Energy Research and Development Division
FINAL PROJECT REPORT

ADVANCED WATER TREATMENT TECHNOLOGIES FOR ONSITE WATER REUSE AT DUDA FARM FRESH FOODS

Prepared for: California Energy Commission
Prepared by: Washington University in St. Louis

SEPTEMBER 2014
CEC-500-2014-082

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ACKNOWLEDGEMENTS

The authors wish to thank Duda Farm Fresh Foods and their employees for their valuable assistance and work during this study. In particular, the authors wish to thank Jaime Montiel, Manuel Alcala, Gabriel Saldivar, Danny Saldivar, and Sandra Roman for their contributions to this study. It could not have been completed without them.

Appreciation and thanks are expressed to Cameron Tapp and Marc DeBrum of ClearWater Tech, LLC, in San Luis Obispo, CA for their help with preliminary water treatment tests on spent water from the Duda plant and for providing design suggestions for the equipment. They are also thanked for allowing the authors to utilize the ozone treatment equipment during a post-lease period such that final data collection could be completed.

Gratitude is expressed to Dr. Charles Sopher of C&S AgriSystems. Inc. in Washington, NC and Richard Peterson of the Northeast Agriculture Tech Corp in Ithaca, NY for providing the original project proposal which was prepared in conjunction with Washington University - St. Louis, Missouri.

Lastly, appreciation is expressed to Dr. Charles Sopher for suggestions during the project and reviewing comments on the final report.

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Advanced Water Treatment Technologies for Onsite Water Reuse, Duda Farm Fresh Foods is the final report for the Advanced Water Treatment Technologies for Onsite Water Reuse project (contract number PIR-10-012), conducted by Washington University in St. Louis. The information from this project contributes to Energy Research and Development Division's Industrial/Agricultural/Water End-Use Energy Efficiency Program.

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ABSTRACT

This study was undertaken to determine if ozone could be used as a water treatment process to sufficiently clean rinse water from a celery processing plant in Oxnard, California to make the water suitable for reuse. The Duda Farm Fresh Foods processing plant uses between 20,000 to 35,000 gallons of potable water per day to clean and bag fresh cut celery. The rising costs of water and sewer charges have led Duda to consider alternative approaches to using either less water or using water for longer periods at the facility. In this study, ozone was applied to the water collected from one of four processing lines. Results show that ozone can improve microbiological quality of the rinse water sufficiently such that the water can be reused. Microbial monitoring must be in place to ensure that microbial populations are below predetermined levels before the treated rinse water is reused.

Data from microbial analyses conducted in this study indicate microbial levels can be reduced sufficiently to allow the water to be used in subsequent shifts at the processing plant. Water reuse may require filtration and a more complete understanding of the interactions between ozone and other antimicrobial agents such as peracetic acid and/or chlorine compounds must be developed.

Ozone has the potential to reduce food processing water use in California by nearly 1 billion gallons per year.

Keywords: California Energy Commission, ozone, food processing, wastewater, water reuse, antimicrobial agents, celery processing

Please use the following citation for this report:

Joe Prijyanonda, John Murphy. Washington University in St. Louis. 2013. ***Advanced Water Treatment Technologies for Onsite Water Reuse, Duda Farm Fresh Foods.*** California Energy Commission. Publication number: CEC-500-2014-082.

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Introduction

Duda Farm Fresh Foods processes fresh-cut celery grown in the Oxnard area. The production process involves washing, cutting, sorting, and packaging celery products. Duda's water use averages nearly 29,000 gallons per day for washing and rinsing the celery products. During the cleaning process, peracetic acid is added to the water as a disinfectant, to control microbial populations. Once the cut celery products and the rinse solutions are separated, the water is returned to the rinse water source and either filtered and rechilled or discharged about once daily depending upon the cleanliness of the water. With water costs and rates for discharge increasing, Duda is interested in technologies that will treat the water and allow it to be reused.

One solution is to use ozone to treat the water used for washing and rinsing the celery products. Ozone water treatment allows the water to be recycled instead of disposed of as wastewater at the end of each day. Recycling the wastewater reduces Duda's overall cost of production.

Background

The project team conducted site visits to Duda Farm Fresh Foods to collect information and formulate initial designs for the ozone water treatment system. The team selected ClearWater Tech, LLC, a designer and manufacturer of ozone generation equipment, to supply the equipment and assist with system design and installation. Celery processing line #2 was selected for the ozone water treatment project because of the four lines operating at the plant, the celery wash and rinse water from this line was deemed to be the poorest quality in terms of solids (dirt and vegetable particles) and possibly microbial content. The project team wanted to show that ozone can be effective in treating Duda's process water under adverse conditions, and treating water from Line #2 allows the team to meet this objective.

The ozone system was installed at Duda's facility at the end of May 2012.

After an initial test run, the team conducted seven data collection runs. The seven runs consisted of three steps:

1. Filling the water storage tank with celery wash and rinse water from line #2.
2. Running the ozone system and treating the water in the tank for at least 4 hours.
3. Discarding the treated water to the drain at the end of the test run.

During the course of each data collection run, the project team collected samples of the water that was being ozonated, which were then sent to a local laboratory and analyzed for total coliform, e.coli and turbidity.

Samples of the facility's tap water were collected each day of the test runs and analyzed as a reference point for comparison to the treated water.

Results

The test runs showed that the ozonation procedure improved water quality fivefold as measured by analysis of total coliform, with no cases of *e.coli*. This result indicates that the ozone procedure has the potential to provide protection from *e.coli*. In most cases, the process was complete after about four hours of treatment, regardless of the starting volume of water. Thus, as an additional safety factor the project team recommends that under this treatment scheme, ozonation should be applied for five hours.

Water Savings

The project team determined that the expected water savings of 15 percent would result in approximately $6,483 per year in water and additional wastewater cost savings. However, much of this savings is offset by the additional testing that would be needed to ensure food safety. Overall, project economics would improve if the testing could be modified or completed in-house.

Electricity Impacts

Based upon the electricity consumption data collected and the volume of water treated, the team estimated that electricity consumption of the ozone water treatment system to be approximately 15 kilowatt hours per 2,500 gallons of treated water. Assuming the system operates 20 days each month for five hours each day, the process would consume about 3,600 kilowatt hours per year. This level of consumption works out to $0.72 per 1000 gallons treated which is often less than the costs of disposing the untreated water into the sewer system. The savings gained by not having to chill approximately 2,500 gallons of fresh water from the main each day resulted in a savings of approximately 35 kilowatt hours per day. This level of electricity savings in the chilled water system completely offsets the 15 kilowatt hour per day electricity consumption of the ozone water treatment system.

These cost estimates do not include the cost of additional microbial testing, which should be calculated in the final analysis.

Conclusions and Recommendations

The study demonstrates the use of ozone as a treatment to clean celery wash water. Using this treatment, the wash water could be reused, minimizing both potable water consumption and sewer discharge fees. Additional studies need to be designed to better understand the optimal number of reuse cycles, along with plans necessary to implement this technology.

Provisions must be made for holding any treated water until microbiological inactivation is verified. Daily microbiological tests are needed.

Another potential savings that was not assessed in this study is the impact of ozone on current sanitation practices at Duda. The Duda plant adds 40 parts per million of periacetic acid to the process water to act as a microbial inhibitor. The treatment works well but is expensive, and it cannot be recovered from the process water. The impact of the interaction of ozone treatments and periacetic acid was not analyzed. This interaction needs to be studied in detail to determine the exact amounts of ozone and peracetic acid that are needed.

CHAPTER 1: Introduction

1.1 Project Background

Duda Farm Fresh Foods (Duda) processes fresh-cut celery grown in the Oxnard area. The production process involves washing, cutting, sorting, and packaging celery products. Duda currently has four celery processing lines. These lines are fed from a preprocessing area outside the plant where the harvested celery is unloaded from trucks and their roots removed using a water-jet knife. Stalk ends and roots along with trash are sold locally as livestock feed.

- Line #1: this line washes pre-cut celery sticks from the field and packages the product into large cardboard containers;
- Line #2: this line dices and washes the raw celery, and packages the product into plastic bags;
- Lines #3 and #4: these two lines cut (using water-jets) the raw celery into sticks, then wash and package the product into plastic bags.

The operation schedule of the processing lines is variable and dependent upon the availability of harvested celery. During the peak seasons, Duda typically operates two shifts per day and some of the processing lines operate from 8 AM until midnight during weekdays and Saturdays (no production on Sundays). The peak seasons occur during October to December and May to June. Cleaning, maintenance, and sanitization activities occur afterhours.

It should be noted that Duda can package special multi-vegetable orders and cleaned radishes, carrots, etc. can be introduced into the production lines and diced and packaged as vegetable mixes. The introduction of these items is a minor event but is mentioned because the exudates from these crops can be much different than from celery and can cause precipitates that may affect ozone treatment of the water being discharged from the plant. The effects of these products were not studied in this project but are being flagged as potential causes of wastewater contamination in future operations.

Duda occupies approximately 40,000 square feet (ft^2) in a facility that has a total floor area of 60,000 ft^2. The remaining 20,000 ft^2 of the facility is occupied by the Dandy Cooling Company (Dandy). The entire facility is a large one-story building with a wall dividing the area occupied by Duda from the area occupied by Dandy. The property in which the building is located is owned by Western Precooling Systems. The three firms, Duda, Dandy, and Western Precooling Systems, are a business joint venture. Operations at the facility began in April 2008.

Duda's portion of the building is comprised of approximately 27,000 ft^2 of production floor area that is maintained at 33-38 degrees Fahrenheit. There are also approximately 13,000 ft^2 of office areas. Dandy's portion of the building is comprised of about 20,000 ft^2 of refrigerated storage area that is maintained at 33-34 degrees Fahrenheit twenty-four hours per day, seven days per week. Duda's processed celery products are stored in the refrigerated warehouse located in Dandy's side of the building until they are shipped out to customers.

1.1.1 Problem Statement

Duda's water use averages nearly 29,000 gallons per day for washing and rinsing the celery products. During the washing and rinsing process, peracetic acid is added to the water to a level of 40 parts per million (ppm) to act as a residual antimicrobial agent and to control microbial populations. Once the cut celery products and the rinse solutions are separated, the water is returned to the rinse water source and either filtered and rechilled or discharged depending on the cleanliness of the water. Typically, wastewater is discharged from each line once each day, at the end of the second shift. Exudates from the cut products, precipitates from various chemical reactions, and dirt from raw products often render the rinse water too contaminated for further use, and the rinse water is expelled into a wastewater stream to the sewer.

