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# Water and Energy Use and Wastewater Production in a Beef Packing Plant

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# WATER AND ENERGY USE AND WASTEWATER PRODUCTION

# IN A BEEF PACKING PLANT

By

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# WATER AND ENERGY USE AND WASTEWATER PRODUCTION IN A BEEF PACKING PLANT

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Accurate information about water and energy use and wastewater production in beef packing plants is scarce. The objective of this study was to collect baseline water and energy use data within a beef packing plant with a special focus on antimicrobial interventions and to collect preliminary wastewater production data in addition. Permanent and portable water flow meters were installed on the plant's plumbing system to collect water flow data from March 2014 to March 2015. A local utility company was hired to meter electricity at antimicrobial interventions using portable data loggers. Metered water flows and temperatures were combined with fundamental thermodynamics principles to estimate natural gas use. Wastewater samples were collected in two sampling events and average BOD, COD, TSS, pH and conductivity are reported. The Total water used for cattle processing was 355 gal./ 1000 lb. BW and the Total metered and estimated energy was 283 MJ/ 1000 lb. BW. The antimicrobial interventions investigated in this study are the Pre-evisceration wash, organic acid spraying, carcass wash and thermal pasteurization. For those antimicrobial interventions, the water (16%) and energy (12%) use, and wastewater production (29% of BOD, 12% of COD and 8% of TSS) was a small portion of the overall use and production. Most of the wastewater

load generation was from manual processes, primarily viscera processing and overnight cleaning, which also have the highest water use and variability. The wastewater analyses suggest that specific streams, like the organic acid spraying, may have an impact on downstream biological treatment processes. Although this study was done at one plant, it is believe that this study is representative of the industry since the main processes and equipment brands are common across the industry. Available historic data suggest that there may have been significant improvements in the water and energy use within beef packing plants.

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*To my country, Palestine*

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# List of Acronyms

| | |
|---|---|
| BOD | 5-day biological oxygen demand |
| BTU | British thermal unit |
| cft. | Cubic foot |
| COD | Chemical oxygen demand |
| gal. | US gallon |
| GJ | Giga joules |
| kg | Kilograms |
| kWh | kilo watt hour |
| lb. BW | pound of live body weight |
| MJ | Mega Joules |
| RTU | Ready to use |
| ST.D | Standard deviation |
| TSS | Total suspended solids |
| US-EPA | United States Environmental Protection Agency |
| USDA | United States Department Of Agriculture |

# Chapter 1 Introduction

## 1.1 Research problem and research reasoning

Recent water and energy use data and wastewater production information in beef packing plants in the United States are scarce. Data scarcity is especially acute when considering specific antimicrobial interventions in a plant. Furthermore, most of the available data are rather old (Schultheisz and Karpati 1984; US-EPA 1974), with unclear system boundaries and of a wide range. Beef processing technologies and microbial safety have improved in the past two decades, but foodborne diseases is still one of the top causes of illnesses and deaths in the United States (Koohmaraie et al. 2005).

Antimicrobial interventions are automated or manual processes that aim at reducing microbial contamination on the beef carcass using either or a combination of water, steam and organic chemicals. New antimicrobial intervention technologies, such as electrostatic spraying of organic acids, are being developed to improve microbiological safety of beef (Phebus et al. 2014). In order to evaluate the impacts of new antimicrobial intervention technologies on the water, energy, and wastewater footprints within a plant, it is important to collect baseline data of the current technologies. In addition, this data are important to evaluate the environmental sustainability of the beef industry. Understanding water use variability within a plant is important to carry out further microbial risk assessment studies, and to help plant operators better understand the water use within the plant. The lack of wastewater production breakdown within meat processing plants was reported by many researchers (Johns 1995; Massé and Masse

2000) and providing such information is essential to develop better wastewater management strategies within the plant.

## 1.2 Overview of the beef industry in the United States

The beef industry in the United States forms the largest single sector in the agricultural industry. According to USDA, the United States produced 20% of the world's beef and exported 13% of the world's exported beef in 2013 (USDA-FAS 2014). The annual beef per capita consumption in the United States is 25.5 kg (USDA-ERS 2014). While the number of beef cattle operations reduced by 19% (0.9 million to 0.729 million), the annual beef production increased from 23 to 26 billion pounds between 1992 and 2012, which suggests improvements in the per head bodyweight and beef yield (Galyean et al. 2011; McMurry 2009; USDA-NASS 2014a; b; US-EPA 2014). The world food demand is expected to increase by 70% by 2050 because of the world population growth; with the limited available resources, it becomes important to monitor the use of water and energy and their impacts on the overall environmental footprint of the beef industry.

Foodborne diseases is one of the top causes of illnesses and deaths in the United States (Batz et al. 2012; Braden and Tauxe 2013; Scallan et al. 2011a). In the United States, it was estimated that foodborne diseases cause 48 million illnesses each year (Gould et al. 2013), 9.4 million of which are caused by known foodborne etiological agents (Painter et al. 2013; Scallan et al. 2011b). Furthermore, annually 482,199 (5%) of foodborne illness cases, 2,650 (0.03%) of foodborne hospitalization cases and 51

(0.005%) of foodborne death cases were associated to consuming of bacteria with beef between 1998 and 2008 in the United States (Gould et al. 2013; Moxley and Acuff 2014; Painter et al. 2013).

## 1.3 Study main objectives

The objectives of this research were as follows:

1. Collect baseline water and energy use data within a beef packing plant with a special focus on antimicrobial intervention processes in order to evaluate the impacts of new antimicrobial interventions on the water and energy use and wastewater production.
2. Develop variability information on water use within a beef backing plant which can be used in future food risk assessment studies.
3. Provide preliminary wastewater production breakdown and characterization within a beef packing plant to understand general trends and verify proposed sample collection and testing methods.

## 1.4 Thesis organization

This thesis is divided into five Chapters. An introduction is provided in Chapter 1, where it gives a brief explanation of the research problem and reasoning, a brief overview of the beef industry and lists the main objectives this study. Chapter 2 summarizes key literature data for water and energy use and wastewater production of beef cattle processing facilities. The research methodology and procedures are explained in Chapter 3. Results of the data collection and analysis of water and energy use and the preliminary wastewater production within a beef packing plant are summarized in Chapter 4. This thesis ends up with summarizing the main conclusions and recommendations for future work. An Appendix provides supplemental information of the wastewater sampling and testing methods.

# Chapter 2 Literature Review

A thorough literature review was conducted in efforts to collect historical data on water and energy use and wastewater production in beef packing plants. Available data in the literature about water use and wastewater production of beef packing plants are limited, especially when considering specific processes within the plant such as antimicrobial interventions. Several researchers reported the lack of data on wastewater production breakdown and characterization within meat processing plants (Johns 1995; Massé and Masse 2000). However, relatively more data was found in the literature regarding the energy use of beef packing plants including some breakdown of the use within the plant. The energy breakdown within plants was primarily for plants located outside the US, which has limitation based on location, process technologies and regulations. The following sections summarize the results of the literature review done in this study.

## 2.1 Water use of cattle processing facilities

Data available related to water use of beef packing plants are of a wide range and unclear system boundaries. Several studies also use simulation-based methods to model the water footprint of the beef industry in the United States (Beckett and Oltjen 1993; Rotz 2013; Rotz et al. 2013). Simulation-based methods are used to estimate the water use footprint based on theoretical calculations and broad assumptions. Care is required in interpreting water footprint values since different system boundaries maybe used. Beckett and Oltjen (1993) used 607 gal./ head for water needed for cattle processing based on personal communication with a commercial slaughterhouse and an increase by 50% of the provided value to insure that any bias is an overestimation. Rotz et al. (2013) did not include cattle processing in the estimated environmental footprints. The water footprint of the beef industry excluding precipitation was 334,195 gal./ 1000 lb. BW in 2011 (Rotz et al. 2013). Often times, results are verified with available actual measurements but does not involve extensive measurement of water use along the beef production steps. While most of the studies focus on the water footprint of the industry, very few researchers scientifically reported the water use of beef packing plants. None of the publications were found to separate the water use within a US beef packing plant between each processing step.

Data related to water use in the beef industry has a large range in the available literature. The reported total water use for a US slaughterhouses ranged from 500 to 2000 gal./ 1000 lb. BW (pounds of body weight) in 1984 (Hansen et al. 2000; Johns 1995; Schultheisz and Karpati 1984). Based on personal communication, it was reported that the water use of beef packing plant was 405 gal./ head in 1993 (Beckett and Oltjen 1993). The reported water use of beef packing plants suggests that it is a small portion on the water footprint of beef production. Furthermore, several studies reported the wastewater flow of beef packing plants. Typically, in beef slaughterhouses, wastewater flow generated is 80% of the water input (Johns 1995). A survey on 24 red meat slaughterhouses, half of which were beef slaughterhouses, reported that in 1974 the wastewater flow ranged from 160 to 2,427 gal./ 1000 lb. BW with a mean value of 639 gal./ 1000 lb. BW (US-EPA 1974). Three beef packing plants surveyed by US-EPA

(2008) reported that wastewater flow was 390 gal./ l000 lb. BW. Stebor et al. (1990) reported the wastewater production of US slaughterhouse of capacity 265 head/hour was 343 gal./ 1000 lb. BW.

## 2.2 Energy use of cattle processing facilities

The energy use in food industry is considered unique to each sector and even plant. The energy use is highly variable since it depends on many factors, including plant size and location, mechanization of the production processes and utilization of processing capacity, equipment age and efficiency, insulation, and temperatures (Banach and Ywica 2010; Campañone and Zaritzky 2010; Cierach et al. 2000; Gogate 2011; Houska et al. 2003; Li et al. 2010; Marcotte et al. 2008; Markowski et al. 2004; Norton and Sun 2008; Tkacz et al. 2000; Wojdalski et al. 2013). A methodology for energy accounting in food processing was published by Singh (1978) and a similar methodology was adapted in this study. Multiple examples of energy analysis in food industries are also available such as sugar beet production and processing (Avlani et al. 1980), manufacturing of yogurt and sour cream (Brusewitz and Singh 1981), spinach processing (Chhinnan and Singh 1980), citrus processing (Mayou and Singh 1980; Naughton et al. 1979), warehouses for frozen foods (Prakash and Singh 2008), canning tomato products (Singh et al. 1980) and fruit coolers (Thompson et al. 2010).

