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TECHNOLOGIES FOR WASTEWATER TREATMENT FROM THE FISH PROCESSING INDUSTRY: REUSE ALTERNATIVES

TECNOLOGIAS PARA O TRATAMENTO DE EFLUENTES DA INDÚSTRIA DO PROCESSAMENTO DE PESCADO: ALTERNATIVAS PARA O REUSO

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ABSTRACT

For the fish processing industry, the treatment proposal for effluents encounters some difficulties, such as high concentration of organic matter and solids in suspension, and lack of uniformity in the composition. Considering this problem, the objective was to evaluate the removal efficiency for different effluent treatment technologies of the mentioned industry and the possibility of reuse. In order to do so performed a survey of effluent treatment systems, verifying the removal rate for pH, total suspended solids (TSS mgL-1), biochemical oxygen demand BOD (mgL-1), chemical oxygen demand COD mgL-1), total nitrogen TN (mgL-1), total phosphorus TP (mgL-1) and oils and greases (mgL-1). The concentrations found were compared to the limit values imposed by the standards for industrial reuse. As a result, it has been found that the combination of multiple processes, using advanced treatment techniques, is appropriate, especially where the purpose is to reuse and/or recycle.

Keywords: fish processing; industrial reuse; wastewater treatment.

RESUMO

Para a indústria de processamento de pescado, a proposição de tratamento para os efluentes encontra algumas dificuldades, como elevada concentração de matéria orgânica e de sólidos em suspensão, e falta de uniformidade na composição. Considerando esta problemática, se objetivou avaliar a eficiência de remoção para diferentes tecnologias de tratamento de efluentes da referida indústria e a possibilidade de reuso. Para tanto, realizou-se em levantamento de sistemas de tratamento de efluentes verificando-se a taxa de remoção alcançada para pH, total de sólidos em suspensão (TSS mgL-1), demanda bioquímica de oxigênio DBO (mgL-1), demanda química de oxigênio COD (mgL-1), nitrogênio total TN (mgL-1), fósforo total TP (mgL-1) e Óleos e graxas (mgL-1). As concentrações encontradas foram comparadas aos valores limites, impostos pelas normas para reuso industrial. Como resultado foi verificado que a combinação de múltiplos processos, com a utilização de técnicas avançadas de tratamento, mostra-se apropriada, principalmente quando a finalidade for o reuso e/ou reciclo.

Palavras-chave: reuso industrial; sustentabilidade; sistemas de tratamento.

INTRODUCTION

The exponential growth of the world's population, with consequent increase in the demand for food, causes direct reflexes in the markets of the fish industry, which undergo a constant expansion process (FAO, 2013; SATO *et al*., 2013). In recent years, world fish production has reached a total supply of 167.2 million tons in 2014, a record high so far, leading to a consumption of 20 kg per capita, covering commercialization in the form of fresh, frozen, smoked and preserved fish (FAO, 2016). Analyzing the participation of developing countries in total fish exports, there has been an upward and continuous trend of these activities in recent decades, surpassing, in some cases, the representativeness of other agricultural commodities such as rice and coffee (FAO, 2016).

As in all production processes, the fish processing industry uses a large volume of water (on average 11 m^3 per ton of processed fish and 15 m^3 per ton in the case of shrimp processing) both before and during the process — especially in the washing, cleaning, storage and refrigeration stages (ARVANITOYANNIS; KASSAVETI, 2008; CHOWDHURY *et al*., 2010; ANH *et al*., 2011; MUTHUKUMARAN; BASKARAN, 2013; CRISTOVÃO *et al*., 2015). Due to this high water consumption and its respective generation of effluent, alternatives for volume reduction and quality improvement should be fostered, either by adopting technologies and procedures that reduce the amount of water used, either by reusing of the same one during the processes.

The commitment to the application of these concepts is a fundamental requirement to achieve industrial practices compatible with the preservation of the environment (JOSÉ *et al*., 2013). It may also lead to a reduction in the direct and indirect costs of the processes through the management of water, energy and raw material used (SOUZA, 2010).

Therefore, the high organic and salt loads present in the effluents from the fish processing stages result in a higher quantity of total suspended solids, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (CHOWDHURY *et al*., 2010; CRISTOVÃO *et al*., 2012; CRISTOVÃO *et al*., 2014b), thus reducing the quality of the final effluent. These organic contaminants can be present in soluble, colloidal and particulate forms (CHOWDHURY *et al*., 2010), including proteins, nutrients, oils and fats (MUTHUKUMARAN; BASKARAN, 2013). In the case of solid residues produced, these are mainly scales, meat, bones, cartilage and viscera (JAMIESON *et al*., 2010; ANH *et al*., 2011). Nevertheless, among the various products from the fish industry, those that present effluents with the presence of more recalcitrant pollutants and metals are those from the production of oil and fish meal, according to studies reported by Antelo *et al*. (2012).

