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Quantification and characterization of effluents from the seafood processing industry aiming at water reuse: A pilot study

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ABSTRACT

In the face of a major global drinking water crisis, it becomes increasingly important to raise concerns on the use of sustainable techniques, mainly those aiming at saving potable water, especially in the seafood industry, that consumes significant amounts of water resources. In this context, the aim of the present study was to carry out industrial water management, quantifying and qualifying effluents from the general activities of a seafood processing industry, in order to identify which effluent exhibited reuse potential. Water use (water balance) was measured at six fish processing steps, and effluent physicochemical and bacteriological analyses were carried out. Direct reuse was not indicated for any of the analyzed effluents, mainly due to high levels of total coliform bacteria (10^4 to 10^7 MPN/100 ml). However, indirect water recycling and reuse can potentially be applied after a simple effluent primary treatment and disinfection from the freezing tunnel and cooling chamber defrosting, in order to supply cooling tower demands. This practice may reduce the total average water consumption of the processing unit by 11% and, if the effluents from the cooling tower purges were to also be reused for other administrative ends, this reduction may reach 21.9%, enhancing the competitiveness of this industry and preserving fresh drinking water.

1. Introduction

For many years, water has been considered an inexhaustible natural resource, but studies and experiences have shown that it is in fact a finite resource, and that its preservation is a necessity. The Agenda 21, the main document produced during the International Conference on Water and the Environment and the Earth Summit (ECO-92), contains 2500 recommendations on how to achieve sustainable development, with one of its topics approaching the issue of water resource protection supply and quality. Therefore, appropriate water consumption/use planning and management is required, with conservation and waste minimization recommended [1]. Due to the increasing worldwide water scarcity problem, on July 28, 2010, the United Nations general assembly recognized the right to potable, clean and safe water and sanitation as a human right essential for the full enjoyment of life [2], reinforcing human rights to quality water.

Industries contribute to 19% of the total water use worldwide. Specifically in the American continent, this rate rises to 34%. In Brazil, 54% of total water withdrawal is destined for irrigation, and 17% for industries, although a lack of available information is detected regarding the amount of wastewater reused for these purposes [3]. The projection for 2050 is that the global water demand (in terms of consumption/use of water) will increase by 55%, mainly due to industrial growth (400%), thermoelectric energy production (140%) and domestic use (130%) [4].

The demand for potable water in seafood industries is very high. Moreover, the generated effluent volume is directly related to the amount of used water. This problem is exacerbated by the discharge of untreated seafood industry effluents, which, in general, contain high organic loads [5,6]. Therefore, the sustainable use of potable water for

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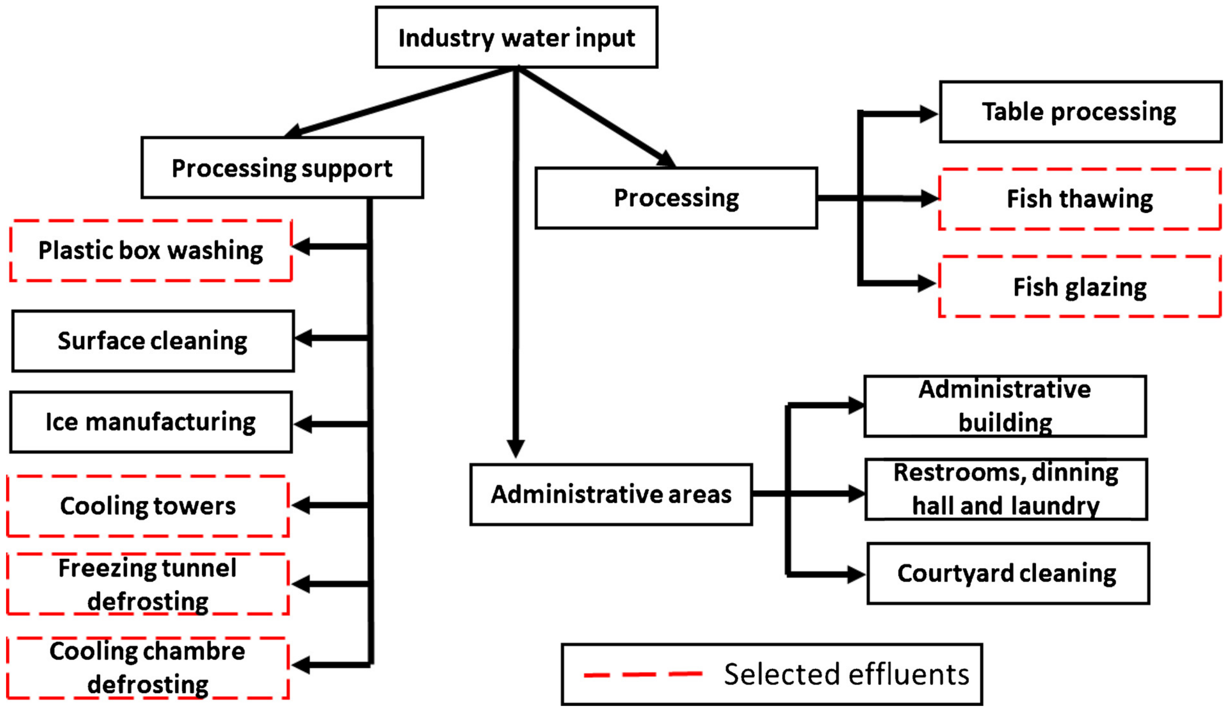

