Reduction of Chloride in Wastewater Effluent

With Utilization of Six Sigma

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ABSTRACT

The objective of this study was to implement a Six Sigma program on a company's wastewater treatment system to determine if the application of the Six Sigma tools would result in a reduction of the chloride concentration. The review of literature included the history of Six Sigma, the Six Sigma problem solving (DMAIC) process, the current state of environmental regulations, as they relate to chloride concentration, and the current technology for chloride removal.

Data was collected from the facilities process owners and SCADA (Shop-floor Collection And Data Acquisition) system. The data was analyzed by a Six Sigma team with incremental changes made to the operation to improve (reduce) the chloride concentration to the facility's wastewater treatment plant. The results demonstrate that Six Sigma can be effective in improving the environmental performance of the wastewater treatment plant by improving the operations that are discharging to the

facility. Finally, the study offers some recommendations the facility, and other similar facilities may investigate to further improve (reduce) the chloride concentration in the discharge stream from their facilities.

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CHAPTER I:

INTRODUCTION

Lean Manufacturing & Six Sigma

Many organizations have improved their performance by implementing lean manufacturing. Lean manufacturing emphasizes elimination of waste from the manufacturing process. The wastes in the manufacturing systems that lean eliminates are

- Overproduction, making more finished goods than needed
- Operators or machines waiting for materials
- Unnecessary transportation of parts
- Over processing, or producing a product that exceeds the customers needs
- Excessive inventory in raw materials, work in progress and finished goods
- Unnecessary movement of operators and machines
- Production of finished goods with defects (Emiliani, 2003)

By elimination of waste, lean manufacturing is able to produce positive improvements in terms of cost and productivity without resorting to cost cutting measures that often result in lower morale and productivity in an organization.

Other organizations have improved their performance by implementing Six Sigma. Six Sigma is a methodology which utilizes statistical analysis to reduce variation and defects, improving the efficiency and the effectiveness of the organization (Breyfogle, 2003). The quality level at most companies is at a four sigma level which means the organization is willingly accepting 6,210 defects per one million opportunities (Brue, 2002). Organizations which have implemented Six Sigma and have made significant strides in reducing the defect level towards the 3.4 defects per million opportunities or less have found their profitability has improved, their customer satisfaction ratings have improved, and as their customer satisfaction ratings improved, their businesses have grown.

Some of the organizations which have implemented lean manufacturing are now starting to implement the Six Sigma methodology as an addition to their lean manufacturing tool box. These organizations are now implementing Lean Six Sigma. The organizations realize that although lean manufacturing helps to reduce defects by reducing waste, implementation of Six Sigma has the potential to further reduce waste and defects. These organizations also found that by using the Six Sigma statistical tools, they can find and eliminate hidden waste within their production process that they were not able to find with the lean manufacturing tools alone (Breyfogle, 2003).

At the same time, some of the organizations that have implemented Six Sigma are starting to implement lean manufacturing as an addition to their Six Sigma system. These organizations are also implementing Lean Six Sigma. These organizations have found that Six Sigma has, in the process of reducing defects, reduced waste, but Six Sigma has not been able to reduce the waste that does not result in defects.

Problem Introduction:

Company ABC, a food processing company implemented lean manufacturing five years ago. The company utilizes sodium chloride, salt, throughout its process to as an ingredient and to chill products. The facility's production level has remained relatively stable over the last several years, while the chloride level in the effluent from the wastewater treatment system has continued to increase. The company sees the increasing chloride trend as an indication of a waste in the production system which lean manufacturing has not been able to identify.

The company is now in the process of adding Six Sigma to their lean manufacturing system. Because the lean manufacturing tools have not been able to identify and reduce chloride levels in the effluent from the wastewater treatment system, the company has determined that the Six Sigma methodology may be the best tool available to identify and reduce the chloride wastes in their manufacturing process.

Statement of the Problem:

The purpose of this study is to determine the sources of chloride in the effluent and to analyze those sources utilizing the various Six Sigma tools to reduce the chloride loading to the wastewater effluent stream. The scope of the project includes all five phases of the Six Sigma DMAIC methodology: define, measure, analyze, improve, and control.

Purpose of the Study:

The purpose of the study is to reduce chloride levels in the effluent from the facility's wastewater treatment plant.

Previous Work:

Company ABC has an Environmental Steering Committee which meets quarterly to review environmental performance. Chloride concentrations in the wastewater effluent are a topic at each meeting. The members of the committee and the Value Stream Managers perform monthly audits of the facility's brine distribution system. The audits concentrate on deposits of salt crystals on piping connections and valves which are a sign of developing problems in the distribution system. Although the audits have been successful in eliminating large leaks and failures in the distribution system, they have not had any affect on the increasing use of salt and the resulting increase of chloride concentration in the effluent from the wastewater treatment plant.

An inline refractometer was installed and tested on one of the applications that utilize salt brine. The intent was to monitor the brine strength and meter saturated brine into the system to maintain a constant brine concentration. The test unit failed on a regular basis due to the aggressive nature of the cleaning chemicals used in the daily sanitation of the equipment.

Quarterly information meetings are held with all employees at the facility. Chloride concentrations are reviewed at each of the meetings with discussion on the importance of chloride reduction. The communication efforts have resulted in short term reductions in chloride concentration following the meetings.

Objective of the Study:

The objective of the study is to apply the Six Sigma tools to analyze the waste stream to determine the sources of chlorides. The Six Sigma tools will then be applied to the identified sources of chlorides to determine what procedures and administrative controls can be put in place to reduce the use of chlorides in the facility. The goals of the study are:

1. Evaluate the waste stream to identify sources of chloride.
2. Evaluate the sources of chloride to determine the largest opportunities for chloride reduction.
3. Evaluate the identified sources and determine what procedures and administrative controls may be put in place to reduce chloride use at the source.

Significance of the Study:

The study will benefit the food processing facility and other businesses that use chlorides in similar manners by developing methods and guidelines that may be used to reduce chloride consumption in their processes.

Some of the benefits that will be achieved through the implementation of the study are:

1. Improved environmental performance of the facility's wastewater treatment plant.
2. Reduction in costs due to chloride savings.
3. Improvement of product quality due to lower use of chloride.
4. A cleaner supply of water to the area's wetlands and fisheries

Assumptions of the Study:

1. The food processing facility is knowledgeable about Six Sigma.
2. Historical data collected by the facility and literature reviewed by the researcher is accurate.
3. Accuracy of in place measurement systems can be verified.
4. Management and workers are willing to test and implement recommendations based on the data analysis.

Limitations of the Study:

The scope of the study is limited to sources of chloride that are identified as significant. Data in the study, provided by the company, will be limited to historical data that is no more than one year old, and data collected from January 3, 2006 to May 31, 2006. Chloride use at the food processing facility may not be typical to that of other firms in the industry.

Definition of Terms:

IC_{25}: Inhibitor Concentration. The concentration of a toxic substance that reduces the reproduction rate of a test species by 25% (EPA, 1994)

KPIV: Key Process Input Variable (Bothe, 2003)

KPOV: Key Process Output Variable (Bothe,2003)

LC_{50}: Lethal Concentration 50%. The concentration of a toxic substance that is lethal to 50% of a test species (EPA, 1994).

Salometer: a hydrometer for indicating the percentage of salt in a solution (Merriam-Webster Online)

CHAPTER II

REVIEW OF LITERATURE

History of Six Sigma:

In 1983, Bill Smith, a reliability engineer at Motorola, determined that if a defect was found and corrected prior to shipment there were probably more of the same or similar defects that were being missed and later found by customers. (Brue, 2002, Gupta, 2004) Smith believed that by reducing defects and increasing yield of number one products, the likelihood of a product failure in the customer's hands would be greatly reduced. Smith found that each improvement in yield resulted in a significant reduction in waste, with a significant improvement in profitability. In 1987, Motorola launched Six Sigma as a corporate-wide program. Bob Galvin, the CEO of Motorola, traveled to each plant to present the Six Sigma methodology and to explain why Six Sigma was such an important part of Motorola's growth strategy. (Larson, 2003) Mikel Harry, Ph.D., a staff engineer at Motorola, had further developed Smith's methodology to reduce defects and by 1989 had published several papers that strongly supported the Six Sigma methodology (Bothe, 2003). At that time, the Motorola University was established and Motorola publicly announced a goal of reducing defects to the Six Sigma level of less than 3.4 defects per million units within five years. By the end of the five year period, Motorola claimed to have saved a total of $1 billion in manufacturing costs, with nearly another $1 billion saved in non-manufacturing operations.

Other companies began following Motorola's Six Sigma lead, including Texas Instruments in 1988, ABB (Asea, Brown, Boveri) in 1993, Allied Signal in 1994 and General Electric in 1995. (General Electric, 2001). In 2000 General Electric began introducing Six Sigma to their customers' facilities (Bothe, 2003). By 2002, the Six Sigma methodology had spread to smaller manufacturing companies and was beginning to be adopted by the service industries.

Six Sigma Methodology:

Mikel Harry and Richard Schoeder documented Motorola's methods and called them the *Breakthrough Approach* (Gupta, 2004). The breakthrough approach is known by the acronym DMAIC for define, measure, analyze, improve and control.

Several tasks must be completed in each step of DMAIC. All tasks are not necessarily required for every Six Sigma project.

DMAIC Steps (Bothe, 2003):

Define the problem:

1. Identify the customer and the customer's critical requirements.
2. Assemble a team of people who are knowledgeable about the process. Be sure to include people who work in the area, the process owners.
3. Determine what the Key Process Output Variables (KPOV) are for meeting the customer's requirements.
4. Determine which KPOV's need to be improved.
5. Review the KPOV to ensure that the right KPOV has been chosen, considering the impact on the customer as well as the impact on the business.
6. Determine the extent of the problem.
7. Develop a clear problem statement with an improvement goal.

8. Determine a time span in which the project can be completed. If the time span is too long, it may be best to redefine the problem, breaking it down into several smaller problems.

Measure the problem:

1. Verify the measurement system that is use for the KPOV.
2. Verify the accuracy of the measurement systems.
3. Determine the current performance level of the process.
4. Determine if the process is stable and in control.
5. Determine the process capabilities, if the process is stable.
6. Determine the process quality (Sigma) level.
7. Compare the process performance against the performance requirements of the customer to determine how much improvement is needed.
8. Develop a flow diagram (map) of the process to identify major steps and potential areas where relevant data may be gathered.
9. Determine the process variables which affect the KPOV that has been identified as needing improvement.

