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Chapter

Biological Treatment of Cannery Wastes

Yung-Tse Hung, Seyedkiarash Sharifiilierdy, Howard H. Paul, Christopher R. Huhnke and Rehab O. Abdel Rahman

Abstract

This chapter reviews various methods of cannery wastewater biological treatment, namely up-flow anaerobic sludge blanket (UASB), sequencing batch reactor (SBR), three-stage aerobic rotating biological contactor (RBC), three sequentially arranged reactors (anaerobic-anoxic-aerobic reactors), lagooning, and anaerobic digestion. The general principles for dealing with the uncertainty of general wastewater treatment plants are applied to control the uncertainty in cannery wastewater treatment. An overview of on the application of Monte Carlo, support vector machine (SVM), artificial neural network (ANN), and genetic algorithm to manage the uncertainty in the biological treatment of wastewater is provided.

Keywords: cannery wastes, up-flow anaerobic sludge blanket, anaerobic digestion, sequencing batch reactor, three-stage aerobic rotating biological contactor, uncertainty in wastewater treatment

1. Introduction

Canned foods were well known and widely used for feeding the armies since the mid-eighteenth century. Nowadays, they play a crucial role in the everyday nutrition of everyone all over the globe, where they provide food with good quality that can last for a long time compared with fresh food. The canned food production industry, as any other industry, includes material processing, storing, and transportation. These activities lead to waste and emission generation and can affect the environment negatively if not well planned and applied. These negative effects might include air and water pollution and soil contamination. Of the major pollutants generated by this industry, the organic pollutants are very crucial [1].

In general, food processing from raw materials requires large volumes of high-grade water, which will become wastewater after usage. In particular, it requires a large volume of potable water for several usages, e.g. raw materials cleaning, fluming, blanching, pasteurizing, processing equipment cleaning, and cooling of the final products. These vast usages require the enforcement of quality criteria for the water used in each application; the best quality usage often requires independent treatment to assure complete freedom from odor and taste and to ensure uniform conditions [1]. The wastewater effluents from this industry are characterized by their large volumes. On average, some 10–20 m^3 wastewaters are produced per tonne of products. The precise characteristics of these wastewaters are highly dependent on the performed processes during the canned food production, i.e. the process of vegetable washing leads to the generation of wastewaters with high loads of some dissolved organics, and particulate matter [2].

The organic content in the wastewater generated as a result of the operation of different processes in the food canning industries is characterized by high concentrations of biodegradable contaminants and variable pH levels. When an environmental reservoir, e.g. a stream or waterway, receives these wastewater effluents, the organic pollutants will consume some of the dissolved oxygen (DO) that exists in the reservoir during their stabilization. This will reduce considerably the DO to levels below that required for the sustainability of lives of the aquatic organisms. The extent of pollution caused by these effluents can be characterized based on the plant capacity, the utilized process, and the characteristics of the raw materials. In this respect, it is beneficial to categorize the plant capacity in terms of population, where seasonal plants are likely to generate waste loads equivalent to 15,000 to 25,000 people, and large plants generate loads up to 250,000 people. The processing of fruit and vegetables is one of the sources of wastewaters, which contain organic matters. Fruit and vegetable canning companies generate wastewaters with high levels of biochemical oxygen demand (BOD), total solid (TS), and suspended solids (SS) [1]. This chapter aims to introduce the available technologies for secondary wastewater treatment that are widely investigated to prevent and control pollution from the food industry. In this respect, the features of the aerobic and anaerobic biological treatment technologies are summarized. Then, an overview of the uncertainty management in biological treatment plants is provided.

2. Cannery wastewater treatment

Due to the nature of the food industry, the preparatory and operational processes of the raw animals, vegetables, and fruits into edible products do not include the application of chemicals. Subsequently, the organic maters in most of the cannery wastewater effluents are best treated using biological treatment, where these matters are rarely present toxicant or inhibitory compounds in their composition. Yet in some operations, e.g. sterilizing and cleaning the equipment, chemicals are used. In particular, disinfectants and caustic soda are used at the end of the processed batch. These effluents could be characterized as short-time concentrated discharges. They may cause shock loads in the wastewater treatment plants that are not designed to deal with these effluents. In this case, the use of equalization unit can achieve acceptable flow equalization and pH adjustment and dilute the high concentration to a nominal concentration that allows safe operation for the biological treatment unit [3].

