FOOD WASTE

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Contents

Summary

Food waste management has become a major task in food processing facilities as environmental regulations worldwide become more stringent. Wastewater from food processing facilities is often high in strength, as indicated by the major water quality parameters, and is more difficult to treat than municipal wastewater. The most effective approach for food waste management is source minimization and by-product recovery. The major components of food waste contributing to this high strength often have high

nutrient values. These substances include proteins, lipids, and carbohydrates that can be used in livestock feed. Most future efforts in food waste management will largely replace the production of waste with the production of secondary products. In many cases, the need to recover by-products provides an opportunity for greater economic return. Some food waste management problems can be addressed through standard practices for good manufacturing, and through multi-disciplinary efforts – engineering, economics, food science and technology, soil science, and chemistry. The remaining waste needs to be treated with proper technologies, which are typically divided into pre-treatment, secondary treatment and advanced treatment processes. The most suitable treatment process is often site specific.

1. Introduction

Waste generation is often a natural consequence of food processing operations such as sugar mill, dairy factories, meat, fish, fruits, and vegetable processing plants. As environmental regulations become increasingly stringent, appropriate management of food wastes has become an essential part of modern food processing management. The amount of waste generation and the manageability of waste generated by a process have become criteria for evaluating the applicability of the process.

There are various types of food waste generated in many steps of production, processing, distributing, and consumption of food. The discussion of this article focuses on food waste related to food processing. Waste can be produced in a food processing plant in different forms, including solid waste, such as shells and residues, and liquid waste, such as wastewater and sludge. This article focuses primarily on wastewater, because wastewater management is more challenging than the management of solids waste.

2. Wastewater Parameters

From a treatment perspective, food waste is characterized by typical parameters that describe the nature of waste and its potential impact on the environment. These parameters can be divided into physical, chemical and biological, mainly including temperature, pH, and concentrations of dissolved oxygen, oil and grease, sulfur, nutrients (nitrogen and phosphorous), biochemical oxygen demand, and chemical oxygen demand. The following discussion briefly explains these parameters.

2.1. Temperature

Temperature of the wastewater determines its thermal impact on the receiving water. In a receiving water body that supports a biological community, temperature needs to be maintained within a certain range. For example, direct discharge of cooling water to streams that support cold water fish species will cause elevated temperature of the stream and adversely impact the fish. Another important aspect of temperature is its impact on decay of waste material in the wastewater. The higher the temperature, the faster the decay rate will be.

2.2. Solids

Solids concentration represents the amount of material contained in water, usually expressed as milligrams of dry weight per liter of water sample. Several terms are typically used for characterizing solids. For example, the total solids represent the amount of residue resulting from evaporation of a wastewater sample at 103 to 105^{o}C. The total solids can be further divided according to particle size into total dissolved solids (TDS) and total suspended solids (TSS). In wastewater analysis, this separation is made by using a filter pad with a pore size of about 2 microns. The dry weight of the residue contained in the water sample that passed through the filter is called TDS, whereas the dry weight of the solids retained on the filter is called TSS. Another commonly used term related to solids is settleable solids, which refers to wastewater solids that settle to the bottom within 1 hour, as measured using a graduated Inhoff cone.

All the solids portions described above can be further characterized as fixed residue or volatile residue. Fixed residue is the ash component produced after the solids material is burned in a muffle furnace at 550^{o}C for 15 to 30 minutes, where the volatile residue is the portion of solids that disappeared during the burning process. Thus, volatile residue is often interpreted as the organic component of the solids, and fixed residue as the oxidized inorganic matter.

Solids in wastewater have various environmental impacts. High TDS increases the salinity of the receiving water. High volatile solids concentration means high organic loading to the receiving water. High TSS concentration increases the turbidity of the receiving water. Higher turbidity in water reduces light transmittance of the water column. Additionally, discharging the wastewater with a high TSS concentration can also alter the habitat of the receiving water due to the deposition of the solids.