Analyze the Data:

1. Using the data collected in the measurement phase, develop a list of potential causes that may be affecting the KPOV.
2. Review the causes and determine which ones have the most potential to improve the KPOV. The causes are often referred to as the Key Process Input Variables (KPIV).

3. Test each of the KPIV's to determine how much of an effect each of the KPIV's have on the KPOV.
4. For each KPIV that is determined to have a strong effect on the KPOV, establish operating limits that may improve the KPOV.

Improve the Process:

1. Develop a list of possible modifications to the KPIV that could improve the KPOV.
2. Review the list of possible modifications, selecting one for testing.
3. Evaluate the selected modification by testing and reviewing the results. Several incremental tests may be required.
4. Assuming the testing is successful, develop an implementation plan and monitor the results. If the testing plan is not successful, go back to step 3 and select a different process modification to test.
5. Verify that the modification has been successful and determine how much of an improvement has been made in the process capability.

Control the Process:

1. Mistake proof the process. Write new procedures, create standardized work, and retrain personnel as necessary.
2. Set up methods to monitor the process to ensure that the new procedures are being followed. Control charts are one method that may be used.
3. Audit the process to ensure that the new procedures are being followed.
4. Transfer ownership of the improved process to the people responsible for operating the process.

Benefits of Six Sigma:

Brue (2002), George (2002), and Gupta (2004) agree on the benefits of Six Sigma. The most important benefit that the authors identify is that Six Sigma requires the involvement and leadership of an organization's top management. With top management leading the way, the expectations of the organization become very clear. The entire organization is rapidly convinced that Six Sigma is not another "flavor of the month" program because the CEO and the General Managers are out on the plant floor helping to determine which problems are suitable for Six Sigma projects and working with the project teams to ensure that the efforts are successful.

Six Sigma improves an organization's profitability. As the defect rate falls, rework falls, increasing profitability. As the rate of product failure in the customers' hands falls, the reputation of the product improves resulting in increased sales which often lead to more work, more hiring and improved job security (Eckes, 2003).

Eckes (2003) also points out that the Six Sigma methodology requires management and workers to learn new skills. As the workers learn the new skills they increase their value to the organization, further improving job security.

Chloride Regulation:

Although the Environmental Protection Agency (EPA, 2002) has recognized that chlorides are a pollutant of concern, the agency has chosen not to regulate chloride as their studies have shown that biological treatment systems are not designed to reduce chloride levels. The EPA's studies have also shown that the chloride level tends to increase from influent to effluent in some biological treatment systems. The EPA has determined the average chloride level in the effluent from large direct discharge meat processing plants is 2,087 mg/l (milligrams per liter), while the Best Available Technology (BAT) for biological treatment of chloride is only capable of reducing chloride levels in the effluent to 2,489 mg/l.

Although the EPA has chosen not to regulate chlorides as a pollutant, the Clean Water Act does not allow the discharge of a toxic substance in toxic amounts to the environment. Under the clean water act the EPA established the requirement for whole effluent toxicity (WET) testing. WET testing requires that five different concentrations of wastewater are tested with 10 different animals to determine the toxicity of the pollutants being discharged (DiGiano, Elian, Francisco, Maerker, LaRocca, n.d.). The insect that is most sensitive to salt and chlorides is an insect species of the water flea known as Ceriodaphnia dubia (C. dubia). The concentration of chloride that is lethal to 50% ,the LC_{50} or the acute whole effluent toxicity value, of the C. dubia is 2,500 mg/l. The concentration of chloride that results in a 25% reduction in the reproduction rate, the IC_{25}, inhibition concentration, is 840 mg/l (Wisconsin Department of Natural Resources, 2000). The IC_{25} is also referred to as the chronic whole effluent toxicity value.

Under *Chapter 1.3 – Representative Data, Reasonable Potential & WET Monitoring* (Wisconsin Department of Natural Resources, n.d.), the Wisconsin Department of Natural Resources has the authority to determine discharge limits on a case by case basis. The discharge limits are based on the receiving body of water and the effluent conditions. The discharge of the effluent into the receiving body of water has to result in a dilution that is below the chronic toxicity for the pollutant being discharged.

The DNR may opt not to enforce a discharge limit if the discharge is less than 4 miles from a non-variance classified water body.

Chapter 1.3 became effective on June 1, 2005. The Wisconsin Department of Natural Resources is required to enforce discharge limits five years after the first renewal of a facility's operating permit after the effective date of Chapter 1.3. If a facility is not able to meet the future discharge limits, the facility will be required to apply for a variance.

The Department of Natural Resources has established a mass chloride limit that is equal to two times the chronic whole effluent toxicity value or a chloride concentration of 1,680 mg/l. The DNR requires that the chloride concentration be reported on a weekly basis. The concentration reported must be the average of six daily samples.

Direct discharge plants have a five year period to comply with the chloride limitation after the first renewal of their operating permit after the effective date of the WET (Whole Effluent Toxicity Testing) regulation on June 1, 2005, or apply for a Chloride Variance, if they are not able to meet the chloride limit.

Mechanical Removal:

Reverse osmosis is a mechanical method that is commercially available to remove chlorides in wastewater. DNR studies show that mechanical methods are expensive. (Wisconsin Department of Natural Resources, n.d.). The DNR estimates the mechanical equipment cost at $1.25 per gallon per day of flow capacity and the operating cost at $1.00/1000 gallons/day per day. Based on the DNR estimates the cost to mechanically remove chlorides from a 1 million gallon per day waste stream would require a $1,250,000 capital investment with an annual operating cost of $365,000.

The regulatory agencies point out that mechanical removal of chlorides results in a highly concentrated chloride solution that can not be put back into the inlet of the wastewater stream, nor can it be land filled, creating an even more expensive waste to dispose (DNR).

The recommendation from the EPA and the DNR is that direct dischargers examine their operations and determine what can be done to reduce the entry of chlorides into their waste streams.

CHAPTER III

METHODOLOGY

Introduction:

The objective of the study is to review the current operation to determine the sources of chlorides in the wastewater plant effluent. The study will examine one of the sources using the Six Sigma DMAIC methodology to determine if there are any procedure changes or administrative controls that may be put into place that will result in the reduction of chloride levels in the wastewater effluent. Each phase of the Six Sigma DMAIC model is described below.

Define:

The first task in the define phase of the study is to determine who is the customer, what are the customer's needs, and how will this study benefit the customer? The second task is to determine who the Six Sigma team members should be. The process owners must be represented on the team. Once the team members are selected, the team needs to determine what is going to be measured and what the units of measurement will be. The team needs to determine what the Key Process Output Variable (KPOV) will be. With the identification of the KPOV, the team will be able to review the current performance to determine the extent of the problem and the difference between the current performance and the expected performance. The last step in the define phase is to refine the problem statement, making it more specific.

Measure:

In the measurement phase the sources of chlorides to the wastewater effluent need to be determined and measured. The facility has been tracking and recording chloride usage at the various production points, both manually and with a SCADA (Shop-floor Collection And Data Acquisition) system, for a number of years.

The researcher will retrieve, review, and analyze the historical information to determine if there are any patterns in the data or sudden changes that may indicate potential problems with the measurements that are being used. The metering and measurement systems being used will be verified to ensure that the data being collected is accurate.

The sources of chlorides, ranked by type of operation, will be analyzed to determine if there is any one that stands out as a major contributor to the problem. If applicable, the selected type of operation may be further broken down to determine if there is a specific item or group within the type that is a major contributor of chlorides. When the measurement step is completed, the team will have selected a specific process or piece of equipment that will be addressed in the attempt to reduce the chloride level in the wastewater effluent. With the refined focus, the data for the selected process will be analyzed to determine the current level of performance, and if the process is in or out of control. If the process is in control, the process capabilities will be determined. With the current level of performance and the process capabilities determined, the team can estimated how much of an improvement can be made in chloride reduction.

The problem statement will then be further refined to reflect the more specific focus of the study with a stated chloride reduction goal.

Analyze:

The team will review the data that has been collected and brainstorm a list of potential causes that affect the KPOV. The potential causes are referred to as Key

Process Input Variables (KPIV). The list of KPIV's will be reviewed to determine which ones have the most potential to affect the KPOV. The KPIV's will be tested to determine the affect that each one has on the KPOV. The operating limits and specifications for each KPIV that show a strong affect on the KPOV will be reviewed. Potential changes in the operating limits and specification of the KPIV's will be documented for further testing.

Improve:

The list of KPIV's for further testing and the potential modifications to the KPIV's were established in the analyze phase. The KPIV's will be reviewed to determine which one is most likely to result in the greatest improvement in the KPOV. The KPIV that is identified as most likely to cause the greatest improvement in the KPOV will be selected for testing. Small incremental changes will be made in the selected KPIV to ensure that there are no negative affects on the KPOV or on the product being produced. If testing is successful, a plan for implementing the change will proceed. If not, another KPIV will be selected and tested.

If the implementation of the change is successful, the team will determine how much of an improvement has been made in the process capability and in the KPOV.

Control:

When it has been determined that the team has improved the KPOV, controls and procedures will be put into place to ensure that the improvement continues and does not fall back to the previous performance level. New procedures will be created or existing procedures will be updated as needed. A standardized work form will be developed for each change that is implemented.

In some cases, changes in the PLC (Programmable Logic Controller) programs may be needed. In those cases, the changes to the programs will be made and documented with notification of the changes issued to the Electronic Technicians so that they are aware of the changes and the reasons for them. This step will ensure that changes to the programs and the reasons for the changes are known by all parties that have access to them and authority to change them.

Process owners have been involved in the team. As a result, the process owners have taken ownership of the changes as they have occurred.

CHAPTER IV

RESULTS

Introduction:

The production levels at Company ABC, a food processing company have remained relatively stable over the last several years. While production levels remained stable, the chloride level in the discharge effluent from the facilities wastewater treatment plant has continued to increase.

