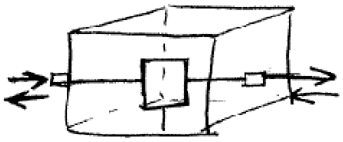
or


ΔT
T2

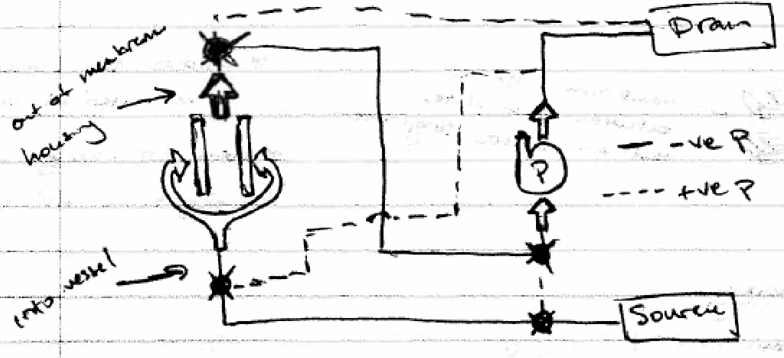
7.





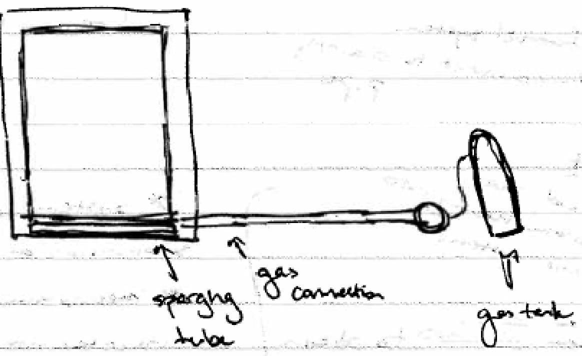


Piping

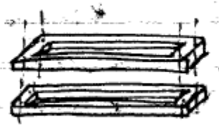


- * Easy to use for technician
- * one pump, one system
- * valve system (3 position)

Sparging System



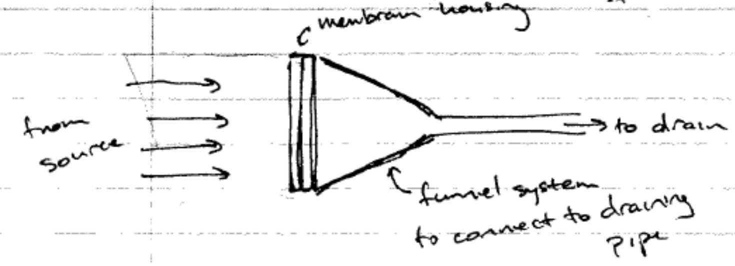
Membram Housing:



* allows for 1 membrane to be tested at one time.

* Have to change membran housing from old to new

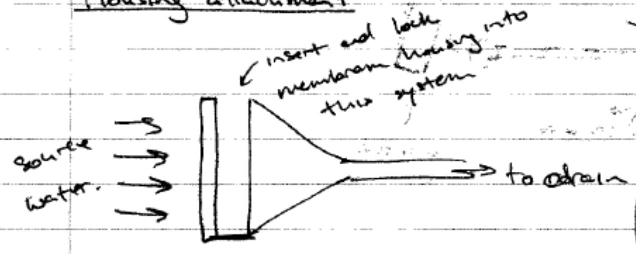
Flow through housing:



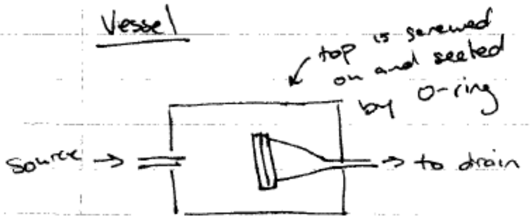
* Membram is completely covered by drain pipe funne

* attached to above housing (tests only 1 membram)

Housing attachment



Vessel

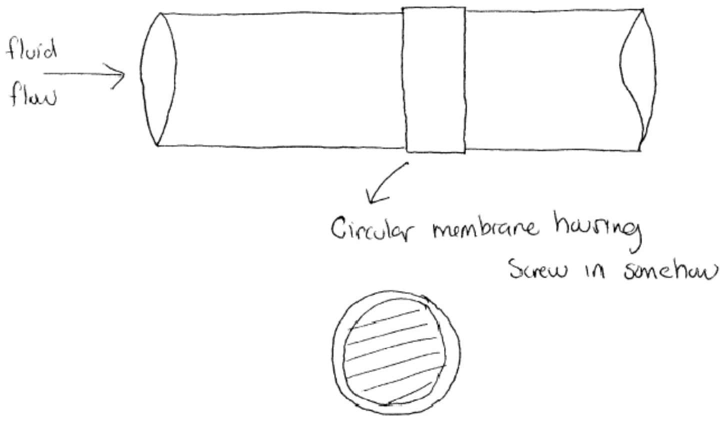


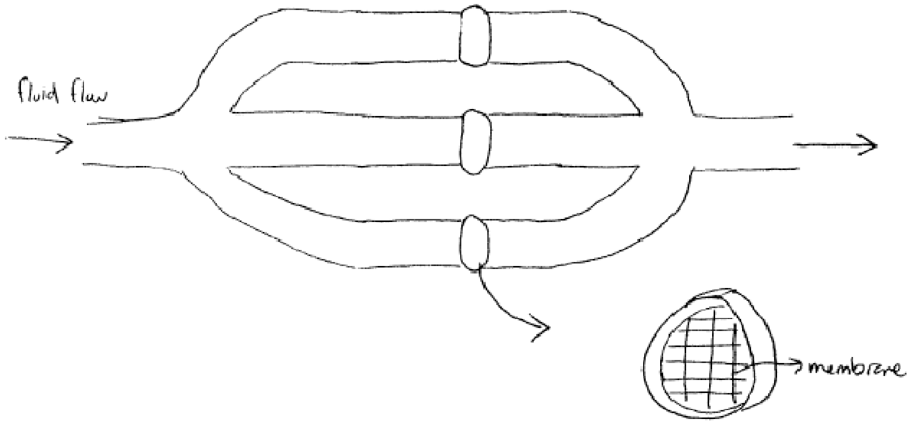
* system allows for submercion of membram

* membram housing is inserted into system

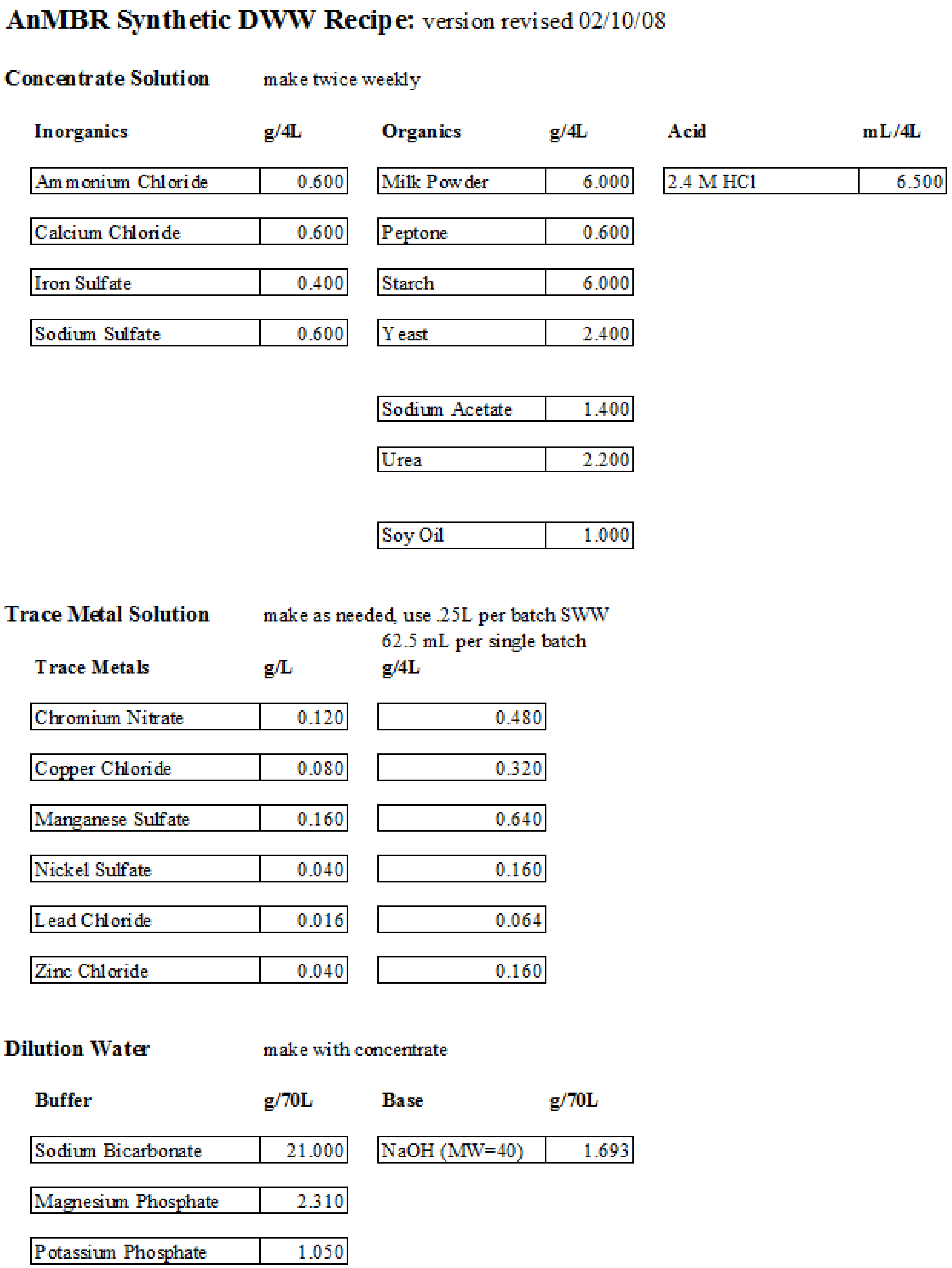
* source and drain pipe are attached to vessel

* housing attachment is attached to vessel


fluid flow
Circular membrane housing
Screw in somehow


fluid flow
membrane

Appendix G: Synthetic Domestic Wastewater (DWW) Recipe (sent via e-mail from Adam Smith)



AnMBR Synthetic DWW Recipe: version revised 02/10/08

Concentrate Solution make twice weekly

Inorganics	g/4L	Organics	g/4L	Acid	mL/4L
Ammonium Chloride	0.600	Milk Powder	6.000	2.4 M HCl	6.500
Calcium Chloride	0.600	Peptone	0.600		
Iron Sulfate	0.400	Starch	6.000		
Sodium Sulfate	0.600	Yeast	2.400		
		Sodium Acetate	1.400		
		Urea	2.200		
		Soy Oil	1.000		

Trace Metal Solution make as needed, use .25L per batch SWW

62.5 mL per single batch

Trace Metals	g/L	g/4L
Chromium Nitrate	0.120	0.480
Copper Chloride	0.080	0.320
Manganese Sulfate	0.160	0.640
Nickel Sulfate	0.040	0.160
Lead Chloride	0.016	0.064
Zinc Chloride	0.040	0.160

Dilution Water make with concentrate

Buffer	g/70L	Base	g/70L
Sodium Bicarbonate	21.000	NaOH (MW=40)	1.693
Magnesium Phosphate	2.310		
Potassium Phosphate	1.050		

Single Batch

Inorganics	g/L
Ammonium Chloride	0.150
Calcium Chloride	0.150
Iron Sulfate	0.100
Sodium Sulfate	0.150
Sodium Bicarbonate	0.300
Potassium Phosphate	0.015
Magnesium Phosphate	0.033

Organics	g/L
Milk Powder	1.500
Peptone	0.150
Starch	1.500
Yeast	0.600
Sodium Acetate	0.350
Urea	0.550
Soy Oil	0.250

Trace Metals	g/L
Chromium Nitrate	0.008
Copper Chloride	0.005
Manganese Sulfate	0.010
Nickel Sulfate	0.003
Lead Chloride	0.001
Zinc Chloride	0.003

Trace Metal Solution

make as needed, use .5L per batch SWW
125 mL per single batch

Trace Metals	g/L
Chromium Nitrate	0.120
Copper Chloride	0.080
Manganese Sulfate	0.160
Nickel Sulfate	0.040
Lead Chloride	0.016
Zinc Chloride	0.040

Appendix H: First Page of Patent No.: US 6,387,262

US006387262B1

(12) **United States Patent**
Rittmann et al.

(10) **Patent No.: US 6,387,262 B1**
(45) **Date of Patent: May 14, 2002**

(54) **HOLLOW-FIBER MEMBRANE BIOFILM REACTOR FOR AUTOHYDROGENOTROPHIC TREATMENT OF WATER**

(75) Inventors: **Bruce E. Rittmann**, Evanston, IL (US); **Kuan-Chun Lee**, Kobe (JP)

(73) Assignee: **Northwestern University**, Evanston, IL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/587,746**

(22) Filed: **Jun. 5, 2000**

(51) **Int. Cl.**^{7} **B01D 63/02**
(52) **U.S. Cl.** **210/321.89**; 210/321.79; 210/321.8; 210/321.88; 210/433.1; 210/483; 210/488; 210/489; 210/490; 210/500.23
(58) **Field of Search** 210/321.6, 321.78, 210/321.79, 321.8, 433.1, 321.87, 321.88, 321.89, 483, 488, 489, 490, 491, 500.23; 422/45, 47, 48

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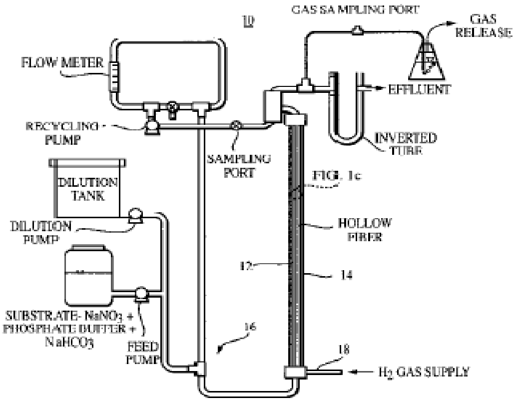
(List continued on next page.)

Primary Examiner—John Kim
(74) *Attorney, Agent, or Firm*—Greer, Burns & Crain, Ltd.

(57) **ABSTRACT**

The reactor includes a hollow fiber membrane bundle. Pressurized hydrogen and water are introduced into a volume containing the fiber bundle. The fibers are free to separate and more independently over most of their length. The fibers have microporous inner and outer layers and a nonporous layer sandwiched between the inner and outer layers and are sealed on one end. Hydrogen is introduced inside the fibers, which are sealed on one end to prevent direct escape of the hydrogen gas. The H_2 gas dissolves then diffuses through the nonporous layer. Water is introduced around the fibers, and the biofilm reaction occurs on the outer surface of the fibers. Oxidized contaminants are removed from the water by the biofilm reaction, which consumes H_2 gas that diffuses through the membrane. The individual fibers are free, over most of their length, to separate in response to the water flow. This prevents excessive biofilm-to-biofilm contact. A gentle environment results in the tube around the membrane bundle for stable biofilm accumulation without channelization or clogging.

4 Claims, 5 Drawing Sheets



Appendix I: First Page of Patent No.: US 5,484,524

US005484524A

United States Patent [19]

MacLaren et al.

[11] **Patent Number:** **5,484,524**

[45] **Date of Patent:** **Jan. 16, 1996**

[54] **WASTEWATER TREATMENT APPARATUS**

[75] Inventors: **David S. MacLaren**, Gates Mills; **Nianfa Tang**, Richmond Hts., both of Ohio

[73] Assignee: **JET, Inc.**, Cleveland, Ohio

[21] Appl. No.: **11,866**

[22] Filed: **Feb. 1, 1993**

[51] **Int. Cl.**^{6} **C02F 3/06**

[52] **U.S. Cl.** **210/151**; 210/195.3; 210/219; 261/DIG. 70

[58] **Field of Search** .... 210/615–617, 210/626, 628–630, 195.3, 150, 151, 219, 220; 261/84, 87, 95, 124, DIG. 70

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(List continued on next page.)

