TERTIARY MICROSCREENING OF POULTRY PROCESSING WASTEWATER

by

BRIAN HARRY KIEPPER

(Under the Direction of Daniel L. Fletcher)

ABSTRACT

Two series of experiments were conducted to measure the effects of tertiary microscreening (screen gaps <200 micron) on conventional wastewater constituents, chemical composition and particulate matter in poultry processing wastewater (PPW). The first series of experiments utilized a bench-scale wet sieving apparatus designed to microscreen PPW from three broiler slaughter plants to 50 micron. Results showed that chemical oxygen demand (COD) had the highest (2733) pre-sieve mean concentration (mg/L), followed by total solids (TS) (2304), total volatile solids (TVS) (1822), total suspended solids (TSS) (1129), and total Kjeldahl nitrogen (TKN) (161). Microscreening reduced the concentration of TSS 30%, TVS 19%, TS 16%, and TKN and COD 8% each. Mean concentrations (mg/L) of chemical elements for pre-sieved samples were sodium (Na) 120, potassium (K) 61, phosphorus (P) 34, calcium (Ca) 26, silicon (Si) 14, magnesium (Mg) 9.0, iron (Fe) 2.0, aluminum (Al) 0.6, zinc (Zn) 0.3, copper (Cu) 0.2, manganese (Mn) 0.1, boron (B) 0.4, molybdenum (Mo) 0.02, nickel (Ni) 0.02, and chromium (Cr) 0.01. The percent (%) fat, protein, crude fiber and ash on a dry weight basis of the recovered particulate solids were 55.3, 27.1, 4.1 and 6.1, respectively. The second series of experiments involved utilizing a pilot-scale vibratory microscreen within the wastewater treatment area of a broiler slaughter plant. Secondary-screened PPW was microscreened using three screen gap sizes: 212, 106 and 45 micron. Results showed that COD (3686) had the highest pre-screen mean concentration (mg/L), followed by TS (2726), TVS (2495), TSS (1353), FOG (fat, oil and grease) (848), and TKN (154). Vibratory microscreening reduced TSS 29%, TKN 27%, FOG 25%, COD 13%, and TKN 5%. The mean moisture for all screened samples collected was 79%. The mean percent (%) fat, protein, crude fiber and ash on a dry weight basis, were 64, 18, 5.0 and 1.5, respectively. Results indicate that tertiary microscreening is not effective at reducing chemical elements present in PPW. There were no significant differences in the removal, reduction or recovery rates of the three microscreen gap sizes.

INDEX WORDS: Poultry processing, Wastewater treatment, Microscreening, COD, TSS, TKN

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B.S., Tennessee Technological University, 1985

M.S., The University of Georgia, 2003

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2007

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May 2007

DEDICATION

For Ginny,

"I've had the boyhood thing of being Elvis.

Now I want to be with my best friend, and my best friend is my wife.

Who could ask for anything more?"

- John Lennon

For Bryce and Brant,

"When I was a boy of fourteen,

my father was so ignorant I could hardly stand to have the old man around.

But when I got to be twenty-one,

I was astonished at how much the old man had learned in seven years."

- Mark Twain

ACKNOWLEDGEMENTS

First, I would like to thank Dr. Dan Fletcher for serving as my major professor and for his advice and motivation throughout the years of balancing my full-time work at UGA with part-time graduate school. I would also like to thank Dr. Julie Northcutt and Dr. Bill Tollner for there advice and service as members of my committee.

I would like to thank my colleagues within the UGA Engineering Outreach Service for their encouragement and support over the years. I would also like to thank Dr. Dale Threadgill, the faculty, the staff and the students in the Department of Biological & Agricultural Engineering for their support.

A special thank you goes to Dr. Jackie Sellers for serving on my committee and, as my direct supervisor, provided me the opportunity to attend class and complete research while fulfilling my responsibilities to the Engineering Outreach Service at UGA. As a friend, Dr. Sellers has always encouraged me with his insight and made me laugh daily with his humor. His positive attitude in the face of life’s daily difficulties is an inspiration to all that know him.

Another very special thank you goes to Dr. Bill Merka who has been my teacher, mentor and friend since the first day I stepped onto the UGA campus. It is his knowledge, devotion, and ground breaking work in poultry processing wastewater assessment and treatment that is the true inspiration for the work this dissertation encompasses. From the day we first plunged under a poultry processing wastewater screen together until today, almost ten years later, I continue to learn from him.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Since the implementation of the Clean Water Act and subsequent creation of the United States Environmental Protection Agency (USEPA) in 1972, poultry meat processors have been required to continually improve the quality of their wastewater effluent discharges. At the same time, poultry processing plant water use has substantially increased in response to United States Department of Agriculture (USDA) food safety protocols, such as the Hazard Analysis Critical Control Point (HACCP) and Zero Tolerance for fecal material programs. This increased water use has resulted in a corresponding rise in process wastewater generation that requires more efficient removal of by-products and pollutants that will allow for effluent discharge within established environmental regulatory limits.

Experiments were conducted using tertiary microscreens to maximize by-product and pollutant removal during physical screening, typically the first wastewater treatment unit operation utilized in U.S. poultry processing facilities. During physical screening gross solids, in the form of offal, are removed from the wastewater stream by primary and secondary screens in preparation for further treatment using advanced chemical and biological systems. However, this area of poultry processing wastewater (PPW) treatment has received little attention beyond being viewed as an offal recovery system, while its true potential as an effective wastewater treatment operation is being overlooked.

Screening is the simplest and most inexpensive form of wastewater treatment available to poultry processors. Screens used for poultry processing wastewater treatment come in two main forms (rotary and shaker), and can be classified as Coarse, with screen gaps > 6.0 mm (0.25 in.), Fine, with gaps ranging from 1.5 to 6.0 mm (0.059 in. to 0.25 in.), Very Fine, with gaps from 0.2 – 1.5 mm (0.008 in. – 0.059 in.), and Microscreens, with gaps < 0.2 mm or 200 microns (0.008 in.).

The first series of experiments involved the use of a bench-scale wet sieving apparatus designed to physically microscreen PPW from three southeastern U.S. broiler slaughter plants down to approximately 50 µm (micron). The objectives of the first series of experiments were to measure the effects of bench-scale microscreening on conventional wastewater constituents, selected chemical elements and recovered particulate matter, as well as analyze the variation between multiple slaughter plants over an eight-week time period.

The second series of experiments involved the installation of a pilot-scale ultrasonic vibratory shaker screen within the wastewater treatment area of a southeastern US broiler slaughter plant. Secondary-screened PPW was microscreened using three distinct screen gap sizes: 212, 106 and 45µm (micron). The objectives of the second series of experiments were to measure the effects of vibratory microscreening on conventional wastewater constituents, selected chemical elements and recovered particulate matter, as well as analyze the variation between screen sizes over an eight-week time period.

CHAPTER 2

LITERATURE REVIEW

U.S. Poultry Meat Industry

The operations of the poultry meat industry can be divided into two major categories: production and processing. Poultry production includes all the functions involved in raising flocks of live birds: breeding, hatching, grow-out, feed manufacture, and production waste handling. Poultry processing can be defined as the functions involved in converting a live bird into meat products and by-products: harvesting, slaughtering, further processing, rendering, and processing waste handling (Sams, 2001a; Northcutt, 2001).

Production Levels

Beginning in the mid-1920s, the U.S. has seen a significant rise in the production of commercially raised poultry that continues today at an annual rate of approximately five percent (Romans *et al.*, 1994). From 1960 to 1998 the U.S. annual rate of young chickens or ‘broilers’ slaughtered increased 510 percent from 1.5 billion to 7.8 billion birds (Ollinger *et al*., 2000). Since the late 1940s, southeastern poultry firms have dominated U.S. poultry meat production and processing. In 1992, over 65 percent of broiler slaughter was conducted in the Southeast region (AL, AR, GA, FL, LA, MS, NC, SC, TN), while the Central Atlantic region accounted for 15 percent (DE, MD, VA, WV), and Southwestern states made up 11 percent (TX, OK, AZ, NM, CA) (Ollinger *et al*., 2000).

Today, U.S. poultry processing plants routinely slaughter over 170 million broilers each week. The USDA's National Agricultural Statistics Service (NASS) reported that in 2005, U.S. poultry processing plants slaughtered over 8.9 billion broilers with a combined live weight of more than 47.5 billion pounds (USDA, 2006).

In the late 1940s and early 1950s, rapid advances in the nutrition, genetics, production techniques, processing technologies, disease control and marketing of U.S. poultry resulted in the development of a highly efficient meat producing industry (Fletcher, 2004). In the 1940s it took approximately 16 weeks to produce a 1.5 kg (3.3 lb) broiler using 6 kg (13.2 lb) of feed. Today, it takes only 6 weeks and 3 kg (6.6 lb) of feed to produce a 1.5 kg (3.3 lb) broiler ready for market (Fletcher, 2004).

The growth of the poultry industry worldwide has been attributed to poultry's ability to adapt to most areas of the world, their affinity for rapid growth and generations rates, as well as their low cost per animal unit. Today, due to poultry's ability to be hatched year around and rearing available in climate controlled confinement, birds can be raised in flocks of several thousands rather than as individual animals as in cattle or swine (Fletcher, 2004; Mountney and Parkhurst, 1995). These qualities have allowed for the development of a highly efficient, mass production industry that is dominated by large vertically integrated poultry companies that own and control several, if not all, of the operations of poultry production and processing (Fletcher, 2004; Sams, 2001a). Table 2.1 shows that U.S. per capita consumption of chicken has grown over the last 40 years to the point that it now exceeds the consumption rate of beef (Ollinger *et al.*, 2000).

Broiler Processing

Young chickens or broilers represent 95% of the total number of all types of poultry slaughtered annually in the U.S. (USDA, 2006). Broilers are processed at plants designed to accept live birds and convert them to whole bird carcasses ready for packaging or further processing. Along with edible products, poultry processing plants also produce by-products in the form of blood, feathers and offal. Offal is defined as the inedible viscera removed from the poultry carcass after USDA inspection (Barbut, 2002). The dressed weight of broilers is approximately 72% of live weight with by-products making up the remaining 28% (Barbut, 2002; Mountney, 1989).

The basic automated poultry slaughtering process in use today was established in the late 1960s (Bugos, 1992). For ease of explanation in this document, the processing of broilers is divided into three major categories: First Processing (slaughter through chilling), Second Processing (parts, deboning and portion control), and Third Processing (marination, coating, emulsified and formed products). The ancillary process of by-product rendering is also presented.

First Processing

First processing begins when live birds enter the plant and are stunned, killed and bled. Feathers and viscera are then removed under USDA inspection. The carcasses are chilled in an ice bath and washed, refrigerated, and either packaged or sent to further processing (Barbut, 2002; Barker *et al.*, 2004; Sams, 2001b). First processing commences with delivery of broilers to the processing plant in stacks of cages on flatbed trucks (Northcutt, 2001). The birds are mechanically dumped from the cages onto a conveyor belt that transports them into the hanging room. In the hanging room the birds are manually removed from the conveyor belt and hung by their feet onto a shackle line to minimize struggling and properly position the bird for mechanical killing (Barbut, 2002; Sams, 2001b; Drewniak *et al.,* 1955; Kotula *et al.,* 1961). Once a bird is hung from a shackle it is "stunned" to render it unconscious prior to killing. There are several methods available to stun birds. The most common involves electrical shock delivered when the head of the bird comes in contact with a saline solution that is electrically charged. The electrical charge passes through the bird to the metal shackle line that serves as a ground (Barbut, 2002; Barker *et al.,* 2004; Sams, 2001b; Stadelman *et al*., 1988). Once the bird has been stunned, mechanical devices cut through the jugular veins and carotid arteries on one or both sides of the neck. Once the neck cut is completed, the blood is allowed to drain from the bird for 2 to 3 minutes. During bleed out, 30 to 50% of the blood drains from the bird which leads to brain failure and death (Barbut, 2002, Barker *et al.,* 2004; Davis and Coe, 1954; Sams, 2001b).

Blood volume in broilers has a curvilinear relationship with body weight. As body weight increases the percent of blood decreases. Research has shown that blood will constitute over 11% of the body weight of a 1.0 kg (2.2 lb) broiler, while blood will only represent approximately 7% of the body weight of a 3.0 kg (6.6 lb) broiler (Kotula and Helbacka, 1966; Newell and Shaffer, 1950a, 1950b; Raj, 2004). The USDA (2006) reported that the average live weight of broilers processed in 2005 was 5.4 pounds. Thus a typical plant processing 200,000 birds per day will collect 22,600 to 37,800 pounds of blood. Assuming the specific gravity of blood to be that of water, a typical plant will collect 2,700 to 4,500 gallons of blood per day.

Once the chickens have bled and died they are ‘scalded’ in hot water to ease the removal of feathers. The speed at which feathers are loosened by scalding depends upon the temperature of the water, amount of agitation and the period of immersion (Barbut, 2002; Barker *et al.*, 2004; Romans *et al.,* 1994; Sams, 2001b). Scalded carcasses are then defeathered. One of the most important developments in the modern poultry processing industry was the invention of the rubber-picking finger. By the mid-1940s rubber fingered picking machines had been developed to the point that they had replaced much of the manual labor formally used to remove feathers by hand (Barbut, 2002; Barker *et al.,* 2004). Feathers account for approximately 7.0 percent of a chicken’s live weight and a typical plant processing 200,000 birds per day will collect approximately 72,000 pounds of feathers (Barbut, 2002). Once defeathered, the head and feet are removed either manually or more typically in modern plants, by mechanical devices (Barbut, 2002; Sams, 2001b).

The broiler carcasses are now removed from one shackle line and placed on a separate shackle line to reduce contamination transfer to the relatively cleaner evisceration area (Sams, 2001b). Using various mechanical devices and manual techniques, the viscera of each carcass is then removed from the body cavity and USDA inspected (Barbut, 2002; Barker *et al.*, 2004; Childs and Walters, 1962; Sams, 2001b). Once the viscera are inspected, many plants remove the heart, gizzard, liver, and neck as edible giblets (Barbut, 2002; Barker *et al.,* 2004). The remaining viscera is removed from the carcass and conveyed by water flume or vacuum system to the offal recovery area. Offal accounts for 17.5% of a broiler’s live weight, thus a typical plant processing 200,000 birds per day will collect about 189,000 pounds of offal (Barbut, 2002).

Carcasses are thoroughly washed both inside and out prior to chilling (Barbut, 2002). The USDA requires that broiler carcasses be chilled to at least 4.4^{o}C (40^{o}F) internal temperature within 4 hours of death (Barbut, 2002; Sams, 2001b). Wet or water-ice immersion is the most popular chilling method used in the U.S. today, however air chilling systems are also available (Barker *et al.,* 2004). Research in the late 1950s and early 1960s revealed that slurries of agitated ice and water in vats were the most effective wet method of chilling (Klose *et al.,* 1960; Mickelberry *et al.,* 1962; Tarver *et al.,* 1956). Due to the implementation of the HACCP and Zero Tolerance food safety programs in the U.S., many poultry processing plants have installed final inside and outside high-pressure bird washing stations for post-chilled carcasses (Barbut, 2002; Pearson and Dutson, 1995). This final washing step has led to 1 to 2 gallon per bird increases in plant potable water consumption (Kiepper, 2003; Merka, 2001).

Second Processing

Second processing is defined here as any process in which a chilled poultry carcass is cut up into parts and meat is the separated from bone. Operations in this category include cut-up, tray packing, deboning, MSC (mechanically separated chicken), MDM (mechanically deboned meat), and portion control (Barbut, 2002; Barker *et al.,* 2004; Sams, 2001c). Deboning of poultry parts is accomplished either by hand or mechanical device. Meat that is deboned by hand has a greater value that meat obtained mechanically, but also has a higher cost of processing (Barbut, 2002; Baker and Bruce, 1989). The waste stream from second processing operations is made up almost exclusively of bone, meat, fat and skin. The recovered by-products from second processing wastewater are usually collected and processed by a renderer.

Third Processing

Third processing is defined here to include all the processes that manipulate poultry meat into value-added, convenience foods for consumers (Hedrick *et al.*, 1994). The third processing category includes batter and breading, curing and smoking, marination, bar-b-que, parfrying, fully cooked RTE (ready to eat) products, and IQF (instant quick frozen) (Fletcher, 2004; Harp and Durham, 1963; Keeton, 2001, Owens, 2001). Due to the use of non-poultry meat ingredients, the wastewater generated by plants in this third processing category is similar to bakery wastewater, with large volumes of highly water soluble carbohydrate materials such as flour, sugar and spices (Kiepper, 2003; Merka, 2001).

Rendering

The process of rendering inedible animal products has changed little over the years and basically consists of cooking raw by-product materials (blood, feathers and offal) to remove moisture and collect fat, protein and bone (Barbut, 2002; Grummer, 1992). The separated materials have a greater value than the raw offal material. Also, cooking significantly increases the stability or ‘shelf life’ of the fat and protein by reducing the moisture content and killing the bacteria present in the raw offal (Barbut, 2002; Romans *et al.*, 1994). In general, raw offal contains 50 percent moisture, 25 percent fat, and 25 percent protein and bone (John, 1991). In 1987, poultry processors supplied the U.S. rendering industry with seven billion pounds of raw by-product, which represented 19.5 percent of their total raw material (John, 1991). Four major products are produced as a result of poultry offal rendering: fat in the form of oil and grease, feather meal, poultry meal, and blood meal (Ockerman and Hansen, 2000; Wessels, 1972).

Wastewater

Wastewater can be defined as the remaining spent water that has been used by humans in homes, commercial establishments, industries, public institutions, and similar entities for various purposes (Sincero and Sincero, 2003). Wastewater enters the environment through either ‘point’ or ‘non-point’ sources. Point sources are finite locations, such as pipes, where wastewater enters water bodies. Conversely, wastewater that comes from diffuse sources such as the runoff from agricultural fields or parking lots is defined as non-point (Welch and Lindell, 1992). Point-source wastewater can be divided into two major categories. The first category is referred to as domestic or ‘sanitary’ wastewater because it is associated with human waste. The second category is referred to as industrial process or ‘non-sanitary’ wastewater (Canter and Harfouche, 2000).

Sanitary Versus Non-Sanitary Wastewater

Sanitary wastewater can be defined as water dirtied by human use and includes spent water from restrooms, bathing, and washing of dishes and cloths (Metcalf and Eddy, 1991). Untreated sanitary wastewater is characterized by a grayish-brown color, strong odor and is relatively dilute. The five major constituents of sanitary wastewater that are targeted for removal through treatment are organics, suspended solids, nitrogen, phosphorus, and pathogenic bacteria (CSUS, 1993; Welch and Lindell, 1992). Table 2.2 shows the typical concentration range for the most common constituents measured in raw sanitary wastewater. Sanitary wastewater generation rates range from 45 to 95 gallons per person per day (Metcalf and Eddy, 1991).