The facilities management team recently decided to conduct Six Sigma training, adding Six Sigma to their lean toolbox. In the initial analysis of potential Six Sigma projects, the facilities' management team determined that reduction of chloride levels in wastewater is a project that, with the application of the Six Sigma tools, has the potential of improving the environmental performance of the facility while improving the quality of one of the water sources to the area's eco-system.

This chapter will discuss how the Six Sigma DMAIC process was applied to assist the facility in their goal of reducing chloride levels in the effluent from the wastewater treatment plant.

Define:

When the goal of reducing the chloride levels in the effluent from the wastewater treatment plant was determined, a team was put together to begin working on the problem which was initially identified as "Reduce the level of chlorides in the effluent from the wastewater treatment plant." The positions that were identified as potential team members were the Environmental Coordinator, Facility Engineering, Maintenance Supervision, Maintenance Mechanic, Value Stream Manager, Line Supervisor and

Equipment Operator. The Value Steam Manager and the Equipment Operator are the process owners.

Chloride levels are recorded in milligrams per liter (mg/l). The team determined that mg/l would be the Key Process Output Variable to be monitored for the project. A brainstorming session was conducted to generate a listing of potential sources of chloride in the wastewater. The potential sources were:

- Background chloride in the water supply
- Salt used in the regeneration of water softeners
- Salt brine used to cool product after cooking (Brine Chillers)
- Ferric Chloride used in the wastewater treatment process
- Product purge during the curing/cooking process
- Brine dumps due to errors in the mixing process
- Waste brine from the curing equipment
- Salt from ingredients and supplies
- Other sources.

The team next reviewed data that had been collected in the facility's utility tracking data base to determine which of the sources might be the largest contributor to the chloride levels in the wastewater effluent. A fishbone diagram was put together listing each of the sources and their chloride contribution, where the chloride contribution could be determined from the utility data base (see Figure 1). The water softener chloride use is based on the manufacturer's specification sheets for the water softeners and the regeneration schedule for them. Ferric Chloride is added to the wastewater treatment process based on mass flow basis at a rate of 60 mg/l. The fishbone diagram and the

Pareto Chart showed that over 72% of the chloride load was due to the brine chilling operations.

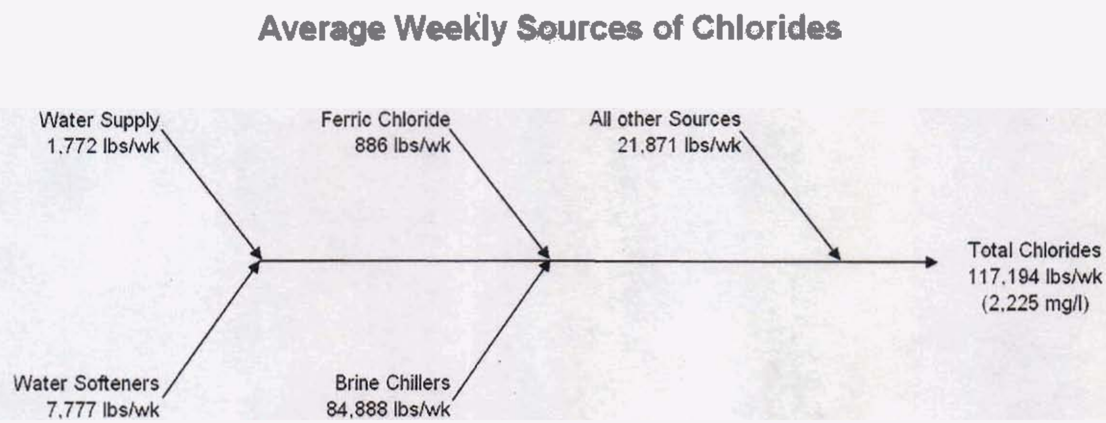


Figure 1: Average Weekly Sources of Chlorides

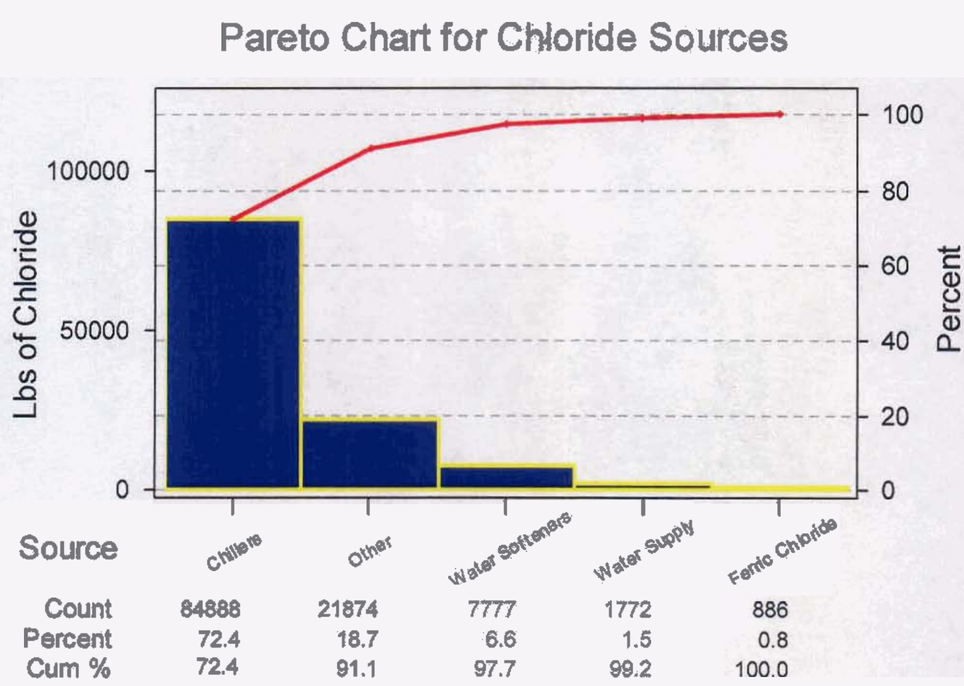
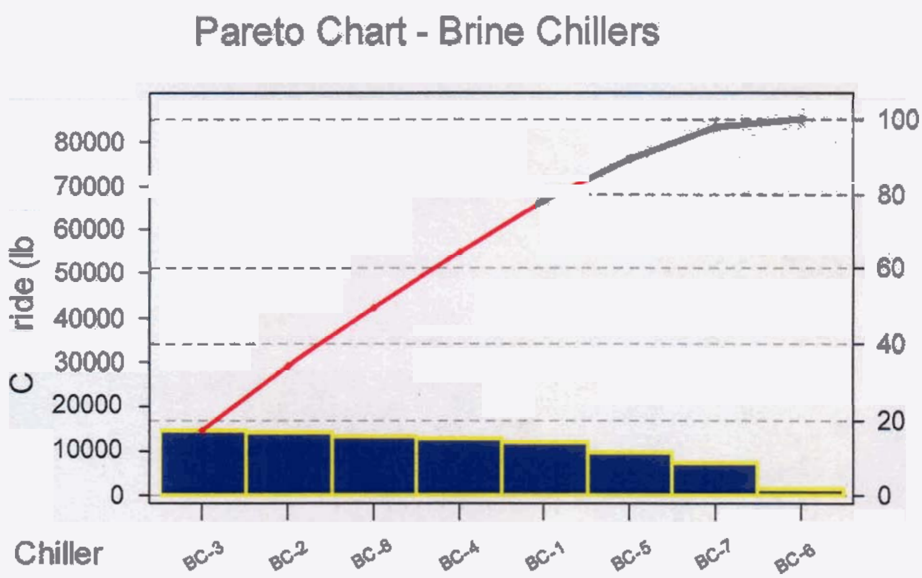


Figure 2: Sources of Chlorides

After reviewing the fishbone diagram and a Pareto chart of the sources, the team determined that historic chloride usage in the brine chillers needed to be reviewed to determine if any one, or any one type, of brine chiller was a major contributor to chloride levels.

There are two types of brine chillers used in the facility. There are continuous chills and batch chillers. The continuous chillers are part of an in-line processing system that automatically moves the product from the oven through the chilling process. For the batch chillers, the product must be physically moved from the ovens to the chillers allowing the product to be chilled.



Chiller	BC-3	BC-2	BC-8	BC-4	BC-1	BC-5	BC-7	BC-6
Count	14658	14099	13215	12841	11912	9483	7260	1421
Percent	17.3	16.6	15.6	15.1	14.0	11.2	8.6	1.7
Cum %	17.3	33.9	49.4	64.6	78.6	89.8	98.3	100.0

Figure 3: Pareto Chart Brine Chillers

Analysis of the Pareto Chart for the Brine chillers (Figure 3) showed that the chloride contribution from the Batch Chillers was relatively consistent between identical units. Brine Chillers 1 and 2, and Brine Chillers 4 and 5 are identical units. Of the identical units, chillers 1 and 5 showed slightly lower chloride contribution. There is a greater travel distance from the ovens to chiller 1 than there is to chiller 2. There is also a greater travel distance to chiller 5 than there is to chiller 4. The extra travel distance results in a lower usage rate for chillers 1 and 5, offering a reasonable explanation for the differences in their chloride contribution. Brine chiller 3 showed the largest single contribution to chlorides. Brine chiller 3 is more centrally located in the facility and has the highest utilization rate of the batch chillers. Brine chillers 7 and 8 are also identical units. The analysis showed a significant difference between these two units, 7,260 lbs per week and 13,215 lbs per week respectively. Brine chiller 6 showed the lowest chloride contribution of any of the chillers. Brine chiller 6 is also used to chill a product that is very different from the products that are chilled in the other systems.

After reviewing the data, the team determined that the first step would be to reduce by 10% the level of chlorides contributed to the effluent from the wastewater treatment plant from Brine Chillers 7 and 8. The second step would be to reduce the level of chloride contribution from the batch chillers by 10%.

Measure:

In the define phase of the project, the team decided the key process output variable was the chloride level in the wastewater effluent, measured in mg/l. The daily chloride concentrations in the effluent from the wastewater treatment plant for the month of January, 2006 are shown in Figure 4. The average chloride concentration for the month was 2,248 mg/l. The weekly average chloride concentrations for the fiscal year 2006 through January 2006 is shown in Figure 5. The average chloride concentration for the fiscal year to date was 2,171 mg/l.