Available literature shows that energy use was reported in different units in the food industry. Singh (1978) used MJ/ kg product, Ramírez et al. (2006) reported electricity as kWh/ tonne of product  and fuel as MJ / tonne of product and Wojdalski et al. (2013) reported various units as shown in Table 2.1. Literature energy data were normalized as MJ/ head, MJ/ 1000 lb. BW or MJ/ 1000 lb. product, using standard energy conversion factors (Bornarke and Richard E. Sonntag 2008), for comparison with the results of this study, as shown in Table 2.1.

**Table 2.1: Literature reported Energy use of beef packing plants.**

| Year | Reported energy use | Calculated equivalent use | Location | Reference |
|---|---|---|---|---|
| 1996-1997 | 807017 BTU/head | 851 MJ/head | United States | (Parker et al. 1997) |
| 1999 | 70-300 kWh/head | 252-1,080 MJ/head | Denmark | (Hansen et al. 2000)[a] |
| 2002 | 2.4 GJ/tHSCW[b] | 1,090 MJ/1000 lb. BW | Australia | (Pagan et al. 2002) |
| 2006 | 60 kWh/tonne product<br>216 MJ/tonne product | 196 MJ/1000 lb. product | Finland | (Ramírez et al. 2006) |
| 2008 | 269-279 kWh/tonne product<br>2.10-2.26 GJ/tonne product | 1,391-1,480 MJ/1000 lb. product | Poland | (Kowalczyk and Netter 2008)[a] |
| 2012 | 1723 MJ/tonne products | 781 MJ/ 1000 lb. product | Poland | (Wojdalski et al. 2013) |

[a] Adapted from (Wojdalski et al. 2013)

[b] tHSCW= tonne of hot standard carcass weight

As listed in Table 2.1, the energy use of beef plants varies. The first column lists the year in which the plant was surveyed, the second and third column list the energy use in the reported unit and the equivalent use. The fourth column shows in which country the surveyed plant was located. Notable difference in the reported values of energy use is observed. Many factors affect the energy use including location, processing techniques (mechanized verses manual), size and age of the plant and system boundaries considered in each study. Only one study reported the energy use of beef plants in the United States (Parker et al. 1997). However, the data were collected two decades ago and only focused on southern part of the US which has relatively high temperatures most of the year.

## 2.3 Wastewater loads of cattle processing facilities

The efficiency of the waste and wastewater management systems is greatly affected by the wastewater loading of the different processes (US-EPA 2008). Reported wastewater characteristics in beef plants is highly variable but provides general guidelines for wastewater strength produced from beef packing plants (Massé and Masse 2000). Several studies reported the wastewater flow of beef packing plants as mentioned in Section 2.1 (Stebor et al. 1990; US-EPA 1974, 2008).

A US-EPA document reported that wastewater generated from three cattle processing facilities had an average of 7,237 mg BOD/L and 1,153 mg TSS/L and the subsequent wastewater load generations were 26.3 lb. BOD/1000 lb. BW and 4.2 lb. TSS/1000 lb. BW (US-EPA 2008). An earlier US-EPA document reported that beef viscera processing BOD loading was from 1.5 to 2.5 lb. BOD/ 1000 lb. BW and blood loading was 2.25 to 3 lb./1000 lb. BW (US-EPA 1974). A study reported that cleaning operations contribute 0.3 to 3 lb. BOD/1000 lb. BW (Macon and Cote 1961; US-EPA 1974). Data collected form the Iowa Department of Environmental Quality showed that cleaning operations contribute from 27% to 56% of the total BOD load (US-EPA 1974).

## 2.4 Summary

Data reported on the water use and wastewater production of a beef packing plant are old. No study was found to breakdown the water use in a US beef packing plant, especially antimicrobial interventions, while few were found to breakdown the wastewater production. However, the breakdown of wastewater production focused only on viscera processing and facility cleaning, which produced the highest loads. Relatively more data were found about the energy use of beef packing plant, but these data are variable and were collected in countries outside the United States. The data gaps in the literature, with the need to evaluate the water and energy use of new antimicrobial interventions led into this study.

# Chapter 3 Materials and Methods

## 3.1 General approach

The study methodology provided in this chapter describes explicitly how the study program was designed to accomplish the objectives of the research. The approach of this study engaged plants staff through working closely with them and holding multiple progress meetings to receive their feedback on our research findings. Several data quantification methods were used to collect water, energy and wastewater data, as explained in the following sections.

## 3.2 Methodology and Procedure

The methodology of this study used the following procedure steps as a systematic approach to quantify the required data and to meet this study's objectives.

### *3.2.1 Step 1: Developing a process flow diagram of the beef packing plant*

This study was conducted at a mid-size Midwestern beef packing plant. Although, each plant process flow is unique and some aspects are considered proprietary, basic steps are common for most plants as illustrated in Figure 3.1. In this process flow diagram, multiple processes were combined in general terms and boxes were made larger to insure uniformity across the industry. At this plant, equipment manufacture by Chad Inc. is used, which is a common brand across the beef packing industry (Plant staff, personal communication 2015).

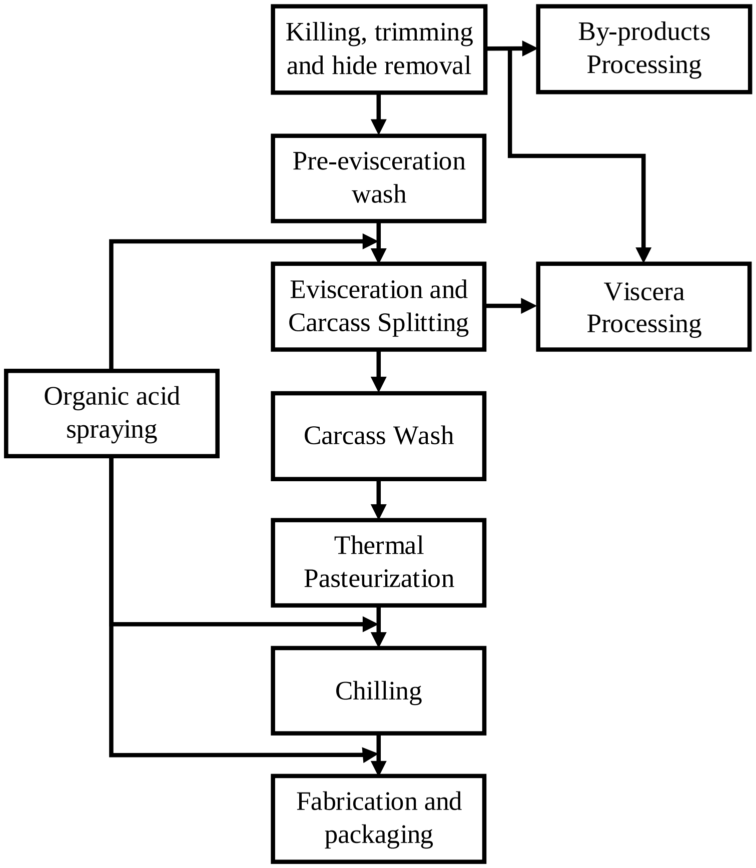


**Figure 3.1: A simplified typical process flow diagram of a beef packing plan**

In a typical beef packing plant, the cattle processing starts after holding the cattle in pens for couple of hours to release stresses gained during transportation. In cattle holding pens, cattle are sprayed with water to for evaporative cooling to prevent hyperthermia (Standing Committee on Agriculture and Resource Management 2002). Cattle are then stunned and bled and blood is collected, mixed with anti-coagulant and transported for further processing. As the cattle legs are trimmed and the carcass is de-hided, proper microbial safety measures are taken; e.g. tails are rubber-banded with plastic bags and legs are washed with water and steam using a special leg washing-vacuum mechanism. Before eviscerating and splitting carcasses, they go through hot water pre-evisceration wash and organic acid spraying. After splitting the carcasses go through carcass wash, thermal pasteurization, and organic acid spraying before chilling and fabrication. Examples of antimicrobial interventions (organic acid spraying and thermal pasteurization) are shown in Figure 3.2.


**Figure 3.2: Examples of a) Organic acid spraying cabinet and b) Thermal pasteurization cabinet** (Gabbett 2009)

### *3.2.2 Step 2: Identify key locations and data collection requirements.*

The size of a systems boundary in the process flow diagram was determined based on the importance of the data collected, expected water and energy consumption, i.e. high consumer verses low consumer, and the practicality of measurement. Different system boundaries were considered in this study to focus on antimicrobial intervention technologies and the total water and energy use and wastewater production. For this plant, six different system boundaries and four types of antimicrobial interventions were considered as illustrated in Figure 3.3.

