Quantification and characterization of effluents from seafood processing industry aiming reuse and water management: a pilot study

J. T. Guimarães*, A.L.M. Souza*, A. I. S. Brígida, D. B. Luiz***, E. F. M. Mesquita***

* Federal Fluminense University (UFF) - Veterinary Hygiene and Technological Processing of Animal Products. R. Vital Brasil Filho, 64 - Icaraí, Niterói - RJ - Brazil.
(E-mail: j*onassguimaraes@gmail.com; andrevetuff@gmail.com; elianafmm@uol.com.br*)
** Embrapa Food Technology. Avenida das Américas, n. 29501 Rio de Janeiro – Brazil.
(E-mail: *ana.iraidy@embrapa.br*)
***Embrapa Fisheries and Aquaculture. Quadra 104 Sul Avenida LO 1 N 34 Conjunto 4, primeiro e segundo Pavimentos, Palmas, Tocantins - Brazil. (E-mail: *danielle.luiz@embrapa.br*)

Abstract
Before a major global drinking water crisis, it becomes increasingly important to concern about the utilization of sustainable techniques, mainly those that aim at saving of potable water. In this way, the objective of this work was to quantify and qualify effluents from general activities in a seafood processing industry, in order to identify which one has the potential for reuse. To this purpose, water use (water balance) was measured at six steps of fish processing, and physicochemical and bacteriological analysis of effluents were carried out. Direct reuse was not indicated for any analyzed effluent, mainly due to high level of total coliform bacteria. However, indirect recycle and reuse can potentially be applied after primary treatment and disinfection of the effluents from defrost of freezing tunnels and defrost of cooling chambers. The monthly-generated volume of these two effluents can supply the demand of the cooling towers. This practice may reduce the total average consumption of the processing unit by 8.7% and if the effluents from the cooling towers are also going to be reused, the total average consumption reach 17.5%, this way, enhancing the competitiveness of this industry and preserving drinking water.

Keywords
Fish industry, reuse, recycle, sustainability, wastewater

INTRODUCTION

The demand of potable water is very high in seafood industries and the volume of effluent generated is directly related to its use. In general, those effluents contain high organic load (Afonso & Bórquez, 2002). Therefore, it is of great importance the sustainable use of potable water for seafood production, applying water and wastewater management practices, mainly focusing in reducing potable water consumption. However, most food manufacturers have not been using these alternatives because of a lack of available information concerning the reuse of effluents for industrial purposes.

The first step in reducing water consumption is to analyse water use patterns carefully 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 (Chowdhury, 2010). The main factor in wastewater reuse remains in matching the effluent from one unit process with the affluent requirements of another unit process to not compromise product quality and hygiene (José, 2013; Luiz, 2012; Choudhury, 2010).

There are great and considerable limitations for wastewater reuse, that are restrictions imposed by legislation and hygienic concerns (Casani et al., 2005). Legal conditions (guidelines and regulations regarding the use and reuse of water in the food industry) have been created, admitting and/or not restricting the use of non-potable water and water from direct and indirect potable reuse (CAC, 1999, 2001, 2007; EPA, 2012).

The recovered water obtained from a food processing operation can be addressed for nonpotable or potable reuse. For potable reuse purposes, the water quality needs to meet potability standards stablished by law, e.g. Guidelines for Drinking-Water Quality (WHO, 2011), the Council Directive 98/83/EC (European Union, 1998) and Portaria nº 2.914 (Brazil, 2011). If the purpose of the reuse is nonpotable applications, like general facility cleaning (floors, walls, ceilings), boiler feed water, cooling water or any other process that did not come into direct or indirect contact with the product, the specific Guidelines for Water Reuse should be followed (EPA, 2012; Greece, 2011; Spain, 2007; CAC, 1999; Brazil, 1997). Some parameters of water quality are not established by these guidelines, because do not present a safety risk for the final product, but can be harmful to other applications.

One of the largest industrial uses for the recovered water is in the cooling towers, because it consumes much water and do not requires so restrictive standards as for potable purposes (EPA, 2004). One of the major issues with reused water in cooling towers relates to occurrence of biological growth when nutrients are present. It can interfere with heat transfer and cause microbiologically induced corrosion from acid or corrosive by-products. Scaling can also be a problem in cooling towers (EPA, 2012).

The purpose of this work was to quantify and qualify the effluents produced from general activities of a frozen and fresh seafood processing industry, identifying those with greater potential for water reuse. This study indicates the importance to carry water management in fish processing industries considering the restrictions and hygiene concerns specific to food industries, aiming minimization of water use/consumption and wastewater production by qualifying and quantifying of produced wastewaters.