Fig. 1. Schematic figure representing water distribution inside the industry and the selected wastewater points to be investigated (effluents exhibiting reuse potential). The dashed red squares indicate the points selected for effluent quantification and characterization. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

seafood processing is of great importance, achieved through applying water and wastewater management practices, mainly focusing in reducing potable water use. However, most food industries have not applied these alternatives, due to a lack of available information concerning effluent reuse for industrial purposes.

Significant and considerable limitations regarding wastewater reuse in food industries should be noted, such as restrictions imposed by legislation, hygienic concerns and the fact that a general guidance for all cases is not available, requiring a study case on each type of industry and its processes [7,8]. Legal conditions, guidelines and regulations regarding the use and reuse of water in food industries have been created, admitting and/or restricting the use of non-potable water and water from direct and indirect potable reuse [9–12].

The reused water obtained from a food processing operation can be addressed for either non-potable or potable reuse. For potable reuse purposes, the water quality should meet the potability standards established by law, e.g. Guidelines for Drinking-Water Quality [13], the European Council Directive 98/83/EC [14] and Brazilian ordinance nº 2.914/2011 [15]. If the purpose of the reuse is a non-potable application, such as general facility cleaning (floors, walls, ceilings), boiler feed water, cooling water or any other process that does not come into direct or indirect contact with the product, specific Guidelines for Water Reuse should be followed [16,11,12,17,18]. However, certain water quality parameters are not established by these guidelines, as this water does not present a safety risk for the final product, although it can be harmful to other applications.

One of the largest industrial uses for reused water is in cooling towers, since they consume significant amounts of water and do not require such restrictive standards as potable purposes [19]. The major issue with reused water in cooling towers is related to the occurrence of biological growth when nutrients are present. This can interfere in heat transfer and cause microbiologically induced corrosion from acid or corrosive by-products. Scaling can also be a problem [12].

The first step in reducing water use is to carefully analyze water use patterns, in order to identify leaks, wasteful practices and ways to address them. Once water use for essential operations has been optimized, water reuse can be considered without compromising product quality and hygiene [20]. The main factor in wastewater reuse remains in matching the effluent from one unit process to the affluent requirements of another unit process while not compromising product quality and hygiene [20–22]. The best way to do this is to carry out a general characterization of the industry's effluents. Effluent characterization in the fish industry consists in submitting the effluents from different processing points, which vary according to the processed fish species, method and processing stage, as well as the manufactured products, to complete water quality parameter analyses. In the seafood industry, the main studies concerning water reuse focus on the characterization and treatment of the effluent at the end of the processing flow [23]. Only some studies have evaluated the potential for more efficient individual effluent reuse [24]. Therefore, the significant difference in quality parameters at each point inside the industry can be evaluated in order to minimize costs with wastewater treatment and to facilitate the reuse process.

In this scenario, the purpose of the present study was to quantify and qualify effluents from general activities of a frozen and fresh seafood processing industry, identifying which effluent exhibits the highest potential for water reuse. This study indicates the importance to carry out water management in fish processing industries, considering the restrictions and hygiene concerns specific to food industries, aiming at minimizing water use/consumption and wastewater production by qualifying and quantifying wastewaters.

2. Methods

This study was carried out in a fish processing plant located in Rio de Janeiro, southeastern Brazil, where the collection and analysis of the samples occurred during the period between 01/2014 and 01/2015. As a preliminary study of water management in the evaluated industry, the general water use/consumption of several points was quantified and the Biochemical Oxygen Demand (BOD) analysis of the effluents indicated the most interesting points to be investigated. The disregarded effluents were mainly related to the processing tables, presenting high BOD

(2000–4000 mg O2/L, data not shown) and would require intense treatment before reuse. In addition, points were selected according to the simplicity of effluent catchment and the importance of the selected point to product processing. Thus, six wastewater points were for this study, aiming at effluent reuse, four considered processing support and two considered processing points (Fig. 1).

Effluents from the six points inside the industry were collected and analyzed monthly during 12 months, comprising fish glazing (E1), freezing tunnel defrosting (E2), cooling chamber defrosting (E3), cooling towers (E4), plastic box washing (E5) and fish thawing (E6). The consumption patterns were compared to effluent characteristics, suggesting which points exhibit reuse potential.

2.1. Effluent quantification

For effluent quantification, the potable water used in each processing step was measured, considering no water loss during processing. Measurements were carried out once a month, during at least three consecutive months, by ultrasonic hydrometer readings installed on the water supply pipe to the selected point. When a flow meter was impractical to install, water consumption was calculated by the flow rate of the water tap and time of use, applying the mean value of at least five measurements.