2.3. pH

The pH is related to the hydrogen ion concentration in the wastewater, thus the wastewaters acidity. Most bacterial and biological life can survive only within a certain pH range. Thus, the wastewater's pH represents its impact on the receiving water's acidity. Environmental regulations for discharge to the environment typically require that pH of the wastewater be within the range 6 to 9. Extreme wastewater pH also adversely affects the performance of chemical and biological wastewater treatment systems, and causes corrosion of equipment as well.

2.4. Dissolved Oxygen

Dissolved oxygen (DO) concentration in wastewater is a measure of oxygen availability in the wastewater. A variety of aquatic life and many types of aerobic bacteria rely on DO for proper function. Adequate DO is required in a water body to support aquatic life. Thus, DO is often the limiting factor in protecting the safety of an aquatic environment because of the competition for DO between different organisms.

2.5. Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a parameter that describes the amount of biological degradable organic matter in wastewater. BOD is determined by measuring the amount of DO consumed in a wastewater sample for a given time period under a given temperature. For example, BOD_5 is typically used in environmental regulations for indicating the amount of DO required for the decay of organic constituents in the wastewater sample within five days at 20°C.

2.6. Chemical Oxygen Demand

Chemical oxygen demand (COD) measures the amount of oxygen needed for chemical oxidization of organic material contained in the wastewater sample. COD represents the maximum impact of wastewater on the DO of the receiving water. COD analysis is conducted using a strong chemical oxidant, which is more rapid than BOD measurement. For specific wastewater, there may be a correlation between COD and BOD values.

2.7. Oil and Grease

Oil and grease are sometimes called fats, oil, and grease. As the names implies, this parameter represents the amount of oil and grease in wastewater. The environmental impact of oil and grease can be noted in several aspects. First, the thin film of oil and grease on the water surface reduces the interchange of air with water, which reduces oxygen diffusion to the water. Secondly, these hydrocarbons and related compounds require more oxygen per unit of weight than other organics to complete their oxidation and thus increase the oxygen demand. Oil and grease are typically less easily biodegradable.

2.8. Nitrogen

Nitrogen exists in different forms and is important to all forms of life. Transformation of nitrogen among different forms is governed by the nitrogen cycle. Most environmentally important nitrogen forms include ammonia, nitrate, nitrogen gas, and organic nitrogen, such as protein. In most food products, nitrogen exists in the form of protein. Decomposition of protein in food waste (or animal waste) by bacteria converts the organic nitrogen to ammonia. In an aqueous solution, ammonia has two forms: NH_3 and NH_4^+. The equilibrium between these two species is determined by pH. The unionized ammonia form (NH_3) is toxic to most aquatic life. Under aerobic conditions, ammonia is converted to nitrite, and then nitrate (NO_3^-) by a group of bacteria called nitrifiers. Nitrate can be readily taken up by plants and converted to organic nitrogen. Nitrate is mobile in soil because of its negative charge. Excessive nitrate leaching to groundwater can cause health problems. High nitrate concentration in drinking water is toxic to humans, especially infants, and livestock. Under anaerobic conditions, nitrate is converted to nitrogen gas biologically through a process called denitrification. Some bacteria or plants can fix nitrogen from nitrogen gas to protein.

Another often used term in food processing wastewater is Total Kjeldhahl Nitrogen (TKN), which measures the concentration total of organic nitrogen and ammonia.

Organic nitrogen can be determined if ammonia is removed from the TKN analysis. The protein content of wastewater can be determined by the organic nitrogen content.

2.9. Phosphorous (P)

Phosphorous as phosphate (PO_4^{2-}) is another essential element in many living organisms, and is often considered the growth limiting factor in numerous water bodies, such as rivers and lakes. Excess P input to receiving water can cause eutrophication in rivers and lakes, characterized by the abundant growth of algae and other aquatic plants, which during the respiration phase at night can deplete the dissolved oxygen in water bodies, causing fish kill and other nuisance conditions.