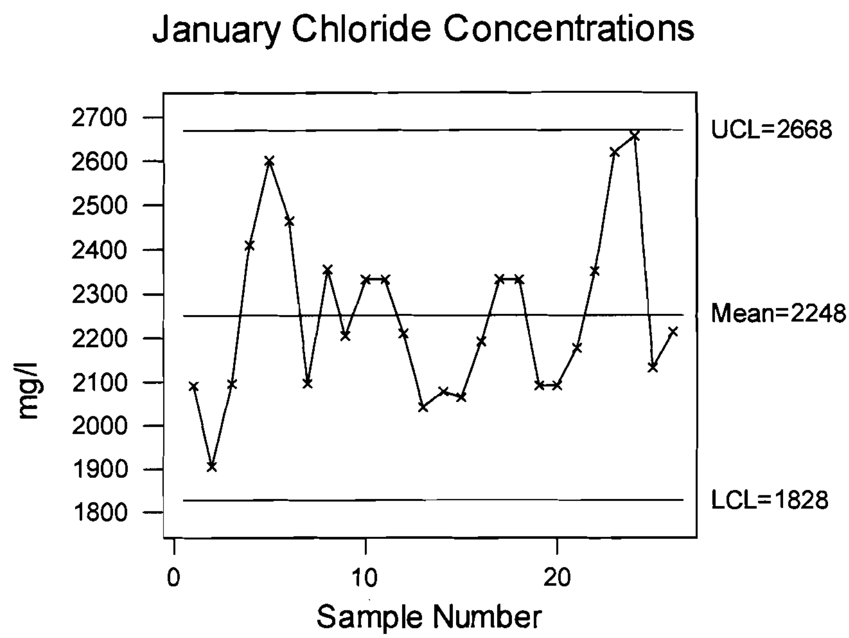


Figure 4: Daily Chlorides January, 2006

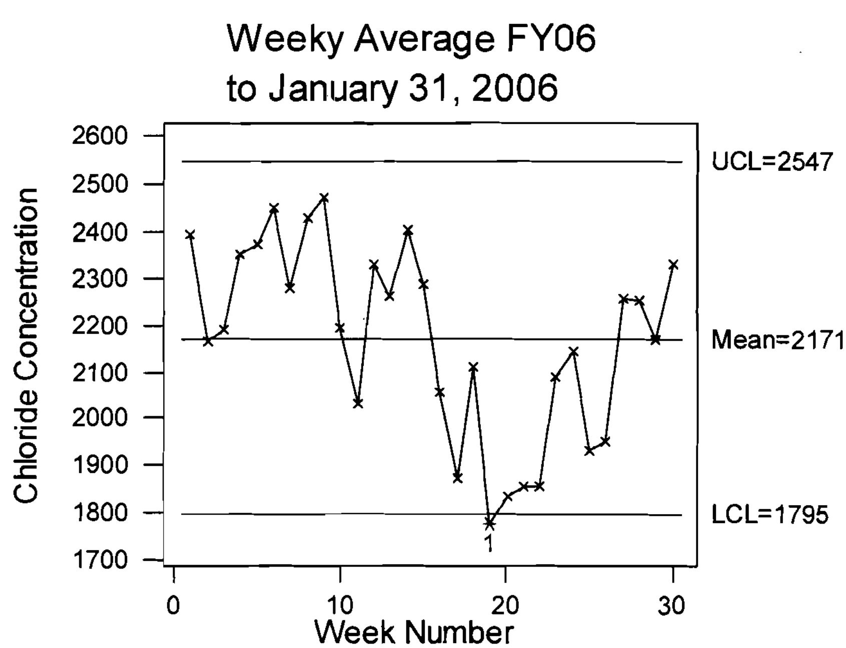


Figure 5: Weekly Chloride Averages FY 06 to January 31, 2006

In the measure phase of the project, the team needed to determine what key process input variables would be measured. The first step in the process was to determine the operating parameters for the brine chills as established by the facility's Quality Control Department, shown in Table 1, below.

Brine Chill Operation Parameters					
Chiller	Lower Specification Limit (LSL)	Upper Specification Limit (USL)	Target Concentration	Temp	Brine / Water Ratio
BC-1	50%	65%	55%	16^{O}F	60%/40%
BC-2	50%	65%	55%	16^{O}F	60%/40%
BC-3	50%	65%	55%	16^{O}F	65%/35%
BC-4	50%	65%	55%	12^{O}F	60%/40%
BC-5	50%	65%	55%	12^{O}F	60%/40%
BC-6	45%	60%	50%	24^{O}F	
BC-7	45%	60%	50%	26^{O}F	
BC-8	45%	60%	50%	26^{O}F	

Table 1: Brine Chill Operation Parameters

Brine Chillers 1 through 5 are equipped with a PLC (Programmable Logic Controller) that charges the chillers with a predetermined, metered mixture of saturated brine and water to reach a brine concentration target. The Brine/Water Ratio programmed in the PLC's results in a brine concentration that is above the target concentration but within the Upper Specification Limit for the chillers.

The Brine Chillers 6 through 8 are equipped with older controls. Saturated brine and water are added to the chiller by setting timers. Brine is metered, allowing the facility to track the amount of brine used in each of the chillers. Brine concentration is monitored on an hourly basis in the chillers. Based on the range of the brine concentrations, from 45% to 75%, (see Figures 6 and 7), and the large difference in brine usage between the two chillers 4,690 gallons of brine per week compared to 8,537 gallons per week, the team decided that the first step in the measurement phase would be to determine if the brine metering systems were accurate.

To determine meter accuracy, a minute of brine was added to the brine reservoir of each chiller, the brine meter totalizer reading was taken, the length and width of the reservoir was measured, and the depth of the brine in the reservoir was measured to allow the amount of brine in the reservoir to be determined and compared to the meter reading. The testing revealed that incorrect parameters had been set up in the meters on Brine Chiller 6 and Brine Chiller 8. The proper parameters were entered into the meter, and the test was repeated. The meter parameters were then fine tuned until the totalizer reading and volume of brine in the reservoir were within the accuracy tolerances specified by the meter manufacturer. After the meter was corrected, brine use and concentration data were collected for a month. The variation in brine concentration in the brine chillers did not change. The average brine use in Brine Chiller 8 did decrease slightly while the brine use in Brine Chiller 6 nearly doubled.

The hourly brine concentration readings from Brine Chillers 7 and 8, for the month of January, 2006, were placed on run charts (Figure 6 and 7). The run charts show that the brine concentrations ranged from the lower specification limit of 45% to 75%, which is above the upper specification limit of 65%. The lower control limit was calculated as 50.15% while the upper control limit was calculated as 64.24%. The run charts clearly show that the process of maintaining brine strength in Brine Chillers 7 and 8 is out of control.

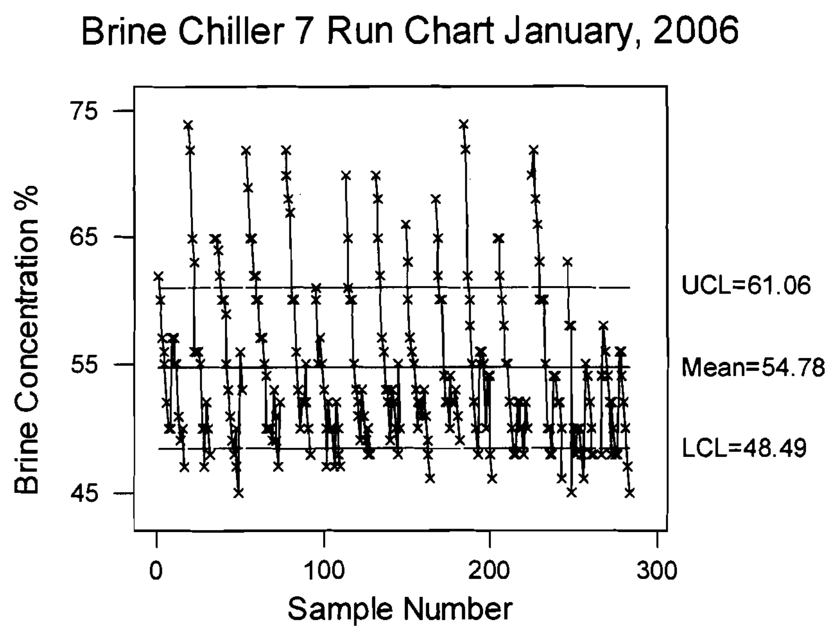


Figure 6: Run Chart for Brine Chiller 7, January, 2006

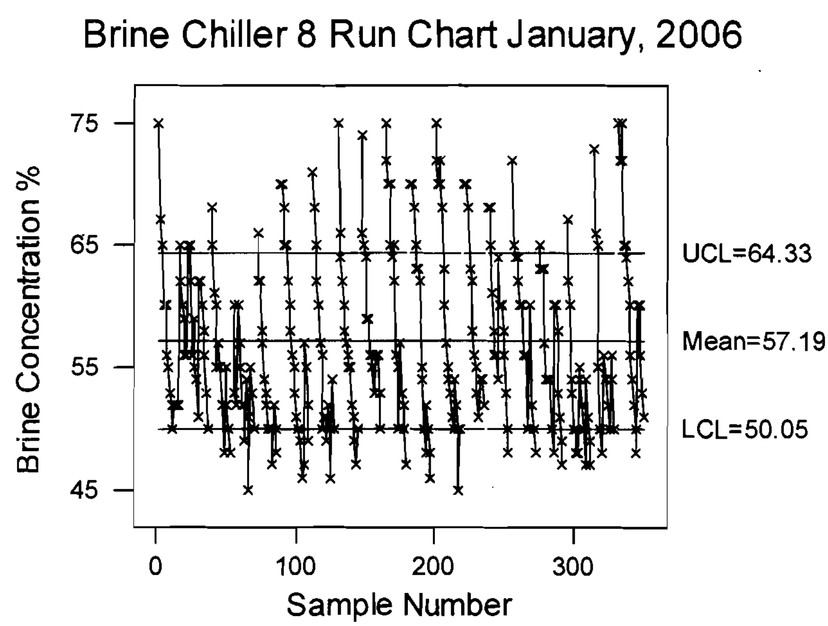


Figure 7: Run Chart for Brine Chiller 8, January, 2006

Analyze:

The first step in the analyze phase of the project was to determine the process capability of the two Brine Chillers (Figure 8 and 9). The range between the lower and upper specification limits for brine strength is 15%. The range between the lowest and highest measured brine concentration was 33%. The process capability analysis projected that the salt concentration in Brine Chiller 7 would be below the lower specification limit (LSL) or above the upper specification limit (USL) approximately 28% of the time. In comparison, the process capability analysis projected that the salt concentration in Brine Chiller 8 would be outside of the specification limits approximately 39% of the time.