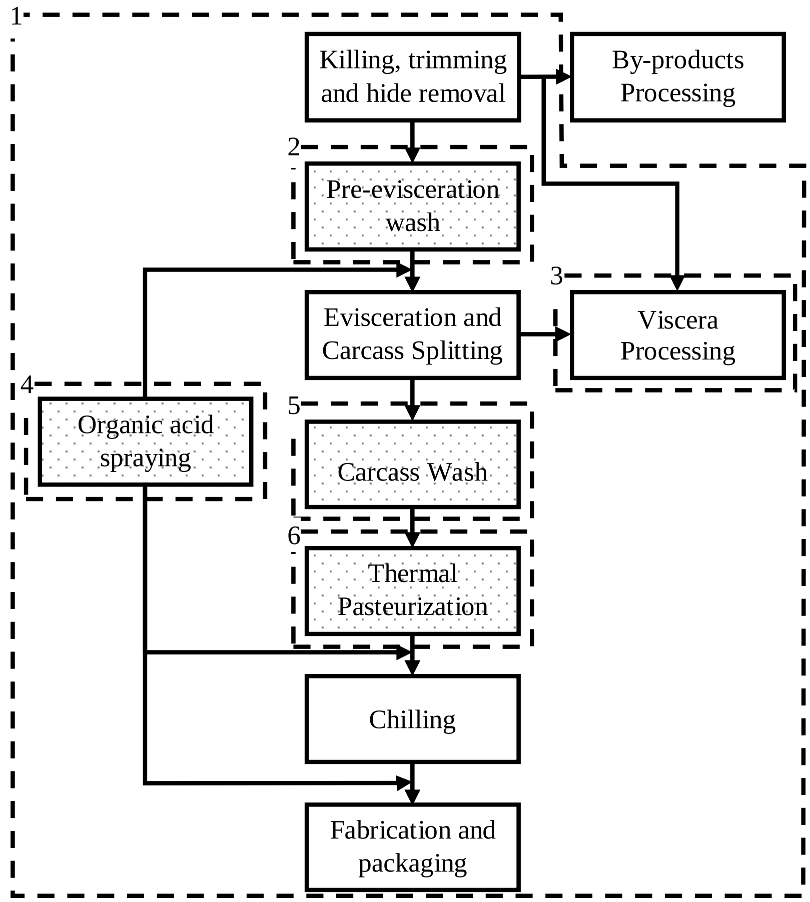


**Figure 3.3: Antimicrobial interventions (hatched boxes) and system boundaries (dashed lines) investigated in this study**

Table 3.1 provides a description of what was measured at each box shown in Figure 3.3 with a number in the upper left corner. These boxes reflect the Total use, antimicrobial interventions and the viscera processing. The antimicrobial interventions examined in this study were the pre-evisceration wash, carcass wash, organic acid spraying and thermal pasteurization, as shown as hatched boxes in Figure 3.3. For normalization, head counts and live weight data were obtained from the plant for the whole period of the study.

**Table 3.1: Study system boundaries description and studies parameters.**

| | System boundary | | | | | |
|---|---|---|---|---|---|---|
| Reference no. | 1 | 2 | 3 | 4 | 5 | 6 |
| Name | Total use | Pre-evisceration wash | Viscera processing | Organic acid spraying | Carcass wash | Thermal pasteurization |
| Studied parameters | | | | | | |
| - Water | P(60˚F)[b] | P(100˚F) | P(100˚F) | P(140˚F) | P(100˚F) | P(185˚F) |
| - Natural gas | P | E | E | E | E | E |
| - Electricity | - | T | T | T | T | T |
| - Wastewater | S[c] | S | S | S | S | S |

[a] Quantification: P= permanent meters, E= estimated based on thermodynamics, T= temporary meters and S= sampled.

[b] Plants main meter was read daily at 5:00 am and 5:00 pm. The plant received its water at around 60˚F. Water used between 5:00 am and 5:00 pm was for cattle processing and called, hereafter, *processing water*. Water used between 5:00 pm and 5:00 am was water used mainly for facility cleaning and called, hereafter, *overnight use* water. The temperature of the overnight use water was 120˚F.

[c] wastewater sampling was done only during overnight cleaning.

At this plant, two hydraulic systems are used to move carcasses through the process steps. The hydraulic systems use low and high pressure pumps to compress oil to move chains through the process steps. The cooling system uses several ammonia compressors for operation.

### *3.2.3 Step 3: Data quantification*

The research methodology of this study focused on quantifying the water and energy use and wastewater production at each process step. The data were collected for 12 months using a combination of permanent meters and temporary meters. In this study, water and energy usage only for cattle processing was concerned, data for office building, human consumption and landscaping were beyond the scope of this study.

**I. Water**

As listed in Table 3.1, several water temperatures are used through the processes. Seven permanent flow meters were installed and connected to a computer database, which was programed to continuously record flow data every five 5 minutes. The permanent meters were two M170, an M120, an M70 and an M35 Recordall Disc Meters and two M2000 Badger Meter M-Series (manufactured by Badger Meter, Inc., Milwaukee, WI). The manufacturer accuracy charts for the meters indicated the measurements were within 1% error. Metering the water use of the viscera processing was not possible, therefore it was estimated based on the hydraulics of its wastewater collection pipe, using jet water flow equation.

In addition, a portable type ultrasonic flow meter, flow transmitter type was FSC-2 and detector type was FSSD-1 (manufactured by Fuji Electric Co., Ltd., Japan), was used to measure water flows for at least a week at each location. The ultrasonic flow meter settings and accuracy were verified in the University of Nebraska-Lincoln hydraulics lab. The ultrasonic flow meter was programed to record data every ten minutes.

## II. Electricity

A local utility company in coordination with the plant's staff performed the electricity measurements at the plant for at least a week at each location. ELITEpro data loggers (manufactured by DENT Instruments, Bend, OR) were installed at the plant's distribution boards to collect electricity usage data for all the cattle processing equipment, hydraulic and cooling systems in the plant. The technical sheets for the data loggers were reviewed and the readings error was found at less than 0.2%.

## III. Natural Gas

The plant provided its daily meter data of the total natural gas use. While most of the natural gas was used by boilers for water heating and building heating during the winter, natural gas estimations were made using summer data when no heating was used for the building. The boilers at the plant generate steam of pressure 105 PSIG and the boilers efficiency was 82% (Plant staff, personal communication 2015). A close boiler efficiency value (81%) was reported in the literature in a beef packing plant (AlQdah 2013), however boiler efficiency is considered plant dependent.

Fundamental thermodynamics principles including water heat capacity and natural gas heat content were combined with water and temperature data to estimate the natural gas used at each process step as described below.

The amount of heat absorbed by water was calculated using $Q=m\times c_p\times \Delta T$ (Widder, 1976); where Q is the heat absorbed by water in BTU, m is the mass of water from measured flow rates (lb.), $c_p$ is the water heat capacity (1 BTU•lb. $^{-1}$•˚F; Bornarke and Richard E. Sonntag, 2008; Tipler and Mosca, 2003) and ΔT is the temperature difference between the inlet water (60˚F) and the end point measured water (˚F).

The amount of natural gas required was calculated using $NG_{req}=\frac{Q}{C_{NG}\times\eta_{boiler}}$; where $NG_{req}$ is the natural gas required (cft.), $C_{NG}$ is the heat content of natural gas (1,040 BTU/cft; US-EIA 2013), and $\eta_{boiler}$ is the boilers efficiency was 82% (Plant staff, personal communication 2015)

## IV. Wastewater

Wastewater production is a factor that influences the environmental sustainability of beef packing plants. Wastewater is also an economic factor to the plants and is regulated by the Departments of Environmental Quality and the Environmental Protection Agency. Wastewater samples were collected from the beef packing plant at the different system boundaries in two sampling events. The samples collected according the sampling and testing matrix, shown in Table 3.2. Wastewater samples were tested for BOD, COD, TSS, pH and conductivity.

**Table 3.2: Wastewater sampling and testing matrix**

| Location | Sampling | Samples tested per event per location | No. of replicates per test | | |
|---|---|---|---|---|---|
| | | | BOD | COD | TSS |
| Pre-evisceration wash, Organic acid spraying, Carcass wash and Viscera processing | A grab sample collected every 2 hours during plant operation. A composite of grab samples was prepared at the lab for testing. | 1 | 5 | 2+ | 4+ |
| Thermal pasteurization | A grab sample collected every 2 hours during plant operation. Each sample was tested separately | 5 | 5 | 2+ | 4+ |
| Overnight use | An Auto sampler was used to collect a sample every 2 hours from 5 pm to 9 pm. Each sample was tested separately | 3 | 5 | 2+ | 4+ |

BOD tests were performed according to Standard Methods for the Examination of Water and Wastewater No. 5210. It was investigated whether a seed was needed for the BOD test, and it was concluded available microbes in the wastewater sample were enough. High purity water is used for dilution water and aerated for more than 24 hours and left at room temperature. The COD tests were performed using Hach Mercury-Free COD2 reagent UHR vials. COD tests were done prior to the BOD tests and used as an indicator for the BOD range. Similar technique was used at Omaha's Missouri River Wastewater Treatment Plant, wastewater lab. TSS tests are performed using Whatman 934-AH RTU Glass Microfiber filters. More information about the wastewater testing is provided in the Appendix.

### *3.2.4 Step 4: Data analysis*

Different software were used to analyze the collected water, energy and wastewater data. Water data form permanent meter were received as a Microsoft Access Database file and the ultrasonic water meter and electricity data loggers data were obtained as Microsoft Excel files. Water use distribution figures were developed using XLSTAT statistical analysis Excel add-in, provided by Addinsoft SARL. Developing water use distribution figure for the viscera processing was not possible since it was calculated based on the hydraulics of the plumping system. The software automatically tests 19 different distributions and selects the best-fit distribution based on the highest Chi-square test p-value. Daily slaughtered cattle head counts and live weights were obtained from the plant and data were normalized as 1000 lb. BW.

## 3.3 Quality measures

The following steps were done during the study period to insure higher quality of our results.

- Ultrasonic water meter was tested at the water lab at the University of Nebraska-Lincoln and compared with an in-line water meter. The ultrasonic meter was found to be within acceptable accuracy. In addition, where possible, the ultrasonic meter readings were compared with in-line meters and were found within acceptable accuracy.
- The Omaha’s Missouri River Wastewater Treatment Plant, wastewater lab was visited to observe wastewater testing methods. Similar methods and practices were

done in our Environmental Engineering lab for testing of wastewater. Wastewater samples were also tested at an external lab to verify our results.

- BOD and COD standard samples were tested to verify the tests. The BOD standard tests were done according to Standard Methods for the Examination of Water and Wastewater No. 5210. COD standard solution of 1000 mg COD/L was tested and used to calibrate the spectrometer. The results from the testes were found within acceptable accuracy.
- A wastewater sampling and testing matrix was designed to account for the nature of the wastewater of each system boundary and composite samples were made to insure that samples are representative.
- Several progress meetings were held with the plant staff to present our results. Feedback and clarification responses were received.
- Recording time intervals were kept small, 10-min for permanent and portable water meters and 5-min for electricity data loggers, to collect high resolution data.
- Although natural gas use was calculated using known water flows and temperatures and thermodynamics fundamentals principles, the plant's natural gas meter data was obtained for from the plant and compared with our calculations results.