Duda has been experiencing an increase in water costs and expects that the rates for both fresh water and wastewater discharge will continue to increase in the future. As such, Duda is interested in technologies that will treat the water used for washing and rinsing the celery products that will allow the water to be reutilized in additional production cycles. If the water can be reused, possibly the biochemical oxygen demand (BOD) surcharges, imposed by wastewater treatment facilities, can be reduced by discharging cleaner water.

1.1.2 Proposed Solution

The proposed solution is to use ozone to treat the water used for washing and rinsing the celery products. Ozone (O_3) water treatment will allow the water to be reused in additional production cycles instead of disposal as wastewater at the end of each day. Reusing the water will allow Duda to realize cost savings because it will reduce the amount of fresh water that Duda purchases as well as the amount of wastewater discharge and charges for the BOD in the wastewater.

1.2 Goals and Objectives

The goal of this project was to determine the effects of the use of ozone to treat the water used in Duda's production processes. The following are the specific objectives of this project:

- To install an ozone water treatment system at Duda's facility that will treat the water used for celery washing and rinsing and return it for re-use in the rinsewater stream;
- To determine if ozone can be an effective method of treating Duda's process water;
- To collect data on the ozone system performance and effectiveness in terms of microbial content reduction and other measures of water quality to make it suitable for re-use as rinsewater;
- To provide Duda with information that could be used to make future decisions on implementing ozone water treatment in the facility's daily operations.

CHAPTER 2:
Baseline Conditions

The following sections provide information on the water and electricity baseline conditions of Duda Farm Fresh Foods.

2.1 Water Consumption Baseline

Duda Farm Fresh Foods uses nearly 29,000 gallons of water per day in celery processing lines, and for cleaning, maintenance, and sanitization activities. In all four processing lines, chilled water at a temperature of 34-36 degrees Fahrenheit is used to wash and rinse the celery product. The chilled water is captured, rechilled and reused within the process lines during the daily operations. There is some loss of chilled water due to condensation, spillage, etc., and additional water must be chilled and constantly added to the system. At the end of each day, the entire amount of chilled water within the system is disposed as wastewater into the sewer.

Lines #3 and #4 use water jets to cut the raw celery; water in the water jets is not chilled or reused, and passes directly to the sewer as wastewater. Cleaning and sanitation activities require 7,000 to 17,000 gallons of tap water each day. A relatively small amount of water is used in the facility's restrooms. Wastewater flows into the sewer at rates of 20-50 gallons per minute (gpm) during the day and approximately 250 gpm at the end of the day.

Duda has a flow meter to record the quantity of wastewater released into the sewer. Since Duda disposes of the entire amount of water in their system at the end of the day, the amount of water disposed is approximately equal to the amount of water purchased from the City of Oxnard. Duda regularly monitors and tests the wastewater for pollutants (e.g. BOD, total dissolved solids (TDS), total suspended solids (TSS), and sulfides) and pH level.

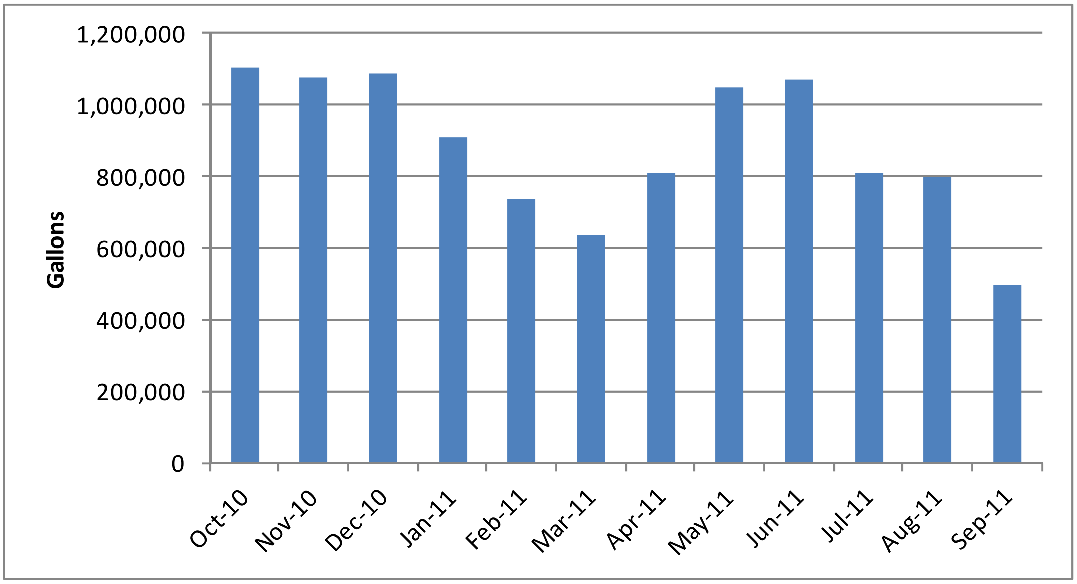
According to the wastewater disposal records, Duda consumed a total of 10,574,150 gallons of water during the 12-month period from October 2010 to September 2011. This represents an average water consumption of 28,970 gallons per day. Table 2 shows the monthly water consumption and Figure 3 is a graphical illustration of the same information. Note that the months of highest water consumption coincide with the peak production periods of October to December and May to June.

Table 1: Water Consumption at Duda Farm Fresh Foods

Month	Gallons	Average (Gallons per Day)
Oct-10	1,103,204	35,587
Nov-10	1,074,940	35,831
Dec-10	1,087,393	35,077
Jan-11	908,065	29,292
Feb-11	737,370	26,335
Mar-11	637,486	20,564
Apr-11	809,795	26,993
May-11	1,046,485	33,758
Jun-11	1,068,996	35,633
Jul-11	806,154	26,005
Aug-11	795,379	25,657
Sep-11	498,883	16,629
Total	**10,574,150**	**28,970**

Source: Water consumption data from Duda Farm Fresh Foods

Figure 1: Water Consumption (Oct. 2010 – Sept. 2011)



Source: Water consumption data from Duda Farm Fresh Foods

2.2 Electricity Consumption Baseline

Duda Farm Fresh Foods shares a building with Dandy Cooling Company. Duda and Dandy have separate electric service accounts with Southern California Edison (SCE). However, the major refrigeration and cooling equipment that provide refrigeration, cooling, and chilled water services to the Duda side of the building are loaded on Dandy's electric service. As such, Duda pays a portion of Dandy's monthly electric bill in addition to its own bill.

The major electricity end uses on Duda's electric service account are:

- Two 100 horse power (hp) water compressors used for the water-jet cutting process in Lines #3 and #4;
- Two pneumatic conveyor units (75 hp and 45 hp) that are used for removing waste products;
- One 25 hp air compressor;
- Four production lines that consist of conveyor motor and pump loads (these lines utilize produce wash water that is chilled by equipment located on Dandy's electric service);
- Lighting in the production floor area is provided by metal halide and T-5 (High Output) fluorescent lamps (6 lamps per fixture);
- The office area is served by a total of 6 packaged rooftop air conditioners, and has T-8 fluorescent lighting fixtures and office equipment.

The major electricity end uses on Dandy's electric service account are:

- Three ammonia compressors that provide the refrigeration and water chilling services for Duda and Dandy. Two of the units are 400 hp screw compressors (one unit has VFD) and one unit is a 200 hp screw compressor (this unit has VFD);
- Ammonia evaporator system (direct-expansion) that refrigerates the warehouse and Duda's production floor area (there are a total of 13 units, and each unit averages 30 tons of cooling capacity and has four fans that are approximately 2 hp each with VFDs);
- Four plate water chillers that utilizes ammonia to produce chilled water for Duda's processing lines (one 7.5 hp pump supplies the chilled water to the lines);
- Two vacuum tube machines that are used to quick-cool the vegetable from the fields before processing/storage (each unit has a 100 hp vacuum pump and refrigeration system);
- One condenser tower that serves the ammonia refrigeration system (750 ton, two 30 hp fans that run about 20% of the time, one 10 hp water pump);
- Total of 14 forklift battery chargers serving 14 forklifts;

- Lighting in the refrigerated warehouse is provided by T-5 (High Output) fluorescent fixtures (six lamps per fixture);
- One 10 ton packaged rooftop air conditioner that cools the office area.

During the 12-month period from September 2010 to August 2011, the total electricity consumption of Duda and Dandy was 885,477 kWh and 1,865,461 kWh respectively (for a combined total of 2,750,938 kWh). The maximum electrical power demand for Duda was 258 kW (during November 2010), and that of Dandy was 598 kW (during December 2010).

The following Table 2 shows the monthly electricity consumption and maximum demand for Duda and Dandy. Figure 2 is a graph of the monthly electricity consumption, and Figure 3 is a graph of the maximum demand.

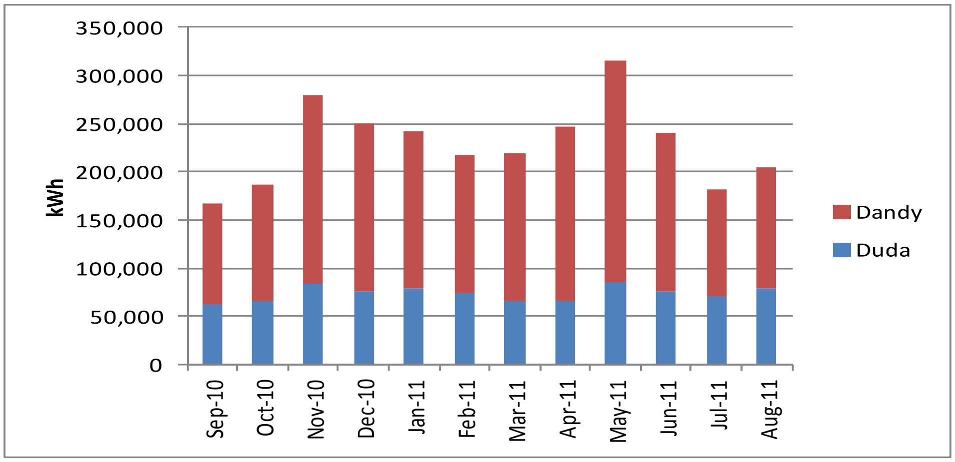
In early 2012, Duda completed the installation of a photovoltaic (PV) system to generate electricity that is used on site. The capacity of this PV system is approximately 500 kW. As such, Duda no longer needs to purchase as much electricity from SCE as that shown in Table 2.