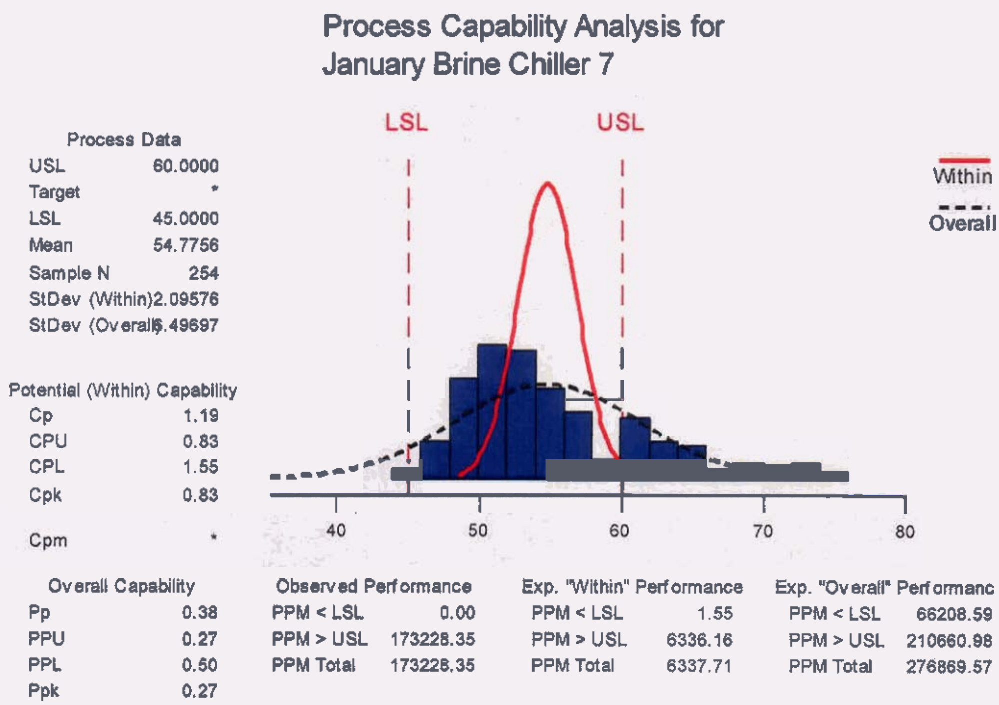


Figure 8: Brine Chiller 7, January, 2006 Process Capability

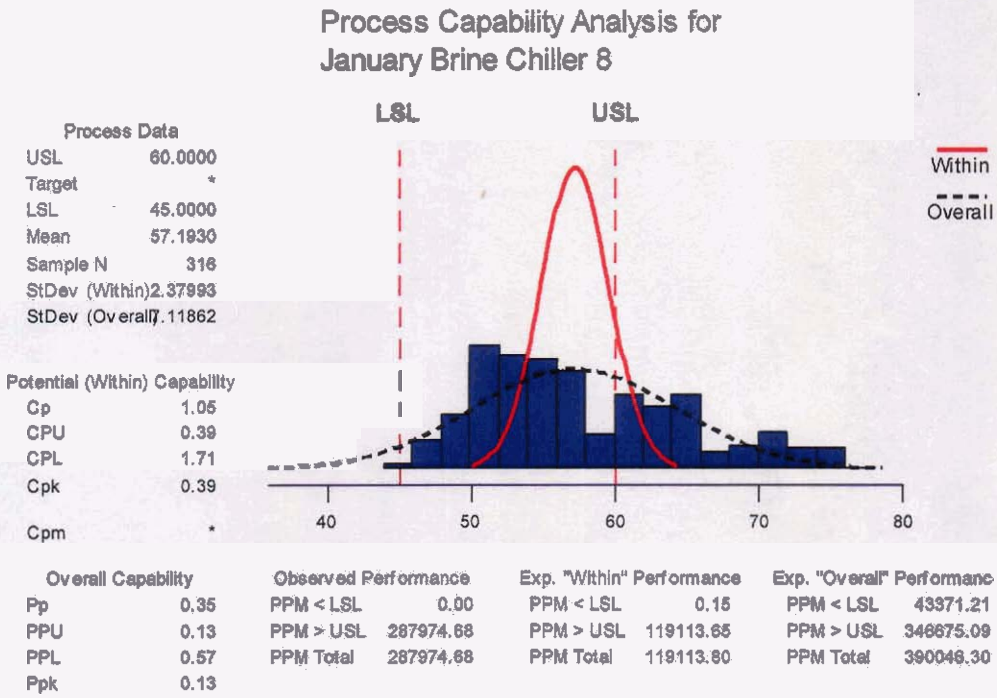


Figure 9: Brine Chiller 8, January, 2006 Process Capability

The second step in the analyze phase was to conduct a problem solving meeting with the process owners to determine why there was such a large range in the brine concentration on a day-to-day and hour-to-hour basis. After reviewing the January run charts (Figures 6 and 7) and the process capability analysis (Figures 8 and 9), decided on a current performance statement of "Chloride usage in the Brine Chillers 7 and 8 is out of control" with a goal of "Reduce chloride usage in Brine Chillers 7 and 8 by 10% by March 31, 2006." The cause and effect analysis from the problem solving meeting is shown in Figure 10. The team then conducted a root cause analysis

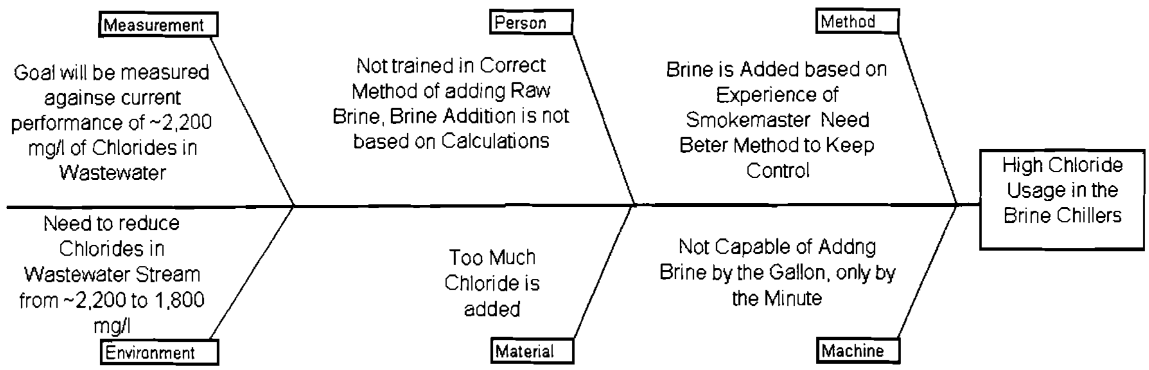


Figure 10: Problem Solving Cause and Effect Diagram

using the 5 Whys approach. The questions and answers that were developed in the exercise were:

1. Why is chloride usage so high? Brine addition is based on experience, not on the brine strength readings. Some Smokemasters (Operators) are trained in reading the salometer. The system is not capable of adding saturated brine by the gallon, only by minutes of flow. The salometer, brine concentration target is too high.
2. Why is brine add-back based on experience? There is no standardized work or guidance to help the operators determine how much brine to add back to the system to maintain brine concentration. Brine is added to the system based on minutes of flow, not gallons.
3. Why is there no standardized work for adding brine? Standardized work has never been an issue in the area.
4. Why is it that the chillers cannot add brine by the gallon? The controllers are not set up for addition by the gallon, only with timers.

5. Why do the operators target a high salometer of 68 to 72% if the target is 50%? It is easier for the operators as they do not have to add brine to the system as often when they add back to a higher brine concentration.
6. Why do operators not know how to read a salometer correctly? There is no standardized work for the operators.
7. Why are the brine meters not accurate? The proper correction factors were not set up in the meters when they were installed.
8. Would lowering the brine concentration to the target work? Would lowering the brine concentration result in lower brine usage and lower chloride levels? Yes.

The problem solving group several steps that needed to be completed to address the root causes that were identified. The steps included establishing a standardized work guide for the operators to follow when adding brine back to the chillers, standardized work for taking and reading the salometer, and reprogramming of the PLC to allow saturated brine to be added to the chillers based on gallons for flow rather than minutes of flow..

A similar procedure was followed to analyze the brine usage in the batch chillers. The team found that the lower specification limit for the brine chillers 1 through 5 was higher than for brine chillers 6 through 8, the target temperature of the brine was 10 to 12 degrees lower for the brine chillers 1 through 5 than for the brine chillers 6 through 8, and that the brine addition to the chillers was controlled by the PLC, charging the chillers and adding brine back into the chillers with a concentration that is higher than the target. The Quality Control department was able to determine that there was no logical reason for the differences in the specifications for the Batch Chillers and agreed to modify the specifications so that all of the batch chillers are the same.

Implement:

The first step in the implementation process was to develop a brine addition and waste schedule for the brine chiller operation while also developing standardized work for the operation of the Brine Chillers. A chart and instructions on how much brine to add back to and dump from the chillers to maintain the proper salt concentration and brine level was prepared for the operators during the same time frame as the operating instruction sheet for checking brine concentration was developed (Figure 11). An operating instruction form (standardized work) was developed that was used to train the operators on the proper method of determining the brine concentration. The operating instruction form was also posted in the work areas allowing the operators to utilize the form as a check list when performing the task. The operating instruction form is shown on the next page, Figure 12. The form is based on the recommendations from the *Salt Users Guide,* published by International Salt in 1992.