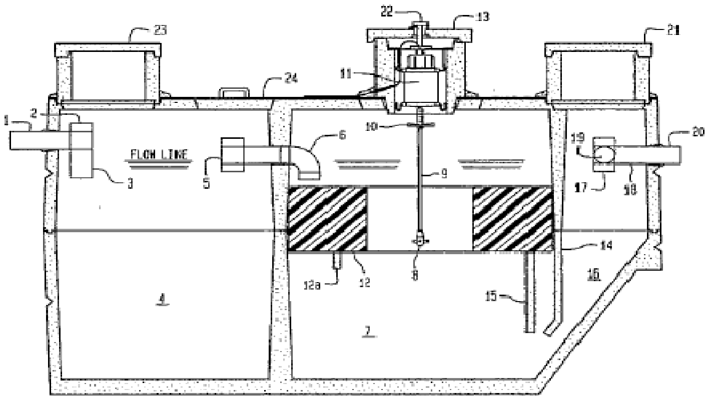
Primary Examiner—Thomas Wyse

Attorney, Agent, or Firm—Thomas M. Champagne; Jon L. Roberts; Roberts & Associates

[57] **ABSTRACT**

A wastewater treatment plant for removal of organic matter, suspended solids and other pollutants comprising a pre-treatment chamber, a biofilm-aeration chamber and a settling chamber. Biofilm grows on biofilm support structure which is stationary and submerged in the mixed liquor of the biofilm aeration chamber. The combination of submerged or surface aeration and suspended solids particle size reduction occurs thereby creating a sufficient fluid flow within the biofilm aeration chamber. This combination of sufficient fluid flow, and reduced size suspended organic particles results in the efficient digestion of organic matter and pollutants by the biofilm growing on the biofilm support structure submerged in the biofilm aeration chamber. This results in a vastly more effective digestive process than conventional processes producing no sludge. Further, resulting treated effluent has a high dissolved oxygen content and low BOD and SS. The apparatus and process has the following advantages: low MLSS concentration, short biofilm incubation time, no clogging of the system, good response to shock loading, high DO in the effluent, consistent effluent quality, sludge is eliminated, wastewater treatment duration is shortened, the process is not temperature sensitive, plant design is greatly simplified, plants of the present invention are small by comparison to conventional plants, the present invention can be a significant step in the treatment of drinking water, energy consumption during treatment is low, the present invention is very cost effective, the process permits other purification processes to be used and the process is volumetrically and BOD insensitive.

13 Claims, 12 Drawing Sheets



Appendix J: First Page of Patent No.: US 6,463,790

US006463790B1

(12) **United States Patent**
Chun et al.

(10) **Patent No.: US 6,463,790 B1**
(45) **Date of Patent: Oct. 15, 2002**

(54) **MEMBRANE FILTRATION METHOD AND APPARATUS FOR SIMULTANEOUSLY AND CONTINUOUSLY MONITORING TIME-BASED MEMBRANE FOULING**

(75) Inventors: **Myung-Suk Chun**; **Jae-Jin Kim**; **Sang-Yup Lee**, all of Seoul (KR)

(73) Assignee: **Korea Institute of Science and Technology**, Seoul (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 44 days.

(21) Appl. No.: **09/678,829**

(22) Filed: **Oct. 4, 2000**

(30) **Foreign Application Priority Data**

May 24, 2000 (KR) 00-27910

(51) **Int. Cl.**^{7} **G01N 11/04**; G01N 15/08; G01N 15/02

(52) **U.S. Cl.** **73/38**; 73/64.56; 73/61.73; 210/741; 210/746

(58) **Field of Search** 73/38, 64.56, 61.73, 73/53.04, 61.47; 210/500.22, 741, 746

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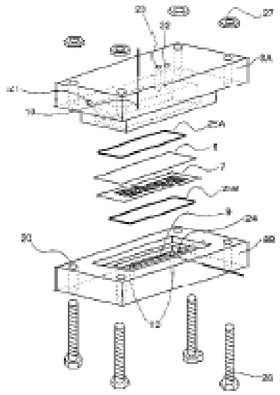
Primary Examiner—Hezron Williams
Assistant Examiner—David J. Wiggins
(74) *Attorney, Agent, or Firm*—Oblon, Spivak, McClelland, Maier & Neustadt, P.C.

(57) **ABSTRACT**

A membrane filtration method and an apparatus for continuously monitoring the state of a membrane during the filtration, particularly for membrane fouling due to cake or gel layers of solutes developed on the surfaces of a filtered membrane, by estimating a membrane potential and a membrane solute rejection while making measurements of a set of physical properties of feed, variations of a streaming potential difference across pores of the membrane, variation in pressure differences between an upstream side and a downstream side of the membrane, and concentration differences between the feed and permeate filtered through the membrane.

8 Claims, 4 Drawing Sheets



Appendix K: First Page of Patent No.: US 5,888,401

US005888401A

United States Patent [19]
Nguyen

[11] **Patent Number: 5,888,401**
[45] **Date of Patent: Mar. 30, 1999**

[54] **METHOD AND APPARATUS FOR REDUCING MEMBRANE FOULING**

[75] Inventor: **Dong Donald Nguyen**, Lawrenceville, N.J.

[73] Assignee: **Union Camp Corporation**, Wayne, N.J.

[21] Appl. No.: **714,752**

[22] Filed: **Sep. 16, 1996**

[51] **Int. Cl.**^{6} **B01D 61/00**

[52] **U.S. Cl.** **210/650**; 210/636; 210/90; 210/97; 210/106; 210/257.2

[58] **Field of Search** 210/636, 650, 210/651, 652, 97, 100, 102, 106, 295, 333.01, 333.1

[56] **References Cited**

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Primary Examiner—Ana Fortuna

Attorney, Agent, or Firm—Dechert Price & Rhoads

[57] **ABSTRACT**

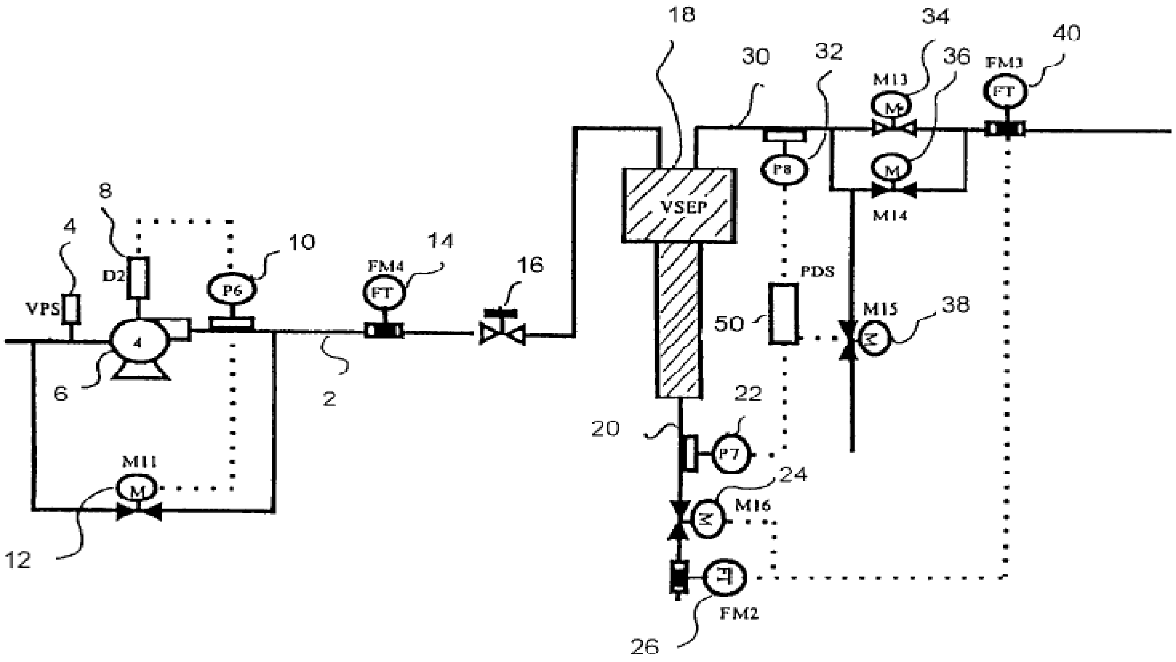
The present invention is directed, among other things, to methods for reducing fouling of a separation membrane having a concentrate side subject to a concentrate pressure (Pc) and a permeate side subject to permeate pressure (Pp), comprising raising an initial permeate pressure (Pp_0) to an increased permeate pressure (Pp_1). The present invention further provides a method of reducing fouling of a membrane having a concentrate side subject to a concentrate pressure (Pc) and a permeate side subject to permeate pressure (Pp), comprising periodically raising an initial permeate pressure (Pp_0) to an increased permeate pressure (Pp_1). Additionally, the present invention provides an improved apparatus for filtering a fluid and methods of reducing membrane fouling in a separation membrane using the apparatus, the improved apparatus comprising a feed inlet having a pump, a filtering apparatus, a concentrate line and a permeate line, the improvement comprising:

on the feed inlet, a first gauge for measuring pressure and a controller for controlling pressure of the fluid passing through the feed inlet pump or for controlling the speed of the feed inlet pump;

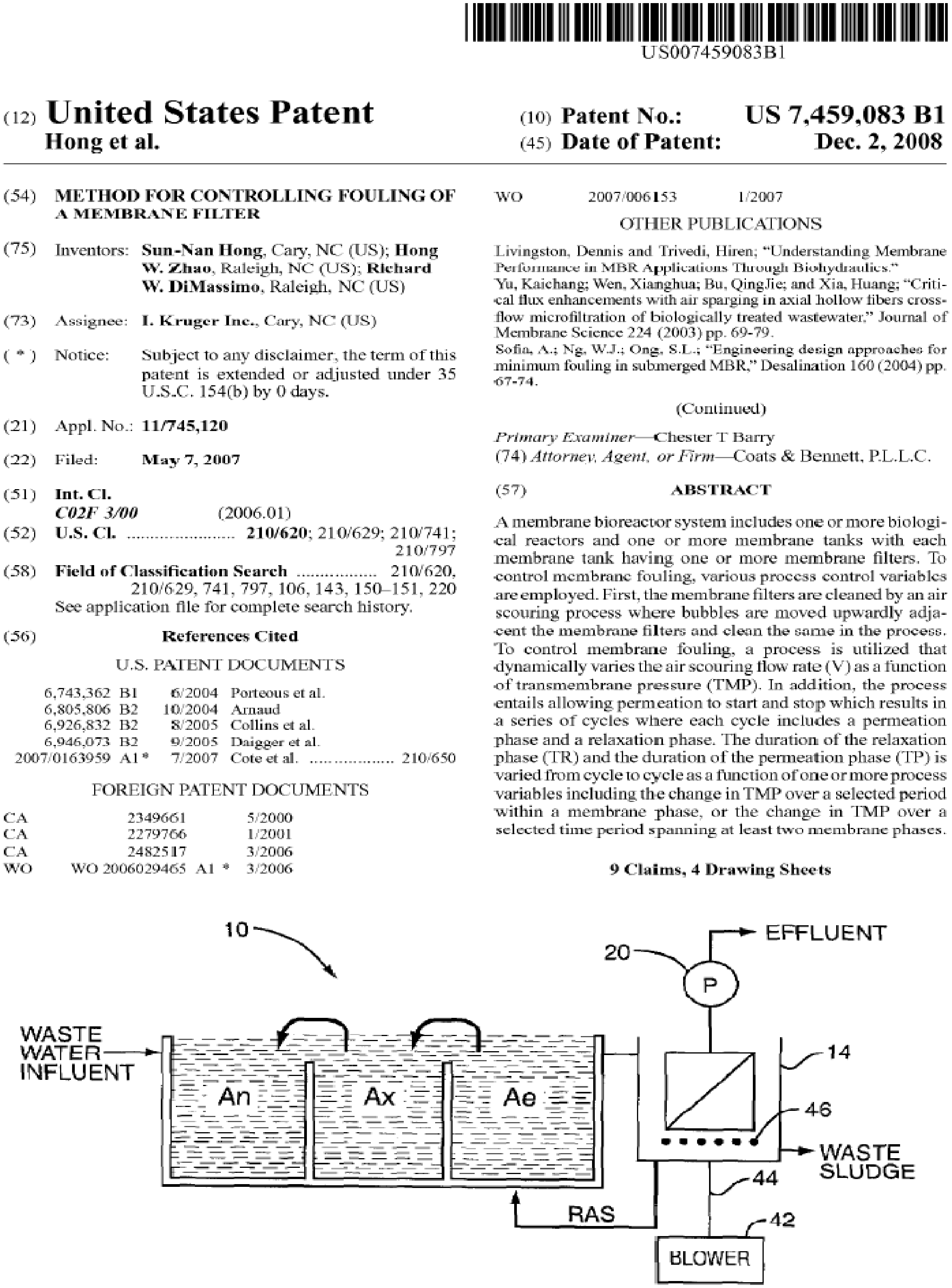
on the permeate line, a second gauge for measuring pressure and a pressure controller for controlling pressure of the fluid passing through the permeate line; and

on the concentrate line, a third gauge for measuring pressure of the fluid passing through the concentrate line.

16 Claims, 1 Drawing Sheet



Appendix L: First Page of Patent No.: US 7,459,083



US007459083B1

(12) **United States Patent**
Hong et al.

(10) **Patent No.: US 7,459,083 B1**
(45) **Date of Patent: Dec. 2, 2008**

(54) **METHOD FOR CONTROLLING FOULING OF A MEMBRANE FILTER**

(75) Inventors: **Sun-Nan Hong**, Cary, NC (US); **Hong W. Zhao**, Raleigh, NC (US); **Richard W. DiMassimo**, Raleigh, NC (US)

(73) Assignee: **I. Kruger Inc.**, Cary, NC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/745,120**

(22) Filed: **May 7, 2007**

(51) **Int. Cl.**
C02F 3/00 (2006.01)

(52) **U.S. Cl.** **210/620**; 210/629; 210/741; 210/797

(58) **Field of Classification Search** 210/620, 210/629, 741, 797, 106, 143, 150–151, 220
See application file for complete search history.

(56) **References Cited**

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(Continued)

Primary Examiner—Chester T Barry
(74) *Attorney, Agent, or Firm*—Coats & Bennett, P.L.L.C.

(57) **ABSTRACT**

A membrane bioreactor system includes one or more biological reactors and one or more membrane tanks with each membrane tank having one or more membrane filters. To control membrane fouling, various process control variables are employed. First, the membrane filters are cleaned by an air scouring process where bubbles are moved upwardly adjacent the membrane filters and clean the same in the process. To control membrane fouling, a process is utilized that dynamically varies the air scouring flow rate (V) as a function of transmembrane pressure (TMP). In addition, the process entails allowing permeation to start and stop which results in a series of cycles where each cycle includes a permeation phase and a relaxation phase. The duration of the relaxation phase (TR) and the duration of the permeation phase (TP) is varied from cycle to cycle as a function of one or more process variables including the change in TMP over a selected period within a membrane phase, or the change in TMP over a selected time period spanning at least two membrane phases.

9 Claims, 4 Drawing Sheets

APPENDIX M: Safety Report

ME 450 Safety Reporting: Fall 2009

Project #: __12_____ **Date:** ___11-11-09________

Report Version #: __1.0____

Project Title: __Membrane Biofilm Analysis Testbed (MBAT)_________

Team Member Names:___Deandre Reagins, John Song, Adithya Varadarajan__________

Team Member Uniquenames:__dreagins, jysong, adithya___________________________

Attach your Safety Report to this cover page and instructions found on Pages 2 and 3.