Unlike sanitary wastewater, spent process wastewaters from commercial and industrial (e.g., poultry processing) facilities are complex and varied, often containing compounds not found in nature (Eckenfelder, 2000; Liu and Liptak, 2000). In 1990, U.S. industries discharged over 285 billion gallons of wastewater each day (Corbitt, 1990). These non-sanitary wastewaters are often highly discolored, turbid, alkaline or acid and unique to the generating industry (Arundel, 1995; Eckenfelder, 2000). Food processing wastewaters, like those found in poultry processing plants are characterized by high organics and suspended solids that is often ten times the strength of sanitary wastewater (Arundel, 1995; Welch and Lindell, 1992).

Clean Water Act - NPDES

In the 1940s the U.S. government began to institute a series of environmental regulations that would eventually culminate with the Clean Water Act. The original 1948 statute, called the Water Pollution Control Act, authorized the Surgeon General of the Public Health Service to prepare comprehensive programs for reducing or eliminating the pollution of interstate waters (Cheremisinoff, 2002). However, despite these early efforts to control water pollution, by the late 1960s many U.S. rivers were little more then open sewers (Sincero and Sincero, 2003). In 1972, in direct response to several major detrimental environmental events, the Federal Water Pollution Control Act Amendments or 'Clean Water Act' was passed (U.S. Congress, 1972). This legislation totally revised previous laws and established the basis for the regulations we operate under today (Sincero and Sincero, 2003). The amendments of 1972 also led to the creation of the United States Environmental Protection Agency (USEPA) (U.S. Congress, 1972).

Poultry Processing Wastewater (PPW) Characterization and Analysis

Typically, broiler slaughter operations consume 5 to 10 gallons of potable water per bird processed, nearly all of which is subsequently discharged as wastewater (CAST, 1995; Kiepper, 2003, USDA, 1971). Using the typical range of wastewater generated per bird and the annual processing rate of over 8.8 billion broilers (USDA, 2006), total wastewater generation by U.S. slaughter plants is between 44 and 88 billion gallons annually. In addition, this high-strength wastewater is often ten times more concentrated with particulates, organics and nutrients then typical domestic sanitary wastewater (Arundel, 1995; Merka, 1989; Welch and Lindell, 1992). The various tissues of poultry lost to the waste stream during processing account for the majority of the particulates, organics and inorganics in poultry processing wastewater (PPW). However, other potential sources include poultry feed, soil from birds, ingredients used in further processing, cleaning chemicals and incoming potable water.

PPW is most often characterized by the form and concentration of the particulates, organics and selected nutrients it contains. The concentration of organics is most often measured using biochemical oxygen demand (BOD) or chemical oxygen demand (COD). The form and concentration of particulate solids is most often obtained using a series of analytical tests including total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), total volatile solids (TVS), and fixed (or inorganic) solids (FS). The selected inorganic nutrients of nitrogen (N) and phosphorus (P) are also commonly used to characterize PPW due to their direct environmental impact relating to the acceleration of the enrichment process of water bodies known as eutrophication (Eremektar *et al.*, 1999; Welch and Lindell, 1992).

Particulates

Particulates, or solids, refer to any matter suspended or dissolved in a wastewater sample. Solids analyses are important in the control and assessment of wastewater treatment processes (CSUS, 1993). Total solids (TS) is the term applied to the solid residue remaining in a container after the water has been evaporated and the sample dried using method 2540 B. Total Solids Dried at 103-105^{o}C (APHA, 1992) and is expressed as a concentration as milligrams per liter (mg/L). TS can be divided into two subcategories based on particle size or organic content. Particle size is represented by TSS and TDS tests, while organic content is represented by TVS (organic) and FS (inorganic) tests (CSUS, 1993).

TSS is defined as the portion of TS retained by a filter with a nominal pore size of 2.0 µm (micron) or smaller, under specific conditions as described in method 2540 D. Total Suspended Solids Dried at 103-105^{o}C (APHA, 1992). The portion of TS that passes through the filter and remains after evaporation are the TDS as described in method 2540 C. Total Dissolved Solids Dried at 180^{o}C (APHA, 1992). Conversely, in terms of general organic content of TS, fixed solids is the term applied to the residue remaining after the combustion of solids at 500^{o}C (method 2540 E.) (APHA, 1992). The weight loss in TS after ignition is the total volatile solids (TVS). It is important to note that determinations of FS and TVS do not precisely distinguish inorganic from organic matter. The weight loss at ignition is not confined to just the organic matter, but will also include the volatilization of mineral salts (APHA, 1992).

The characterization of wastewater effluent particulates from U.S. poultry processing plants dates back to the late 1960s. Camp and Willoughby (1968) reported broiler processing wastewater levels at 650 mg/L for TS and 196 mg/L for TSS. Carawan *et al.* (1974) reported on a North Carolina broiler processing plant discharging effluent with TS of 697 mg/L and a TSS level of 375 mg/L. In an industry-wide survey published in 1975, the U.S. Environmental Protection Agency reported on the variation in particulate concentration in PPW. The review reported a TSS range of 200 to 700 mg/L and TS range of 600 to 1000 mg/L. Merka's 1989 study of wastewater pollutant concentrations and loadings in a broiler slaughter plant reported that the final plant effluent had an average TSS of 1,446 mg/L and TVS of 1745 mg/L. Rusten *et al.* (1998) analysis of PPW that had passed through a 250 micron rotary screen and a grease trap showed TSS readings ranging from 40 to 3700 mg/L (1360 mg/L average). Particulates wastewater streams have also been isolated within poultry processing plants. Hamm (1972) sampled wastewater from seven discrete processing functions at ten plants and found that the scalder produced wastewater with the highest average TVS (1180 mg/L).

Particle size analysis was conducted in a series of slaughterhouse effluent studies in the late 1980s. These studies showed that 40 to 50 percent of the chemical oxygen demand (COD) in post-screened slaughterhouse wastewater (1.0mm or 1000µm) was coarse, suspended particulates, which were insoluble and only slowly biodegradable (Johns, 1995; Sayed *et al.*, 1987; Sayed and De Zeeuw, 1988). Research using laser diffraction technology has shown that the majority of particles in secondary screen poultry wastewater are found in the 75 to 125 micron range (Kiepper, 2002).

Organics

BOD measures the oxygen consumed by microorganisms in a measured volume of wastewater during the biochemical degradation of organic matter (carbonaceous demand) and oxidation of certain types of inorganic matter such as sulfides and ferrous iron. It may also measure the oxygen used to oxidize reduced forms of nitrogen (nitrogenous demand) unless a specific inhibitor is added prior to testing. The test involves calculating the change in the concentration of dissolved oxygen (DO) after a wastewater sample is held over a 5 day period at $20^{o}C \pm 1^{o}C$ as described in method 5210 B. 5-Day BOD Test (CSUS, 1993; APHA, 1992).

COD is used as a measure of the oxygen equivalent of the organic matter content of a wastewater sample that is susceptible to oxidation by a strong chemical oxidant. Although multiple methods are approved for COD, the most commonly used is the 5220 D. Closed Reflux, Colorimetric Method (APHA, 1992) in which potassium dichromate ($K_2Cr_2O_7$) is used as the chemical oxidant. Because the reagents utilized in the COD test oxidize more of the matter present in a wastewater sample, COD results will be significantly higher than BOD results for the same sample. However, COD can be related empirically to BOD. Since the COD test can be completed within a few hours, it has a distinct advantage over BOD as a wastewater treatment management tool.

One specific classification of organics with special interest in PPW is fat, oil and grease (FOG). In the analysis of FOG (5520 B. Partition-Gravimetric Method, APHA, 1992), an absolute quantity of a specific substance is not measured. Rather, groups of substances with similar physical characteristics isolated based on their common solubility in an organic extracting solvent (CSUS, 1993; APHA, 1992).

The profiling of the organic strength of wastewater effluents from U.S. poultry processing plants dates back to the late 1940s. Porges (1950), Teletzke (1961), and Camp and Willoughby (1968) reported that mean BOD concentration from multiple broiler processing plants were 1275, 664 and 473 mg/L, respectively. In 1969, Nemerow reported a BOD of 630 mg/L when he averaged the results for the processing and sanitation effluents from a broiler slaughter plant. Glide (1968) reported an effluent BOD level of 660 mg/L for a combined poultry slaughter and cannery operation. In addition, Glide noted that the slaughter operation was responsible for 80 percent of the organic load in the wastewater stream.

Carawan *et al.* (1974) reported on a North Carolina broiler processing plant discharging effluent with a BOD of 506 mg/L. In 1973, Singh *et al.* noted the wide fluctuation in BOD concentrations, which averaged 746 mg/L, during monthly testing completed at four Virginia (USA) broiler processing plants. The USEPA (1975) also revealed a wide fluctuation in the concentration of organics in PPW. The industry-wide review reported a BOD range of 500 to 1300 mg/L. A similar fluctuation in BOD concentrations (780 to 1250 mg/L) was reported by a research team led by Chen in 1976 following the sampling of nineteen Mississippi broiler processing plants. Whitehead (1976) reported a final broiler processing plant effluent BOD of 1116 mg/L, with a corresponding COD reading of 1691 mg/L.

However starting in the 1980s, poultry slaughter rates per plant continued to steeply increase as a result of new automated processing systems. As a result, there was a corresponding increase in wastewater pollutant concentrations resulting in mean BOD concentrations commonly in excess 2000 mg/L (Merka, 1989; Merka, 2001).

In 1989, Merka completed a comprehensive study of wastewater pollutant concentrations and loadings in a broiler slaughter plant. The final plant effluent had an average BOD of 2178 mg/L, COD of 3772 mg/L, and FOG of 776 mg/L. Rusten *et al.* (1998) tested PPW that had passed through a 250 micron rotary screen and a grease trap. The BOD levels ranged from 660 to 6400 mg/L (1940 mg/L average), and FOG ranged from 55 to 3570 mg/L (970 mg/L average). Eremektar *et al.* (1999) reported PPW effluent BOD concentrations ranging from 1000 to 2100 mg/L and COD levels of 1500 to 3500 mg/L.

Individual high-strength organic waste streams have also been isolated and analyzed within poultry processing plants. Porges and Struzeski (1962) reported that uncollected blood had a BOD of 92,000 mg/L, and contributed 40 percent of a broiler slaughter plant's final effluent organic load. In 1972, Hamm sampled wastewater from seven discrete processing functions at ten plants and found that the scalder produced wastewater with the highest average COD (2268 mg/L). Woodward *et al.* (1972) reported that 26 percent of a processing plant's BOD load was attributed to the flume transportation of viscera. Approximately seven percent of the BOD load was attributed to the scalder and an additional seven percent to the chiller overflow. Carawan *et al.* (1974) also measured the organic concentration from seven process functions and found the highest contaminations in the giblet chiller (3958 mg/L COD). Whitehead (1976) reported that supernatant from an offal trailer had the highest BOD (7050 mg/L), while chiller overflow has the least (830 mg/L BOD). Lilliard reported in a 1978 study that the highest organic load was produced by a neck chiller (1723 mg/L BOD) and a gizzard splitter (1484 mg/L BOD).

Inorganics

PPW contains small amounts of many inorganic chemical elements that can alter the efficiency of wastewater treatment systems and adversely effect environmental regulatory permits (Arundel, 1995; Merka, 2001). These chemical elements of interest include aluminum (Al), boron (B), cadmium (Cd), calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), magnesium (Mg), molybdenum (Mo), nickel (Ni), phosphorus (P), potassium (K), silicon (Si), sodium (Na), sulfur (S) and zinc (Zn). Inorganic elements, in the nutritive forms of minerals, play important roles in the development and physiology of poultry, and thus a portion of these elements are deposited in the wastewater produced during the processing of poultry. However, the various tissues of poultry are not the only contributors of chemical elements to the wastewater stream. Other sources of chemical elements in PPW include: (1) undigested and partially digested poultry feed, (2) soil from birds, transportation equipment and live haul areas, (3) various solutions used in further processing operations such as marination, (4) various cleaning chemicals used in the plant, and (5) incoming potable water.

Inorganic Elements in Poultry Nutrition

Beyond the gross nutritional requirements for protein, carbohydrates, fats and certain vitamins in poultry diets, chemicals elements play essential roles in poultry development and physiology. In many cases, the required quantities of these elements are small in comparison to the gross requirements, but their roles are essential nonetheless. These elements, often referred to as minerals, are required by poultry for the formation of the skeleton, as integral parts of hormones, as activators of enzymes and for the maintenance of osmotic homeostasis (North and Bell, 1990; Simons, 1986).

Minerals are represented in the inorganic ash left when the organic matter in biological material is completely oxidized and the water is removed. Although the majority of minerals are located within the skeleton, a significant amount is also found is the soft tissues. Minerals make up 3 to 5 percent of the chicken. These chemical elements cannot be synthesized within the body of poultry and thus must be provided in the diet. Nutritive minerals can be divided into four categories: (1) required macrominerals, (2) required microminerals, (3) functionary minerals, and (4) contaminant or toxic minerals. Macrominerals are required in relatively large quantities and are generally expressed as a percentage of a poultry ration.

Macrominerals are most often associated with structured parts and acid-base elements. The macrominerals of importance to poultry nutrition include calcium, phosphorus, potassium, magnesium, sulfur and sodium. Microminerals, or trace elements, are required in relatively small quantities and are most often expressed in parts per million (ppm) within poultry rations. Microminerals are generally associated with the activation of or as integrated parts of enzymes. Microminerals of interest include copper, iron, manganese and zinc. Functional minerals can be defined as trace minerals that may improve growth, feed efficiency and overall appearance, or alleviate toxicity, but are not directly required as an enzymatic factor. The functional minerals of importance include chromium, molybdenum and silicon (Patrick and Schaible, 1980).

Calcium and phosphorus are the two most abundant minerals found in poultry, mainly due to their essential role in bone and egg shell formation (Coon *et al*., 2002; Leske and Coon, 2002). Approximately 99 percent of Ca and 80 percent of P in poultry are found in the skeleton. A Ca-P deficiency results in a condition known as rickets, which is characterized by ‘rubbery’ bones (Patrick and Schaible, 1980). Poultry diets must not only contain the required minimum amounts of calcium and phosphorus, but they must also be present in the correct ratio. A ratio of 1.5 to 2.0 parts of Ca to one part of P is optimum for starting and growing rations (North and Bell, 1990). Phosphorus plays a fundamental role in skeletal and phospholipid membrane structures, ATP energy transfer, enzyme systems, DNA and RNA linkages and fat translocation (Labier and Leclercq, 1994). Phosphorus also constitutes approximately 16 percent of bone ash (Patrick and Schaible, 1980). Within cells, P is key in the phosphorylation of proteins or nucleotides which are the basis for energy transport and hormonal messaging (Labier and Leclercq, 1994; Patrick and Schaible, 1980).

Sodium (Na) and potassium (K) play a critical role in the acid-base equilibrium within poultry physiology. The cells constantly regulate the internal concentration of each mineral in order to maintain their normal function and integrity. The best known of these systems is the sodium pump (Na+ K+ ATPase) which transport sodium from the cell and, inversely, concentrates potassium within it. This pump functions with ATP as a source of energy (Larbier and Leclercq, 1994). Poultry rations usually require supplemental feeding of salt (NaCl) to satisfy the bird’s requirement for sodium (North and Bell, 1990). Due to the possible adverse effects of salt, sodium bicarbonate is often substituted for a portion of the sodium chloride in poultry rations (Leeson and Summers, 2005). On the other hand, potassium is widely found within raw materials of plant origin, and almost always in greater amounts than required by poultry. Thus, poultry feedstuffs are seldom deficient in potassium and supplementation is usually not required (Labier and Laclercq, 1994; North and Bell, 1990).

Magnesium is an essential constituent of tissues and body fluids. It is predominantly present within cells where it is involved in reactions associated with ATP. Therefore all tissue synthesis, together with muscular activity, requires magnesium. Normally, bulk poultry ration ingredients contain adequate levels of magnesium, so supplementation is not required (Labier and Leclercq, 1994; Patrick and Schaible, 1980).

Copper, iron, manganese and zinc are trace elements in poultry nutrition that play critical roles in poultry health and thus must be closely monitored in feedstuffs. Rations containing low levels of these trace minerals cause deficiencies which lead to specific health problems, while high levels result in toxicity (Labier and Laclercq, 1994).

Copper is associated with blood formation, hemorrhages and bone deformities in poultry (Patrick and Schaible, 1980). Red blood cells contain iron, and copper is necessary for iron utilization when hemoglobin is formed, thus low levels of Fe and Cu will lead to anemia. Manganese is abundant in poultry bones and mitochondria. Its chief function in poultry rations is to prevent perosis or 'slipped tendon', a condition where the hock joint becomes enlarged and the gastrocnemius tendon at this location slips from the condyle (Labier and Laclercq, 1994; North and Bell, 1990; Pesti *et al.,* 2005).

Zinc is a co-factor in several essential enzymes including lactate dehydrogenase, alkaline phosphatase and carbonic anhydrase. It is also required for proper feathering and growth. High concentrations are found in the bones and kidneys (Labier and Laclercq, 1994; North and Bell, 1990). In poultry, zinc not only serves as a nutrient, but can also be used as a dietary supplement used for molt induction to initiate a second egg-laying cycle (Park *et al.,* 2004).

Inorganic Elements in Poultry Tissues

The presence and concentration of inorganic elements in poultry tissues has been reported by many researchers. Tamate (1987) and Alcaide-Castinera *et al.* (1995) reported on the mineral and heavy metals contents of retail meat products, including chicken. Maskova *et al.* (1994) documented retentions of Ca, Cu, Na, Fe, K, Mg, P and Zn during cooking of beef, pork and chicken meat. In 1995, Hecht and Kumpulainen analyzed samples of beef, veal, pork, chicken, and turkey meat for Ca, Cd, Cu, Fe, Mg, Mn, Ni, Pb and Zn. In 1999, Demirbas reported on levels of 12 inorganic elements in the hearts, gizzards, livers, spleen and kidneys of chickens. Potassium (K) had the highest average concentration (mg/100g) of the inorganic elements evaluated in hearts (180) and gizzards (237). Phosphorus was the second most prevalent, followed in order by Mn, Na, Mg, Ca, Zn, Fe, Pb, Hg and Cd. Potassium also had the highest average concentration (mg/kg) in liver (216), kidney (222) and spleen (216) tissue. Phosphorus was the second most prevalent, followed in order by Na, Mg, Zn, Ca, Cu, Fe, Pb, Cd, Hg and Mn.