METHODS

This work was carried out in a seafood processing plant in the southeast region of Brazil, which produces different fresh and frozen seafood products. The effluents from six common points to all processes of the industry were analyzed: glazing (E1), defrost of freezing tunnels (E2), defrost of cooling chambers (E3), cooling towers (E4), plastic box wash machine (E5) and thawing fish (E6). The consumption pattern were compared with the effluents characteristics, therefore, it may be suggested which points have the potential for reuse.

Effluents quantification

The quantification of potable water used in each processing step was measured daily by readings of ultrasonic hydrometers installed on the pipe that supplied water to the selected point. When it was impractical to install a flow meter, the water consumption was calculated by the flow rate of the water tap and time of use.

- Glazing water: it was used a dipping method for glazing the products. The consumption was measured by the calculating method for water and converting the ice weigh in volume of water.
- Defrost of freezing tunnels: was realized at least once a day, using a hose for spray water directly into the ice formed at freezer evaporator coil and the consumption was measured by the calculation method.

- Defrost of cooling chambers: was realized by an automatic water spraying system and the consumption was measured using a hydrometer.
- Cooling towers: was used a system of water recirculation and the consumption was measured using a hydrometer.
- Plastic box wash machine: it was an automatic machine with spray water system. The consumption was measured using a hydrometer.
- Thawing fish: it was used plastic containers for thawing the fish. The container was filled of water through a hose and the water was renewed once a day. The consumption was measured by the calculation method.

Effluents characterization

The effluents samples were collected monthly for a year, totalizing 12 samples per effluent. Physicochemical and bacteriological analyses were carried out according to the methodologies described at "Standard Methods for the Examination of Water and Wastewater" (APHA, 2012) (table 1). The classified parameters were: biochemical oxygen demand (BOD5.20), chemical oxygen demand (COD), pH, Ammonia nitrogen, total nitrogen, total solids, alkalinity, colour, turbidity, hardness, oil and grease (O&G), chloride, conductivity, aluminium, iron and total coliform bacteria.

Table 1. Methods used for analysis of various parameters.

Parameter analyzed	Method
BOD	SMEWW 5210-B. - 5-Day BOD Test
COD	SMEWW 5220 - D - Closed Reflux, Colorimetric Method
PH	SMEWW4500H+B – Eletrometric Methods
Ammoniacal nitrogen	SMEWW 4500 NH3- F - Phenate Method
Total nitrogen	SMEWW 4500-N
Total solids	SMEWW 2540 B. - Total Solids Dried at 103-105oC
Alkalinity	SMEWW 2320 B. Titration Method
Colour	SMEWW 2120 C - Spectrophotometric - Single-Wavelength Method
Turbidity	SMEWW 2130 B. Nephelometric Method
Hardness	SMEWW 2340 C. EDTA Titrimetric Method
O&G	SMEWW 5520 D - Soxhlet Extraction Method
Chloride	SMEWW 4500-Cl- B - Argentometric Method
Conductivity	SMEWW 2510 B - Laboratory Method
Total aluminium	SMEWW 3030 E- Nitric Acid Digestion and 3111D - Direct Nitrous Oxide-Acetylene Flame Method
Total iron	SMEWW 3030E - Nitric Acid Digestion and 3111B - Direct Air-Acetylene Flame Method
Total coliforms	SMEWW 9223 B- Enzymatic Substrate Coliform Test

Analysis of effluents with potential for reuse

The results from the effluents analysis were compared to the water standards for industrial use and reuse accordingly with its intended use (EPA, 2012; Greece, 2011; Spain, 2007; European Union, 1998; Brazil, 1997) (Table 2). In this study, it was used only European Union (1998) reference as potable water standard, because it is similar to the Brazilian legislation (Brazil, 2011) and Guidelines for Drinking-Water Quality (WHO, 2011).

Table 2. Water standards for industrial reuse and effluent discharge.

Parameter (unit)	European Union, 1998[1]	Brazil, 1997[2]	EPA, 2012[3]	Spain, 2007[4]	Greece, 2011[5]
$DBO_{5,20}$ (mg/L)		<20	≤ 30		≤10
COD (mg/L)		<50			
Ammoniacal nitrogen (mg/L)		<5			
O&G		<30			
Total suspended solids (mg/L)		<20	≤ 30	<35	≤10
Aluminium (mg/L)	0,2				
Ammonium (mg/L)	0,5				
Chloride (mg/L)	250				
Colour (HU)	15				
Conductivity (µS/cm-1 at 20 °C)	2500				
pH	6.5–9.5	6.0–9.0	6.0-9.0		6.0–9.0
Iron (mg/L)	0,2				
Total coliform bacteria (MPN/100 ml)	0				
Fecal coliform bacteria (MPN/100 ml)	0	<1000	≤ 200	<1000	≤ 5
Turbidity (NTU)	1				≤ 2

1 European Standard for potable water
2 Brazilian standard for treated effluent discharge on 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

RESULTS AND DISCUSSION

The water consumption of the determined points in the studied seafood industry were first quantified and the results are presented at the table 3. The points with largest water consumption was the E3, E4 and E5 (606.98, 667.63, 213.53 m^3, respectively), being the most indicated effluents to apply the water reuse, only in relation to the total volume.