However, Norton and Misiewicz (2012) point out those measures to reduce water consumption may have little overall effect if not used in conjunction with treatment technologies, aiming at water reuse in industrial plant operations. It should also be considered that, for the reuse of recovered water, the key question is still to select the appropriate treatment technology to meet the quality requirements, according to the specific category of reuse at a low cost (YI *et al*., 2011) of deployment and operation. Therefore, the identification and design of prevention, recycling and reuse measures were associated to the adequate treatment of waste (ARVANITOYANNIS; KASSAVETI, 2008; ANH *et al*., 2011) and closed industrial systems, presenting itself as an important tool for sustainable management (EPA, 2012). The commitment to the application of these concepts is a fundamental requirement to achieve industrial practices compatible with the preservation of the environment (JOSÉ *et al*., 2013). It may also lead to a reduction in the direct and indirect costs of the processes through the management of water, energy and raw material used (SOUZA, 2010).

The high organic and salt loads present in the effluents from the fish processing stages result in a higher quantity of total suspended solids, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (CHOWDHURY *et al*., 2010; CRISTOVÃO *et al*., 2012; CRISTOVÃO *et al*., 2014b), thus reducing the quality of the final effluent. These organic contaminants can be present in soluble, colloidal and particulate forms (CHOWDHURY *et al*., 2010), including proteins, nutrients, oils and fats (MUTHUKUMARAN; BASKARAN, 2013). The solid residues produced are mainly scales, meat, bones, cartilage and viscera (JAMIESON *et al*., 2010; ANH *et al*., 2011). Nevertheless, among the various products from the fish industry, those that present effluents with the presence of more recalcitrant pollut-

ants and metals are the ones from the production of oil and fish meal, according to studies reported by Antelo *et al*. (2012).

When effluents are destined for reuse, there may still be a need for additional treatments, with the integration of different processes, in order to guarantee the quality and suitability for the intended use (BARCELÓ *et al*., 2011; ALCALDE SANZ; GAWLIK, 2014). These guarantees become more rigid in the case of effluents from fish processing, due to the specific criteria of the meat industry, mainly for direct recycling in the processes of preparation, handling and packaging of food, in which the use of drinking water is needed (CHOWDHURY *et al*., 2010; NORTON; MISIEWICZ, 2012).

However, there is a possibility that drinking water may be replaced by treated effluents in some food industry processes, provided it does not compromise public health (CODEX ALIMENTARIUS COMMISSION, 2001). In this context, this work aims to identify more suitable technologies for the treatment of effluents from the fish processing industry, and to evaluate the possibility of reuse and/or recycling of these effluents in these industries, taking into account the restrictions and legal limits for the food sector.

METHODOLOGY

This study comprised the analysis of different effluent treatment technologies, including conventional and advanced systems, to remove the following parameters: pH, total suspended solids (TSS; mgL^{-1}), BOD (mgL^{-1}), COD (mgL^{-1}), total nitrogen (TN; mgL^{-1}), total phosphorus (TP; mgL^{-1}) and oils and greases (mgL^{-1}). The treatments considered were:

- Physical: sedimentation; sedimentation/decanting; floating; sedimentation and FAD; filtration in membranes (microfiltration, ultrafiltration); activated charcoal; ultraviolet radiation; microfiltration, ultrafiltration, nanofiltration; membrane separation; reverse osmosis;
- Chemical: coagulation/flocculation; chemical flocculation; ozonation; adsorption and advanced oxidation processes; and
- Biological: activated sludge; filtration/anaerobic biofilter; anaerobic biofilter; bioreactors; aerobic reactor and photo-bioreactors.

In order to evaluate the potential for reuse or recycle of the treated effluent by one or more of the described technologies, the data from physical, chemical and biological characterization of effluents were compared to the quality requirements determined by the regulations dealing with reuse and/or industrial recycling, with Royal Decree 1620 (SPAIN, 2007), Ministerial Decree of Greece (JMD 145116/2011), North American guidelines (EPA, 2012) and Brazilian regulations NBR 13.969 (ABNT, 1997) (Chart 1). The use of these specific regulations came about because they deal with industrial reuse.

RESULTS AND DISCUSSION

Characterization and technologies for treatment of effluents from fish processing

The processing stages of the fish industry can vary according to the size, seasonality and productivity of each industrial unit, which directly implies changes in the characteristics of the generated effluents (ANH *et al*., 2011). According to Ghaly *et al*. (2013), most fish processing industries process fish using the following steps: fish grading, surface sludge removal, peeling, washing, head removal, evisceration, finning, filleting, filleting, sorting packaging, labeling and distribution.

