# Wachusett Brewery Environmental Improvement

**A Major Qualifying Project Report**
**Submitted to the Faculty**
**of the**

## WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements
for a Bachelor of Science Degree
in the field of Chemical Engineering

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## Abstract

This project serves as a continuation of the previous year's MQP research on the effluent waste stream of Wachusett Brewing Company (WBC). This year's team investigated temperature and pH of the brewery effluent and recommend solutions to any problems with non-compliance of local regulations. The team also generated alternative means to dispose of spent yeast, grains and trub, common waste products of the brewing process. Research was conducted to determine the best methods of disposal based on environmental impact, sustainability and cost.

## Acknowledgements

The project team would like to give a special thanks to our advisors Professor Zhou and Professor Nowick for all of their guidance. We would also like to thank Kevin Buckler of the Wachusett Brewery and all of the Wachusett staff for collecting samples for the team and recording data for the gant charts. The team also appreciates the effort put in by Brian Almeida to draft the settling tank sketch.

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# 1 Introduction (Project Brief)

Currently the Wachusett Brewing Company (WBC) has a verbal agreement covering the discharge of process wastewater to the local Publicly Owned Treatment Works (POTW), Fitchburg East. This agreement was created when the brewery first started production in 1993. Due to the continued success and growth of the WBC and the results and determinations of the 2008 MQP, the WBC sponsored a 2009 MQP project to evaluate their wastewater discharge system and methodology As a continuation of a 2008 MQP, the reporting project team was assigned to evaluate the current brewery operations and effluent discharges and to recommend process modifications that would be beneficial to WBC, and to provide recommendations for better managing the higher volume of wastewater discharges that would undoubtedly accompany any future production increases. Of particular interest to WBC were the pH, temperature and volume of the wastewater discharges.

In addition to the process wastewater concerns, WBC is also interested in evaluating alternative methods for disposing the spent process byproducts, namely the spent yeast, grains and trub. To ensure sustainability, any suggested modifications were evaluated from a cost and environmental impact perspective.

# 2 WBC Basic Brewing Background

During the brew process grains are milled and soaked in hot water to extract fermentable sugars, a process called mashing (Bridgewater, 2008). The next processes, lautering and sparging, extract more sugars and separate the grains from the sugar water referred to as wort. These processes result in the first source of waste that was to be investigated for the project; after the mashing, lautering, and sparging the spent grain is discarded and sent to a local dairy farmer for cattle feed.

The wort is then boiled in the brew kettle. At this time hops, sugars and other flavorings are added. Hops, flowers from the hop plant, are used for adding bitterness and aroma to the wort, but must be removed after the boil. During the boil some proteins are denatured and fall out of solution; this material is called trub. After the boil the wort is cooled and the hops and trub are collected. The trub and hops are the second waste source to be investigated.

The wort is transferred to a fermentation vessel and yeast is added to begin fermentation. During the fermentation process, yeast collects on the bottom of the vessel. The first layer that accumulates is typically spent, or at least ineffective, yeast. This yeast is discharged to the POTW. The second layer is viable yeast that has settled properly and can be reused, but only for the same type of beer being produced. The third layer is yeast that remains in suspension and which if not removed could produce hazy beer if reused, and therefore is also discharged to the wastewater treatment plant. The discharged yeast was the third area of waste to be evaluated.

Finally the fermented wort, now called beer, is filtered through diatomaceous earth and then bottled or packaged into kegs. The whole brewing process is very sensitive to contamination by wild yeast and bacteria and for that reason must be cleaned and sanitized thoroughly. All vessels are cleaned with a caustic solution (sodium hydroxide and water), and in some cases with Nitric acid or Phosphoric acid. The caustic solution is the primary cleaning and sanitizing agent and is therefore the leading source of high pH effluent.

Currently any effluent that is discharge to the wastewater treatment plant first flows through an underground settling tank located just west of the front of the building. The settling tank was originally installed and used as an oil-water separator for the auto-shop that had previously occupied the building. The tank is now used to allow solid particles in the wastewater to collect on the bottom of the tank. The WBC has a regular schedule for the pump-out of the tank to remove settled solids accumulation.

# 3 Past WPI /Wachusett MQP Summaries

Ever since Kevin Buckler (WPI Class of '89), Peter L. Quinn ('89) and Edward (Ned) LaFortune III ('90) graduated from WPI and started Wachusett Brewing Company in December 1994, they have kept a strong relationship with their alma mater. The brewery began sponsoring WPI MQP projects in August 1995, and since then, has taken on six more projects, with topics ranging from energy audits to quality control and environmental assessments.

Following are summary descriptions of WPI MQP projects that have been completed and have some relation to the 2009 MQP project.

## 3.1 Microbrewery Energy Use: An Audit of the Wachusett Brewing Company (1996)

February 1996

Joseph Schaffer

For this project, Schaffer designed and conducted an energy audit for the brewery. The two uses of energy studied were for the overall process and refrigeration. The audit was separated into two portions: a general evaluation, the macroaudit, as well as detailed study of each component in the system, the microaudit. Schaffer concluded that there were several ways to increase efficiency in the plant, including adding insulation to cold storage tanks and the brew kettle and obtaining hot water from water on tap at the brewery instead of the brew kettle. It was also recommended that the temperature probes in cold storage tanks be calibrated on a more frequent basis.

## 3.2 Wachusett Brewery: Process and Quality Analysis (1997)

April 1997

David Bilodeau, Justin Hallman, Jeremy Strange, Matthew Willis

This project was designed to establish the efficiency of Wachusett Brewery's new bottling line, which was achieved by completing a multi-component analysis of the newly instituted line. One component entailed characterizing the amount of air delivered to the bottles with respect to competing industry brewers. Another was to estimate the shelf life of the products. It was determined through qualitative (taste tests) and quantitative (calculations of percent acetaldehyde via gas chromatography) measures that an increase in beer storage temperature causes acceleration in the ethanol-to-acetaldehyde spoiling reaction, thus ruining the desired taste of the product.

## 3.3 Analyzing Oxygen Ingress at Wachusett Brewing Company (2005)

April 2005

Pamela Giasson

This project analyzed how variables in the packaging process affect the rate of oxygen ingress of bottled beer. Giasson designed and conducted experimental testing of dissolved oxygen in bottles over time. It was determined that the current packaging process at Wachusett Brewery was effective at creating a barrier between bottled beer and the atmosphere. The project also discusses the need for further experimentation among different types of bottle caps to ensure cost effectiveness. Giasson examined the variables that may affect oxygen ingress:

- Eight different crowner heads on crowning machine
- Filler rate

- Crown/bottle cap manufacturer (Crown, Cork & Seal, Pelliconi, Taensa)
- Type of polymer lining (oxygen absorbing or standard lining
- Storage temperature

Giasson concluded that WBC's process for their bottle tops was effective at creating an oxygen barrier seal. However, one recommended area for further experimentation is the two different types of crowns manufactured by Crown, Cork & Seal. Giasson's experiment proved that both types provide similar results, and the oxygen scavenging lining of Crown, Cork & Seal may not be a cost effective option for WBC.

### 3.4 Quality Control Improvement for Wachusett Brewing Company (2006)

April 2006

Alicia Groth

This project provides recommendations for quality program improvement at WBC. The existing quality program at WBC and quality programs in other breweries and related industries were analyzed to find areas for improvement. Brewing process consistency, product stability and quality, and process optimization were the focus for recommendations. One recommendation, testing for microbial contamination, would reduce the potential for batch recalls, saving the brewery $3980 per batch if the problem is identified before packaging. Groth also suggests the following methods to increase batch consistency: investment in a spectrophotometer to determine color and bitterness; a gas chromatograph to identify sources of off-flavoring; a turbidimeter to indicate level of haze; and a material and energy balance to locate areas of improvement in the brewing process. To date, it is unknown whether the brewery has adopted these suggestions or not.

### 3.5 Separation Improvement Project for Wachusett Brewing Company (2007)

April 2007

Jordan Croteau, Julie Mahony, Michael Miller, Scott Misiaszek

This project was an evaluation of the product and yeast separation options that could be considered to replace the diatomaceous earth filters currently in use and find a suitable alternative that will be both more efficient and less costly. The team gathered data, opinions, and information on many separation methods that were currently being used in the food industry. The team investigated diatomaceous earth, Niro Combi filters, the Millipore Bevliner Membrane

Unit, and two types of centrifuges as possible separation techniques. The team performed a base estimate for the investment WBC would have to make, and the team also presented the advantages and disadvantages of each idea. The base investment for each option was estimated; the least expensive being refurbishment of an on-site centrifuge ($30,000), and the most expensive option being the Millipore Bevliner Membrane Unit ($54,000 - $179,000). No final recommendation was made regarding the best method for separation.

### 3.6 Environmental Assessment of the Wachusett Brewing Company (2008)

April 2008

Alicia Bridgewater, Brian Conner, Michael Slezycki

This project summarizes an environmental assessment of the Wachusett Brewing Company, considering wastewater, solid and general wastes, and air emissions. This assessment includes research into all applicable environmental regulations on a national, state, and local level, and determination of compliance through qualitative and quantitative process and waste stream analysis. The brewery process, including diagrams of mass balances for the brewing and cleaning processes. The project concludes with recommendations for the brewery to decrease environmental impact. Most of the data collected and analyzed was used in this WBC MQP, including TSS, BOD, COD, and pH data for each effluent stream in the brewery.

## 4 Methodology

The primary objective concerning the wastewater stream will be determining adequate management methods for ensuring continuing wastewater discharge compliance solutions for any possible future changes of the effluent as the brewery capacity is increased in the future years. The MQP team will have to consider current regulations for both pH and temperature and make sure that proposed solutions are well within the constraints in anticipation for stricter regulations in the future. The governing regulations could change either through regulatory agency modifications or City of Fitchburg Publically Operated Treatment Works (POTW) demands or a significant increase in wastewater discharge volume.

With regards to the discharged yeast and trub, the goals are to ultimately find feasible outlets for these brew process byproducts that would benefit both the Brewery and the environment.

## 4.1 Background Research

A previous WPI Major Qualifying Project was conducted with the Brewery one year prior. As part of the project, last year's MQP team researched local, state, and federal regulations regarding the wastewater effluent released from the Brewery. This MQP team also obtained samples of the waste streams, which often included cleaning chemicals to determine the values for BOD, COD, TSS and pH for each of the effluent streams. These cleaning chemicals contain both Sodium Hydroxide and Sulfuric Acid, two extensively utilized food industry cleaning chemicals. Also used are Nitric acid and Phosphoric acid.

The two effluent streams that were analyzed included spent yeast, grain and trub, and all of the brewery wastewater streams. All these waste and byproduct streams must be managed individually due to the nature of their generation and chemical/physical properties. Disposal methods of the yeast, trub and grain, which contain solid matter, were evaluated in order to determine the most environmentally focused and economically justified method of disposal. Some of the recycle and disposal methods that were evaluated will now be discussed.

