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Physicochemical characterization of Atlantic Canadian seafood processing plant effluent

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ABSTRACT

The purpose of this study was to conduct a preliminary assessment of the potential impacts of Atlantic Canadian seafood processing effluents on the aquatic environment through physical-chemical characterization. Shellfish and finfish effluent samples were collected and characterized by biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), turbidity, total suspended solids (TSS), ammonia nitrogen (NH_3-N), adsorbable organic halides (AOX), soluble BOD_5 and soluble COD. Effluent concentration ranges were BOD_5 (179 to 276 mg L^{-1}), COD (458 to 1717 mg L^{-1}), turbidity (28.8 to 88.3 NTU), TSS (27.2 to 120.1 mg L^{-1}), NH_3-N (1.5 to 12.9 mg L^{-1}) and AOX (3.2 and 0.4 mg L^{-1}) for flatfish and salmon processing effluents respectively, and cleanup shift AOX (3.5 and 0.5 mg L^{-1}). The characteristics of these effluents assessed have the potential to contaminate and degrade receiving water body environments. Improved performance may be possible with further treatment technology optimization on an effluent-specific basis.

1. Introduction

The seafood industry in Atlantic Canada is recognized internationally for its quality, leadership, and innovation. The Atlantic Canadian fisheries sector accounts for 85% of total landings in Canada. There are approximately 800 seafood processing plants in Atlantic Canada, which accounted for 800,000 tons of seafood landings worth approximately 1.5 billion dollars and 30,000 processing jobs. Major categories of species processed include lobster (35–45%), finfish (20–25%: groundfish, herring, salmon), shellfish (scallop, crab, shrimp, 10% each) and fishmeal (AMEC, 2003; Adams et al., 2005; ACOA, 2006; Lalonde et al., 2007; Pinfold, 2007).

Seafood processing plant configurations and processes vary significantly across the industry. Processing begins with the raw product being delivered to the plant by either vessel or truck. For finfish, skinning and filleting followed by freezing and glazing are common processing steps. For shellfish, cooking, cooling, and shelling steps are implemented. In both cases, various levels of post processing packaging are possible such as canning, curing, salting, and smoking (Brodersen, 1973). The consumption of such high volumes of water (cleaning and washing raw materials) results in the discharge of large quantities of wastewater, or effluent, created by the contact of fish product with the process water (Seafish, 1999; Garcia-Sanda et al., 2003; Lim et al., 2003; Tchoukanova et al., 2003; Islam et al., 2004; Sirianuntapiboon and Srikul, 2006; Wang et al., 2006).

The continued growth of the fish-processing industry, the necessity for reduction of pollutants, and the need to maximize returns on raw material have encouraged producers to seek new ways of utilizing the wastes, which have mainly relied on converting the organics in solid waste to various marketable products such as bait, fertilizers, fish oil, and organic acids (Mathur et al., 1988; Lim et al., 2003). The wastewater, however, has traditionally been disposed of by industrial or municipal waste treatment with surcharges and has been a serious waste disposal problem in the fish-processing industry. At the same time, this industry is attempting to improve wastewater handling management strategies due to more stringent environmental legislation. Industrial wastewater originates from manufacturing processes, is usually of a more variable character and in many cases less amenable to treatment (Aizenchtadt et al., 2008).

Seafood processing wastewater is typically high in biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), organic matter, suspended solids, nutrients, and ammonia nitrogen. Consequently, the direct discharge of these waste streams has the potential to degrade receiving water environments through localized depletions of dissolved oxygen, eutrophication, and aquatic toxicity (Carawan, 1991; Seafish, 1999; Sirianuntapiboon and Nimnu, 1999; Tchoukanova et al., 2003; Islam et al., 2004; Wang et al., 2006; Thériault et al., 2007; Jamieson et al., 2009, Chowdhury et al., 2010).

To avoid this impact, characterization and treatment of seafood processing wastewater before discharge has been proposed (Sohsalam et al., 2008). The characterization of this wastewater is complicated by

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the wide variability in effluent contaminant concentrations associated with plant process design, fish species, water consumption demands and production schedules (Carawan, 1991: Seafish, 1999; Afonso and Bórquez, 2002; Adams et al., 2005; Ferjani et al., 2005; Wang et al., 2006; Lalonde et al., 2007; Jamieson et al., 2009). As a result, critical examination in these three areas has been limited, particularly for Atlantic Canada.

In addition to the organic material present in the effluent, there is also the issue of disinfection agents and cleaning chemicals. As mentioned previously, seafood processing plants not only disinfect their source water but also use strong cleaning agents after each processing shift. These agents include chlorine, caustics, degreasers, and various other chemicals (AMEC, 2003; Lalonde et al., 2007). The use of chlorine specifically creates the potential for the formation of disinfection by-products (DBP) in the effluent through the interaction of chlorine with the natural organic material (NOM) (Metcalf and Eddy Inc., 2003). DBPs such as trihalomethanes (THMs) are human carcinogens and are well documented in potable water treatment processes (Mishra et al., 2014). However, DBP formation has not been well characterized in the seafood processing industry, although the presence of DBPs is often suspected as chlorine residuals in seafood processing source water can vary from 1 mg L^{-1} to 7 mg L^{-1} (Tchoukanova et al., 2003).