Table 2: Electricity Consumption and Maximum Demand

	Energy (kWh)		**Max. Demand (kW)**	
	Duda	**Dandy**	**Duda**	**Dandy**
Sep-10	62,668	103,707	232	350
Oct-10	66,146	120,449	240	540
Nov-10	83,310	196,945	258	574
Dec-10	76,446	174,119	255	598
Jan-11	79,551	162,938	Missing	571
Feb-11	74,186	142,786	229	542
Mar-11	65,418	153,245	232	578
Apr-11	65,563	181,781	Missing	Missing
May-11	85,825	229,028	248	586
Jun-11	75,923	164,006	220	547
Jul-11	71,374	110,728	216	362
Aug-11	79,067	125,729	216	329
Total	**885,477**	**1,865,461**		

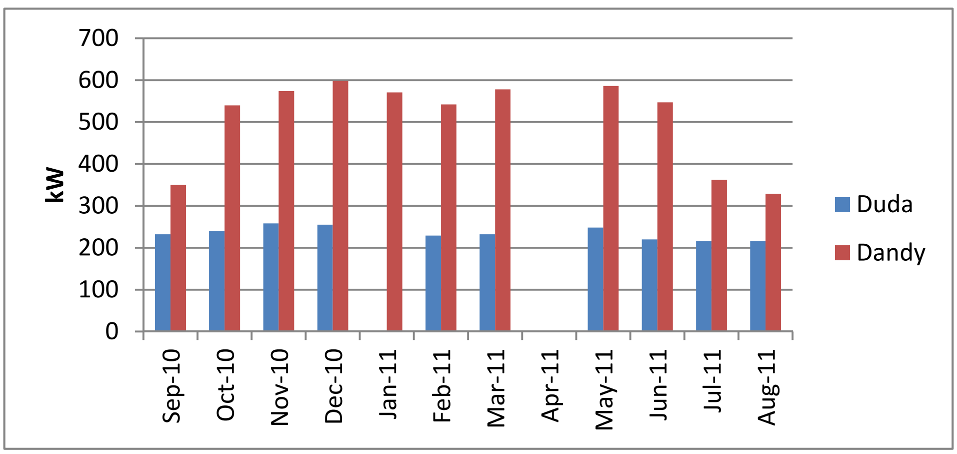
Source: Electricity billing data from Duda Farm Fresh Foods

Figure 2: Monthly Electricity Consumption (Sept. 2010 – Aug. 2011)



Source: Electricity billing data from Duda Farm Fresh Foods

Figure 3: Maximum Electricity Demand (Sept. 2010 – Aug. 2011)



Source: Electricity billing data from Duda Farm Fresh Foods

2.3 Chemical Usage Baseline

In order to control the microbial levels and provide a residual antimicrobial treatment, Duda adds peracetic acid (brandname: Tsunami 100) to the vegetable wash and rinse water used in the processing lines. An anti-foaming agent (brandname: Antifoam #10) is also added to the chilled water. Table 3 shows the quantity of each chemical used during the period June to September 2011.

Duda uses Tsunami 100 at an average rate of 5 gallons per day, and Antifoam #10 at an average rate of 1.6 gallons per day.

Table 3: Chemicals Added to Water Used in Processing Lines

	Tsunami 100		Antifoam #10	
	Gallons	Gallons per Day	Gallons	Gallons per Day
Jun-11	151.0	5.8	43.0	1.7
Jul-11	113.0	4.2	41.0	1.5
Aug-11	131.0	4.9	39.5	1.5
Sep-11	132.0	5.1	43.5	1.7
Average	**131.8**	**5.0**	**41.8**	**1.6**

Source: Data from Duda Farm Fresh Foods

2.4 Microbial Baseline

Duda routinely conducts microbial testing of the celery products but they do not normally test the microbial characteristics of the wash and rinse water. As with any food product, microbial characteristics of the celery vary depending on conditions at harvest and handling before processing. A sampling of values for total plate counts is given in Table 4.

Table 4: Total Plate Counts of Celery Product

Date	Total Plate Count (CFU/g)
Jun. 8, 2010	5,000
Jul. 7, 2010	13,000
Aug. 3, 2010	4,000
Sept. 14, 2010	50
Oct. 12, 2010	5,000
Nov. 9, 2010	2,000
Dec. 7, 2010	1,000
Jan. 5, 2011	2,000
Feb. 8, 2011	1,250
Mar. 8, 2011	40,000
Jun. 1, 2011	13,000

Source: Data from Duda Farm Fresh Foods (CFU = colony forming unit)

CHAPTER 3: Ozone System Design and Test Plan

This chapter describes the installation of the ozone water treatment system at Duda Farm Fresh Foods, as well as the post-installation plans for testing and data collection.

3.1 Ozone System Design Process

The project team conducted site visits to Duda Farm Fresh Foods during the period from July 2011 to February 2012, to collect information and formulate initial designs for the ozone water treatment system. During that time, the project team also selected ClearWater Tech, LLC to assist with ozone system design, supply the equipment, and assist with installation of the equipment. ClearWater Tech was selected due to their proximity to Duda and their willingness to pretest Duda's washwater streams prior to equipment design. As part of the design and preparation activities, the project team collected celery wash and rinse water from Duda's facility and delivered the collected water to ClearWater Tech for testing. This was done to ensure that ClearWater Tech could produce ozone equipment capable of treating Duda's process water.

Of the four celery processing lines at Duda, Line #2 was selected for the ozone water treatment project because the celery wash and rinse water from this line was deemed to be the poorest quality in terms of solids (dirt and vegetable particles) and possibly microbial content of all the lines. The project team wanted to show that ozone can be effective in treating Duda's process water under adverse conditions, and treating water from Line #2 allows the team to meet this objective.

ClearWater Tech assisted with the final designs of Duda's ozone water treatment system in February 2012, and manufactured the ozone system during the March–April 2012 timeframe. However, the ozone system was not installed at Duda's facility until the end of May 2012, due to a delay in the purchase and installation of a 3,000-gallon water storage tank.[1]

3.2 Implemented Ozone System Design

The ozone water treatment system was installed by ClearWater Tech on May 30, 2012. Figure 4 shows a schematic of the installed ozone system.

The ozone system consists of the following main components:

- ozone generator, model# CD30nx (see Figure 5);
- oxygen concentrator, model# Aerous 15 (see Figure 6);

[1] The 3,000-gallon water storage tank is an important component of the designed ozone water treatment system. The project team procured the tank from another supplier, and this supplier took nearly three months to deliver the tank.

- ozone injector, check valve assembly, and vacuum break (see Figure 7);
- Rosemount 1056 ozone ppm controller (see Figure 8);
- electrical junction box (see Figure 5);
- booster pump with basket filter, 2 hp (see Figure 9); and
- 3,000 gallon water storage tank (see Figure 10).

The ozone generator, oxygen concentrator, ozone ppm controller, and electrical junction box are packaged together and mounted to a skid.

Figure 4: Schematic of Ozone Water Treatment System Installed at Duda

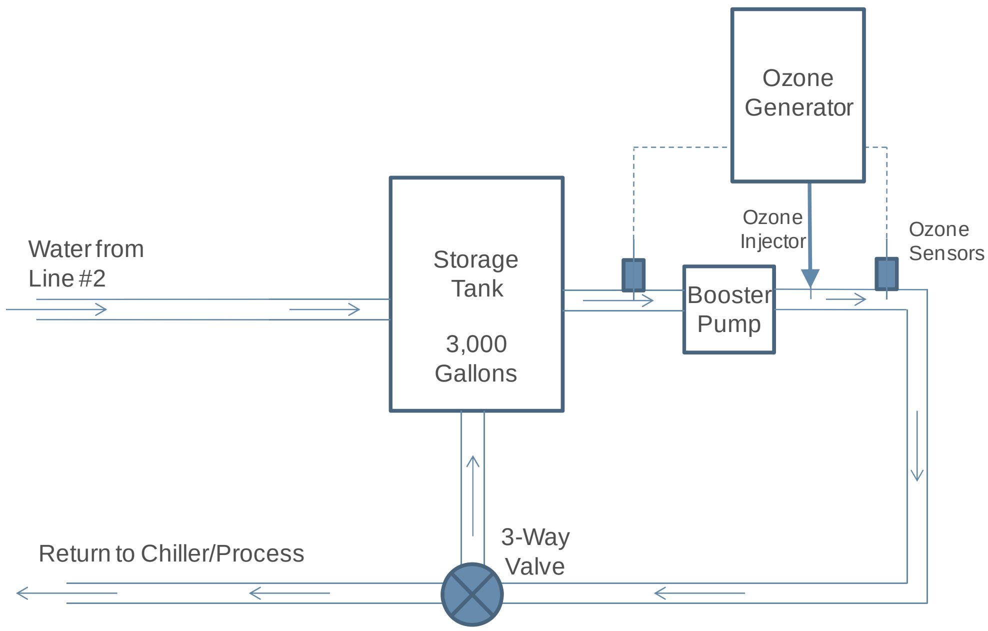


Figure 5: Ozone Generator and Electrical Junction Box

Figure 6: Oxygen Concentrator

Figure 7: Ozone Injector, Check Valve Assembly and Vacuum Break

Figure 8: Ozone PPM Controller

Figure 9: Booster Pump

Figure 10: 3,000 Gallon Water Storage Tank

Under this arrangement, water from Line #2, can be directed into the 3,000-gallon tank at the end of Duda's production day instead of disposal to the sewer. The tank and the ozone system are connected in a closed-loop, and the booster pump serves to circulate the water within this loop. ClearWater Tech designed the system such that the ON/OFF switch within the electrical junction box controls the operation of the entire system, including the booster pump. In order to ozonate the water within the tank, all that is needed is to move the switch to the ON position. Once the water has been ozonated, it is possible to pump the treated water back into Line #2 for reuse by opening the necessary valves within the piping system (although this was never done at any point during this demonstration project). All the necessary water pipe work connecting Line #2, the storage tank, and the ozone generator was conducted by Duda personnel.

ClearWater Tech supplied all the components for the ozone water treatment system under a rental agreement. The project team returned the ozone system to ClearWater Tech when the project ended in December 2012. The 3,000 gallon tank remains at the Duda facility.

3.3 Post-Installation Testing and Data Collection

One of the main objectives of this project is to evaluate the performance of the ozone system in the treatment of actual water taken from Line #2 at the end of the production day. The following sections describe the testing and data collection procedures that were implemented by the project team.

