

Environmental Management & Pollution

Food and Chemical Carcinogenesis

9.1 Heterocyclic Amine Carcinogens in our Diet

Heterocyclic amine carcinogens in our diet etiological agents for human cancer. Human risk estimates and cancer etiology attributed to the consumption of mutagens and carcinogens in our food are difficult to evaluate, as these toxicants come from numerous sources in our diet. As discussed above, mycotoxins, such as aflatoxin B₁ are formed by fungi growing on poorly stored grain products and can be strong liver carcinogens, especially in individuals infected by the hepatitis B virus. PAH such as benzo[a]pyrene, as combustion products, are present in wood fires or flame grilling and can be deposited on food from fat dripping onto the coals during this type of cooking. These compounds are generally potent carcinogens in experimental animals, but are quite ubiquitous in our environment.

Another important class of carcinogens in food is the heterocyclic amines. These compounds are potent mutagens and moderately potent carcinogens at numerous organ sites in rodents and in the liver of non-human primates. They are produced when muscle foods are heated above 180 °C for long periods of time. The levels in meat products can reach hundreds of parts per billion (ppb), but are generally lower in chicken and beef cooked to a well-done state. By virtue of their frequent presence in meat, they present a problem in widespread exposure in the diet of non-vegetarians.

At least sixteen, and possibly more, different heterocyclic amines have been isolated from cooked foods. Four of these compounds can consistently be identified in well-done meat products from the North American diet. The majority (more than 75%) of epidemiology studies designed to evaluate the health significance of these animal carcinogens have linked consumption of well-done meat products to cancer of the colon, breast and stomach. However, a causal linkage has not been firmly established, since some well designed studies found no statistically significant positive correlation between consumption of diets containing heterocyclic amines and incidence of colon or other cancers.

Studies employing DNA adducts and urine metabolites as molecular biomarkers suggest that individuals may differ in their susceptibility to these carcinogens. Polymorphisms in metabolic activation and detoxification, as well as DNA repair genes may contribute to this variability. Variable exposures and genetic differences in a large number of genes, each probably having small impact (i.e., low penetrance) complicate estimation of individual risks. Additional variables are introduced by modulation of internal dose and exposure by interactions with other foods in the diet as well as individual differences in adsorption of the carcinogens. It is therefore essential to put these variables into perspective, in assessment of risks to the general population attendant to consumption of dietary carcinogens.

A related chemical, acrylamide, has recently been identified in starch-based foods such as potato chips and French fries cooked using high temperature deep-frying and baking methods. This compound is weakly- or non-mutagenic in in vitro tests and weakly carcinogenic to experimental animals, but in comparison to the heterocyclic amines are present in large (part-per million) quantities in these starch-derived products. These compounds do not have the strong genotoxic properties of the other food-borne carcinogens discussed in this lesson, such as aflatoxin B1, benzo[a]pyrene and the heterocyclic amines, but the exposure levels may be quite high.

In terms of mode of action, current knowledge about the heterocyclic amines indicates that the underlying mechanisms are comparable to those involved in the carcinogenicity of many other environmental carcinogens. Exposure, metabolism, DNA damage, repair of the damage, mutations and tumors all result from or are impacted by the etiological agent. For heterocyclic amines all these steps fit into the etiological pathway.

9.2 Pollution from Food Processing Factories & Environmental Protection

The food industry is now facing increasing pressure to ensure that their company's activities are environmentally sensitive, but there is also increased internal pressure to maintain or increase profitability in the face of fierce competition. The food-processing industry has special concerns about the health and safety of the consumer.

Key resources used by the food-processing industry include the water, raw materials and energy. Traditionally, the food-processing industry has been a large water user. Water is used as an ingredient, an initial and intermediate cleaning source, an efficient transportation conveyor of raw materials, and the principal agent used in sanitizing plant machinery and areas. Although water use will always

be a part of the food-processing industry, it has become the principal target for pollution prevention, source reduction practices.