In 2002, Al-Najdawi and Abdullah reported on inorganic element levels in mechanically (MDM) and hand-deboned (HDM) chicken meat. Potassium had the highest average concentration (mg/100g) of the inorganic elements evaluated in both the MDM (474) and HDM (607) samples. Sodium was the second most prevalent, followed in order by Ca, Mg, Fe, Al, Mn and Zn. Calcium had the largest variation between the MDM (196) and HDM (15). This significant difference was attributed to more bone and bone marrow being present in MDM.

Inorganic Elements in Dirt

The dirt that falls from birds and transportation equipment within the live haul areas of poultry processing plants, as well as the dirt washed off of the birds during processing, make a significant contribution to the amount of inorganic chemical elements contained in the wastewater stream. Dirt is a general term that is used to define the unconsolidated, thin, variable layer of mineral and organic material that covers most of the earth's land surface. Oxygen (O) and silicon are the two most abundant elements in the earth's crust (Gardiner and Miller, 2004; Singer and Munns, 1999). Oxygen makes up approximately 49% of the earth's crust, while silicon makes up 31%. Other significant elements in soil (with associated percentage of earth's crust) include aluminum (7.2), iron (2.6), calcium (2.4), potassium (1.5), sodium (1.2), and magnesium (0.9) (Gardiner and Miller, 2004; Singer and Munns, 1999).

Since oxygen is by far the most abundant element in the earth's crust, nearly all groups of soil minerals, including silicates, oxides, phosphates and sulfates, are ionic solids in which O^{2-} is the primary anion. The most common cations in soils are Si^{4+}, Al^{3+}, Fe^{3+}, and Mg^{2+}. However, soil also contains significant amounts calcium, phosphorus, boron, molybdenum, copper, iron, manganese and zinc, in varying amounts and ionic forms. Notably, calcium is more plentiful in soil than any other plant nutrient. Thirteen of the 16-plus essential elements in plants are supplied by soil. These essential elements include three macronutirents (nitrogen, phosphorus, potassium), three secondary nutrients (calcium, magnesium, sulfur), and seven micronutrients (boron, chlorine, copper, iron, manganese, molybdenum, zinc) (Schaetzl and Anderson, 2005). Boron is a nonmetal and forms a weak acid in soils. It is essential in plants for protein and cell wall formation, sugar translocation and pollinations. Copper exist in soils mostly as cupric (Cu^{2+}) and cuprous (Cu^{+}), and is essential in many plant enzymes. Manganese occurs as a Mn^{2+} ion in soils, and is involved in many enzyme systems and in electron transport (Gardiner and Miller, 2004). Zinc, copper, nickel and other metals are found naturally in soils whose parent materials are metalliferous (Gerrard, 2000).

Inorganic Elements in Potable Water

Pure water is a colorless, tasteless, and odorless compound containing only hydrogen and oxygen. In addition, it suspends fine solids (Reynolds and Richards, 1996). Because water that exists at and below the earth's surface is in contact with soil and rock, some portion of minerals contained in the soil and rocks will be dissolved into the water. Because of the properties of water and the properties of each chemical element, the actual occurrence and concentration of an element in natural water can vary widely. When minerals dissolve in water, the chemical element is usually ionized. These ions occur as either cations (positively charged ions) or anions (negatively charged ions). The most abundant cations (>1.0 ppm) found in natural waters are sodium (Na^{+}), potassium (K^{+}), calcium (Ca^{2+}) and magnesium (Mg^{2+}). The major anions (>1.0 ppm) found in natural waters include sulfate (SO_4^{2-}) and silicate (SiO_4^{4-}) (Sullivan *et al.*, 2005). The median concentrations of the major chemical elements found in surface and groundwater are shown in Table 2.3. Minor elements (1.0 ppb – 1.0 ppm) in natural waters include aluminum, boron, chromium, iron, lead, manganese, molybdenum, phosphorus and zinc. Trace elements (<1.0 ppb) in natural waters include cadmium (Cd) and nickel (DeZuane, 1990; Sullivan *et al.*, 2005).

Inorganic Elements in Cleaning Agents

To ensure the continued production of safe and wholesome food products, poultry processors use multiple chemical agents to clean and sanitize plant structures and equipment (Kiepper, 2004). The non-sanitary wastewater produced by these operations is discharged through the process wastewater stream. Most of these cleaning and sanitation chemicals contain chemical elements either in significant quantities as active ingredients or in trace amounts as the result of manufacturing. Sodium and phosphorus are the most abundant elements found in cleaning and sanitation chemicals. Sodium most often occurs within caustic cleaners and sanitizers within sodium hydroxide and sodium hypochlorite solutions. Phosphorus most often occurs in acidic cleaners and sanitizers as phosphoric acid (Kiepper, 2004).

Inorganic Element Analysis in Wastewater

Emission spectroscopy using inductively coupled plasma (ICP) was developed in the 1960s as a rapid, sensitive, and convenient method for the determination of inorganic elements in wastewater samples (APHA, 1992). ICP consists of a flowing stream of argon gas ionized by an applied radio frequency field typically oscillating at 27.1 MHz. This field is inductively coupled to the ionized gas by a water-cooled coil surrounding a quartz ‘torch’ that supports and confines the plasma (APHA, 1992). Wastewater samples with a substantial concentration of TSS must be digested. An aerosol sample is generated in a nebulizer and then carried into the plasma through an injector tube located within the torch. An almost complete disassociation of molecules occurs prior to measurement of elemental concentrations at various spectroscopy wavelengths (APHA, 1992).

Discharge of Inorganic Elements by Poultry Processors

Phosphorus is the only element of the 18 investigated that has received significant attention in scientific literature, due to the potential adverse environmental impact of P discharged from poultry processing plants. In 1999, Eremektar *et al.* reported P levels in untreated poultry processing wastewater. During four separate sampling events, the team reported P concentrations of 48.0, 16.0, 18.0, and 40.0 mg/L. In 1998, Rusten *et al.* reported on effluent from a poultry processing plant that was pretreated using a 250 μm (micron) rotating drum screen followed by a grease trap. Total phosphorus levels ranged from 14.1 to 18.5 mg/L, with an average value of 16.1 mg/L. Pierson and Pavlostathis (2000) reported that post-DAF (dissolved air flotation) wastewater contained total phosphorus concentrations ranging from 5.0 to 20.0 mg/L.

Research conducted in France during the late 1990s revealed that food processing industries contributed 53 percent of the phosphorus entering municipal wastewater treatment facilities (Tusseau-Vuillemin, 2001). The main sources of the phosphorus discharges were from meat processing, dairy industries, and vegetable processing. The majority of the tested industries produced wastewater effluent containing 90 to 500 kg P/day (Tusseau-Vuillemin, 2001). In the U.S., phosphates are widely used in meat processing industries to improve product binding, water holding capacity, yield, and to retard spoilage caused by oxidation (Lin and Lin, 2002). Trisodium phosphate (TSP) has seen wide use in U.S. poultry processing plants. Bender and Brostsky (1991) reported that TSP reduces microbial contamination on carcass surfaces. The USDA has approved TSP to be utilized in poultry processing to reduce possible contamination of *salmonella* (Giese, 1992, 1993) and *Escherichia coli* O157:H7 (Kim and Slavik, 1994).

Proximate Composition

Proximate composition or analysis can be defined as the gross analytical determination of the percentage of various components found in a sample. The various components typically include, but are not limited to, moisture, dry matter, fat, protein, ash and fiber (AOAC, 1995). Proximate composition plays an important role in research due to its ability to provide information on nutritive content, changes during processing, and effects of handling and storage (Iwe and Ngoddy, 1998; Rincon *et al.*, 1998). Moisture content refers to how much water is present in sample. Dry matter refers to the material left over once the moisture has been removed from a sample (AOAC, 1995; Schieber *et al.*, 2005).

In the determination of fat within a sample, an absolute quantity of a specific substance is not measured. Rather, groups of substances with similar characteristics are determined quantitatively on the basis of their common solubility in an organic extracting solvent. The term "fat" is thus defined as any material recovered as a substance soluble in the chosen solvent (AOAC, 1995; APHA, 1992; Harbers, 1994).

Proteins are highly complex polymers, made up of combinations of 20 different amino acids. At the elemental level, proteins contain 50 to 55 percent carbon, 6 to 7 percent hydrogen, 20 to 23 percent oxygen, 12 to 19 percent nitrogen, and 0.2 to 3.0 percent sulfur (Damodaran, 1996). Traditionally, total Kjeldahl nitrogen (TKN) was the analytical method of choice for protein. However, due to growing environmental regulatory pressure associated with the disposal of hazardous materials from the TKN method, the Dumas combustion technique began to receive renewed attention in the late 1980s (Buckee, 1994).

In the Kjeldahl procedure, protein content is determined measuring the amount of nitrogen present in a sample. The protein content can be calculated assuming a ratio of protein to nitrogen for the specific sample being analyzed. The Kjeldahl procedure is divided into three parts: digestion, distillation, and titration. In the digestion step, organic nitrogen is converted to ammonium sulfate with a catalyst at 370^{o}C. During the second step of distillation, the digested sample is made alkaline with NaOH, and nitrogen distilled off as NH^3 is trapped in a boric acid solution. Finally, the amount of ammonia nitrogen in the solution is quantified by titration with H_2SO_4 (AOAC, 1995).

Ash refers to the inorganic residue remaining after either ignition or complete oxidation of organic matter in a sample (Harber, 1994; Miller, 1996). Three ashing procedures are available: dry ashing, wet ashing, and low-temperature plasma dry ashing. Dry ashing is most popular methods due to its simple procedures, safety, requires no reagents or blank subtraction, and little attention is required from technician once ignition begins (Nielson, 1998).

Fiber is the fraction in foods that contains the cellulose and other carbohydrates which are insoluble and cannot be dissolved by weak acid or alkali solutions (USDA, 1963). Similar to lipids, fiber is defined by the method used to measure it. Both insoluble plant cell-wall materials, primarily cellulose and lignin, and non-starch, water-soluble polysaccharides are components of fiber. This material includes cellulose, hemicelluloses, pectin and lignin (BeMiller and Whistler, 1996). Proximate composition is a proven method of determining the gross constituents found in poultry tissues (Ang, 1986; Barnes and Watts, 1976; Meiners *et al*., 1982; USDA, 1979, 1986; Wladyka and Dawson, 1968; Wu and Shiau, 2002).

Poultry Processing Wastewater Treatment

The majority of the soluble and particulate material in poultry processing wastewater must be removed prior to discharge in order to achieve compliance with established environmental regulations (USEPA, 1975). Depending on the degree of treatment required, poultry processors have the option of utilizing physical separation, physical/chemical treatment and/or biological treatment systems. Each system type possesses unique treatment advantages and operational difficulties.

Physical Separation

Initially, the principle of physically removing the solids from the liquid in wastewater appears simple. However in practice this principle becomes a complex function of interactions between the properties of the wastewater stream being treated and the separation method being utilized. A large variety of physical separation methods are available for the removal of solids from wastewater included in the basic categories of screening, filtration, flotation and sedimentation (Torrens, 2001).

Screening, filtration and dissolved air flotation (DAF) are widely used in the poultry processing industry for the removal of suspended solids and fat, oil and greases (FOG) from wastewater. Technologies exploring the use of alternative separation methods such as electroflotation and ion exchange have been investigated, but inherent technical difficulties or unfavorable economics have prevented widespread use (Bull *et al.*, 1982; Johns, 1995). Also, due to the retention volumes and time required to produce the quiescent environment for the settling of particulates, sedimentation is not a practical method for use within modern poultry processing plants (Torrens, 2001).

Screening

Screening is the placement of a perforated surface in a wastewater stream designed to retain particulate matter greater in size than the surface gap openings (Arundel, 1995). Screens are the most popular form of primary physical treatment used in poultry processing wastewater treatment (Kiepper, 2003). Screens serve a dual purpose. First, screens recover offal that is a valuable commodity for the poultry rendering industry. Second, screens prepare wastewater for further treatment by removing the larger solid particles from the waste stream that might otherwise impede the operation and maintenance of downstream equipment and treatment processes (Pankantz, 1995). Screening is often the first, simplest and most inexpensive form of treatment. Screens used for poultry processing wastewater treatment come two main forms (rotary and shaker), and are often classified as Coarse, with gaps <6.0 mm (0.25 in) Fine, with gaps 1.5 to 6.0 mm (0.059 in to 0.25 in), Very Fine, with gaps 0.2 – 1.5 mm (0.008 in – 0.059 in), and Microscreens, with gaps < 0.2 mm (0.008 in) (WEF, 1998). Screens can be utilized as stand alone units or in series, which allows coarser screens to remove larger particles before further screening by finer mesh units (Laughlin and Roming, 1993). Screens must be sized properly to handle both the hydraulic flow and particle size of the wastewater stream to prevent 'blinding', which is defined as the overload of a screen that results in the coating over of the gaps preventing the passage of water (AWWA, 1977). Common problems associated with screening include mechanical failures and blinding due either to the overloading of the screen or to under sizing of screen gaps (Arundel, 1995; Pankrantz, 1995).

The most common form of screens utilized by the poultry processing industry are rotary types. Rotary or drum screens come in two basic forms: internally-fed and externally-fed. In internally-fed rotary screens, wastewater and associated solids are fed inside a rotating drum. Water drains through the drum surface, while the solids are retained inside and are conveyed to offal handling equipment. On externally-fed units, wastewater and solids flow over the outside of a rotating drum. Wastewater passes through the drum surface, while the solids rotate on the outside of the drum and are scraped off on the opposite side of the entry point. Shaker screens are also used in poultry processing plants, but are less common then rotary screens. Shaker screens utilize a flat perforated platform that is vibrated at a relatively low rate, allowing solids to be retained on the platform while water flows by gravity through the perforated plate (Walsh, 1993). The placement of screens within poultry processing plants is important to their overall effectiveness. In 1976, Mellor and Gardner reported that a Texas broiler slaughter plant reduced BOD from 880 to 680 mg/L and TSS from 1050 to 270 mg/L when they relocated their primary feather and viscera rotary screens from a post-transfer pump position to a pre-pump position at the headworks of the plant's wastewater treatment system. Although virtually all U.S. poultry processing plants utilize screening for the recovery of offal, little published literature exists documenting the effects screening has on wastewater treatment.

Vibratory Screening

Vibratory screening, also referred to as rotating or vibro-energy screening, is defined as the use of countercurrent weights, rotated at a high speed to create a vibrating screen surface that allows the pass through of liquid, while retaining and transporting solids along the screen surface for recovery. Vibratory screens should not be confused with the shaker screens traditionally used in poultry processing to recover offal. Shaker screens utilize the same basic principles as vibratory screens, but operate at a much slower rate. The use of high-speed vibratory screens in the separation of solids from wastewater dates back to the 1950s when municipal wastewater treatment plants in Germany began utilizing vibrating screens for sludge dewatering (WPCF, 1969). In 1968, Fairbank and Bramball reported the first documented use of a vibratory screen in separating livestock wastewater. Their experience treating dairy wastewater emphasized the solid washing characteristics and high-flow capabilities of vibratory screens.

Successful solid separation using a high-speed vibratory flat-panel screen is dependent on establishing a pattern of wastewater travel over the screen surface that gives the desired operating efficiency and final product consistency (Ngoddy, 1974). This pattern is a function of the physical properties of the wastewater, the rotational speed of the countercurrent weights, the nominal gap openings in the screen surface, and the overall angle of the screen panel bed. The net vibrational force is specifically attributed to a complex sinusoidal, multi-dimensional function. However this complex function can be simplified by understanding that both vertical and horizontal forces are acting on the wastewater during vibratory screening (Ngoddy, 1974). The vertical component force is responsible for vertical motion of particles on the screen surface. This force tends to compress the solids and squeeze out liquids. The horizontal component force is responsible for the horizontal flow pattern that moves the dewatered solids across the screen surface for recovery. It is the interaction of these two forces that create the complex function. Vibratory screens serve two functions. The first is to produce a cleaner wastewater and the second is to produce a low moisture 'cake' of solids. Therefore, the measures of vibratory screen performance are most often the reduction in concentration of total solids (TS) in wastewater and the moisture content of the recovered cake (Ngoddy, 1974).

Filtration

Filters work similar to screens, but instead of a perforated surface, a media such as sand, synthetic fibers or membranes retains the particulate matter (AWWA, 1977). As the wastewater is forced through the voids or pores of the filter medium, the particulates are retained on the medium surface or, in some cases, on the walls of the pores (Cheremisinoff, 2002; Dickey, 1961). Unlike screens however, filters are more commonly used to 'polish' wastewater effluents just prior to discharge after the majority of particulates have been removed. This is because poultry processing wastewater particulates are dominated by organic lipid and protein based colloids, which form highly resistant, tight, non-porous cakes during filtration (Cummins, 1942). In 1984, Chang reported that effluent from a dissolved air flotation system at the poultry processing plant had a "very high resistance to filtration", although effective filtration was reported on chiller water effluent. In 1993, Walsh reported on the use of polishing filters at a North Carolina turkey plant that helped eliminate chronic BOD and TSS violations. The use of membrane filtration in poultry processing wastewater has been explored by multiple researchers (Del Pozo *et al.*, 2000; Lo *et al.*, 2005; Shin and Kosink, 1980). However due to concerns with rapid membrane fouling, successful practical applications have been limited to less turbid waste streams, such as chiller effluent and final effluent polishing (Yushina and Hasegawa, 1994; Le Roux and Belya, 1999).

One important phenomena inherent to screens and filters is the retention of particulates smaller than the gap openings in the screen or filter surface. The rate of retention is a complex function of the interactions between the size of the openings, the screen or filter material, and the properties (e.g., structure, components) of the particulates (Logan *et al.*, 1993). Malone *et al.* (1979) determined that 50 percent of particulates with a mean diameter of 16 µm were removed by a 22 µm mesh. Logan (1993) found that 8 percent of particles and 50 percent of the total particulate mass was retained by a 210 µm pore diameter mesh, even though all of the particles were less then 100 µm.