### 4.1.1 Biodiesel

Fossil fuels are both a limited and costly resource, which has sparked interest in alternative fuels. Of the many areas of research, one stands out as a possibility to use the WBC spent solids to produce fuel. Biodiesel uses organic compounds and alcohol to create a fuel that can be used in many diesel engines. This source for alternative energy has been heavily researched and many biodiesel production facilities have been built over the past few years. Three facilities were located in Massachusetts that could provide the opportunity to recycle the spent solids from the Brewery as substitute fuels and also help to provide alternative energy.

### 4.1.2 Compost

Another option that provides an environmentally friendly way to process the spent solids from the Brewery is composting. Composting would allow for the disposal of the solid waste from the Brewery and in turn be transformed into fertilizer, a desirable by-product. This option would be beneficial in minimizing waste because it will be reused to create another product that has an available market.

Mass Natural was a composting company of particular interest. The company site is located in between WBC and a farm where the spent grain is currently being used as animal feed.

The primary obstacle with this option is that the Brewery would be charged to dispose of their waste here. The fee is based on total weight, which is an issue because the yeast slurry is largely water.

#### *4.1.2.1 Current Solids Loading*

In order to determine how much solid material was present in the yeast slurry, a total of 16 samples were taken and analyzed. There are three times during the course of the fermentation process that yeast is discharged from the vessels. The yeast separates into three layers during fermentation. The first discharge, which would be expected to contain the highest solids loading, contains yeast that has settled prematurely due to death of the cells or some other reason that is undesirable for fermentation. The second discharge contains viable yeast that settles properly and can be used in subsequent batches; much of this yeast is retained and reused. The last discharge, often referred to as an evac, releases yeast that takes much longer to settle and would cause a hazy appearance to the beer if reused. Each discharge was analyzed at different points during the process because of an anticipated change in percent solids from start to finish for the process. Samples from the first two discharges were collected during the beginning, middle and end of the process. Only two samples were acquired from the last discharge, at the beginning and the end.

Evaporating dishes were cleaned, dried and weighed. After recording the initial mass of each of the dishes, the yeast samples were shaken, to ensure adequate dispersion of the solids in the liquid, and then poured into the dishes. Each dish, filled with yeast slurry, was then weighed again and then placed in a drying oven at 221°F. After drying for 24 hours the samples were removed from the oven and re-weighed. Using Equations 1-3 in Appendix I, the percentage of solids, by weight, in the slurries was determined. The solids analysis was conducted twice with samples collected on two separate weeks to ensure the accuracy of the results; the results are show in the tables found in Appendix II.

#### *4.1.2.2 Increasing Solids Loading*

The results from the percent solids analysis of the yeast slurry prompted inquiry into drying options to increase the loading. One company, Alfa Laval, proved to be a useful possibility to remove excess water/beer from the yeast slurry. One such process that uses centrifugation was determined to be excessive for the current production rate of the Brewery, in that it is designed to perform on a much larger scale. Instead, a decanting process was recommended by an Alfa Laval associate. This process would effectively draw off some of the liquid from the slurry to increase the percent solids.

### 4.1.3 Animal Feed

The Wachusett Brewery currently sends spent grain to a local farm to be used as animal feed. Research was conducted to determine if the yeast and trub could be used for the same purpose. An article in American Brewer reported, "The world's 1.5 billion cattle produce 18 per cent of the greenhouse gases that cause global warming" (O'Brien, 2007). Several sites agreed that animal feed is neither an efficient or environmentally friendly means of disposing spent grains. Another problem with this method of waste disposal is that if yeast is also to be used as feedstock, it must first be made inert by subjecting the cells to high temperatures or some chemical. Based on this requirement, introduction of yeast into the animal feed would be costly.

### 4.1.4 Waltham Technologies

Waltham Technologies is a start-up company looking to use genetically engineered blue-green algae to clean wastewater specifically from beverage industries. The wastewater would pass through a bioreactor that is loaded with the algae. The algae would consume matter in the wastewater and effectively lower some of the waste products in the water. Additionally, the algae could be engineering in such a way to provide a beneficial by-product. Possible by-products include enzymes to be used in industrial applications and oils that can be used for biodiesel. Currently the company is in its start-up phase so there are several questions that still need to be answered. The process may involve training and certification of operators and clearance from the DEP to be used as an acceptable method of wastewater treatment.

### 4.1.5 Holding Tank

After reviewing the 2008 MQP report that had been completed at the WBC, it was evident that there were significant pH fluctuations between highly basic and highly acidic conditions. The use of a holding tank to allow pH adjustment was investigated. The tank's intended purpose would be to collect wastewater from several different brewery processes in a manner that would allow low pH effluent to mix with high pH effluent. Ideally the resulting pH would be in an acceptable range after the mixture equilibrated.

To simulate the holding tank, samples were collected from a yeast discharge and a fermentation vessel cleaning. The pH of both samples was calculated separately. Subsequently, the samples were combined in a 600 mL beaker, 250 mL each. The pH was then taken immediately. The solution was allowed to sit for five hours and the pH was tested each hour. The test was run in this fashion to ensure there wasn't a pH drift with time.

## 4.2 Settling Tank

All wastewater is sent down a drain that leads to a settling tank located underground about 10 feet from the Brewery. The tank is used to settle out solids before being discharged to the wastewater treatment plant. The tank is routinely evacuated (via vacuum) to remove any built up solids at the bottom of the tank. Prior to conducting this MQP project, very little was known about the tank and additional information was requested on the tank. Kevin Buckler scheduled a tank cleaning with the intent of determining the dimensions and construction of the tank. Following the tank cleanout the contractor determined the dimensions.

### 4.2.1 Temperature and pH Monitoring

For the purpose of monitoring the outgoing effluent, a pH and Temperature monitoring system was purchased and installed by the WBC. Several data loggers and probes were researched to determine a suitable device for monitoring the effluent. A Madgetech data logger was determined to be the best option for the intended purpose. The battery-powered logger was able to collect data at intervals as short as 30 seconds, as well as record both temperature and pH readings. The logger met all of MQP team and Wachusett requirements and was available at an acceptable price for the brewery. The pH and temperature probes were purchased from the Omega Company, a spec sheet for each of these can be found in Appendix III. The probes were selected based on the fact that they were designed for industrial applications with the possibility of being easily removed and cleaned of build up on the probes.

### 4.2.2 Probe Installation

The temperature and pH probes were both unable to be completely submerged in the tank. To address this issue, the probes were attached to PVC tubing, which was longer than the tank was deep, to prevent wastewater from damaging non-submersible portions of the probe. The probes were positioned in such a way that the effluent readings were taken directly before the wastewater was discharged. The probe/pipe assembly was installed in such a way that they could easily be removed for inspection, cleaning and maintenance, if necessary.

#### 4.2.3 Data Verification

After the installation of the probe, the test data acquired was reviewed. Several samples were taken over the course of a few weeks. To justify the accuracy of the logger data, samples were collected manually. The time that the samples were taken were recorded. The samples were manually tested for pH and temperature immediately after they had been collected. These values were compared to values reported by the data logger at the same time.

### 4.3 Effluent and Process Correlation

In order to fully understand the graphical representation of the temperature and pH variation during normal operations, a Gant chart was created. The chart identified when discharges started and stopped for all processes that created wastewater. Unfortunately, the Wachusett Brewery does not run at a set or repeatable schedule. Instead, there are fluctuations depending on the time of year and other unforeseeable circumstances. To ensure optimal accuracy and meaning, the Gant chart was created (Appendix IV) during a specific week when the data logger was also collecting information. The information obtained from the logger was then compared to the chart data to determine lag times, and process length versus variation of the logger data. The comparison also allowed for the ability to determine how temperature and pH fluctuation varied with different process wastewater discharges. It was necessary to investigate process effects on pH and temperature because, as noted in the 2008 MQP project, different cleaning processes require different volumes of wastewater and concentrations of caustic and acid.

## 5 Results and Discussion

After completing the methodology previously discussed, the team produced several results from the analysis of effluent from the WBC and further investigation into the brewery operations. The following is a detailed explanation of our findings that were relevant to the project.

## 5.1 Logger Data

The pH and temperature data logger provided information into the chemical properties of the effluent when it was sent to the street sewer pipeline. The logger recorded data at a sample rate of 1 per minute. The data points were compiled graphically in Appendix V. The black lines on the graphs of the logger data indicate the times that a process was occurring. The vertical position is arbitrary and is meant to serve only as an indication of time. The lines are not label but can be compared to the information found in the Gant chart. The data shows that there were multiple times when the brewery effluent exceeded pH and temperature regulations as set forth by the Mass. Department of Environmental Protection (DEP) and East Fitchburg POTW pH must be in the range of 5.5-10 and the temperature must not exceed 140°F. There were also times at which the pH of the effluent dropped below the minimum pH of 5.5. The data collected from the logger made it evident that the WBC must make a change in their process or determine an alternative means of managing and disposing the wastewater effluent if their waste discharge exceeds the 15,000 gallon maximum in the future.

Based on the data that was collected at the same time that the Gant chart was created, the running average pH was 6.86, and the temperature average was 83.48°F. Both of these values are well within the required EPA regulations for discharge to a POTW. The pH minimum was 4.26 and the maximum was 12.1. These values would be in violation of the DEP regulated discharges and would need to be adjusted before being discharged, should Wachusett be regulated in the future. The maximum temperature attained during this period was 143°F, which is just above the required 140°F threshold. This property should also be adjusted before discharge because there are several occasions when the temperature comes very close to the 140 degree maximum.

The information obtained from the logger also allowed the team to calculate the running averages for both pH and temperature. Because there was some mixing taking place in the settling tank, it can only be assumed that buffers from the caustic or yeast slurry were accounted for, and the calculated average was relatively accurate. Based on this finding, the team was able to explore the option of using a holding tank to neutralize pH and temperature.

The data also allowed for a correlation between the processes taking place in the brewery and what was being discharged from the settling tank. This information allowed for a better understanding of the current mixing potential in the tank.

## 5.2 Gant Chart

In order to compare the results from the data logger with the brew process we created a Gant chart that outlined what processes were taking. The process start and stop times were marked down and compiled to form the Gant chart that can be seen in Appendix IV. Due to the fact that many processes continue for hours and that some start very early in the morning, members of the WBC staff were asked to note process times because it was not practical for the team to be available in order to record the data. The chart, along with the data from the logger, allowed for the effluent and process correlation. The data from the chart was plotted against the logger data to show any lag or variation between process operation and effluent properties.

The effluent data collected from the logger was predictable based on the Gant chart. There was a slight lag between process start time and changes in the effluent stream, but it was no longer than expected. Unfortunately some process notes were not recorded that caused gaps in the Gant information. There were also some anomalies where the pH rose during a process that produced low pH effluent. This was again attributed to the fact that some processes were not recorded, primarily the keg washing operation and bottling.

## 5.3 Percent Solids

The results from the percent solids analysis of the yeast slurry, Appendix II, revealed a fairly low quantity of yeast by weight. The maximum loading was about 14% at the beginning of the first discharge, and the minimum was around 5.5% at the end of the first discharge. The data showed that paying to compost the slurry, as is, would result in paying a large amount for beer that is mixed in with the yeast. Composting could still be a viable option, but the percent yeast by weight must be increased to drive down the cost. Increasing the solids loading would require separation of the beer and yeast, but drying the slurry would be both costly and time consuming.