Brine Addition

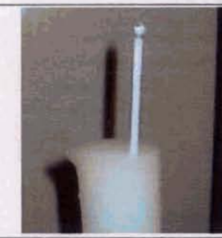
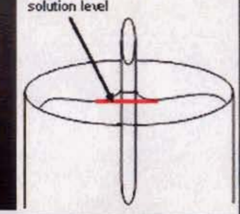
Salometer Reading	Brine Addition (Gallons)	Drain Time (Seconds)
54%	33	18
53%	59	33
52%	85	48
51%	102	59
50%	119	69
49%	142	85
48%	164	100
47%	197	124
46%	227	148
45%	243	161

Figure 11: Brine Addition Chart

OPERATION INSTRUCTION FORM (OIF)

Plant:

Department: Brine Chillers	Operation: Hydrometer Reading	Area:	Position: Smokemaster	Prepared By:	Date: 03/13/06

NO.	OPERATION SEQUENCE (WHAT)	KEY POINTS (HOW)	REASONS / ILLUSTRATIONS (WHY)
1	Fill a graduated cylinder with a brine sample to the point of overflowing	*You may need to "top-off" the sample as the head/foam flattens	
2	Insert the Hydrometer into the graduated cylinder and submerge the hydrometer 2 -3 graduations lower than a normal reading and let go of it	*Make sure hydrometer is dry before submerging in brine solution. *Fill Brine to the top of the graduated cylinder	 
3	Let the Hydrometer stabilize in the the graduated cylinder and settle for 10 - 15 minutes	*It is important to let the brine solution and hydrometer sit together and stabilize at this temperature. A 10 - 15 minute wait will improve the accuracy of the reading/result (by 2 -4 degrees)	
4	Read the Hydrometer at the meniscus	*An accurate reading is very important as just one degree can result in in a 40-50 gallon brine loss (unneeded add) *Take the reading at the "level plane" of the brine solution, probably one (1) graduation below the "crowned" level (see diagram to the right).	 
5	Record the Hydrometer reading, your initials, time, Fill amount, temperature and sump level and any notes on the "CFS Brine Salinity Check Sheet"		  

COMMENTS
1
2

SYMBOL LEGEND	Revision Date	Operator	Supervisor	Supt./Mgr	Safety	QA	Other
NOTE: Place symbols at each step of analysis where required.							

Figure 12: Standardized Work to Check Salt Concentration

The PLC program for the batch brine chillers was modified to vary the brine concentration based on the required brine temperature. When the brine temperature is required to be at or less than $20^{O}F$, the brine will be loaded and added to the chillers at a 55% concentration. When the required brine temperature is above $20^{O}F$, the brine will be loaded and added to the chillers at a 50% concentration. The updated specification table is shown in Table 2 on the next page.

Brine Chill Operation Parameters (Revised)					
Chiller	Lower Specification Limit (LSL)	Upper Specification Limit (USL)	Target Concentration	Temp	Brine / Water Ratio
BC-1	45%	60%	50%	$+20^{O}F$	50%/50%
			55%	$\leq 20^{O}F$	55%/45%
BC-2	45%	60%	50%	$+20^{O}F$	50%/50%
			55%	$\leq 20^{O}F$	55%/45%
BC-3	45%	60%	50%	$+20^{O}F$	50%/50%
			55%	$\leq 20^{O}F$	55%/45%
BC-4	45%	60%	50%	$+20^{O}F$	50%/50%
			55%	$\leq 20^{O}F$	55%/45%
BC-5	45%	60%	50%	$+20^{O}F$	50%/50%
			55%	$\leq 20^{O}F$	55%/45%
BC-6	45%	60%	50%	$24^{O}F$	
BC-7	45%	60%	50%	$26^{O}F$	
BC-8	45%	60%	50%	$26^{O}F$	

Table 2: Revised Brine Chill Operation Parameters

Control:

Controls must be implemented to ensure that over time the brine use in the chillers does not return to previous levels. The following actions were taken to ensure that any reductions in brine use and chloride concentrations continue into the future:

- The use of the operating instruction form (Figure 11).
- The brine addition chart (Figure 12).

- The revised Brine Chill Operation Parameters (Table 2).
- The temperature set point and brine mixing formula in the PLC's on the batch brine chillers was password protected, requiring an Electronic Technician or Value Stream Manager to change set points.
- Steps were added to the job plan in the Computerized Maintenance Management System (CMMS) requiring a qualified Electronic Technician to install/replace/repair flow meters to ensure that the proper correction factors are programmed into the meter when installed.

CHAPTER 5

DISCUSSIONS

Summary of Results:

The brine addition chart went through several revisions. The initial revisions were designed to make the instructions more user friendly for the operators. The salometer is designed and calibrated to accurately measure the brine concentration when the brine temperature is 60^{O}F. The operating temperature of the brine in the facility's chillers ranged from 16^{O}F to 25^{O}F. The correction factor for the salometer is to adjust the reading by 1% for each 10^{O}F difference between the brine temperature and the calibration temperature of the salometer (International Salt, 1992). For example, if the salometer reading is 52% and the brine temperature is 24^{O}F, the actual corrected salometer is (52-((60-24)/10, or 48.6%. The brine addition chart was adjusted so that the recommended volume of brine to add back to the system was based on the setpoint temperature for the brine, eliminating the need for the operators to calculate the actual brine concentration.

The initial requirement of draining some brine off the system prior to adding fresh brine was eliminated. The Process Owners initially believed that adding brine without draining would result in an overflow condition in the brine chillers. The team found that the brine level dropped to the point that excessive amounts of saturated brine needed to be added to the system to maintain the minimum operating level when a drain step occurred. There was enough brine being carried out of the system on the product, that simply adding brine to maintain concentration resulted in a stable brine level in the chiller.

As control of the brine concentration improved, and the risk of freezing the heat exchangers lowered, the brine addition chart was adjusted downward to move the average brine concentration to the lower end of the operating range to reduce brine usage which was expected to assist in reducing chloride levels in the wastewater effluent. The current version of the Brine Addition table is designed to allow the operators to control the brine concentration between 45% and 50% (Figure 13). Brine concentration is checked hourly in the continuous chillers. Figure 14 shows the hourly brine concentrations since January 1, 2006 in Brine Chiller 7 while Figure 15 shows the same information for Brine Chiller 8. The initial testing was done with Brine Chiller 7. The testing started in the area of sample 300 where an initial downward shift of the brine concentration can be seen. At approximately sample 600, the brine concentration was adjusted downward and the operators were instructed to charge the chiller with 500 gallons of saturated brine at the Monday morning start up. Minor adjustments were made to lower brine concentration after sample 750. The year to date brine concentration in chiller 7 was lowered from 54.78% to 51.10%, a reduction of 6.72%. Since the most recent change in the brine addition schedule, the brine concentration has averaged 47.11% (Figure 16), a reduction of 14.00%.

When the team was comfortable with results from Brine Chiller 7, the standardized work and brine addition schedule was implemented on Brine Chiller 8, approximately at sample 600. After sample 600, as minor adjustments were made to Brine Chiller 7, they were implemented on Brine Chiller 8. On a year to date basis, the average brine strength in Brine Chiller 8 has been reduced from 57.19% to 51.82%, a reduction of 9.39%. Since the most recent change in the brine addition schedule, the brine concentration has averaged 47.09% in Brine Chiller 8 (Figure 17), an overall reduction of 17.66%. The run chart does show that the brine concentration started to trend downward before any changes were implemented. The team attributes the downward trend to the increased attention that was directed at the operation of the two chillers. Both chillers are under the control of the same operator.

Brine Addition

Corrected Salometer Reading	Brine Add Back (Gallons)			
49	13.6			
48	27.1			
47	40.7			
46	54.3			
45	67.8			

Monday Startup:

The initial brine charge, on startup on Monday mornings, to achieve 50^{O}S target is 500 gallons and ~4.5 minutes of water

Daily Startup Afer CIP

At start up during the week, check the brine salometer after it has been returned to the brine sump **and chilled to operating temperature**. Add brine to the sump based on the chart above. If the salometer is 50^{O}S or higher, do not add brine.

Normal Operation (Hourly):

During normal operation, find the salometer reading in in the chart above. Go over to the next column on the right and add the gallons of brine indicated.

Do not Dump Brine from the System.