# Chapter 4 Results and Discussion

The findings of the water, energy and wastewater analysis completed during this study are presented in the following two sections. The data presented were normalized to hide the identity of the plant and to ease the comparison with literature data.

## 4.1 Water and Energy use of antimicrobial interventions

The water use monitoring at the plant occurred between March 2014 and March 2015. All water and energy data were normalized per 1000 lb cattle body weight killed (1000 lb BW). For this purpose, heads killed and cattle live weight data for the period of the study were obtained from the plant. The average live weight was 1390 lb per cattle head. The operating capacity of the plant is presented as percentage of the maximum capacity to protect the identity of the plant.

### *4.1.1 Water*

The average total water use of the plant was 355 gal./ 1000 lb. BW. The water use of a beef packing plant is a small fraction of the water footprint of the beef industry excluding precipitation (334,195 gal./ 1000 lb. BW, Rotz et al. 2013).

The percent of water used for cattle processing was 54.5% including the antimicrobial interventions (15.7%) of the total water used at the plant. The overnight water use was 38.9% and unmetered use including losses was 6.6% of the total water used at the plant. In 1984, the total water use for US slaughterhouses ranged from 500 to 2000 gal./ 1000 lb. BW and for US processing plant ranged from 755 to 3500 gal./ 1000 lb. BW (Hansen et al. 2000; Johns 1995; Schultheisz and Karpati 1984). The collected data suggests that there has been notable improvement on the Total water use of beef packing plants.

The plant receives its water through two main inlets, one for cattle processing usage and one for human use, firefighting and landscaping. Throughout the year, the temperature of the water is constant and around 60°F. The diurnal total water use pattern for a typical week when the plant was operating at high capacity is shown in Figure 4.1. This data was collected using an ultrasonic flow meter that collected data every 10 minutes.

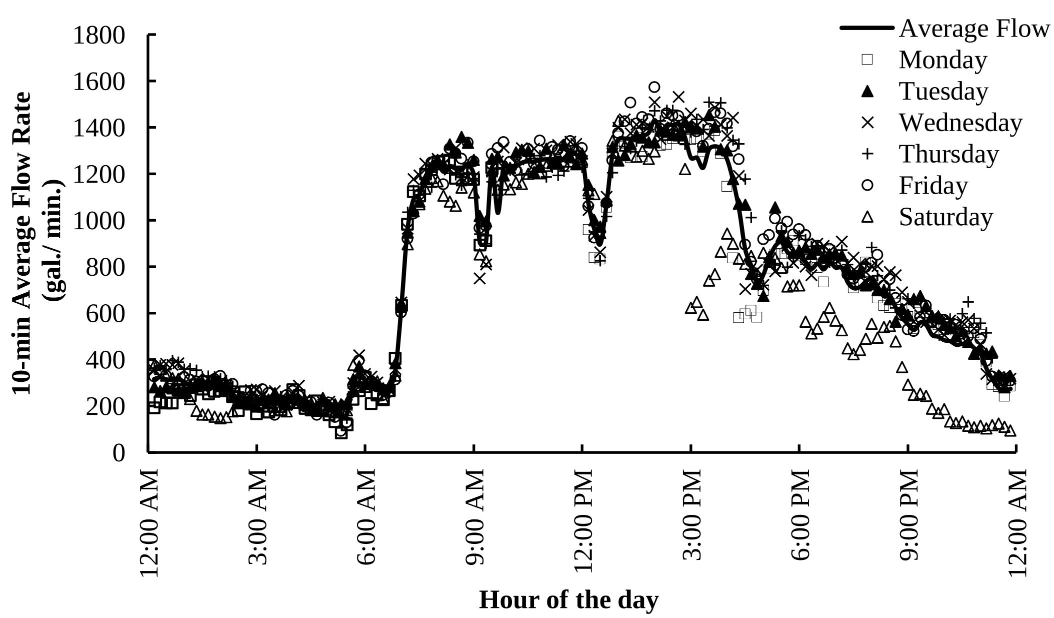


**Figure 4.1: Diurnal Total water flow pattern at the beef packing plant**

Figure 4.1 shows that the start of the shift was at 6:30 am and the end of shift was around 3:15 pm each day for the measurement period. Similarity in the water use during the weekdays is noticed, especially during the time period when cattle was processed. The water flow pattern shows that the water use was reduced during the breaks and the water use slightly increased after 12:00 pm, since minor cleaning activities started in the afternoon.

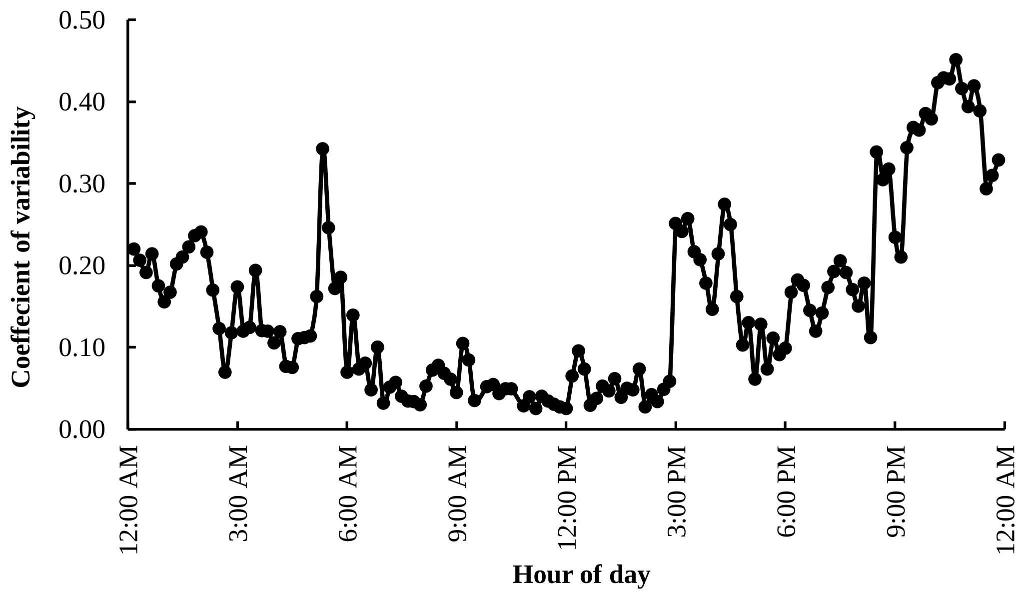


**Figure 4.2: Diurnal Total water use variability**

The 10-min. based coefficient of variability for the collected data of the total water flow pattern for the data in Figure 4.1 is shown in Figure 4.2. It is noticed that the coefficient of variability between 6:30 am and 3:30 pm was lower than elsewhere. Because most of the operations are consistent each day, the variability of the water use at specific times of the day is relatively low from day to day. On the other hand, the variability of the overnight use, mainly facility cleaning, was relatively high, because most of the cleaning techniques are manual and based on human judgment.

Table 4.1 lists the average water use values at each process step. The data presented in the second column is normalized by 1000 lb. BW. In the third column, the percent of the water use of each step is provided.

**Table 4.1: Water use at the beef packing plant**

| | Average water use | |
|---|---|---|
| Use | gal./ 1000 lb. BW | % |
| Antimicrobial interventions | 55.7 | 15.7 |
| Viscera processing | 138.1 | 38.8 |
| Overnight Use | 138.4 | 38.9 |
| Unmetered | 22 | 6.6 |
| **Total** | **355.6** | **100** |

The antimicrobial interventions investigated in this study were pre-evisceration wash, organic acid spraying, carcass wash and thermal pasteurization, as shown in Figure 3.3. Table 4.1 shows that antimicrobial interventions used a small portion of the total water use. The pre-evisceration wash, which used 100˚F water, consumed 12 gal,/ 1000 lb. BW. At this plant, three organic acid spraying cabinets were used as shown in Figure 3.3. Quantifying the water used at each of the three locations was not possible, therefore water use of two cabinets was quantified and normalized for three locations. The organic acid spraying, which used 140˚F water, consumed 1.9 gal./ 1000 lb. BW. The carcass wash, which used 100˚F water, was the highest water consumer among the antimicrobial interventions. The carcass wash consumed 30 gal./ 1000 lb. BW. The high consumption was due to larger carcass surface area after splitting and also to reduce higher contamination risk after removal of viscera. Thermal pasteurization at this plant used water recycling system. The water was heated to 185˚F and the temperature of the recycled water was measured at an average of 140˚F using a portable infrared thermometer. The water was renewed at least twice a day and the process used steam injection to reheat the water. The thermal pasteurization used 11.6 gal./ 1000 lb. BW (15 gal./head). The manufacturer's recommended water use for hot water pasteurization without recycling is 50 gal./head (Chad Equipment 2014). Using a recycling system at this plant reduced the water use of the thermal pasteurization by 70%. Unmetered water uses (e.g., water use on the fabrication floor, head wash, knife washer) contributed to 6.6% of the total water use.

Based on these data, it is recommended to look at further resource recovery technologies for the water used for viscera processing and overnight to reduce the water footprint and to further improve environmental sustainability of the plant.

The variability of water use for each process step is essential to perform microbial risk assessment studies. Using collected water use data, distribution plots were developed for five system boundaries listed in Table 4.2 and shown in Figure 4.3. Developing water use distribution for the viscera processing was not possible since it was calculated based on hydraulics. Figure 4.3 shows the distribution of the discrete water use data and the continuous distribution curves for the best-fit and normal distributions. On these plots the water use is presented on the x-axis and the frequency (day count for each water use) is presented on the y-axis. The parameters for the distributions are provided in Table 4.2.