3. Aerobic treatment of cannery wastewaters

Aerobic wastewater treatment processes could be applied using several technologies, i.e. pond and lagoon-based treatments; surface and spray aeration; oxidation ditches; trickling filters; septic or aerobic tanks; activated sludge; and aerobic digestion. In this section, sequencing batch reactor (SBR), activated sludge (AS), rotating biological contactor (RBC), and aerobic lagoons (AELs) for treating food processing wastewater are discussed.

3.1 Sequencing batch reactor (SBR)

In general, SBR is a fill-and-draw activated sludge system for wastewater treatment. In that system, wastewater effluent is added to a single batch reactor, where treatment is achieved by removing undesirable components, and then, the effluent is discharged. In the same single batch reactor, equalization, aeration, and clarification are conducted.

The formation of granules in aerobic conditions has been possible and appears as a promising technique for treating high-strength or highly toxic wastewaters. It appeared that aerobic granules were successfully cultivated only in SBR. The cyclic operation of SBR consisted of influent filling, aeration, settling, and effluent removal [4].

The development of aerobic granular sludge to achieve simultaneous removal of COD, phosphorous (P), and nitrogen (N) from saline fish-canning wastewater was investigated by Campo [5]. In that work, a 1.6-L SBR with a hydraulic retention time (HRT) of 0.25 d and a volumetric exchange ratio (VER) of 50% was used. The wastewater fed to the SBR was collected from a fish-canning factory located in the south of Galicia (Spain). The SBR was operated in 3-hour cycles comprising 60-min anaerobic feeding, 112-min aeration, 7–1-min settling, and 1–7-min effluent discharge. The salt concentration was approximately 10.4 ± 0.8 g NaCl/l, and the applied organic loading rate (OLR) equals 5.4 ± 1.9 kg COD/(m^{3}d). Under these conditions, aerobic granules were detected after operational time equals 34 days. Some filamentous bacteria were detected on the surface of the aggregates. The granular biomass has a volatile suspended solids (VSS) concentration of 1.34 gVSS/l, density near 11.5 gVSS/l granule, and mean diameter of 1.35 mm. After 41 days of operation, fluffy-flocculent suspension was formed in the presence of the granules. This behavior was attributed to the salinity and the respectively high fraction of slowly biodegradable COD in the influent (35% of total COD). The study reported good removal efficiencies of soluble COD nearly equal to 80%. The phosphorus and ammonium were mainly concluded to be removed to cover the minimum metabolic demand of heterotrophic bacteria. The study indicated that the enrichment of the biomass with slow growing autotrophic and phosphorus-accumulating bacteria in a saline environment requires a longer operational time [5].

3.2 Activated sludge (AS)

The most commonly used biological wastewater treatment technology is the activated sludge. In that technology, the activated sludge (bacterial biomass suspension) is used to degrade the organic pollutants. Over years, various activated sludge processes have been developed. Depending on the design of the AS unit, the wastewater treatment plant (WWTP) can degrade organic carbon substances and remove nutrients, i.e. N and P. In some biological wastewater treatment systems, activated sludge was attached to a surface to form a bio-film. Examples of these systems are integrated fixed-film activated sludge systems, rotating biological reactors, trickling filters, and moving bed bio-film reactors [6].

3.3 Rotating biological contactor (RBC)

RBC process entails the contact between the wastewater and the biological medium that is used to degrade the organic contaminants. A RBC is described as a device that "consists of a series of closely spaced, parallel discs mounted on a rotating shaft which is supported just above the surface of the wastewater" [4, 7]. RBCs are used to remove biodegradable organic matter and convert ammonia-N and organic-N to nitrate-N. Operational problems caused by high organic loading rates restrict the use of RBCs for partial removal of organic matter (i.e. for "roughing" treatment). However, they can be used quite effectively for the substantial removal of organic matter. Process effluent (i.e. clarified) five-day biochemical oxygen demand (BOD5) and total suspended solids (TSS) concentrations can easily be reduced to less than 30 mg/l each, and even lower can be obtained in some instances [8].

3.4 Aerobic lagoons (AELs)

Aerobic lagoons (AELs) are designed and operated to exclude algae. This is accomplished by two means. First, sufficient mixing is used to keep all biomass from the treatment system in suspension, thereby providing turbidity that restricts penetration of light into the water column. The mixing also has the effect of making the solid retention time (SRT) equal to the hydraulic retention time (HRT). Second, the HRT is controlled to values less than the minimum SRT for algal growth (about two days). Because algae are excluded, oxygen must be delivered by mechanical means [8].