The Safety Report is to be completed by your team and must be approved by your section instructor (or approved substitute) prior to any hands-on experimentation, manufacturing or testing of your prototype.

The safety hazards inherent in your experimental plans, component selection, manufacturing methods, assembly techniques, and testing must be expressed and evaluated before any hands-on work with safety consequences will be allowed to proceed.

The purpose of this safety report is to assure that you have thought through your hands-on work before it begins, and that you have shared your plans with your Section Instructor. You may submit more than one version. This will likely be necessary as your project evolves.

APPROVAL:

Name: ____________________________

Signature: ____________________________

Date: ____________________________

1. **Executive Summary**

Experimental Data Collection:

No experimental work needs to be performed before the design.

Component Design:

Consideration was made to the nature of the influent fluid to our system when designing components. Components needed to resistant to acids and bases so as not to cause corrosion and vessel failure. Each component was checked for both temperature and pressure rating to ensure that it was suitable for our system.

System Design:

The combination of our system design and the low operating pressure that the system will encounter result in a safety factor of 2000 for the vessel against failure. All vessel components are made of stainless steel and are at least ¼" thick.

Manufacturing:

To manufacture our parts, the processes include: Sawing, CNC milling, drilling, and taping, and TIG welding. There are hazards associated with these operations that include sharp edges, flying debris, fast moving equipment, and extremely high heat. Our entire team has been safety trained to work in the machine shop and John Song enrolled in welding training earlier in the semester. He will be responsible for the welding portion of our operation. We will use proper protective equipment and we will be under supervision of shop supervisors during manufacturing. We have attempted to order parts that are as close to the size we require as possible to minimize the need for machining.

Assembly:

Assembly does not pose a high risk. Components will be attached using screws, bolts, and screw in connections. Some components of our system are heavy (25lb) so we will be sure to employ proper lifting techniques and ensure that the system is stable so that it does not tip over at any point.

Testing:

Testing is a key aspect of this project as the key customer requirements are that the system contain water securely and be able to operate anaerobically. Fluid must be able to circulate through the system with no leakages at any point within the system. All testing will be conducted at pressures < 10 psi

2. Experimentation Plans Prior to Design Completion

For your experimentation, list what data you will be collecting and why. Are any experiments that might have safety risks unnecessary? Why/Why not?

For the experimental validation of the MBAT system, a visual inspection of the system will be conducted while the system is pressurized to a maximum of 10 psi to determine if there are any air or water leaks. No data will be collected via a DAQ system at this time. The validation experiments do not pose a significant safety risk as they are at low pressures and we will use only water for validation testing of our design. We will use PPE during our testing.

3. Purchased Component and Material Inventory

Provide an inventory of all materials (solid materials such as aluminum/wood/etc.) and purchased components you will be using. Why are these materials and components necessary?

a. Complete an FMEA for any purchased components that have safety risks. Provide the FMEA table as an appendix to this Safety Report and summarize the results in your own words for the main report body.

Vessel Components:

1. Vessel Tube

Material: 316 Stainless Steel

Stock Shape and Dimensions: Cylinder (6.065 in ID x 12 in L)

Source McMaster Carr

Description: The vessel is where filtration will take place and is the main component of the body of our system. We will cut this cylinder down to 10” in length. We will TIG weld a square shaped end cap to one end of the vessel. We will TIG weld a square shaped mount for the headplate onto the other end of the cylinder.

2. Head Plate

Material: 410 Stainless Steel

Stock Shape and Dimensions: Rectangular Plate (8 in W x 24 in L x 0.25 in D)

Source McMaster Carr

Description: This is the first of three components that will be machined from the 8” x 24” rectangular plate. We will machine a 8” x 8” rectangle from the stock piece for the head plate, bottom plate, and head plate mount. The head plate is a key component of our system as it will support the membrane housing vertically during operation. Holes will be machined into the head plate for tube fittings and sensors to detect the relevant parameters of our system. Additionally 4 holes will be drilled in each corner of the plate in which bolts will be inserted to attach the head plate to the vessel.

3. Bottom Plate

Material: 410 Stainless Steel

Stock Shape and Dimensions: Rectangular Plate (8 in W x 24 in L x 0.25 in D)

Source McMaster Carr

Description: This is the second of three components that will be machined from the 8” x 24” rectangular plate. The bottom plate will be TIG welded to the bottom of the vessel tube (#1) and will provide an airtight/watertight seal for the end of the cylinder as well as a base that will support the MBAT during operation.

4. Head Plate Mount

Material: 410 Stainless Steel

Stock Shape and Dimensions: Rectangular Plate (8 in W x 24 in L x 0.25 in D)

Source McMaster Carr

Description: This is the third of three components that will be machined from the 8” x 24” rectangular plate. A 6.035” diameter hole will be machined from the middle of the plate using CNC. A groove will also be machined into the plate into which an O-ring will be inserted. The bottom plate will be TIG welded to the top of the vessel tube (#1). Four holed will be drilled into each corner of the plate concentric with those drilled in the Head Plate. The head plate mount will allow for a secure connection between the head plate, its components, and the vessel.

5. Barbed Tube Fitting

Material: Polyethylene

Shape and Dimensions: 3/16” Barb Size,

Source McMaster Carr

Description: The barbed pipe fitting will be mounted onto the top of our head plate. The polyethylene materials is resistant to chemicals that may be present in the influent water (acids, bases, etc.) The connection will route the flow from the source into the MBAT system.

6. Compression Tube Fitting

Material: 316 Stainless Steel

Shape and Dimensions: For 5/16"-20 UNF thread size, 2” in length

Source: McMaster Carr

Description: 2 of these compression tube fittings will be screwed into the head plate. They will be connected to the effluent and sparging tubing. They are made out of stainless steel to ensure that there they are chemically resistant and resistant to corrosion. The membrane housing will be connected to the bottom of one of these compression fittings via a screw on connection that is part of the membrane housing system. These fittings match what is currently in the system which adds to the ease of use.

7. O-Ring

Material: Viton® Fluoroelastomer

Shape and Dimensions: 6-1/2" ID, 6-3/4" OD, 1/8" Wide

Source: McMaster Carr

Description: The O-ring is mounted onto the head plate mount inside a grove that is machined via CNC. When the head plate is attached to the mount the O-ring will be compressed helping to create an airtight watertight seal during operation.

System Components

1. Differential Pressure Transducer

Quantity: 1

Vendor: Omega

Catalog Listing: PX26-015DV

Description: The differential pressure transducer will be used to measure the pressure drop across the membrane which will be used determine the amount of membrane fouling that is occurring in the system. It has a pressure range of +/15 psi

2. Reactor Temperature (Pipe Fitting Probe)

Quantity: 1

Vendor: Omega

Catalog Listing: WU-08516-71

Description: This probe will be screwed into a 1/8” hole in the head plate and will be sued to measure the temperature of the water within the vessel. It is capable of measuring temperatures ranging from -250 to 1100 degrees Celsius.

3. In-Line Temp Gauge (Flow Through Probe)

Quantity: 2

Vendor: Masterflex

Catalog Listing: HV-93835-02

Description: The in-line temperature probes will be used to measure the temperature of the inlet and outlet flows. The gauge has connections on each end that will be attached to the tubing. It is important that this temperature difference and does not exceed +/- 3 degrees Celsius.

4. Precision Tygon Tubiing

Quantity: 25 ft
Vendor: Masterflex
Catalog Listing: HV-06429-25

Description: Tygon chemical pump tubing offers excellent chemical compatibility in a clear, flexible peristaltic pump tube. This material is compatible with many challenging fluids including concentrated acids, strong bases, and organic solvents. This type of tubing will be used for all our flows in the system. The tubing is suited for operating pressure

5. Sparging Gas Pressure Gauge

Quantity: 1
Vendor: Honeywell
Catalog Listing: 060-0743-11TJG

Description: all-welded stainless steel sensors built for industrial applications that require high accuracy and measurement stability. This gauge is a strain gage based transducer. It will be used to measure the pressure of the sparging gas which we will correlate to a flow rate. The gauge is rated to 10000 psi.

6. Sparging Gas High Pressure Solenoid Valve

Quantity: 1
Vendor: Honeywell
Catalog Listing: 060-0743-11TJG

Description: This valve will control the flow of sparging gas to the system It is normally closed valve opens when energized and closes when de-energized.

8. Vertical Liquid Level Sensor

Quantity: 1
Vendor: Omega

Catalog Listing: LV-20

Description: This liquid level sensor will be connected directly to the motor and will function as on off switch. When the water level becomes too low the sensor will activate turning on the influent pump which will pump water into the vessel. The switch will shut off when the water level in the vessel has reached an adequate level

9. Peristaltic Pump System with Pump Head

Quantity: 2

Vendor: Masterflex

Catalog Listing: HV-07524-50

Description: This pump is a type of positive displacement pump used for pumping a variety of fluidsdigital pump drive featuring programmed calibration will be used as the influent and effluent pumps of our system.

LabView Components

The primary function of our system is testing hence several of our components deal with measuring and recording information such as temperature and pressure. We were fortunate to be provided with a DAQCard-6036E as well as a SC-2345 signal conditioning board (both from National Instruments) that could be used for our testing purposes. We were also provided with several thermocouple modules and one analog voltage input module that could be used for a pressure transducer. The only components that required purchasing were the transducers, some of the signal conditioning modules to interface the transducers with the DAQ and the wires and connector ends that connect the transducers to the modules. All of the signal conditioning modules will be ordered directly from National Instruments in order to ensure compatibility with the provided DAQ setup. The remainder of our components will be ordered from various vendors such as Omega or Masterflex depending on the component that best meets our testing needs. Our components are described below:

1. Differential Pressure Transducer
    - Quantity 1
    - Vendor Omega
    - Part Number PX26-015DV

Description:

The differential pressure gauge measures the pressure difference between two different fluid flows. This transducer will be used to measure the pressure differential across the membrane. The sensor is made of silicon which has high corrosion resistance and the differential pressure range is +/- 15 psig. The operating temperature is -40 to 85 degrees C and the output from the sensor ranges from 16.7 mV to 100mV.

2. Connector, Push-On Style, Crimp Contact

Quantity	2
Vendor	Omega
Part Number	CX136-4

Description:

This connector will be used to connect the differential pressure transducer to the corresponding voltage module on the signal conditioning board. There will be one connector at the transducer and one at the end of the connector wire (see part 3) used to connect to the module.

3. Multi-Conductor Cable

Quantity	1 spool (100 feet)
Vendor	Omega
Part Number	TX4-100

Description:

This 4 conductor copper wire with PVC insulation will be used to connect the pressure transducer to the voltage module using the push on style connectors on each end (see part 2).

4. High Precision True Gauge Pressure Transducer

Quantity	1
Vendor	Honeywell Sensotec
Part Number	060-0743-11TJG

Description

This pressure transducer is provided to us by our sponsors. It will be used to measure the pressure of the sparging gas in the system. It has a pressure range of 0-10000 psig. The voltage output of this transducer is 0-5V DC. The outer casing is made out of 304 stainless steel.

5. High Pressure Solenoid Valve

Quantity	1
Vendor	Clark Cooper
Part Number	EH40-04-D012-XP

Description

The high pressure solenoid valve will be used to control the flow of the sparging gas. It has a pressure rating of 5000psig and has a solenoid voltage of 12V DC. It is applicable for use with

High Pressure air, water, hydrogen, nitrogen and similar gases. It has a ¼” NPT outlet and inlet. The internal O-ring seals are made of Buna-N while the system is made of various types of Stainless Steel.

6. Analog Voltage Input Module

Quantity	1
Vendor	National Instruments
Part Number	SCC-AI02

Description:

This Module will be used on the signal conditioning board as the interface between the pressure transducer and the DAQ.

7. Digital Output Module

Quantity	1
Vendor	National Instruments
Part Number	SCC-DO01

Description:

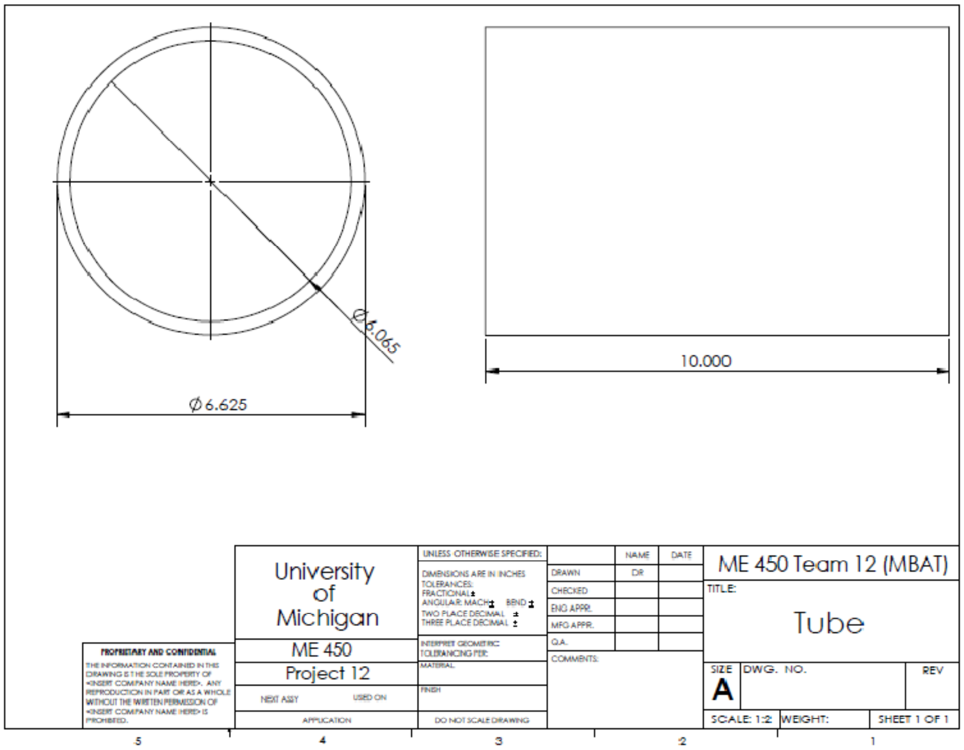
This module will be used on the signal conditioning board as the interface between the high pressure solenoid valve and the DAQ. It will be used to send electric signals to the valve to indicate the open/close positon.

4. **CAD Drawings and DesignSafe Summary for Designed Parts**

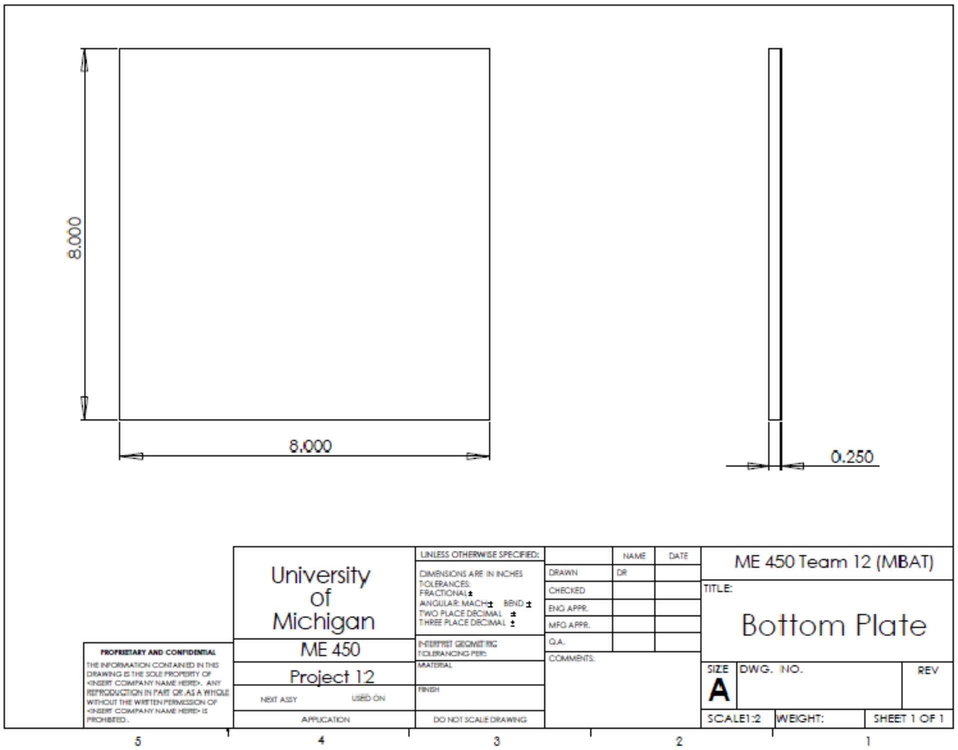
Provide CAD drawings for components you have designed and will manufacture.

a. Conduct a risk assessment using Designsafe software (available on CAEN) for each designed component and for the full assembly of components constituting your design. Provide the Designsafe output as an appendix to this safety report and summarize the results in your own words for the main report body.