Figure 13: Current Brine Addition Schedule

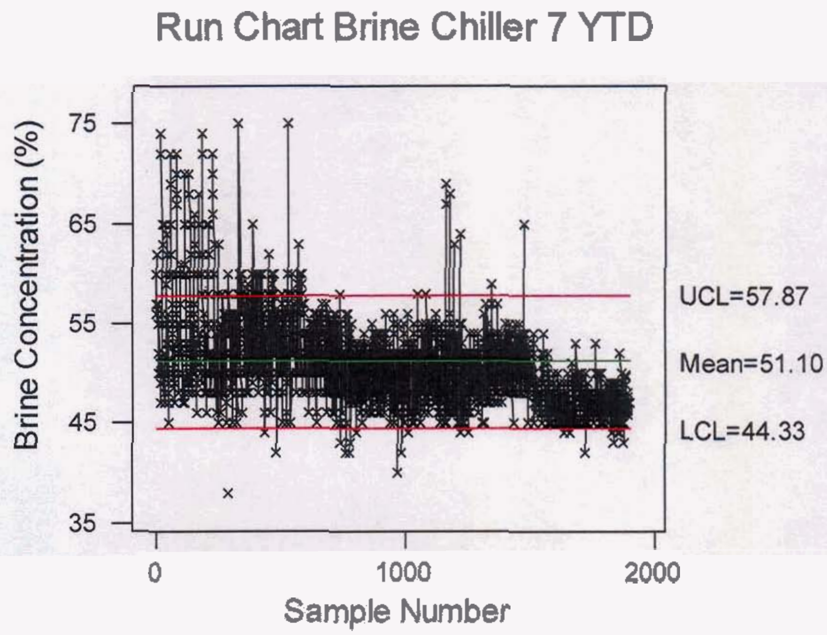


Figure 14: Brine Chiller 7 Run Chart Year to Date

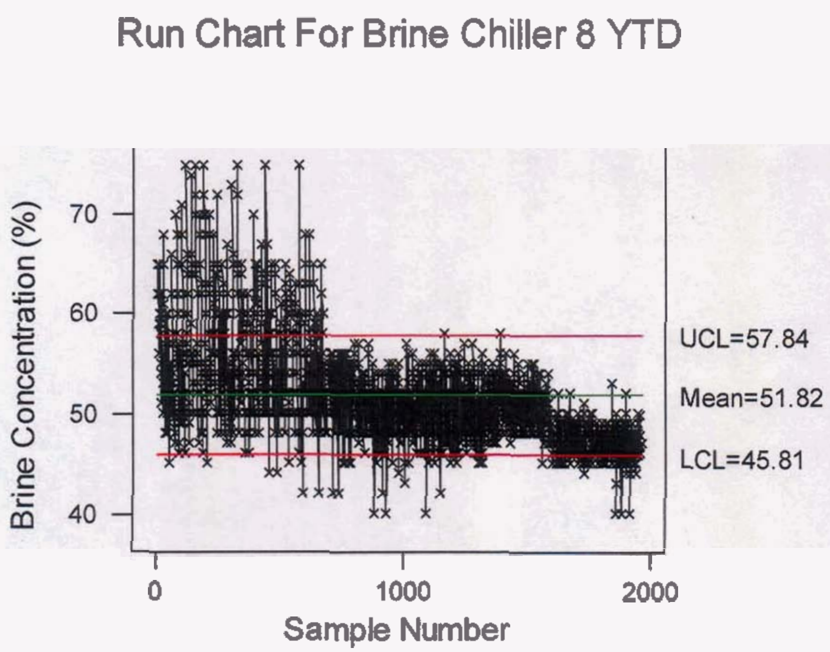


Figure 15: Brine Chiller 8 Run Chart Year to Date

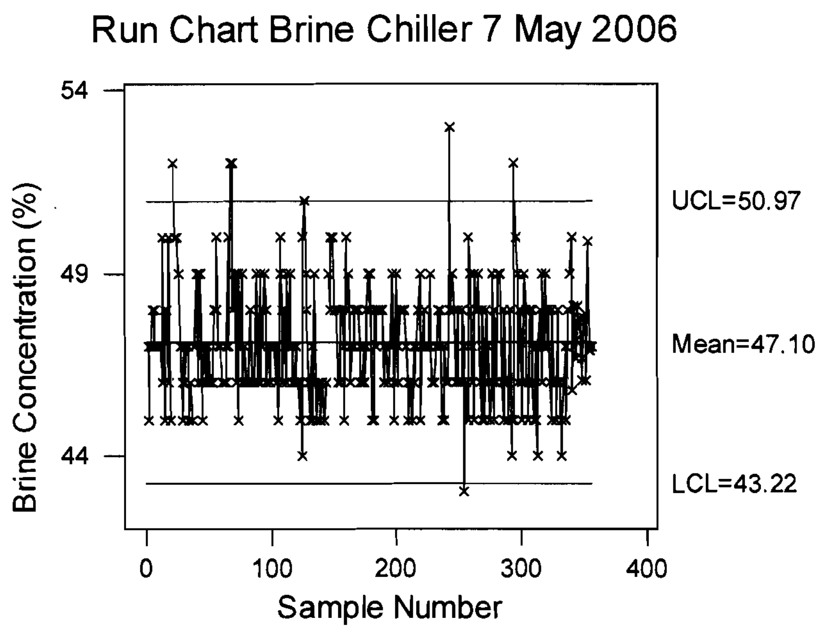


Figure 16: Brine Chiller 7 – Current Run Chart

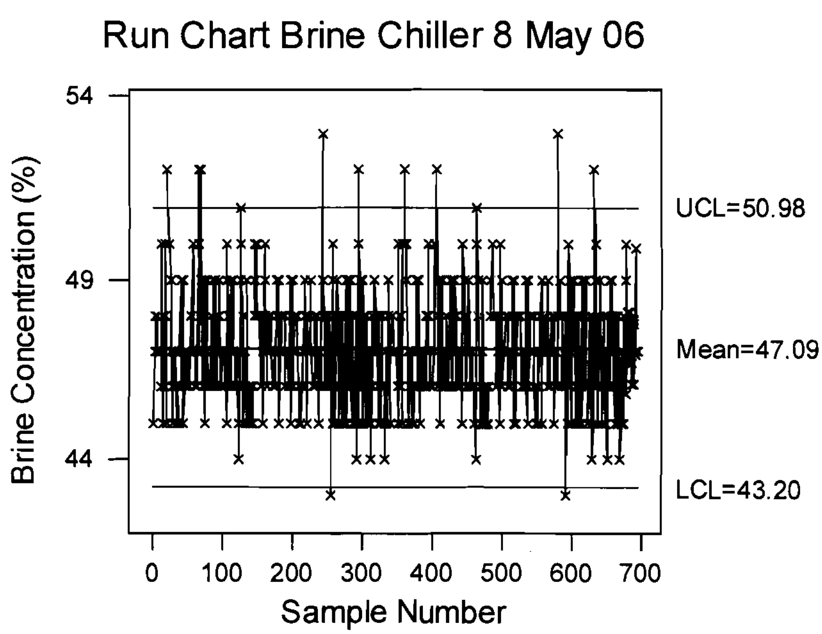


Figure 17: Brine Chill 8 Most Recent Run Chart

The capability of the process to maintain brine concentration has improved as shown by comparing Figures 8 and 9 with Figures 18 and 19 or by reviewing Table 3.

	Brine Chiller 7		Brine Chiller 8	
	Previous	Current	Previous	Current
Mean	54.8%	47.10%	57.19%	47.09%
Std. Dev.	6.50%	1.75%	7.12%	1.55%
C_p	1.19	1.89	1.05	1.94
C_{PU}	0.83	3.24	0.39	3.33
C_{PL}	1.55	0.53	1.71	0.54
C_{PK}	0.83	0. 53	0.39	0.54
P_P	0.38	1.43	0.35	1.61
P_{PU}	0.27	2.45	0.13	2.76
P_{PL}	0.50	0.40	0.57	0.45
P_{PK}	0.27	0.40	0.13	0.45

Table 3: Process Capability Comparisons

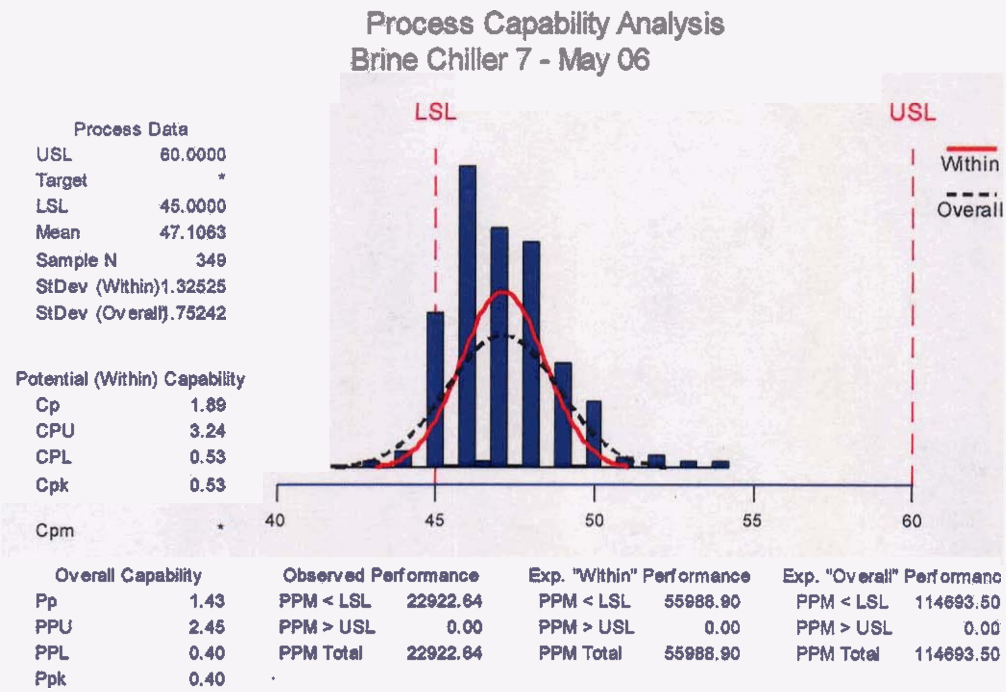


Figure 18: Current Process Capability Brine Chiller 7

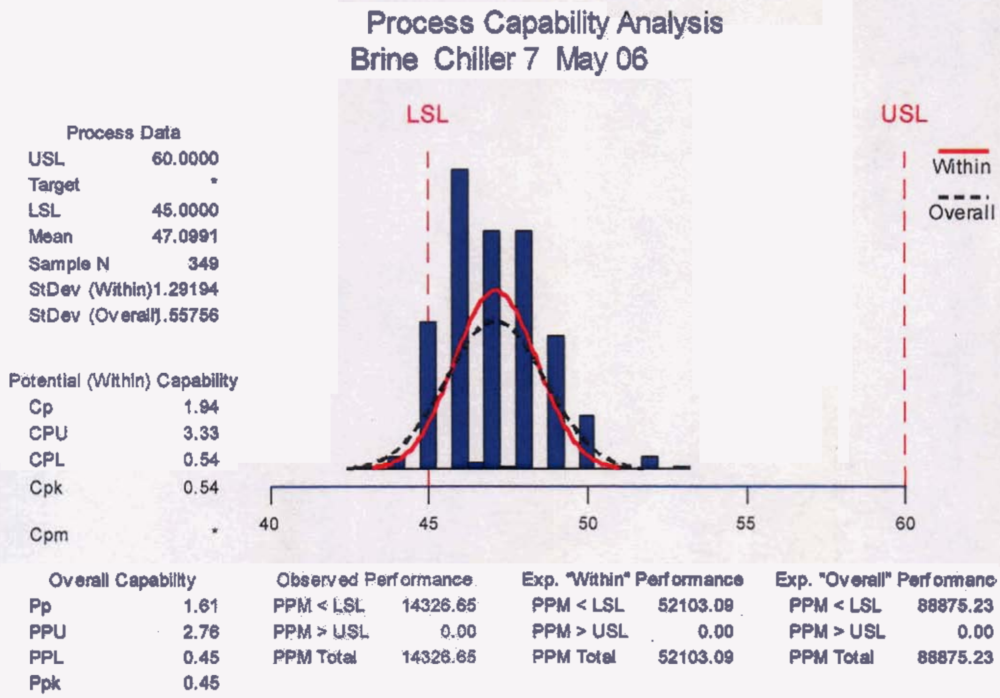


Figure 19: Current Process Capability Brine Chiller 7

The process capability studies on the chillers show that while that risk of operating above the upper specification limit has been virtually eliminated, the risk of operating below the lower specification limit has greatly increased. The risk of freezing the heat exchangers is relatively low until the brine concentration drops below 41%. The chiller operators have been given the discretion to allow the brine strength to drop below the lower specification limit (45%) at the end of the production run to reduce brine waste. The expectation of in-specification performance has been increased from 72.3% to 88,5% while reducing the brine concentration by 14.00% in Brine Chiller 7. In Brine Chiller 8 the expectation of in specification performance has been increased from 61% to 91.1% while reducing the brine concentration by 17.6%.