Physical/Chemical Treatment

The most popular form of physical/chemical treatment utilized by U.S. poultry processors is dissolved air flotation (DAF) (Harper *et al.*, 1988). DAF is a process where water-solid separation is achieved by the introduction of fine gas (usually air) bubbles to the wastewater stream. The efficiency of the system is enhanced by the addition of chemicals to adjust pH and improve the flocculation of particulate matter (Karpati and Szabo, 1984; Travers and Lovett, 1985). DAF technology saw widespread application in meat processing plants starting in the late 1970s in Europe, New Zealand and the U.S. aimed at protein recovery from wastewater. It was soon discovered that DAF provided a 75 to 80 percent reduction in biochemical oxygen demand (BOD) (Hopwood, 1977; Johns, 1995).

In DAF systems, wastewater is placed under pressure where it is saturated with air. One the wastewater reaches adequate saturation, the pressure is release and microbubbles form that attach to the solid particles in wastewater causing a solid-gas matrix. The resulting increased buoyancy of the matrix causes it to rise to the surface of the water where it can be collected and removed by mechanical skimming. The use of DAF technology has seen widespread application since the mid-1960s (WEF, 1998). The most important aspect of an effectively operating DAF unit is bubble size (Cassell *et al.*, 1975). DAF units produce bubbles that are microscopic in size.

Typical DAF bubble size distribution is in the range of 10 to 100 μm. DAF bubbles give wastewater a milky white appearance (WEF, 1998). To increase removal efficiencies most DAF systems also utilize a variety of flocculent chemicals that aid in the coagulation of the solid materials in the waste stream (Newswanger and Zuern, 1980). In 1976, Reed and Woodard reported on the critical relationship between pH and aluminum sulfate chemical dosage in DAF units treating poultry processing wastewater. Woodard *et al.* (1977) installed and tested a DAF system in a Maine poultry processing plant and determined the optimum dosages of aluminum sulfate, soda ash, and cationic polyelectrolyte for the treatment system. In 1982, Tookos used pilot plant scale units to show that DAF technology was superior to sedimentation in the treatment of poultry processing wastewater, especially in larger plants. Hopkins (1988) documented that effluent from DAF units treating high strength poultry processing wastewater achieved BOD and TSS levels below 250 mg/L and FOG results less then 100 mg/L. Harper *et al.* (1988) highlighted the importance of frequent jar tests for better pH control, which is critical to optimizing solids removal. The skimmed material from DAF units is considered a viable by-product and is utilized by the poultry rendering industry (Ockerman and Hansen, 2000). The most common problems associated with operating DAF units are mechanical failures and poor solids separation (WEF, 1998).

Biological Treatment

Biological treatment or 'biotreatment' is defined as the treatment of wastewater by microorganisms in a controlled environment. The microorganisms convert biodegradable, organic particles and some inorganic materials in wastewater into a more stable cellular mass that can be separated from the water fraction. Biotreatment systems require little or no chemical inputs, and can achieve greater then 90 percent removal efficiencies of pollutants in poultry processing wastewaters (CSUS, 1992). Typical biotreatment systems include activated sludge systems, lagoons, trickling filters, and septic tanks (Nemerov and Dasgupta, 1991).

Anaerobic digestion results in the conversion of organic matter into methane and carbon dioxide via a series of interrelated microbial metabolisms under 'septic' (no free oxygen present) conditions. Anaerobic digestion has an important advantage over aerobic processes in that power requirements are comparatively minimal since aeration is not necessary for treatment to proceed. However, the low pollutant levels required for the final effluent are typically not achievable anaerobically, hence further treatment under aerobic conditions is usually necessary (Nguyen and Shieh, 2000).

Activated sludge is the most widely used aerobic wastewater treatment process within the poultry processing industry (Kiepper, 2003). An activated sludge system consists of two main process units: the aeration basin and the clarifier. The aeration basin provides an environment for the breakdown of soluble and particulate pollutants by microorganisms known collectively as 'activated sludge'. The clarifier provides a quiescent environment that allows the activated sludge solids to separate by flocculation and gravity sedimentation from the treated wastewater (CSUS, 1992).

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Tables

Table 2.1. Annual U.S. per capita consumption of chicken, turkey, and beef (Lbs.)

Product	1960	1963	1967	1972	1977	1982	1987	1992	1997	1999
Chicken[1]	27.8	30.8	32.4	41.7	40.2	47.0	57.4	67.8	72.7	78.8
Turkey	6.3	6.9	8.7	9.0	8.8	10.6	14.7	17.9	17.6	17.8
Beef	64.2	69.9	78.8	85.1	91.5	76.9	73.7	66.3	66.9	65.4

[1] *Includes broilers and mature hens.*
Ollinger et al., 2000

Table 2.2. Typical composition of raw sanitary wastewater.

Parameter	Unit	Weak	Medium	Strong
Biochemical Oxygen Demand (BOD)	mg/L	110	220	400
Chemical Oxygen Demand (COD)	mg/L	250	500	1000
Total Organic Carbon (TOC)	mg/L	80	160	290
Total Suspended Solids (TSS)	mg/L	100	220	350
Nitrogen (total as N)	mg/L	20	40	85
Phosphorus (total as P)	mg/L	4	8	15
Fat, Oil & Grease (FOG)	mg/L	50	100	150
Alkalinity (as $CaCO_3$)	mg/L	50	100	200
Chlorides	mg/L	3	5	10
Total Coliforms	no/100 ml	10^6 - 10^7	10^7 - 10^8	10^7 - 10^9

mg/L = milligrams per liter, no/100 ml = number of colony forming units per 100 milliliters
Metcalf and Eddy, 1991

Table 2.3. Median concentrations of the major chemical elements in natural waters.

Elements	Surface water (mg/L)	Groundwater (mg/L)
Cations		
Calcium	15.0	50.0
Sodium	6.3	30.0
Magnesium	4.1	7.0
Potassium	2.3	3.0
Anions		
Sulfate	3.7	30.0
Silica	14.0	7.4

Sullivan et al., 2005

CHAPTER 3

BENCH-SCALE TERTIARY MICROSCREENING: EFFECTS OF SLAUGHTER PLANT AND TIME ON GROSS COMPOSITION OF POULTRY PROCESSING WASTEWATER PARTICULATE MATTER[1]

[1]Kiepper, B.H., W.C. Merka and D.L. Fletcher. To be submitted to the *Poultry Science.*

Abstract

Experiments were conducted to compare the effects of slaughter plant and time on the gross composition of particulate matter recovered from poultry processing wastewater (PPW). Composite samples of wastewater from three poultry slaughter plants were collected after secondary rotary screens over eight consecutive weeks. Samples were collected using automatic samplers programmed to collect 1 L of wastewater every 20 minutes for 24 h. Each sample was thoroughly mixed and 60 liters were passed through a series of sieves (2.0 mm, 1.0 mm, 500 µm and 53 µm). The solids recovered from the 53 µm screen were subjected to proximate analysis to determine percent moisture, fat, protein, crude fiber and ash. The fat, protein, crude fiber and ash on a dry weight basis, were 55.3, 27.1, 4.1 and 6.1, respectively. There was a significant difference in protein and ash between slaughter plants. There were no significance differences for any of the analyses when analyzed by week. The variation in gross composition of PPW particulate matter between 53 and 500 µm was more influenced by plant source than week.

Keywords Poultry Processing, Wastewater Treatment, Microscreening, Particulate Matter, Proximate Analysis

Introduction

In 2005, U.S. poultry processors slaughtered 8.9 x 10^9 broilers, producing 16.0 x 10^6 metric tons (35.4 x 10^9 lbs) of ready-to-eat product, representing a 74 percent yield. The remaining 26 percent or 5.5 x 10^6 metric tons (12.2 x 10^9 lbs) of the total live weight of broilers was converted to non-edible poultry by-products, mainly consisting of offal (USDA, 2006). Offal is a general term used to describe inedible poultry by-products that are normally not acceptable for human consumption and typically includes feathers, blood, heads, intestinal tracts and their contents (Barbut, 2002; Romans *et al.,* 1994).

Process wastewater generated at an average rate of seven gallons per bird from carcass and equipment washing is used to transport offal out of plant production areas. Offal handling systems, typically consisting of primary and secondary mechanical rotary screens can be expected to remove up to 75 percent of offal from the wastewater stream. These recovered by-products are used as raw material by the rendering industry to produce fat in the form of oil and grease, feather meal, poultry meal, and blood meal (Ockerman and Hansen, 2000; Wessels, 1972). The remaining 25 percent of smaller particulate solids travel with the wastewater stream to additional chemical and/or biological wastewater treatment processes where these solids must be removed prior to discharge in accordance with current environmental regulations. Although advanced wastewater treatment systems are effective in removing small particulate matter, the processes adulterate and reduce the value of the separated material. Poultry processors often pay to dispose of these adulterated solids.

Published data on the concentration and overall loading of organics, solids, and nutrients in poultry processing wastewater dates back to the late 1940s. Porges (1950) reported that the biochemical oxygen demand (BOD) concentration in wastewater effluent from a broiler processing plant was 1257 mg/L. Extensive data has since been published concerning PPW in terms of analytical parameters required by environmental regulatory permits (Teletzke, 1961; Carawan et al., 1974; Merka, 1989; Rusten, 1998; Eremektar et al., 1999). However, little published data exists on the physical properties or gross composition of the particulate matter contained in PPW, which is essential to the evaluation of advanced physical separation systems. The use of laser diffraction technology has shown that the majority of particles in post-screened poultry slaughter wastewater are found in the 75 to 125 µm (micron) range (Kiepper, 2002). However, no published data exists as to gross composition of this particulate matter. Experiments were conducted to determine the gross composition of fine particulate matter recovered from PPW by wet sieving, and to compare the variation in gross composition across multiple slaughter plants as well as within slaughter plants over time.

Materials and Methods

Three broiler slaughter plants located in the southeast United States were selected for wastewater sampling. A summary of these three plants' processing and wastewater treatment unit operations is presented in Table 3.1. Waste generation in the three slaughter plants is comparable. Offal and wastewater are generated in three major areas of the plant. The kill/defeathering operation combines feathers and uncollected blood in one wastewater stream. A second wastewater stream captures solids, bird wash effluent and equipment washdown water used in the evisceration process. The third area captures the runoff and washdown water from the live haul area where birds are removed from trailers and loaded into the facility.

Sample Collection

A specific sampling site was identified within each facility's wastewater treatment area. Each sampling site was located after both the primary and secondary screens, yet prior to any downstream wastewater treatment units. Each site was within an accessible open channel or pit that allowed for adequate mixing of screen effluents prior to sampling.

Sampling was conducted once per week over a consecutive eight-week period. In each replicate trial, 72 liters of post-secondary screened wastewater were collected from each sampling site using an automatic wastewater sampling unit. Samples were collected using a modified ISCO Model 3700 Auto Sampler (Teledyne-ISCO, Los Angeles, CA) programmed to collect 1 L of wastewater every 20 minutes (3 L per hour) over 24 hours. In the normal configuration, these samplers can collect a maximum of 24 liters of sample. To accommodate the collection of 72 liters of wastewater, the sampler's regular collection base unit was replaced by a 100-liter insulated cooler. The cooler contained sealed ice packs to maintain a temperature below 4^0C.

The three sampling units were then transported to the University of Georgia Poultry Research Center (UGAPRC) in Athens, Georgia (USA), where each facility's composited sample was wet sieved. To obtain a particulate sample, approximately 60 liters of wastewater was passed through a wet sieving apparatus (Barros *et al.,* 2002; Fuller and Butman, 1988; Veehan and Hamelers, 2002). The wet sieving apparatus consisted of a Octagon 2000 sieve shaker base (CSC Scientific, Fairfax, VA), and four stainless steel sieves with nominal gap openings of 2.0 mm, 1.0 mm, 500 µm and 53 µm (Endecotts Ltd., London, UK). To collect a sample, the composited sample in the cooler was well mixed and three liter sub-samples were poured through the apparatus in succession until the entire 60 liter sample was processed. The particulate matter retained by the 53 um sieve (representing the particulate solids between 53 and 500 micron) was then collected, sealed in a 1 L glass jar and held below 4^0C.

Analytical Method

The particulate solids samples were analyzed for moisture, fat, protein, fiber and ash. Moisture was determined using rapid microwave drying method for moisture in meat and poultry products (AOAC Method 985.14). Fat, protein, fiber and ash were determined using AOAC Methods 920.39, 990.03, 962.09 and 923.03, respectively (AOAC, 1995). The percentage of fat, protein, fiber and ash were calculated as percent dry matter using the formula:

*%DM = (% of Constituent in Sample / Reciprocal of % Moisture in Sample)*100*

Statistical Analysis

All laboratory analyses were run in duplicate and averaged. The main effects of plant (3) and replicate, or week (8) were analyzed using the ANOVA option of the general linear models procedures of SAS software (SAS Institute, 1988). The main effects for plant and replicate were determined using the plant and replicate interaction mean square error. Means were separated using Tukey-Kramer Multiple Comparison Procedure (SAS Institute, 1988).

Results and Discussion

The poultry processing and wastewater treatment operations at the three broiler processing facilities are summarized in Table 3.1. Plant A, B and C processed on average 340,000, 245,000 and 140,000 broilers per day during the experimental period, respectively. All three plants also have further processing cut-up operations. All wastewater samples were collected after the secondary wastewater screens.

Table 3.2 summarizes the ANOVA p-values of mean comparisons for fat, protein, ash and fiber for slaughter plants and weekly repetitions. Statistical analysis using ANOVA ($p>0.05$) revealed that there was significant differences in the means for protein ($p=0.0044$) and ash ($p=0.0108$), but no significant difference in the means for fat ($p=0.1752$) or fiber ($p=0.1547$) when comparisons were made between plants. Conversely, there was no significant difference in the means for fat, protein, ash or fiber over time. The variation in gross composition of PPW particulate matter between 53 and 500 µm was more influenced by plant source than week.

The cumulative mean proximate analysis results by plant for protein and ash are shown in Table 3.3. Fat was the predominate constituent in samples recovered from all three plants. The overall average percent dry matter (%DM) for Fat was 55.3%. The second most prevalent constituent in the particulate solids samples was Protein, with an overall average of 27.1%DM. The average for the individual plants for Protein was 22.8% for Plant 1, 33.1% for Plant 2, and 25.4% for Plant 3. Ash had an overall average of 6.1%DM, with individual plant averages of 4.5% for Plant 1, 8.2% for Plant 2, and 5.7% for Plant 3. Finally, Crude Fiber accounted for 4.1% of the overall average DM.

The predominance of fat is significant due to its negative impacts on advanced physical separation systems. Fat recovery in wastewater using either mechanical screens or filters has been traditionally difficult. Membrane and sand filters are even more vulnerable to clogging or blinding from fat in wastewater than mechanical screens. The use of membrane filtration in poultry processing wastewater has been explored by multiple researchers (Del Pozo et al., 2000; Lo et al., 2005; Shin and Kosink, 1980). However due to concerns with rapid membrane fouling, successful practical applications have been limited to less turbid waste streams, such as chiller effluent and final effluent polishing (Yushina and Hasegawa, 1994; Le Roux and Belya, 1999). Fat clogged filters can result in significantly higher costs for filter cartridge or media removal and replacement. Commonly used shaker and rotary type mechanical screens can also have gap openings quickly blinded by fat, causing backups and overflows.

Future sampling of poultry slaughter wastewater is also impacted by the variation in proximate analysis identified in these experiments. To make future work applicable to the entire U.S. poultry processing industry, it is essential that wastewater samples from selected poultry slaughter plants represent the industry as a whole. These results indicate that there is more variation between individual slaughter plants than within a plant over time. Thus, emphasis in future sampling events should be placed on obtaining samples from multiple slaughter plants, with less emphasis placed on obtaining samples over time.

Acknowledgements

This study was supported in part by State and Hatch funds allocated to the Georgia Agricultural Experiment Station and by research funds provided by the United States Poultry & Egg Association (USPOULTRY), Research Project No.601.

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Tables

Table 3.1. Summary of broiler processing and wastewater treatment operations at three southeastern U.S. poultry slaughter plants.

Operation	Plant A	Plant B	Plant C
Birds Slaughtered per Day	340,000	245,000	140,000
Other Processing Operations:			
- Cut-Up	X	X	X
- Marination		X	
- Deboning	X		X
Wastewater Treatment			
- Wastewater Generation (MGD*)	1.75	1.35	0.75
- Physical Systems			
Screen Types*	IR	IR	IR
No. of Screens	3	3	2
Feather Screen Gap Size (µm*)	1588	3175	1500
Viscera Screen Gap Size (µm*)	3175	4550	1500
Secondary Screen Gap Size (µm*)	508	508	508

* *MGD – Million Gallons per Day, IR – Internally Fed Rotary*

Table 3.2. ANOVA p-values for mean comparison of proximate analysis parameters for particulate solids collected by tertiary microsieving of wastewater from three southeastern U.S. poultry slaughter plants.

Main Effect	df	Fat	Protein	Ash	Fiber
Plant	2	.1752	*.0044*	*.0108*	.1547
Rep	7	.3393	.3752	.1937	.2122

Significant differences (p<0.05) in italics

Table 3.3. Proximate analysis percent dry matter (%DM) of particulate solids collected by tertiary microsieving of wastewater from three southeastern U.S. poultry slaughter plants.

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Proximate Analysis	Plant A	Plant B	Plant C	Mean
Fat	-	-	-	55.3
Protein	22.8*b* ± 2.2	33.1*a* ± 2.0	25.4*b* ± 1.9	27.1
Ash	4.5*b* ± 0.8	8.2*a* ± 0.5	5.7*ab* ± 1.0	6.1
C. Fiber	-	-	-	4.1

n=8

CHAPTER 4

BENCH-SCALE TERTIARY MICROSCREENING:

EFFECTS OF MICROSCREENING ON CONCENTRATION OF PARTICULATES, ORGANICS AND INORGANICS IN POULTRY PROCESSING WASTEWATER[1]

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[1]Kiepper, B.H, W.C. Merka and D.L. Fletcher. To be submitted to the *Water Research.*

Abstract

Experiments were conducted to compare the effects of slaughter plant and time on the reduction in concentration of five wastewater analytical parameters and 15 inorganic elements following tertiary microscreening of poultry processing wastewater (PPW). Composite samples of wastewater from three poultry slaughter plants were collected after secondary rotary screens over eight consecutive weeks. Samples were collected using automatic samplers programmed to collect 1 L every 20 minutes for 24 h, and were passed through a series of sieves (2.0 mm, 1.0 mm, 500 µm and 53 µm). Samples of wastewater pre- and post-sieving were collected for analyses. COD had the highest pre-sieve mean concentration (2733 mg/L), followed by TS (2304 mg/L), TVS (1822 mg/L), TSS (1129 mg/L), and TKN (161 mg/L). Mean concentrations (mg/L) of elements for pre-sieved samples were Na 120, K 61, P 34, Ca 26, Si 14, Mg 9, Fe 2, Al 0.6, Zn 0.3, Cu 0.2, Mn 0.1, B 0.04, Mo 0.02, Ni 0.02 and Cr 0.01. There were significant differences ($p>0.05$) in the means of all of the analytical tests for pre- and post-sieve concentration when comparisons were made between plants, with the exception of P, Mo and Ni. There were no significant differences over time. Thus, variation was influenced more by plant source than week. Results indicate that tertiary microscreening would be expected to reduce TSS by approximately 30%, TVS by 19%, TS by 16%, and TKN and COD 8% each. Four of the 7 elements with mean concentrations >1 mg/L (Na, K, P, Mg) were generally unaffected by tertiary microscreening. Ca, Si and Fe had mean percent reductions of 10, 10, and 23 percent, respectively.