The characteristics and the way the effluents were quantified are described below for each selected point:

- Fish glazing: a dipping method for glazing the products is used. Water consumption was measured by the calculating method and also by converting the ice weight into water volume;
- Freezing tunnel defrosting: carried out at least once a day, using a hose to spray water directly onto the ice formed in a freezer evaporator coil. Water consumption was measured by the calculation method;
- Cooling chamber defrosting: an automatic water spraying system was used and water consumption was measured using a hydrometer;
- Cooling towers: a water recirculation system was used and water consumption was measured using a hydrometer;
- Plastic box washing: an automatic machine comprising a water spraying system was used. Water consumption was measured using a hydrometer;
- Fish thawing: plastic containers for fish thawing were used. The containers were filled with water through a hose and the water was renewed once a day. Water consumption was measured by the calculation method.

The total water use in the industry was obtained considering all points displayed in Fig. 1. Moreover, water volume used only for processing activities was obtained by the sum of all investigated points, namely processing tables, fish glazing and fish thawing.

2.2. Effluent characterization

Effluent samples exhibiting reuse potential were collected monthly for a year, totaling 12 samples per effluent, and the water temperature was measured at each sampling time. Physicochemical and bacteriological analyses were carried out according to the methodologies described in the Standard Methods for the Examination of Water and Wastewater [25] (Table 1). The analyzed parameters and the respective determination method for wastewater are presented in Table 1. The studied industry processes different types of seafood, in which the main species, according to economic importance and consumer preference, are Atlantic salmon (*Salmo salar*), shrimp (*Penaeidae*), common dolphinfish (*Coryphaena hippurus*), Alaska pollock (*Theragra chalcogrammus*), dogfish (*Squalidae*), basa fish (*Pangasius bocourti*) and hake (*Merluccius spp*.).

2.3. Analysis of effluents exhibiting reuse potential

The results from the effluents analyses were submitted to statistical analyses using the R software [27]. Data were first submitted to the Shapiro-Wilk normality test and the Bartlett test for homogeneity of variances. When normality and homogeneity were proven, a variance analysis of the results was carried out, applying the F test to detect significances at the $p < 0.05$ level, followed by the Scott-Knott test to compare mean effluent results.

The results were compared to water standards for industrial use and reuse according to their intended use [16,12,14,17,18] (Table 2). In this study, only the European Union [14] reference as potable water standard was used, as it is similar to the Brazilian legislation [15] and the Guidelines for Drinking-Water Quality [13].

3. Results and discussion

3.1. Effluent quantification

The results of the water consumption of the determined points in the studied seafood industry are presented in Table 3. The points with highest water consumption were the Cooling chamber defrosting (E3), Cooling towers (E4) and Plastic box washing machines (E5) (606.98, 667.63, 213.53 m^3, respectively), thus being the most indicated water reuse effluents, in relation to the total volume only.

3.2. Physicochemical effluent characteristics

The characteristics of each effluent exhibiting reuse potential were also evaluated, and presented in Table 4. In general, the effluents can be reused directly or after treatment, depending on their intended use, the water quality required in a particular operation and effluent characteristics. Furthermore, it is recommended that the water should flow in the opposite direction of the product-processing flowchart [7,28].

The effluents results for Fish glazing (E1) and Plastic box washing (E5) were similar, with no statistical difference for all parameters ($p > 0.05$), except for a slight difference in total solid content ($p < 0.05$).

The points Freezing tunnel defrosting (E2) and Cooling chamber defrosting (E3) presented similar results for 11 parameters ($p > 0.05$). Parameters exhibiting the greatest difference were pH, total solids, alkalinity, conductivity and chloride, which may be related to the different ice-thawing methods.

The effluent from the Cooling towers (E4) presented specific characteristics with no similarity to any other point. Furthermore, E4 displayed higher pH (9 ± 1), total solids (2282 ± 911 mg/L), alkalinity (520 ± 387 mg/L of $CaCO_3$), hardness (104 ± 93 mg/L), chloride (212 ± 98 mg/L) and Conductivity (2547 ± 943 μS/cm) levels, probably due to the water evaporation and mineral and ion concentration in the cooling towers [12].

The Fish thawing point (E6) also exhibited specific characteristics, with higher BOD (497 ± 606 mg O_2/L), COD (687 ± 848 mg/L), alkalinity (301 ± 234 mg/L of $CaCO_3$) and color (106 ± 121 HU) levels and moderate hardness (81 ± 55 mg/L), chloride (191 ± 248 mg/L) and conductivity (1034 ± 1022 μS/cm) levels. These increased parameters may be related to the fish-thawing method, of submerging the fish in water for long periods of time (up to 24 h).

Overall, the collected data presented high standard deviations, explained by the fact that several species are processed at the evaluated industry, that seasonal alterations occur during the year and even by the time the effluents were collected for analysis. These reasons may, thus, influence seafood characteristics and, consequently, effluent quality [20,29].

When carrying out studies on water reuse, it is important to consider the possibility of effluent segregation, which is carried out by separating effluents with similar physico-chemical and microbiological

Table 1
Methods used for analysis of the parameters evaluated in the present study.