3.3.1 Data Collection Plan

After an initial test run, the project team conducted seven data collection runs. The seven runs consisted of:

1. Filling the water storage tank with an amount of celery wash and rinse water from Line #2. The water was taken at the end of the production day to obtain the "dirtiest" condition, and to simulate the situation where the water would be treated and reused during the next production day.
2. Running the ozone system and treating the water in the tank for at least 4 hours. During this run, the following data was collected at regular time intervals:[2]
    a. the ozone concentration (in units of ppm) at the inlet to the ozone injector (outlet from the tank) - this data can be read directly from the Rosemount Ozone Controller console;
    b. the ozone concentration (in units of ppm) at the outlet of the ozone injector (inlet to the tank) - this data can be read directly from the Rosemount Ozone Controller console;
    c. the oxidation-reduction potential (ORP) – this was measured at the outlet from the ozone injector by using an ORP meter that records in units of millivolts (mV);
    d. spot measurement of the electric power (kW) consumed by the ozone system and booster pump.
3. Discarding the treated water to the drain at the end of the test run.

[2] The project team varied the time interval of data collection through the course of the seven test runs. For Run #1, the interval was 5 minutes. For Run #2, #3, and #4, the interval was 10 minutes. For Run #5 and #6, the interval was 30 minutes. For Run #7, the interval was 15 minutes.

Data from the initial test run was not collected and is not reported herein, but the following is a discussion of the qualitative observations from the test run. After the equipment was installed by ClearWater Tech, Duda staff operated the equipment overnight. The collected water was treated for a minimum of 12 hours. During this period the project team postulated that there was complete oxidation of the particulate matter and precipitates were formed. Laboratory costs to analyze these precipitates were not included in the scope of the original project. The precipitates were a slimy, starchy byproduct that coated and eventually plugged the basket filter within the system pump. This created concern to the Duda staff, but subsequent research showed that it was not necessary to ozonate for that length of time to reduce microbial populations to an acceptable level. Run times of approximately five hours usually reduced microbial levels to an acceptable point.

3.3.2 Microbial Test Plan and Procedures

During the course of each data collection run, the project team also conducted microbial sampling of the water that was being ozonated.[3] The project team collected water samples in 100 mL collection jars at various intervals during the test run, and these samples were sent to a local laboratory for the following analysis:

- total coliform count in units of most probable number (MPN) per 100 mL - done for all runs except the first run ;
- *e. coli* count in units of most probable number (MPN) per 100 mL - done for all runs except the first run;
- turbidity in units of nephelometric turbidity units (NTU) – done only for Run #5, #6, and #7.

Additionally, samples of the facility's tap water were also collected on each day of the test runs and sent to the laboratory for analysis. These "blank" samples serve as a control or reference point for comparing the laboratory results of the treated water.

[3] However, no microbial sampling was conducted for the first run (Run #1).

CHAPTER 4:
Data Collection, Analysis, and Results

This chapter presents the results of the ozone system tests and the data collected by the project team, and includes a discussion of the findings.

4.1 Data Collection

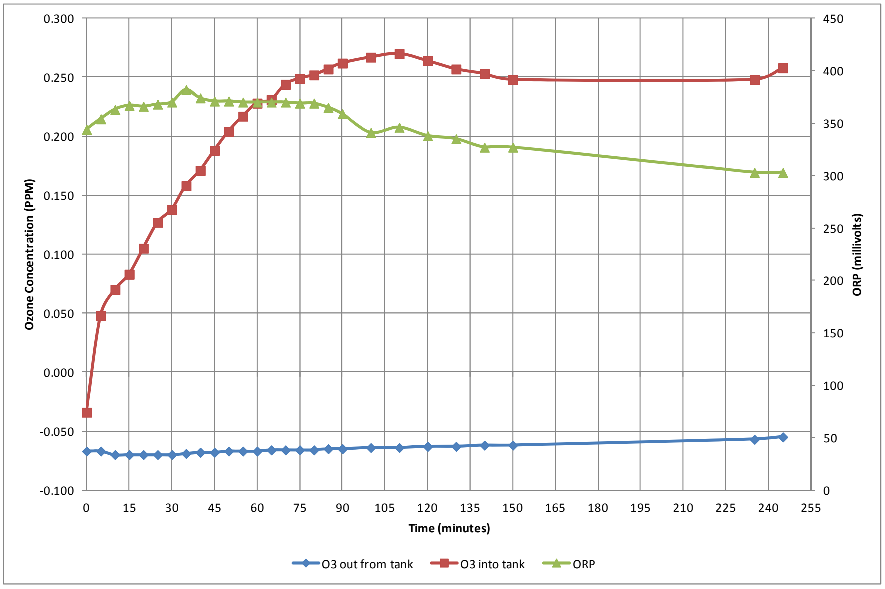
The procedures used in conducting the data collection runs of the ozone water treatment system were outlined in the previous chapter. The following sections present the data and results of each of the seven runs.

4.1.1 Run #1 – October 9, 2012

Run #1 was conducted on October 9, 2012 using 700 gallons of celery wash and rinse water. The water was taken at the end of the previous day's production run, which only involved one 8-hour shift. The run started at 9:30AM and ended at 2:15PM. Table 5 shows the ozone concentration and ORP data collected during Run #1.

Table 5: Run #1 Ozone Concentrations and ORP

Time (min)	O_3 out from tank (ppm)	O_3 into tank (ppm)	ORP (mV)
0	-0.067	-0.034	344
5	-0.067	0.048	354
10	-0.070	0.070	363
15	-0.070	0.083	367
20	-0.070	0.105	366
25	-0.070	0.127	368
30	-0.070	0.138	370
35	-0.069	0.158	382
40	-0.068	0.171	374
45	-0.068	0.188	371
50	-0.067	0.204	371
55	-0.067	0.217	370
60	-0.067	0.228	370
65	-0.066	0.231	370
70	-0.066	0.244	370
75	-0.066	0.249	369
80	-0.066	0.252	369
85	-0.065	0.257	365
90	-0.065	0.262	359
100	-0.064	0.267	341
110	-0.064	0.270	346
120	-0.063	0.264	338
130	-0.063	0.257	335
140	-0.062	0.253	327
150	-0.062	0.248	327
235	-0.057	0.248	303
245	-0.055	0.258	303



4.1.2 Run #2 – October 10, 2012

Run #2 was conducted on October 10, 2012 using 1,230 gallons of celery wash and rinse water. The water was taken at the end of the previous day's production run, which involved two 8-hour shifts. The run started at 9:40AM and ended at 12:10PM. Table 6 shows the ozone concentration and ORP data, and Table 7 shows the microbial results for Run #2.

Table 6: Run #2 Ozone Concentrations and ORP

Time (min)	O_3 out from tank (ppm)	O_3 into tank (ppm)	ORP (mV)
0	-0.061	0.000	257
10	-0.062	0.479	306
20	-0.062	0.522	379
30	-0.057	0.526	460
40	-0.049	0.530	372
50	-0.041	0.542	367
60	-0.024	0.563	351
70	-0.008	0.591	414
80	0.031	0.595	427
90	0.078	0.641	470
100	0.131	0.672	520
110	0.168	0.711	478
120	0.228	0.755	420
130	0.285	0.791	520
140	0.339	0.836	532
150	0.394	0.870	444

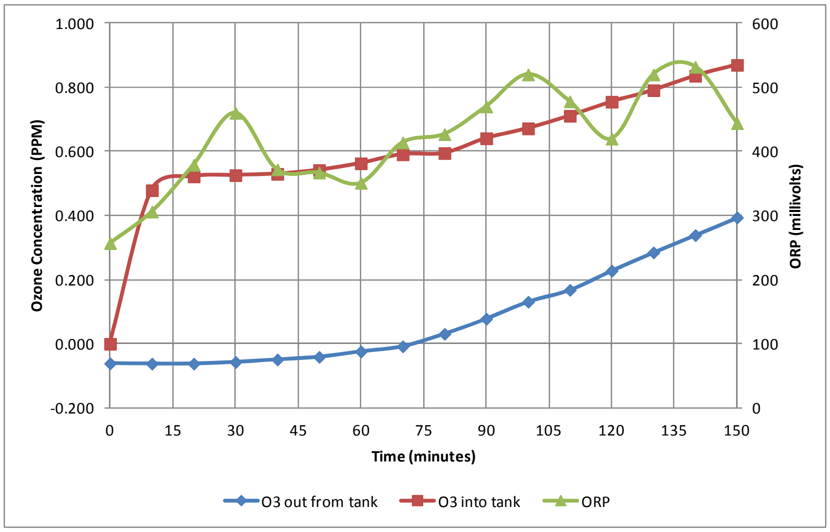
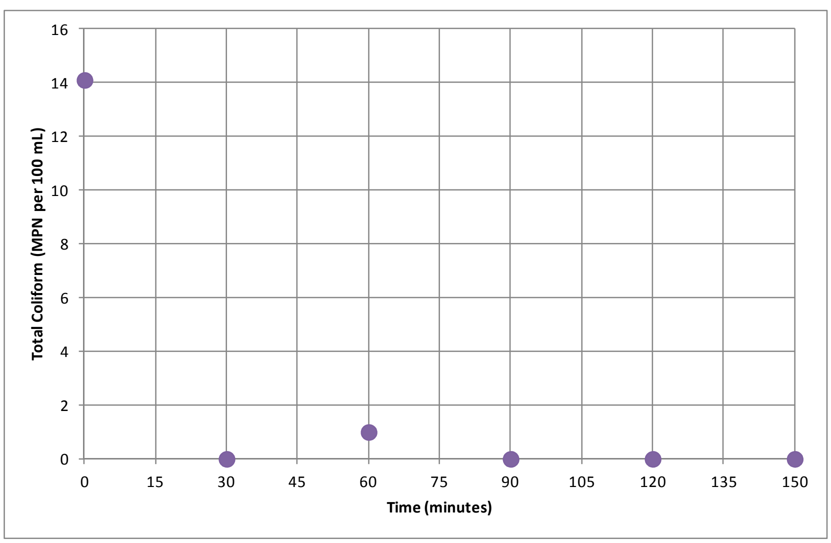


Table 7: Run #2 Microbial Results

Time (min)	Total Coliform (MPN per 100 mL)	*e. coli* (MPN per 100 mL)
0	14.1	<1
30	<1	<1
60	1	<1
90	<1	<1
120	<1	<1
150	<1	<1
Blank	<1	<1



4.1.3 Run #3 – October 23, 2012

Run #3 was conducted on October 23, 2012 using 650 gallons of celery wash and rinse water. The water was taken at the end of the previous day's production run, which involved two 8-hour shifts. The run started at 9:50AM and ended at 1:30PM. Table 8 shows the ozone concentration and ORP data, and Table 9 shows the microbial results for Run #3.

