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Biological Treatment Systems for Fish Processing Wastewater - A Review

U. Parvathy*†, K. H. Rao*, A. Jeyakumari* and A. A. Zynudheen****
*Mumbai Research Centre of Central Institute of Fisheries Technology, Vashi, Navi Mumbai-400 703, India
**ICAR- Central Institute of Fisheries Technology, Matsyapuri P.O., Cochin-682 029, India
***ICAR-National Academy of Agricultural Research Management, Rajendranagar, Hyderabad-500 030, India
†Corresponding author: U. Parvathy

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ABSTRACT

Processing of fish involves mainly the application of various preservation techniques for retaining a superior quality and enhancing shelf life. It also covers aspects like value-addition to produce a wide variety of products. But during these fish processing operations large quantity of effluents, which contain active microorganisms in various forms are being generated. Depending on the processing operation involved, the level of contamination varies. This high-strength wastewater from fish processing industry is of great concern world-wide and hence recently stringent liquid effluent policies are being adopted. A number of treatment strategies at different levels are applicable for reducing this risk, however biological treatment is one of the best options for fish processing wastewater, rich in organic matter. Biological treatment includes both aerobic and anaerobic processes. Aerobic processes such as activated sludge, lagoons, trickling filter and rotating biological contactor are suitable for organics removal. The anaerobic processes can also remove 80-90% organics and produce biogas. A combination of both anaerobic digestion and aerobic process is regarded as an effective approach to reduce the contaminants in fish processing wastewater.

INTRODUCTION

Fish processing refers to the processes involved right from the time the fish is caught or harvested to the time the final product is delivered to the customer. In practice, it is extended to cover any aquatic organisms harvested for commercial purposes, whether caught in wild fisheries or harvested from culture systems. The most common processes involved in fish processing plants are filleting, freezing, drying, fermenting, canning and smoking (Palenzuela-Rollon 1999). Fish processing operations generate potentially large quantities of waste and by-products from inedible fish parts and endoskeleton shell parts from crustacean peeling process viz., particles of flesh, skin, scales, bones, visceral mass (viscera, air bladder, gonads and other organs), head, fins, shells or liquid stick water. Depending on the species processed, the solid wastes make up to 30-40% of the total production. Among these different types of waste generated, fish viscera alone contributes 15-25% of the total body weight (Jini et al. 2011). These wastes are rich in organic content and subsequently a high BOD because of the presence of blood, tissue and dissolved protein. Seafood processing operations generate approximately 1-72.5 kg of BOD per tonne of product with fish filleting processes typically producing 12.5-37.5 kg of BOD for every tonne of product (Tay et al. 2004). It also typically has a high content of nitrogen and phosphorus (IFC 2007) with the main components of these processing wastes being lipids and proteins (Gonzalez 1996). The volume and concentration of wastewater from fish processing depends mainly on the raw fish composition, additive used, processing water source and the unit process. At present, management of these fishery wastes is one of the main problems having the greatest concern and impact on the environment (Ahumada et al. 2004, Gilberg 2004). These effluents typically high in nutrients results in algal blooms, offensive odour, acutely lethal discharges, localized areas of anoxia etc. (AMEC 2003). The environmental impact of a product, process or activity during its life cycle can be evaluated by new approaches like life cycle assessment (LCA) (Mattsson & Sonesson 2003, AIPCE-CEP 2011).

Proper selection of a dump site at sea for the reception of waste is of paramount importance. Small operations in isolated areas usually do not cause adverse environmental impact if the wastes are discharged into a large receiving body of water with adequate mixing. But when large amounts of fish processing wastes are generated in one location or in close together and are discharged into a small part of the sea with poor water exchange, adverse environmental impact may occur (Midlen & Redding 1998) and hence need to be properly treated before discharging to the surrounding water bodies (AMEC 2003). Care needs to be taken to find dispersive sites that make the waste more available to consuming organisms. The guidelines values for the fish processing wastewater for discharge are given in Table 1.