The purpose of the project was to determine if utilization of the Six Sigma methodology could reduce the chloride concentration in the effluent from the facility's wastewater treatment plant. In the month prior to the start of the project the chloride average weekly chloride concentration in the effluent was 2,248 mg/l (Figure 4) while the fiscal year to date (July, 2005 through January, 2006) weekly average was 2,171 mg/l (Figure 5). In comparison, in May of 2006, the average chloride concentration was 1,615 mg/l (Figure 20) while the fiscal year to date average chloride concentration had dropped to 1,980 mg/l (Figure 21). The average weekly concentration during the month of May

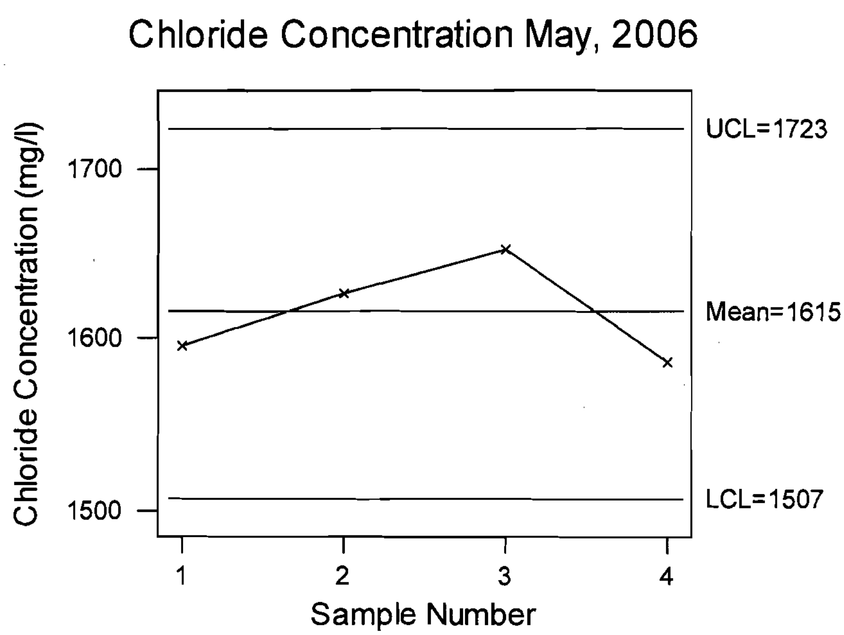


Figure20: Chloride Concentration May, 2006

was 25.6% below the year to date weekly average at the end of January and 18.4% below the year to date average.

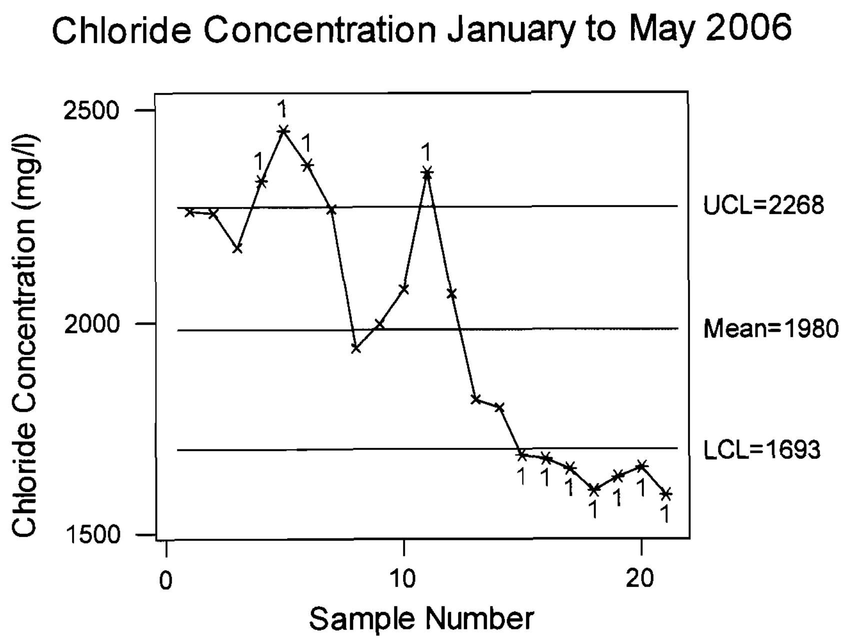


Figure 21: Chloride Concentration January to May 2006

Utilizing the Six Sigma methodology to analyze the sources of chlorides in the effluent from the wastewater treatment plant, then following the sources upstream, and using the Six Sigma tools to define, measure, analyze, improve and control the operation, has had a significant effect on the facility's efforts to reduce the chloride concentration. As a result of this study, formal guidelines have been established for the operation of the continuous brine chilling systems, rather than allowing the systems to be operated solely by operator experience.

Future Research:

The Relationship Between Brine Temperature and Chill Rate:

The mindset in the facility, and in the industry, is that colder is better. Several of the brine chill operators mentioned that the product often reaches a given temperature and stays at that temperature until the product is pulled from the brine chiller and allowed to temper in a holding cooler. In several chillers the set-point for the brine temperature was $16^{O}F$, which is well below the freezing point of the product. The product may be crust frozen, sealing the heat inside the product. Further studies should be done to determine the relationship between brine temperature and the rate of product cooling. The facility may find that by allowing the brine temperature to rise, the product may cool more quickly. A warmer brine temperature will allow the facility to use a lower concentration of brine, further reducing chloride use.

Brine Pressure and Chill Rate:

The Brine Chillers 6, 7, and 8 utilize a deluge system to chill the product. The cold brine is fed into perforated trays that mimic a cold shower over the product. The other Brine chillers have a pressure pump that discharges the brine through spray nozzles to create a distribution patter. The operators have noticed that there appears to be more brine loss from the tracks in the newer chillers that operate at a higher pressure. Further testing should be done to determine if the product can be cooled just as quickly with a lower pressure spray

Extension of Brine Life:

Brine is re-utilized in the three of the brine chillers for up to a week. Consideration should be given to implementing similar brine reuse programs in the other chillers to reduce chloride use.

Ultra-filtration equipment is available on the market that is capable of removing bacteria from liquids. With further testing, the facility may be able to extend brine life beyond a week using a combination of ultra-filtration, pasteurization, and rechilling of brine.

Other Sources:

Water softeners accounted for approximately 6.6% of the chlorides in the wastewater effluent. The current method of water softening needs to be investigated. It may be possible to reduce the salt use in the water softeners by as much as 50% if the resin bed can be fluffed with air injection, similar to the method that is used in the regeneration of the resin beds for corn syrup and salt brine purification system.

Reference List:

Bothe, D., (2003) *Accelerated Six Sigma Green Belt Certificate Program.* Cedarburg, WI: International Quality Institute, Inc.

Breyfogle III, Forrest, (2003). *Implementing Six Sigma,* Hoboken, NJ: John Wiley & Sons, Inc.

Brue, G., (2002). *Six Sigma for Managers,* New York, NY: McGraw-Hill Companies, Inc.

DiGiano, F., Elais, M., Francisco, M., LaRocca, C., Maerker, M. *Report 276: Chronic Toxicity Bioassay with Ceridaphnia dubia:* (n.d.) Retrieved April 8, 2006 from http://www2.ncsu.edu/scsu/wrri/reports/cisco.html

Eckes, G., (2003). *Six Sigma for Everyone.* Hoboken, NJ: John Wiley & Sons, Inc.

Emiliani, Bob, (2003) *Better Thinking, Better Results,* Kensington, Ct: The Center for Lean Business Management LLC

General Electric (2001) *Six Sigma at GE 2001.* Retrieved April 8, 2006 From http://www.gehealthcare.com/twzh/sourcing/data/6S.ppt

General Electric, (n.d). *What Is Six Sigma? The Roadmap to Customer Impact* Retrieved February 25, 2006 from http://www.gepowercontrols.com/ex/news_events/six_sigma.htm

George, Michael L. (2002) *Lean Six Sigma, Combining Six Sigma Quality with Lean Speed* New York: McGraw-Hill

Gupta, P., (2004). *Six Sigma Business Scorecard,* New York, NY: McGraw-Hill Companies, Inc.

Larson, A., (2003). *Demystifying Six Sigma,* New York, NY: American Management Association

Mack, Lindsey, *Food Preservation in the Roman Empire* Retrieved February 24, 2006, from http://www.unc.edu/courses/rometech/public/contents/survival /Lindsay_Mack/Food_Preservation.htm

United States Environmental Protection Agency, (January 2002). *Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Meat and Poultry Products Industry Point Source Category (40 CFR 423),* EPA-821-B-01-007

United Stated Environmental Protection Agency, Environmental Monitoring Systems Laboratory, (1994) *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organism.* EPA/600/4-92/002. Retrieved April 8, 2006 from http://epa.gov

Wisconsin Department of Natural Resources, (n.d.) *Chapter 1.3 – Representative Data, Reasonable Potential & WET Monitoring,* Retrieved on February 7, 2006 from http://dnr.stat.wi.gov/org/water/wm/ww/biomon.docs/cap1X3MonitoringLimits.pdf

Wisconsin Department of Natural Resources, (2000) *Chapter 2.10 – Chlorides and WET Testing,* (2000). Retrieved on February 7, 2006 from http://dnr.stat.wi.gov/org/water/wm/ww/biomon.docs/cap2X10chloridewed.pdf

Wisconsin Department of Natural Resources, (n.d.) *Chloride Variance Information and Worksheet*, Retrieved on February 7, 2006 from http://dnr.stat.wi.gov/org/water/wm/ww/applications/chloride_wksht.pdf