## 5.4 Settling Tank

After pumping out the settling tank, measurements were taken to determine the dimensions of the tank. The tank was found to be 8’ in height and 4’ in diameter; however, the effective height of the effluent was only 5’ because of the outlet design. Also, there is a 2’ gap from the bottom of the tank to the outlet of the tank; the gap allowed for the collection of settled solids. Based on the dimensions that were determined the team calculated the working volume of the tank to be 471 gallons. Originally the team assumed there would be some mixing occurring in the tank before discharge, but based on the data collected during the 2008 MQP there are 4,000-11,000 gallons of wastewater effluent discharged on a daily basis. The lack of significant mixing was verified by the data collected from the logger.

### 5.5 Holding Tank Simulation

It was expected that the yeast slurry would have some substances that would act as a pH buffer. A simulation of a holding tank was conducted to more accurately determine what the pH of two effluent streams would be after mixing. A caustic solution that had been collected from a fermentation vessel wash, and yeast slurry that had been collected from a yeast discharge were tested for their pH, the results can be found in Appendix VI. The caustic wash was measured to be pH 10 and the yeast slurry was measured at pH 4.5. After mixing the yeast and caustic in equal volumes (250 mL) the pH reached equilibrium at 7.5-8. The measured pH was well within the required 5.5-10 pH range required by the EPA. If a holding tank was monitored for pH and temperature, mixing of high and low pH streams could prevent future occurrences that result in pH readings outside the regulations. It could also be used to prevent high temperature readings, however there were only a few instances that the discharge temperatures were above the required threshold level.

## 6 Recommendations

Based on the methodology and subsequent results, several future recommendations can be made to greatly improve Wachusett Brewery's impact on the local environment, thus making it a more efficient and sustainable operation. Throughout the project, the team met with several companies to discuss waste treatment methods and how to recycle the three major material byproducts leaving the brewery—spent yeast, grain, trub, and waste water, which often contains caustic solution. By installing a pH probe to monitor the brewery's major outlet stream, this provides an efficient monitoring solution to conform to local environmental regulations. However, with an increasing global concern with the environment and sustainability, the Wachusett Brewery must foster additional procedures to deal with their outlet waste streams. This section outlines the future possibility of utilizing composting alongside centrifugation, genetically engineered blue-green algae, and other methods relating to maintaining an appropriate pH of the waste streams.

## 6.1 Composting

Today's breweries use a significant amount of water for their brewing process, which in turn generates a large amount of waste. The fairly old, yet highly efficient process of composting allows for the biodegradation of organic matter by microorganisms. Many breweries use composting as a tool to recycle their spent yeast, allowing their waste to be utilized in an effective way.  Fortunately, the contents of brewery waste byproducts are relatively safe and do not contain harmful pathogenic microorganisms or heavy metals that are associated with other industrial waste byproducts. Therefore, most composting companies are welcome to the idea of accepting waste from a brewery.

In terms of Wachusett Brewery, our team collaborated with Bill Paige, the owner of Mass Natural, a composting company located in Westminster, MA. While Mass Natural accepts most waste, they charge by weight. Therefore, depending on the percent solids of the leftover yeast, grain, and trub, Wachusett Brewery could potentially be transporting and paying for a large amount of liquid present in their spent materials. According to our results, the average percent solids for the waste streams was near 10%.  This fairly low number means that the brewery would be paying for composting mostly water.

## 6.2 Decanter

Fortunately, the process of decanting the yeast slurry may provide the brewery with a viable option in terms of increasing the percent solids, as well as recovering beer from surplus yeast to be used in the holding tank neutralization process.


**Figure 1.  Alfa Laval Decanter**

Alfa Laval AB is a Swedish company specializing in heating, cooling, and separating products in a variety of industries. Alfa Laval has developed a series of decanters that are used in different industries to increase the percent solids, removing excess water. Compared to more elaborate centrifugation systems, Alfa Laval's decanters provide a more economically suitable way to thicken the yeast slurry. The decanter appears to be the most logical short-term solution to Wachusett Brewery's issue of thickening the yeast slurry. This system will not only provide increased percent solids, but will also generate excess low-pH beer that can be used in the mixing tank, making it the most sensible recommendation. The estimated cost for this unit would be $150,000-200,000. The yeast slurry could effectively be dried to about 28% yeast by weight, which is almost double the percent solids than currently achieved. Also Alfa Laval will set up the unit for an evaluation period; if the decanter doesn't meet the brewery's expectations it will be removed free of charge.

## 6.3 Centrifugation

Alfa Laval also develops a machine, the BRUX 510, which is used by breweries across the world to recover beer from their waste streams. The BRUX uses concentrate tubes to force yeast to the center of the machine where it leaves the separator under pressure.

**Figure 2. Brux 510 Centrifugation Model**

The figure above shows how the vortex nozzles regulate the flow of concentrate for lower inlet concentrations and higher inlet concentrations. While the decanter may be the most sensible short-term recommendation for dealing with the yeast slurry, the BRUX is a suitable long-term recommendation for the brewery. While the BRUX performs a similar process to the decanter, its main advantage is in recovering beer that can be bottled and sold, unlike the decanter, where the excess beer is lower in quality. Providing the brewery with recovered beer can save the company a large amount of money per year. Unfortunately, there are some significant drawbacks when considering the BRUX. It is unlikely a microbrewery such as Wachusett would have the space to contain such a large system. Additionally, the installation, upkeep, and other expenses of the BRUX make it a long-term recommendation, since the brewery cannot currently gain back significant money if beer were recovered using the BRUX. With the current production rate of the WBC the BRUX would have a long return-on-investment with the initial unit cost being roughly $500,000. However, this process may be practical in that it can dry the yeast slurry and recover 'good' usable beer unlike the decanter.

## 6.4 Genetically Engineered Algae

Part of the team's early methodology involved interviewing Peter Luciano from Waltham Technologies, an emerging bioengineering company. The main goal of Waltham Technologies is to genetically engineer blue-green algae to simultaneously clean wastewater while creating a profitable material. While the science to engineering algae is a fairly new discovery, the practical applications could greatly benefit the brewery and its future goal of implementing environmentally friendly processes. By determining an appropriate product, the algae could be engineered specifically for the brewery's needs. A portable bioreactor system would be installed and waste streams such as the yeast slurry would enter the reactor, react with the engineered algae, and generate the product, which would be sold by the brewery. The generated product would be oil that could be sold to other industries, generating a profit for WBC.

While this technology is a safe, profitable, and maintainable way to provide a cleaner waste stream, there are several limitations. First, Waltham Technologies is an emerging company that is still working to complete a proof of concept. Therefore, utilizing the services of Waltham Technologies would have to be a long-term prospect, within the next five to ten years. Second, it is essential to consider the practicality of using this method to recycle streams from a relatively small brewery. The initial capital required to set up the entire system may be extremely expensive. Even if the algae generate a product, the amount of product could be small compared to the cost of setup and implementation. Third, after a product is produced in the bioreactor, there is still a significant level of purification that must take place in order to isolate the product. Purification techniques are relatively expensive and its overall cost may not be worth the investment.

## 6.5 Effluent pH and Temperature

Upon viewing both the pH and temperature graphs generated by the data logger, the team concluded that several adjustments must be made to ensure that the pH of the tank remains within a suitable range. It was found that the waste streams during a caustic wash drove the pH to significantly high levels, and yeast discharges yielded acidic pH values. The washing and rinsing of many of vessels use hot water that was being discharged at temperatures that exceeded the allowable limits.

### 6.5.1 Holding Tank Neutralization and Release

To manage the pH and temperature variations a containment vessel to temporarily store caustic or acidic waste should be used. Unlike direct mixing, this method would allow the brewery to continue its operations on the same schedule instead of timing high and low pH processes to mix in the settling tank. An employee may be required to check the pH and temperature after mixing with another waste stream. If the pH falls outside the proper range, additional caustic or acidic material must be added to further drive the pH towards neutral. However, only necessary effluent would be mixed in this tank; there would be no addition of pure acid or caustic to adjust the pH. After this, the mixture can be safely released into the brewery's waste stream. There is however a problem with this method. The process of obtaining and installing a containment vessel would require money, time, and additional cleaning, and would also require regulatory approval. The pH and temperature of the effluent in the vessel would also have to be monitored to determine when the mixture met the EPA requirements and could be discharged. If used in combination with the decanter, excess beer pulled off by the decanter could still be used to neutralize pH because the beer quality would not be high enough to use in the final product.

## Bibliography

Bridgewater, Alicia et. al. Minimization of Environmental Impact of Wachusett Brewing Company Processes. Worcester Polytechnic Institute. 2008.

O'Brien, Chris. Grains of Possibility: Ways to Use Spent Brewing Grains. 2007. http://beeractivist.com/2007/04/15/grains-of-possibility-ways-to-use-spent-brewing-grains

# Appendix I. Calculations

**Yeast Solids Calculation**

$$M_S = M_{Ti} - M_D \qquad 1.$$

$M_S$ = Mass of Slurry
$M_{Ti}$ = Mass Total Initial (Dish + Slurry)
$M_D$ = Mass of Dish

$$M_Y = M_{Tf} - M_D \qquad 2.$$

$M_Y$ = Mass of Yeast °
$M_{Tf}$ = Mass Total Final (Dish + Yeast)
$M_D$ = Mass of Dish

$$Percent\ Solids = \frac{M_Y}{M_S} \qquad 3.$$

# Appendix II. Yeast Solids Results

Jan. 09

WPI Scale #25321

Trial 1

| Discharge | Sample Label | Dish | Dish and Yeast | Yeast | Dried D + Y | Dried Yeast | Percent Solids |
|---|---|---|---|---|---|---|---|
| | | g | g | g | g | g | % |
| 1st Start | **A** | 39.09 | 49.39 | 10.30 | 40.50 | 1.42 | 13.76 |
| 1st Mid | **B** | 39.03 | 53.13 | 14.10 | 40.17 | 1.14 | 8.11 |
| 1st End | **C** | 36.43 | 54.74 | 18.31 | 37.45 | 1.02 | 5.59 |
| 2nd Start | **D** | 42.85 | 48.03 | 5.19 | 43.41 | 0.57 | 10.94 |
| 2nd Mid | **E** | 37.50 | 50.78 | 13.28 | 38.43 | 0.92 | 6.96 |
| 2nd End | **F** | 35.62 | 57.16 | 21.54 | 37.08 | 1.46 | 6.79 |
| 3rd Start | **G** | 37.37 | 54.79 | 17.42 | 38.56 | 1.19 | 6.83 |
| 3rd End | **H** | 39.52 | 52.18 | 12.66 | 40.31 | 0.79 | 6.24 |