The key environmental issues for the food industry include the following:

- **Wastewater.** Primary issues of concern are biochemical oxygen demand (BOD); total suspended solids (TSS); excessive nutrient loading, namely nitrogen and phosphorus compounds; pathogenic organisms, which are a result of animal processing; and residual chlorine and pesticide levels.
- **Solid Waste.** Primary issues of concern include both organic and packaging waste. Organic waste, that is, the rinds, seeds, skin, and bones from raw materials, results from processing operations. Inorganic wastes typically include excessive packaging items that are, plastic, glass, and metal. Organic wastes are finding ever-increasing markets for resale, and companies are slowly switching to more biodegradable and recyclable products for packaging.

Excessive packaging has been reduced and recyclable products such as aluminum, glass, and high-density polyethylene (HDPE) are being used where applicable. The food processing factories should follow the major technological innovations in the industry, including those in clean technologies and processes. Clean technologies include:

- a) **Advanced Wastewater Treatment Practices.** Use of wastewater technologies beyond conventional secondary treatment.
- b) **Improved Packaging.** Use of less excessive and more environmentally friendly packaging products.
- c) **Improved Sensors and Process Control.** Use of advanced techniques to control specific portions of the manufacturing process to reduce wastes and increase productivity.
- d) **Food Irradiation.** Use of radiation to kill pathogenic microorganisms.
- e) **Water and Wastewater Reduction (Closed Loop/Zero Emission Systems).** Reduction or total elimination of effluent from the manufacturing process.

9.3 Food Processing

Food processing can be divided into four major sectors including fruit and vegetables; meat, poultry, and seafood; beverage and bottling; and dairy operations. All of these sectors consume huge amount of water for processing food. A considerable part of these waters are potential wastewaters to be treated for safe disposal to the environment.

Fruit and Vegetable Food-Processing Sector

The primary steps in processing fruits and vegetables include:

1. General cleaning and dirt removal
2. Removal of leaves, skin, and seeds
3. Blanching
4. Washing and cooling
5. Packaging
6. Cleanup

Wastewater and solid wastes are the primary area of pollution control within the fruit and vegetable food-processing industry. Their wastewater is high in suspended solids, and organic sugars and starches and may contain residual pesticides. Solid wastes include organic materials from mechanical preparation processes that is, rinds, seeds, and skins from raw materials. For the most part, solid waste that is not resold as animal feed is handled by conventional biological treatment or composting.

The total amount of material generated is a function of the amount of raw material moved through a facility, for example, for a given weight of apples processed comes a set amount of peel and seed waste. Attempts to decrease solid waste streams have not been an area of great development for pollution prevention opportunities and clean technologies. Pre-treatment opportunities intended to reduce the amount of raw materials lost to the waste stream have been an area of clean technology development. For the most part, the majority of clean technology advances and research have been in reducing the volume of wastewater generated in food processing operations.

Most fruit and vegetable processors use traditional biological means to treat their wastewater. Advancements in the degradation chemistries of pesticides have aided in reducing their quantities and toxicity in process wastewater. Washing fresh produce (also known as surface treatment) can reduce the overall potential for microbial food safety hazards. This is an important step since most microbial contamination is on the surface of fruits and vegetables. If pathogens are not

removed, inactivated, or otherwise controlled, they can spread to surrounding produce, potentially contaminating a significant proportion of the produce. Sanitizers or anti-microbials in wash water and other processing water may be useful in reducing pathogens on the surface of produce and/or reducing pathogen build-up in water.

The effectiveness of a sanitizer depends on its chemical and physical nature, treatment conditions (such as water temperature, pH, and contact time), resistance of pathogens, and the nature of the fruit or vegetable surface. Chlorine is a commonly used anti-microbial. Chlorine dioxide, trisodium phosphate, organic acids, and ozone have also been studied for use as anti-microbials in produce wash water. All chemical substances that contact food must be used in accordance with FDA and EPA regulations.