Table 3. Results from effluents quantification.

Effluent points	Daily average water consumption (m^3)	Monthly average water consumption (m^3)
E1 - Glazing	1.78	53.38
E2 - Defrost of freezing tunnels	2.82	67.60

E3 - Defrost of cooling chambers	25.29	606.98
E4- Cooling towers	27.82	667.63
E5 - Plastic box wash machine	8.90	213.53
E6 - Thawing fish	2.79	83.81
Total estimated from processing unit	255.80	7673.94

The characteristics of each effluent were also studied and the results are presented in table 4. In general, the effluents can be reused directly or after treatment depending on its intended use, the water quality required in that operation and the characteristics of the effluent (Casani, 2005).

Table 4. Mean values and standard deviations of the effluents analysis results (Characterization).

Parameters	Glazing	Defrost of freezing tunnels	Defrost of cooling chambers	Cooling towers	Plastic box wash machine	Thawing fish
BOD (mg O_2/L)	158.9 ± 72.4	21.1 ± 30.8	15.4 ± 19.3	7.8 ± 4.8	120.8 ± 68.0	497.4 ± 605.5
COD (mg/L)	233.7 ± 88.6	39.2 ± 35.4	34.3 ± 42.1	25.2 ± 21.4	179.1 ± 98.4	687 ± 848.4
pH	7.33 ± 0.6	7.4 ± 0.9	8 ± 0.8	8.7 ± 0.6	7.3 ± 0.5	7.2 ± 0.4
Ammoniacal nitrogen (mg/L)	20.9 ± 15.6	3.68 ± 1.8	3.8 ± 9.5	0.04 ± 0.05	14.7 ± 8.3	28.3 ± 25.6
Total nitrogen (mg/L)	70.7 ± 58,6	19.4 ± 11.3	14 ± 16.4	14 ± 19.7	47.2 ± 30,9	76.0 ± 62.9
Total solids (mg/L)	482.1 ± 140.0	237.9 ± 89.8	641.2 ± 625.8	2282 ± 911.0	378.2 ± 180.3	1248.9 ± 1304.8
Alkalinity (mg/L de $CaCO_3$)	222.6 ± 215.4	98.2 ± 31.8	327.8 ± 510.4	520.3 ± 386.8	200.8 ± 144.0	301.3 ± 233.6
Colour (uH)	30.4 ± 33.6	14.2 ± 7.9	24.6 ± 22.1	10.4 ± 3.9	15.8 ± 8.2	106.2 ± 121.3
Turbidity (UNT)	91.1 ± 145.5	27.1 ± 32.3	16.9 ± 22.9	3.4 ± 2.4	30.5 ± 19.7	43.1 ± 43.6
Hardness (mg/L)	47.5 ± 8.0	40.3 ± 9.1	42 ± 16.2	103.9 ± 92.9	52.1 ± 13.0	81.3 ± 55.1
O&G (mg/L)	30 ± 15.3	<10	<10	<10	33.3 ± 21.4	38.4 ± 47.6
Chloride (mg/L)	32.4 ± 9.1	19.6 ± 17.7	70.7 ± 104.7	212.3 ± 98.1	30.0 ± 19.1	191.1 ± 248.1
Conductivity (µS/cm)	437.7 ± 97.2	255.7 ± 29.0	737.3 ± 872.1	2546.7 ± 942.7	450.3 ± 125.3	1033.9 ± 1022.3
Total aluminium (mg/L)	0.3 ± 0.25	0.7 ± 0.9	0.7 ± 0.7	0.1 ± 0.10	0.2 ± 0.10	0.6 ± 1.0
Total iron (mg/L)	0.1 ± 0.08	1.0 ± 1.4	2.1 ± 3.8	0.07 ± 0.03	0.2 ± 0.08	0.4 ± 0.4
Total coliform bacteria (MPN/100mL)	$3x10^7$	$5.1x10^5$	$2.4x10^4$	$8.2x10^5$	$2.3 x10^7$	$2.6 x 10^7$±

According to the physicochemical characteristics of the effluents, the most indicated for reuse were E2, E3 and E4, because these samples had lower levels of parameters related to organic matter (DBO, COD, ammoniacal nitrogen, total nitrogen, turbidity, O&G and total coliform bacteria) than the others. It can be explained, because these effluents were not exposed to the seafood product. In contrast, the effluents produced from E1, E5 and E6, had high levels of parameters related to organic content, because the water used in this process has come into direct or indirect contact with the seafood product, this way, being more difficult to treat, requiring different kinds of treatment to reduce its levels (Chowdhury, 2010; Cristóvão et al., 2015).