Apr. 09

WPI Scale #25321

Trial 2

| Discharge | Sample Label | Dish | Dish and Yeast | Yeast | Dried D + Y | Dried Yeast | Percent Solids |
|---|---|---|---|---|---|---|---|
| | | g | g | g | g | g | % |
| 1st Start | **A** | 39.09 | 50.02 | 10.93 | 40.51 | 1.42 | 13.01 |
| 1st Mid | **B** | 39.03 | 49.06 | 10.03 | 40.04 | 1.01 | 10.05 |
| 1st End | **C** | 36.43 | 50.07 | 13.64 | 37.64 | 1.22 | 8.91 |
| 2nd Start | **D** | 42.85 | 48.35 | 5.50 | 43.51 | 0.67 | 12.17 |
| 2nd Mid | **E** | 37.50 | 51.12 | 13.62 | 38.42 | 0.92 | 6.73 |
| 2nd End | **F** | 35.62 | 54.89 | 19.27 | 36.84 | 1.22 | 6.35 |
| 3rd Start | **G** | 37.37 | 54.91 | 17.54 | 38.56 | 1.19 | 6.78 |
| 3rd End | **H** | 39.52 | 55.01 | 15.49 | 40.44 | 0.92 | 5.93 |

# Appendix III. Spec Sheets

## Logger

MADGETECH
WE BUILD DATA LOGGERS

## PHTEMP101

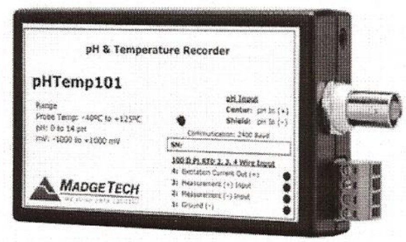
### PH & TEMPERATURE DATA LOGGER

### Features

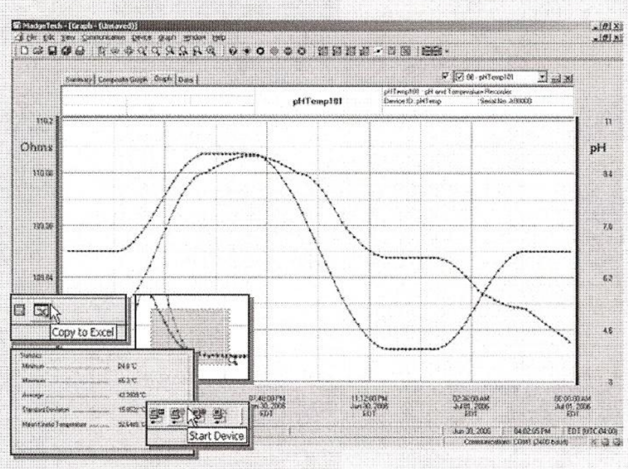
- Low cost
- Miniature size
- User-friendly
- Automatic temperature compensation
- Programmable start time
- Real-time operation
- Programmable engineering units
- N.I.S.T. traceable

### Applications

- Surface and ground water quality monitoring
- Environmental and wetlands monitoring
- Industrial influent and effluent
- Water districts and municipal water systems
- Process water quality
- Recreation and park management
- Pulp and paper industry
- Wastewater monitoring




The pHTemp101 is a miniature, battery powered, stand alone pH and temperature recorder. This is an all-in-one compact, portable, easy to use device that will measure and record up to 13,107 measurements per channel. The pHTemp101 will directly connect to many commonly used pH electrodes, in addition, the pHTemp101 will also directly connect to many ORP electrodes. The storage medium is non-volatile solid state memory, providing maximum data security even if the battery becomes discharged. The device can be started and stopped directly from your computer and its small size allows it to fit almost anywhere. The PHTemp101 makes data retrieval quick and easy. Simply plug it into an empty com port and our user-friendly software does the rest.




**MadgeTech Data Recorder Software** displays pH and temperature data in an easy to use graph.

The Windows®-based software package allows the user to effortlessly collect, display and analyze data. A variety of powerful tools allow you to examine, export, and print professional looking data with just a click of the mouse.

Click MadgeTech Software for more information or to download the software.

201 Route 103 West · PO Box 50 · Warner, NH 03278 · Phone: (603) 456-2011 · Fax: (603) 456-2012 · info@madgetech.com

## PHTEMP101 SPECIFICATIONS*

**Temperature****

**Measurement Range:** -200 to +850°C (0 to +5000Ω)
**Resolution:** 0.01°C (0.001Ω)
**Calibrated Accuracy:** ±0.1°C @ 25°C ambient (±0.015Ω)
**Input Connection:** Removable screw terminal; 2,3 or 4-wire interface

**pH**

**Measurement Range:** 0.00 to 14.00pH (-1000 to +1000mV)
**Resolution:** 0.01pH (0.1mV)
**Calibrated Accuracy:** ±0.1pH (±1mV)
**Input Connection:** Female BNC jack
**Input Resistance:** $10^{12}$ Ω typical

**Start Modes:** Software programmable immediate start or delay start up to six months in advance
**Real Time Recording:** May be used with PC to monitor and record data in real time

**Memory:** 13,107 readings per channel; 26,214 total readings
**Reading Rate:** 1 reading every 2 seconds to 1 every 12 hours
**Calibration:** Digital calibration through software
**Calibration Date:** Automatically recorded within device
**Battery Type:** 9V lithium or alkaline battery included; **user replaceable**
**Battery Life:** 1 year typical with lithium battery at 25°C
**Data Format:** Date and time stamped °C, °F, K, °R, Ω; pH, V, mV, engineering units specified through software
**Time Accuracy:** ±1 minute/month (at 25 °C; RS232 cable not in use)
**Computer Interface:** PC serial or USB (interface cable required); 2,400 baud
**Software:** Windows 95/98/ME/NT/2000/XP based software
**Operating Environment:** -5 to +50°C, 0 to 95%RH (non-condensing)
**Dimensions:** 4.5" x 2.4" x 1.0" x (115mm x 61mm x 26mm)
**Weight:** 4 oz (120 g)
**Approvals:** CE

**Temperature specifications based on ideal 100 Ω Pt RTD compliant with IEC 751 (1983) and ITS-90, 5000 Ω FSR

For use in harsh environments, this device must be well protected from weather, steam and harsh chemicals

BATTERY WARNING: DISCARD USED BATTERY PROMPTLY. KEEP OUT OF REACH OF CHILDREN. DO NOT DISPOSE OF IN FIRE, RECHARGE, PUT IN BACKWARDS, DISASSEMBLE, OR MIX WITH OTHER BATTERY TYPES. MAY EXPLODE, FLAME, OR LEAK AND CAUSE PERSONAL INJURY.

## SOFTWARE FEATURES

**Multiple Graphs:** Simultaneously analyze data from several units or deployments; easily switch to a single data series
**Real-Time Recording:** Collect and display data in real-time while continuing to log
**Graphical Cursor:** One click displays readings by time, value, parameter or sample number
**Data Table:** Instantly access tabular view for detailed dates, times, values, and annotations
**Scaling Options:** Autoscale function fits data to the screen, or allows user to manually enter their own values
**Formatting Options:** Change colors, line styles, plotting options, show or hide channels quickly

**Statistics:** Calculate averages, min, max, standard deviation, and mean kinetic temperature with the touch of a button
**Export Data:** Export data in a variety of common formats, or switch to Excel® with a single click
**Calibration:** Automatically calculate and store calibration parameters
**Logger Configuration:** Easy set up and launch of data loggers with immediate or delayed start, preferred sample rate, and device ID
**Communications:** Automatically sets up communications port, or lets user select configuration
**Printing:** Automatically print graphical or tabular data

*SPECIFICATIONS ARE SUBJECT TO CHANGE WITHOUT NOTICE. SPECIFIC WARRANTY AND REMEDY LIMITATIONS APPLY. CALL 1-603-456-2011 OR GO TO WWW.MADGETECH.COM FOR DETAILS.

## ORDERING INFORMATION

| Model | Description | Price (U.S.) |
|---|---|---|
| PHTEMP101 | pH and Temperature Recorder | $399.00 |
| IFC110 | Software, manual and RS232 interface cable | $99.00 |
| IFC200 | Software, manual and USB interface cable | $119.00 |
| NIST | N.I.S.T. Calibration Certificate | Call for Pricing |
| U9VL-J | Replacement battery for pHTemp101 | $15.00 |

For Quantity Discounts call 603-456-2011 or email sales@madgetech.com

**ASK ABOUT OUR OTHER DATA RECORDERS**

| | |
|---|---|
| Temperature | Pulse/Event/State |
| Humidity | Low Level Current |
| Pressure | Low Level Voltage |
| pH | RF Transmitters |
| Level | Intrinsically Safe |
| Shock | Spectral Vibration |

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DOC-1032009-00 REV A 2006.06.30

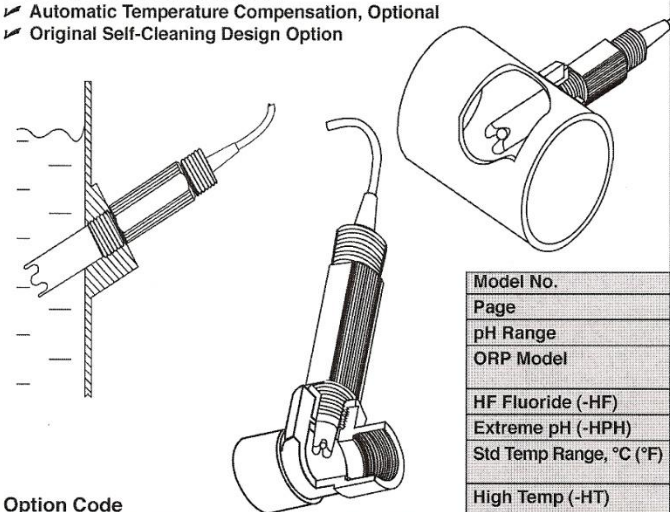
## pH Probe

# INDUSTRIAL pH INSTRUMENTATION & ELECTRODES

## Universal Industrial Sensors

MADE IN USA RoHS

- Universal Solution to Ground Loop with Optional Solution Ground or Differential Amplifier
- PPS/Ryton® Strong Molded Body
- Ideal for In-Line or Submersible Use
- 100 PSI Operating Pressure
- Porous PTFE Double Junction
- Automatic Temperature Compensation, Optional
- Original Self-Cleaning Design Option



| Model No. | PHE-7352-15 | PHE-7451-15 | PHE-7353-15 |
|---|---|---|---|
| Page | D-37 | omega.com/phe7451 | D-37 |
| pH Range | 0 to 14 | 0 to 14 | 0 to 14 |
| ORP Model | ORE-7352-15 $175 | ORE-7451-15 $175 | ORE-7353-15 $190 |
| HF Fluoride (-HF) | $50 | $50 | $50 |
| Extreme pH (-HPH) | $30 | $30 | $30 |
| Std Temp Range, °C (°F) | 0 to 80 (32 to 176) | 0 to 80 (32 to 176) | 0 to 80 (32 to 176) |
| High Temp (-HT) | 110°C $35 | 110°C $35 | 110°C $35 |
| Reference Cell | KCl-AgCl/dbl | KCl-AgCl/dbl | KCl-AgCl/dbl |
| Triple Junction (-TJ) | $45 | $45 | $45 |
| Cable/Connector, m (ft) | 4.5 (15)*/BNC | 4.5 (15)*/BNC | 4.5 (15)*/BNC |
| Length, mm (in) | 150 (5.9) | 140 (5.5) | 120 (4.7) |
| Diameter, mm (in) | 22 (0.87) | 22 (0.87) | 22 (0.87) |
| Installation | ¾ MNPT | ¾ MNPT | ¾ MNPT |
| Insertion Length, mm (in) | 23 (0.91) | 12.5 (0.49) | 59 (2.32) |
| Optional Insertion L | 59 mm PHE-7353 | 59 mm PHE-7354 | 23 mm PHE-7352 |
| Solution Ground (-SG) | $45 | $45 | $45 |
| ATC (-PT100) | $40 | $40 | $40 |
| ATC (-PT1K) | $40 | $40 | $40 |
| ATC (-TH700) | $40 | $40 | $40 |
| ATC (-R3K) | $40 | $40 | $40 |
| Amplifier (-AMP) | $100 | $100 | $100 |
| Diff. Amp (-DIF) | N/A | N/A | N/A |
| Base Price | $135 | $135 | $150 |