4. Anaerobic treatment of cannery wastewaters

This class of biological wastewater treatment technology utilizes microorganisms to degrade the organic pollutants in the absence of oxygen. The sludge in the anaerobic biological reactor consists of anaerobic bacteria and other microorganisms. Food processing wastewaters are particularly suitable for anaerobic treatment processes, firstly because of their high organic load and secondly because they rarely contain toxicants or inhibitory compounds [2].

4.1 Up-flow anaerobic sludge blanket (UASB)

The UASB process makes use of suspended growth biomass, but the gas-liquid-solids separation system is integrated with the bioreactor. The operating conditions within the reactor could be adjusted to allow the formation of large, dense, and readily settleable particles that can lead to the accumulation of very high concentrations of SS, on the order of 20 to 30 g/l as VSS. These high suspended solids concentrations allow significant separation between the SRT and HRT, and operation at relatively short HRTs, often on the order of two days or less, even when the SRT is long. The three-phase UASB reactor allows the achievement of compact and cheaper units due to its ability to separate the gas, water, and sludge mixtures under high turbulence conditions. It has multiple gas hoods for the separation of biogas and can be operated in a one-metre-height reactor that prevents the formation of floating layers [9]. Due to the extremely large gas/water interfaces, the turbulence is greatly reduced, so it is possible to operate the treatment process with relatively high loading rates of 10–15 kg/m^{3}d [8].

UASB technology is known for its efficiency in treating wastewaters with high carbohydrate content. In this respect, the wastewater effluents from the canning industry are efficiently treated by microbes to produce a nutrient-rich starting material for anaerobic hydrogen production. This has led to the wide application of up-flow anaerobic sludge blanket (UASB) reactor for the treatment of the wastewater effluents from food processing plants [10]. These reactors are well known for their ability to withstand variations in wastewater quality and complete shutdown of the reactor in off season [11].

Anaerobic treatment of a highly alkaline fruit-cannery lye-peeling wastewater was investigated, using an up-flow anaerobic sludge blanket (UArSB) reactor. Only a short initializing period was required before COD reduction and OLR had stabilized at 85 to 90% and 2.40 kg COD/m^{3}d, respectively. With subsequent increases in OLR to 8.1kgCOD/m^{3}d, the COD reduction remained between 85 and 93% and biogas production peaked at 4.1 l/d (63% methane). After 111 days, the COD and reactor pH started to decrease and the gas production was reported to decrease after 102 days and continue to decrease to reach the lowest value of 0.93 l/d after 129 days. Subsequent reductions in the OLR, by reducing influent COD, had no effect on reactor stability. This reduction in the reactor performance was attributed to the inhibition of methanogenesis due to the sodium accumulation of sodium (potentially >20,000 mg/l) in the biomass [10, 12].

4.2 Anaerobic digestion

Anaerobic digestion (AD) is used for the stabilization of particulate organic matter. An anaerobic digester is well mixed with no liquid-solids separation. Consequently, the bioreactor can be treated as a continuous stirred tank reactor (CSTR) in which the HRT and SRT are identical. An SRT of 15 to 20 days is typically used, although SRTs as low as 10 days have been used successfully and longer SRTs are employed when greater waste stabilization is required [8].

For several cannery waste streams, the recovery of useful by-products could be achieved by anaerobic digestion. High COD content fruit and vegetable wastes (>50,000 mg/l) have been treated successfully by AD using a HRT of 10 days and a sludge age of 80 days. For elder sludges, the SS build-up within the reactor reached 30,000 mg/l, but at higher concentrations settling became a problem. Generally, successful treatment of food processing wastes could be achieved using AD with a retention time greater than 10 days and gas production of up to 0.75 m^3/kg volatile solids [9, 11].

4.3 SHARON-Anammox process

A Single reactor system for High activity Ammonium Removal Over Nitrite (SHARON) is a treatment process, which utilizes partial nitrification process for the degradation of ammonia and organic nitrogen components from wastewaters. The process results in stable nitrite formation, rather than complete oxidation to nitrate. The process relies on controlling the pH, temperature, and retention time to prevent the nitrate formation by nitrite-oxidizing bacteria, e.g. Nitrobacter. The wastewater denitrification that employs SHARON reactors can proceed with an anoxic reduction, such as Anammox. In the Anammox process (anaerobic ammonium oxidation), nitrite and ammonium are converted into nitrogen gas under anaerobic conditions without the need to add an external carbon source. In comparison with conventional N-removal processes, the SHARON process results in a reduction of required aeration energy and carbon source.