Meat, Poultry, and Seafood Sector - The primary steps in processing livestock include:

1. Rendering and bleeding
2. Scalding and/or skin removal
3. Internal organ evisceration
4. Washing, chilling, and cooling
5. Packaging
6. Cleanup

Meat, poultry, and seafood facilities offer a more difficult waste stream to treat. The killing and rendering processes create blood by-products and waste streams, which are extremely high in BOD. These facilities are very prone to disease spread by pathogenic organisms carried and transmitted by livestock, poultry, and seafood. This segment of the food processing industry is by far the most regulated and monitored.

Waste streams vary per facility, but they can be generalized into the following: process wastewaters; carcasses and skeleton waste; rejected or unsatisfactory animals; fats, oils, and greases (FOG); animal feces; blood; and eviscerated organs. The primary avenue for removal of solid waste has been its use in animal feed, cosmetics, and fertilizers. These solid wastes are high in protein and nitrogen content. They are excellent sources for recycled fish feed and pet food. Skeleton remains from meat processing are converted into bonemeal, which is an excellent source of phosphorus for fertilizers. FOG waste (typically from industrial fisheries) is used as a base raw material in the cosmetics industry.

Beverage and Fermentation Sector

The primary steps in processing beverages are

1. Raw material handling and processing
2. Mixing, fermentation, and/or cooking
3. Cooling
4. Bottling and packaging
5. Cleanup

Wastewater and solid waste are the primary waste streams for the beverage and fermentation sector. Solid wastes result from spent grains and materials used in the fermentation process. Wastewater volume of "soft drink processes" is lower than in other food-processing sectors, but fermentation processes are higher in BOD and overall wastewater volume compared to other food-processing sectors.

Ozone technology has proven very useful in the beverage market since the earliest 20th century. In bottled water plants, ozone can be used to disinfect product water without leaving any residual taste or odor. At beverage plants, ozone can reduce or eliminate the need for chemical or high temperature disinfections during clean-in-place (CIP) cycles, reducing downtime and chemical costs.

Dairy Sector - A majority of the waste milk in dairy wastewaters comes from start-up and shutdown operations performed in the high-temperature, short time (HTST) pasteurization process. This waste is pure milk raw material mixed with water. Another waste stream of the dairy sector is from equipment and tank-cleaning wastewaters. These waste streams contain waste milk and sanitary cleaners and are one of the principal waste constituents of dairy wastewater. Over time, milk waste degrades to form corrosive lactic & formic acids. Approximately 90% of a dairy's wastewater load is milk.

Can Cooker Products - Water plays a role in most of the problems associated with metal food containers after processing. Whether steam, hot water or cold water, each can serve as the vehicle to transport undesirable substances. It is important to understand, when designing an effective, comprehensive water treatment program, how these mechanisms chemically interact.

9.4 Wastewater from Food Processing Factories

Food-processing wastewater can be characterized as nontoxic, because it contains few hazardous and persistent compounds. With the exception of some toxic cleaning products, wastewater from food-processing facilities is organic and can be treated by conventional biological technologies. Part of the problem with the food-

processing industry's use and discharge of large amounts of water is that it is located in rural areas in which the water treatment systems (i.e., potable and wastewater systems) are designed to serve small populations. As a result, one medium-sized plant can have a major effect on local water supply and surface water quality. Large food-processing plants will typically use more than 1,000,000 gallons of potable water per day.

Publicly owned treatment works (POTW) that receive food-processing wastewater with BOD5 values greater than 250 to 300 mg/L typically will add an additional surcharge for treatment. Any company is subject to fines by environmental enforcement agency when they discharge to a receiving water treatment works and exceeding their permitted BOD5 discharge level. Due to increased enforcement of discharge regulations and escalating POTW surcharges, many food-processing facilities are taking steps to either reduce, recycle (or renovate), and/or treat their wastewaters before they discharge them.

Another contaminant of food-processing wastewaters, particularly from meat-, poultry-and seafood-processing facilities, is pathogenic organisms. Wastewaters with high pathogenic levels must be disinfected prior to discharge. Typically, chlorine (free or combined) is used to disinfect these wastewaters. Ozone, ultraviolet (UV) radiation, and other nontraditional disinfection processes are gaining acceptance due to stricter regulations on the amount of residual chlorine levels in discharged wastewaters.