Other factors to be considered in production, and which will influence the characteristics of the effluents, are the type of fish to be processed, the water supply system used, the volume of effluent generated and the concentrations of biochemical demand for oxygen and suspended solids (BARROS *et al*., 2009; CHOWDHURY *et al*., 2010; ALEXANDRE *et al*., 2011; CRISTOVÃO *et al*., 2012).

Regarding the type of fish, Arvanitoyannis and Kassaveti (2008) report variations in the quantity of effluents from the fish filleting process, where the volume generated for white fish was between 5 and 11 m^3 and for oily fish, between 5 and 8 m^3 for each ton of processed fish. These authors also cite variations in the concentration of pollutants, depending on the type of fish, in which white fish presented values of 35 kg for BOD and 50 kg for COD, while for oily fish the values were 50 kg for BOD and 85 kg for COD. The presence of high concentrations of organic matter, salts, oils and greases, pH, and ammonia can directly affect the efficiency of effluent treatment systems in the fish processing industry, especially when using biological treatments (SUNNY; MATHAL, 2013).

The occurrence of these variations in operating conditions makes it difficult to plan a single treatment unit capable of meeting the requirements for all types of effluents produced in this type of industry (SOUZA *et al*., 2012). Therefore, the characterization of effluents, including daily volume, flow rates and associated pollutant load, is fundamental for an efficient design of the treatment systems. The determination of the performance requirements of the treatment systems depends directly on a detailed evaluation of the quality of the effluents to be treated (MALATO *et al*., 2011).

The relationship between the characteristics and the selection of the most appropriate technologies for the treatment of effluents plays a fundamental role in establishing the possibilities of discharge, reuse or recycling. In some cases, due to effluent specificities, additional treatment processes may be required for the removal of recalcitrant contaminants (LUIZ *et al*., 2012) and for inactivation and removal of pathogenic microorganisms. Depending on the parameters listed for the determination of effluent quality, fish processing units, and desired levels of removal, technologies involving physical, chemical and biological systems may be used (MUTHUKUMARAN; BASKARAN, 2013). Considering the segregation of effluent streams and the availability of treatment technologies, it is possible to adapt from simpler processes to the combination of multiple processes to achieve the requirements for direct discharge or reuse of these effluents.

Treatment processes

Since the use of primary physical or physicochemical processes in the treatment of effluents with high suspended solids contents is technically adequate, the use of natural sedimentation or centrifugation technologies, aided by the addition of coagulants and/or flocculants (Chart 2), can be used in the removal of these

Chart 1 – Required quality of reuse water, to be used in industry, established by Brazil, Spain, USA and Greece.

Parameter	Limit concentrations adopted by the Regulations
pH	6–9 (EPA, 2012) 6.5–8.4 (SPAIN, 2007) 6.5–8.5 (JMD, 2011) 6–8 (ABNT, 2007)
TSS (mgL^{-1})	≤ 10 mg/L (80% of samples) JMD (2011) ≤ 35 mg/L (SPAIN, 2007) ≤ 5 mg/L (EPA, 2012)
BOD (mgL^{-1})	≤ 30 mg/L (EPA, 2012) ≤ 10 mg/L (80% of samples) JMD (2011)
COD (mgL^{-1})	
TN (mgL^{-1})	30 mg/L (JMD, 2011)
TP (mgL^{-1})	1-2 mg/L (JMD, 2011)
Oils and Greases (mgL^{-1})	*

TSS: total sedimentable solids; BOD: biochemical oxygen demand; COD: chemical oxygen demand; NT: total nitrogen; PT: total phosphorus; N. Ammoniacal: ammoniacal nitrogen; *parameters not indicated by the regulations adopted.

materials contained in effluents from the fish processing industry (CRISTOVÃO *et al*., 2012).

Coagulation/flocculation processes with $FeCl_3$ (Chart 2) for the treatment of fish canned effluents were used by Fahim *et al*. (2001), resulting in removal rates of 95.4% total solids, 92% oils and greases, 89.3% BOD and 87.5% COD (Chart 2). In turn, Cristovão *et al*. (2012) (Chart 2), using sedimentation and coagulation/ chemical flocculation treatments for fish processing effluents, obtained total solids removal rates and oils and greases of 86.0 and 99.7%, respectively. These levels of removal give the effluent adequate characteristics to be submitted to secondary treatment processes, in order to reduce the concentration of organic components at appropriate levels for subsequent discharge (CRISTOVÃO *et al*., 2014a).

However, one factor to be considered in the use of these treatment methods is the generation of sludge

Chart 2 – Example of conventional and advanced processes and operations used for the treatment of fish processing effluents.