The application of the successive SHARON-Anammox processes was tested to treat the wastewater from a fish cannery plant. The effluents generated from the anaerobic digestion are characterized by their salinity up to 8000–10,000 g NaCl m^{-3}, organic carbon content (1000–1300 g $TOCm^{-3}$), and high ammonium content (700–1000 g $NH_{+4}^{-}Nm^{-3}$). In the SHARON reactor, nearly half the ammonia is oxidized to NO^{-}_{2}-N via partial nitrification. Then, SHARON effluent was directed to feed the Anammox reactor. The system was reported to attain average nitrogen removal of 68%. The bacterial population distribution in the Anammox reactor, followed by FISH analysis and batch activity assays, did not change significantly despite the continuous entrance to the system of aerobic ammonium oxidizers coming from the SHARON reactor. Most of the bacteria corresponded to the Anammox population and the rest with slight variable shares to the ammonia oxidizers. Despite the continuous variations in the amounts of ammonium and nitrite in the feed wastewater, the Anammox reactor showed an unexpected robustness. Only in the period when NO^-_2-N concentration was higher than the NH^+_4-N concentration did the process destabilized and it took 14 days until the nitrogen removal percentage decreased to 34% with concentrations in the effluent of 340 g NH^+_4-Nm^{-3} and 440 g NO^-_2-N m^{-3}, respectively. That study concluded that this successive application of SHARON-Anammox reactors is successful in treating high nitrogen and saline effluents with acceptable control on the ratio between the NO^-_2-N and NH^+_4-N [13].

4.4 Anaerobic membrane bioreactors (An-MBR)

An-MBR can be simply defined as a biological treatment process operated without oxygen and using a membrane to provide solid–liquid separation. The advantages offered by this process over conventional anaerobic systems and aerobic MBR are widely recognized [12].

Saline wastewaters are known for their negative impact on the performance of the biological treatment units. Sodium chloride is widely used, not only for cooking and to melt snow and ice, but also in a wide variety of food industries including food canning, seafood processing, milk processing, etc. In particular, the operation of the seafood processing industry leads to the generation of wastewaters with high soluble and colloidal pollutants and a high concentration of N and SS. For these effluents, the application of conventional biological treatment is not efficient. It was reported that the efficiency could be enhanced by reducing the sodium toxicity with compatible solutes that can increase the sludge activity. Moreover, the anaerobic membrane bioreactor reduces the COD concentration in the wastewater [14].

4.5 Anaerobic filter (AF)

AF consists of a fixed bed biological reactor with one or more series of filtration chambers. This technology relies on the entrapment of the particles in the wastewater on the filter media and the subsequent degradation of the organic matter by the active biomass attached to the surface of the filter media [15]. As the anaerobic biomass should grow on the filter media, 6–9-month start-up period is required for AF to attain the full treatment capacity. The filter can be inoculated with anaerobic bacteria to reduce the start-up time, and the flow should be gradually increased [13, 16].

4.6 Blanket/anaerobic filter

Hybrid UASB/AF systems combine aspects of the UASB process with aspects of the AF process. Influent wastewater and recirculated effluent are distributed across the bioreactor cross section and flow upward through granular and flocculent sludge blankets where anaerobic treatment occurs. The effluent from the sludge blanket zone enters a section of media similar to that used in AF systems where gas-liquid-solids separation occurs. Treated effluent then exits the media section and is collected for discharge from the bioreactor. Gas is collected under the bioreactor cover and is transported to storage and/or use. The hybrid UASB/AF process primarily uses suspended biomass, and process loadings are similar to those used with the UASB process. The solids removal system is similar to that used with the UASB process [8].

A research study on the treatment of wastewater generated from vegetable processing was conducted. In this project, an anaerobic filter, a fluidized bed reactor, and an up-flow anaerobic sludge blanket reactor associated with an anaerobic filter were designed, constructed, and tested [5]. For the anaerobic filter, the removal efficiency for COD was reported to exceed 80% for HRT of 16 h, at temperatures ranging from 20 to 31°C. The FBAR was operated at HRT of 2 h with mean COD removal efficiency of 63%. The UASB/AF achieved mean COD removal efficiency of 80% at HRT of 6 h [17].