Table 8: Run #3 Ozone Concentrations and ORP

Time (min)	O_3 out from tank (ppm)	O_3 into tank (ppm)	ORP (mV)
0	-0.060	0.056	357
10	-0.074	0.114	405
20	-0.076	0.124	433
30	-0.076	0.131	429
40	-0.076	0.140	432
50	-0.076	0.153	434
60	-0.075	0.173	432
70	-0.074	0.195	428
80	-0.074	0.216	413
90	-0.073	0.232	407
100	-0.072	0.247	408
110	-0.070	0.264	394
120	-0.069	0.288	400
130	-0.069	0.300	403
140	-0.070	0.312	403
150	-0.067	0.325	405
160	-0.067	0.332	407
170	-0.067	0.343	414
180	-0.066	0.350	415
190	-0.066	0.360	413
200	-0.064	0.370	414
210	-0.064	0.376	414
220	-0.063	0.383	412

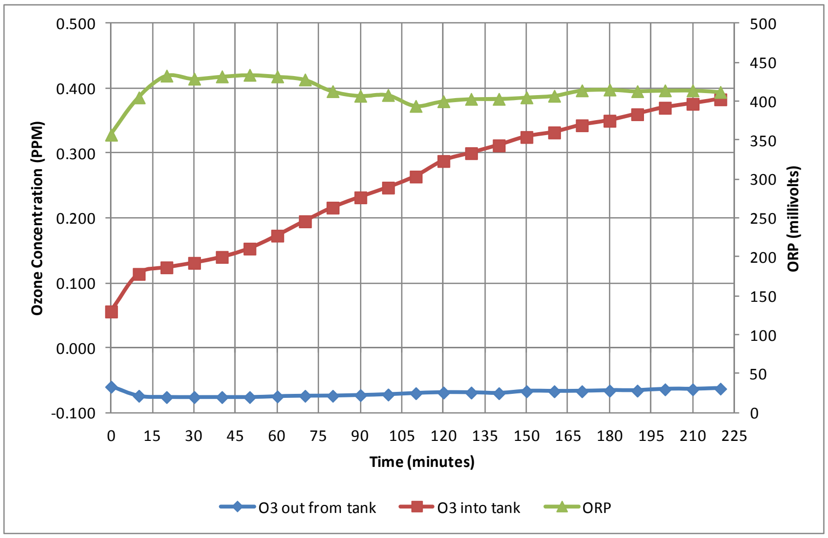
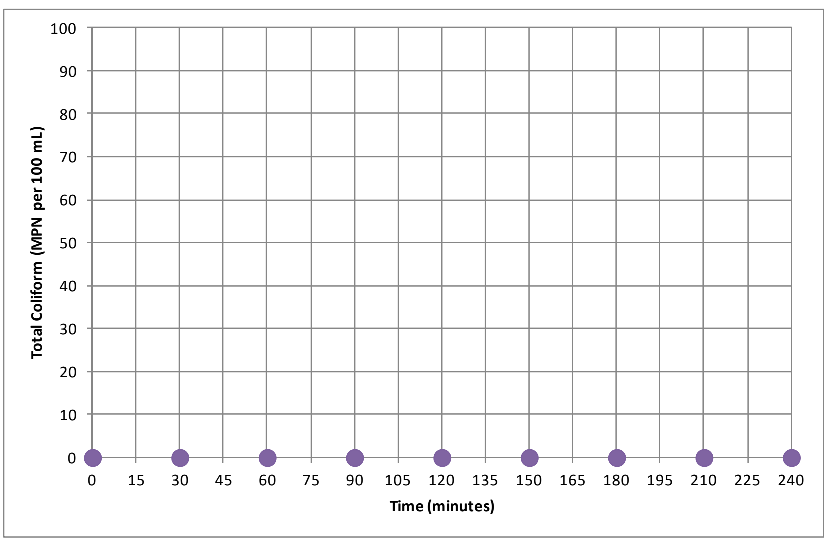


Table 9: Run #3 Microbial Results

Time (min)	Total Coliform (MPN per 100 mL)	*e. coli* (MPN per 100 mL)
0	<1	<1
30	<1	<1
60	<1	<1
90	<1	<1
120	<1	<1
150	<1	<1
180	<1	<1
210	<1	<1
Blank	<1	<1



4.1.4 Run #4 – November 9, 2012

Run #4 was conducted on November 9, 2012 using 600 gallons of celery wash and rinse water. The water was taken at the end of the previous day's production run, which involved two 8-hour shifts. The run started at 9:00AM and ended at 12:50PM. Table 10 shows the ozone concentration and ORP data, and Table 11 shows the microbial results for Run #4.

Table 10: Run #4 Ozone Concentrations and ORP

Time (min)	O_3 out from tank (ppm)	O_3 into tank (ppm)	ORP (mV)
0	-0.037	-0.010	356
10	-0.072	0.089	411
20	-0.072	0.106	430
30	-0.071	0.122	431
40	-0.072	0.146	427
50	-0.071	0.167	442
60	-0.072	0.145	445
70	-0.071	0.228	445
80	-0.071	0.255	440
90	-0.069	0.286	436
100	-0.070	0.312	434
110	-0.066	0.344	434
120	-0.066	0.350	431
130	-0.066	0.362	429
140	-0.065	0.366	421
150	-0.064	0.374	418
160	-0.064	0.381	414
170	-0.064	0.389	413
180	-0.063	0.395	414
190	-0.063	0.402	411
200	-0.062	0.415	411
210	-0.060	0.421	411
220	-0.060	0.427	402
230	-0.060	0.433	394

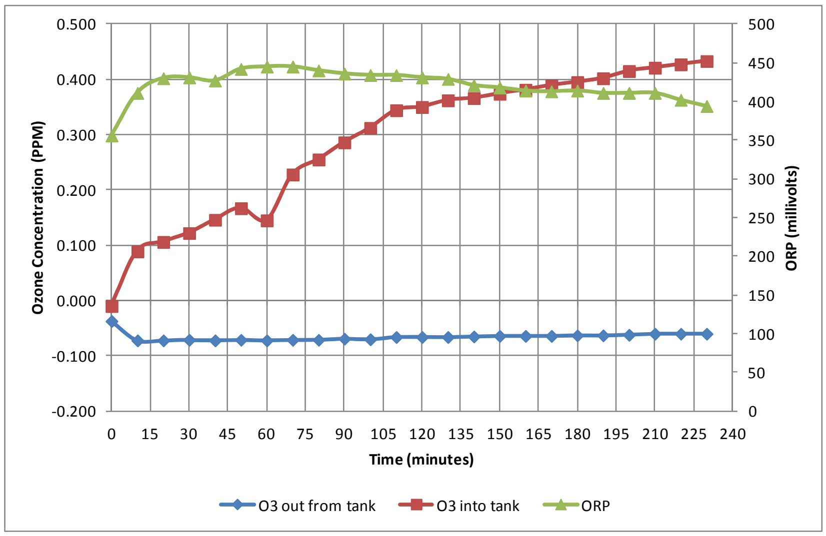
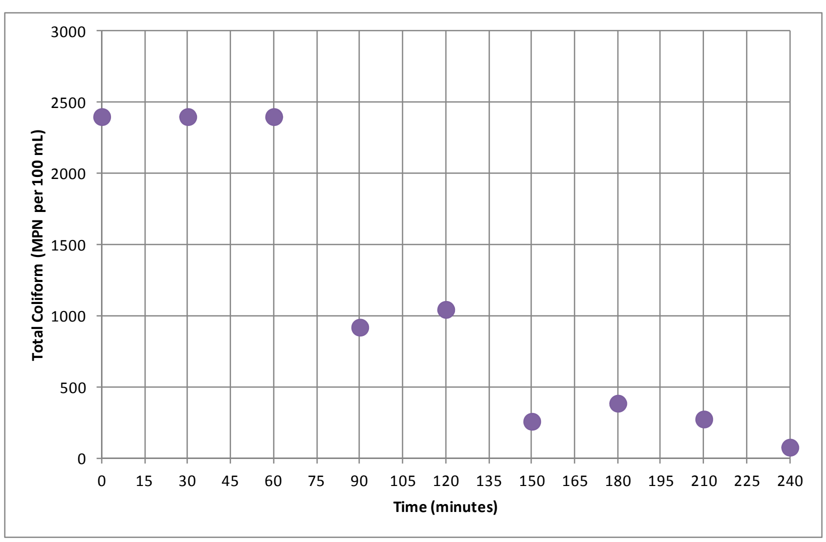


Table 11: Run #4 Microbial Results

Time (min)	Total Coliform (MPN per 100 mL)	*e. coli* (MPN per 100 mL)
0	>2,400	<1
30	>2,400	<1
60	>2,400	<1
90	921	<1
120	1,046	<1
150	260	<1
180	387	<1
210	276	<1
240	78	<1
Blank	<1	<1



4.1.5 Run #5 – November 20, 2012

Run #5 was conducted on November 20, 2012 using 600 gallons of celery wash and rinse water. The water was taken at the end of the previous day's production run, which involved two 8-hour shifts. The run started at 8:50AM and ended at 1:50PM. Table 12 shows the ozone concentration and ORP data, and Table 13 shows the microbial and turbidity results for Run #5.