Treatment	Conventional		Advanced	References
Physical	Sedimentation Sedimentation / Decanting Floating Sedimentation and FAD Filtration in Membranes (microfiltration, ultrafiltration) Activated charcoal Ultraviolet Radiation	Cristovão *et al*. (2012); Cristovão *et al*. (2012); Cristovão *et al*., (2014a); Jamieson *et al*. (2010); Muthukumaran e Baskaran (2013); Mittal (2006); Pérez-Galvéz *et al*. (2011). Kuca e Szaniawska (2009) Arvanitoyannis *et al*. (2008) Malato *et al*. (2011)	Microfiltration, ultrafiltration, nanofiltration Membrane Separation Reverse osmosis	Pérez-Galvéz *et al*. (2011); Arévalo *et al*. (2012) Drost *et al*. (2014); Bhattacharya *et al*. (2013) Kuca e Szaniawska (2009).
Chemical	Coagulation / Flocculation Chemical Flocculation Ozonation	Fahim *et al*. (2001); Cristovão *et al*. (2012). Arvanitoyannis *et al*. (2008)	Adsorption Advanced Oxidation Processes	Arvanitoyannis *et al*. (2008) Luiz *et al*. (2012); José *et al*. (2013).
Biological	Activated Sludge Filtration / anaerobic biofilter Anaerobic Biofilter Bioreactors Aerobic Reactor Photo-bioreactors	Cristovão *et al*. (2015) Muthukumaran e Baskaran (2013) Muthukumaran e Baskaran (2013) Alexandre *et al*. (2011) Andrade *et al*. (2010) Riaño *et al*. (2011)		

(KUCA; SZANIAWSKA, 2009), which could be a disadvantage in the adoption of these processes. It should also be considered that the use of sedimentation as a single treatment process could imply the non-removal of the majority of suspended solids, which contributes to the organic load (Chart 2) (MUTHUKUMARAN; BASKARAN, 2013).

Considering the high levels of oils and greases in the effluents of this industrial branch (ISLAM, *et al*. 2004; MUTHUKUMARAN; BASKARAN, 2013), preliminary treatment will always be necessary for this purpose (Chart 2), which has the potential to effectively remove oils, greases and other sedimentary contaminants present in effluents.

When combining sedimentation processes and FAD (Chart 2) for the treatment of fish processing effluents (JAMIESON *et al*., 2010), there is reduction of 95% for the total suspended solids, 60% for COD, and 50% for nitrogen. However, it should be taken into account that the organic matter dissolved in the effluent is difficult to be removed; therefore, treatments employing only FAD are not suitable for the removal of high concentrations of these contaminants.

In order to achieve higher levels of removal, effluents can also undergo secondary treatment processes, which, in the case of the food industries, are conventionally submitted to biological treatments (anaerobic or aerobic) combined with other processes, due to their high organic matter and nutrients (ARVANITOYANNIS *et al*., 2008; CHOWDHURY *et al*., 2010). These same treatments can also be used to remove suspended solids remaining from the primary treatment (MUTHUKUMARAN; BASKARAN, 2013). As a result of the microbiological activity, this process leads to a decrease in COD and BOD, which can reach removal levels of up to 98% (NAJAFPOUR *et al*., 2006; ARTIGA *et al*., 2008).

Although aerobic processes are traditionally used in the treatment of industrial effluents, anaerobic systems are more suitable for the treatment of fish processing effluents. This is because these systems are capable of converting organic pollutants, characteristic of these types of effluents, into a small amount of sludge and a large amount of biogas, at a significantly lower cost when compared to aerobic systems (CHOWDHURY *et al*., 2010; STEINEL; MARGANE, 2011; SUNNY; MATHAL, 2013). In this context, Muthukumaran and Baskaran (2013) concluded that the use of a system consisting of a filtration unit and an anaerobic biofilter (Chart 1) would be suitable for the secondary effluent treatment of fish processing industries due to their capacity to remove BOD and COD. Another anaerobic system that can be used for this purpose is bioreactors supplied with prehydrolysed effluents (Chart 2). Adopting this technology, Alexandre *et al*. (2011) achieved COD removals of up to 90.9%, as well as a reduction in the amount of oils and greases by almost ten times when compared to the reference bioreactor (without enzymatic pre-hydrolysis).

Also using anaerobic biological processes combined with enzymatic hydrolysis, Duarte *et al*. (2015) achieved COD removals of 97.5%, after 68 hours, indicating that these conditions can be adopted for the industrial scale. The application of these enzymes has grown due to their ability to catalyze a wide variety of reactions, including the hydrolysis of oils and greases in effluent from the fish processing industry (ALEXANDRE *et al*., 2011). Thus, enzymatic pretreatment facilitates the sedimentation of the sludge and increases the efficiency of the biological treatment, avoiding the accumulation of fats in those (DUARTE *et al*., 2015).