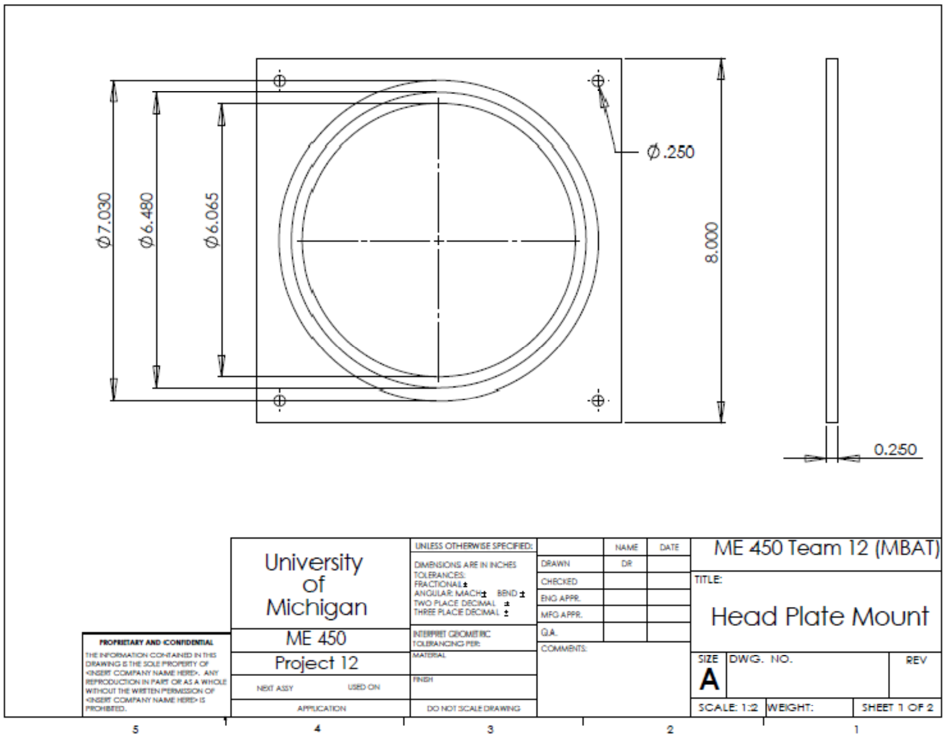
Tube



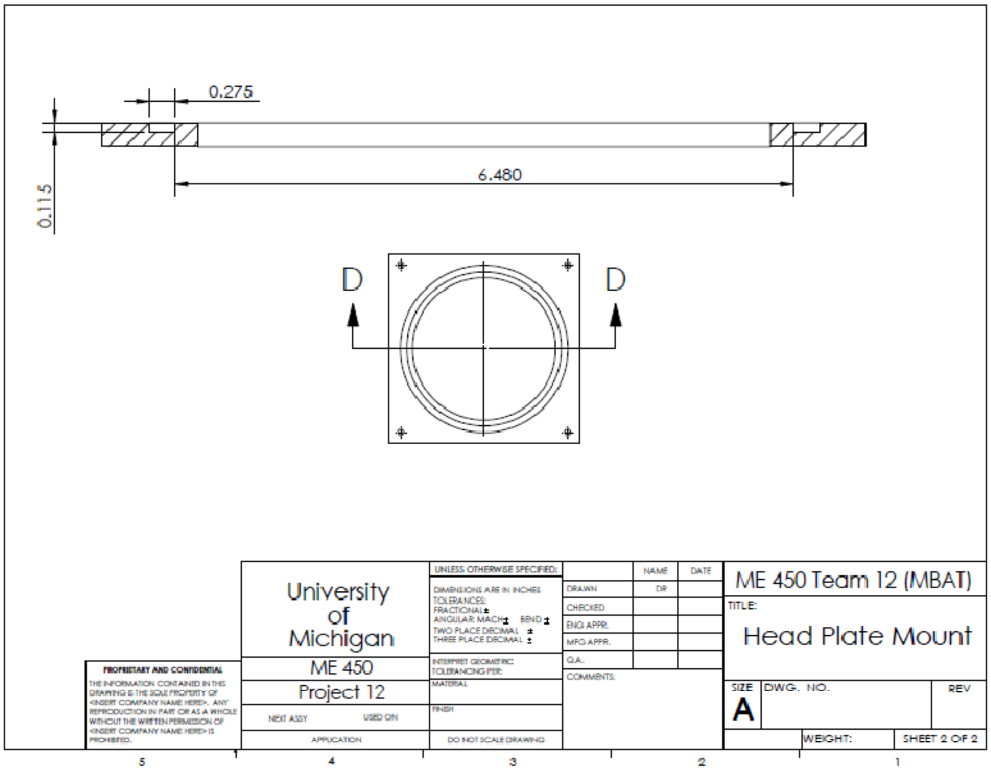
Bottom plate



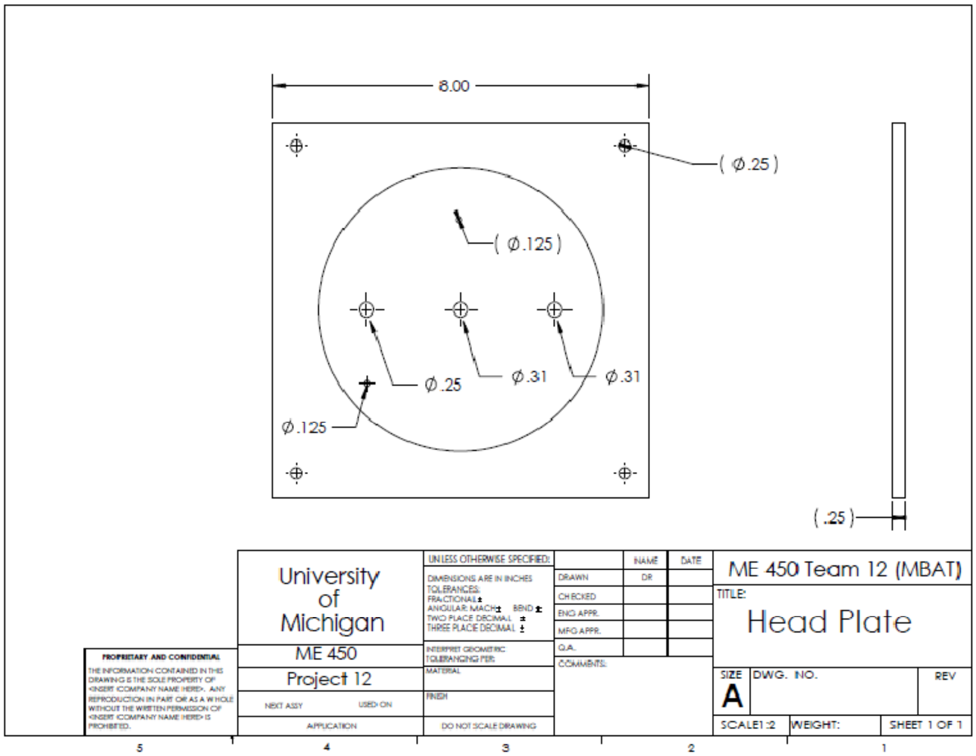
Head Plate Mount



Head Plate Mount O-Ring Groove



Head Plate



Design Safe Analysis

Design Safe was utilized to assess the risk associated with the manufacturing, assembly, and operation of the MBAT system. There are some inherent risks associated with the leakage of toxic chemicals from the vessel during operation. The MBAT system will be tested before in lab operation to ensure that the system and airtight but it is important that all connection are made securely to avoid any leaks. Hazards from chemicals can be reduces by wearing proper PPE (lab coat, gloves, eyewear) when handing components of the system. We have designed the system to maintain integrity well beyond the stresses that they system will experience so failure by explosion is practically negligible.

The system weight should be considered when moving the system. Proper lifting techniques should be applied to avoid any injuries during this process. The square base plates add stability to the system so that it will not tip during operation but we recommend that the system by clamped to a flat surface during operation to ensure that this risk is minimized.

5. Manufacturing

Provide a list of all fabrication or manufacturing activities you will perform. Where will these activities take place? Why are these processes necessary?

- *b. CAD drawings for parts to be manufactured are required (per #4 above).*
- *c. For machining or forming processes, list special setup requirements and the operational conditions that will be employed (e.g., speeds, feeds, etc.).*

Vessel Construction: Four components will be used to construct the vessel; the head plate, ring, base plate, and cylindrical tube. The vessel will be constructed after machining a 12" 316 Stainless Steel pipe with an outside diameter of 6.625" and an inside diameter of 6.357". The pipe will be cut down to 10" using the lathe machine with a lathe spindle speed of 40.6 rotations per minute with a high speed steel tool bit . The 8"x24"x¼" 410 stainless steel plate will be will be cut into thirds, lengthwise, producing roughly three 8"x8"x¼" plates. The stainless steel plate will be cut using the band saw with the tool speed at 50 feet per minute as indicated on the band saw machine in the machine shop. It is important to note that these will not be the exact measurements since cutting the material will inevitably remove some as well, but this will not be a problem. Two out of the three plates will also have to be further machined to produce the ring and the head plate.

Ring: One plate will be CNC machined to include a 6.357" diameter centered hole, the same size as the inner diameter of the cylindrical pipe. Four holes will be drilled and tapped to allow for the ¼"-20 bolts that will be used to secure the head plate to the ring. Additionally, a groove with a width of 0.185" and a depth of 0.115" needs to be machined into the ring for the O-ring. A drawing of the ring can be seen in the head plate model CAD drawing in section 4. CNC machining will be required because of the accuracy needed to machine the circles.

Head Plate: The second plate will be machined to include holes to allow for the following:

- Membrane housing to effluent flow tube
- Influent flow tube
- Reactor temperature probe
- Sparging gas tube

A drawing can be seen for the head plate below in Section 4.

Welding

The base plate and the ring will be welded to the ends of the cylindrical pipe via tungsten inert gas (TIG) welding. The TIG welding process is commonly used in applications for thin sections of stainless steel and is the best way to weld our components to minimize the metal warping from the heat.

TIG welding, like any other type of welding, can be dangerous if the proper precautions are not taken. The TIG welding process produces intense ultraviolet radiation which can cause a form of sunburn and trigger the development of skin cancer in the most extreme form. Flying sparks and droplets of molten metal can also be present which can cause severe burns and start a fire if flammable material is nearby. However, if done properly, very few sparks or metal droplets are produced. It is essential that the welder wear protective clothing, which includes leather gloves, a closed collar shirt to protect the neck and throat area, a protective long sleeve jacket and a welding helmet to prevent retinal damage and ultraviolet burns to the cornea. The ultraviolet burn to the cornea is also known as Arc eye and is very painful if adequate eye protection is not worn.

Welders are also exposed to dangerous gases and particulate matter. The arc produced in TIG welding produces short wavelength ultraviolet light, which causes surrounding air to break down and form ozone, a molecule comprising of three oxygen atoms; heavy metals can be inhaled into the lungs. Proper ventilation will be required during the welding process.

5. **Assembly**

How and where will your components be assembled? On what basis do you conclude that the assembly will not fail before use, during use, or after use?

Pressure Vessel Sub-Assembly

The pressure vessel sub assembly is the portion of the system that will house the membrane Figure 1 below shows a CAD model of the pressure vessel sub assembly.

Figure 1: Pressure Vessel Sub Assembly

This sub assembly was assembled using the following components:

- Bottom Plate

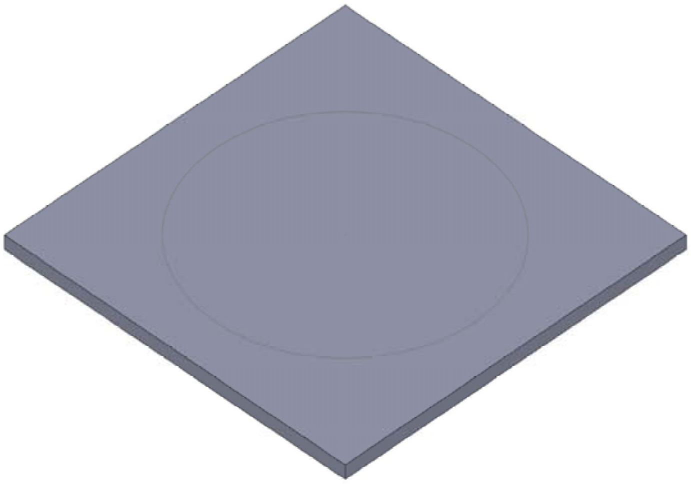


Figure 2: Bottom Plate

- Vessel Tube

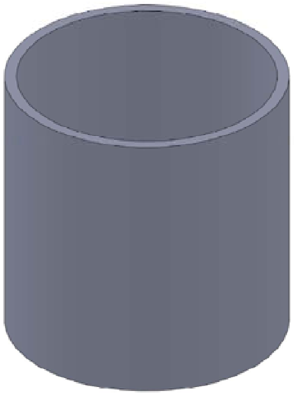


Figure 3: Vessel Tube

- Head Plate Mount

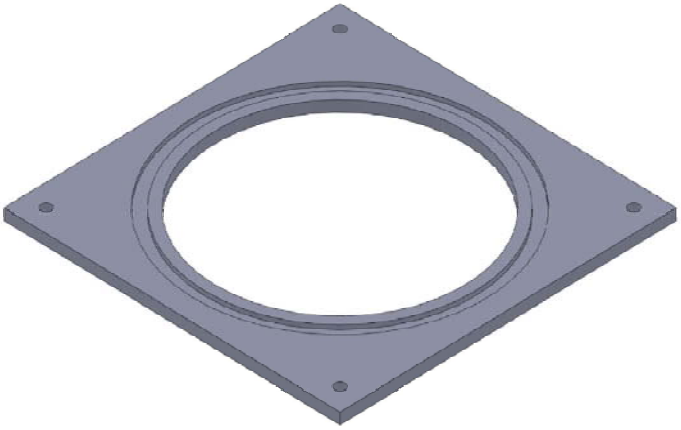


Figure 4: Head Plate Mount

- O-Ring

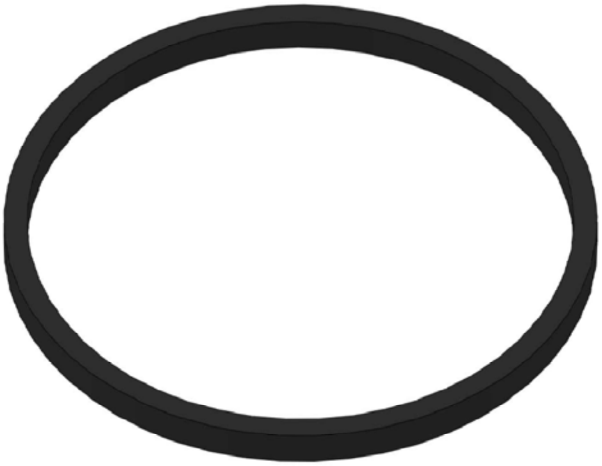


Figure 5: O-Ring

This sub assembly was assembled using the following steps:

3. Attach the bottom plate and the head plate mount to each end of the vessel tube using Tungsten Inert gas welding, creating the object shown in Figure 6. Ensure that the circle in the head plate mount is concentric with the opening of the vessel tube. (John add more detail if necessary)

Figure 6: Pressure Vessel

2. Affix the O-Ring to the head plate mount using (decide on type of adhesive). Ensure that the O-Ring is connected securely to the head plate mount.