The pH of a wastewater is of paramount importance to a receiving stream and POTW. Biological micro organisms, used in wastewater treatment, are sensitive to extreme fluctuations in pH. Companies that are found to be the responsible polluter are fined and/or ordered to shut down operations until their pH level meets acceptable values. Wastewater discharge values that range from 5 to 9 on the pH logarithmic scale are usually acceptable. Low pH values are more damaging to a receiving stream and POTW biological treatment process.

The food-processing industry utilizes water to meet its individual day-to-day needs. Fifty percent of the water used in the fruit and vegetable sector is for washing and rinsing. Water is the primary ingredient in products for the beverage and fermentation sector, and dairies utilize water as the standard cleaning agent for process machinery.

9.5 Defining Load Using BOD 5 and COD

Chemical oxygen demand (COD) and biochemical oxygen demand (BOD₅) are common measurements used to determine water quality. They measure the strength of the waste stream by measuring the oxygen required to stabilize the wastes. The five-day biochemical oxygen demand (BOD₅) value is used as a gauge to measure the level of treatment needed to discharge a wastewater safely to a receiving water treatment center. The BOD for all food-processing wastewater is relatively high compared to other industries. A high BOD level indicates that a wastewater contains elevated amounts of organic material, dissolved and/or suspended solids, minerals, nitrogen and phosphorus.

COD and BOD₅ are important to the food processing industry because they can be used to indicate lost product and wasteful practices. High BOD₅ and COD levels indicate increased amounts of product lost to the waste stream. Measurements at various process locations can help locate sources of waste. At any point in a particular food processing operation, the relationship between BOD₅ and COD is fairly consistent.

9.6 Environmental Protection & Source Reduction

The most effective method of environmental protection and reducing your disposal costs is to decrease the volume of waste material and by-products generated in the production process. If less waste is generated, then less material needs to be disposed of. Source reduction should be the most logical starting point for reducing disposal costs since your company is in business to produce a saleable product, not waste materials or by-products.

Examples of source reduction include:

- a) Use brooms and scrapers to clean floors and equipment while they are dry before washing them down with water.
- b) Use high-pressure spray washes during cleanup to conserve water.
- c) Dedicate mixing lines to certain products to reduce changeover cleanups.
- d) Minimize spills and leaks on the production line to prevent raw materials from becoming wastes.

9.7 Management Alternatives

If source reduction is not a viable solution, management alternatives exist, including:

- A. Using the food by-product as an animal feed.
- B. Composting or land spreading the food by-product.
 - a. Animal Feed

Feeding food by-products directly to livestock allows for former wastes to be useful again. In addition, the quantity of liquid and solid waste is reduced when by-products are fed to livestock rather than being disposed of in landfills or wastewater treatment plants.

Composting and Land Spreading - When it is impractical to feed by-products to livestock, both composting and land spreading the food waste are viable alternatives. Both methods degrade food by-products into a useful soil additive called "humus." Composting degrades by-products above ground in a concentrated area, while land spreading degrades by-products beneath the soil in a cultivated field.

Composting. With proper management, food by-products can be kept out of the landfill and instead be composted and added to the soil at appropriate rates. Composting has the following benefits:

- 1) Low transportation costs. The by-products can be composted on site, and the resulting humus can have a volume and weight reduction of up to 40 percent.
- 2) Low capital investment. Composting is a batch process that can be done by using either a mound or a windrow system. In both systems all the by-products are managed to accelerate biological breakdown.
- 3) Good for seasonal processors. For a company (such as a cannery) that only processes food for several months a year, composting may be a suitable alternative to animal feeding or land filling. Livestock producers may be unwilling to switch to a livestock feed that is only available for a short period.
- 4) Long shelf life. Humus can be stored without spoiling and applied to enrich the soil as needed.