For economic and environmental sustainability, fish processing effluent treatment needs to be considered in order to obtain water with quality requirements that allow its reuse or recycling for industrial process. Regarding the organic matter degradation, the food industry wastewaters are conventionally submitted to biological treatments, as their wastewaters are normally rich in organic matter and nutrients. Wastewater pollutant removal efficiencies of greater than 90 percent can be achieved with biological treatment (Kiepper 2001). The microorganisms used are responsible for the degradation of the organic matter and the stabilization of organic wastes (Arvanitoyannis& Kassaveti 2008). The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) significantly decrease as the result of the microbiological activity (Raquel et al. 2012). The organic wastes from fish processing sites are in the form of liquids, sludges or solids and biological treatment is applied to all three forms of wastes. Based on the utilization of oxygen, microbes in the system can be classified as aerobic, anaerobic or facultative and since most of them present in wastewater treatment systems use the organic content of the wastewater as an energy source to grow, they are classified as heterotrophs from a nutritional point of view. The population active in a biological wastewater treatment is mixed, complex and interrelated. For example, in a single aerobic system, members of the genera *Pseudomonas, Nocardia, Flavobacterium, Achromobacter* and *Zoogloea* may be present, together with filamentous organisms like *Beggiatoa* and *Spaerotilus*. In a perfect system, protozoans and rotifers are usually present and are useful in consuming dispersed bacteria or non-settling particles (Gonzalez 1996).

Wastewater treatments by biological means are broadly classified as aerobic or anaerobic and all operations can be classified on the basis of their microbial population, into either fixed film or dispersed growth processes (Michael & David 2011). Fixed film reactors have biofilms attached to a fixed surface where organic compounds are adsorbed into the biofilm and aerobically degraded also referred to as “attached growth processes” (biological filtration). In suspended growth processes (biological aeration), the microorganisms mix freely with the wastewater and are kept in suspension by mechanical agitation or mixing by air diffusers (Hammer & Hammer 2011).

Aerobic processes: The basic aerobic treatment process involves providing a suitable oxygen rich environment for organisms that can reduce the soluble and colloidal organic portion of the waste into microbial biomass, with subsequent removal of the biomass by settling or mechanical separation thereby reducing organic matter and BOD (USEPA 2000). In aerobic process for meeting the nutritional requirements, the microorganisms use the waste stream as a source of major elements, minor elements, trace elements and growth factors. Wastewater from fish processing units require less addition of nutrients, but adequate oxygen is essential for successful operation of the systems. Aerobic wastewater treatment processes, broadly divided into suspended and attached-growth processes, include activated sludge systems, lagoons (oxidation ponds), trickling filters and rotating biological contactors (Chowdhury et al. 2010). Aerobic lagoons and various forms of the activated-sludge process are examples of suspended-growth processes; trickling filters and rotating biological contactors (RBCs) are examples of attached-growth processes. Both use a diverse population of heterotrophic microorganisms that use molecular oxygen in the process of obtaining energy for cell maintenance and growth (Metcalf & Eddy 2002).

Activated sludge system: The activated sludge process was developed in 1914 by Arden and Lockett. It was so called because it involved the production of an activated mass of microorganisms capable of aerobically stabilising the organic content of waste (EPA 1997). In this system, wastewater is introduced into an aerated tank containing microorganisms, which are collectively referred to as activated sludge or mixed liquor. Aeration is achieved by the use of submerged diffused or surface mechanical aeration or a combination of both which maintain the activated sludge in suspension. Following a period of contact between the

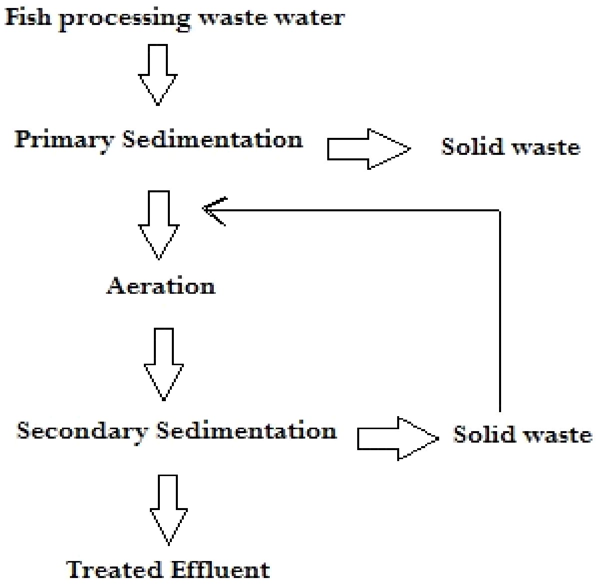

Fig. 1: Activated sludge process.