** To order with 6 m (20') cable, replace "-15" in model no. with "-20" and add $5 to price.*
*** To order with 6 m (20') cable, replace "-10" in model no. with "-20" and add $10 to price.*

### Option Code

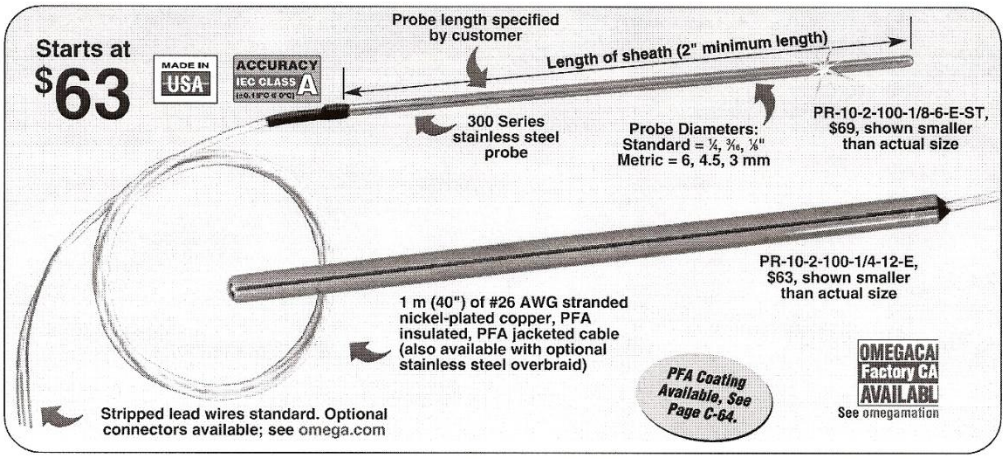
| Order Suffix | Description | Additional Cost |
|---|---|---|
| -AMP | Battery powered amplifier | $100 |
| -HT | High temperature reference cell | 35 |
| -HPH | High pH glass | 30 |
| -HF | HF/Fluoride resistant | 50 |
| -PT100 | 100 Ω Pt RTD† | 25 to 50* |
| -PT1K | 1000 Ω Pt RTD† | 25 to 50* |
| -SG | Solution ground | 45 |
| -SCO | Self-cleaning option mounting (cleaning cage sold separately model no. PHEH-SCO, **$75**)†† | 30 |
| -TJ | Triple junction reference cell | 45 |
| -ULT | Combination of ATC, triple junction, high temp, and solution ground | 125 |

*Available with pH electrodes only. Not available with option "-ORP"*
*† Refer to individual electrodes for ATC pricing.*
*†† Only available with PHE-7451, PHE-7354, PHE-9151, or PHE-9153.*

**Temperature Probe**

# General Purpose RTD Probes
## With PFA Jacketed Cables for Laboratory Applications

- Transitions Directly to Lead Wires (No Transition Fitting)
- Compact Design for Applications with Space Restrictions
- Available in Standard and Metric Sizes
- Temperature Range: -200 to 600°C (Cable and last 2" of probe to 260°C)
- High-Accuracy Wire Wound, 100 Ω Class "A" DIN Platinum Elements per IEC 751 (alpha = 0.00385 Ω/Ω/°C)
- 2-, 3-, 4-Wire Constructions Available




### Standard Dimensions

**MOST POPULAR MODEL HIGHLIGHTED!**

**To Order** *(Specify Model Number)*

| Model Number | Lead Wire Style* | Sheath Length | Price ¼" Dia. | Price ³⁄₁₆" Dia. | Price ⅛" Dia. |
|---|---|---|---|---|---|
| PR-10-2-100-(*)-6-E | 3 Wire | 6" | $63 | $69 | $69 |
| PR-10-2-100-(*)-12-E | 3 Wire | 12" | 63 | 69 | 69 |
| PR-10-2-100-(*)-18-E | 3 Wire | 18" | 66 | 72 | 72 |
| PR-10-2-100-(*)-24-E | 3 Wire | 24" | 69 | 75 | 75 |

* Specify ***"-1/8"***, ***"-3/16"***, or ***"-1/4"*** for probe diameter in inches (see page C-61 for ⅙" diameter probes). To order with shrink tube strain relief, specify ***"-ST"*** at end of model number. To order probes in intermediate lengths, change model number, using next longer probe price. Over 24", add **$1** per inch of probe length. Stainless steel overbraid or BX cable also available. For leads longer than 40", add lead length to end of model number and **$2.25** per foot to the price.

***Ordering Example: PR-10-2-100-1/8-12-E-OTP,*** *100 Ω, class "A" RTD with a ¼" diameter by 12" long probe, 40" of 3-wire cable and OTP connector,* ***$76.***

### Metric Dimensions

**To Order** *(Specify Model Number)*

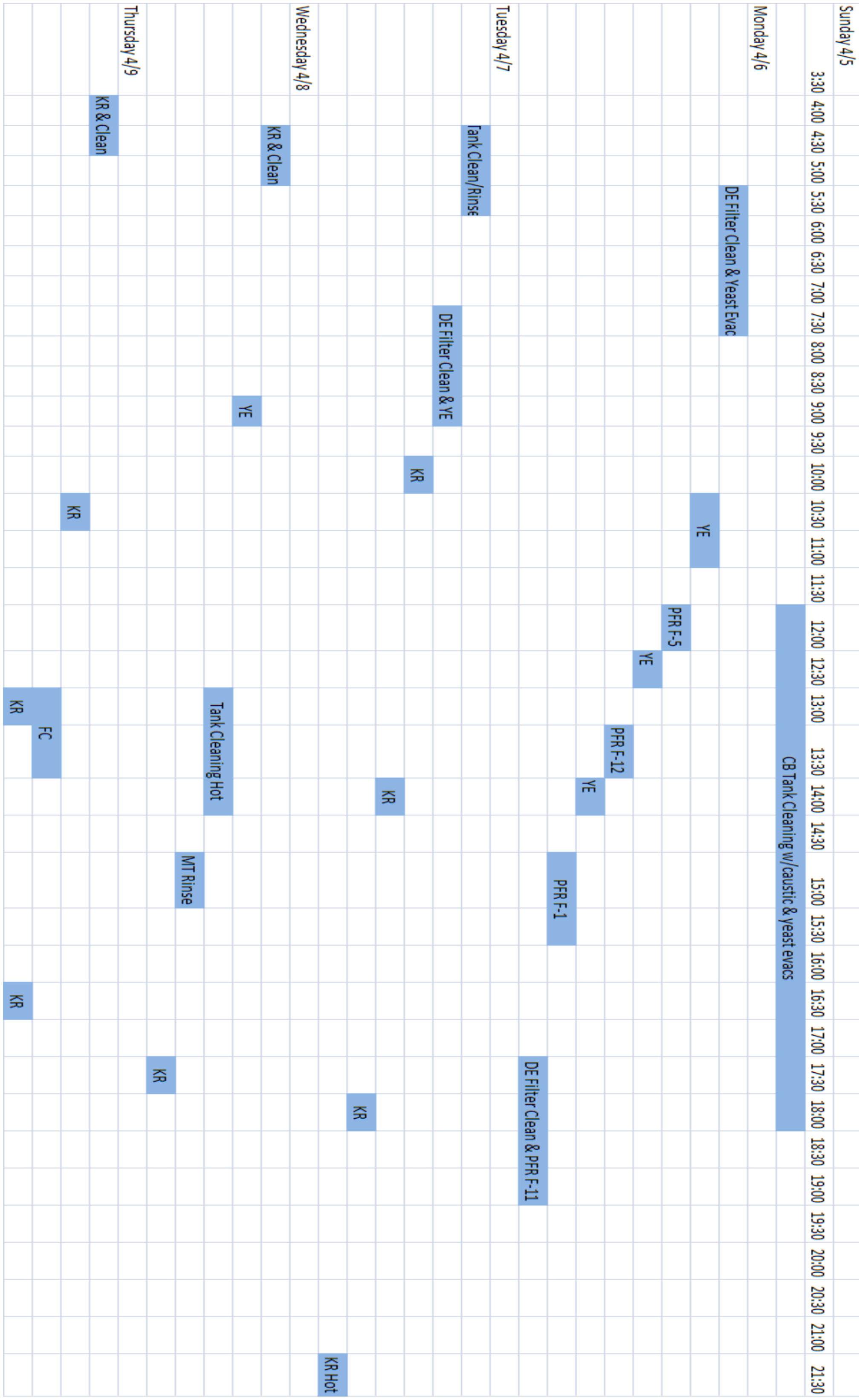
| Model Number | Lead Wire Style* | Sheath Length | Price 6 mm Dia. | Price 4.5 mm Dia. | Price 3 mm Dia. |
|---|---|---|---|---|---|
| PR-10-2-100-(*)-150-E | 3 Wire | 150 mm | $63 | $69 | $69 |
| PR-10-2-100-(*)-300-E | 3 Wire | 300 mm | 63 | 69 | 69 |
| PR-10-2-100-(*)-450-E | 3 Wire | 450 mm | 66 | 72 | 72 |
| PR-10-2-100-(*)-600-E | 3 Wire | 600 mm | 69 | 75 | 75 |

* Specify ***"-M30"*** for 3 mm, ***"-M45"*** for 4.5 mm or ***"-M60"*** for 6 mm for probe diameter in millimeters (see page C-61 for 1.5 mm diameter probes). To order with shrink tube strain relief, specify ***"-ST"*** at end of model number. To order probes in intermediate lengths, change model number, using next longer probe price. Over 600 mm, add **$1.25** per 25 mm of probe length. For leads longer than 1 m, add lead length to end of model number, and **$7** per meter to price.