Analyzed parameter	Method	Reference
Alkalinity	SMEWW 2320 B. Titration Method	APHA, [25]
Ammoniacal nitrogen	SMEWW 4500 NH3- F - Phenate Method	APHA, [25]
Biological Oxygen demand (BOD)	SMEWW 5210-B. - 5-Day BOD Test	APHA, [25]
Chloride	SMEWW 4500-Cl- B - Argentometric Method	APHA, [25]
Chemical oxygen demand (COD)	SMEWW 5220 - D - Closed Reflux, Colorimetric Method	APHA, [25]
Color	SMEWW 2120 C - Spectrophotometric - Single-Wavelength Method	APHA, [25]
Electrical Conductivity (EC)	SMEWW 2510 B - Laboratory Method	APHA, [25]
Hardness	SMEWW 2340 C. EDTA Titrimetric Method	APHA, [25]
Oil and Grease (O&G)	SMEWW 5520 D - Soxhlet Extraction Method	APHA, [25]
pH	SMEWW4500H + B – Eletrometric Methods	APHA, [25]
Total aluminium	SMEWW 3030 E- Nitric Acid Digestion and 3111D - Direct Nitrous Oxide-Acetylene Flame Method	APHA, [25]
Total coliform bacteria (TCB)	SMEWW 9223 B- Enzymatic Substrate Coliform Test	APHA, [25]
Total nitrogen	SMEWW 4500-N	APHA, [25]
Total solids (TS)	SMEWW 2540 B. - Total Solids Dried at 103-105 °C	APHA, [25]
Turbidity	SMEWW 2130 B. Nephelometric Method	APHA, [25]
Total dissolved solid (TDS), calculated	TDS = EC x K K (correlation factor) = 0.55	Walton, [26]
Total suspended solid (TSS), calculated	TSS = TS - TDS	APHA, [25]

Table 2
Water standards for industrial reuse and effluent discharge.

Parameter (unit)	European Union [14][1]	Brazil [16][2]	EPA [12][3]	Spain [18][4]	Greece [17][5]
BOD (mg O_2/L)	n.e.	< 20	≤ 30	n.e.	≤10
COD (mg/L)	n.e.	< 50	n.e.	n.e.	n.e.
O&G	n.e.	< 30	n.e.	n.e.	n.e.
Ammoniacal nitrogen (mg/L)	n.e.	< 5	n.e.	n.e.	n.e.
TSS (mg/L)	n.e.	< 20	≤ 30	< 35	≤10
Turbidity (NTU)	1	n.e.	n.e.	n.e.	≤ 2
Color (HU)	15	n.e.	n.e.	n.e.	n.e.
pH	6.5–9.5	6.0–9.0	6.0-9.0	n.e.	6.0–9.0
EC (μS/cm-1 at 20 °C)	2500	n.e.	n.e.	n.e.	n.e.
Chloride (mg/L)	250	n.e.	n.e.	n.e.	n.e.
Aluminium (mg/L)	0,2	n.e.	n.e.	n.e.	n.e.
TCB (MPN/100 ml)	0	n.e.	n.e.	n.e.	n.e.
Fecal coliform bacteria (MPN/100 ml)	0	< 1000	≤ 200	< 1000	≤ 5

n.e. – not established.
[1]European Standard for potable water.
[2]Brazilian standard for treated effluent discharged to superficial waters.
[3]USA standards for water reuse in cooling towers.
[4]Spanish standard for water reuse in industrial cleaning process.
[5]Greece standard for wastewater reuse as cooling water.

characteristics, providing optimum treatment for each case [30,31]. This segregation may lead to energy savings, higher treatment efficiency and less costs regarding wastewater discharges.

Based on the effluent characteristics of the six selected points aiming at minimum treatment, the most indicated for reuse were E2, E3 and E4, as these samples presented lower levels organic matter-related parameters (BOD, COD, ammoniacal nitrogen, total nitrogen, turbidity, O&G and total coliform bacteria) compared to the other points. This can be explained by the fact that these effluents were not exposed to the seafood products. In contrast, effluents produced at E1, E5 and E6 displayed higher levels of organic-content related parameters, as the water used in the processes carried out at these points exhibits either direct or indirect contact with the seafood products, thus being harder to treat, requiring different kinds of treatment to reduce the levels of the aforementioned parameters [20,23].

Table 3
Wastewater quantification in the present case study of a seafood processing industry.

Effluent points	Daily average water use* (m^3)	Monthly average water use* (m^3)	Percent of the total water use* (%)
E1 – Fish glazing	1.78	53.38	0.70
E2 – Freezing tunnel defrosting	2.82	67.60	1.10
E3 - Cooling chamber defrosting	25.29	606.98	9.89
E4- Cooling towers (purge water)	27.82	667.63	10.88
E5 - Plastic box washing	8.90	213.53	3.48
E6 – Fish thawing	2.79	83.81	1.09
Total water use: processing, support and administrative areas	*255.80*	*7673.94*	*100.00*

* Considering that no use of other liquids and that the fish processing steps do not generate increased wastewater volume, but only solid residues, the average water volume use is similar to the effluent generation.