Table 1: Effluent levels for fish processing (Source: IFC 2007).

Pollutants	Units	Guideline Value
pH	pH	6-9
BOD_5	mg/L	50
COD	mg/L	250
Total nitrogen	mg/L	10
Total phosphorus	mg/L	2
Oil and grease	mg/L	10
Total suspended solids	mg/L	50
Temperature increase	°C	<3[b]
Total coliform bacteria	MPN[a]/100 mL	400
Active Ingredients/Antibiotics	To be determined on a case specific basis	

Notes:[a] MPN = Most Probable; Number[b] At the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use, potential receptors andassimilative capacity

wastewater and the activated sludge, the outflow passes to a secondary settling tank where the cells are settled and the settled biomass is recycled partially to the aeration basin (Fig. 1), whereas, the treated wastewater is generally discharged after disinfection (Yasui et al. 1996). Sufficient biomass, required to degrade the organic load, is maintained by recycling of the cells (Raquel et al. 2012). As the cells are retained longer in the system, they start to produce extra cellular slime which favours flocculating. As reported by Hug (2006), foaming is a common operational problem during this process in many wastewater treatment plants. This problem can be reduced by decreasing the flow from the aeration basin to the settling tank or reducing the sludge resident time in the settler, either by increasing the rate of recycle to the aeration basin, increasing the rate of sludge collection from the bottom, or increasing the sludge wasting rate from the system. The main products of this process are carbon dioxide, water and new cells (Perez et al. 2010). The concentration at which the mixed liquor is maintained in the aeration tank affects the efficiency of the treatment and the treatment efficiencies are assessed in terms of Total Organic Carbon (TOC) removal. The aerobic biological treatment leads to a very large decrease in the TOC value of the wastewater from fish canning industry. The activated sludge process is also capable of reducing BOD and suspended solids by 70-90% (USEPA 2000). In addition, more than 95% reduction in ammonia nitrogen is also possible at temperatures above 10°C and dissolved oxygen concentrations above 2 mg/L.

Activated sludge process can be modified by changing the location of the aeration devices resulting in tapered aeration and step aeration processes; providing two biological reactors for contact stabilization-one for the sorption of organic materials by the activated sludge and the other for bio-oxidation of the sorbed materials; applying different recirculation rate; the food to microorganism ratio and the mixed liquor/suspended solids concentration. Based on these modifications, the variants of activated sludge process include conventional type, complete mix type, extended aeration systems, oxidation ditches and sequencing batch reactors (Metcalf & Eddy 2002, USEPA 2004, Michael & David 2011).

Lagoons: Lagoons are comparatively cheaper than other treatment processes, although they require larger land area (USEPA 2004). Aerated lagoons are earthen basins, used in place of concrete or steel tanks for suspended growth biological treatment of wastewater and solids are not recycled into the system (Tay et al. 2004). Although diffused air systems are used for aeration and mixing, fixed and floating mechanical aerators are more common. Natural aeration occurs in diffused air systems by air diffusion at the water surface by wind or thermal-induced mixing and by photosynthesis (USEPA 2002). Algae and cyanobacteria (blue-green algae) are the microorganisms responsible for most of the photosynthetic activity in a naturally aerated lagoon. Naturally aerated lagoons are approximately 1 to 2 feet deep, so that sunlight can penetrate the full lagoon depth to maintain photosynthetic activity throughout the day. Mechanically aerated lagoons do not have a depth requirement because oxygen is supplied artificially instead of by algal photosynthesis (Zhang 2001). When wastewater flows through the system, bio-oxidation of organic matter occurs due to microorganisms to form CO_2, ammonia, inorganic radicals and new microorganisms. They are classified as the completely mixed lagoon (aerobic or completely suspended) in which the concentration of solids and dissolved oxygen are maintained fairly uniform throughout the depth, and the facultative (aerobic-anaerobic or partially suspended) lagoons wherein there is accumulation of solids in the bottom which undergo anaerobic decomposition, while the upper portions are maintained aerobic (Tay et al. 2004, USEPA 2002).