Figure 7: Pressure Vessel Sub Assembly

Head Plate Sub Assembly

The Head Plate Sub Assembly consists of the connections for the inlet, outlet, and sparging tubes. It is also the mount location for the system temperature sensor and the vertical level sensor. The final head plate sub assembly is shown in Figure 8.

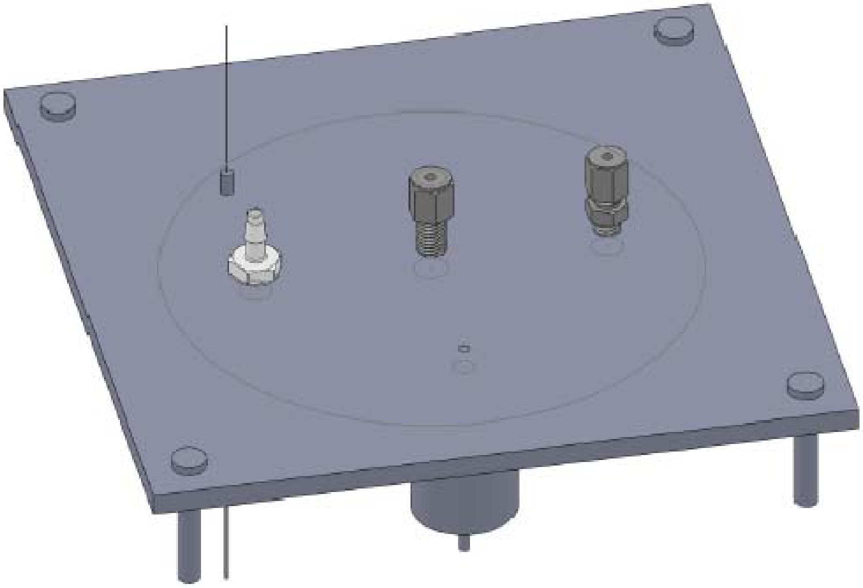


Figure 8: Final Head Plate Sub Assembly

The Head Plate assembly was constructed using the following steps:

4. Connect the barbed pipe fitting and the compression fitting to the head plate. The barbed pipe fitting should be screwed into the ¼”hole while the compression tube fittings should be screwed into the 3/10” holes. Ensure that each fitting is tightened securely to ensure that air and water tight conditions are maintained.

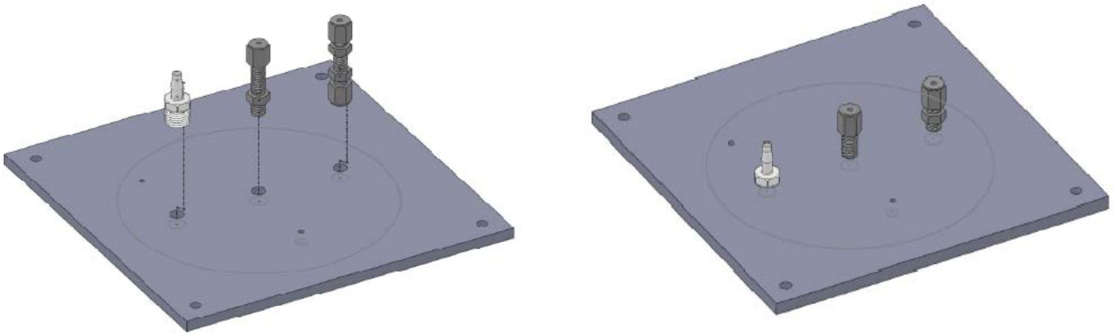


Figure 9: Head Plate Assembly Before (left) and after (right) installation of Barbed Fittings

5. Screw the vertical level sensor into the 1/8” threaded hole that directly adjacent to the center compression fitting Afterwards, insert the temperature probe into the head plate by screwing the head portion of the probe into the remaining threaded 1/8” hole at the bottom of the head plate. This step is illustrated in Figure 10. Once again, insure that each

component is screwed tightly into each hole to ensure that the system is water-tight and air-tight.

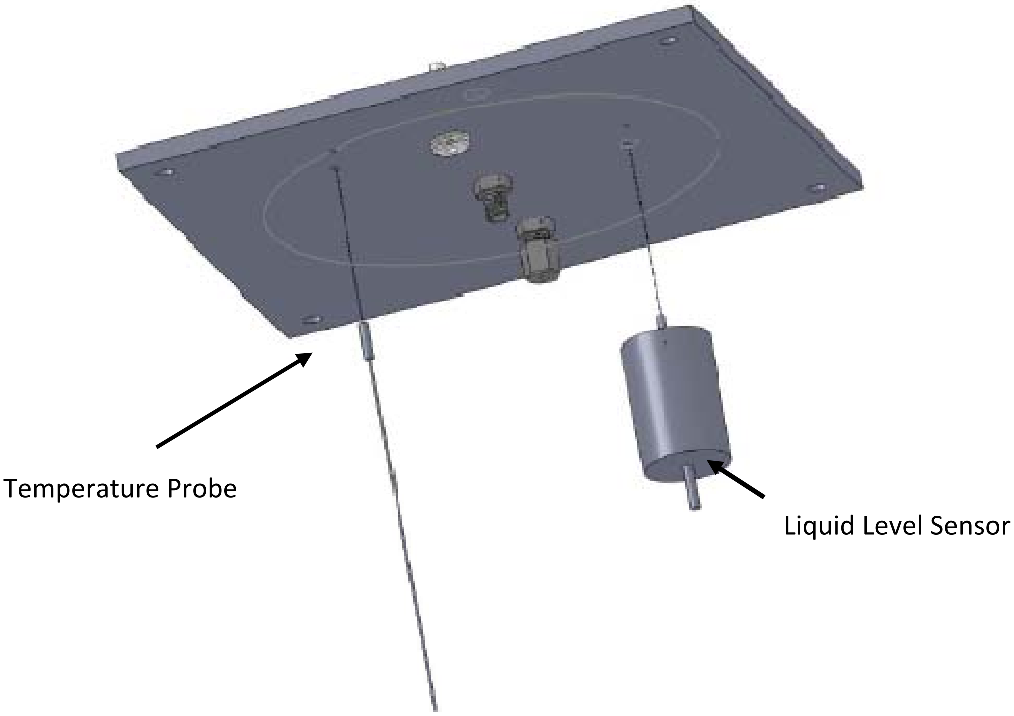


Figure 10: Incorporation of Temperature and Level Sensor Probes

6. Upon removal of the membrane from the AnMBR (instructions for that process are in a separate document), the membrane housing should look as shown in Figure 11.

Figure 11: Membrane Housing

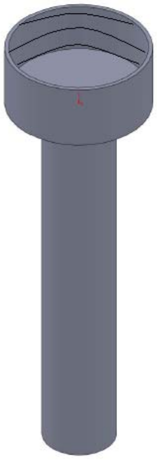


Figure 12: Membrane Housing Connector

Notice the connector rising from the top of the membrane housing (denoted by the arrow). The top of this connector features a threaded end connection. To connect the membrane housing to the head plate, screw this threaded connection over the threaded end of the middle compression fitting. Ensure that this is a tight connection. This step is shown in Figure 13. The temperature probe and the level sensor which were installed in previous steps are omitted for clarity.

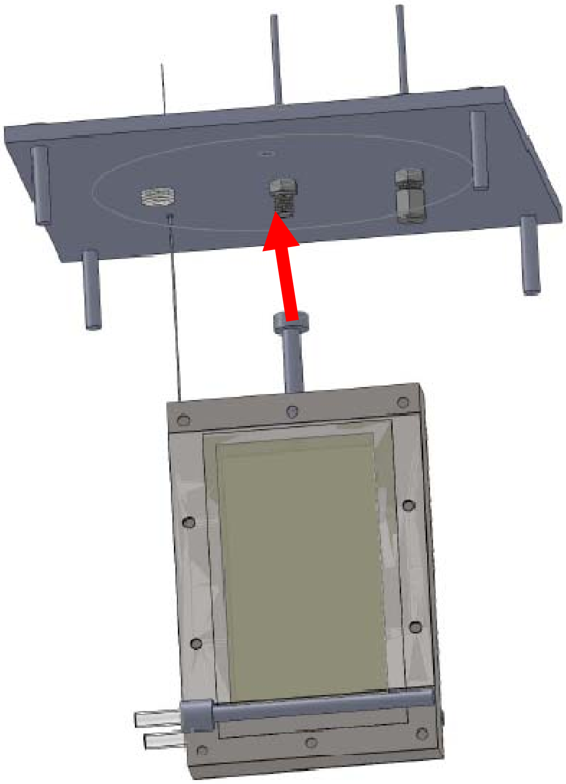


Figure 13: Connection of Membrane Housing to Head Plate

To connect the influent tube to the head plate slide the tubing onto the fitting as shown in Figure 14 and 15. Press the tubing down onto the fitting so that there is a tight fit. Clamps may be needed to ensure a tight fit between the tube and the fitting. The same process shown to the right can be repeated for the sparging tube inside the vessel.

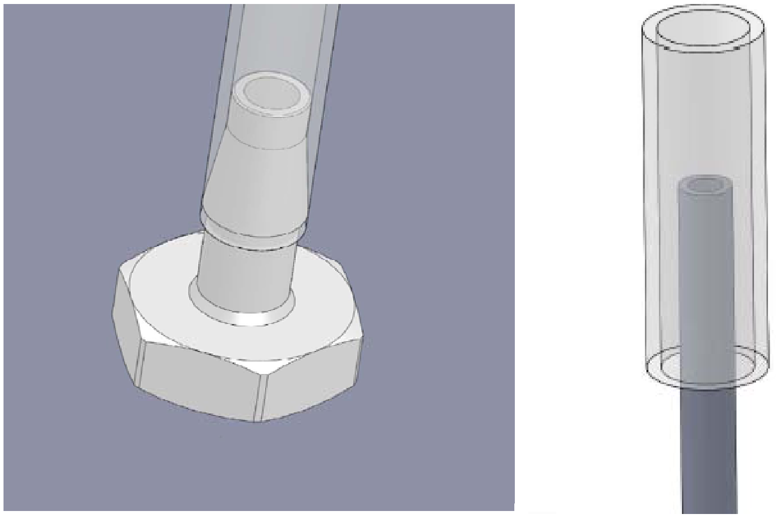


Figure 14: Connection of Tubing to Fittings

4. The Head Plate Sub Assembly can be connected to the vessel itself by inserting bolts through each of the 4 holes in each corner of the head plate. Each of these bolts should be tightened securely by hand to maintain airtight conditions.

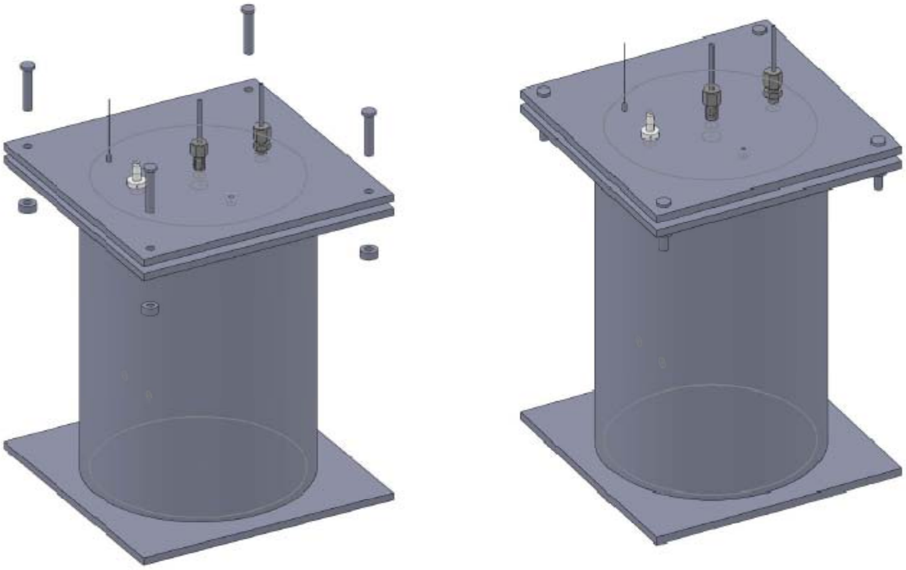


Figure 15: MBAT System before and after Installation of Screws and Bolts

6. Design Testing and Validation

How and where will your final design be tested? Which design specifications are being validated through the testing? Do you plan to test aspects of your design as you manufacture your prototype, or are you going to be validating a finished prototype after most/all manufacturing has been completed?

- *a. What would you consider to be your first major test of the design?*
- *b. Have you arranged with your Section Instructor to have a cognizant individual present at your first major test? Who will this be? When do you expect this first test to take place?*

Experimental Validation Plan

During operation the system will be required to hold water and operate anaerobically under pressure. The goal of our experimental testing will be to determine if the system is both water and air tight under the maximum operating pressure of 5psi. If testing proves that our system is both airtight and watertight we will conclude that the integrity of our vessel is sufficient for in lab use.

The Procedure

Two experimental trials will be performed on our system: the first to ensure that the system is airtight and the second to prove that the system is water tight. Protective eyewear will be worn at all times during our testing.

Air Tight Testing: The vessel will be assembled and all openings of the vessel will be sealed . A small length of tubing will be attached to each fitting. Two of the lengths of tubing will be sealed with rubber stoppers. The third will be left open. Attached to this open length of pipe will be a small bicycle pump. The vessel will then be completely submerged vertically in water. Using the pressure reading on the pump as a guide, the vessel will pressured up to 10 psi in increments of 1 psi. During the entire length of testing, we will check to ensure that no air bubbles are rising to the surface as this would show that the system is not completely airtight. We will use our data and observation to complete the table below.

Pressure Reading (psi)	Leakage (Air Bubbles Observed)
1	Y/N
2	Y/N
3	Y/N
4	Y/N
5	Y/N
6	Y/N
7	Y/N
8	Y/N
9	Y/N
10	Y/N

Water Tight Testing: Water Tight Testing will occur in a manner similar to Air Tight testing. The vessel will be filled with water before testing. All openings of the vessel will be sealed except for one and a bicycle pump will be utilized in the same was as the previous testing. The vessel will but be submerged in water but placed a large bucket to ensure no large spills if leaking does occur. Using the pressure reading on the pump as a guide, the vessel will pressured up to 5psi in increments of one psi. During the entire length of testing, we will check to ensure that no moisture is seen on the outside of the vessel as this would show that the system is not completely watertight. We will use our data to complete the table below.

Pressure Reading (psi)	Leakage (Water Observed)
1	Y/N
2	Y/N
3	Y/N
4	Y/N
5	Y/N
6	Y/N
7	Y/N
8	Y/N
9	Y/N
10	Y/N

Interpreting Results: Using the completed tables we will analyze the data. If no leakages are found during both tests it can be said that our system is viable and will operate as planned during in lab operation.

APPENDIX A: MSDS Sheets

Water

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1. Product Identification

Synonyms: Hydrogen oxide; Dihydrogen oxide; Distilled water
CAS No.: 7732-18-5
Molecular Weight: 18.02
Chemical Formula: H_2O
Product Codes:
J.T. Baker: 4022, 4201, 4212, 4216, 4218, 4219, 4221, 6906, 9823, 9831, XL-317
Mallinckrodt: 6795, H453, V564

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2. Composition/Information on Ingredients

Ingredient	CAS No	Percent	Hazardous
Water	7732-18-5	100%	No

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3. Hazards Identification

Emergency Overview

Not applicable.