Overall, fish processing plant effluents aiming at reuse can be divided into two categories before treatment, effluents containing low organic loads, such as those produced from ice defrosting, cooling systems and surface cleaning, among others with no direct contact with the products, and effluents comprising higher organic loads, characterized by processing steps involving direct contact with the products, such as fish eviscerating, filleting, glazing, thawing and washing.

3.3. Possibility of effluents reuse

In the case of the pilot industry evaluated herein, direct reuse was not possible for either potable or non-potable activities. All analyzed effluents exhibited at least two parameters above potable water limits, mainly total coliform bacteria, present in high levels in all effluents, with higher counts (10^5-10^7 MPN/100 ml) detected at E1, E4, E5 and E6. Other parameters, in addition to total coliforms that also influence non-potable reuse, were determined at high levels, such as total solids (E4, E6), ammoniacal nitrogen (E1, E5, E6), BOD and COD (E1, E5, E6) and O&G (E1, E5, E6).

Total coliform bacteria counts, which include both fecal and environmental species, are only established for potable water and can be used to assess the cleanliness and integrity of distribution systems and the potential presence of biofilms. For others uses, such as non-potable effluent reuse, fecal coliform bacteria counts are recommended, which

Table 4
Characterization of effluents from a seafood industry aiming at reuse.*

Parameters	E1 – Fish glazing	E2 - Freezing tunnels defrosting	E3 - Cooling chamber defrosting	E4 - Cooling towers (purge water)	E5 - Plastic box washing	E6 – Fish thawing
Alkalinity (mg/L of $CaCO_3$)	223 ± 215^{ab}	98 ± 32^{c}	328 ± 510^{b}	520 ± 387^{a}	201 ± 144^{ab}	301 ± 234^{ab}
Ammoniacal nitrogen (mg/L)	21 ± 16^{a}	4 ± 2^{b}	4 ± 10^{b}	0.04 ± 0.05^{c}	15 ± 8^{a}	28 ± 26^{a}
BOD (mg O_2/L)	159 ± 72^{ab}	21 ± 31^{c}	15 ± 19^{c}	8 ± 5^{c}	121 ± 68^{b}	497 ± 606^{a}
Chloride (mg/L)	32 ± 9^{b}	20 ± 18^{c}	71 ± 105^{b}	212 ± 98^{a}	30 ± 19^{b}	191 ± 248^{a}
COD (mg/L)	234 ± 89^{ab}	39 ± 35^{c}	34 ± 42^{c}	25 ± 21^{c}	179 ± 98^{b}	687 ± 848^{a}
Color (uH)	30 ± 34^{ab}	14 ± 8^{bc}	25 ± 22^{abc}	10 ± 4^{c}	16 ± 8^{bc}	106 ± 121^{a}
EC (μS/cm^{-1})	438 ± 97^{c}	256 ± 29^{d}	737 ± 872^{c}	2547 ± 943^{a}	450 ± 125^{c}	1034 ± 1022^{b}
Hardness (mg/L)	48 ± 8^{bc}	40 ± 9^{c}	42 ± 16^{bc}	104 ± 93^{ab}	52 ± 13^{ab}	81 ± 55^{a}
O&G (mg/L)	15 ± 12^{a}	< 10	< 10	< 10	16 ± 14^{a}	22 ± 32^{a}
pH	7.3 ± 1^{c}	7 ± 1^{c}	8 ± 1^{b}	9 ± 1^{a}	7 ± 1^{c}	7.2 ± 0.4^{c}
Temperature (°C)	1.4 ± 1.7^{d}	8 ± 2^{c}	19 ± 3^{b}	26 ± 2^{a}	27 ± 6^{a}	11 ± 7^{c}
Total aluminium (mg/L)	0.3 ± 0.3^{abc}	0.7 ± 1^{a}	0.6 ± 0.7^{ab}	0.1 ± 0.1^{c}	0.2 ± 0.1^{bc}	0.6 ± 1^{ab}
TCB (MPN/100 mL)	$3 \times 10^{7\ a}$	$4.7 \times 10^{5\ b}$	$2.1 \times 10^{4\ b}$	$8.2 \times 10^{5\ a}$	$2.2 \times 10^{7\ a}$	$2.6 \times 10^{7\ a}$
Total nitrogen (mg/L)	71 ± 59^{a}	19 ± 11^{b}	14 ± 16^{b}	14 ± 20^{b}	47 ± 31^{a}	76 ± 63^{a}
TS (mg/L)	482 ± 140^{c}	238 ± 90^{e}	641 ± 626^{cd}	2282 ± 911^{a}	378 ± 180^{d}	1249 ± 1305^{b}
TDS (mg/L)	241 ± 54^{b}	141 ± 16^{b}	406 ± 480^{b}	1401 ± 519^{a}	248 ± 69^{b}	569 ± 562^{b}
TSS (mg/L)	241 ± 145^{bc}	112 ± 65^{c}	236 ± 220^{bc}	881 ± 445^{a}	167 ± 113^{c}	680 ± 793^{ab}
Turbidity (UNT)	91 ± 146^{a}	27 ± 32^{bc}	17 ± 23^{c}	3 ± 2^{d}	31 ± 20^{ab}	43 ± 44^{ab}