Table 12: Run #5 Ozone Concentrations and ORP

Time (min)	O_3 out from tank (ppm)	O_3 into tank (ppm)	ORP (mV)
0	-0.060	0.071	237
30	-0.076	0.125	305
60	-0.074	0.188	323
90	-0.073	0.294	294
120	-0.069	0.397	323
150	-0.068	0.423	*
180	-0.066	0.446	322
210	-0.064	0.465	318
240	-0.062	0.49	313
270	-0.061	0.514	329
300	-0.058	0.532	327

** missing data point*

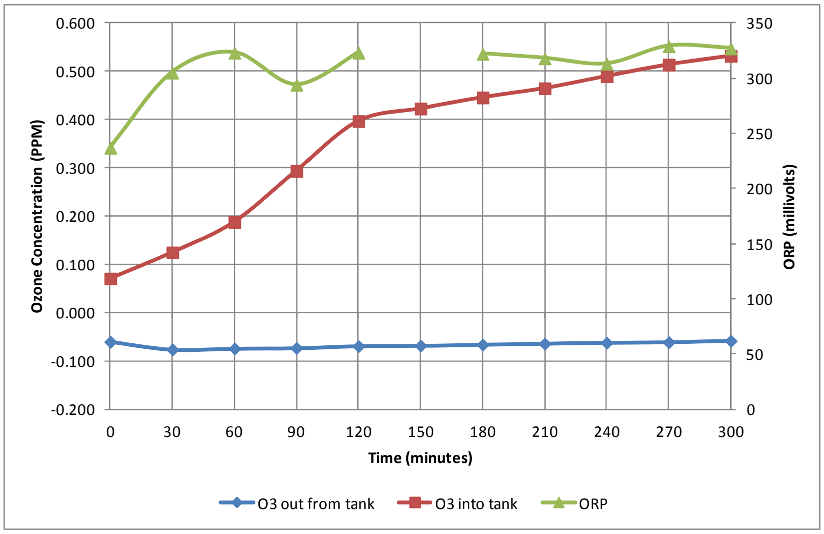
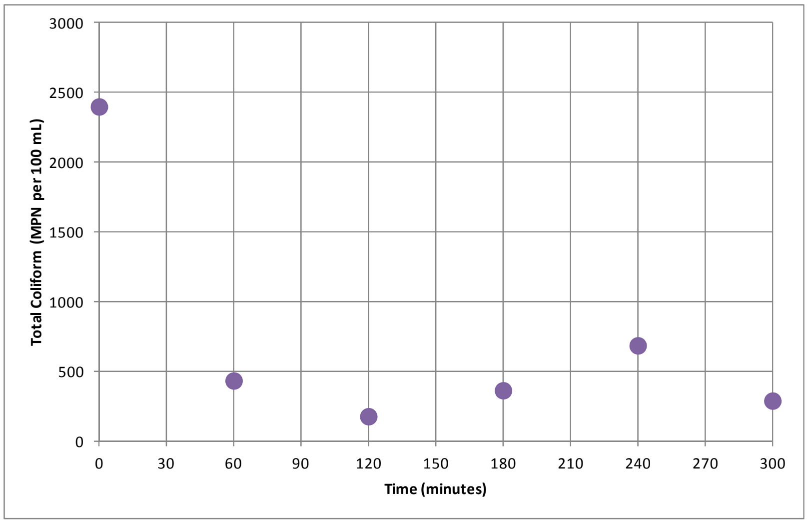


Table 13: Run #5 Microbial and Turbidity Results

Time (min)	Total Coliform (MPN per 100 mL)	*e. coli* (MPN per 100 mL)	Turbidity (NTU)
0	>2,400	<1	64
60	435	<1	40
120	179	<1	40
180	365	<1	39
240	687	<1	37
300	291	<1	35
Blank	<1	<1	Not Avail.



4.1.6 Run #6 – December 4, 2012

Run #6 was conducted on December 4, 2012 using 650 gallons of celery wash and rinse water. The water was taken at the end of the previous day's production run, which involved two 8-hour shifts. The run started at 8:40AM and ended at 1:40PM. Table 14 shows the ozone concentration and ORP data, and Table 15 shows the microbial and turbidity results for Run #6.

Table 14: Run #6 Ozone Concentrations and ORP

Time (min)	O_3 out from tank (ppm)	O_3 into tank (ppm)	ORP (mV)
0	0.052	-1.020	383
30	0.133	-0.075	450
60	-0.072	0.278	461
90	-0.073	0.372	465
120	-0.071	0.400	458
150	-0.069	0.423	467
180	-0.067	0.444	455
210	-0.066	0.478	450
240	-0.064	0.508	*
270	-0.063	0.533	453
300	-0.061	0.567	433

** missing data point*

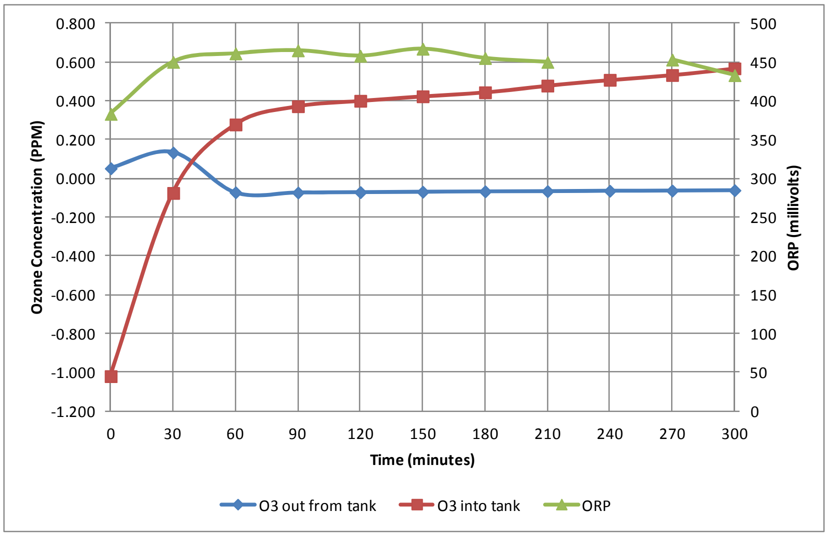
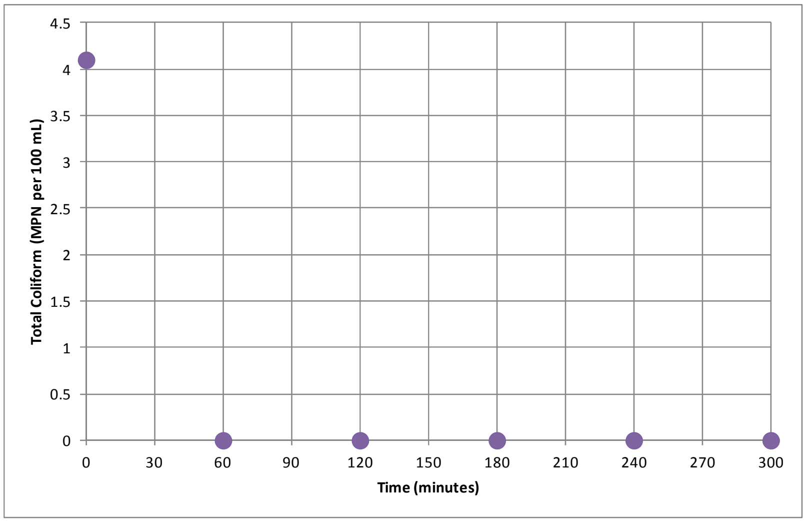


Table 15: Run #6 Microbial and Turbidity Results

Time (min)	Total Coliform (MPN per 100 mL)	*e. coli* (MPN per 100 mL)	Turbidity (NTU)
0	4.1	<1	75
60	<1	<1	59
120	<1	<1	55
180	<1	<1	53
240	<1	<1	52
300	<1	<1	47
Blank	Not Avail.	Not Avail.	0.14



4.1.7 Run #7 – December 7, 2012

Run #7 was conducted on December 4, 2012 using 200 gallons of celery wash and rinse water. The water was taken at the end of the previous day's production run, which involved two 8-hour shifts. The run started at 9:00AM and ended at 13:00PM. Table 16 shows the ozone concentration and ORP data, and Table 17 shows the microbial and turbidity results for Run #7.

Table 16: Run #7 Ozone Concentrations and ORP

Time (min)	O_3 out from tank (ppm)	O_3 into tank (ppm)	ORP (mV)
0	-0.062	0.095	
15	-0.065	0.150	295
30	-0.066	0.311	374
45	-0.065	0.416	382
60	-0.066	0.449	386
75	-0.062	0.463	414
90	-0.061	0.495	399
105	-0.060	0.510	402
120	-0.058	0.509	388
135	-0.058	0.520	384
150	-0.056	0.515	374
165	-0.055	0.551	368
180	-0.054	0.526	362
195	-0.053	0.554	347
210	-0.052	0.487	345
225	-0.051	0.491	342
240	-0.049	0.485	346

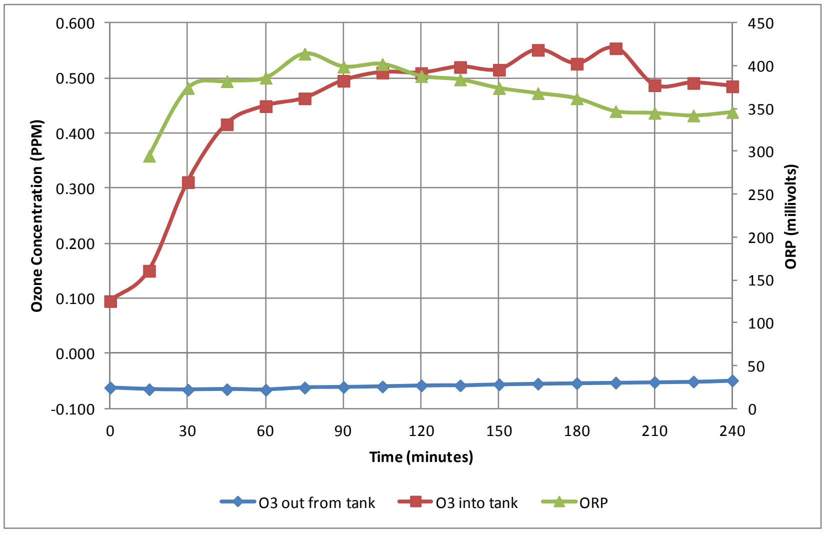


Table 17: Run #7 Microbial and Turbidity Results

Time (min)	Total Coliform (MPN per 100 mL)	*e. coli* (MPN per 100 mL)	Turbidity (NTU)
0	>2,400	<1	56
30	>2,400	<1	40
60	2,400	<1	49
120	>2,400	<1	39
180	>2,400	<1	28
240	>2,400	<1	30
Blank	<1	<1	0.22

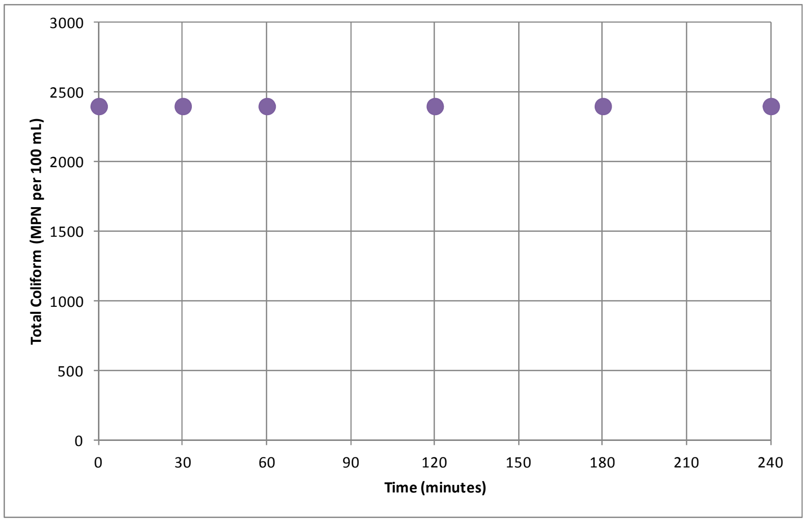


Figure 11 shows a photograph of the water samples taken at the start and end of Run #7.