The physicochemical composition of the effluents generated by marine products processing is well known to be quite variable (Seafish, 1999; Ferjani et al., 2005). Several analyses must be carried out to obtain the major physicochemical characteristics of an effluent discharged by marine products processing plants. Common parameters used to evaluate wastewater of an organic nature are BOD_5, COD, TSS, turbidity, and NH_3-N. BOD_5 and COD are used to measure the oxygen demand required for the degradation of the organic matter in effluent discharged to the receiving water environment. Elevated BOD and COD levels in the effluent can result in lowered dissolved oxygen levels in the receiving water body that can negatively impact aquatic organism growth and reproduction. TSS and turbidity are used to measure suspended particulate matter in the water and are indicators of water clarity. Elevated TSS levels can clog fish gills and smother benthic habitat, among other impacts. Elevated turbidity can cause water temperatures to rise as suspended particles absorb heat (US EPA, 2010). NH_3-N can be found in the blood and urine of most fish species and is a by-product of organic matter decomposition (Tchoukanova et al., 2003; Lalonde et al., 2007). The unionized form of NH_3-N is toxic to marine organisms at low concentrations (EC, 2003).

Adsorbable organic halide (AOX) analysis quantifies organic matter associated with halides (chlorine, bromine, or fluorine). As stated previously, chlorine is often used as a disinfectant in seafood processing to ensure product safety and for general cleaning purposes. This creates the potential for AOX formation in seafood processing effluent. Chlorinated organic compounds can bioaccumulate in the aquatic environment and may cause toxicity in marine organisms (Metcalf and Eddy Inc., 2003; Jamieson et al., 2009).

To enable a better understanding of seafood processing effluents and its potential impacts on the environment in Atlantic Canada, the objective of this paper was to characterize effluent quality from Atlantic Canadian seafood processing plants. Effluent quality was defined by quantifying pH, free chlorine, BOD_5, COD, TSS, turbidity, and NH_3-N. As well, AOX and soluble BOD_5 and COD analysis were conducted on select effluent samples.

2. Materials and methods

2.1. Collection of processing effluent

Samples were collected from Atlantic Canadian seafood processing effluents streams using Sigma 900 Programmable Auto-samplers (*shellfish*: American lobster; Jonah crab and Snow crab; *finfish*: Yellowtail flatfish and Atlantic salmon) to obtain a representative sample over one discrete processing shift. American Lobster and Jonah Crab samples were collected in the winter while Yellowtail flatfish and Atlantic salmon samples were collected in the summer; Samples were collected through non-toxic polyvinyl chloride tubing into a food grade plastic drum and refrigerated (4 to 8 °C) until analysis was conducted.

Typical processing shifts were 6–8 h in length depending on raw product availability. The sampler was normally programmed to collect 1 L every 5–10 min. This resulted in the collection of 80–100 L of the sample over a shift. A collection of effluent for absorbable organic halide (AOX) analysis occurred via the autosampler as well but was directed to an 8-L amber glass bottle instead of the plastic drum. Glass bottle preparation consisted of an acetone and hexane wash to remove potential organic contamination. Only 125 mL of sample was required for analysis but 4 L was collected over a processing shift to obtain a representative composite sample. The sample was decanted into a smaller bottle provided by an accredited third party laboratory for preservation and shipment.

2.2. Effluent characterization

Effluent characterization was carried out at the Centre of Water Resources Studies Laboratory, Dalhousie University within 24-h of sample collection. Temperature and pH were measured using a HACH® SensION 378™ Benchtop Multi-Parameter Meter. Physico-chemical analyses were performed, in triplicate, using standard methods (APHA, 1995) as follow: **Free chlorine** (mg Cl_2 L^{-1}): was performed using a HACH DR2010 Spectrophotometer (HACH Method 10102 - *N*-diethyl-*p*-phenylenediamine (DPD) Method). **Biochemical oxygen demand** (BOD_5): was performed initially by several dilutions ranging from 3, 5, 10, 15, and 20 mL per 350 mL of de-ionized (DI) water to determine BOD_5 strength. After initial analysis, it was found that a 10 mL dilution would result in consistent and accurate BOD_5 measurements. **Chemical oxygen demand** (COD): was performed using a HACH DR4000 Spectrophotometer (HACH Method 8000 - Reactor Digestion Method). Several dilutions were required for each effluent consisting of 1:4, 1:2, and 1:1 mixtures of effluent with DI water. Once the COD was determined a single dilution, typically 1:4, was chosen to use for further analysis. **Total Suspended Solids** (TSS): in the case of seafood processing effluent the majority of the TSS is an organic material consisting of proteins, lipids, and carbohydrates (Islam et al., 2004). As such, the high organic component makes TSS an indicator for oxygen demand. A 1:2 effluent/DI water dilution was used in order to facilitate filtering and prevent plugging. **Ammonia Nitrogen** (NH_3-N): was measured in the processing effluent to provide an indication of ammonia toxicity using a HACH DR2010 Spectrophotometer (HACH Method 8038 - Nessler Method). Levels of NH_3-N varied significantly among effluents samples. Several dilutions were necessary to determine ammonia concentration and a suitable dilution to use going forward. Typically, a 1:5 or 1:4 effluent/DI water solutions was used. **Turbidity** (as NTU): was measured using a bench-top HACH 2100P Turbidity Meter in Nephelometric Turbidity Units (NTU). This parameter correlates well with TSS and can be used as a TSS surrogate measurement. The turbidity of the effluent samples did not require dilutions to enable a reading and was measured immediately after each treatment run. **Insoluble versus soluble BOD_5 and COD components**: this analysis was conducted on the Yellowtail flatfish and Atlantic salmon effluents only. Two raw samples of each effluent were filtered through 0.45 μm glass fiber filters and analyzed for BOD_5 and COD. Filtrate analysis results were expressed as a percent of the raw effluent BOD_5 and COD values representing the soluble portion of the BOD_5 and COD. **Adsorbable organic halides** (AOX): the potential for DBP formation was assessed using AOX analysis. It was hypothesized that there may be a difference between processing and cleanup shift AOX levels due to the focused use of disinfectants and cleaning agents during cleanup. Effluent was collected on a glass solvent rinsed glass bottle during the

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