*Values are expressed as means ± standard deviation. a–d Means with different lowercase superscripts in the same row indicate statistical difference ($p < 0.05$).

can indicate fecal pollution, but are still regarded as less reliable than *Escherichia coli* counts [13]. However, the high total coliform bacteria levels found in this study were a limiting factor, preventing the direct reuse of effluents in any other procedure or processing stage, as this analysis may indicate the presence of other microorganisms. In Industry, for higher accuracy, the fecal coliform counts and *E. coli* confirmation test must be considered, which may enable the direct reuse of the effluents for non-potable purposes if proven to be absent of *E. coli* and fecal coliform counts below the limits established in legislation.

Comparing effluents E2, E3 and E4 to guidelines on water reuse and discharge to superficial waters (Table 2), BOD and pH were below or close to the maximum limits established for reuse. However, only Brazilian standards (1997) describe limits for COD, ammoniacal nitrogen and O&G, albeit for effluent discharges. Total suspended solids (TSS) and fecal coliform bacteria levels were not determined herein, but could be estimated as being present, due to the high total solid levels and total coliform bacteria. For general purposes, these effluents can probably be reused after a primary treatment (sedimentation/flotation and coagulation/flocculation) for suspended solid reduction, followed by a disinfection process (examples: UV disinfection or chlorination) to eliminate fecal coliforms [23,32,33].

Other technologies for wastewater decontamination aiming at water reuse are currently being studied, such as pulsed light, membrane filtration, ozonation and power ultrasound [28]. According to Anese et al. [34] in a study regarding the fresh-cut industry, the application of power ultrasound for 5 min reduced inoculated *Listeria monocytogenes, Escherichia coli* and *Salmonella enterica* in 5 log, indicating that this may be an effective tool to improve disinfection and could be applied to other food industries.

Studies on wastewater treatment apply O&G and TSS to measure primary treatment efficiency [35,36]. Furthermore, these parameters are important for water reuse, but a maximum limit has been stipulated only for TSS (≤ 30 mg/L, Table 2). In the present study, only total solids (TS) were directly evaluated, as this is a simple analysis to carry out, while TSS and TDS were only estimated (Table 1). TSS values in E2, E3 and E4 effluents were 112 ± 65, 236 ± 220 and 881 ± 445 mg/L, respectively.

According to [35,36], the best primary treatment system reported in their study, capable of removing TSS from wastewater, comprised a sedimentation step followed by coagulation/flocculation, which achieved maximum O&G and TSS removals of 75% and 48%, respectively, during the sedimentation step and 99.2% and 85.8% during the coagulation/flocculation process. If using the primary system cited in that study, TSS values of E2, E3 and E4 effluents could be reduced to 8 ± 5, 18 ± 16 and 65 ± 33 mg/L. Thus, effluents E2 and E3, which already exhibit low BOD (21 and 15 mg O_2/L) levels, could be easily reused for non-potable purposes.

Although effluents E2 and E3 were the most suitable for reuse, due to the low levels of organic-related parameters and total solids, leading to cheaper and easier wastewater treatment, the other investigated effluents (E1, E4, E5 e E6) may also be reused. In this case, additional treatments (secondary treatment by activated sludge, reverse osmosis and filtration) are required to adjust parameters to guidelines and legislations established for water reuse or even for drinking water [23,37].

3.3.1. Proposed wastewater treatment method prior to reuse in cooling towers

As discussed previously, effluents E2 and E3 are suitable for reuse. An interesting destination for these effluents is to supply the makeup water (reclaimed water) demand of the cooling towers (Table 3), in order to replenish losses through evaporation and purges [12]. The characteristics of the E2 + E3 blend are presented in Table 4. Prior to wastewater reuse in cooling towers, this blend (Table 5) must be treated to remove TSS, BOD and coliform bacteria to below cooling water standards (Table 2). The proposed method for wastewater treatment prior to reuse in cooling towers was based on references presented in Fig. 2, since these treatments are relatively simple and could reduce TSS, O&G, BOD and TCB to levels compliant with the legislation for cooling tower water reuse ([12], Table 2). The proposed method was based on conventional wastewater treatment consisting of primary treatment and disinfection. The primary treatment comprised two stages: sedimentation (1.5 h) followed by flocculation/coagulation (400 mg/L of $FeCl_3$) [35,36]. These stages also could comprise coagulation (addition of chemical coagulants (aluminium + polymer) as necessary) followed by filtration through sand or activated carbon [38]. The last stage comprises disinfection as proposed by Bailey et al. [32], of UV light (30 mW/cm^2) followed by chlorination (2 − 3 mg/L residual chlorine). Chlorination is required as a disinfectant regarding biofilms developed on cooling towers surfaces due to the presence of microbial cells, which may also give rise to microbiologically influenced corrosion [39].

Therefore, the E2 (freezing tunnels defrosting) and E3 (cooling chambers defrosting) effluent blend as reuse water for the cooling

Table 5
Characterization of an effluent blend[1] prior to treatment aiming at reuse.