Keywords Poultry Processing, Wastewater Treatment, Microscreening, COD, TSS, TKN

Introduction

In 2005, U.S. poultry processors slaughtered 8.9 x 10^9 broilers (USDA, 2006), using an average of seven gallons per bird and generating approximately 60 – 65 billion gallons of high-strength wastewater. Poultry processing wastewater (PPW) is most often characterized by the form and concentrations of the gross organics, particulate solids and selected inorganic chemical elements it contains. The concentration of organics or 'strength' of the wastewater is most often measured using the analytical methods biochemical oxygen demand (BOD) or chemical oxygen demand (COD). Merka (1989) and others have reported BOD mean concentrations in PPW in excess of 2000 mg/L, and values greater than 3500 mg/L for COD.

The form and concentration of particulate solids is most often obtained using a series of analytical tests including total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), total volatile solids (TVS), and fixed (or inorganic) solids (FS) (APHA, 1992). The selected inorganic chemical elements of nitrogen (N) and phosphorus (P) are also commonly used to characterize PPW due to their direct environmental impact relating to the acceleration of the enrichment process of water bodies known as eutrophication (Eremektar, 1999). Total Kjeldahl nitrogen (TKN) is one common analytical method used to determine the concentration of nitrogen in a wastewater sample (APHA, 1992).

PPW also contains small amounts of additional chemical elements that can alter the efficiency of wastewater treatment systems and adversely effect environmental regulatory limits. These chemical elements of interest include aluminum (Al), boron (B), calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), magnesium

(Mg), molybdenum (Mo), nickel (Ni), potassium (K), silicon (Si), sodium (Na), and zinc (Zn). Chemical elements, in the nutritive forms of minerals, play important roles in the physiology and development of poultry, and thus a portion of these elements are deposited in the wastewater produced during the processing of poultry. However, the various tissues of poultry are not the only contributors of chemical elements to the wastewater stream. Other potential sources include: (1) undigested and partially digested poultry feed, (2) soil from birds, transportation equipment and live haul areas, (3) various solutions and other ingredients used in further processing operations such as marination, (4) various cleaning chemicals used in the plant, and (5) incoming potable water.

Most of the organics, particulates and selected inorganic elements in PPW must be removed prior to discharge in order to meet environmental regulatory compliance limits. Poultry processors treat their wastewater streams by first using physical separation to remove and recover gross solids, followed by advanced chemical and/or biological treatment. The most common physical separation method utilized by poultry processors is screening. Screens serve a dual purpose. First, screens recover offal (e.g., feathers, heads, viscera) that is a valuable commodity for the poultry rendering industry. Second, screens prepare wastewater for further treatment by removing the larger solid particles from the waste stream that might otherwise impede the operation and maintenance of downstream equipment and treatment processes (Pankantz, 1995).

Screening is often the first, simplest and most inexpensive form of treatment. However, screens must be sized properly to handle both the hydraulic flow and particle size of the wastewater stream to prevent ‘blinding’, which is defined as the overload of a screen that results in the coating over of the gaps preventing the passage of water (WEF, 1998). Wastewater screens come two main forms (rotary and shaker), and are often classified as Fine, with gaps 1500 – 6000μm (micron) (0.059 in. to 0.25 in.), Very Fine, with gaps 200 – 1550μm (0.008 in. – 0.059 in.), and Microscreens, with gaps < 200μm or 200 micron (0.008 in.) (WEF, 1998). Most poultry processors utilize multiple primary and secondary screens in the Fine and Very Fine range to removed gross solids and particulates prior to advanced treatment systems. However, previous research using laser diffraction technology has shown that the majority of particulate matter in post-secondary screened PPW is found in the 75 to 125 μm (micron) (0.075 – 0.125mm) range (Kiepper, 2002). Thus the majority of particulate matter in PPW is within the microscreening range.

Experiments were conducted to compare the effects of slaughter plant and time on the reduction in concentration of five wastewater analytical parameters and 15 inorganic elements following tertiary microscreening of PPW down to 53 micron. Composite samples of wastewater from three poultry slaughter plants were collected after secondary rotary screens over eight consecutive weeks. COD, TS, TVS, TSS, and TKN were monitored along with Al, B, Ca, Cu, Cr, Fe, K, Mg, Mn, Mo, Na, Ni, P, Si and Zn.

Materials and Methods

Three broiler slaughter plants located in the southeast United States were selected for wastewater sampling, and weekly composite samples were collected as previously described in Chapter 3. Each of the three weekly composite samples was handled in an identical manner. First, the composited sample was well mixed and a 1-liter grab sample was collected in a glass jar. Approximately 60 liters of wastewater was then passed through a wet sieving apparatus (Barros *et al.,* 2002; Fuller and Butman, 1988; Veehan and Hamelers, 2002). The wet sieving apparatus consisted of a Octagon 2000 sieve shaker base (CSC Scientific, Fairfax, VA), and four stainless steel sieves with nominal gap openings of 2.0 mm, 1.0 mm, 500 µm and 53 µm (Endecotts Ltd., London, UK). Effluent from the wet sieving apparatus was collected in a stainless steel bucket. The sample in the bucket was thoroughly mixed and a 1-liter grab sample was collected in a glass jar. The samples were transported to the University of Georgia Water and Feed Laboratory (Athens, Georgia) for analysis.

Analytical Methods

The six (6) weekly pre- and post-sieved wastewater samples were analyzed for the following wastewater parameters using the corresponding standard method (APHA, 1992): COD (5220 D. Closed Reflux, Colormetric Method), TS (2540 B. Total Solids Dried at 103 – 105^{o}C), TVS (2450 E. Fixed and Volatile Solids Ignited at 500^{o}C), TSS (2540 D. Total Suspended Solids Dried at 103 – 105^{o}C), TKN (4500-N_{org} C. Semi-Micro-Kjeldahl Method), inorganic elements (3120B. ICP: Inductively Coupled Plasma).

Statistical Analysis

All laboratory analyses were run in duplicate and averaged. The main effects of plant (3) and replicate, or week (8) were analyzed using the ANOVA option of the general linear models procedures of SAS software (SAS Institute, 1988). The main effects for plant and replicate were determined using the plant and replicate interaction mean square error. Means were separated using Tukey-Kramer Multiple Comparison Procedure (SAS Institute, 1988).

Results and Discussion

As reported in an earlier study, Plant A, B and C processed on average 340,000, 245,000 and 140,000 broilers per day during the experimental period, respectively (Kiepper, 2007).

Conventional Wastewater Parameters

Tables 4.1 and 4.2 summarize the ANOVA p-values of mean comparisons for COD, TS, TVS, TSS and TKN by plant and weekly repetition based on pre-sieve, post-sieve, and microscreening concentration and percent reduction. Statistical analysis ($p<0.05$) revealed that there was significant differences in the means for all of the analytical tests for pre- and post-sieve concentration when comparisons were made between plants. There were also significant differences in means between plants for TVS and TSS for microscreening concentration and percent reduction. However, there was no significant difference in means for concentration and percent reduction for COD, TS and TKN between plants.

When comparisons were made over time, there was no significant difference in the means any of the analytical tests. Thus, the variation in pre- and post concentrations, as well as effects of microscreening concentration and percent reduction for the selected wastewater measurements was more influenced by plant source than week.

The means concentration (mg/L) for pre- and post-sieved wastewater samples, as well as concentration (mg/L) and percent (%) reductions for COD, TS, TVS, TSS and TKN by plant are shown in tables 4.3 through 4.6. Percent reduction was calculated by subtracting the post-sieved from the pre-sieved concentration, and then dividing the difference by the pre-sieved concentration and multiplying the result by 100.

COD had the highest concentrations of the five wastewater parameters tested. The overall COD average for all pre-sieve and post-sieved samples was 2733 mg/l and 2528 mg/l, respectively. TS overall average concentrations were 2304 mg/l for pre-sieved samples and 1932 mg/l for post-sieved samples. The overall TVS average of pre-sieve and post-sieved samples was 1822 mg/l and 1479 mg/l, respectively, while TSS overall average concentrations were 1129 mg/l for pre-sieved samples and 782 mg/l for post-sieved samples. TKN had the lowest concentrations of wastewater parameters tested. The overall TKN average concentration of pre-sieve and post-sieved samples was 161 mg/l and 149 mg/l, respectively.

The pair-wise means comparison showed that there was no significant difference in pre- and post-sieve concentration between Plant A and B for COD, TS, TVS and TKN. However, Plant C had significantly higher concentrations from the other two plants in all four of the parameters. This trend did not extend to the TSS results in which Plants B and C were not significantly different in pre-sieve concentration, however Plant A was significantly lower.

The parameter most affected by the sieving of post-screened poultry processing wastewater was TSS. For all samples analyzed, the overall average reduction for TSS was 30.4%. The average reductions for the individual plants were 27.4% for P1, 37.0% for P2, and 26.8% for P3. The second most prevalent parameter reduction in the samples was TVS. TVS had an overall average reduction of 18.9% for all samples collected. The reduction averages for the individual plants for TVS were 16.4% for P1, 21.9% for P2, and 18.3% for P3. TS had an overall average concentration reduction of 16.2%, TKN 7.8% and COD 7.5%. COD was the least affected by the removal of the solids.

Statistical analysis ($p>0.05$) revealed that there was no significant difference in the means for the reduction in concentration (mg/L) or percentage for COD, TS or TKN when comparisons were made between plants. However, statistically significant differences were seen between the plant means for TSS and TVS.

Results indicate that tertiary screening would be expected to have the greatest impact in reducing TSS, at an average reduction percentage for an individual plant ranging from 27% to 37%. Expected reduction percentages for TVS from tertiary screening would range from 16% to 22%. TS would be expected to be reduced by approximately 16%, while TKN and COD would be reduced by approximately 8%.

Inorganic Elements

Table 4.7 summarizes the mean concentrations of 15 chemical elements in post-secondary screened PPW over a consecutive eight-week period. Sodium had the highest combined mean concentration of 120 mg/L. Na was the only element with concentrations in excess of 100 mg/L. Potassium (61 mg/L), phosphorus (34 mg/L), calcium (26 mg/L) and silicon (14 mg/L) had overall mean concentrations ranging from 10 – 100 mg/L. Magnesium (9 mg/L) and iron (2 mg/L) had overall mean concentrations ranging from 1.0 – 10 mg/L. The remaining eight elements (Al, Zn, Cu, Mn, B, Mo, Ni, and Cr) all had mean concentrations below 1.0 mg/L.

The mean concentrations (mg/L) of Na were significantly different in all three slaughter plants, which were 126.1, 144.2 and 89.3 for Plants A, B, and C, respectively. Notably, the highest mean concentration for sodium was Plant B, which also was the only processing plant that marinates poultry meat as an onsite further processing operation. Sodium is a major component of many marinates and thus is a probable significant contributor to the overall sodium level seen in Plant B's wastewater stream. The mean concentrations of phosphorus (Plant A: 33.9, Plant B: 34.8, Plant C: 31.9) were not significantly different between plants, and were within the range of previous published data for phosphorus levels in pre-screened PPW (Eremektar *et al.,* 1999).

Plant C had significantly higher mean concentrations of calcium (47 mg/L) and magnesium (17 mg/L) then Plants A and B (Ca: 16 mg/L, Mg: 5 mg/L). Plants A and B are located in the same geographic area and are supplied with potable water by the same municipality. Conversely, Plant C pumps potable water from onsite wells. It is probable that the well water used by Plant C is significantly harder than that supplied by the municipality to the other two facilities. Hardness is the term given to the measurement of the concentration of mineral ions in water. Hardness is mainly a measure of the Ca and Mg ions in the form of carbonates, but may also include other minerals as well as bicarbonates and sulfates (DeZuane, 1990).

Tables 4.8 and 4.9 summarize the ANOVA p-values of mean concentrations of the 15 chemical elements by plant and weekly repetition. Statistical analysis ($p>0.05$) revealed Na, K, Ca, Si, Mg, Fe, Al, Zn, Cu, Mn, B, and Cr, all had significant differences when mean comparisons were made between plants. Only phosphorus, molybdenum and nickel had no significant difference when comparisons were made between plants. Conversely, none of the 15 elements showed a significant difference in mean concentrations when comparison were made over time. These results indicates that the overall mean concentration of elements in post-secondary screened PPW will vary significantly from poultry plant to poultry plant, but non-significant variation will occur within an individual plant over time.

Tables 4.10 and 4.11 summarize the reduction in concentration (mg/L) and percentage (%) of the 15 elements following microscreening by wet sieving to 53 microns. Four of the seven elements with overall mean concentrations greater than 1.0 mg/L (Na: 1.1% reduction, K: 0.9% reduction, P: 2.8% reduction, Mg: 2.4% reduction) were generally unaffected by tertiary microscreening, and thus are likely more concentrated in the dissolved or soluble phase of PPW wastewater. The other three elements of calcium, silicon, and iron had substantial overall mean percent reductions of 10.2, 10.3, and 21.3 percent, respectively. However, it is important to note that these three elements also had significant differences in concentration and percent removal rates between plants. As an example, Plant B had a significantly higher ($p<0.0001$) initial concentration (18.1 mg/L) and removal rate (26.3%) for Si than the other two plants (Plant A: 7.4 mg/L and 1.2%, Plant C: 16.4 mg/L and 3.4%). There were no significant differences between plants in concentration or percent reduction for 10 of the 15 elements examined (Na, K, P, Mg, Zn, Cu, Mn, B, Mo and Ni). There were significant differences between plants for Ca, Si, Fe, Al and Cr. Calcium was the only element in which there was a significant difference between plants for reduction in concentration ($p=0.0146$), but not for percent reduction ($p=0.5668$).

Acknowledgements

This study was supported in part by State and Hatch funds allocated to the Georgia Agricultural Experiment Station and by research funds provided by the United States Poultry & Egg Association (USPOULTRY), Research Project No.601.

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Tables

Table 4.1. ANOVA p-values for mean comparisons by plant for wastewater samples collected during tertiary microsieving at three southeastern U.S. poultry slaughter plants.

Test	Pre-Sieve Concentration	Post- Sieve Concentration	Concentration Reduction	Percent Reduction
COD	*.0069*	*.0077*	.4072	.7866
TS	*<.0001*	*<.0001*	.2535	.2575
TSS	*.0003*	*.0041*	*<.0001*	*.0041*
TVS	*.0001*	*.0002*	*.0229*	*.0406*
TKN	*<.0001*	*<.0001*	.0600	.1733

Significant differences (p<0.05) in italics

Table 4.2. ANOVA p-values for mean comparisons by week for wastewater samples collected during tertiary microsieving at three southeastern U.S. poultry slaughter plants.

Test	Pre-Sieve Concentration	Post- Sieve Concentration	Concentration Reduction	Percent Reduction
COD	.6694	.4874	.2635	.0618
TS	.7383	.6983	.7418	.6615
TSS	.6680	.6399	.8498	.8722
TVS	.4468	.5587	.6471	.9003
TKN	.9996	.9999	.6870	.7528

Table 4.3. Pre-sieve mean concentrations (mg/L) of secondary-screened wastewater samples collected at three southeastern U.S. poultry slaughter plants.

Test	Plant A	Plant B	Plant C	Cumulative Mean
COD	2499*b* ± 112	2544*b* ± 166	3157*a* ± 153	2733
TS	2063*b* ± 71	2139*b* ± 24	2709*a* ± 111	2304
TVS	1620*b* ± 77	1673*b* ± 44	2174*a* ± 112	1822
TSS	884*b* ± 46	1255*a* ± 58	1248*a* ± 74	1129
TKN	125*b* ± 4.5	123*b* ± 2.5	236*a* ± 9.5	161

n=8

Table 4.4. Post-sieve mean concentrations (mg/L) of secondary-screened wastewater samples collected during tertiary microsieving at three southeastern U.S. poultry slaughter plants.

Test	Plant A	Plant B	Plant C	Cumulative Mean
COD	2331*b* ± 105	2346*b* ± 133	2906*a* ± 153	2528
TS	1743*b* ± 54	1749*b* ± 49	2303*a* ± 101	1932
TVS	1354*b* ± 69	1306*b* ± 36	1776*a* ± 92	1479
TSS	642*b* ± 37	791*ab* ± 47	913*a* ± 64	782
TKN	117*b* ± 4.3	111*b* ± 2.8	219*a* ± 8.1	149

n=8

Table 4.5. Reduction in concentration (mg/L) achieved by microsieving secondary-screened wastewater samples from three southeastern U.S. poultry slaughter plants.

Test	Plant A	Plant B	Plant C	Mean
COD	-	-	-	206
TS	-	-	-	372
TVS	266*b* ± 24	367*ab* ± 30	398*a* ± 41	344
TSS	242*b* ± 23	464*a* ± 36	335*b* ± 27	347
TKN	-	-	-	12

n=8

Table 4.6. Reduction in concentration as a percentage (%) achieved by microsieving secondary-screened wastewater samples from three southeastern U.S. poultry slaughter plants.

Test	Plant A	Plant B	Plant C	Mean
COD	-	-	-	7.5
TS	-	-	-	16.2
TVS	16.4*b* ± 1.3	21.9*a* ± 1.5	18.3*ab* ± 1.5	18.9
TSS	27.2*b* ± 2.0	37.0*a* ± 2.4	26.8*b* ± 1.8	30.4
TKN	-	-	-	7.8

n=8

Table 4.7. Concentration (mg/L) of 15 chemical elements in secondary-screened processing wastewater collected from three southeastern U.S. broiler slaughter plants.