Figure 11: Water Samples for Laboratory Analyses

4.2 Electricity Consumption of Ozone Water Treatment System

The project team conducted spot measurements of the electric power consumed by the ozone system on the following occasions:

- during the initial testing of the system after installation (on June 19, 2012);
- during Run #1 on October 9, 2012; and
- during Run #7 on December 7, 2012.

Each of the spot measurements were made after the system had been running for at least 30 minutes. Table 18 presents the data from the spot measurements.

Table 18: Spot Measurement of Electrical Power Consumed by Ozone System

	June 19, 2012		October 9, 2012		December 7, 2012	
	Entire System (including booster pump)	**Booster Pump Only**	**Entire System (including booster pump)**	**Booster Pump Only**	**Entire System (including booster pump)**	**Booster Pump Only**
Voltage (single phase)	199.3 V	Not Avail.	199.6 V	200.9 V	201.6 V	Not Avail.
Current	14.47 A	Not Avail.	15.14 A	11.53 A	14.05 A	11.04 A

Power Factor	0.994	Not Avail.	0.993	0.994	0.995	Not Avail.
Wattage	2,868 W	Not Avail.	3,001 W	2,304 W	2,821 W	Not Avail.

4.3 Observations and Analysis of Results

The testing protocol was designed to evaluate and establish a suitable method for using ozone as a treatment technique for improving water quality so that the celery wash water could be reused at the Duda processing facility. The wash water was stored in a large tank and treated in a batch process, where ozone was injected into a side stream which was then discharged back into the tank. Over time, the entire volume of wash water in the tank was treated with ozone.

One of the primary goals of the testing procedures was to determine if a measured ozone residual in the water pumped from the storage tank was a suitable indicator of completion of the ozonation procedure. Unfortunately, in only one run did the ozone residual in that water stream become positive even though the microbiological results indicate that that water quality treatment objective was completed. The process was typically complete after about four hours of treatment, regardless of the starting volume of water. Thus, as an additional safety factor the project team recommends that under this treatment scheme, ozonation should be applied for five hours.

Both visual observations and the results of the microbiological testing suggest that ozone reduces the microbiological levels in the wash water. In nearly all runs, the microbiological quality of the water was improved, although not to potable water quality levels. The one exception to this result was the final run, Run No. 7, where all of the samples measured MPN values in excess of 2,400 per 100 mL. The initial quality of the wash water was very poor (dirty water high in microbes). However, visual observations of the water as shown on Figure 11 suggest that the ozone was effective in removing color and, presumably, some of the biological contamination.

Additionally, there were no cases where any level of *e. coli* was detected in the treated wash water. This is crucial because while total coliform levels can vary, there should be no *e.coli* contamination in the wash water applied to the product. Duda's ongoing water quality testing suggests that the presence of *e. coli* in the wash water at any level is a rare occurrence, but the ozone treatment system must inactivate any and all levels encountered to ensure a safe final product. The treatment results indicate that the ozone has the potential to provide this type of protection.

In six of the seven runs, the microbiological quality of the water, as measured by MPN analysis of total coliform, improved a minimum of five-fold. This is a strong performance but was expected given ozone's excellent biocide properties. The sole exception to this performance was the final run (Run 7), where the microbiological quality of the treated water seemed unchanged. This may have been a sampling error, but it points to an important operational constraint which should be implemented into this treatment scheme.

If a full scale system were to be implemented, Duda will need to hold the treated water until microbial testing is complete, which is typically about 24 hours. Thus, if a sample was found to have not been treated as needed, it could be sent to the sewer rather than risk the chance of contaminating the next day's processed product. There are quicker, but less accurate methods of ascertaining microbiological water quality, which could be considered but would require detailed testing. These methods could potentially be employed but they should be used cautiously, and only after verifying that they suitably mimic results from standard procedures such as MPN.

4.4 Potential Savings and Impacts

4.4.1 Water Savings

The project team projected that water savings at Duda would be between 2,500 and 5,000 gallons per day, or approximately 15 percent of the water consumed at the facility. The potential savings associated with lower water use and reduced sewage fees are presented on Table 19. These savings are estimates because sewage fees are based in part on the strength of the sewage (usually BOD levels). The ozone system could be used to reduce the BOD levels of the sewage if the wastewater were to be treated prior to discharge. Estimating this impact is beyond the scope of this project.

Table 19: Potential Water Savings at Duda using Ozone Water Treatment System

Month	BOD[1] (mg/L)	TSS[1] (mg/L)	Existing Flow (gpd)	Monthly Cost[2] (USD)	New Flow (gpd)	New Monthly Cost[2] (USD)
July 2010	828	163	15,910	$2,734	13,410	$2,304
Aug 2010	1342	261	16,000	$3,846	16,000	$3,846
Sep 2010	528	100	17,707	$2,325	15,207	$1,997
Oct 2010	522	134	35,587	$4,759	33,087	$4,425
Nov 2010	643	247	35,831	$5,665	33,331	$5,270
Dec 2010	639	190	35,077	$5,346	32,577	$4,965
Jan 2011	584	136	29,292	$4,133	26,792	$3,780
Feb 2011	274	133	26,335	$2,763	23,835	$2,500
Mar 2011	471	155	20,564	$2,668	18,064	$2,344
Apr 2011	700	149	26,993	$4,203	24,493	$3,814
May 2011	380	196	33,758	$4,151	31,258	$3,843
Jun 2011	174	69	35,633	$3,116	33,133	$2,898
Totals	Annual Savings=$ 3,723 sewer Annual Savings=$2,760 water[3]			$ 45,708		$ 41,985

(1) BOD & TSS values are based on the average of two grab samples collected and analyzed monthly; these values are used to compute monthly sewage cost. Unless wastewater is treated before discharge to the sewer system, strength values will not change.

(2) Monthly cost estimates are based on existing formula applied to industrial discharges by the city of Oxnard, California.

(3) Annual Water savings are based on 2,500 gpd saved for 20 days each month for 12 months per year, using current city water rates of $ 4.60 per 1,000 gallons.

The information in Table 19 indicates that the 15% water savings at Duda would result in approximately $6,483 per year in water and wastewater cost savings. However, some of the cost savings is offset by the additional testing that would be needed to ensure food safety. The team assumed that this testing would require daily microbiological testing of the process water, at a projected cost of $ 4,800 per year. The project costs severely impacts overall savings. Overall project economics would improve if the testing could be modified (or completed in-house).

An additional test to consider would be to use the treatment approach on consecutive days with the goal of limiting discharges from the processing lines to the sewer to once per week. Under this scenario, water savings would approach 750,000 gallons per year for Duda, with anticipated cost savings under this approach much larger because that would include both the potable water saved and the cost of sewer discharges. The treatment system, however, would incur additional electric costs annually plus the one-time investment in the ozone treatment systems and suitable storage tanks. There is limited room for additional water storage tanks so presumably a larger tank (with greater height) and additional treatment capacity would be necessary.

Approximately 30 billion gallons of water are used annually in California for food processing of fruits and vegetables[4]. Ozone, as a water reuse treatment chemical, has applicability across a wide range of food processing plants, especially in the cut vegetable area. If the 15 percent savings can be replicated in only 5 percent of California's food processors, annual water savings would be approximately 225 million gallons per year. This is very close to the project average daily demand for the East Bay Municipal Utility District for year 2015.[5]

4.4.2 Electricity Use Impacts

Electricity impacts due to the ozone water treatment system are small. Based on the electrical data collected and the volume of water treated, the project team computed that electricity consumption of the ozone water treatment system to be approximately 15 kWh per 2,500 gallons treated water.[6] Assuming that the system operates 20 days per month for five hours each day, the system would consume approximately 3,600 kWh per year. At current electricity rates (approximately $0.12 per kWh), this level of consumption equates to approximately $432 per year, or $ 0.72 per 1,000 gallons treated. This is rather inexpensive and oftentimes cheaper than direct disposal to the sewer system. This cost estimate does not include the cost of additional microbial testing, which should be calculated in the final analysis.

The project team also attempted to estimate the anticipated savings gained by not having to chill approximately 2,500 gallons of fresh water from the main each day. This savings would only be realized if the storage tank was insulated, allowing the treated water to be stored at a temperature lower than the ambient.[7] In this analysis, the project team assumed that the treated water is stored and maintained at 45 degrees F, new water from the main is typically 65 degrees F, and the water chilling system has a coefficient of performance (COP) of 3.5. Under these assumptions, using the treated water in the process would allow Duda to avoid chilling 2,500 gallons of water from 65 to 45 degrees each day (it would still need to be chilled down to 35 degrees F for use in the production process), resulting in a savings of approximately 35 kWh per day. This level of electricity savings in the chilled water system would completely offset the 15 kWh per day electricity consumption of the ozone water treatment system.

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[4] *California Food Processing Industry Technology Roadmap*, California Energy Commission, prepared by California Institute of Food & Agricultural Research, University of California, Davis, June, 2004

[5] *Urban Water Management Plan 2010*, Water Resources Planning Division, East Bay Municipal Utility District, June 2011

[6] The installed ozone water treatment system draws approximately 3 kW of power, and it takes approximately 5 hours to treat 2,500 gallons of celery wash water.

[7] The installed 3,000 gallon storage tank is not insulated.

4.3 Summary of Findings

The study results demonstrate the potential to use ozone as a treatment to clean celery wash water. By using ozone, the wash water could be reused, thereby minimizing both potable water consumption and sewer discharge fees. The study team made no attempt to optimize the reuse scheme during this project, although it is technically feasible to ozonate and reuse the wash water multiple times prior to discharge. Additional studies need to be designed to better optimize the number of reuse cycles, along with plans necessary to implement this technology.