**Table 4.2: Water use distribution-fitting parameters**

| | Best fit distribution | | | | Normal distribution | | |
|---|---|---|---|---|---|---|---|
| Water Use | Type | μ | σ | Chi-square p-value | μ | σ | Chi-square p-value |
| Processing water | Logistic | 215.84 | 10.12 | 0.2975 | 217.21 | 20.80 | 0.0009 |
| Overnight use | Log-normal | 4.92 | 0.13 | 0.2758 | 138.36 | 18.71 | 0.0432 |
| Pre-evisceration wash | Logistic | 11.91 | 0.21 | < 0.0001 | 11.92 | 0.43 | < 0.0001 |
| Organic acid spraying | Logistic | 1.90 | 0.06 | 0.2975 | 1.91 | 0.14 | 0.0031 |
| Carcass wash | Weibull (3) | β=3.31 γ=13.18 | μ=18.51 | 0.1597 | 31.28 | 2.87 | 0.1291 |
| Thermal pasteurization | Logistic | 11.60 | 0.78 | 0.2588 | 11.61 | 1.51 | 0.0386 |

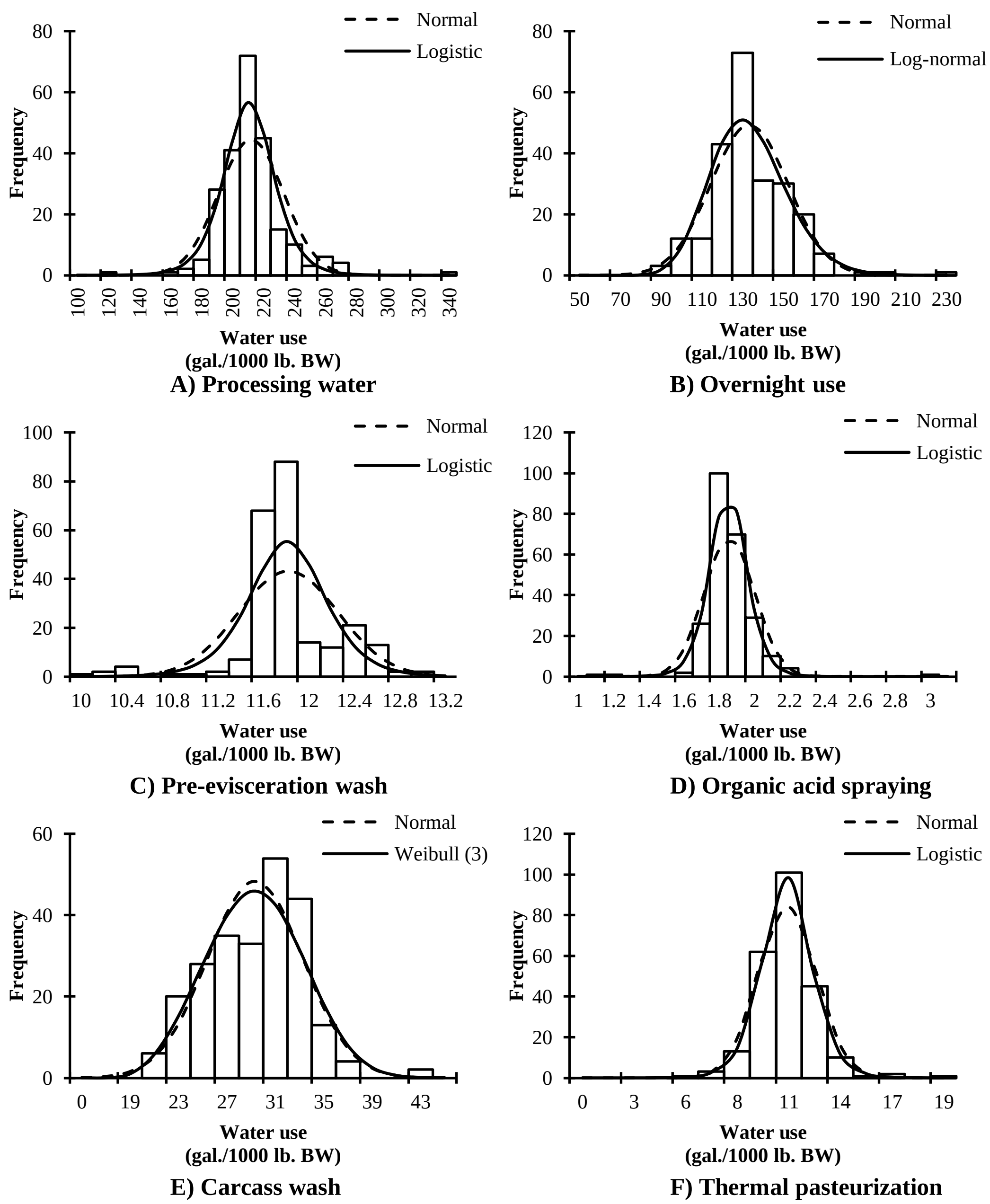


**Figure 4.3: Water use distributions for processing water, overnight use and antimicrobial interventions.** (Frequency is the day count for each water use)

To further explore variability in water use, for the process steps described in Table 3.1, collected water data from 12 months of data collection were plotted against the operating capacity, shown in Figure 4.4. The running capacity of the plant was compared with the maximum capacity to calculate the percent of operating capacity. The head counts and the maximum capacity of the plant are not reported here for plant protection. Although the 95% confidence levels of the trend lines are very tight, this analysis provide general sense of the water use trends in the plant.

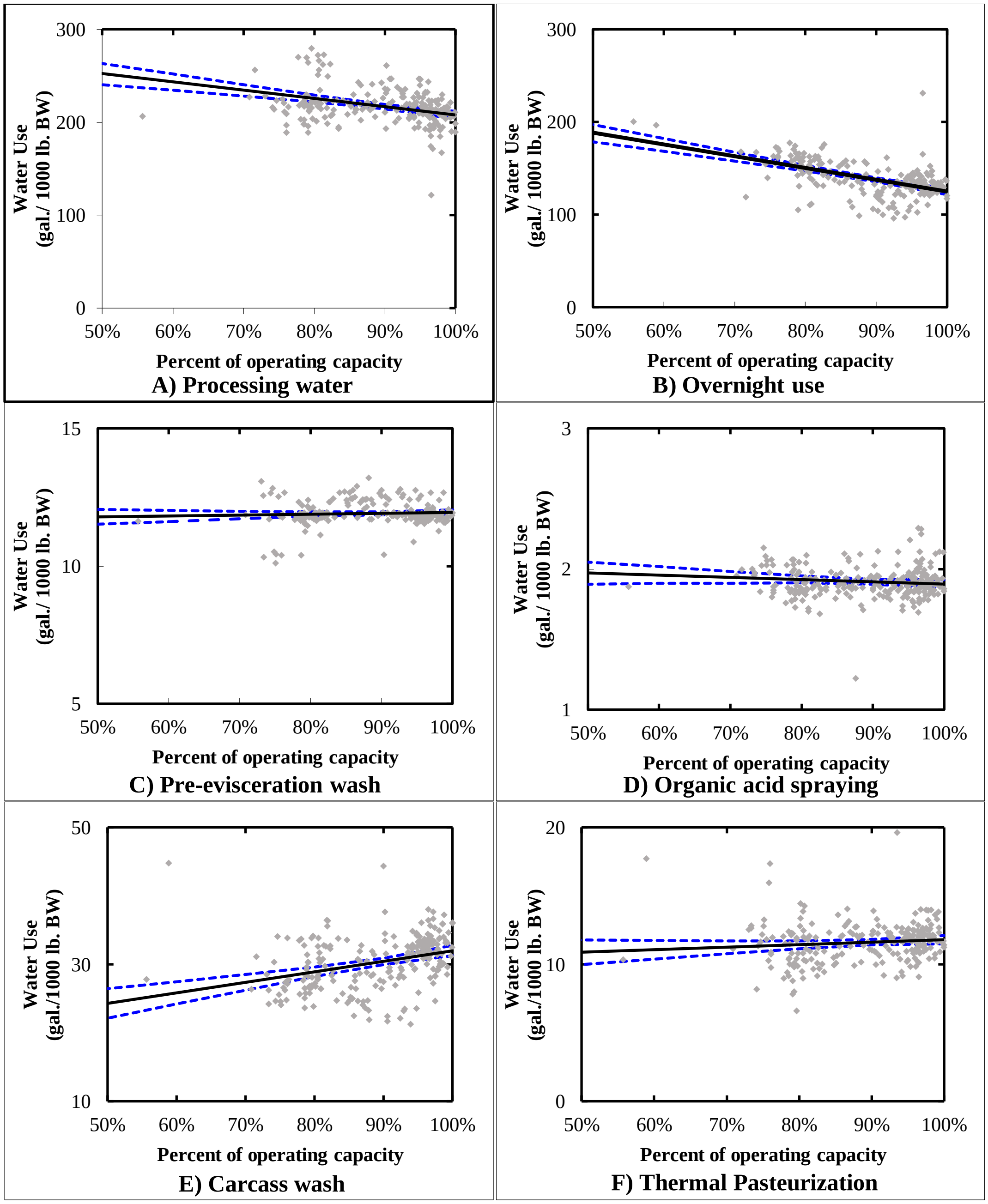


**Figure 4.4: The relationship between the operating capacity of the plant and the water use (Dashed line: 95% confidence interval)**

The regression lines for A) processing water and B) overnight water use show reduction in the water used with increasing the percentage of the operation capacity.

Because of the water use data is very variable, linear regression lines have low $R^2$ values. However, these regression lines illustrate increasing or decreasing trends with increasing the operation capacity. The decreasing trends for the overall processing water and overnight use show that the plant becomes more water efficient with increasing the number of cattle slaughtered per day. The reduction in the water mainly is because of the un-automated processes water use. For example, the water used for overnight cleaning of the facility is not relevant to number of heads slaughtered and almost constant every day, as shown in Figure 4.5, therefore assuming the same amount of water used each day for cleaning, and normalizing it by the actual number of heads slaughter would show a decreasing trend. Similar trend may be expected for the viscera processing.