Land spreading. If your company has sufficient land, it is possible to incorporate food byproducts directly into the soil on site. A farmer can be paid to take the by-products to a suitable field. Again, with proper management, food is kept out of the landfill and is used to enhance the soil. Land spreading has the following benefits:

1. A separate compost facility is not necessary.
2. The finished product does not have to be stored.
3. The finished product does not have to be transported. It is left in the soil as a plant nutrient.

CLEAN TECHNOLOGY DEVELOPMENTS

Because wastewater generation is the industry's biggest area of concern, the following clean technologies focus on source reduction, recycling, reuse, and treatment of wastewater. *Clean technologies* are defined as "**manufacturing processes or product technologies that reduce pollution or waste, energy use, or material use in comparison to the technologies that they replace.**" The food-processing industry has special concerns about the health and safety of the consumer. It should be noted that some of the technologies outlined in the report target both human health and environmental pollution issues. Common source reduction methods employed at most plants include improving good housekeeping practices, making process modifications, substituting more environmentally friendly raw materials, and segregating waste streams. Some simple cost-effective means of achieving source reduction include installing automatic shut-off valves, using low - flow or air injected faucets/spray cleaners, switching from chemical caustic peeling processes to mechanical peeling, and converting from water to mechanical conveyance of raw materials through a production line.

Advanced Wastewater Treatment Practices Description.

Advanced wastewater treatment is defined as any treatment beyond secondary (or biological) treatment. These treatment practices are employed to target specific discharge constituents that are of concern. Typically, pathogens, suspended solids, dissolved solids, nitrogen, and phosphorus are removed in advanced wastewater treatment. The following is a listing of some technologies being used in advanced wastewater treatment.

- A. Membrane applications
- B. Disinfection
- C. Charge separation
- D. Other separation practices.

Membrane applications focus on separating water from contaminants, using semi permeable membranes and applied pressure differentials. In generic terms, they work like window screens that let air but not insects and other larger objects pass through. The smaller the screen holes, the smaller the objects need to be to pass through. Pressure is applied to reverse the natural equilibrium between the clean water and wastewater. The basic principle of natural equilibrium is that the clean water tends to migrate to the wastewater side to equalize the concentrations across the membrane. Mechanical pressure is used to force water molecules from the wastewater side to the clean water side and, thus, a "high-tech" filtration of the

wastewater occurs. In the past, the energy needed to apply the pressure and the fragility of the membrane surface made use of these alternatives economically unjustifiable.

There are varying degrees of membrane filtration. Microfiltration, ultrafiltration (UF), and reverse osmosis (RO) are the current membrane systems used commercially. The filtering capabilities of each (i.e., ability to filter based on contaminant particle size) decrease respectively. Microfiltration is only recommended for removing particles from 0.05 to 2 microns in size, UF is used for particles and suspended solids from 0.005-0.1 microns, and RO is used for particles, suspended solids, and dissolved solids in the Angstrom range (e.g., molecular weight above 200).

Problems with membrane applications include befouling of the membrane and fragility of the membrane surface. Toxic synthetic compounds can oxidize the surface of the membrane, thus, destroying it. New innovations in membrane technology have advanced the "cleanability" and reuse of membranes. The use of stainless steel and ceramic materials for membranes has greatly improved their use in advanced wastewater treatment.

Sanitary conditions have always been a concern for food products created in the manufacturing process. In recent years, they have also become a requirement of wastewater effluent. As for water treatment practices, **disinfection** through chlorination has been the quickest means of disinfecting wastewater. Disinfection has come under criticism due to chlorination byproducts and toxicity concerns that residual chlorine pose to aquatic life. The two principal means of disinfecting wastewater without using chlorination are ozone disinfection or UV disinfection. Ozonation works on the same principle as chlorination but leaves no residual in the treated wastewater and does not produce the magnitude of disinfection byproducts that chlorination produces. UV disinfection is even more environmentally friendly than ozone but requires more space and cleaner wastewater to be effective. Both technologies require high capital and operating costs.