2.10. Sulfur

Sulfur compounds in wastewater are a major problem for some food processors. The use of sulfur dioxide in pre-treatment of fruits or sodium bisulfide in processing may result in sulfur content in wastewater. Sulfur compounds exist in water primarily as sulfide and sulfate ions or precipitates. Hydrogen sulfide, a product of anaerobic processes, can cause bad odor problems.

3. Characteristics of Food Processing Wastewater

3.1. Waste Generation and Waste Load

The characteristics of wastewater generated by food processing plants can vary considerably due to the diversity of the food industry and other factors, such as size of operation and number of products produced, levels of processing, material conveyance, cleanup and housekeeping, and process water usage. Table 1 displays typical values for water consumption and pollutant contribution in beef, turkey, and broiler processing in the United States. Additionally, Table 2 gives the characteristics of meat processing effluent reported from New Zealand. For the purpose of reference, Table 2 also provides typical characteristics of domestic wastewater in the USA.

Animal Type	**Pollutant Load, kg/1000 animal**			**Water Usage**
	BOD_5	TSS	Fat and Grease	Liters/animal
Beef	3044	3112	200	1325
Turkey	77	118	27	96
Broiler	22	26	3.6	22

Table 1. Water consumption and pollutant contributions for beef, turkey, and broiler processing.
[From: Ross C.C. and Valentine G.E. (1990). An Overview of Environmental Concerns in the Meat and Poultry Processing Industry. In *Agricultural and Food Processing Waste*, 66-75. Proceedings of the Sixth International Symposium on Agricultural and Food Processing Wastes, December 17-18, 1990. Chicago, Illinois. ASAE Publication 05-90, American Society of Agricultural Engineers, St. Joseph, Michigan, USA.]

Parameter	Meat Processing	Domestic
	(Cooper and Russell, 1992)	(Liu, et al., 1997)
BOD_5	700-1800	110-400
COD	1000-3000	250-1000
TKN	70-240	20-85
Ammonia-N	5-50	12-50
TSS	200-1200	100-350
Fat	100-900	50-150
TP	5-20	4-15

Table 2. Comparisons of characteristics of meat processing effluent and raw domestic wastewater (mg/l).
[From: Cooper R.N., and Russell J.M. (1992). The New Zealand Meat Processing Industry, Present Effluent Treatment Practices and Future Directions (eds. L. McElvaney, C.C. Ross, and G.E. Valentine, Jr.), 95-108. Proceedings of the 1992 Food Industry Environmental Conference, November 9-10, 1992. Atlanta, Georgia: Georgia Tech Research Institute.]

Clearly, meat-processing wastewater has a much higher oxygen demand and TSS than domestic wastewater, and thus has great pollution potential. Such information on wastewater characteristics, along with data on wastewater volume generation, can be used to estimate the waste loading, and is essential in selecting wastewater management strategies.

4. Regulatory Issues

Various nations have passed legislations to limit waste discharge into the environment. These regulations specify treatment technologies, establish discharge standards, or specify discharge rates. In the United States, discharge of wastewater from a point source is governed by the National Pollution Discharge Elimination System (NPDES). The NPDES is administered by the states with EPA oversight. Facilities discharging directly into the waters of the United States must obtain NPDES permits that place limits on the quantity and quality of effluents. These limits are based on a case-by-case evaluation of potential environmental impacts. Discharge permits are designed as an enforcement tool, with the ultimate goal of meeting ambient water quality standards.

Effluent limits are specific control requirements that apply to a specific point-source discharge. They are based on both national effluent guidelines and state water quality standards. Effluent limitation determines the NPDES conditions in a specific permit. The effluent limits and permit requirements specified in a NPDES permit are generally based on the best available technology (BAT) and the water quality requirement of the receiving water. The technology standards can be the effluent guidelines, effluent limits, and definition of BAT. In the United States, the federal effluent guideline governs specific pollutant discharges from each type of industry regulated. Table 3 lists the industries and the corresponding regulations that are related to food.