Element	Plant A	Plant B	Plant C	Cumulative Mean
Sodium (Na)	126.1*b* ± 2.5	144.2*a* ± 7.4	89.3*c* ± 2.7	119.9
Potassium (K)	53.3*b* ± 0.7	41.3*c* ± 0.2	88.3*a* ± 3.1	61.0
Phosphorus (P)	-	-	-	33.5
Calcium (Ca)	17.1*b* ± 0.6	14.6*b* ± 0.4	47.1*a* ± 2.0	26.3
Silicon (Si)	7.38*c* ± 0.34	18.1*a* ± 0.69	16.4*b* ± 0.37	14.0
Magnesium (Mg)	5.36*b* ± 0.09	4.52*b* ± 0.08	17.0*a* ± 0.52	8.96
Iron (Fe)	1.19*b* ± 0.08	2.14*a* ± 0.24	2.15*a* ± 0.11	1.83
Aluminum (Al)	0.30*b* ± 0.02	0.85*a* ± 0.07	0.74*a* ± 0.08	0.63
Zinc (Zn)	0.23*b* ± 0.01	0.24*b* ± 0.04	0.37*a* ± 0.03	0.28
Copper (Cu)	0.26*a* ± 0.01	0.03*c* ± 0.003	0.19*b* ± 0.02	0.16
Manganese (Mn)	0.09*b* ± 0.003	0.07*b* ± 0.004	0.15*a* ± 0.01	0.10
Boron (B)	0.03*b* ± 0.002	0.03*b* ± 0.002	0.05*a* ± 0.003	0.04
Molybdenum (Mo)	-	-	-	0.02
Nickel (Ni)	-	-	-	0.02
Chromium (Cr)	0.011*b* ± .001	0.009*b* ± .001	0.019*a* ± .002	0.01

n=8

Table 4.8. ANOVA p-values for chemical elements with pre-sieve concentration means >1.0 mg/L for secondary-screened wastewater samples collected at three southeastern U.S. poultry slaughter plants.

Main Effect	df	Na	K	P	Ca	Si	Mg	Fe
Plant	2	*<.0001*	*<.0001*	.2069	*<.0001*	*<.0001*	*<.0001*	*.0004*
Rep	7	.9609	.9998	.7067	.9999	.9995	.9999	.8802

Significant differences (p<0.05) in italics

Table 4.9. ANOVA p-values for chemical elements with pre-sieve concentration means <1.0 mg/L for secondary-screened wastewater samples collected at three southeastern U.S. poultry slaughter plants.

Main Effect	df	Al	Zn	Cu	Mn	B	Mo	Ni	Cr
Plant	2	*<.0001*	*.0016*	*<.0001*	*<.0001*	*<.0001*	.7074	.6365	*.0003*
Rep	7	.9393	.3235	.9831	.9899	.6605	.1418	.2878	.5475

Significant differences (p<0.05) in italics

Table 4.10. Reduction in concentration (mg/L) of 15 chemical elements achieved by microsieving secondary-screened wastewater samples from three southeastern U.S. poultry slaughter plants.

Element	Plant A	Plant B	Plant C	Cumulative Mean
Na	-	-	-	1.7
K	-	-	-	0.6
P	-	-	-	1.0
Ca	1.4*b* ± 0.38	1.5*b* ± 0.39	5.9*a* ± 1.89	2.9
Si	0.1*b* ± 0.1	4.8*a* ± 0.43	0.6*b* ± 0.43	1.8
Mg	-	-	-	0.3
Fe	0.2*b* ± 0.07	0.9*a* ± 0.25	0.3*ab* ± 0.13	0.5
Al	0.03*b* ± 0.01	0.28*a* ± 0.08	0.19*ab* ± 0.04	0.17
Zn	-	-	-	0.04
Cu	-	-	-	0.017
Mn	-	-	-	0.009
B	-	-	-	0.003
Mo	-	-	-	0.006
Ni	-	-	-	0.004
Cr	0.003*b* ± 0.0008	0.001*b* ± 0.0007	0.007*a* ± 0.001	0.004

n=8

Table 4.11. Reduction in concentration of 15 chemical elements as a percentage (%) achieved by microsieving secondary-screened wastewater samples from three southeastern U.S. poultry slaughter plants.

Element	Plant A	Plant B	Plant C	Cumulative Mean
Na	-	-	-	1.1
K	-	-	-	0.9
P	-	-	-	2.8
Ca	-	-	-	10.2
Si	1.2*b* ± 1.5	26.3*a* ± 1.9	3.4*b* ± 2.3	10.3
Mg	-	-	-	2.4
Fe	12.0*b* ± 4.6	36.0*a* ± 6.6	15.9*ab* ± 5.7	21.3
Al	11.5*b* ± 3.1	30.8*a* ± 5.2	25.9*ab* ± 3.8	22.7
Zn	-	-	-	13.5
Cu	-	-	-	10.2
Mn	-	-	-	8.6
B	-	-	-	7.7
Mo	-	-	-	17.5
Ni	-	-	-	19.2
Cr	24.7*ab* ± 5.8	14.0*b* ± 6.7	36.9*a* ± 2.3	25.2

n=8

CHAPTER 5

PILOT-SCALE TERTIARY MICROSCREENING:

EFFECTS OF VIBRATORY MICROSCREENING ON GROSS COMPOSITION AND RECOVERY OF POULTRY PROCESSING WASTEWATER PARTCULATE MATTER[1]

[1]Kiepper, B.H., W.C. Merka and D.L. Fletcher. To be submitted to the *Poultry Science.*

Abstract

Experiments were conducted to compare the effects of tertiary microscreen gap size and time on the gross composition and recovery of particulate matter recovered from secondary screened poultry processing wastewater (PPW). A high-speed vibratory screen was installed within the wastewater treatment area of a broiler slaughter plant after the existing primary and secondary rotary screens. Screen panels with nominal gap size openings of 212, 106 and 45 micron were tested. Effluent from the plant's secondary screens was pumped to the vibratory microscreen and particulate matter samples collected one day per week over eight consecutive weeks. The solids recovered were subjected to proximate analysis to determine percent moisture, fat, protein, crude fiber and ash. The average moisture for all samples collected was 79%. The mean percent fat, protein, crude fiber and ash on a dry weight basis, were 64, 18, 5 and 1.5, respectively. Volume of particulate matter recovered was determined by the concentration (mg/L) of total solids (TS) in pre- and post-screened wastewater samples. The mean concentration of TS recovered for all screen runs was 668 mg/L. There was no significant difference in the performance of the three screen sizes with regard to proximate composition or volume of particulate matter recovered.

Keywords Poultry Processing, Wastewater Treatment, Microscreening, Particulate Matter, Proximate Analysis

Introduction

In 2005, U.S. poultry processors slaughtered 8.9×10^9 broilers (USDA, 2006). A typical broiler slaughter facility processing 200,000 large birds a day, weighing an average of 7.0 pounds and with a typical yield of 72 percent, will produce approximately 400,000 pounds of offal (Ockerman and Hansen, 2000). Offal is a general term used to describe inedible poultry by-products that are normally not acceptable for human consumption and typically includes feathers, blood. heads, intestinal tracts and their contents (Barbut, 2002; Romans *et al.,* 1994).

Typical offal handling systems, consisting of primary (typically with 1500 to 3000 micron gap openings) and secondary (typically with 250 to 500 micron gap openings) mechanical screens, can be expected to remove about 75 percent of the offal in the form of macro-solids from the wastewater flumes (feather and viscera) exiting the production floor. These macro-solids are recovered as unadulterated primary offal for sale to the rendering industry. However the remaining 25 percent of smaller particulate solids (approximately 100,000 pounds in the above example) travel with the wastewater stream to additional chemical and/or biological wastewater treatment processes where the vast majority must be removed prior to discharge in accordance with current environmental regulations. These advanced wastewater treatment processes alter or adulterated recovered solids, thus reducing their uses and value. Currently, many poultry processing plants must pay to dispose of these adulterated solids.

The U.S. poultry processing industry would receive substantial economic and environmental benefit by reducing the amount of particulate matter entering advanced wastewater treatment systems through the use of tertiary microscreening (screens with gap openings < 250 microns), thus decreasing wastewater treatment costs and the adulterated solids produced by current slaughter operations.

In this study, a pilot-scale high-speed vibratory screen (Brandt Industries, Houston, TX) was placed subsequent to existing primary and secondary internally-fed rotary screens within a US broiler slaughter plant's wastewater treatment area. Vibratory screening, also referred to as rotating or vibro-energy screening, is defined as the use of countercurrent weights, rotated at a high speed to create a vibrating screen surface that allows the pass through of liquid, while retaining and transporting solids along the screen surface for recovery. Vibratory screens should not be mistaken for shaker screens traditionally used in poultry processing to recover offal. Shaker screens utilize the same basic principles as vibratory screens, but operate at a much slower rate. The use of high-speed vibratory screens in the separation of solids from wastewater dates back to the 1950s when municipal wastewater treatment plants in Germany utilized vibrating screens for sludge dewatering (WPCF, 1977). In 1968, Fairbank and Bramball reported the first documented use of a vibratory screen in separating livestock wastewater. Successful solid separation using a high-speed vibratory flat-panel screen is dependent on establishing a pattern of wastewater travel over the screen surface that gives the desired operating efficiency and final product consistency. This pattern is a function of the physical properties of the wastewater, the rotational speed of the countercurrent weights, the nominal gap openings in the screen surface, and the overall angle of the screen panel bed. Vibratory screens serve two functions. The first is to produce a cleaner wastewater and the second is to produce a low moisture 'cake' of solids. Therefore, obvious measures of vibratory screen performance include the reduction in concentration of total solids (TS) in wastewater and the moisture content of the recovered cake (Ngoddy *et al.,* 1974). The main objective of this study was the increased recovery of fine particulates in the wastewater stream as unadulterated offal. Three microscreen sizes (212, 106 and 45 micron) were evaluated. Pre- and post-microscreened wastewater samples were collected and analyzed for TS concentration. The solids retained by each screen size were analyzed for proximate composition to determine moisture, fat, protein, fiber and ash. The appearance and progression of screen blinding was monitored. Statistical analysis was used to compare variation of different screen gap sizes over time. The economic impact of particulate matter removal from post-screened poultry processing wastewater based on increased offal revenue was also evaluated.

Materials and Methods

Microscreening took place within the wastewater treatment area of a southeastern US broiler processing plant that slaughters approximately 340,000 birds per day. All of the whole processed carcasses go on to the cut-up and deboning operations. The plant operates a traditional two-production, one-sanitation shift schedule over a five-day workweek. Wastewater is generated in three major areas of the facility. The first is the kill/defeathering operation area that results in feathers and uncollected blood combining in a water flume. A second area captures the wastewater generated during the evisceration process along with any associated waste from the cut-up and deboning operations. These sources combine into a single 'viscera' wastewater flume. Finally, the third area captures the runoff and clean up water from the live haul area where the live birds are removed from trailers and loaded into the facility.

Within the plant's offal recovery/wastewater treatment area, the feather flume flows to a primary, internally-fed 1588 micron (1/16 or 0.0625 inch gap openings) fine rotary screen. The viscera flume flows through an internally-fed 3175 micron (1/8 or 0.125 inch gap openings) fine rotary screen. Finally, wastewater flow from the live haul area flows into the treatment plant and receives no primary screening. The primary screened wastewater from the feather and viscera flumes and unscreened wastewater from the live haul area combine in an equalization pit. Wastewater is pumped from the pit to a secondary, internally-fed 508 micron (0.020 inch gap opening) very fine wedgewire rotary screen. All of the solid by-products recovered by the screens are conveyed to trailers and transported offsite for rendering.

A pilot-scale two-panel vibratory mechanical screen (Brandt Industries, Houston, TX) was installed adjacent an existing secondary internal rotary screen within the offal recovery area of the plant. Effluent from the secondary screen was pumped to the vibratory screen using a sump pump fitted with a high-pressure hose. A mechanical ball valve was installed on the inlet of the vibratory screen to allow control of influent flow. Effluent from the vibratory screen was collected and sent via a discharge pipe back to the secondary screen effluent stream. The vibratory screen discharge pipe was fitted with an effluent sample port using a standard ball valve. Screen operation involved first installing a set of two screen panels with the same nominal gap sizes (212, 106, or 45 micron). Once the screen panels were installed, the screen was turned on and allowed to come up to operating speed. The screen was operated for approximately 10 minutes per run. An experimental run consisted of operating the screen three separate times (once each with the three screen sizes) during the normal first processing shift.

The order in which screens were used during each experimental run was randomized. One experimental run was conducted per week, over an eight week period. The day per week for each weekly run was selected at random. One-liter grab samples of vibratory screen influent and effluent were collected during each screen run for total solids (TS) analysis. Solids retained on the surface of each set of screens were collected in a large plastic bin. Once an adequate volume was collected, the solids in the bin were mixed and a 1-liter sub sample was collected and placed on ice.

Analytical Methods

The influent and effluent vibratory screen wastewater samples were analyzed for total solids concentration using method 2540 B. Total Solids Dried at 103 – 105^{o}C (APHA, 1992). The particulate solids samples were analyzed for moisture, fat, protein, fiber and ash using proximate composition methods. Moisture was determined using rapid microwave drying method for moisture in meat and poultry products (AOAC Method 985.14). Fat, protein, fiber and ash were determined using AOAC Methods 920.39, 990.03, 962.09 and 923.03, respectively (AOAC, 1995).

Statistical Analysis

All laboratory analyses were run in duplicate and averaged. The main effects of screen size (3) and replicate, or week (8) were analyzed using the ANOVA option of the general linear models procedures of SAS software (SAS Institute, 1988). The main effects for plant and replicate were determined using the plant and replicate interaction mean square error. Means were separated using Tukey-Kramer Multiple Comparison Procedure (SAS Institute, 1988).

Results and Discussion

Table 5.1 summarizes the ANOVA p-values of mean comparisons for moisture, fat, protein, ash and fiber by screen size and weekly repetitions. Statistical analysis using ANOVA (p>0.05) showed no significant difference in the means between the three screen sizes (p=0.9052) for percent moisture. However, there was a significant difference in the percent moisture means when compared over the eight weeks (p<0.0001). Mean separation results for moisture by week are shown in Table 5.2 with significant differences notated. There was no significant difference in the %DM means for fat (p=0.6933), protein (p=0.9613), fiber (p=0.1619) or ash (0.6537) when comparisons were made between the screen sizes. However, statistically significant differences were seen in percent dry matter for fat (p<0.0001), protein (p=0.0009) and ash (p=0.0003) when comparisons were made over time. Fiber means (p=0.0758) were not significantly different over time. Results of the mean separation tests by week for fat, protein, fiber and ash are shown in Table 5.2 with significant differences notated.

The average percent moisture for all samples was 79.1%. Moisture for samples collected from the 212 micron screen ranged from 70.4 to 84.5% (78.6% mean). Moisture of samples recovered from the 106 micron screen ranged from 71.3 to 83.2% (79.2% mean). Moisture content of the samples from the 45 micron screen ranged from 72.2 to 85.5% (79.6% mean). The proximate composition results showed that fat was the predominate constituent in samples recovered from all three screen sizes. The cumulative mean percent dry matter (%DM) for fat was 63.5, protein 17.5, fiber 4.8 and ash 1.5.

The volume of solids recovered during screen runs was calculated using total solids (TS) concentration data collected from the influent and effluent wastewater grab samples. TS are defined as the material remaining once a measured volume of wastewater has been evaporated and the solids dried to remove all moisture. Thus, it can be utilized to accurately calculate how much particulate matter is recovered by a screen per volume of wastewater and this information used to predict total expected additional offal recovery. The difference between the pre- and post-vibratory screened TS results of each sample accurately represented the particulate matter removed by the screen. Statistical analysis ($p>0.05$) showed that there was no significant difference in the means of TS concentration from the three screens ($p=0.8416$). Thus, the overall average of all screens combined (668mg/L) was used for the offal recovery calculations.

The concentration (mg/L) of TS can be converted to a dry matter mass per day using a loadings equation that multiplies the concentration (mg/L) by the daily flow volume in million gallons per day (MGD) and by the conversion factor of 3.79 for kilograms per day (kg/d) or 8.34 for pounds (US) per day (lbs/d). Using this equation the average concentration of TS recovered by microscreening can be converted to an expected daily dry matter mass of additional offal:

(Concentration)	(Flow/Day)	(Conversion Factor)	= Mass/Day
(668 mg/L)	(1.0 MGD)	(3.79)	= 2532 kg/d dry weight
(668 mg/L)	(1.0 MGD)	(8.34)	= 5571 lbs/d (US) dry weight

Proximate composition results showed the mean percent moisture for all samples collected during the experiments was 79.1%:

79.1% Moisture – 100% = 20.9% Dry Matter (DM)

(2532 kg/d dry weight) / (0.209) = 12115 kg/d wet weight offal

(5571 lbs/d dry weight) / (0.209) = 26656 lbs/d (US) wet weight offal

(12115 kg/d wet weight) / (1000 kg/metric ton) = 12.1 metric tons/d wet weight

(26656 lbs/d wet weight) / (2000 lbs/ ton US) = 13.3 US tons/d wet weight

Based on these calculations, a US poultry processing plant producing 1.0 MGD of wastewater per day could expect to recover approximately 12000 kg or 12 metric tons (26500 lbs or 13 US tons) of additional unadulterated offal every day. If the poultry processing plant's offal is valued at 3 cents ($0.03) per pound ($60/ton), then

(13 US tons/day) ($60/ton) = $780/ day, and at 260 processing days per year

($780 /day) (260 days/yr) = $202,800 in additional revenue

Since the value of offal, like other commodities, fluctuates, the additional revenue generated by offal recovery using tertiary microscreening will also fluctuate. Using the calculation above, Figure 5.1 predicts the amount of additional annual revenue that can be expected to be generated from the installation of a vibratory tertiary screen based on an individual plant's flow (0.5 to 2.5 MGD) and current value of offal ($0.01 to $0.05 per lb US).

Acknowledgements

This study was supported in part by State and Hatch funds allocated to the Georgia Agricultural Experiment Station and by research funds provided by the United States Poultry & Egg Association (USPOULTRY), Research Project No.617.

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Tables and Figure

Table 5.1. ANOVA p-values for mean comparison of proximate analysis parameters for particulate solids collected by three tertiary microscreens (212, 106 and 45μm) from secondary-screened poultry processing wastewater.

Main Effect	df	Moisture	Fat	Protein	Fiber	Ash
Screen Size	2	.9052	.6933	.9613	.1619	.6537
Rep	7	*<.0001*	*<.0001*	*.0009*	.0758	*.0003*

Significant differences (p<0.05) in italics

Table 5.2. Mean separation of moisture, fat, protein, fiber and ash by week for particulate solids collected by three tertiary microscreens (212, 106 and 45µm) from secondary-screened poultry processing wastewater.