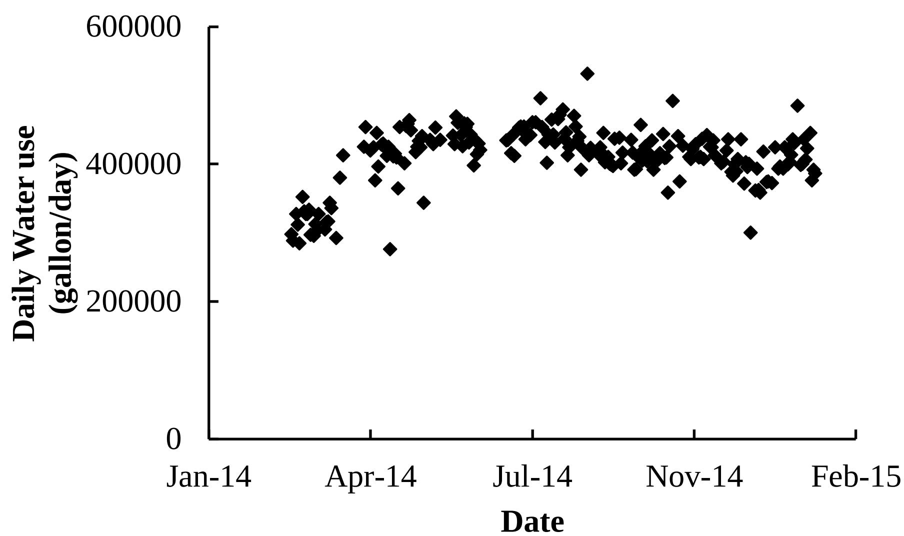


**Figure 4.5: Overnight water use.**

The trend lines for the antimicrobial interventions are relatively flat as the water use values and range are smaller that processing water and overnight use. Among the antimicrobial interventions, the carcass wash had the most increasing slope. However, it is not clear why the reason the water use of the carcass increases with increasing the operating capacity. Furthermore, the increasing trends of the antimicrobial interventions are considered much lower than the negative trends for the processing water and the overnight use. Because the antimicrobial interventions consumed less than 16% of the processing water, the increasing trends of the antimicrobial interventions have minimal effect on the trend of the overall processing water.

### *4.1.2 Electricity*

Electricity is widely used in a beef packing plant, especially for cooling and to operate pumps and conveyers. Data loggers were programed to record average power use (kW) on 5 minutes intervals. A summary of collected electricity use, normalized as kWh/ head and MJ/1000 lb. LW, is provided in Table 4.3.

**Table 4.3: Summary of electricity use at the beef packing plant**

| | Electricity use | | |
|---|---|---|---|
| Use | kWh/head | MJ/1000 lb. BW | % |
| Pre-evisceration wash | 0.02 | 0.05 | <1 |
| Organic acid cabinets | 0.01 | 0.03 | <1 |
| Carcass wash | 0.28 | 0.73 | 1.5 |
| Thermal pasteurization | 0.34 | 0.88 | 1.8 |
| Viscera processing | 0.04 | 0.10 | <1 |
| Cooling | 17.55 | 45.55 | 91 |
| Hydraulic system | 1.07 | 2.78 | 5.5 |
| **Total** | **19.31** | **50.12** | **100** |

The total electrical energy consumed by antimicrobial interventions was minimal (less than 6%). Most of the antimicrobial interventions use pumps, fans and vacuums that are low electric consumers. The cooling system and hydraulic systems, which use several compressors and high capacity pumps, were the largest electric consumers.

### *4.1.3 Natural Gas*

Natural gas is mainly used for water heating in the beef packing plant and a small portion for building heating. The average metered daily natural gas consumption of the plant for June, 2014 was 668,400 cft./day. The calculations suggested that about 11.5% of the daily natural gas consumption was used by the antimicrobial interventions, as listed in Table 4.4.

**Table 4.4: Estimated natural gas use at the beef packing plant**

| | Natural gas use | | |
|---|---|---|---|
| Use | cft./ head | MJ/ 1000 lb BW | % |
| Pre-evisceration wash | 6.5 | 5.12 | 2.2 |
| Organic Acid cabinets | 2.8 | 2.25 | 0.9 |
| Carcass wash | 18.2 | 14.43 | 6.2 |
| Thermal Pasteurization | 6.4 | 5.05 | 2.2 |
| Viscera processing | 70.1 | 55.46 | 23.9 |
| Overnight | 106.2 | 84.00 | 36.1 |
| Unaccounted | 83.7 | 66.23 | 28.5 |
| **Total** | **293.9** | **232.5** | **100** |

Among the antimicrobial interventions, the carcass wash was the highest natural gas consumer. Because the thermal pasteurization system recycles hot water, it also recycles heat energy. The manufacturer’s recommended recycled and make-up water use for a hot water thermal pasteurization system is 50 gal./head. At this plant, the recycled water temperature was measured at an average of 140˚F. The mass and energy balance analysis shows that using a water recycling system reduces the natural gas use by about 64%.

The overnight use and the viscera processing used 64.9% of the total natural gas used at the plant. Unaccounted for uses consumed an estimate of 28.5% of the total natural gas used at the plant. Those unaccounted for uses included, but not limited to, uses on the fabrication floor, heating of unmetered water, heat losses during conveyance, pipe leaks and other uses on the plants wastewater treatment facility.

The energy used to heat water may vary significantly from plant to plant due to boiler and piping efficiency which is influenced by the plant age and size. In addition, different types of fuels may be used such as methane or diesel. But the water heating data at this plant provide a general sense on where the energy for heating water is required in the plant.

The combined electricity and estimated natural gas energy was 283 MJ/ 1000 lb. BW or 363 MJ/ head. The total energy use (MJ/1000 lb. BW) at the beef packing plant is shown in Figure 4.6. The antimicrobial interventions used 10% of the total energy in the plant, while viscera processing, overnight and cooling used 65% of the total energy used. This suggest that any improvements in the energy use of these processes would effectively impact the plants total energy use. Processes like viscera processing and overnight cleaning of the facility, which have greater variability in the water use and done manually, can be further studied and evaluated for potential water and energy savings. However, this energy breakdown is considered plant specific and depends on many factors as explained earlier. The unaccounted energy use, which includes unmetered water, leaks, etc., is considered relatively high, however the focus in this study was on the antimicrobial interventions. .

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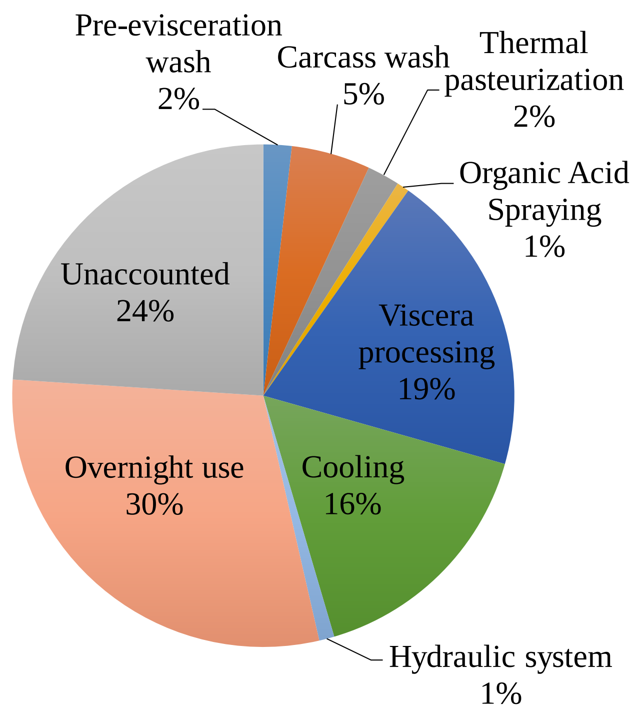


**Figure 4.6: Total energy use at the beef packing plant** (MJ/1000 lb. BW)

Although energy use is considered plant specific and system boundaries maybe different, the historical energy uses of beef packing plants, shown in Table 2.1, suggest that there may have been important improvements in the energy efficiency of beef packing plants in the US.

## 4.2 Wastewater Load Analysis in a Beef Packing Plant

### *4.2.1 Introduction*

Wastewater samples were collected at the system boundaries as explained in Table 3.2 in two sampling events. The sampling was done in beginning of January and the end of March 2015 (every quarter year). The Appendix provides supplemental in information about the sampling and testing methods. Between the sampling events, the plant made several changes on its wastewater management system in efforts to improve their wastewater treatment efficiency. The goal of the wastewater testing in this plant was to verify wastewater sampling and testing methods and to define basic loadings and characteristics to help understand wastewater load generation in the plant. The tests were performed at the Environmental Engineering lab at the University of Nebraska-Lincoln.

### *4.2.2 Present data*

In the Midwest, most of the cities regulate beef packing plants wastewater discharge to collection systems based in BOD and TSS. Nonetheless, some cities include other parameters such as oil and grease. If a plant discharges its wastewater directly into a water body, its discharge permit may include nutrients. A brief survey was done to collect wastewater regulatory parameters and results are provided in the Appendix. In this preliminary study, BOD, COD, TSS, pH and conductivity were reported.

Due to the high strength of the wastewater, wide ranges in the characteristics were found in the collected samples. Table 4.5 lists the average and standard deviation (ST.D) of the wastewater characteristics for each of the sampling events. The results of the BOD test of the Viscera processing in the second sampling event did not fall within the standard methods acceptable criteria, therefore it was eliminated. This suggests that the testing methods need to be reviewed in order to reduce the variability. The testing at the external lab was done based on one grab samples at the antimicrobial interventions (results provided in the Appendix, Table A.3). Since the wastewater parameters depend on the location, sampling techniques and time of the day for some locations (where water recycling is used), the results from the external lab were significantly different from the data presented here.