SAF-T-DATA$^{(tm)}$ Ratings (Provided here for your convenience)

Health Rating: 0 - None
Flammability Rating: 0 - None
Reactivity Rating: 1 - Slight
Contact Rating: 0 - None
Lab Protective Equip: GOGGLES; LAB COAT
Storage Color Code: Green (General Storage)

Potential Health Effects

Water is non-hazardous.

Inhalation:
Not applicable.
Ingestion:
Not applicable.
Skin Contact:
Not applicable.
Eye Contact:
Not applicable.
Chronic Exposure:
Not applicable.
Aggravation of Pre-existing Conditions:
Not applicable.

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4. First Aid Measures

Inhalation:
Not applicable.
Ingestion:
Not applicable.
Skin Contact:
Not applicable.
Eye Contact:
Not applicable.

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5. Fire Fighting Measures

Fire:
Not applicable.
Explosion:
Not applicable.
Fire Extinguishing Media:

Use extinguishing media appropriate for surrounding fire.

Special Information:

In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode.

6. Accidental Release Measures

Non-hazardous material. Clean up of spills requires no special equipment or procedures.

7. Handling and Storage

Keep container tightly closed. Suitable for any general chemical storage area. Protect from freezing. Water is considered a non-regulated product, but may react vigorously with some specific materials. Avoid contact with all materials until investigation shows substance is compatible.

8. Exposure Controls/Personal Protection

Airborne Exposure Limits:

Not applicable.

Ventilation System:

Not applicable.

Personal Respirators (NIOSH Approved):

Not applicable.

Skin Protection:

None required.

Eye Protection:

None required.

9. Physical and Chemical Properties

Appearance:

Clear, colorless liquid.

Odor:

Odorless.
Solubility:
Complete (100%)
Specific Gravity:
1.00
pH:
7.0
% Volatiles by volume @ 21C (70F):
100
Boiling Point:
100C (212F)
Melting Point:
0C (32F)
Vapor Density (Air=1):
Not applicable.
Vapor Pressure (mm Hg):
17.5 @ 20C (68F)
Evaporation Rate (BuAc=1):
No information found.

10. Stability and Reactivity

Stability:
Stable under ordinary conditions of use and storage.
Hazardous Decomposition Products:
Not applicable.
Hazardous Polymerization:
Will not occur.
Incompatibilities:
Strong reducing agents, acid chlorides, phosphorus trichloride, phosphorus pentachloride, phosphorus oxychloride.
Conditions to Avoid:
No information found.

11. Toxicological Information

For Water: LD50 Oral Rat: >90 ml/Kg. Investigated as a mutagen.

--------\Cancer Lists\--

	---NTP Carcinogen---		
Ingredient	Known	Anticipated	IARC Category
Water (7732-18-5)	No	No	None

12. Ecological Information

Environmental Fate:

Not applicable.

Environmental Toxicity:

Not applicable.

13. Disposal Considerations

Whatever cannot be saved for recovery or recycling should be flushed to sewer. If material becomes contaminated during use, dispose of accordingly. Dispose of container and unused contents in accordance with federal, state and local requirements.

14. Transport Information

Not regulated.

15. Regulatory Information

--------\Chemical Inventory Status - Part 1\---------------------------------

Ingredient	TSCA	EC	Japan	Australia
Water (7732-18-5)	Yes	Yes	Yes	Yes

--------\Chemical Inventory Status - Part 2\---------------------------------

		--Canada--		
Ingredient	Korea	DSL	NDSL	Phil.
Water (7732-18-5)	Yes	Yes	No	Yes

--------\Federal, State & International Regulations - Part 1\----------------

	-SARA 302-		------SARA 313------	
Ingredient	RQ	TPQ	List	Chemical Catg.

Water (7732-18-5)	No	No	No	No

--------\Federal, State & International Regulations - Part 2\----------------

	-RCRA-	-TSCA-	
Ingredient	CERCLA	261.33	8(d)
Water (7732-18-5)	No	No	No

Chemical Weapons Convention: No TSCA 12(b): No CDTA: No
SARA 311/312: Acute: No Chronic: No Fire: No Pressure: No
Reactivity: No (Pure / Liquid)

Australian Hazchem Code: None allocated.

Poison Schedule: None allocated.

WHMIS:

This MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

16. Other Information

NFPA Ratings: Health: **0** Flammability: **0** Reactivity: **0**

Label Hazard Warning:

Not applicable.

Label Precautions:

Keep in tightly closed container.

Label First Aid:

Not applicable.

Product Use:

Laboratory Reagent.

Revision Information:

No Changes.

Disclaimer:

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Prepared by: Environmental Health & Safety
Phone Number: (314) 654-1600 (U.S.A.)

APPENDIX B: FMEA

Project #	12	**Report Ver:**	1	**Date:**	Nov. 20, 2009				
Project Title:	Membrane Bioreactor Analysis Testbed								
Team Members:	Deandre Reagins, John Song, Adithya Varadarajan								
Part Number, Name, & Functions	Potential Failure Mode	Potential Effect(s) of Failure	**Severity (S)**	Potential Cause(s) / Mechanism(s) of Failure	**Occurrence (O)**	Current Design Controls / Tests	**Detection (D)**	Recommended Action(s)	**RPN (=S x O x D)**
#1: Differential Pressure Transducer	Loose fittings / incomplete seal	Water leak / pressure leak		Improper assembly, manufacturing defects		Visual inspection of connections, manual tightness testing		Inspect each connection. Watch for leaks.	
	Fracture / parts separate	Flying debris		Manufacturing defects		Built to withstand 200 psi		Inspect each purchased part. Test assembly by running system and watch for leaks.	
#2: Reactor Temperature Probe	Loose fittings / incomplete seal	Pressure leak		Improper assembly, manufacturing defects		Visual inspection of connections, manual tightness		Inspect connection. Watch for leaks.	

						testing			
#3: In-line temperature probe	Loose fittings / incomplete seal	Water leak, pressure leak		Improper assembly, manufacturing defects		Visual inspection of connections, manual tightness testing		Inspect each connection. Watch for leaks.	
#4: Inlet Tubing: Supplies wastewater source to vessel	Loose fittings / incomplete seal	Water leak, pressure leak		Improper assembly, manufacturing defects		Visual inspection of connections, manual tightness testing		Inspect each connection. Watch for leaks.	
	Fracture / parts separate	Flying debris, water leak, pressure leak		Manufacturing defects		Built to withstand 20 psi		Inspect each purchased part. Test assembly by running system and watch for leaks.	
#5: Outlet Tubing: Connects effluent water to drain	Loose fittings / incomplete seal	Water leak, pressure leak		Improper assembly, manufacturing defects		Visual inspection of connections, manual tightness testing		Inspect each connection. Watch for leaks	
	Fracture / parts	Flying debris water leak,		Manufacturing defects		Built to withstand 20		Inspect each purchased part. Test assembly by running	

	separate	pressure leak				psi		system and watch for leaks	
#6: Peristaltic pump system with pump head	Loose fittings / incomplete seal	Water leak, pressure leak		Improper assembly, manufacturing defects		Visual inspection of connections, test before integration into system		Inspect each purchased part. Test assembly by running system	
	Fracture / parts separate	Water leak, pressure leak		Manufacturing defects				Inspect each purchased part. Test assembly	
#7: Effluent flow meter: A bucket and weigh scale	Fracture / holes	Water leak		Improper assembly, manufacturing defects		Visual inspection of bucket		Inspect each part and test for water leaks	
#8: Sparging gas pressure gauge: part of gas sparging subsystem	Fracture / incomplete seal	Pressure leak		Improper assembly, manufacturing defects		Visual inspection of connection, test before integration into system		Inspect each part. Test subassembly before integration with system	
#9: Sparging gas high pressure solenoid valve: controls gas flow of	Loose fittings / incomplete seal	Pressure leak		Improper assembly, manufacturing defects		Visual inspection of connection, test before integration into system		Inspect each part. Test subassembly before integration with system.	

sparging gas									
#10: Refrigerator	Fracture	No refrigeration		Manufacturing defects		Visual inspection of refrigerator before use		Inspect refrigerator before use	
#11: Horizontal level switch: used to control water level inside vessel	Loose fittings / incomplete seal	Pressure leak		Improper assembly, manufacturing defects		Visual inspection of connection, test before integration into system		Inspect each part, test before integration into system	

designsafe Report

Application:	ME 450 Team 12	Analyst Name(s):	John Song, Adithya Varadarajan, Deandre Reagins
Description:		Company:	ME 450
Product Identifier:	Membrane Biofilm Analysis Testbed (MBAT)	Facility Location:	EWRE
Assessment Type:	Detailed		
Limits:			
Sources:			

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	**Hazard / Failure Mode**	**Initial Assessment Severity Exposure Probability**	**Risk Level**	**Risk Reduction Methods /Comments**	**Final Assessment Severity Exposure Probability**	**Risk Level**	**Status / Responsible /Reference**
operator normal operation	electrical / electronic : energized equipment / live parts	Serious Remote Negligible	Low	fixed enclosures / barriers	Serious Remote Negligible	Low	In-process
operator normal operation	electrical / electronic : improper wiring	Slight Remote Unlikely	Low		Slight Remote Unlikely	Low	In-process
operator normal operation	electrical / electronic : water / wet locations	Serious Remote Unlikely	Moderate	fixed enclosures / barriers, prevent energy buildup, safety mats / contact strip, other presence sensing devices	Serious Remote Unlikely	Moderate	In-process
operator normal operation	electrical / electronic : software errors	Minimal Occasional Possible	Moderate		Minimal Occasional Possible	Moderate	TBD
operator normal operation	electrical / electronic : power supply interruption	Slight Occasional Possible	Moderate		Slight Occasional Possible	Moderate	In-process
operator normal operation	ergonomics / human factors : lifting / bending / twisting	Minimal Frequent Unlikely	Moderate		Minimal Frequent Unlikely	Moderate	In-process
	material handling : movement to / from storage	Minimal Frequent Probable	High	gloves, special clothing	Minimal Remote Probable	Moderate	In-process

APPENDIX C: Design Safe Report

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
operator normal operation	environmental / industrial hygiene : solvents	Slight Frequent Possible	High	gloves, special clothing	Slight Frequent Unlikely	Moderate	In-process
operator normal operation	environmental / industrial hygiene : trace metals	Slight Frequent Unlikely	Moderate		Slight Frequent Unlikely	Moderate	In-process
operator normal operation	environmental / industrial hygiene : wastewater contamination	Slight Frequent Possible	High	gloves, special clothing	Slight Frequent Unlikely	Moderate	In-process
operator normal operation	environmental / industrial hygiene : corrosion	Slight Frequent Possible	High	gloves, special clothing	Slight Frequent Unlikely	Moderate	In-process
operator normal operation	environmental / industrial hygiene : contamination	Slight Frequent Possible	High	gloves, special clothing	Slight Frequent Unlikely	Moderate	In-process
operator normal operation	ventilation : recirculating air	Minimal Frequent Unlikely	Moderate		Minimal Frequent Unlikely	Moderate	In-process
operator normal operation	chemical : failure at key points and trouble spots	Serious Remote Unlikely	Moderate		Serious Remote Unlikely	Moderate	In-process
operator normal operation	chemical : acids	Serious Frequent Possible	High	gloves, special clothing	Serious Remote Unlikely	Moderate	In-process
operator normal operation	chemicals and gases : nitrogen	Slight Frequent Possible	High		Slight Frequent Unlikely	Moderate	In-process
operator normal operation	chemicals and gases : oxygen	Minimal Frequent Possible	Moderate		Minimal Frequent Possible	Moderate	In-process
operator normal operation							
operator normal operation	fluid / pressure : fluid leakage / ejection	Slight Frequent Unlikely	Moderate	prevent energy buildup	Slight Frequent Unlikely	Moderate	In-process
operator normal operation	environmental / industrial hygiene : hazardous waste	Serious Frequent Unlikely	High	gloves, special clothing	Serious Remote Unlikely	Moderate	In-process
operator load / unload materials	mechanical : pinch point	Slight Frequent Unlikely	Moderate		Slight Frequent Unlikely	Moderate	In-process
operator normal operation	environmental / industrial hygiene : poisons	Serious Occasional Unlikely	Moderate		Serious Occasional Unlikely	Moderate	In-process

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
operator load / unload materials	ergonomics / human factors : lifting / bending / twisting	Slight Frequent Probable	High	instruction manuals	Slight Frequent Unlikely	Moderate	In-process
operator load / unload materials	material handling : movement to / from storage	Minimal Occasional Probable	Moderate		Minimal Occasional Probable	Moderate	In-process
operator load / unload materials	environmental / industrial hygiene : effluent / effluent handling	Slight Occasional Probable	High		Slight Remote Probable	Moderate	In-process
operator load / unload materials	environmental / industrial hygiene : corrosion	Slight Frequent Unlikely	Moderate		Slight Frequent Unlikely	Moderate	In-process
operator load / unload materials	environmental / industrial hygiene : contamination	Slight Frequent Unlikely	Moderate		Slight Frequent Unlikely	Moderate	In-process
operator load / unload materials	chemical : skin exposed to toxic chemcial	Serious Frequent Possible	High	gloves, special clothing	Serious Occasional Unlikely	Moderate	In-process
operator load / unload materials	chemical : irritant chemicals	Serious Frequent Possible	High	gloves, special clothing	Serious Occasional Unlikely	Moderate	In-process
operator load / unload materials	chemical : failure at key points and trouble spots	Slight Frequent Unlikely	Moderate	gloves, special clothing	Slight Frequent Unlikely	Moderate	In-process
operator load / unload materials	biological / health : unsanitary conditions	Serious Frequent Unlikely	High	gloves, special clothing	Slight Remote Unlikely	Low	In-process
operator sort / inspect parts	ergonomics / human factors : lifting / bending / twisting	Minimal Frequent Unlikely	Moderate		Minimal Frequent Unlikely	Moderate	In-process
operator sort / inspect parts	material handling : movement to / from storage	Minimal Frequent Probable	High		Minimal Remote Probable	Moderate	In-process
operator sort / inspect parts	environmental / industrial hygiene : poisons	Serious Occasional Unlikely	Moderate	gloves, special clothing	Serious Occasional Unlikely	Moderate	In-process

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
operator sort / inspect parts	environmental / industrial hygiene : solvents	Serious Occasional Unlikely	Moderate	gloves, special clothing	Serious Occasional Unlikely	Moderate	In-process
operator sort / inspect parts	environmental / industrial hygiene : trace metals	Serious Occasional Unlikely	Moderate	gloves, special clothing	Slight Occasional Unlikely	Moderate	In-process
operator sort / inspect parts	environmental / industrial hygiene : effluent / effluent handling	Slight Occasional Probable	High	gloves, special clothing	Slight Occasional Unlikely	Moderate	In-process
operator sort / inspect parts	environmental / industrial hygiene : wastewater contamination	Slight Occasional Probable	High	gloves, special clothing	Slight Occasional Unlikely	Moderate	In-process
operator sort / inspect parts	environmental / industrial hygiene : corrosion	Serious Occasional Probable	High	gloves, special clothing	Serious Occasional Unlikely	Moderate	In-process
operator sort / inspect parts	environmental / industrial hygiene : contamination	Serious Remote Unlikely	Moderate	gloves, special clothing	Serious Remote Unlikely	Moderate	In-process
operator position / fasten parts and components	mechanical : pinch point	Serious Occasional Probable	High	instruction manuals	Slight Occasional Possible	Moderate	In-process
operator position / fasten parts and components	electrical / electronic : water / wet locations	Slight Occasional Unlikely	Moderate		Slight Occasional Unlikely	Moderate	In-process
operator position / fasten parts and components	ergonomics / human factors : excessive force / exertion	Serious Occasional Possible	High		Serious Remote Possible	Moderate	In-process
operator position / fasten parts and components	fluid / pressure : surges / sloshing	Slight Occasional Unlikely	Moderate	prevent energy buildup	Slight Occasional Unlikely	Moderate	In-process
operator minor adjustments to machine	electrical / electronic : software errors	Serious Occasional Probable	High		Minimal Occasional Probable	Moderate	In-process
operator minor adjustments to machine	fluid / pressure : fluid leakage / ejection	Minimal Remote Possible	Low		Minimal Remote Possible	Low	In-process