***Ordering Example: PR-10-2-100-M45-150-E-OTP,*** *100 Ω, class "A" RTD with a 4.5 mm diameter by 150 mm long probe, 1 m of 3-wire cable and OTP connector,* ***$76.***

C-51

## Appendix IV. Gant Chart

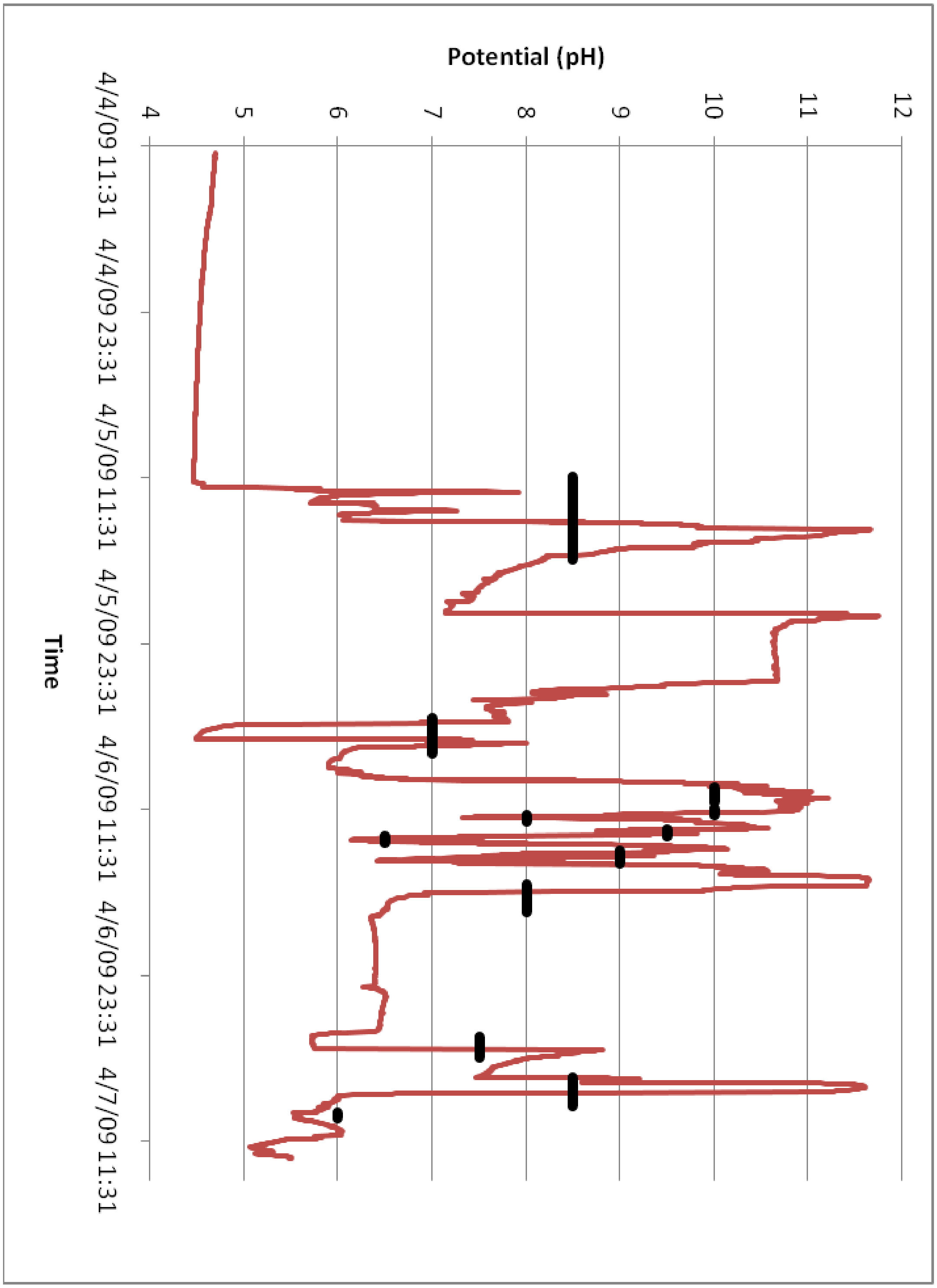


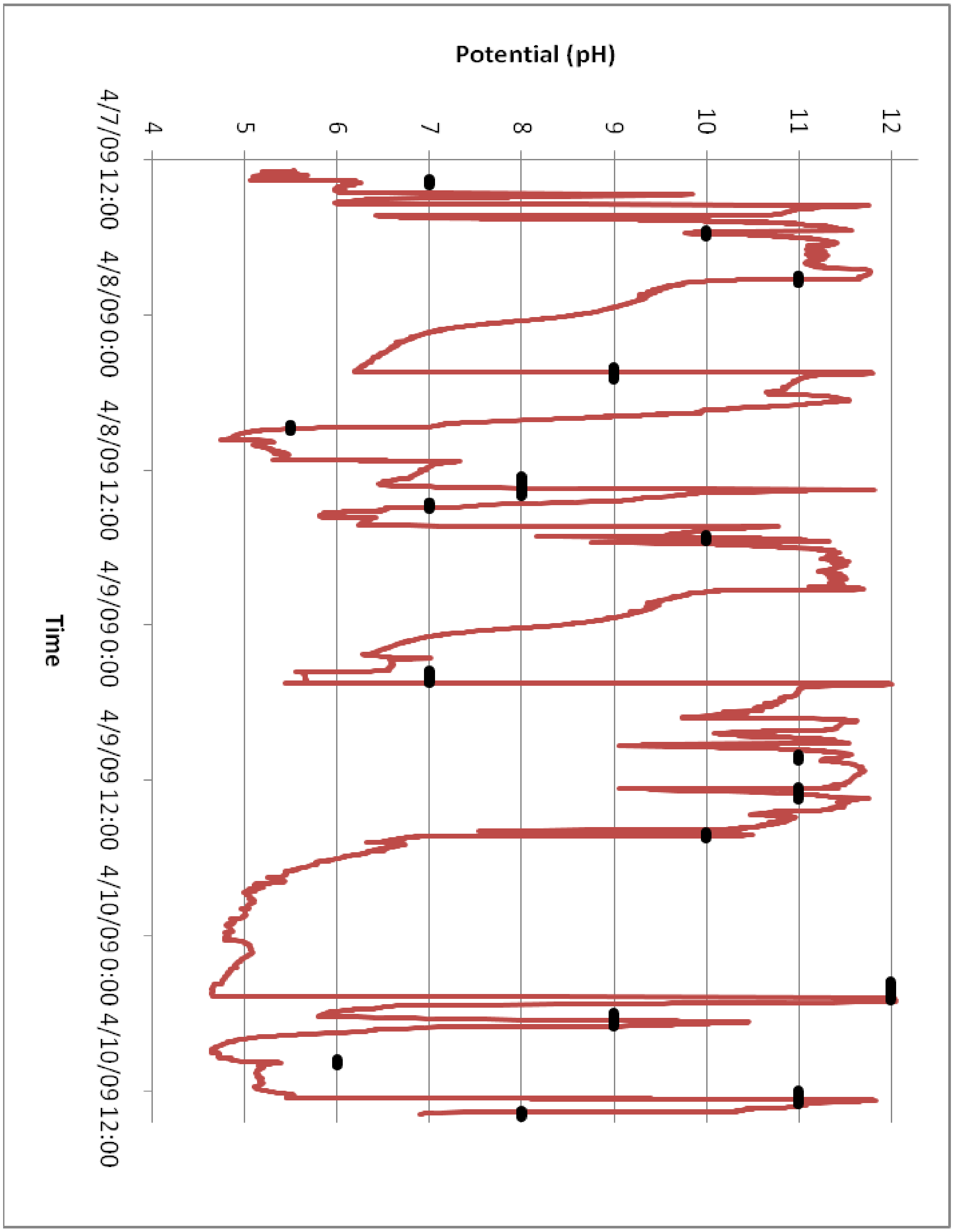
| Friday 4/10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3:30 | 4:00 | 4:30 | 5:00 | 5:30 | 6:00 | 6:30 | 7:00 | 7:30 | 8:00 | 8:30 | 9:00 | 9:30 | 10:00 | 10:30 | 11:00 | 11:30 | 12:00 | 12:30 | 13:00 | 13:30 | 14:00 | 14:30 | 15:00 | 15:30 | 16:00 | 16:30 | 17:00 | 17:30 | 18:00 | 18:30 |
| | KR & Clean | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | YE | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | KR | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | Tank Clean | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | KR | | | | | | | | | |
| Saturday 4/11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | KR & Clean | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | KR | | | | | | | | | | | | | | | | | | |
| Sunday 4/12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | CB Caustic Cleaning | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | YE | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Monday 4/13 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | DE Filter Clean | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | YE | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | YE | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Tuesday 4/14 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | Tank Clean | | | | | | | | | |

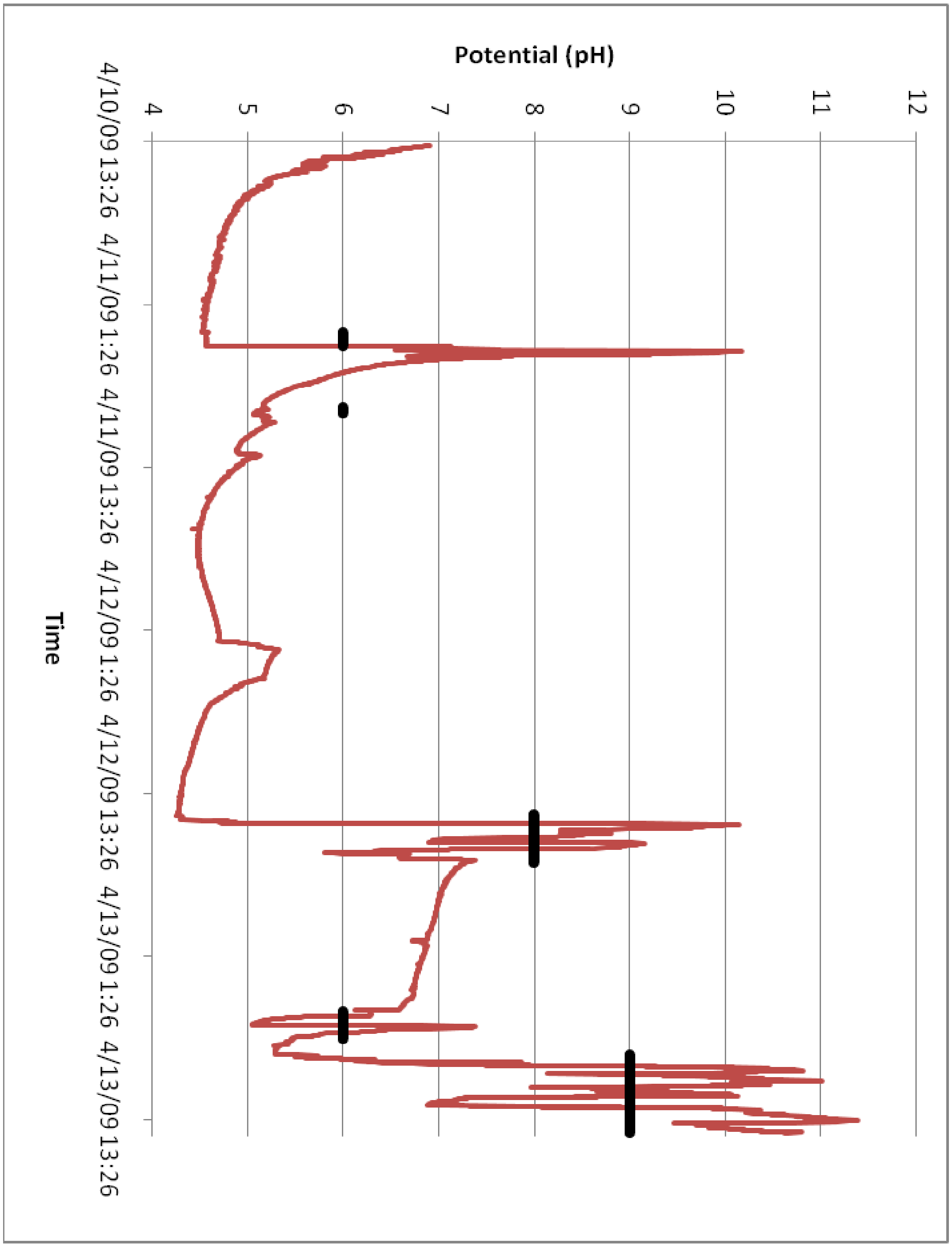
| Key | |
|---|---|
| FC | Fermenter Cleaning |
| KR | Kettle Rinse |
| MT | Mash Tun |
| PFR | Post Filtration Rinse |
| YE | Yeast Evac |