When it comes to nutrient removal, when using an aerobic reactor (Chart 2) to analyze the efficiency in the conversion of ammoniacal nitrogen to nitrate in effluent from fish slaughterhouses, Andrade *et al*. (2010) demonstrated that this treatment technology was efficient. The percentage of conversion to nitrate reached 86%, when under conditions of ammoniacal nitrogen concentration of 70 mg. L^{-1} and with air flow of 2 L.min-1. Riaño *et al*. (2011) point out that microalgae-based process can also be applied in the treatment of effluents from fish processing using photo-bioreactors (Chart 2); these authors were able to achieve NT removal of 95% and PT of 74%, in addition to the reduction of carbon dioxide emissions.

On the microorganisms, although these biological treatment processes manage to remove between 95 – 99%, the presence of remaining pathogenic organisms renders water unsuitable for direct reuse (CRISTOVÃO *et al*., 2015). Therefore, it is necessary to use disinfection to inactivate their action when present in the effluents (JOSÉ *et al*., 2013).

However, when activities require more rigors, such as effluent reuse and recycling systems, it is also recommended to use tertiary treatment techniques. In this sense, microfiltration, ultrafiltration, nanofiltration and reverse osmosis technologies (Chart 2) present an important advantage when compared to conventional purification processes (PÉREZ-GALVÉZ *et al*., 2011). It is also worth mentioning the use of membrane separation treatment technologies (Chart 1), which allow the generation of effluent with low organic load that can be reused (KUCA; SZANIAWSKA, 2009). In addition, this process allows recovering part of the solid material to be used as raw material in other processes, instead of transforming it into sludge (PÉREZ-GALVÉZ *et al*., 2011).

Arévalo *et al*. (2012) carried out a comparative study between microfiltration and ultrafiltration processes (Chart 2) for the treatment of effluents for reuse purposes. The results showed that effluents treated by ultrafiltration presented higher quality and met the requirements of the Spanish legislation (SPAIN, 2007) regarding parameters for unrestricted reuse (TSS, turbidity, *Escherichia coli* and intestinal nematodes).

Another process studied in order to reduce the organic load of the waste from the fish processing industry was purification by means of low pressure separation with ceramic membranes (Chart 2). The results demonstrated high capacity of reduction of the organic matter by the process of ultrafiltration, especially of microbiological contaminants. Moreover, according to Bhattacharya *et al*. (2013), the use of ceramic membranes has the advantage of high shelf life, good chemical resistance, high working temperature, and can be sterilized.

In general, conventional effluent treatment techniques are not sufficient to obtain an effluent with characteristics suitable for reuse, provided it is necessary to meet criteria or guidelines that establish specific quality restrictions (MEDAWARE, 2005). In these cases, the use of advanced treatment procedures for the removal of high concentrations of pollutants or recalcitrant compounds is required (UNEP, 2005; MITTAL, 2006). This level of treatment is also indicated when the presence of dissolved solids, including salts and organic products, is identified in the effluents (STEINEL; MARGANE, 2011).

In order to meet more stringent quality criteria, advanced oxidation processes (POAs) (Chart 2) are presented as an excellent alternative (LUIZ *et al*., 2012; JOSÉ *et al*., 2013). POAs are able to simultaneously remove organic matter and nitrate; however, there are many parameters to be also taken into account, such as the concentration of organic compounds and the free oxygen content in the environment, but the efficacy of these treatments depends mainly on whether the oxidant is selective or not, on the presence of oxidative traps and on the oxidant dosage used (LUIZ *et al*., 2012).

However, adsorption (Chart 2) is recognized as one of the most efficient and promising techniques for the elimination of multiple compounds. This process is recognized as a surface phenomenon by attracting varied fluid compounds (gas or liquid) to the surface of a solid adsorbent, and promoting bonds through physical or chemical adhesion. As an example of application, Activated Carbon (AC) has been used in the treatment of effluents due to its large porous surface area, which provides stronger adsorption forces (ARVANITOYANNIS *et al*., 2008).

The efficiency of this mechanism in the removal of pollutants from the manufacture of oils derived from fish can be noted. Antelo *et al*. (2012) cite studies with removal values of up to 99%. Accompanied by these factors, activated carbon also has controllable pore structure, thermostability, low acid/base reactivity and a wide removal capacity for various types of organic and inorganic pollutants dissolved in aqueous medium.

Also, techniques that use membrane systems for the separation of ions from the solutions, based on Reverse Osmosis (OR) (Chart 2), are indicated for the removal of salts and dissolved minerals, as well as for the removal of pathogens. This type of treatment is usually used in conjunction with a conventional treatment, overcoming the deficiencies of these methods (BHATTACHARYA *et al*., 2013), or together with other advanced treatment processes, as mentioned above, for the production of high quality effluents, which can be reused or discharged into water bodies (MEHTA, 2015).