40 CFR Part	Source
405	Dairy Products
406	Grain Mills
407	Canned and Preserved Fruits and Vegetables
408	Canned and Preserved Seafood
409	Sugar Processing
432	Meat Products

Table 3. Categorical industrial effluent guideline and standards.

Some regulations also specify allowable treatment/disposal methods for a given industry. For example, in the State of Washington, USA, six treatment/disposal methods have been authorized for fresh fruit packing: (1) lined evaporative lagoons or ponds with no discharge of contained material except through evaporation, (2) dust abatement, spreading of process wastewater over interior gravel roads, or bin lots, either through a sprinkler system or by truck/tank hauling, (3) land application, (4) percolation ponds or ditches, (5) surface water, and (6) POTWs or on-site treatment methods. For discharge to a public owned treatment work (POTW), the processor must first obtain written certification of the acceptance of wastewater discharge. Additional conditions for discharging to a POTW follow: (1) must comply with all federal, state, and local pre-treatment standards and ordinances, (2) must not combine any sanitary wastewater with prohibited process water, (3) must not exceed specific numerical limits of discharge as given in permit, and (4) must not discharge toxic chemicals that could upset municipal wastewater treatment facilities.

5. Management and Treatment Processes

5.1. Waste Reduction Strategies

The most efficient way of food processing waste management is through waste source reduction. These include waste minimization, water conservations, and by-product recovery. These measures are not only environmentally sound, but also economically beneficial.

Waste minimization prevents pollutants from entering the wastewater system and produces a minimum amount of waste. This includes in-plant modification and procedural changes in current practice, which could involve new equipment or techniques. However, the basic method of processing is generally not altered.

Many on-site practices can prevent solid waste from getting into the wastewater steams. For example, screens and similar solids removal systems should be installed downstream from processing operations that discharge residues into wastewater. Spillage should be avoided as much as possible and food residues, such as spoiled or damaged whole units, seeds, stems peels, etc., should not be allowed to enter the wastewater stream.

Water conservation can reduce the cost directly related to water usage and the cost related to wastewater treatment. In food processing, water is generally used for washing incoming material, hydraulic transportation, grading, and inspection, separation of debris or culls from raw material, incorporation into product, blanching, cleaning up, heating, and cooling. The first choice of water conservation is water recycling and reuse. Recycling refers to reusing the water, usually treated, in the same application. Reuse refers to using processed water, treated or untreated, in other applications where the quality requirements are usually less critical. For example, there are several recycling options in canned fruits and vegetable processing: (1) the flume water used for transporting raw, unpeeled commodities, (2) retorted can cooling water recycled through a cooling tower, and brine systems used in pickling or curing. In product transport, dry transport by mechanical or pneumatic conveying systems can be substituted for some hydraulic transport systems prior to hydraulic washing. Also, raw incoming fruits and vegetables can be dry cleaned, by using vibrating screens and air blowers to remove loss dirt, leaves, and twigs.

Significant amounts of water consumption can be saved through well planned water recycling and reuse. However, the build up of organic and mineral compounds, microbial populations, and temperature (increases or decreases) must be considered. Each successive contact of water with the product contributes to changing the quality of water, and measures should be taken to ensure acceptable water quality conditions for the recycled applications. Typical methods include: (1) treating the recycling water, using screens, filters or cooling towers (or heaters) to re-establish acceptable quality conditions of solids content and temperature, (2) disinfecting the microbial populations, to meet the sanitary conditions, and (3) adding make-up water to recycled water stream, to dilute stream and provide acceptable quality conditions or to maintain desired water volume. Additionally, any recycling and reuse program must meet the requirements of federal and state food regulatory agencies.

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Biographical Sketch

Shulin Chen is an Associate Professor in the Department of Biological Systems Engineering at Washington State University. His research and teaching interests are related to wastewater treatment agricultural waste management, aquacultural engineering, and bioresource utilization. Specific research topics include natural systems for wastewater treatment, watershed modeling, decision support system for animal nutrient management, recirculating aquacultural systems, and conversion of agricultural wastes and residues to biochemicals.