Parameters	Blend	Blend (maximum value)	Blend (minimum value)
Alkalinity (mg/L of CaCO3)	305 ± 460	1681	48
Ammoniacal nitrogen (mg/L)	3.8 ± 8.5	29.6	0.01
BOD (mg O2/L)	16 ± 18	65	1
Chloride (mg/L)	66 ± 95	286	10
COD (mg/L)	33 ± 38	144	10
Hardness (mg/L)	42 ± 15	65	15
O&G (mg/L)	< 10	< 10	< 10
Temperature (°C)	18 ± 3	22	15
TCB (MPN/100mL)	6.7×10^4	5.24×10^5	1.8×10^0
Total nitrogen (mg/L)	14 ± 14	49	3
TS (mg/L)	601 ± 565	1721	93
TDS[2] (mg/L)	379 ± 432	1242	62
TSS[3] (mg/L)	222 ± 201	672	32

[1]Blend: mixture of effluents from freezing tunnel (E2) and cooling chambers (E3) defrosting for reuse in cooling towers (E4). TDS[2]: estimated total dissolved solids (Table 1). TSS[3]: calculated total suspended solids (Table 1).

towers exhibits potential for success after primary treatment and disinfection (Fig. 3), due to the lower total solids and conductivity values observed in E2 and E3 in comparison to E4. In addition to physicochemical characteristics, the monthly-generated volume of the blend can supply the cooling tower water demand. Another positive fact that the blend wastewater exhibits a low temperature of 18 ± 3 °C, increasing the thermal efficiency of the heat exchangers in the cooling towers. In the case of processes that demand an efficient heat exchange, such as cooling towers, the use of a previously cooled water is desired in order to increase the efficiency of the process and to save energy.

Wastewater reuse as cooling water requires further attention, as the variables depend on recirculation rates, scale potential and may cause solid accumulation on equipment. The primary constituents resulting in scale potential from recycled water to be used in cooling towers are calcium, magnesium, sulphate, alkalinity, phosphate, silica, and fluoride. Total dissolved solids (TDS), which will remain in the recirculated water after evaporation, must be removed or treated to prevent accumulation [12,19].

The TDS is an aggregate measure of all dissolved cations and anions in water and is mainly related to conductivity [40,41]. Even though TDS is an important parameter concerning water reuse in cooling towers, it is not stipulated in international guidelines, which establish only suspended solids. According to the EPA [12], removal of these solids is accomplished by discharging a portion of the cooling water, referred to as blow-down water, which is usually treated by a chemical process and/or a filtration/softening/clarification process before disposal for wastewater treatment.

In the present seafood industry, the wastewater used in cooling towers could once again be reused. Possible reuse for that wastewater, which do not require a high water quality standard, include toilet flushing, courtyard washing, garden irrigation and vehicle washing.

3.4. Water consumption reduction

A theoretical reduction in water consumption by reusing the freezing tunnel and cooling chamber defrosting effluents may reduce the total average consumption of the processing unit by 11%. If the cooling tower purge effluents will also be reused for other non-potable purposes, the total average reduction in water consumption in the processing unit may achieve 21.9% (these figures are derived from Table 3).

In Manzocco et al. [28], who evaluated water management in a fresh-cut industry, the implementation of direct reuse of wastewater from the processing steps flowing in the opposite direction to product advancement along the different washing steps contributed to reduce water needs by more than 30%

Alkaya and Demirer [6] implemented a water recycling system (water collection channel, screening unit, sedimentation/floatation unit and ozonation unit) for anchovy thawing and gutting processes in a seafood industry, achieving 45% total water savings inside the industry.

Other water management strategies could be applied to improve water savings, or even the reuse of more contaminated effluents, depending on the company's capacity to invest in water treatment and the willingness to apply these changes, but the investment costs are usually paid over time. These reductions in water consumption imply in decreased water funding costs/water treatment, wastewater treatment/