In addition to the removal of carbonaceous and nitrogenous material, disinfection processes guarantee the efficiency of the reduction or inactivation of pathogenic organisms, minimizing environmental and health risks. Among the oxidants used for disinfection, chlorine is one of the most widely used chemicals (MEDAWARE, 2005; CRISTOVÃO *et al*., 2015), as it is a very effective disinfectant for most microorganisms; 99% of bacteria and viruses can be successfully removed by this treatment (MALATO *et al*., 2011). This efficacy can be influenced by the presence of suspended solids, organic matter and ammonia in the water, and depends on the water temperature, pH, the degree of the mixture and the time of contact (MEDAWARE, 2005). To disinfection, ozonation (Chart 2) can also be used as a strong oxidant (ARVANITOYANNIS *et al*., 2008; MALATO et al., 2011), and may be more effective than chlorine in destroying viruses and bacteria. Ozone has been shown to be suitable for the transformation of high organic pollutants into inorganic carbon. It has an efficacy in color removal, contributing to the maintenance of dissolved oxygen content (MEDAWARE, 2005), and may increase the biodegradability of effluents by removing refractory or toxic compounds from microorganisms (ARVANITOYANNIS *et al*., 2008). However, it is necessary to know in detail which organic contaminants are present in the effluents for tertiary treatment, in order to validate whether the use of simple ozonization or the use of POAs would be more effective (LUIZ *et al*., 2012). Another treatment option that can be used for this purpose is the Ultraviolet (Uv) disinfection (Chart 2), in increasing use in industrial plants. This is justified by the high efficiency in the elimination of most viruses, bacteria and protozoa, besides the ease of operation (MALATO *et al*., 2011). The treatments using this type of radiation are especially used in processes to obtain water for reuse (MITTAL, 2006).

Other treatments at the tertiary level are indicated to perform a treatment of effluents from fish processing, capable of producing water for reuse in the industry. Cristovão *et al*. (2015) suggest a sequence of processes, as follows: sedimentation/flotation; coagulation/flocculation; biological treatment by activated sludge process; filtering by sand filter; reverse osmosis and Uv disinfection. As a final result of the treatment systems, there is a removal of 99.9% of dissolved organic carbon, 99.8% of oils and greases, and 98.4% of total suspended solids, 99.1% of conductivity, above 96% of anions and cations and 100% of heterotrophic bacteria.

Studies conducted by Cristovão *et al*. (2014b) demonstrated that combined biological treatment and advanced oxidation processes by the fenton reagent for effluents from the processing of canned fish achieved a reduction of organic carbon of 64.4%, reaching a minimum value of 20 mgL^{-1}. There was also a decrease in COD values (minimum value of 90 mgL^{-1}), being below the limits of the legislation of Portugal for direct discharge in the water bodies or sewage systems.

The fact that fish processing industries generate a large volume of effluents containing high salts, organic matter and oils and greases makes their treatment complex and rather difficult to comply with the emission limits for industrial effluents. In addition, the great variation in the composition of these effluents, due to the different processes of production and types of fish, increases the difficulty of the treatment. For example, significant differences can be observed for concentrations in a single parameter: pH ranging from 5.5 to 7.6; SST concentrations of 324 to 9407 mgL^{-1}; BOD concentrations between 463 and 19.200 mgL^{-1}; and COD 825 to 21.821 mgL^{-1}. The nutrients also followed the same trend: NT, from 21 to 471 mgL^{-1} and PT from 2.7 to 291 mgL^{-1}, as well as oils and greases, with concentrations between 78 and 3.656 mgL^{-1} (Chart 3).

It is suggested that the separation of effluents into categories (using segregation processes) can improve the performance of treatment systems depending on the level of removal to be achieved. The combination of the most similar chains in terms of physic-chemical and microbiological characteristics allows an ideal treatment for each type of effluent, providing greater energy savings, higher efficiency and lower cost of disposal. To facilitate the destination of the same to different types of reuse and/or recycling, especially in cases related to industries, restrictions are determined according to the application of treated effluent.

Another problem to be faced when using water reuse systems in meat products industries is the limitation imposed by the regulations (Chart 3). Reuse in these industries is generally restricted to direct or indirect reuse for operations where water does not come into contact with the product being processed or, in some situations, with the person handling it (FERRACIOLLI *et al*., 2017).

An example of this problem is the US regulations, which, although providing for various types of effluent reuse applications, present recycling restrictions in the food processing industry. In this case, water reuse is governed according to the criteria of each state and

Chart 3 – Physical-chemical characteristics of final effluents from the fish processing industry and admitted concentrations for industrial reuse.