5. Cannery wastewater treatment with anaerobic-anoxic-aerobic system

Anoxic process is widely used in wastewater treatment. Anoxic means depletion or deficiency of oxygen. Anoxic process is a biological treatment process by which NO_3-N is converted to molecular nitrogen gas in the absence of oxygen.

A system comprised of anaerobic-anoxic-aerobic reactors was tested to treat the wastewater from tuna cooker. This wastewater stream is characterized by high COD and N concentrations. The up-flow anaerobic sludge blanket reactor was used to achieve the anaerobic digestion in a two-step process. In the first, the COD concentration was varied and ORLs up to 4 g COD/(l.d) were achieved. In the second step, the 6 g COD/l and the HRT were varied between 0.5 and 0.8 day, and this step led to ORLs less than 15 g COD/(l.d). The denitrification process was carried out in an up-flow anoxic filter, and the result of the project indicated that the efficiency of this process is dependent on the supplied carbon content. For optimum carbon content, the ratio between the COD and N equalled 4 and the denitrification percentage equalled 80%. Finally, the nitrification was reported to be fixed at 100% ammonia removal regardless of the amount of carbon in the range of 0.2–0.8 g TOC/l. The variation of the recycling ratios between the denitrification and nitrification reactors in the range of 1–2.5 was found to affect the efficiency of the COD and N-removal percentage, where 90 and 60% removal for COD and N was reported at recycling ratio between 2 and 2.5 [15].

6. Uncertainty in cannery wastewater

There are several types of uncertainties that should be addressed during the design of a wastewater treatment plant, e.g. the variation in strength and quantity of wastewater entering into the plant, the diversity, and the dynamics of the microbial community. An uncertainty analysis for a pre-denitrification plant that uses an activated sludge unit was performed [18]. The unit consists of five compartments: the first two are anoxic and the last three are aerobic. Three scenarios were considered in that study that cover the uncertainty due to stoichiometric, bio-kinetic and influent parameters; uncertainty due to hydraulic behavior of the plant and mass transfer parameters; and uncertainty due to the combination of both scenarios. The study concluded that parameters related to the first and second scenarios introduce significant uncertainties in the plant performance measures. In addition, it was stated that the applied uncertainty farming technique largely affects the uncertainty estimates.

The Monte Carlo simulation was intensively used to simulate the design and upgrade of wastewater treatment plants under uncertainty in balancing effluent costs, violating effluent quality standards, predicting the disinfection performance, generating different influent compositions for posterior process performance evaluation or as a pragmatic procedure to automate the calibration of ASM models, and considering the impact of the input parameter uncertainty on the multi-criteria evaluation of control strategies at wastewater plant [19–22].

Due to the complexity and non-linearity of wastewater treatment plant operations, mathematical models are generally not sufficient to predict the performance of WWTPs. Therefore, AI models have been proposed as an alternative model to linear methods. The methods for minimizing the effect of uncertainty in wastewater characteristics and wastewater flow on wastewater treatment reported in the literature have included support vector machine (SVM) and artificial neural network (ANN) [23]. An optimization model to control uncertainty in operation of wastewater treatment from the shale gas production has been reported in the literature [24]. In addition, genetic algorithms have been developed to model and optimize a biological wastewater treatment plant [25].

Information regarding uncertainty in the wastewater treatment plants in treating cannery wastewater is lacking in the literature. However, the principles governing uncertainty in wastewater treatment plants can be applied to control uncertainty in cannery wastewater treatment.

7. Conclusions

The following conclusions can be reached based on the review of literature in cannery wastewater treatment:

- The wastewater that is generated in food canning industries contains high quantities of organic material, a high level of biodegradables and variable pH levels.

- The food processing industry requires a large amount of potable water for a variety of non-consumption usages, such as for initial cleaning of raw material, fluming, blanching, pasteurizing, cleaning of processing equipment, and cooling of finished product.

- The nature of the organic matter of cannery industry wastewater makes it suitable for biological treatment.

- Flow equalization and influent pH control normally have enough diluting and neutralizing effect to permit the use of biological processes for cannery wastewater treatment.

- Various treatment processes using aerobic and anaerobic treatment can be applied for the treatment of cannery wastewater, depending upon wastewater strength.

- Information regarding uncertainty in wastewater treatment plants in treating cannery wastewater is lacking in the literature. However, the principles governing uncertainty in wastewater treatment plants can be applied to control uncertainty in cannery wastewater treatment.

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