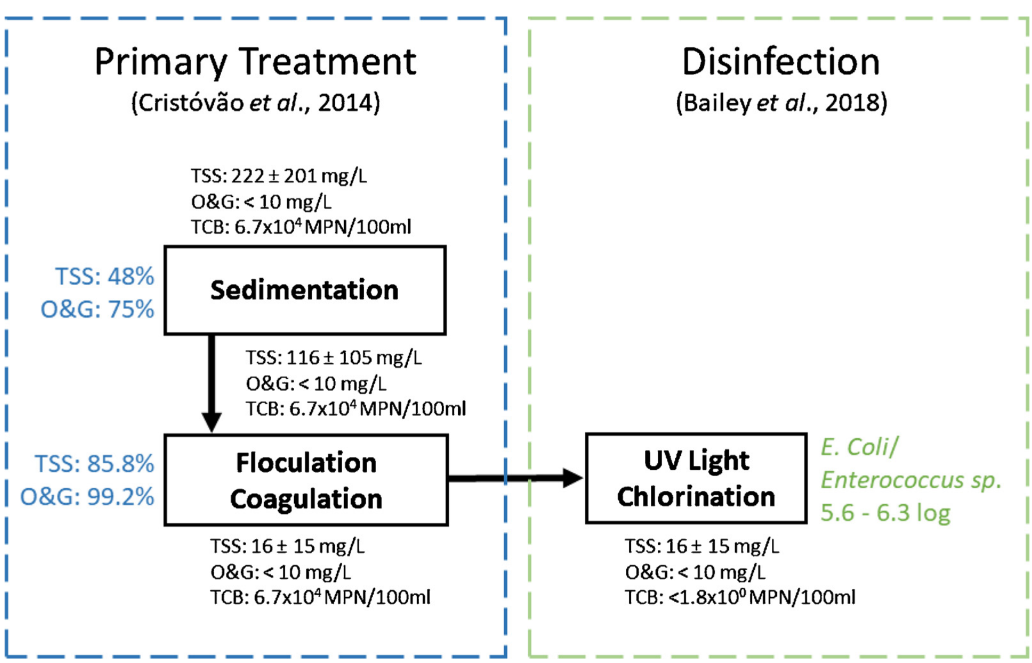

Fig. 2. Proposed wastewater treatment method prior to reuse in cooling towers. The data presented in percentage and log, next to the boxes indicating the treatments, indicates the reduction achieved in each treatment.

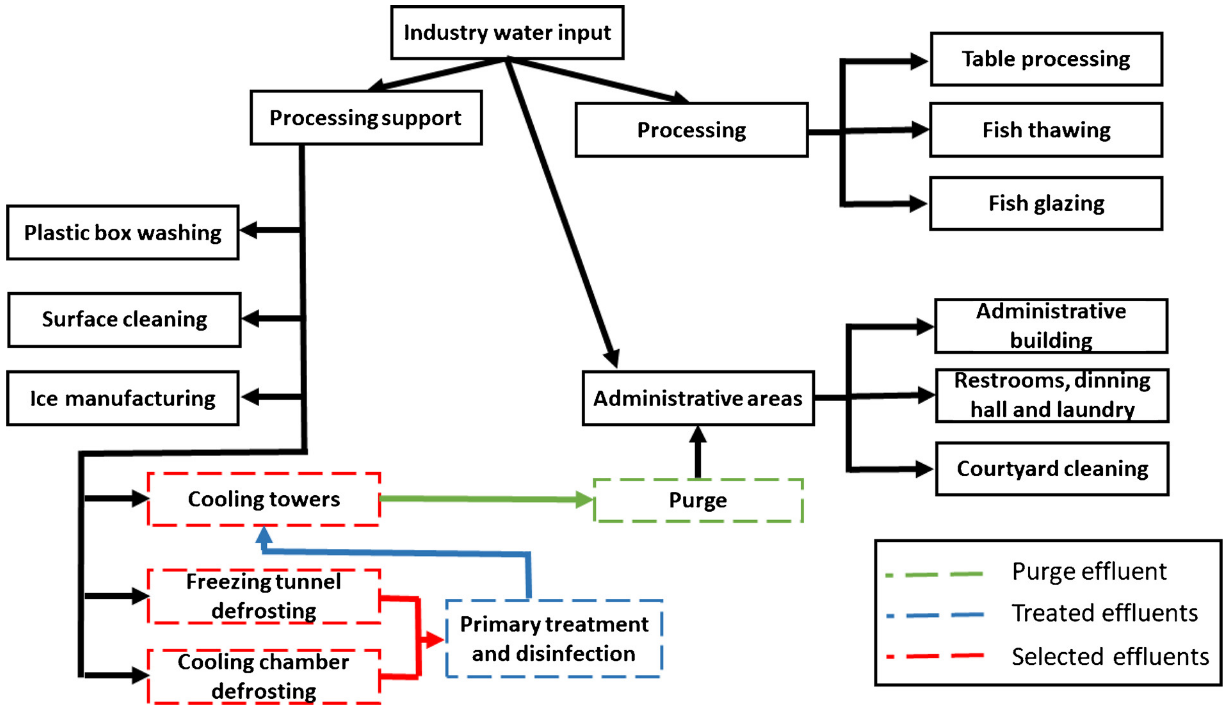

Fig. 3. Schematic figure representing effluent reuse after primary treatment and disinfection and reuse of the cooling tower purge.

effluents discharge, supplies and energy, also providing marketing actions for the industry as a sustainable company.

4. Conclusions

Effluent characterization is essential when carrying out water management in a seafood industry aiming at wastewater reuse. It allows for the application of specific treatments and segregation of similar effluents according to their characteristics, which may facilitate the water reuse process and improve wastewater treatment efficiency.

Some types of effluents from the studied seafood processing industry exhibited potential to be used as reuse water after primary treatment and disinfection for non-potable uses, for example, to meet the water demand of the cooling towers, enhancing the competitiveness of this industry. Furthermore, since the fish processing industry consumes large amounts of water and the demand for manufactured fish goods has increased, the implementation of water management and wastewater reuse techniques must be recognized and stimulated, as industrial wastewater reuse is an excellent alternative to the preservation of fresh drinking water.

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