Week	Moisture	Fat	Protein	Fiber	Ash
1	80.7*ab* ± 0.8	56.7*c* ± 1.2	17.9*ab* ± 0.7	-	2.5*a* ± 0.35
2	80.6*ab* ± 0.2	60.0*bc* ± 1.3	16.8*ab* ± 0.9	-	2.4*a* ± 0.27
3	71.3*d* ± 0.5	73.3*a* ± 2.7	11.1*b* ± 0.2	-	0.9*b* ± 0.03
4	74.0*cd* ± 0.8	76.0*a* ± 3.1	12.8*b* ± 0.8	-	0.9*b* ± 0.07
5	77.8*bc* ± 1.0	70.4*ab* ± 3.2	15.3*b* ± 0.6	-	1.0*b* ± 0.03
6	82.6*a* ± 1.5	58.2*c* ± 1.1	22.3*a* ± 3.7	-	1.2*b* ± 0.12
7	83.3*a* ± 0.1	57.3*c* ± 2.4	22.1*a* ± 0.8	-	1.0*b* ± 0.15
8	82.8*a* ± 1.0	55.8*c* ± 0.6	21.6*a* ± 2.5	-	1.8*ab* ± 0.43
Mean	79.1	63.5	17.5	4.7	1.5

n=3

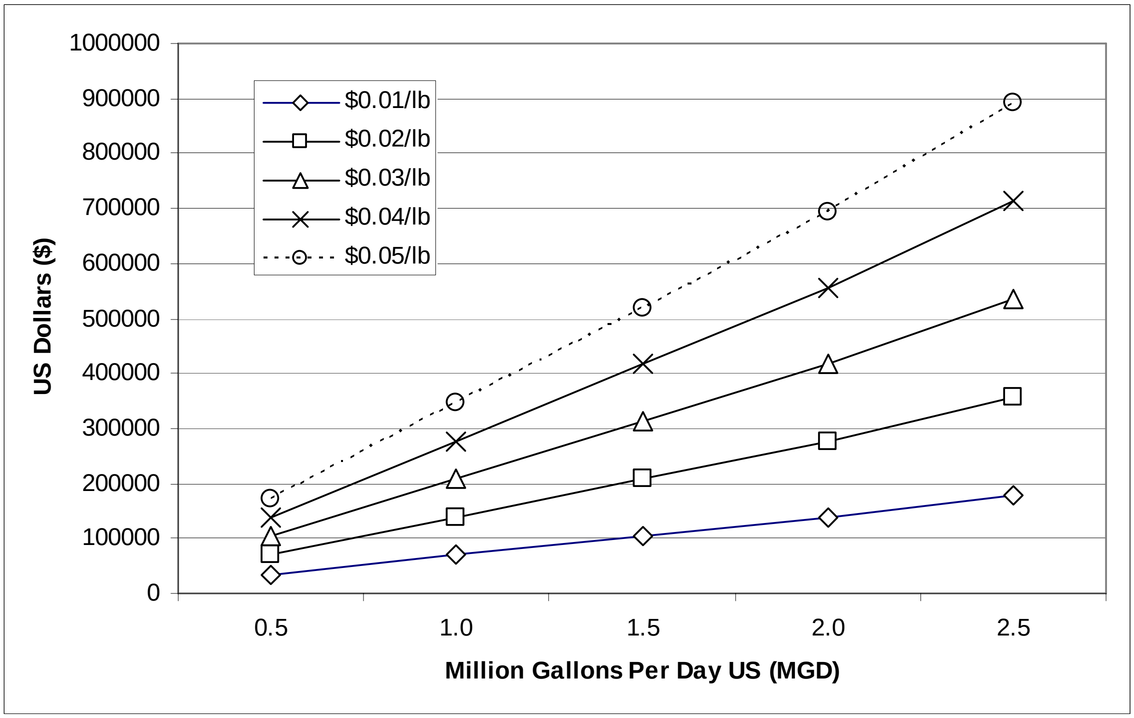

Figure 5.1. Potential additional annual revenue generation from added primary offal recovery from tertiary vibratory microscreening of poultry processing wastewater based on 668 mg/L total solids concentration.

CHAPTER 6

PILOT-SCALE TERTIARY MICROSCREENING:

EFFECTS OF VIBRATORY MICROSCREENING ON PARTICULTES, ORGANICS AND INORGANICS IN POULTRY PROCESSING WASTEWATER[1]

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[1]Kiepper, B.H., W.C. Merka and D.L. Fletcher. To be submitted to the *Water Research.*

Abstract

Experiments were conducted to compare the effects of tertiary microscreen gap size and time on the reduction of selected wastewater analytical parameters and inorganic elements in poultry processing wastewater (PPW). A high-speed vibratory screen was installed within the wastewater treatment area of a broiler slaughter plant after the existing primary and secondary internally-fed rotary screens. Screen panels with nominal gap size openings of 212, 106 and 45 micron were investigated. COD had the highest pre-microscreen mean concentration of the wastewater parameters tested (3686 mg/L), followed by TS (2726 mg/L), TVS (2495 mg/L), TSS (1353 mg/L), FOG (848 mg/L), and TKN (154 mg/L). There were no significant differences in the means for the analytical tests for pre- and post-screen concentrations when comparisons were made by screen size. Conversely, there were significant differences in the means of post-screen samples when comparisons were made over time. The variation in mean concentrations for COD, TS, TSS, TVS, FOG and TKN were more influenced by week than screen size. Results showed that tertiary microscreening can be expected on average to reduce COD by 13%, TS by 24%, TSS by 29%, TVS by 27%, TKN by 5% and FOG by 25%. Average pre-screened concentrations (mg/L) for inorganic elements in prioritized order were: Na 77.6, K 64.8, P 22.3, S 20.0, Ca 15.5, Si 6.15, Mg 5.66, Fe 1.33, Al 0.40, Cu 0.26, Zn 0.17, Mn 0.07, B 0.021, Mo 0.013 and Cr 0.011. Cd, Ni and Pb were all below detectable limit (BDL). Results indicate that tertiary microscreening would not be effective at reducing chemical elements present in poultry processing wastewater.

Keywords Poultry Processing, Wastewater Treatment, Microscreening, COD, TSS, TKN

Introduction

In 2005, U.S. poultry processors slaughtered 8.9 x 10^9 broilers (USDA, 2006), using an average of seven gallons per bird and generating approximately 60 – 65 billion gallons of high-strength wastewater. Poultry processing wastewater (PPW) is most often characterized by the form and concentrations of the gross organics, particulate solids and selected inorganic elements it contains. The concentration of organics or 'strength' of the wastewater is most often measured using the analytical methods biochemical oxygen demand (BOD) or chemical oxygen demand (COD). One specific classification of organics with special interest in PPW is fat, oil and grease (FOG). Merka (1989) and others have reported BOD concentrations in PPW in excess of 2000 mg/L, values greater than 3500 mg/L for COD, and FOG concentrations over 750 mg/L (Eremektar *et al.*, 1999; Rusten *et al.*, 1998).

The form and concentration of particulate solids are obtained using a series of analytical tests including total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), total volatile solids (TVS), and fixed (or inorganic) solids (FS) (APHA, 1992). Merka (1989) reported that plant effluent had an average TSS of 1,446 mg/L and TVS of 1745 mg/L. The selected inorganic elements of nitrogen (N) and phosphorus (P) are also commonly used to characterize PPW due to their direct environmental impact relating to the acceleration of the enrichment process of water bodies known as eutrophication (Eremektar *et al.*, 1999; Welch and Lindell, 1992). Total Kjeldahl nitrogen (TKN) is one common analytical method used to determine the concentration of nitrogen in wastewater (APHA, 1992).

PPW also contains small amounts of many inorganic elements that can alter the efficiency of wastewater treatment systems and adversely effect environmental regulatory permits. These elements of interest include aluminum (Al), boron (B), cadmium (Cd), calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), magnesium (Mg), molybdenum (Mo), nickel (Ni), phosphorus (P), potassium (K), silicon (Si), sodium (Na), sulfur (S) and zinc (Zn). Inorganic elements, in the nutritive form of minerals, play important roles in the development and physiology of birds, and thus a portion of these elements are deposited in the wastewater produced during the processing of poultry (Al-Najdawi and Abdullah, 2002; Demirbas, 1999; Hecht and Kumpulainen, 1995; Maskova *et al.*, 1994). However, the various tissues of poultry are not the only contributors of chemical elements to the wastewater stream. Other sources of chemical elements in PPW include: (1) undigested and partially digested poultry feed, (2) soil from birds, transportation equipment and live haul areas, (3) various solutions and other ingredients used in further processing operations, (4) various cleaning chemicals used in the plant, and (5) incoming potable water.

Most of the organics, particulates and inorganic elements in PPW must be removed prior to discharge in order to meet environmental regulatory compliance limits. Poultry processors treat their wastewater streams by first using physical separation to remove and recover gross solids, followed by advanced chemical and/or biological treatment. The most common physical separation method utilized by poultry processors is screening. Screens serve a dual purpose. First, screens recover offal (e.g., feathers, heads, viscera) that is a valuable commodity for the poultry rendering industry. Second, screens prepare wastewater for further treatment by removing the larger solid particles from the waste stream that might otherwise impede the operation and maintenance of downstream equipment and treatment processes (Arundel, 1995; Pankantz, 1995). Typical PPW screening systems consist of primary (typically with 1500 to 3000 micron gap openings) and secondary (typically with 250 to 500 micron gap openings) internally-fed rotary screens.

In this study, a pilot-scale high-speed vibratory screen was placed subsequent to existing primary and secondary internally-fed rotary screens within a US broiler slaughter plant's wastewater treatment area. Vibratory screening, also referred to as rotating or vibro-energy screening, is defined as the use of countercurrent weights, rotated at a high speed to create a vibrating screen surface that allows the pass through of liquid, while retaining and transporting solids along the screen surface for recovery. Vibratory screens should not be mistaken for shaker screens traditionally used in poultry processing to recover offal. Shaker screens utilize the same basic principles as vibratory screens, but operate at a much slower rate. Experiments were conducted to compare the effects of tertiary microscreen gap size and time on the reduction of selected wastewater analytical parameters and inorganic elements in poultry processing wastewater (PPW). COD, TS, TSS, TVS and TKN were monitored, along with Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Si and Zn. Screen panels with nominal gap size openings of 212, 106 and 45 micron (equivalent to 70, 140 and 325 standard US mesh, respectively) were investigated.

Materials and Methods

Microscreening took place within the wastewater treatment area of a north Georgia (USA) broiler processing plant that slaughters approximately 340,000 birds per day. All of the whole processed carcasses go on to the cut-up and deboning operations. The plant operates a traditional two-production, one-sanitation shift schedule over a five-day workweek. Wastewater is generated in three major areas of the facility. The first is the kill/defeathering operation area that results in feathers and uncollected blood combining in a water flume. A second area captures the wastewater generated during the evisceration process along with any associated waste from the cut-up and deboning operations. These sources combine into a single 'viscera' wastewater flume. Finally, the third area captures the runoff and clean up water from the live haul area where the live birds are removed from trailers and loaded into the facility.

Within the plant's offal recovery/wastewater treatment area, the feather flume flows to a primary, internally-fed 1588 micron (1/16 or 0.0625 inch gap openings) fine rotary screen. The viscera flume flows through an internally-fed 3175 micron (1/8 or 0.125 inch gap openings) fine rotary screen. Finally, wastewater flow from the live haul area flows into the treatment plant and receives no primary screening. The primary screened wastewater from the feather and viscera flumes and unscreened wastewater from the live haul area combine in an equalization pit. Wastewater is pumped from the pit to a secondary, internally-fed 508 micron (0.020 inch gap opening) very fine wedgewire rotary screen. All of the solid by-products recovered by the screens are conveyed to trailers and transported offsite for rendering. The secondary screened wastewater flows to a dissolved air flotation (DAF) unit for further treatment and final discharge to the local municipal sewer system. Solids skimmed from the DAF unit are decanted in a tanker truck prior to shipment to offsite rendering.

A pilot-scale two-panel vibratory mechanical screen (Brandt Industries, Houston, TX) was installed adjacent an existing secondary internal rotary screen within the offal recovery area of the plant. Effluent from the secondary screen was pumped to the vibratory screen using a sump pump fitted with a high-pressure hose. Effluent from the vibratory screen was collected and sent via a discharge pipe back to the secondary screen effluent stream. The vibratory screen discharge pipe was fitted with an effluent sample port using a standard ball valve. Screen operation involved first installing a set of two screen panels with the same nominal gap sizes (212, 106, or 45 micron). Once the screen panels were installed, the screen was turned on and allowed to come up to operating speed. The screen was operated for approximately 10 minutes per run. An experimental run consisted of operating the screen three separate times (once each with the three screen sizes) during the normal first processing shift. The order in which screens were used during each experimental run was randomized. One experimental run was conducted per week, over an eight week period. The day per week for each weekly run was selected at random.

During each screen run a 1-liter influent grab samples was collected from the header box of the screen in a glass jar. Continuous flow to the screen was allowed for a minimum of 3 minutes before the influent sample was collected to ensure adequate mixing. As soon as the influent sample was taken, a 1-liter effluent grab sample was collected from the sampling port. Each experimental trial resulted in three influent and three effluent samples. All wastewater samples were place on ice and transported to the University of Georgia Feed and Water Laboratory (Athens, Georgia) for analysis.

Analytical Methods

The six (6) weekly pre- and post-screened wastewater samples were analyzed for the following wastewater parameters using the corresponding standard method (APHA, 1992): COD (5220 D. Closed Reflux, Colormetric Method), TS (2540 B. Total Solids Dried at 103 – 105^{o}C), TVS (2450 E. Fixed and Volatile Solids Ignited at 500^{o}C), TSS (2540 D. Total Suspended Solids Dried at 103 – 105^{o}C), TKN (4500-N_{org} C. Semi-Micro-Kjeldahl Method), and FOG (5520 B. Partition-Gravimetric Method (APHA, 1992). Also, each sample was analyzed using Method 3120B. Inductively Coupled Plasma (ICP) to obtain a concentration for Al, B, Ca, Cd, Cr, Cu, Fe, Mn, Mg, Mo, Ni, P, Pb, K, S, Si, Na and Zn (APHA, 1992).

Statistical Analysis

All laboratory analyses were run in duplicate and averaged. The main effects of screen size (3) and replicate, or week (8) were analyzed using the ANOVA option of the general linear models procedures of SAS software (SAS Institute, 1988). The main effects for plant and replicate were determined using the plant and replicate interaction mean square error. Means were separated using Tukey-Kramer Multiple Comparison Procedure (SAS Institute, 1988).

Results and Discussion

Particulates and Organics

Tables 6.1 and 6.2 summarize the ANOVA p-values of mean comparisons for COD FOG, TS, TSS, TVS and TKN by screen size and weekly repetition based on pre-screen, post-screen, and reduction in concentration and percent reduction. Statistical analysis ($p>0.05$) revealed that there was no significant differences in the means of any of the conventional parameters when comparisons made between screen sizes. There were significant differences in means by week for post-screened concentration of FOG, TS, TVS and TKN. There were also significant differences in percent reduction means for TS and TVS for weekly comparisons. Although there were no other significant differences in means by week, weekly means had much more variation than screen size. Thus, the variation in pre- and post screened concentrations, as well as effects of reduction in concentration and percent reduction for the conventional wastewater parameters were more influenced by week than screen size. The analytical results for the pre- and post-vibratory screened wastewater samples are summarized in Table 6.3. The table shows the range of the eight analytical results per parameter, as well as the mean. Percent reduction was calculated by dividing the post-screened concentration by the pre-screened concentration and multiplying the result by 100.

COD had the highest concentrations of the wastewater parameters tested. The COD concentration (mg/L) means for pre- and post-screened samples were 3686 and 3180, respectively. Total Solids was the next highest concentrated parameter with a pre-screened mean of 2726 mg/L and a post-screened mean of 2058 mg/L. TVS had pre- and post-screened means of 2495 mg/L and 1830 mg/L, respectively. TSS had a pre-screened average of 1353 mg/L and a post-screened mean of 958 mg/L. FOG had pre- and post-screened means of 848 mg/L and 632 mg/L, respectively. Finally, TKN had the lowest concentrations (mg/L) with a pre-screened mean of 154 and a post-screened mean of 147. The highest reduction in concentration (mg/L) was seen Total Solids (668), followed by

TVS (665), COD (506), TSS (395), FOG (215) and TKN (7). Perhaps more indicative of the true impact of the tertiary screen on the wastewater stream, the reduction in concentration was also calculated as a percentage. When calculated as a percentage, TSS (29%) becomes the wastewater parameter with the largest reduction in concentration, followed by TVS (27%), FOG (25%), TS (24%), COD (13%), and TKN (5%).

It was hypothesized that tertiary microscreening would substantially reduce the concentration of conventional wastewater parameters, especially those associated with solids (TS, TSS, TVS), with which the results were consistent. However, it was also hypothesized that the removal rates of the microscreens would increase significantly with each incremental decrease in screen size, which did not occur. Because of this lack of difference in performance, it would be most advantageous to use microscreens with the gap opening size which minimize blinding. On the surface one would assume that this would be the largest gap opening screen available, however the physical characteristics of the solids in an individual processing plant might be such that a smaller gap opening is more effective.

Inorganic Elements

Tables 6.4 and 6.5 summarize the ANOVA p-values of pre-screen mean concentrations of 15 of the 18 inorganic elements analyzed with detectable values by screen size and weekly repetition. Statistical analysis ($p>0.05$) revealed 14 of the elements had no significant difference when mean comparisons were made by screen size, with the exception being iron. Conversely, 10 of the 15 elements (Na, K, P, S, Ca, Si, Cu, Zn, Mn and B) analyzed showed a significant difference in concentration means when compared over time. The other 5 elements (Mg, Fe, Al, Mo and Cr) showed no significant difference by weekly repetition. The mean concentrations of the eighteen (18) inorganic elements examined in pre- and post-screened wastewater samples are summarized in Table 6.6. Sodium had the highest average pre-screened concentration (77.6 mg/L). Four other chemical elements had pre-screen concentration (mg/L) means above 10: K 64.8, P 22.3, S 20.0, and Ca 15.5. Three elements had pre-screen concentration means between 1 - 10mg/L: Si 6.2, Mg 5.7, and Fe 1.3. Seven (7) elements had pre-screened concentration means below 1.0 mg/L (Al, Cu, Zn, Mn, B, Mo and Cr), while three elements (Cd, Ni and Pb) were below detectable limits (BDL).