**Table 4.5: Wastewater characteristics average and (ST.D) for two sampling events.**

| | Sampling Event No. 1 | | | Sampling Event No. 2 | | |
|---|---|---|---|---|---|---|
| Wastewater production | BOD(ST.D) mg\L | COD(ST.D) mg\L | TSS(ST.D) mg\L | BOD(ST.D) mg\L | COD(ST.D) mg\L | TSS(ST.D) mg\L |
| Pre-evisceration wash | 6091(1639) | 7890(1195) | 2804(153) | 1106(383) | 1560(30) | 300(187) |
| Organic Acid spraying | 5491(1179) | 5920(142) | 208(77) | 18900(0) | 25275(65) | 575(164) |
| Carcass wash | 2802(141) | 3343(29) | 1612(577) | 3458(808) | 3720(300) | 1300(308) |
| Thermal pasteurization | 3626(3070) | 5429(3800) | 2154(1535) | 6375(1637) | 6775(255) | 2125(383) |
| Viscera processing | 2736(450) | 7775(15) | 2370(307) | -[a] | 27140(410) | 9767(544) |
| Overnight use | 764(257) | 3065(252) | 942(430) | 1907(363) | 5648(4584) | 1383(840) |

[a] did not fall within the standard methods acceptable criteria

Table 4.5 shows notable differences between the two sampling events at most of the locations. The carcass wash had the least BOD and COD standard deviation in the two sampling events. Generally, the standard deviations in the second sampling event were lower, since experience was gained in sampling and testing from the first sampling event. The samples for the overnight use were collected using an automatic sampler located in a wastewater collection basin where all wastewater form the plant was screened and drained. The difference in the wastewater parameters may have been due to the difference in the automatic sampler tube position (top verses bottom). Also, the rotor screen was changed between the two sampling events. Organic acid spraying had the largest difference between the wastewater parameters in the two sampling events; however the results of the second sampling event are closer to the results of the samples done at external lab (provided in the Appendix). The standard deviation for the thermal pasteurization was noticed to be higher than the rest of the samples. Since the collected grab samples were tested separately, the standard deviation accounts for the temporal difference in the collected samples. The thermal pasteurization uses a water recycling system, therefore the wastewater quality significantly changes through the day, and therefore the standard deviation is higher. This is also valid for the overnight cleaning wastewater, but standard deviation is lower since water is not recycled and less samples were tested. On the other hand, composite samples had lower standard deviation, since temporal difference in the wastewater quality was eliminated by compositing the samples.

In order to provide a general sense of the wastewater characteristics, average BOD, COD and TSS, pH and conductivity from the two sampling events are listed in Table 4.6. In addition, BOD/COD ratios are provided.

**Table 4.6: Average wastewater characteristics from two sampling events**

| Location | BOD (mg/L) | COD (mg/L) | TSS (mg/L) | BOD/COD ratio | pH | Conductivity (µs/cm) |
|---|---|---|---|---|---|---|
| Pre-evisceration wash | 3599 | 4725 | 1552 | 0.80 | 8.29 | 755 |
| Organic acid spraying | 12195 | 17398 | 392 | 0.70 | 2.79 | 1669 |
| Carcass wash | 3130 | 3532 | 1456 | 0.89 | 8.30 | 690 |
| Thermal Pasteurization | 5001 | 6102 | 2139 | 0.84 | 7.93 | 759 |
| Viscera processing | 2736 | 17458 | 6068 | 0.16 | 8.56 | 820 |
| Overnight use | 1335 | 4357 | 1163 | 0.31 | - | - |

As listed in Table 4.6, the BOD/COD ratio for the collected samples was within a reasonable range except for the viscera processing and overnight use. There are several of explanations why a BOD/COD ratio could be low. Since a spectrometric method was used to measure the COD of the samples and wastewater samples were turbid, the results of the COD test maybe overestimated. In addition, different chemicals are used in cattle viscera processing and may serve as inhibitors to the bacteria in the BOD test.

The pH values of all the sampling points were above 7 except for the organic acid spraying. Since organic acids are mixed with water to achieve the required log disinfection, it was expected that the wastewater pH would be this low. Streams with low pH may have implications for subsequent biological treatment processes if not neutralized through dilution or pH adjustment.

Generally, electrical conductivity is a function of cations and anions present in the sample and the presence of oils and fats wastewater reduce the electrical conductivity. Since the water use and contact time between the organic acid solution and a beef carcass was less than of the rest of the antimicrobial interventions, less fat were observed in the wastewater collected for the organic acid spraying. Therefore, the electrical conductivity of the organic acid spraying was much higher than the rest of the antimicrobial interventions.

To understand the relative wastewater load generation within the plant, average BOD, COD and TSS were combined with water use data, as shown in Figure 4.7. The BOD load of the viscera processing and the overnight use was 0.2 lb. BOD/ 1000 lb. BW and 0.1 lb. TSS/ 1000 lb. BW, which are similar to what was reported in the literature (Macon and Cote 1961; US-EPA 1974). Figure 4.7 shows that that viscera processing and overnight use produce most of the wastewater loadings of BOD, COD, and TSS. On the other hand, wastewater productions of antimicrobial interventions were much lower. The relative proportions of antimicrobial interventions production of BOD load were higher than COD and TSS load.

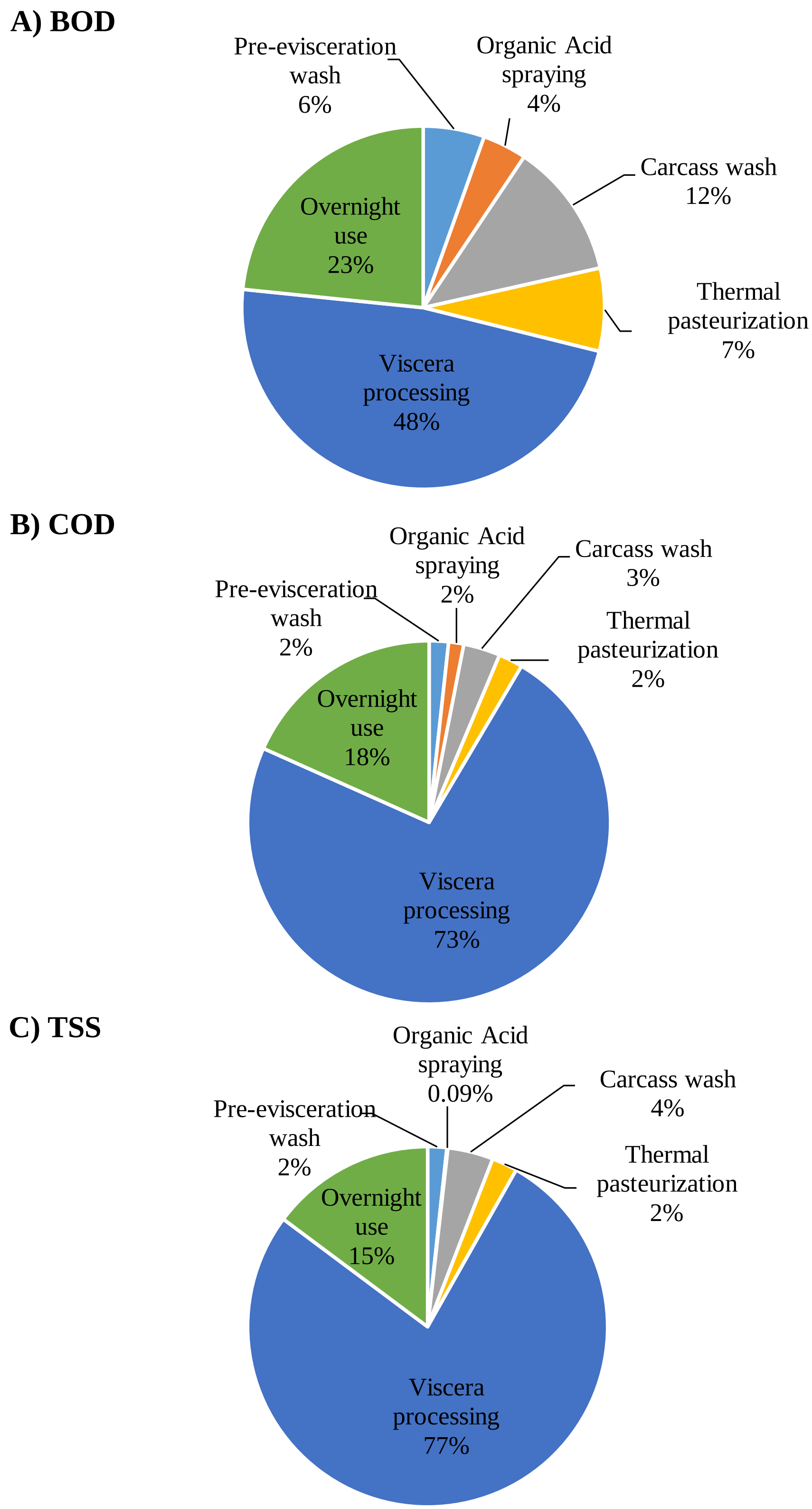


**Figure 4.7: Wastewater loading breakdown in a beef packing plant**

### *4.2.3 Preliminary conclusions*

Although only two sampling events were done in this study, the wastewater testing highlighted important preliminary data about the wastewater production within the plant. The wastewater analysis of the beef packing plant concluded the following points

- The characteristics of the wastewater produced with the plant are of high strength, which affect wastewater management strategies within the plant that aims at meeting the regulatory discharge criteria.
- A notable variability in the results between the two sampling events was noticed. Using a spectrometer method for the COD test may give misleading COD values since the wastewater had high TSS concentrations. Therefore, for some of the processes the BOD/COD ratios were low, which also suggest that inhibitors may have been present in the wastewater giving misleading BOD values.
- Although wastewater streams from antimicrobial interventions were of high strength, their proportion from the COD (9%) and TSS (8%) generation was not as high as their share in the water use (16%) which was higher for the Viscera processing and the overnight cleaning of the plant. Therefore, the wastewater loading from the Viscera processing and overnight cleaning of the facility would have high impact on the environmental sustainability of the plant.
- Wastewater stream from organic acid spraying has low pH (2.79) which could potentially impact downstream biological treatment processes if not neutralized through dilution or pH adjustment.

# Chapter 5 Conclusions and future work

## 5.1 Main conclusions

This study was conducted in one plant and it is realized that each plant is unique and may have limitations based on age, location and efficiency of equipment, but it is believed that findings are representative of the industry, since key antimicrobial interventions are common in the industry. This data provide a general sense of the relative water and energy use, and wastewater production within a beef packing plant and provide insights that are not otherwise available in the technical literature. The following are the main conclusions of this study.