Parameter	Characteristics	Reference	Concentrations limits adopted by the Regulations
pH	7.2–7.6 6.0–7.0 6.85 6.13–7.14 5.5–7.2 6.3–7.0 7.67 6.7–7.1	Palenzuela-Rollon *et al.* (2002); Najafpour *et al.* (2006); Aloui *et al.* (2009); Cristovão *et al.* (2015); Alexandre *et al.* (2011); Cristovão *et al.* (2012); Muthukumaran e Baskaran (2013); Riaño *et al.* (2011)	6–9 (EPA, 2012) 6.5–8.4 (SPAIN, 2007) 6.5–8.5 (JMD, 2011) 6–8 (ABNT, 2007)
TSS (mgL^{-1})	2.000 324–3.150 324–9.407 615–657	Najafpour *et al.* (2006); Cristovão *et al.* (2015); Cristovão *et al.* (2012); Muthukumaran e Baskaran (2013)	≤ 10 mg/L (80% of samples) (JMD, 2011) ≤ 35 mg/L (SPAIN, 2007) ≤ 5 mg/L (EPA, 2012)
BOD (mgL^{-1})	5.100 1.600 463–4.569 1.129–19.200 2500–3500	Najafpour *et al.* (2006); Aloui *et al* (2009); Cristovão *et al.* (2015); Cristovão *et al.* (2012); Muthukumaran and Baskaran (2013)	≤ 30 mg/L (EPA, 2012) ≤ 10 mg/L (80% of samples) (JMD, 2011)
COD (mgL^{-1})	2.718 6.000–9.000 3.400 1.147–8.313 1.313–12.333 1.967–21.821 1.518 3.238–3.745 825–1.978	Palenzuela-Rollon *et al.* (2002); Najafpour *et al.* (2006); Aloui *et al* (2009); Cristovão *et al.* (2015); Alexandre *et al.* (2011); Cristovão *et al.* (2012); Muthukumaran and Baskaran (2013); Riaño *et al.* (2011)	
TN (mgL^{-1})	21–471 98–211 112 341–352 46–50	Cristovão *et al.* (2015); Cristovão *et al.* (2012); Muthukumaran and Baskaran (2013); Riaño *et al.* (2011)	30 mg/L (JMD, 2011)
TP (mgL^{-1})	13–47 16,6–67 197–291 2.7–10.7	Cristovão *et al.* (2015); Cristovão *et al.* (2012); Muthukumaran and Baskaran (2013); Riaño *et al.* (2011)	1–2 mg/L (JMD, 2011)
Oils and Greases (mgL^{-1})	232 156–2.808 78–3.656 409–2.841	Palenzuela-Rollon *et al.* (2002); Cristovão *et al.* (2015); Alexandre *et al.* (2011); Cristovão *et al.* (2012);	*

TSS: total sedimentable solids; BOD: biochemical oxygen demand; COD: chemical oxygen demand; NT: total nitrogen; PT: total phosphorus; N. Ammoniacal: ammoniacal nitrogen; *parameters not indicated by the regulations adopted.

presents limits for microbiological and physical-chemical parameters for reuse in cooling towers, irrigation, sanitary discharges, aquifer recovery, among others (EPA, 2012) (Chart 3). However, some countries have advanced in the elaboration of norms for the food industry, as is the case of Spain and Greece, which already have reuse criteria for food processing and cleaning waters (Chart 3), more stringent monitoring (ALCADE SANZ; GAWLIK, 2014).

In the case of Spain, Royal Decree 140 (SPAIN, 2003) establishes sanitary criteria for the quality of water for human consumption, providing that drinking water must be clean and safe, not containing any type of micro-organism, parasite or substance, in quantities or concentrations which constitute a risk to human health, in addition to meeting specific requirements for microbiological, chemical and radioactive parameters (SPAIN, 2003). The Joint Ministerial Decision of Greece nº. 14.5116 (JMD, 2011) establishes the measures, limits (Chart 3) and procedures for the reuse of treated effluents. In the case of Brazil, the regulation used is technical norm NBR 13.969 (ABNT, 1997) (Chart 3), which, although not specific for effluent reuse, presents the effluent concentration limits for reuse. Four classes of reuse water and their respective quality standards were defined.

Therefore, in order to choose the most appropriate technologies for the treatment of effluents from the fish processing industry, it is necessary to define the intended destination, either for their discharge into water sources or for their application in reuse and/or recycling systems. Based on related legislation, the available technologies can be related to the levels of removal required. The removal efficiency for some parameters of effluent treatment technologies from the fish processing industry are presented in Chart 4.

It is worth mentioning the treatment made up of the following units: sedimentation, flotation/coagulation/flocculation, activated sludge, sand filter, reverse osmosis and Uv disinfection, proposed by Cristovão *et al*. (2012) (Chart 4) for the parameters of dissolved organic carbon, oils and greases, SST, anions and cations, and heterotrophic bacteria.