Logger Data

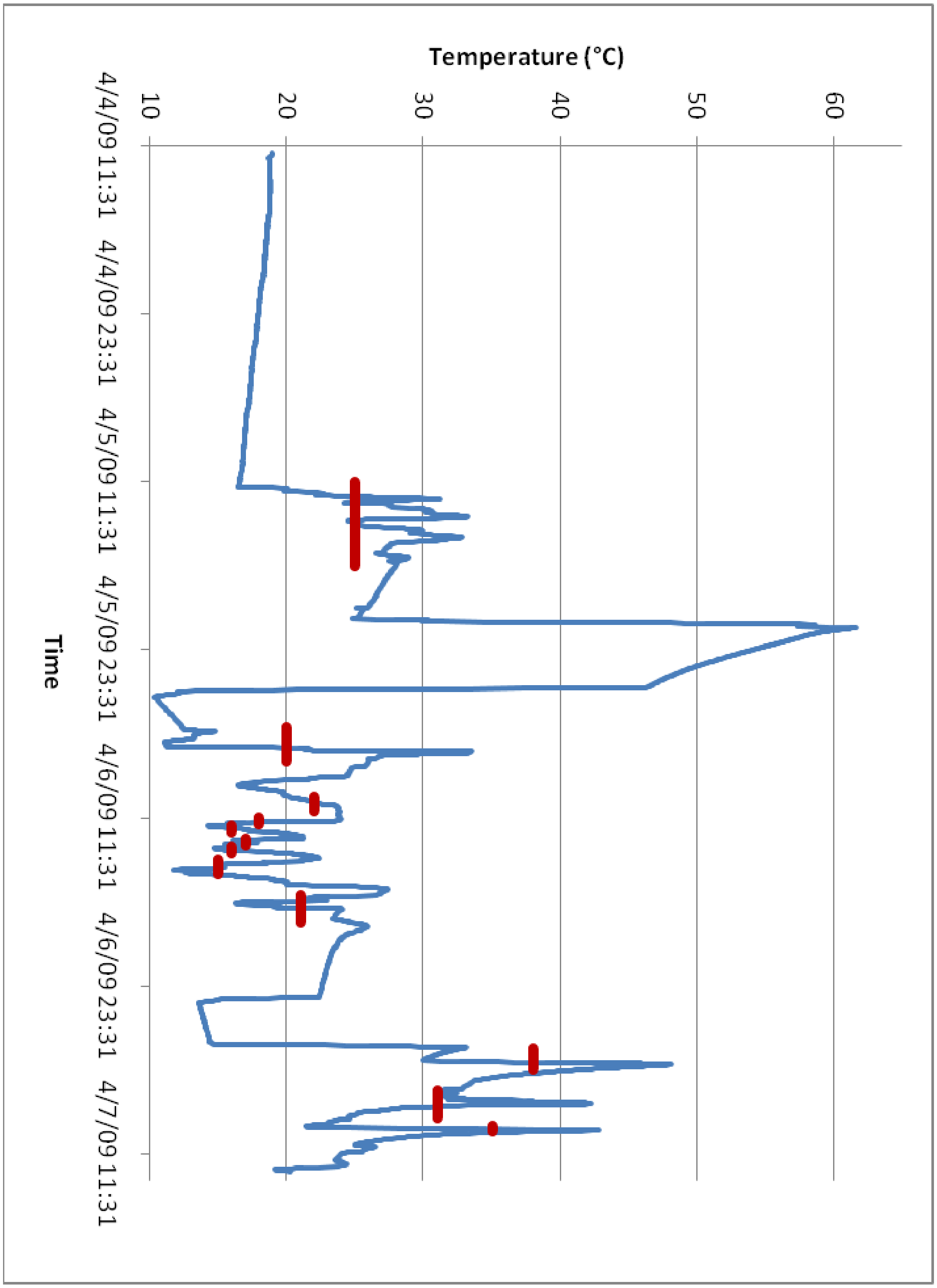
**Potential (pH)**

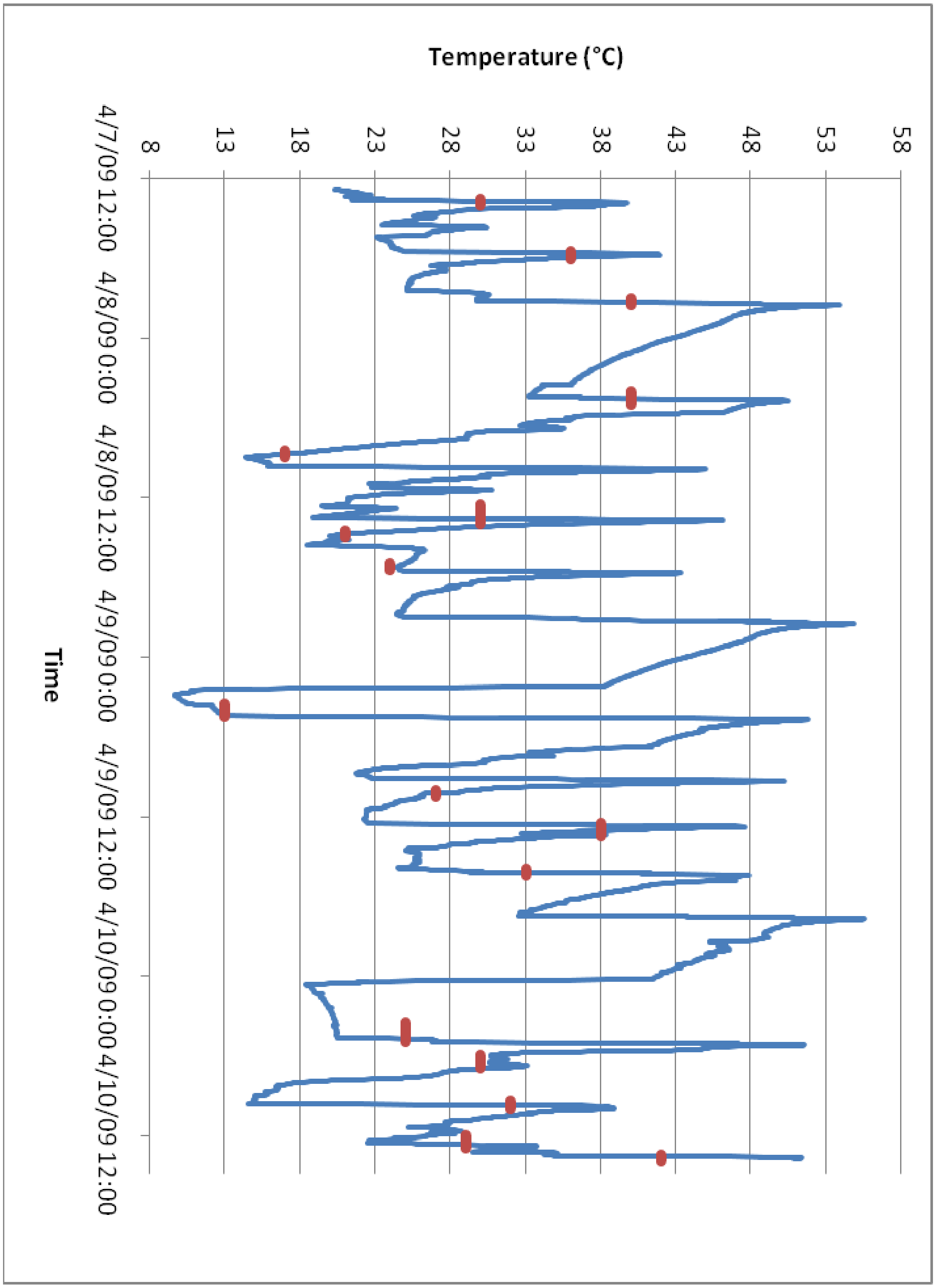



Potential (pH)
4
5
6
7
8
9
10
11
12
4/7/09 12:00
4/8/09 0:00
4/8/09 12:00
4/9/09 0:00
4/9/09 12:00
4/10/09 0:00
4/10/09 12:00
Time


Potential (pH)
4
5
6
7
8
9
10
11
12
4/10/09 13:26
4/11/09 1:26
4/11/09 13:26
4/12/09 1:26
4/12/09 13:26
4/13/09 1:26
4/13/09 13:26
Time