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
operator basic troubleshooting	electrical / electronic : software errors	Slight Occasional Probable	High		Slight Occasional Possible	Moderate	In-process
operator basic troubleshooting	fluid / pressure : surges / sloshing	Minimal Remote Possible	Low		Minimal Remote Possible	Low	In-process
operator basic troubleshooting	fluid / pressure : fluid leakage / ejection	Serious Occasional Probable	High	gloves, special clothing	Serious Occasional Unlikely	Moderate	In-process
operator shut down	electrical / electronic : water / wet locations	Slight Occasional Possible	Moderate		Slight Occasional Possible	Moderate	In-process
operator shut down	electrical / electronic : software errors	Minimal Occasional Possible	Moderate		Slight Occasional Possible	Moderate	In-process
operator shut down	electrical / electronic : power supply interruption	Minimal Remote Unlikely	Low		Minimal Remote Unlikely	Low	In-process
operator shut down	fluid / pressure : fluid leakage / ejection	Minimal Remote Unlikely	Low		Minimal Remote Unlikely	Low	In-process
operator clean machine	material handling : movement to / from storage	Slight Remote Possible	Moderate	gloves, special clothing	Slight Remote Possible	Moderate	In-process
operator clean machine	environmental / industrial hygiene : poisons	Slight Occasional Probable	High	gloves, special clothing	Slight Occasional Unlikely	Moderate	In-process
operator clean machine	environmental / industrial hygiene : wastewater contamination	Serious Occasional Unlikely	Moderate	gloves, special clothing	Serious Occasional Unlikely	Moderate	In-process
operator clean machine	environmental / industrial hygiene : contamination	Serious Occasional Probable	High	gloves, special clothing	Serious Occasional Unlikely	Moderate	In-process
operator clean machine	chemical : skin exposed to toxic chemcial	Serious Occasional Probable	High	gloves, special clothing	Slight Occasional Unlikely	Moderate	In-process

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
operator clean machine	chemical : irritant chemicals	Serious Occasional Possible	High	gloves, special clothing	Slight Occasional Possible	Moderate	In-process
operator clean machine	chemical : acids	Serious Occasional Probable	High	gloves, special clothing	Slight Occasional Unlikely	Moderate	In-process
operator clean machine	fluid / pressure : surges / sloshing	Serious Occasional Probable	High	prevent energy buildup	Slight Occasional Unlikely	Moderate	In-process
operator clean machine	fluid / pressure : fluid leakage / ejection	Serious Occasional Possible	High	prevent energy buildup	Slight Occasional Possible	Moderate	In-process
engineer All Tasks	mechanical : cutting / severing	Serious Occasional Possible	High	safety glasses, instruction manuals			In-process
engineer develop new designs	None / Other : Not a hazard						In-process
engineer modify parts / components	mechanical : cutting / severing	Minimal Remote Negligible	Low				In-process
engineer modify parts / components	mechanical : stabbing / puncture	Serious Remote Possible	Moderate				In-process
engineer modify parts / components	mechanical : break up during operation	Serious Remote Unlikely	Moderate				In-process
engineer modify parts / components	electrical / electronic : energized equipment / live parts	Serious Remote Unlikely	Moderate				In-process
engineer modify parts / components	electrical / electronic : shorts / arcing / sparking	Slight Remote Probable	Moderate				In-process
engineer modify parts / components	electrical / electronic : improper wiring	Serious Remote Probable	High	fixed enclosures / barriers			In-process

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
engineer modify parts / components	electrical / electronic : water / wet locations	Serious Remote Possible	Moderate				In-process
engineer modify parts / components	electrical / electronic : software errors	Serious Remote Possible	Moderate				In-process
engineer modify parts / components	ergonomics / human factors : human errors / behaviors	Slight Remote Possible	Moderate				In-process
engineer modify parts / components	ergonomics / human factors : deviations from safe work practices	Slight Remote Negligible	Low	instruction manuals			In-process
engineer modify parts / components	ergonomics / human factors : interactions between persons	Slight Remote Unlikely	Low				In-process
engineer modify parts / components	heat / temperature : severe heat	Serious Occasional Possible	High	gloves, special clothing, instruction manuals	Serious Occasional Unlikely	Moderate	On-going [Daily]
engineer modify parts / components	noise / vibration : fatigue / material strength	Minimal None Negligible	Low				In-process
engineer modify parts / components	material handling : movement to / from storage	Minimal None Negligible	Low				In-process
engineer modify parts / components	environmental / industrial hygiene : poisons	Minimal Occasional Negligible	Low				In-process
engineer modify parts / components	chemical : skin exposed to toxic chemcial	Slight Occasional Possible	Moderate				In-process
engineer modify parts / components	chemical : irritant chemicals	Slight None Possible	Low				In-process
engineer modify parts / components	chemical : failure at key points and trouble spots	Slight Remote Unlikely	Low				On-going [Daily]

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
engineer modify parts / components	chemical : mixing incompatible chemicals	Slight None Negligible	Low				On-going [Daily]
engineer conduct tests	mechanical : fatigue	Minimal Remote Negligible	Low				Complete [11/20/2009]
engineer conduct tests	mechanical : break up during operation	Serious Remote Negligible	Low				Complete [11/20/2009]
engineer conduct tests	ergonomics / human factors : human errors / behaviors	Minimal None Negligible	Low				Complete [11/20/2009]
engineer conduct tests	ergonomics / human factors : deviations from safe work practices	Minimal None Negligible	Low				On-going [Daily]
engineer conduct tests	chemicals and gases : oxygen	Minimal None Negligible	Low				On-going [Daily]
engineer conduct tests	fluid / pressure : high pressure air	Slight None Possible	Low				
engineer conduct tests	fluid / pressure : explosion / implosion	Minimal Remote Possible	Low				Complete [11/20/2009]
engineer conduct tests	fluid / pressure : surges / sloshing	Minimal Occasional Possible	Moderate				On-going [Daily]
engineer conduct tests	fluid / pressure : fluid leakage / ejection	Slight Remote Negligible	Low				
engineer design components / systems	None / Other : Not a hazard	Slight Remote Unlikely	Low				
engineer trouble shooting	electrical / electronic : software errors	Minimal None Negligible	Low				

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
engineer trouble shooting	electrical / electronic : power supply interruption	Slight Remote Unlikely	Low				
engineer trouble shooting	ergonomics / human factors : human errors / behaviors	Slight Remote Unlikely	Low				
engineer trouble shooting	chemical : skin exposed to toxic chemcial	Serious Remote Possible	Moderate				
engineer trouble shooting	chemical : irritant chemicals	Slight Occasional Unlikely	Moderate				
engineer trouble shooting	chemical : failure at key points and trouble spots	Slight Remote Unlikely	Low				
engineer trouble shooting	chemicals and gases : oxygen	Minimal None Negligible	Low				
engineer trouble shooting	fluid / pressure : fluid leakage / ejection	Slight None Negligible	Low				
engineer adjust software program / controls	electrical / electronic : energized equipment / live parts	Slight Remote Negligible	Low				
engineer adjust software program / controls	electrical / electronic : improper wiring	Minimal None Negligible	Low				
engineer adjust software program / controls	electrical / electronic : overloading	Minimal None Negligible	Low				
engineer adjust software program / controls	electrical / electronic : software errors	Minimal Frequent Possible	Moderate				
engineer adjust software program / controls	electrical / electronic : power supply interruption	Minimal Remote Negligible	Low				

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
engineer communicate with / supervise others	ergonomics / human factors : interactions between persons	Minimal None Negligible	Low				
engineer inspect machinery	material handling : movement to / from storage	Minimal None Negligible	Low				In-process
engineer inspect machinery	chemical : skin exposed to toxic chemcial	Slight Occasional Possible	Moderate				In-process

Appendix N: LabVIEW Setup Overview

The entire LabVIEW code needs to be set up in a loop due to the requirement for continuous data recording over the course of each experiment from start to stop. The primary aspects of the LABVIEW interface are listed in the following section along with a brief overview of the set up procedure.

1. Differential Pressure -- Using the differential pressure transducer (Omega Part No. PX26-015DV), the labVIEW interface will incorporate a real time waveform and numerical display of the trans-membrane pressure. This data will also be recorded with time stamps for future research.The following steps indicate the sensor setup procedure
    a. The differential pressure transducer needs to be connected on two sides. One side connects to the effluent flow and one to the inlet flow and the pressure difference is computed between the two. These connections can be accomplished by using T-shaped barbed connectors on the inlet and outlet streams and routing side streams to the sensor.
    b. Once the transducer has been connected to the flow, it then has to be connected to theDAQ via the Signal conditioning board and analog voltage input module (National Instruments Part No. SCC-AI02) using the 4pin connector (Omega Part No. CX136-4) and connector wire (Omega Part No. TX4-100).

2. System Temperature – Using the K-Type thermocouple (Omega Part No. KQSS-116G-12), the labVIEW interface will incorporate a real time waveform and numerical display of the MBAT temperature. This data will also be recorded with time stamps for future research. This is useful for the purposes of maintaining the system temperature. The following steps indicate the sensor setup procedure
    a. The thermocouple probe needs to be mounted onto the head plate of the MBAT system. This is done using the Yor-Lok Tube Adapter Compression Fitting (McMaster Part No. 5182K435) in order to ensure an airtight seal. The compression fitting is fixed to the head plate and the thermocouple is inserted into it. The compression section is then tightened to seal the probe in place.
    b. Once the thermocouple has been attached to the MBAT, we use the thermocouple connector to connect to the DAQ via the signal conditioning board and the analog thermocouple module (National Instruments Part No. SCC-TC01).

3. Mass Flow Rate – The OHaus Adventurer Pro 2101C Weighing scale will be incorporated for real time measurement of the mass flow rate and this will be converted into a volume flow rate of the effluent that will be displayed on the LabVIEW interface. The data will be recorded with time stamps for future analysis. The sensor setup procedure is as follows

    a. The weighing scale will be set up with a beaker or receptacle placed on top and the tare weight will be set. The effluent tubing will lead to this beaker and collect here.
    b. Once the scale has been set up with the MBAT system, it will be connected with a 9pin RS232 connector to the main computer.

4. Outlet Pump Control – The Masterflex Computer Compatible/Programmable Peristaltic Pump (HV-07551-10) will be incorporated in order to control the rate of flow for the outlet and the application of positive pressure. It will also be used to activate and automate the cleaning process of backflushing. There will be no data recording involved with this, only control and operation.
    a. The pump will be connected in line to the effluent tubing coming from the membrane housing connector on the head plate of the MBAT.
    b. It will be connected to LabVIEW with a 9pin RS232 serial connector.

For the LabVIEW interface, the following is an overview of the various aspects.

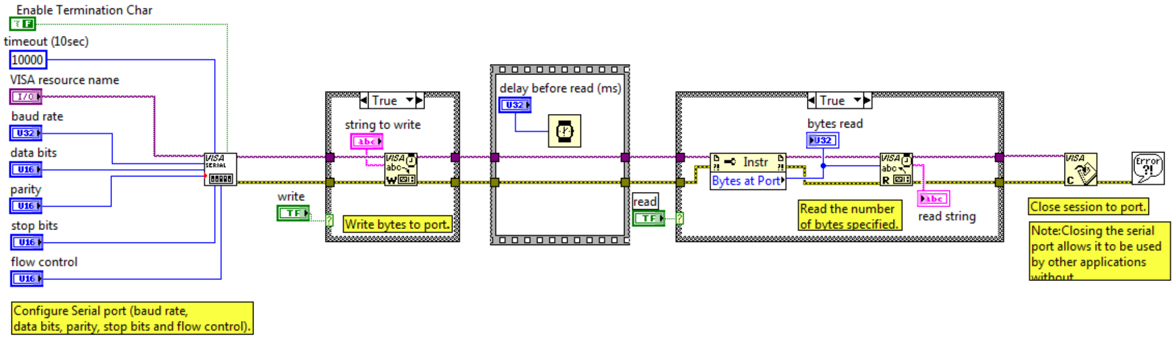
DAQ Setup

Reading Data – This procedure can be accomplished for the pressure and temperature gauges using a DAQ Assistant module in the block diagram. For each sensor, the corresponding port that it is connected to on the signal conditioning board needs to be selected (ai0,ai1 etc). For the thermocouple, the correct thermocouple type (type K) and temperature range (-200 to +1350) and cold junction compensation (25C) needs to be entered. The pressure data is received as a voltage signal.

Processing Data – The thermocouple data does not require processing and can be directly displayed as a waveform or recorded for future reference. The pressure transducer data is received as a voltage reading and this needs to be converted to the corresponding pressure value. These conversion factors can be obtained from information sheets available on the Omega website (http://www.omega.com/ppt/pptsc.asp?ref=PX26) and once applied, the pressure data will be ready for display as a waveform and for recording.

Serial Connection Setup

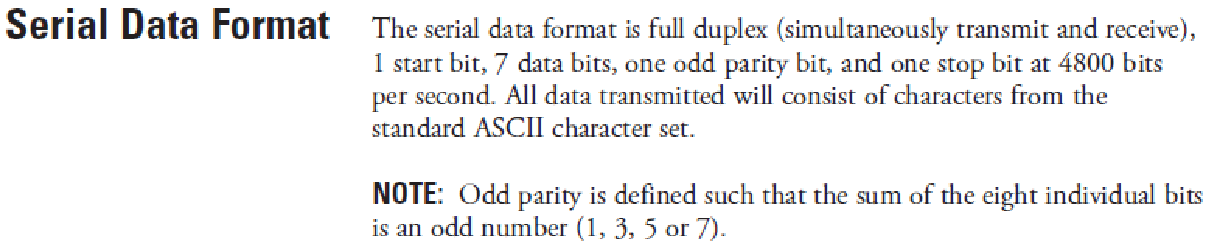
This is the section of the LabVIEW that our team faced the most difficulty with as it was something we had no prior experience with. Our team members had worked with sensors and LabVIEW in the past but never with serial interfaces. The overview of the set up for these serial interfaces has been discussed in the following section. Both of the serial interfaces would be controlled using a serial read write VI, a screen shot of the example VI file is indicated below.



OHaus Weighing Scale – This would be hooked up to the research computer using a standard 9pin RS232 cable. The scale would then be controlled using the serial VI system in LabVIEW. An introductory version of a serial VI can be found in the examples for LabVIEW 8.6. The primary issue with the programming of the weighing scale interface arose from the complete lack of documentation for the serial control options of out scale model AV2102. Our team was unable to find documentation for this on the manufacturers website and we would like to recommend that OHaus be contacted in order to determine the serial control syntax before incorporating this into the sytem.

Masterflex L/S Computer Compatible Peristaltic Pump – This would connected to the research computer using an RS232 interface and controlled using the serial VI system in LabVIEW as well. The syntax for the programming and control of this interface has been listed in the Masterflex Instruction Manual (found at http://www.masterflex.com/catalog/manual_pdfs/07523-80,-90.pdf) and this manual can be used as guidelines for incorporating the pump system. Some of the important excerpts from this manual have been indicated below.