Although removal rates did not reach 100%, or the treatment unit had not been tested for several parameters, other treatment technologies were promising, such as the system used by Cristovão *et al*. (2012), composed of sedimentation units and coagulation/flocculation (Chart 4); The system used by Cristovão *et al*. (2014a) (Chart 4), or those that adopted a single treatment unit, such as the rotary bioreactor (Chart 4), with a removal capacity of 98% COD (NAJAFPOUR *et al*., 2006). Even if the study did not present data for other parameters, obtaining such removal rate for organic matter is significant. Microfiltration with ceramic membranes (Chart 4) (KUCA; SZANIAWSKA, 2009); The Photo-bioreactor (Chart 4) studied by Riaño *et al*. (2011), the activated sludge system (Chart 4), Cristovão *et al*. (2015).

The treatment technologies used allowed high levels of removal to be achieved. However, it is necessary to consider the variation in the concentrations of the compounds present in these effluents, depending on the species of fish processed, forms of processing and quantity processed (ANH *et al*., 2011; CHOWDHURY *et al*., 2010; CRISTOVÃO *et al*., 2012). The use of a standard treatment system, capable of meeting the needs of the fish processing industries, is becoming less viable since the variability of the industrial activities and the types of effluents generated are a limiting factor when designing projects. This problem can be evidenced when analyzing effluent treatment technologies for reuse and/or recycling in the fish industry, where most studies are concentrated in experiments confined to laboratory environments, using pilot scale analyses, while few cases present data on economic and technical feasibility with full scale application.

FINAL CONSIDERATIONS

The identification and design of prevention, recycling and reuse measures associated with the adequate treatment of waste and closed industrial systems is an important tool for management. The possibility of reuse of effluents is among the most important issues, when the objective is to promote sustainability of the industry, because the consequences of failures in waste management affect social, environmental and economic aspects.

Due to the peculiarities presented by the effluents of the industry under study (fish processing), the use of systems composed by the combination of physical and chemical or biological processes has been used in an appropriate way for the discharge of effluents into water bodies and reuse for less restrictive purposes such as irrigation, Recharge of aquifers and hydro-sanitary facilities.

Chart 4 – Levels of removal of effluent pollutants from the fish processing industries according to the treatment technologies used.

Treatment	Parameters	Removal	Reference
Sedimentation and Coagulation/ Flocculation	TSS Oils and Greases	86.0% 99.7%	Cristovão *et al*. (2012)
Sedimentation and FAD	TSS COD TN	95.0% 60.0% 50.0%	Jamieson *et al*. (2010)
Coagulation/Flocculation with $FeCl_3$	TSS BOD COD Oils and Greases	95.4% 89.3% 87.5% 92.0%	Fahim *et al*. (2001)
Photo-bioreactor	COD NT PT	71.0% 95.0% 74.1%	Riaño *et al*. (2011)
Rotary Bioreactor	COD	98.0%	Najafpour *et al*.(2006)
Discontinuous Mixed Reactor and Compact Filter Reactor	TN Dissolved Organic Carbon	99.9% 88.0%	Huiliñir *et al*. (2012)
Activated Sludge	Dissolved Organic Carbon	88.0%	Cristovão *et al*. (2015)
Microfiltration with ceramic membranes	BOD COD Oils and Greases	72.0% 60.0% 73.0%	Kuca and Szaniawska (2009)
Ultrafiltration with ceramic membranes	COD Proteins	86.0% 77.0%	Pérez-Gálvez *et al*. (2011)
Bioreator and Ultrafiltration by membranes	COD	92.0%	Artiga *et al*. (2008)
Microfiltration and Membrane Nanofiltration	Oils and Greases Volatile Solids Total solids Proteins	69.0% 64.0% 22.0% 66.0%	Afonso and Bórquez (2002)
Biological treatment and advanced oxidation by reagent Fenton	Total Organic Carbon	64.4%	Cristovão *et al*. (2014b)
Sedimentation/flotation; Coagulation/ flocculation; Biological treatment by activated sludge process; Filtering by sand filter; Reverse osmosis and UV disinfection.	Dissolved Organic Carbon Oils and Greases TSS Anions and Cations Heterotrophic Bacteria	99.9% 99.8% 98.4% 96.0% 100.0%	Cristovão *et al*. (2015)

TSS: total sedimentable solids; BOD: biochemical oxygen demand; COD: chemical oxygen demand; NT: total nitrogen; PT: total phosphorus; N. Ammoniacal: ammoniacal nitrogen.

For industrial reuse without the requisite potability, tertiary level treatment technologies should be added to these systems, such as those intended to meet more stringent levels of removal, such as those recommended by the US, Spain and Greece regulations.

For the reuse and recycling in fish processing industries, with the need to meet drinking requirements, it is recommended to use a combination of processes with the use of advanced treatment techniques, with the need to use disinfection technologies.

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