- The total water use of the beef packing plant was 355 gallon/1000 lb. BW, which is a small fraction of the beef industry footprint (334,195 gal./ 1000 lb. BW, Rotz et al. 2013).
- The antimicrobial interventions investigated in this study are the pre-evisceration wash, organic acid spraying, carcass wash and thermal pasteurization. For those antimicrobial interventions, the water (16%), energy (12%), and wastewater production (29% of BOD, 12% of COD and 8% of TSS) is a small portion of the overall use.
- The majority of the water and wastewater generation were from the manual operations, these are viscera processing and the overnight cleaning. Therefore, they introduce high variability into the resource use and wastewater production and have high impact on the sustainability of the plant.

- The variability in the water use was less during the cattle processing period as opposed to cleaning, which suggest that having mechanized processes, like antimicrobial interventions, reduces variability. Also, a decrease in the total water use of the plant was observed as the plant operated at higher capacity. This suggests that the plant becomes more efficient at higher operation capacity.
- Water use distributions for antimicrobial interventions as well as the total water use were presented and summarized to be used in future risk assessment studies.
- The process steps with the highest wastewater loadings are the same as those with the highest water use. Wastewater stream from organic acid spraying has low pH (2.79) which could potentially impact downstream biological treatment processes if not neutralized through dilution or pH adjustment. Wastewater data from the two sampling events was notably variable which suggest that further testing method need to be investigated.

## 5.2 Recommendations for future work

The research presented in this thesis is a part of an ongoing study, which aims at providing more accurate and representative water and energy use and wastewater productions within beef packing plants. Therefore based on this body of research, the following points may be merited in future work.

1) The water and energy quantification approach developed in this study can be used to collect data from other beef packing plants. It is advised to work closely with plants staff and receive their feedback on the findings. Every plant is unique,

therefore the generalized process flow diagram should verified and modified to account for any changes in the plant. If, in a plant, in-line metering are available, they can be used to verify portable meters data. It is suggested using actual meters to quantify water use of viscera processing to analyze its variability. Presenting the data in a normalized way can help evaluate the plant to plant water and energy use differences and also helps in comparing with other agricultural sectors (e.g. pork). If access to multiple plants is available, a comparison between the water and energy use with the plant capacity is expected to show that larger plants are more efficient.

2) Although testing methods used were similar to those used at Omaha's Missouri River Wastewater Treatment plant, wastewater lab, further procedures should be investigated in order to reduce the variability of the test results. Looking at available methods and procedures for sampling and testing of high strength wastewater should be helpful. The influent wastewater at the Wastewater Treatment Plant is not high strength wastewater, since wastewater is pretreated before discharge into the wastewater collection system. It is suggested to dilute the wastewater sample from 10 to 20 times before testing. Diluting the samples would reduce wastewater strength to normal strength, which can reduce the sensitivity of the wastewater tests. Although the COD vials used were high range vials, using a diluted sample would reduce the turbidity of the sample, which would give more accurate COD readings. In addition, spectrometric method verses titration method should be investigated.

3) It is recommended to characterize the wastewater within the plant for oil and grease, proteins and nutrients (for examples TKN, Ammonia-N, TP and Sodium) The need for characterization within a plant is reported by various researchers (Johns 1995; Massé and Masse 2000). In addition, characterizing wastewater streams within the plant would provide data for better wastewater management strategies. Characterizing wastewater streams would highlight streams that potentially affect the performance of subsequence biological treatment processes, e.g. low pH in organic acid spraying. It would also highlight potential opportunities for resource recovery, like proteins.
4) By combining the water use data of antimicrobial intervention processes provided in this study with available literature data, a food risk assessment model can be developed so an analysis can be performed to compare the relative risk reduction and resource use of each process step. Assessing the associated risk with water reduction will help in optimizing the processing to achieve the acceptable risk using less water and energy.
5) No data is available in the technical literature that assesses the risk associated with different cleaning techniques. Facility cleaning consumes the majority of the resources and produces a large load of the wastewater. Assessing the risk of different cleaning techniques to investigate opportunities for water and wastewater minimization would positively impact the sustainability of the beef packing plants. In order to assess this risk, extensive data collection on microbial cross-contamination associated with different cleaning techniques needs be done.

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# Appendix

## Wastewater testing at a beef packing plant

### A.1 Introduction

Wastewater production in food processing is an important environmental and economic factor that is regulated by different agencies. The wastewater produced from beef packing plants are usually of high strength. Many compounds contribute to the wastewater characteristics of a beef packing plant, including blood, fats, grease and organic acids sprayed for disinfection. This appendix describes the sampling and testing program used in this study for wastewater testing at the beef packing plant.

### A.2 Minor objective

The objective of the preliminary wastewater testing in the beef packing plant was to verify wastewater sampling and testing methods and to define basic loadings and characteristics. In addition, to provide a general sense of the relative wastewater loading with the plant.

### A.3 Wastewater characteristics of interest

Regulatory wastewater discharge limits and surcharges for industrial wastewater vary between cities. Also, the wastewater characteristics of concern vary depending on the city. This is highly due to the treatment and dilution capabilities of the cities' wastewater collection system and wastewater treatment plants. Table A.1 summarizes the outcomes of a survey done on industrial wastewater regulations for the Midwest cities.

**Table A.1: Regulatory wastewater characteristics in cities located in the Midwest**

| City | Wastewater Characteristics | Source |
|---|---|---|
| Dodge City, KS | BOD, TSS, TDS, Oil and Grease | http://www.dodgecity.org/documents/3/2014%20Sanitary%20Sewer_201403251128057625.pdf |
| West Point, NE | BOD and SS | http://www.ci.west-point.ne.us/PdfFiles/Minutes/Minutes-March-2-2010.pdf |
| Crete, NE | BOD and SS | http://www.crete-ne.com/documents/20/Crete%20Wastewater%20Facility%20Plan.PDF |
| Lincoln, NE | BOD and SS | https://www.lincoln.ne.gov/city/attorn/lmc/ti17/ch1760.pdf#page=3&view=fitH,350 |
| Wichita, KS | BOD, SS, Oil and Grease | http://www.wichita.gov/Government/Departments/PWU/Pages/WasteWaterTreatment.aspx |

All of the regulatory criteria include BOD and SS as they are a critical wastewater treatment factors. However, in efforts to understanding the wastewater characteristics at different locations, the study considered BOD, COD, TSS, pH and conductivity. The flowing sections briefly explain the sampling and testing protocols used at the beef packing plants.

## A.4 Sampling locations

There are many locations at a beef packing plant where wastewater samples can be obtained. However, the following list shows the sampling locations or system boundaries were wastewater samples were collected for the purpose of this study.

- Pre-evisceration wash cabinet
- Organic Acid spraying
- Carcass wash
- Thermal pasteurization

- Viscera processing
- Overnight use (facility cleaning)

## A.5 Sampling

Obtaining reliable samples is important to minimize error and uncertainty. By insuring the sample truly represents the wastewater stream, using proper sampling, handling and storage techniques of samples increases the reliability of the collected data. Therefore a sampling and testing matrix was developed to insure that the samples collected and tests performed were at a high quality, as shown in Table A.2.

**Table A.2: Wastewater sampling and testing matrix**

| Location | Sampling | Samples tested per event per location | No. of replicates per test | | |
|---|---|---|---|---|---|
| | | | BOD | COD | TSS |
| Pre-evisceration wash, Organic acid spraying, Carcass wash and Viscera processing | A grab sample collected every 2 hours during plant operation. A composite was prepared at the lab for testing. | 1 | 5 | 2+ | 4+ |
| Thermal pasteurization | A grab sample collected every 2 hours during plant operation. Each sample was tested separately | 5 | 5 | 2+ | 4+ |
| Overnight use | An Auto sampler was used to collect a sample every 2 hours from 5 pm to 9 pm. Each sample was tested separately | 3 | 5 | 2+ | 4+ |

To overcome the variability of the wastewater characteristics, time composite samples were prepared at the lab. Water flow data showed that obtaining a time based composite sampling was proper. The collected samples were stored in a cooler with ice till transport to the lab and tested on the same day of collection. The samples were homogenized for at least 5 minutes effort to reduce the sample's heterogeneity. Multiple replicates were tested for wastewater characteristics in order to obtain representative data.

### A.6 Wastewater Testing

Since information about wastewater strengths at the different processes in a beef packing plants is limited in the literature, preliminary tests using a single grab sample at different locations was performed at an external lab ahead of the wastewater testing performed at UNL lab. The results of the tests are shown in Table A.3.

**Table A.3: Wastewater testing results form an external lab**

| Location | COD (mg/L) | BOD (mg/L) | BOD/COD ratio |
|---|---|---|---|
| Pre-evisceration wash | 348 | 218 | 0.63 |
| Carcass wash | 1422 | 1227 | 0.86 |
| Thermal pasteurization | 4200 | 3500 | 0.83 |
| Organic Acid Spraying | 38046 | 19560 | 0.51 |

BOD tests are performed according to Standard Methods for the Examination of Water and Wastewater no. 5210. High purity water was used for dilution water and aerated for more than 24 hours and left at room temperature. The COD tests are performed using Hatch Mercury-Free COD2 reagent UHR vials. COD tests were used to determine the possible BOD ranges. TSS tests were performed using Whatman 934-AH RTU Glass Microfiber filters. Table A.3 shows the BOD dilution ranges used for the purpose of this study. Trials were done to determine whether a seed was needed for BOD test and it was found that not using a seed was proper. Tests performed at the lab gave general sense of the possible BOD/COD ratios.

**Table A.3: Dilutions rate for BOD test**

| Sample volume (mL)<br>*(Added to 300 mL BOD bottle)* | Max. BOD (mg/L) | Min. BOD (mg/L) |
|---|---|---|
| 1 | 2100 | 600 |
| 2 | 1050 | 300 |
| 5 | 420 | 120 |
| 10 | 210 | 60 |
| 0.5 | 4200 | 1200 |
| 0.25 | 8400 | 2400 |
| 0.1 | 21000 | 6000 |
| 0.05 | 42000 | 12000 |