Aerobic lagoons, which are also known as aerobic stabilization ponds, are large, shallow, earthen basins that use algae in combination with other microorganisms in wastewater treatment. Low-rate ponds, which are designed to maintain aerobic conditions throughout the liquid column, may be up to 5 feet deep. High-rate ponds are usually shallower, with a maximum depth of 1.5 feet. In these ponds, oxygen is supplied by a combination of natural surface aeration and photosynthesis. Aerobic stabilization ponds can be operated in parallel or in a series. To maximize performance, intermittent mixing is necessary. Without aeration, settled solids form an anaerobic zone at the bottom of the pond (Nicholas 1996). Facultative lagoons are deeper and with smaller surface areas than aerated or aerobic lagoons, varying in depth from 5 to 8 feet. Biochemical reactions in facultative lagoons are a combination of aerobic and anaerobic degradation reactions (Zhang 2001). Waste is treated by bacterial action occurring in an upper aerobic layer, a facultative middle layer, and a lower anaerobic layer. Aerobic bacteria degrade the waste in the upper layer, where oxygen is provided by natural surface aeration and algal photosynthesis. Settleable solids are deposited on the lagoon bottom and degraded by anaerobic bacteria. The facultative bacteria in the middle layer degrade the waste aerobically when dissolved oxygen is present and anaerobically otherwise. The major operational difference between these lagoons is the power input, which is in the order of 2.5-6 W/m^3 for aerobic lagoons while the requirement for facultative lagoons is of the order 0.8-1 W/m^3 (Tay et al. 2004).

Another modification includes the addition of another pond in series or a settling tank to remove the sludge. Dual-Power, Multi Cellular (DPMC) aerated lagoon systems are considered innovative as recent as a decade ago which essentially consists of four cells in series (Rich 1999). In DPMC, solid stabilization rates as well as the frequency of sludge removal from the system are to be considered during the system designing. With aerated lagoons approximately 90-95% BOD removal efficiency can be achieved for seafood processing wastewater.

Trickling filters: The primary mechanism of a trickling filter is not filtering action of fine pores, but rather diffusion and microbial assimilation. Trickling filter is one of the most common attached growth processes which consist of a bed of highly permeable media to which microbial flora attaches, a distribution system for uniform wastewater supply and an under drainage system for collecting the treated wastewater and any microbial solids that gets detached from the media. Two types of media are commonly used in trickling filters, stone media and synthetic media (Michael & David 2011). As synthetic media replaced stone, the term biological tower was introduced (Hammer & Hammer 2011). The bed can be of gravel, crushed stone or slag having a size of about 5-10 cm. Regular packings of plastic material are also becoming more common recently due to its lighter weight, better flow distribution, larger void space and specific area. The microbes that grow on the gravel bed absorb the organic matter as the water flows through the filter bed (Leslie et al. 1999). As the microbial slime grows and gets thicker, some of the inner portions of the biomass will get deprived of oxygen and nutrients and hence detaches off the supporting media and leaves the filter bed which is settled in the final clarifier for treatment and disposal (Gonzalez 1996). This process is known as "sloughing" and can be a periodic or continual process depending on the organic and hydraulic loading rates. The hydraulic loading rate is usually adjusted to maintain continual sloughing and a constant slime layer thickness (Metcalf & Eddy 2002). Trickling filters have been classified as low-rate, intermediate-rate, high-rate, super high-rate, roughing and two-stage, based on the filter medium, hydraulic and BOD loading