This section indicates the serial data format (Page 3-28 of instruction manual)

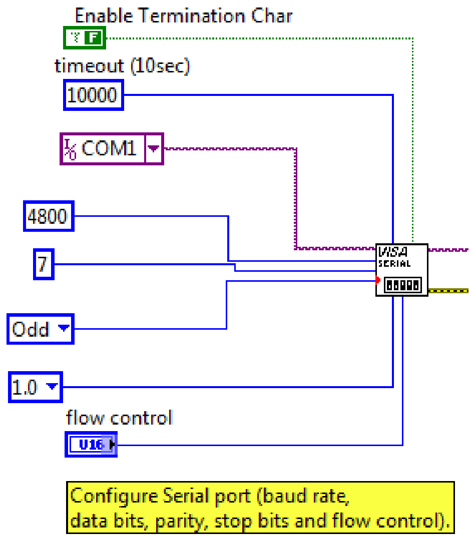


Serial Data Format

The serial data format is full duplex (simultaneously transmit and receive), 1 start bit, 7 data bits, one odd parity bit, and one stop bit at 4800 bits per second. All data transmitted will consist of characters from the standard ASCII character set.

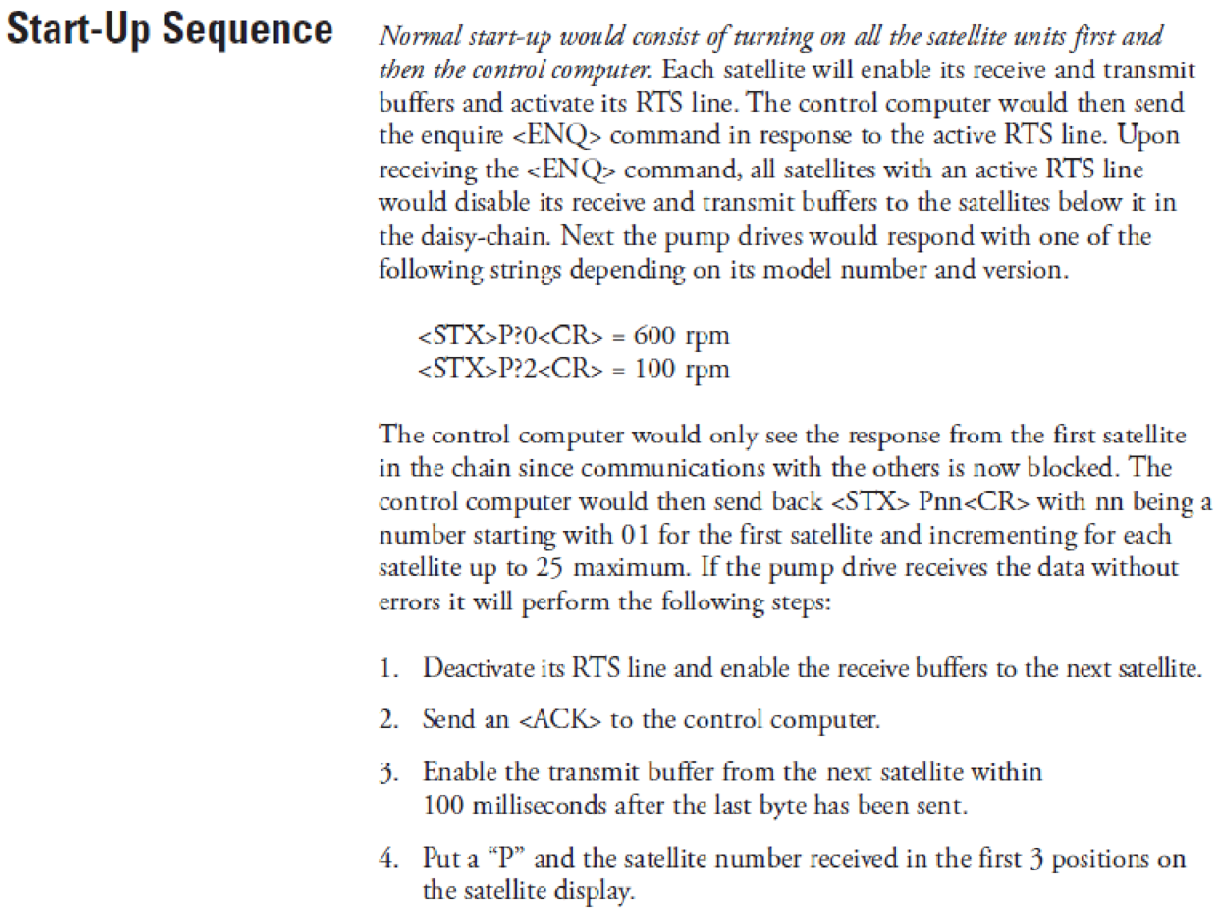
NOTE: Odd parity is defined such that the sum of the eight individual bits is an odd number (1, 3, 5 or 7).

A screenshot of the serial data format incorporated into a LabView serial VI is indicated below



Configure Serial port (baud rate, data bits, parity, stop bits and flow control).

The following sections indicate the Start-up sequence information (Page 3-28 and 3-29 of the manual)



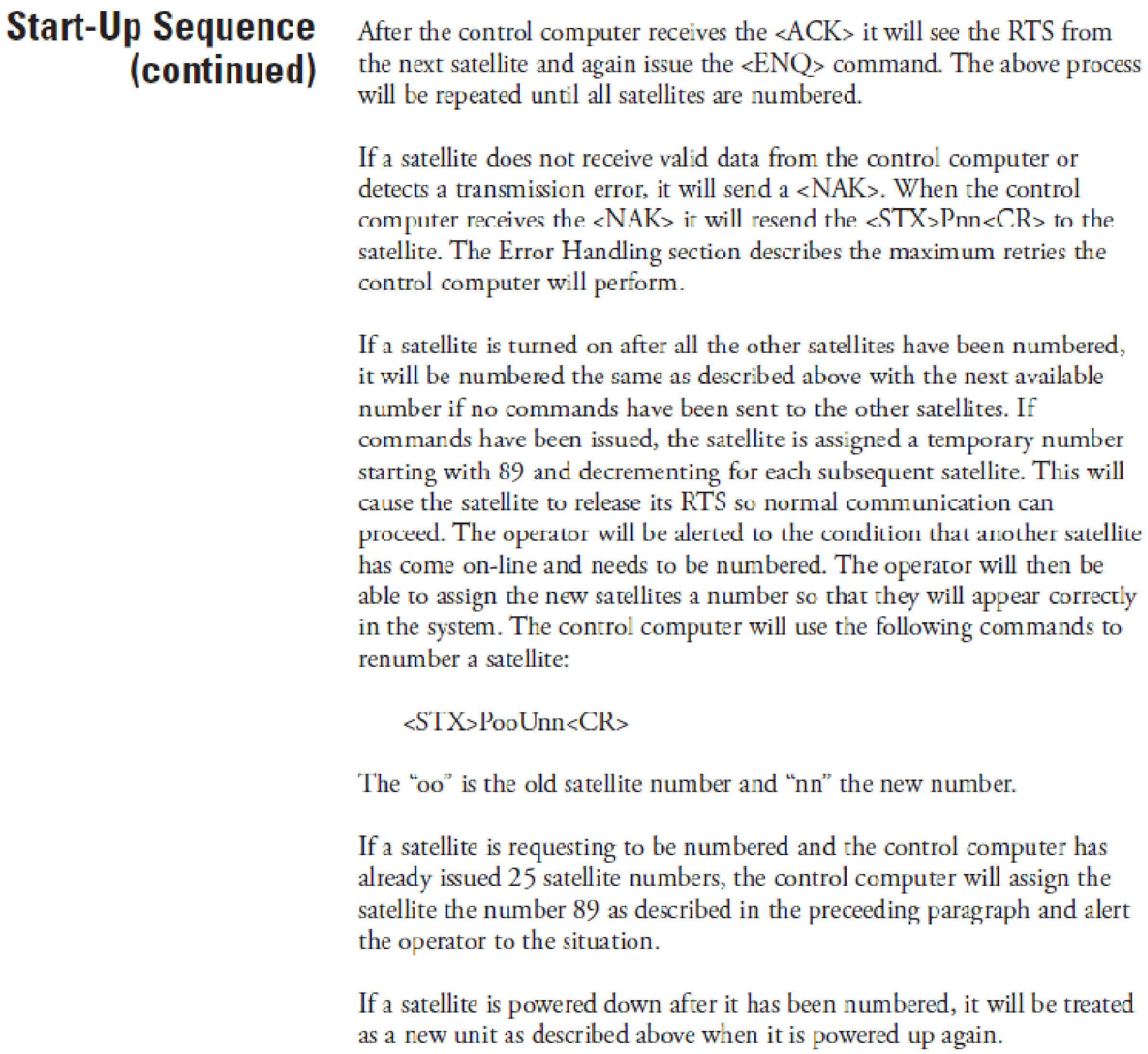
Start-Up Sequence

Normal start-up would consist of turning on all the satellite units first and then the control computer. Each satellite will enable its receive and transmit buffers and activate its RTS line. The control computer would then send the enquire <ENQ> command in response to the active RTS line. Upon receiving the <ENQ> command, all satellites with an active RTS line would disable its receive and transmit buffers to the satellites below it in the daisy-chain. Next the pump drives would respond with one of the following strings depending on its model number and version.

<STX>P?0<CR> = 600 rpm
<STX>P?2<CR> = 100 rpm

The control computer would only see the response from the first satellite in the chain since communications with the others is now blocked. The control computer would then send back <STX> Pnn<CR> with nn being a number starting with 01 for the first satellite and incrementing for each satellite up to 25 maximum. If the pump drive receives the data without errors it will perform the following steps:

1. Deactivate its RTS line and enable the receive buffers to the next satellite.
2. Send an <ACK> to the control computer.
3. Enable the transmit buffer from the next satellite within 100 milliseconds after the last byte has been sent.
4. Put a "P" and the satellite number received in the first 3 positions on the satellite display.



Start-Up Sequence (continued)

After the control computer receives the <ACK> it will see the RTS from the next satellite and again issue the <ENQ> command. The above process will be repeated until all satellites are numbered.

If a satellite does not receive valid data from the control computer or detects a transmission error, it will send a <NAK>. When the control computer receives the <NAK> it will resend the <STX>Pnn<CR> to the satellite. The Error Handling section describes the maximum retries the control computer will perform.

If a satellite is turned on after all the other satellites have been numbered, it will be numbered the same as described above with the next available number if no commands have been sent to the other satellites. If commands have been issued, the satellite is assigned a temporary number starting with 89 and decrementing for each subsequent satellite. This will cause the satellite to release its RTS so normal communication can proceed. The operator will be alerted to the condition that another satellite has come on-line and needs to be numbered. The operator will then be able to assign the new satellites a number so that they will appear correctly in the system. The control computer will use the following commands to renumber a satellite:

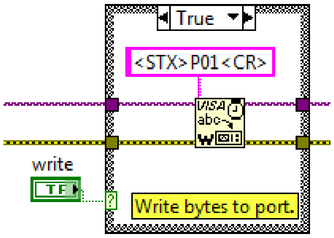
<STX>PooUnn<CR>

The "oo" is the old satellite number and "nn" the new number.

If a satellite is requesting to be numbered and the control computer has already issued 25 satellite numbers, the control computer will assign the satellite the number 89 as described in the preceeding paragraph and alert the operator to the situation.

If a satellite is powered down after it has been numbered, it will be treated as a new unit as described above when it is powered up again.

The following screenshot indicates a sample write interface from a LabVIEW serial VI that sends a general startup sequence message



The section on the following page indicates the format for sending commands to the pump via the serial interface (Page3-30 of the manual). More information regarding the syntax and the operating commands can be found at http://www.masterflex.com/catalog/manual_pdfs/07523-80,-90.pdf

Command Format

Most commands from the control computer are preceded with the start of text <STX> character (02 hex), a satellite identification letter (P for Pump, M for mixer) and a two digit satellite number (01 through 89). Numbers 00 and 90 through 99 are reserved for special cases. When the same command is to be executed by all pump drives, 99 is sent for the satellite number. Following the command character is the parameter field which varies in size from zero characters to 32 depending on the command. A carriage return <CR>, (0D hex) is used to indicate the end of a command string. (**NOTE**: the exceptions to this computer issued command format are <ENQ>, <ACK> and <NAK>.) See Figure 3-15.

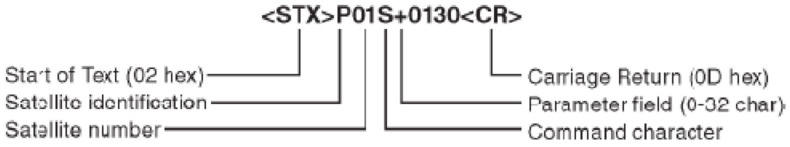


Figure 3-16. Command Format

More than one command can be put in a command string as shown following:

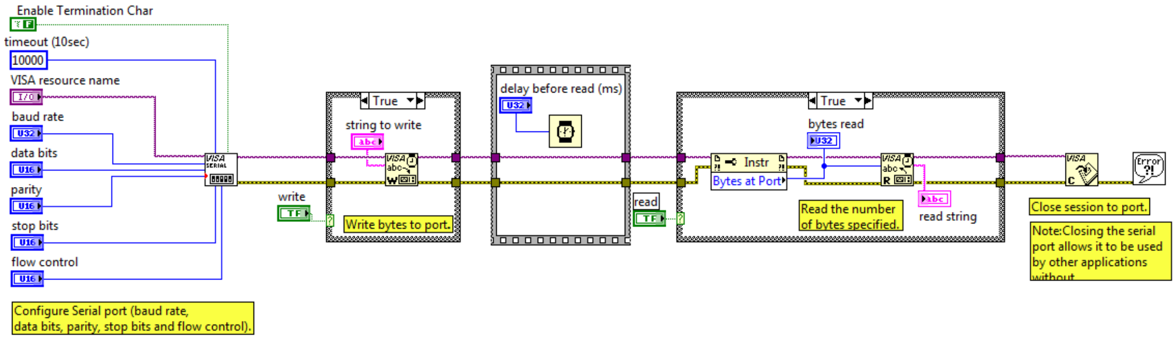
<STX>P09S+0500.0V08255.37G <CR>

The above multiple command string example would set the speed at pump satellite 09 to 500.0 rpm, clockwise direction, set 8255.37 revolutions and start the drive. The maximum number of characters allowed in one pump drive string is 38, including <STX>, Pnn and <CR>.

Command Features

1. INITIALIZING
   Before a pump drive can be controlled, it must first be numbered. If any command is issued before this is done, the satellite will not respond.
2. SETTING SPEED
   If a SPEED command is issued after the speed has already been set, the new speed will be used. If the pump drive is running and a different direction is sent to the pump, the pump will send back a <NAK>. A "H" command must first be issued before the direction can be reversed.
3. SETTING REVOLUTIONS
   When "Revolutions To Go" are set with the "V" command, they are added to the total revolutions to go counter. The maximum this counter can be is 99999.99. If a revolutions to go count is sent to the pump drive which would cause the counter to overflow past 99999.99, the pump drive will not add the value to its revolutions to go counter and will send the control computer a <NAK>. The revolutions to go counter can be set to zero by using the "Z" command, which will also cause the pump to stop if it is running when the "Z" command is received.

Based on the above information from the Masterflex Instructions Manual we'd like to suggest one method of programming the Pump Interface



The serial VI can be set up with one fixed data format in terms of the serial port configuration (far left area of above image). In order to establish complete control, an extensive translating conditional statement list needs to be generated.

Essentially, this statement list will convert user commands into the pump control syntax and will convert the pump syntax that is returned in the read statements into readable messages.

For example, if the user wanted to run the pump at a speed of 10rpm continuously, the actual LabVIEW interface will only indicate a slider or a text box to enter the pump speed. This pump speed will be read by the conditional statements and translated into the corresponding Pump Command which in this case reads as

<STX>P01S+010G<CR>

Setting up conditional statements that correspond to various commands will be a long drawn process and could possibly be overcome by using a simple conversion method that converts from a user controlled volume suction rate (mL/min) into the corresponding command. We recommend that this be possibility be analyzed further in order to reduce the need for excessive conditional statements.