**Temperature (°C)**




Temperature (°C)
8
13
18
23
28
33
38
43
48
53
58
4/7/09 12:00
4/8/09 0:00
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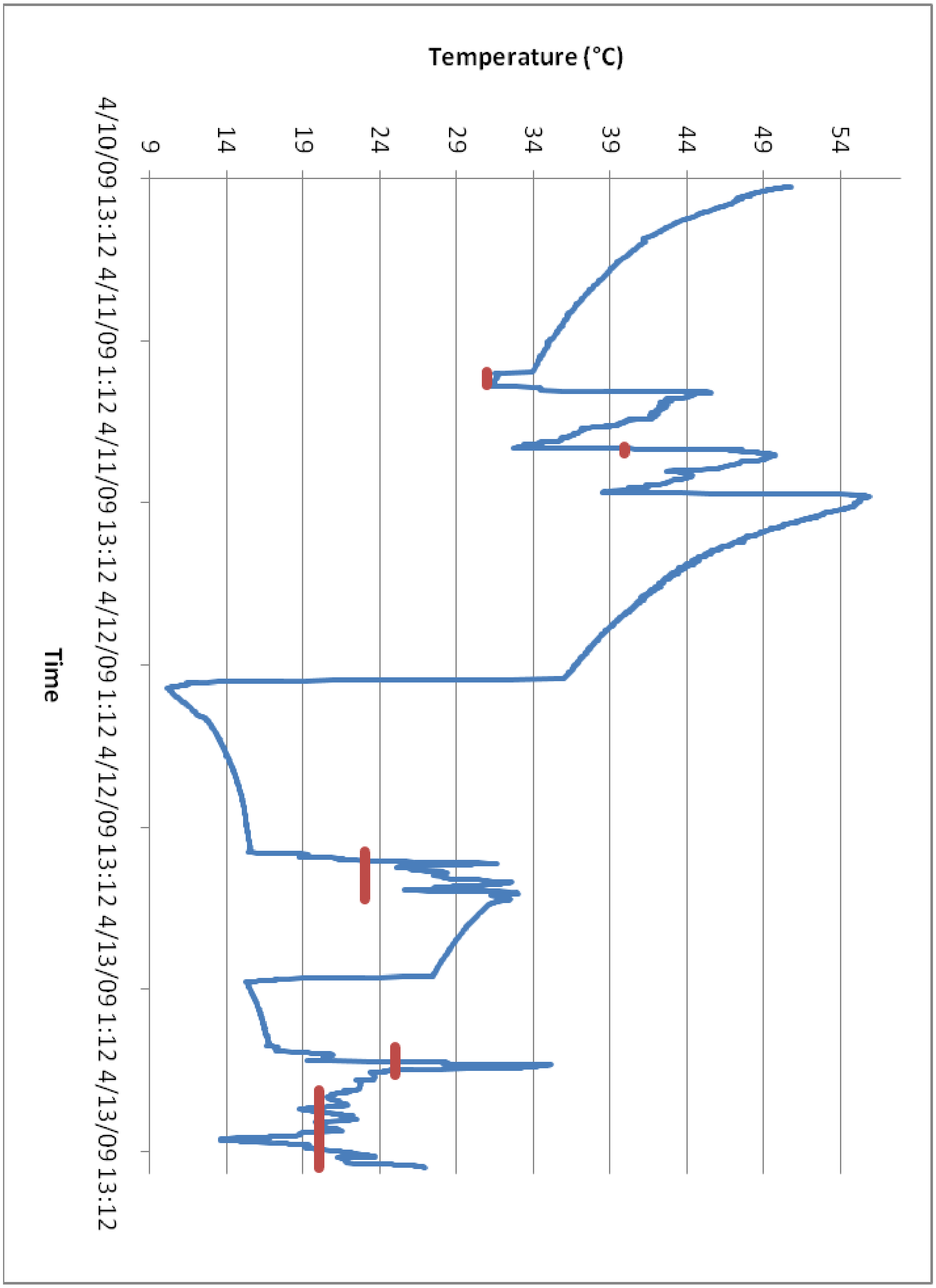
4/9/09 0:00
4/9/09 12:00
4/10/09 0:00
4/10/09 12:00
Time

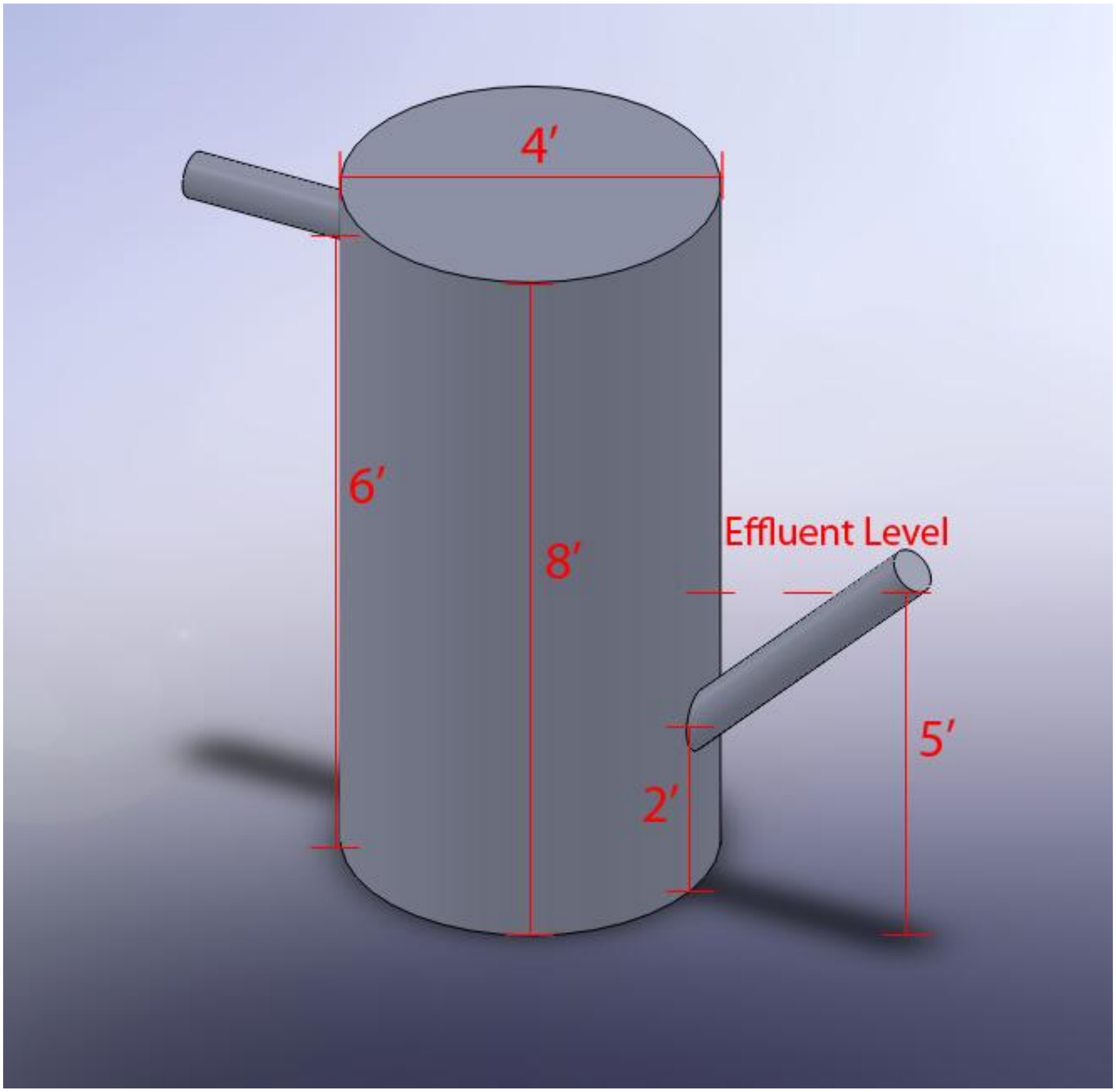

Temperature (°C)
9
14
19
24
29
34
39
44
49
54
Time
4/10/09 13:12
4/11/09 1:12
4/11/09 13:12
4/12/09 1:12
4/12/09 13:12
4/13/09 1:12
4/13/09 13:12

# Appendix V. Holding Tank Simulation

April 15, 2009
Start: 2:00 PM
End: 7:00 PM
Mix 250 mL of each in a 600 mL Beaker

| Solution | pH |
|---|---|
| Caustic Solution: | 10 |
| Yeast Slurry: | 4.5 |
| Mix hr 0: | 8.5-9 |
| Mix hr 1: | 8-8.5 |
| Mix hr 2: | 7.5-8 |
| Mix hr 3: | 7.5-8 |
| Mix hr 4: | 7.5-8 |
| Mix hr 5: | 7.5-8 |

## Appendix VI. Settling Tank Diagram



## Appendix VII. Project Proposal

**Worcester Polytechnic Institute**
**Chemical Engineering Major Qualifying Project**
**For Wachusett Brewing Company**

Wachusett Brewery Environmental Improvement
Bethany Bouchard, Craig DiGiovanni, Kevin Wilson

**Introduction:**

With an ever growing focus on environmental impacts related to chemical processes, intelligent use of chemicals, recycling, and proper disposal of waste streams have become essential to sustainability. It is expected that many industries will have to make changes to their processes as a result of the tightening environmental restrictions. Wachusett Brewery has decided to take a preemptive approach to the sustainability challenge and plans to investigate possible solutions to anticipated problems. The WPI 2008/2009 MQP team has been assigned to work collaboratively with the Brewery to qualify and quantify current process outputs and to explore various options to reduce effluent byproducts or to recycle them it in an environmentally friendly manner. The project plans to focus on two major areas: pH and temperature of the wastewater stream and alternative uses for spent yeast and trub. Trub is a residue that results from the settling of hop leaves and the denaturing of proteins that fall out of solution during the wort boil. The other major by-product of the brew process is yeast. Currently this material accumulates in the settling tank and is then pumped out periodically. In order to minimize both the cost of disposal and environmental impact the MQP team is considering and evaluating various options for alternative disposal.

**Objectives:**

The primary objective concerning the wastewater stream will be determining solutions for any possible non-compliance regarding the properties of the effluent as the brewery capacity is increased in the future years. The MQP team will have to consider current regulations for both pH and temperature and make sure that proposed solutions are well within the constraints in anticipation for strict regulations in the future. With regards to the yeast and trub, the goals are to ultimately find feasible outlets for these byproducts that would benefit both the Brewery and the environment.

**Deliverables:**

1. Analysis of the variation of pH and temperature of the wastewater stream with respect to the brewing process schedule.

2. Detailed protocol for recommended operation to minimize the aforementioned effluent variations.
3. Evaluation of possible outlets for spent yeast and trub that are economically and environmentally sustainable.

**Methodology:**

In order to understand the properties of the wastewater stream, the MQP team will spec out for Wachusett Brewery purchase a pH and temperature data logger along with the necessary measurement probes. These probes will be installed in the settling tank to monitor change in pH and temperature during normal daily operation. From this data the MQP team will be able to determine necessary changes, if any, needed to prevent future wastewater discharge violations. This procedure will take place over several periods to examine typical variations throughout the various production runs. Assuming the effluent does not meet, or is very close to, the environmental regulations we will suggest process modifications that would adjust the pH in a controlled manner without disturbing current operations.

Before considering possible recommendations for the yeast and trub, the MQP team will complete an analysis of the substances that may be of interest when disposing the material. This includes, but is not limited to, the determination of the solids and water content. The MQP team will then consider possible options for the disposal of the effluent which could possibly include farm animal feed, composting and biofuels.

Once an understanding of the brewery effluent generation and discharge is established, further modifications to the discharge schedule may be necessary to meet environmental requirements. The MQP team will work with the brewery to better define wastewater discharge compliance. This will assist the Wachusett Brewery in their goal of maintaining environmental conformity.

**Project Completion Schedule:**

Install pH and temperature probes and logger – 2/12/09
Determine water composition of spent yeast – 2/16/09
Chart pH and temperature variations – 3/6/09
Determine yeast drying procedure – 3/6/09
Determine outlet for yeast – Early D-term
Determine SOP for maintaining acceptable effluent pH & temperature – Early D-term

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