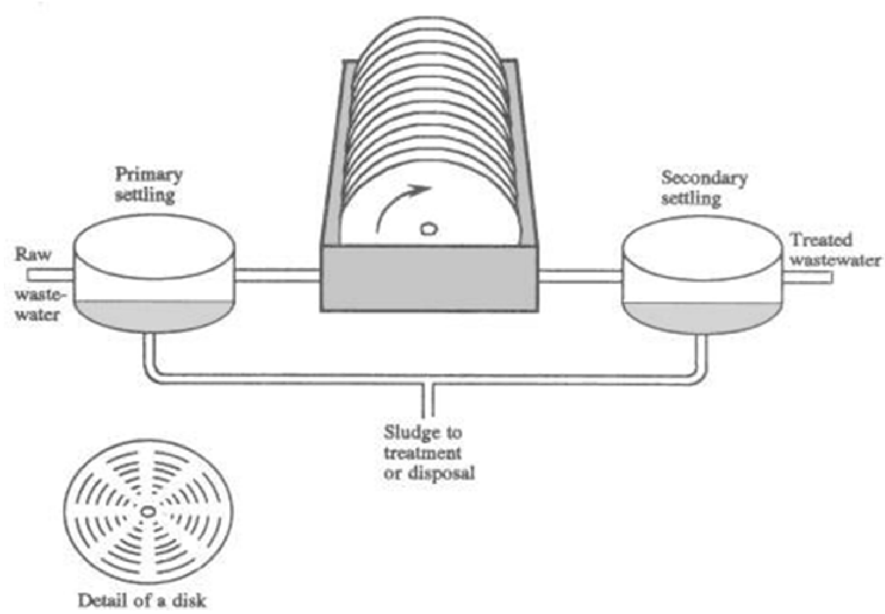

Fig. 2: Rotating biological contactor (RBC) unit (Gonzalez 1996).

rates, recirculation ratio and depth. Low-rate and intermediate-rate trickling filters traditionally use rock or blast furnace slag as filter media; while high-rate filters employ only rock. Super high-rate filters use plastic media, while roughing filters use plastic or redwood media and two-stage filters may be constructed using plastic or rock media. As with all biological systems, low temperatures reduce the degrading capacity of trickling filters and hence in cold areas trickling filters may be covered (Gonzalez 1996, Michael & David 2011).

Rotating biological contactors: A rotating biological contactor (RBC) is basically an attached growth process similar to the trickling filter providing the advantages of both of biological fixed film and partial mixing (Tay et al. 2004). They employ media disks of corrugated, light plastic material (up to 3.5 m dia) which rotates at 1 to 3 rpm when immersed up to 40% in the wastewater (Fig. 2). The attached biomass absorbs air when exposed and when immersed the microorganisms absorb the organic load (Reynolds & Richards 1996). A biomass of 1-4 mm thickness grows on the surface and excess is teared off the disks and is separated from the liquid in the secondary settling tank (Neji et al. 2002). Both trickling filter and rotary bio-contactors need little maintenance, laboratory control and minimum operation time. RBC efficiency is affected by disc rotational speed, hydraulic retention time, loading rate, disk submergence and temperature. A multi stage RBC is generally suitable for a high-strength wastewater such as wastewater from a fish-processing industry (Chowdhury et al. 2010). According to Najafpour et al. (2006), an RBC reactor provides more stability, requires lower energy and there is no necessity of sludge recycling. The major advantages of RBCs are (i) relatively low installation cost and short hydraulic retention time, (ii) high specific surface area and biomass concentration, (iii) insensitivity to toxic substrate, (iv) less accumulation of sloughed bio-film and partial mixing, (v) low energy consumption, (vi) operational simplicity, (vii) ability to combine secondary treatment with ammonia removal by nitrification, especially in multistage systems, and (viii) resistance to shock loads (Chowdhury et al. 2010). The major disadvantage is the need to enclose them, especially in cold climates, to maintain high removal efficiencies, control odours, and minimize problems with temperature sensitivity.