Based on these results tertiary microscreening would not be effective at reducing the concentration of inorganic elements present in PPW. Figures 6.1 and 6.2 show the concentration range of each element. The elements are grouped by mean concentration greater than or less than 1.0 mg/L. These results indicate that the variation in mean concentration of elements in post-secondary screened PPW was more influenced by week than screen size.

Acknowledgements

This study was supported in part by State and Hatch funds allocated to the Georgia Agricultural Experiment Station and by research funds provided by the United States Poultry & Egg Association (USPOULTRY), Research Project No.617.

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Tables and Figures

Table 6.1. ANOVA p-values of screen mean comparisons of six (6) conventional wastewater parameters generated by tertiary microscreening of secondary-screened broiler processing wastewater using three gap sizes (212, 106 and 45μm).

Test	Pre-Screen Concentration	Post-Screen Concentration	Concentration Reduction	Percent Reduction
COD	.7371	.9604	.3342	.3525
FOG	.6464	.8337	.3938	.3397
TS	.7230	.6182	.8416	.9450
TSS	.2163	.1783	.4525	.4801
TVS	.8260	.6532	.8756	.9603
TKN	.9397	.9364	.8778	.9153

Table 6.2. ANOVA p-values of weekly mean comparisons of six (6) conventional wastewater parameters generated by tertiary microscreening of secondary-screened broiler processing wastewater using three gap sizes (212, 106 and 45µm).

Test	Pre-Screen Concentration	Post-Screen Concentration	Concentration Reduction	Percent Reduction
COD	.0525	.0966	.3042	.4920
FOG	.1561	*.0400*	.2880	.1298
TS	.0501	*.0021*	.0998	*.0315*
TSS	.0752	.5032	.1426	.4444
TVS	.0614	*.0346*	.0878	*.0362*
TKN	.1274	*.0460*	.4659	.3926

Significant differences ($p<0.05$) in italics

Table 6.3. Range and mean concentrations (mg/L) of six (6) conventional wastewater parameters generated by tertiary microscreening of secondary-screened broiler processing wastewater using three gap sizes (212, 106 and 45µm).

	Pre-Screen		Post-Screen		Concentration Reduction		Percent Reduction	
Test	Range (mg/L)	Mean (mg/L)	Range (mg/L)	Mean (mg/L)	Range (mg/L)	Mean (mg/L)	Range (%)	Mean (%)
COD	2870-4570	3686	2200-3650	3180	70-1370	506	2-30	13
FOG	532-1231	848	289-843	632	44-605	216	6-52	25
TS	1470-4310	2726	1300-2770	2058	20-2350	668	1-55	24
TSS	840-2300	1353	610-1620	958	120-910	395	9-52	29
TVS	1370-4280	2495	1130-2430	1830	40-2330	665	2-54	27
TKN	114-190	154	107-170	147	0-33	7	0-17	5

n=8

Table 6.4. ANOVA p-values for chemical elements with pre-microscreen concentration means >1.0 mg/L for secondary-screened broiler processing wastewater samples collected from three microscreen gap sizes (212, 106 and 45µm).

Main Effect	df	Na	K	P	S	Ca	Si	Mg	Fe
Screen	2	.9875	.5091	.5423	.3454	.2773	.2352	.1498	*.0441*
Rep	7	*.0007*	*.0026*	*.0015*	*.0092*	*.0037*	*.0376*	.0791	.1932

Significant differences (p<0.05) in italics

Table 6.5. ANOVA p-values for chemical elements with pre-microscreen concentration means <1.0 mg/L for secondary-screened broiler processing wastewater samples collected from three microscreen gap sizes (212, 106 and 45µm).

Main Effect	df	Al	Cu	Zn	Mn	B	Mo	Cr
Screen	2	.1674	.6095	.8731	.8390	.6110	.0764	.6517
Rep	7	.1299	*<.0001*	*<.0001*	*<.0001*	*<.0001*	.5902	.1924

Significant differences (p<0.05) in italics

Table 6.6. Mean concentrations (mg/L) of 18 chemical elements in secondary-screened broiler processing wastewater.

Element	Cumulative Pre-Screen Concentration (mg/L)	Cumulative Post-Screen Concentration (mg/L)	Reduction in Concentration (mg/L)
Sodium (Na)	77.6	78.1	(0.5)
Potassium (K)	64.8	65.4	(0.6)
Phosphorus (P)	22.3	22.3	0.0
Sulfur (S)	20.0	19.9	0.1
Calcium (Ca)	15.5	15.4	0.1
Silicon (Si)	6.15	6.00	0.15
Magnesium (Mg)	5.66	5.70	(0.04)
Iron (Fe)	1.33	1.11	0.22
Aluminum (Al)	0.40	0.32	0.08
Copper (Cu)	0.26	0.26	0.00
Zinc (Zn)	0.17	0.16	0.01
Manganese (Mn)	0.07	0.07	0.00
Boron (B)	0.021	0.020	0.001
Molybdenum (Mo)	0.013	0.009	0.004
Chromium (Cr)	0.011	0.012	(0.001)
Cadmium (Cd)	BDL*	BDL*	-
Nickel (Ni)	BDL*	BDL*	-
Lead (Pb)	BDL*	BDL*	-

* *Below detectable limit*

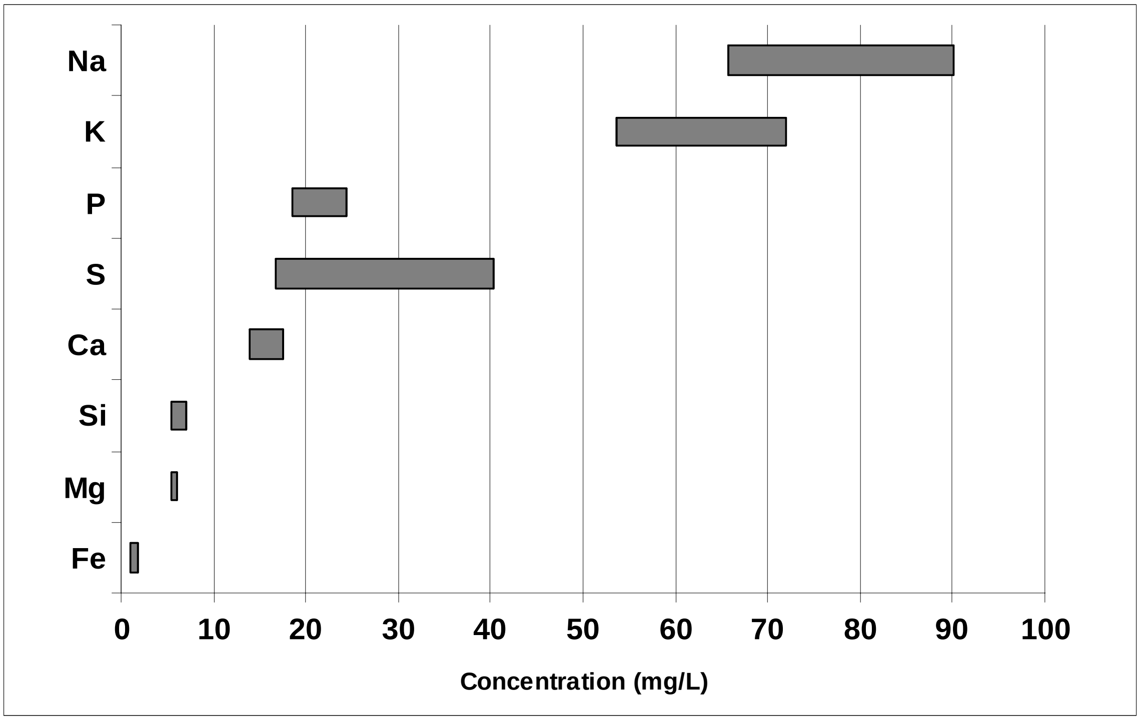

Figure 6.1. Concentration range over eight (8) weeks for chemical elements with means >1.0 mg/L in secondary-screened broiler processing wastewater.

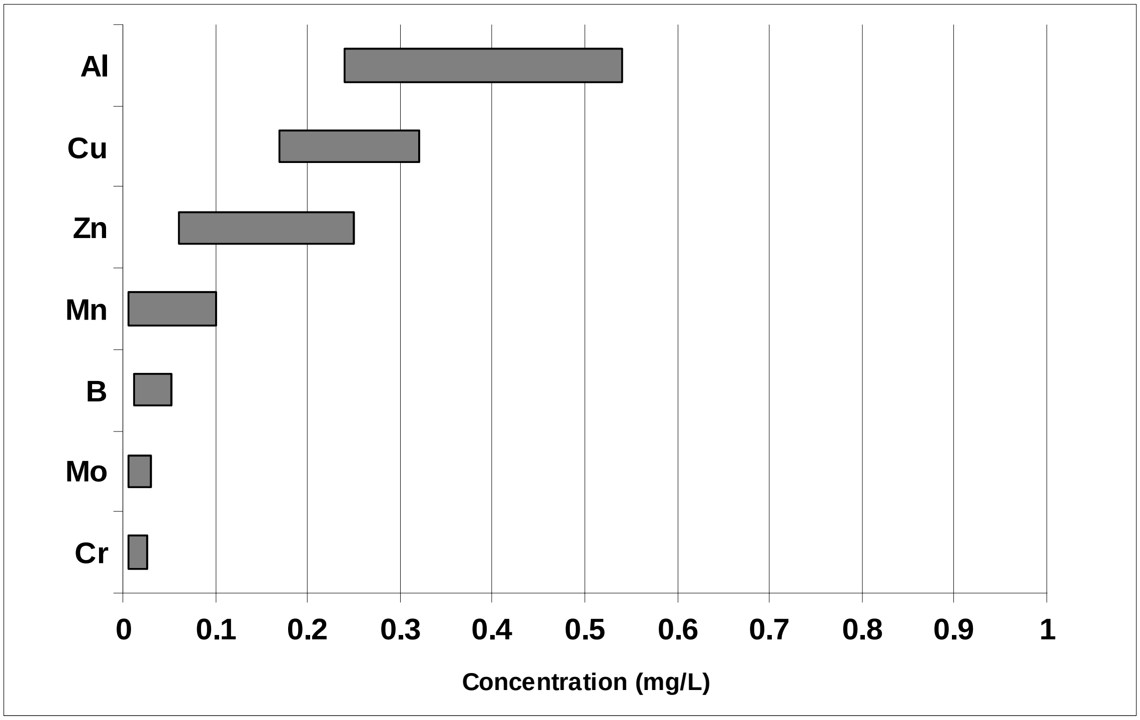

Figure 6.2. Concentration range over eight (8) weeks for chemical elements with means <1.0 mg/L in secondary-screened broiler processing wastewater.

CHAPTER 7

SUMMARY AND CONCLUSIONS

Two series of experiments are described in chapters 3 through 6. The first series involved the bench-scale (BS) wet-sieve microscreening of post-secondary screened PPW from three plants, while the second series involved the pilot-scale (PS) vibratory microscreening of post-secondary screened PPW from one plant using three different screen gap sizes. The similarities of the two series of experiments included the physical means of separation (high-speed vibratory microscreening), the range of microscreening achieved (~50 – 500 micron), and the use of the same plant across the two series of experiments (Plant A). These similarities allow for comparisons to be made between the two series of experiments. Conversely, the differences between the two series of experiments included the number of plants sampled (BS: 3, PS: 1), the volume of wastewater microscreened (BS: 60 L, PS: 4000 L), and the type wastewater sampling conducted (BS: composite, PS: grab). These differences must be taken into consideration when comparisons are made between the two series of experiments.

Tertiary Microscreening: Recovered Solids

Fat was the predominate dry matter constituent, and protein the second most prevalent, in the solids recovered by the microscreens in both series of experiments. In the case of ash, %DM results showed that it was the third most prevalent constituent (ahead of fiber) in the BS experiments, but the least prevalent constituent of the four analyzed in the PS experiments. It is believed that the dissimilarity in %DM ash content stems from the two difference types of wastewater samples collected during the BS and PS experiments. Composite samples were collected over a 24-hour period during the BS experiments, while 1-liter grab samples were collected during the first processing shift during the PS experiments. Thus the grab samples did not contain wastewater from the washdown of the live haul area that enters the wastewater treatment system for a short duration after the conclusion of second shift processing. The relative low volume of wastewater from the live haul area is nonetheless highly concentrated with dirt and soil from the birds and processing plant transportation equipment, which is a significant source of inorganic matter in a poultry processing plant's wastewater stream (Kiepper, 2003). It is hypothesized that the absence of the inorganic matter contribution from the live haul area in the PS experiments led directly to the low mean concentration of ash. Thus, the ash content of solids recovered by tertiary microscreening is more accurately represented by the BS experiments.

The mean concentration of total solids (TS) recovered during the PS experiments was substantially higher than the mean concentration of TS removed from Plant A samples during the BS experiments. Again, it is hypothesized that the dissimilarity in concentration values between the two series of experiments stems from the two difference types of wastewater samples collected during the BS and PS experiments. The composite samples that were collected over a 24-hour period during the BS experiments included the relative high-volume, low-concentrated wastewater generated during the sanitation shift. Conversely, the grab samples collected during the PS experiments were isolated to the higher concentrated first processing shift. This would result in the BS samples having lower overall concentration of TS. In this case, the PS results are more indicative of the actual values expected in a full-scale tertiary microscreening operation since screen operation would be isolated to high concentrated flow times (e.g. first and second processing shifts). Based on the results of both series of experiments, it is concluded that the presence of live haul washdown wastewater will have a direct effect on particulate matter ash content.

Tertiary Microscreening: Wastewater Treatment

Particulates and Organics

The wastewater analytical tests of total solids (TS), total volatile solids (TVS), and total suspended solids (TSS) were utilized in both series of experiments to measure the impact of tertiary microscreening on reduction of particulate matter in PPW, while chemical oxygen demand (COD) was used to measure the reduction of organic matter. For the PS experiments, fat, oil and grease (FOG) was utilized along with COD to determine organic matter removal. Table 7.1 compares the pre- and post-sieved concentration and concentration reduction from Plant A isolated from the BS experimental data and PS experiments. Again, the composite samples from the BS experiments contained the wastewater generated during the sanitation shift. Conversely, the grab samples collected during the PS experiments were isolated to the first processing shift. The PS results are more indicative of the values expected in a full-scale tertiary microscreening operation since screen operation would only take place during the processing shifts.

It was hypothesized that there would be significant differences in the concentration reduction between screen sizes, which did not occur. It is unclear whether the lack of significant difference in screen size was a function of the physical properties of the PPW being screened or the operational properties of the vibratory screen, or a combination of the two factors. Regardless, it is concluded based on these results that the determination of the screen gap size chosen for installation in a tertiary vibratory microscreen system be based on factors other than the smallest gap size available. These other factors would include capital investment and payback, operation and maintenance costs, ease of operation, flow capacity, ability to use multiple screen gap sizes and availability of automated screen cleaning systems to minimize blinding.

Inorganics

Table 7.2 compares the pre- and post-sieved means of the 15 inorganic elements analyzed from Plant A, isolated from the BS and PS experiments. K, Mg, Fe and Al had higher mean concentrations in the PS experiments as compared to the BS experimental data and Cu was unchanged, the remaining 10 elements had lower mean concentrations in the PS experiments than in the BS experiments. As hypothesized the concentration of the elements remained basically unchanged following tertiary microscreening. Eight of the analyzed elements saw mean concentration reductions (S, Ca, Si, Fe, Al, Zn, B and Mo), but the average decrease was less than 0.1 mg/L. Four elements (Na, K, Mg and Cr) had increases in mean concentrations that averaged less than 0.3 mg/L, while P, Cu and Mn were unchanged.

Tertiary Microscreening: Application

Both series of experiments showed that fat is the predominate dry matter constituent in fine particulate solids in post-secondary screened poultry slaughter wastewater. Fat in wastewater is traditionally difficult to handle with mechanical screening. Commonly used shaker and rotary type screens can have gap openings quickly clogged or “blinded” by fat, causing backups and overflows. Filters (e.g., membrane, sand) are even more vulnerable to fat in wastewater. Fat clogged filters can result in significantly higher costs for cartridge or media removal and replacement.

Visual observation of the vibratory test screen showed that blinding also occurred in this type of microscreen, and at a relatively high rate. Within a normal 10 to 15 minute screen run with any of the three screen sizes, the operator needed to use an available high-pressure sanitary water hose to rinse the screen surface approximately every 5 minutes to prevent blinding. Under these conditions a full-scale tertiary vibratory screening would require some type of intermittent screen surface wash system, similar to the traveling or static bar wash systems utilized currently on internal rotary screens, to prevent blinding during extended operation.

Tables

Table 7.1. Comparison of COD, TS, TVS and TSS means from Plant A in bench-scale (BS) and pilot-scale (PS) experiments.

Test	Exp.	Pre- (mg/L)	Post- (mg/L)	Reduction (mg/L)	Reduction (%)
COD	BS	2499	2331	168	7
	PS	3686	3180	506	14
TS	BS	2063	1743	320	16
	PS	2726	2061	665	24
TVS	BS	1620	1354	266	16
	PS	2495	1830	665	27
TSS	BS	884	642	242	27
	PS	1353	958	395	29

Table 7.2. Comparison of mean concentrations (mg/L) of chemical elements in secondary screened broiler processing wastewater from Plant A in bench-scale (BS) and pilot-scale (PS) experiments.

Element	BS Experiments: Concentration Mean (mg/L)	PS Experiments: Concentration Mean (mg/L)	Difference (mg/L)
Sodium (Na)	126.1	77.6	48.5
Potassium (K)	53.3	64.8	11.5
Phosphorus (P)	33.9	22.3	11.6
Sulfur (S)	-	20.0	-
Calcium (Ca)	17.1	15.5	1.6
Silicon (Si)	7.38	6.15	1.23
Magnesium (Mg)	5.36	5.66	0.30
Iron (Fe)	1.19	1.33	0.14
Aluminum (Al)	0.30	0.40	0.10
Copper (Cu)	0.26	0.26	0.00
Zinc (Zn)	0.23	0.17	0.06
Manganese (Mn)	0.09	0.07	0.02
Boron (B)	0.031	0.021	0.010
Molybdenum (Mo)	0.019	0.013	0.006
Chromium (Cr)	0.012	0.011	0.001
Cadmium (Cd)	-	BDL*	-
Nickel (Ni)	0.016	BDL*	-
Lead (Pb)	-	BDL*	-

**Below Detectable Limit*