Provisions must be made for holding any treated water until microbiological inactivation is verified. This entails sampling the treated water and testing from total coliform, *e. coli* and other organisms such as salmonella and listeria. These details are important but can be easily addressed. Daily microbiological tests would be needed.

Another potential savings, that was not assessed in this study, is the impact of ozone on current sanitation practices at Duda. The Duda plant adds 40 ppm of periacetic acid to the process water to act as a microbial inhibitor. The treatment works well but is expensive, and it cannot be recovered from the process water. The impact of the interaction of ozone treatments and periacetic acid was not analyzed. This interaction needs to be studied in detail to determine the exact amounts of ozone and peracetic acid that are needed.

In the case of Duda Farm Fresh Foods and their celery processing plant, the ozone treatment times of 4 to 5 hours are necessary for approximately 2,500 gallons of wash water. Given Duda's current operating schedule and the ozone system set-up, this treatment time could be completed between shifts and overnight when the plant is not in operation. The project team estimates that this approach could save Duda approximately 750,000 gallons of water per year, or roughly 15 percent of their annual water consumption. If applied broadly across California, this technology could save as much as 230 million gallons per year of water.

CHAPTER 5: Technology Review

Ozone is a well-known treatment approach in the water and wastewater industry. In the United States, it has had only limited use given its technical complexity and energy costs. Given our abundance of cheap, clean water and a readily available supply of chlorine, there has been historical resistance to using ozone. In Europe, ozone is recognized as a particularly effective and valuable water treatment process. This section dispels some of the myths surrounding ozone use in the United States of America.

5.1 Technical Feasibility

Ozone's technical feasibility is well established. Companies like ClearWater Tech LLC, which rented the ozonation equipment to the project team for this study, produce ozone generation equipment for a variety of applications that is "off the shelf". However, the "off the shelf" approach can cause some problems. Ozone's interactions with water and wastewater can be unique and highly dependent on the pollutants and condition of the treated water. Thus, pilot testing is crucial to successfully implementing the process. Many ozone system suppliers provide reliable and effective equipment, but site-specific understanding of the unique chemistry occurring during ozonation also needs to be considered for each application. System failures may result if the proper ozone dose, application method, and dose location are not fully developed for each application.

5.2 Cost-Effectiveness

Preliminary estimates based on the results from this study suggest that ozone treatment can be cost effective under the correct set of circumstances. In food processing facilities where food contamination is a very real concern, there can be great reluctance to deviate from the accepted practice of discharging all water used on a daily basis. This is the most prudent course of action if a facility is unable or unwilling to implement certain safeguards to ensure treatment objectives are met. In the case of this study, a large storage tank to hold the treated water was installed and water could be reused only after microbiological testing confirmed that the water is clean.

There are many places, particularly throughout California, where water scarcity is a major concern. In these locations, water costs both for treatment and disposal are destined to increase. Ozone treatment of process water for reuse purposes can be very cost-effective in these locations. Further, ozone water treatment represents wise public stewardship of a non-renewable public good.

5.3 Technology Transfer Plan

As an industry, ozone treatment of water is an established industry, particularly in Europe. However, applications in food processing and other industrial settings in the United States are quite limited, and there seems to be reluctance to implement new treatment technologies without compelling regulatory or economic reasons. Thus, a technology implementation will have to wait until those regulatory or economic forces come into place. Meanwhile, the efficacy of this technology should be advertised as broadly as possible.

Ozone is unique in that its use requires both expertise in the construction and assembly of the equipment, which equipment suppliers can readily provide, and an understanding of ozone reactions in Food Processing. Understanding these ozone reactions is crucial because the ramifications of too little or too much ozone can be dire. For instance, during this study the water which was initially ozonated for a long period of time, led to various operational problems.

Governmental agencies can provide guidance on proper application of ozone to specific applications, such as in food processing and wastewater disinfection. This guidance must be provided to any business seeking to implement the technology in order to ensure success.

Thus, one technology transfer approach that is likely to be successful would entail a partnership between governmental agencies and ozone equipment suppliers. The governmental agencies would be a neutral, unbiased source of technical information on ozone applications, expected dosages, and anticipated costs and benefits. Equipment suppliers, on the other hand, could supply the practical knowledge and apparatus necessary to make various water reuse schemes in the food processing industry a reality.

An alternative approach is to formulate a technology partnership with design engineers specifically targeted to the food processing industry. These design engineers may team with equipment suppliers and offer technology transfer products such as; Technical Bulletins, Technical Case Studies, Technology Workshops, Webinars, and/or equipment displays. These can be developed as a program by the California Energy Commission or included in one or more of the many food processor trade ally groups in California.

CHAPTER 6:
Production Readiness Plan

Ozone in food processing is an emerging industry that requires a unique combination of equipment knowledge combined with practical experience for proper application. Despite the tremendous potential of ozone to reduce water use in California, this combination of expertise is often lacking in the businesses that market ozone equipment and food processors that use the equipment.

The technology is ready-made for use in a wide variety of industrial applications but will require research to properly deploy the equipment. Given that industrial applications are unique, the technology can only be properly employed by treating each application in a unique fashion. Each ozone treatment unit deployed to conserve water should rely on a skilled technician with knowledge in both equipment operation and proper ozone application.

An analogous situation can be found in the heating and cooling industry. Complex systems provide heating and cooling to our nation's buildings, but "installation" often consists of setting the equipment in place and switching it "on". It is not uncommon that newly installed systems are not integrated with other building systems or optimized in anyway. Ozone water treatment has the same potential concerns.

Thus, a product readiness plan needs to address proper equipment design and site application. For instance, equipment sales could include a commissioning contract, which in turn could become the industry standard.

6.1 Factors Affecting Commercial Viability

Industries can be risk-averse and unwilling to invest in alternative processing methods. Food processors are particularly risk-averse given the potentially catastrophic costs associated with product contamination and potential product recalls. This attitude is typically a function of economics. Both energy and water are relatively cheap in the U.S., making investments in technologies to save them a significant challenge. For instance, many energy conservation programs currently underway are mandates from government and include rebates or other incentives to lower the costs of new technologies. Even with the success of these programs, progress is slow. Water conservation is an even harder sell, given its abundance and often very low costs.

Yet, many food processors in California, recognizing the importance of clean water to their livelihood, are diligent in conserving this precious resource. There is great interest in identifying and implementing approaches to treating and reusing water on-site whenever and wherever possible. It is likely that there are specific locations where such an approach may be both technically and economically feasible. Thus, promotion of the technology is needed.

6.2 Manufacturing Requirements and Costs

While existing cost trends point towards a future California severely strained by water resources, that day has not yet arrived. Currently, Duda pays about $ 4.60 per 1,000 gallons for potable water. While this rate is more than double the national average, the total cost of water represents only a small portion of Duda's overall production costs and do not receive a high priority. Given that businesses will invest only in capital projects with the best return on investment, those projects developed to improve water efficiency generally fall below acceptable levels.

By adopting this technology, Duda would choose to invest in its own wastewater treatment system. That may make sense for the state of California as a whole, but may not make sense for Duda. It is easier (and in some ways cheaper) to contract wastewater treatment to the local municipality. Further, adopting a new treatment system would require Duda personnel to obtain a new set of skills beyond its current core competencies and outside of its mission of processing cut vegetables.

6.3 Investment Requirements

There are both monetary and institutional investments in adopting ozone treatment of processing water on site. The monetary investments are well understood, and given the wide array of equipment suppliers, this investment would follow a standard design-build-operate approach common to any other capital investment. As noted above, those businesses planning to adopt this technology should include provisions for after-installation consultation services by the vendor to ensure that the system operates correctly. The actual operation of these systems has been greatly simplified but choosing an appropriate dosage can be problematic. After-installation technical services should alleviate these concerns and ensure a successful implementation.

The second investment requirement is of an institutional nature. Adopting on-site treatment of water for reuse would entail commitment on the part of the business to own and operate a system that it currently does not use. This means that staff must learn new skills, provide monitoring and maintenance, and employ additional testing to ensure that the system operates as designed. Given the past history of water costs in California and the U.S., it has not been economically feasible to make this institutional and monetary investment into something already done by a municipality. As municipal rates rise, those economic equations are likely to change.

6.4 Full Production Implementation Plan

There are significant stumbling blocks to the widespread adoption of these technologies in the state of California. Implementing a more decentralized approach to industrial water treatment will require significant efforts at educating potential adopters of this approach, along with the wide variety of vendors, suppliers and consultants that provide services and advice to these companies. Thus, a significant effort of educational programs and demonstration studies is necessary to fully implement this technology across the state of California.

The California Energy Commission is uniquely situated to provide this service. The Commission's reports and studies are well-respected for their unbiased viewpoints. In addition, the Commission can bring together a variety of stakeholders to support the broader adoption of ozone water treatment technology. Given the Commission's status as a public agency, it is in an excellent position to make the case for the societal benefits possible from broader adoption of ozone water treatment. A broad educational effort, complete with both short-course type technology transfer sessions coupled with demonstrations, is needed for further implementation of this technology. The California Energy Commission is positioned to lead the state in this effort to alleviate water supply constraints and demonstrate a method of extending our precious water resources.

GLOSSARY

Acronym or Abbreviation	Definition
A	amps
BOD	biochemical oxygen demand
COP	coefficient of performance
CFU	colony forming unit
CFU/g	colony forming unit per gram
Dandy	Dandy Cooling Company
Degrees F	degrees Fahrenheit
Duda	Duda Farm Fresh Foods
e. coli	Escherichia coli bacteria
Ft^2	Square feet
GPD	gallon per day
GPM	gallon per minute
HP	horse power
KW	killowatt
kWh	kilowatt hours
Min	minutes
mL	milliliter
MPN	most probable number
mV	millivolt
NTU	nephelometric turbidity units
ORP	oxidation-reduction potential
O3	ozone
pH	a measure of the acidity or basicity of an aqueous solution
PPM	parts per million

PV	photovoltaic
RD&D	Research, Development and Demonstration
SCE	Southern California Edison
T-5 Fluorescent Lighting Fixtures	tubular fluorescent light, 5/8 inch diameter bulb
T-8 Fluorescent Lighting Fixtures	tubular fluorescent light, 1 inch diameter bulb
TDS	total dissolved solids
TSS	total suspended solids
USD	United States dollars
V	volts
VFD	variable frequency drive
W	watt