Anaerobic treatment: Anaerobic process will also to a greater extent convert organic dissolved solids to organic suspended solids and they will convert a significant proportion of the organic materials to gases, predominantly CO_2 and methane commonly referred to as biogas (Clanton 1997). The main advantages, particularly for bigger plants, are (i) low operating costs, (ii) low space requirements, (iii) valuable biogas production, and (iv) low sludge production. Anaerobic systems are well suited for the treatment of fish processing wastewater because a high degree of BOD removal can be achieved at a significantly lower cost compared to aerobic systems and generate a smaller quantity of highly stabilized, and easily dewatered, sludge. Also, the methane-rich gas which is generated can be captured for use as a fuel (Johns 1995). Anaerobic treatment is the result of several reactions: the organic load present in the wastewater is first converted to soluble organic material which in turn is consumed by acid producing bacteria to give volatile fatty acids, carbon dioxide and hydrogen. The methane producing bacteria consume these to produce methane and carbon dioxide. The biogas produced by the microbial activity typically contains 30 to 40 % carbon dioxide, 60 to 70 % methane and trace amounts of hydrogen sulfide and other gases (Metcalf & Eddy 2002, Nielsen 1996). High removal efficiencies (75-80%) can be obtained by this process in fisheries wastewater with loads of 3 or 4 kg of Chemical Oxygen Demand (COD)/day/m^3 of digester.

Anaerobic process is temperature sensitive and hence in some cases heating is provided to the digester to reach temperatures of 30°-35°C. Imhoff tank is a relatively simple system used originally instead of heated digesters and is used for plants of small capacities. It consists basically of a two-chambered rectangular tank, usually built partially underground. The wastewater enters the upper compartment which acts as a settling basin while in the lower part the settled solids are stabilized anaerobically. According to the Meat and Poultry Products (MPP) detailed survey, anaerobic lagoons are the most commonly used anaerobic unit process for treating MPP wastewaters (USEPA 2004). However, high-rate anaerobic processes include anaerobic contact (AC), up-flow anaerobic sludge blanket (UASB), and anaerobic filter (AF) processes (Johns 1995). These alternatives are especially appealing in situations where land for lagoon construction or expansion is not available.

Recovery of biomolecules from fish processing waste: As per the recent estimate by Bhaskar et al. (2010), global generation of fish industry waste exceeds 63 million metric tonnes and is known to be a good source of recoverable biomolecules. Researchers across the globe are focusing on methods to recover the biomolecules in order to reduce organic load dumped into the environment as well as to decrease the pollution related problems (Bhaskar et al. 2008, Rao & Stevens 2006, Rustad 2003). Lactic acid fermentation, an anaerobic process is well known technology for recovery of biomolecules from various kinds of solid wastes generated from different industries based on animal processing including fish (Amit et al. 2009, Gao et al. 2006, Rao & Stevens 2006). Fish viscera are not only rich in different biomolecules but also beneficial lactic acid bacteria (LAB) with probiotics properties (Balcazar et al. 2008). Fermentation using LAB is an effective means of *in situ* acid generation in turn preserving the waste through ensilation (Shirai et al. 2001) or allowing recovery of lipids/proteins (Amit et al. 2009). LAB have been used as probiotics due to their properties including antibacterial, immunomodulation, control of intestinal homoeostasis, resistance to gastric acidity, and bile acid resistance (Tannock 2004).

CONCLUSION

Wastewater management in a fish-processing industry is of great concern world-wide and biological treatment of such wastewater can be one of the best options. Biological treatments are generally part of secondary treatment systems and they remove the non-settling solids and the dissolved organic load from the effluents by using microbial populations. The microorganisms present in the system degrade the organic matter and stabilize the organic wastes. They can be classified into aerobic, anaerobic or facultatively anaerobic based on the way in which they utilize oxygen. Aerobic processes include activated sludge, lagoons, trickling filter and rotating biological contactor which are suitable for organics removal and anaerobic processes can also achieve high (80-90%) organics removal and produce biogas. Based on the nature of fish processing wastewater, a combination of both anaerobic and aerobic process is found to be optimal.

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