Analysing the case of the pilot industry, the direct reuse was not possible, for both potable and nonpotable reuse. All the effluents analyzed had at least two parameters above the limits for potable water, mainly total coliform bacteria that was observed in high levels for all effluents, but higher ($>10^7$) in E1, E5 and E6. Other parameters, in addition to the total coliforms, influencing nonpotable reuse was found in high levels, as total solids (E3, E4, E6), ammoniacal nitrogen (E1, E5, E6), DBO and COD (E1, E5, E6) and O&G (E1, E5, E6).

The total coliform bacteria, which includes both fecal and environmental species, is 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, as nonpotable reuse of effluents is stablished the analysis of fecal coliforms bacteria, which can indicate fecal pollution, but is still regarded as a less reliable as *Escherichia coli* (WHO, 2011). However, the high levels of total coliform bacteria found in this study was a limiting factor, that prevented the directly reuse of effluents in any other procedure or processing stage, because it may indicate the presence of other microorganisms.

Comparing the effluents E2, E3 and E4 to the guidelines for water reuse cited before, the parameters BOD, COD, ammoniacal nitrogen, O&G and pH are below or close to the maximum limits established. Suspended solids and fecal coliforms bacteria levels, not determined in our analysis, could be estimated to be present, because of the high total solids and total coliform bacteria. For general reuse purposes, these effluents can be reused after treatment, in this case, a primary treatment (sedimentation/flotation and coagulation/flocculation) for suspended solids reduction and a disinfection process (UV disinfection or chlorination) to eliminate the fecal coliforms (Cristóvão et al., 2015; Gonzalez, 1996).

The effluents may also be reused to supply the water demand of the cooling towers, which have been the primary industrial users of reclaimed water. However, the water reuse for this purpose requires some additional attention, because of the scale potential and solids accumulation on equipment. The primary constituents resulting in scale potential from recycled water to be used in cooling towers are calcium, magnesium, sulfate, alkalinity, phosphate, silica, and fluoride. For total dissolved solids (TDS), which will remain in the recirculated water after evaporation, it must be removed or treated to prevent the accumulation (EPA, 2012; EPA, 2004).

The TDS is an aggregate measure of all dissolved cations and anions in water and is mainly related to the conductivity parameter (Dietrich, 2015; Niekerk et al., 2014). Even though TDS is an important parameter to water reuse in cooling towers, it is not stipulated in the international guidelines, only suspended solids. In this study, the effluent E4 had high levels of total solids (2282 mg/l) and conductivity (2546 µS/cm), indicating high TDS levels. According to EPA (2012), 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. Therefore, we observed a potential use of E2 and E3 effluents as reuse water for the cooling towers, after primary treatment and disinfection. Besides the physicochemical characteristics, the monthly-generated volume of these two effluents can supply the water demand of the cooling towers.

Although the effluents E2 and E3 were the most suitable for reuse, because of the low levels of organic related parameters and total solids making the wastewater treatment easier and cheaper, the other studied effluents (E1, E4, E5 e E6) may also be reused. In this case, become necessary to use additional treatments (Secondary treatment by activated sludge, reverse osmosis and filtration) to adjust the parameters to the guidelines and legislations stablished for water reuse or even for drinking water (Cristóvão et al., 2015; Mavrov; Bélières, 2000).

A theoretical reduction in water consumption by the application of the effluents from defrost of freezing tunnels and defrost of cooling chambers as reuse water may reduce the total average consumption of the processing unit by 8.7%. If the effluents from the cooling towers are also going to be reused for other nonpotable purposes, the total average consumption of the processing unit may reduce 17.5%. These reductions in water consumption implies in reductions of water funding costs/water treatment, wastewater treatment/effluents discharge, supplies and energy, furthermore, it provides marketing actions as a sustainable company.

CONCLUSIONS

Some types of effluents from seafood processing industry can potentially be used as reuse water after primary treatment and disinfection for nonpotable uses, for example, to meet the water demand in the cooling towers, enhancing the competitiveness of this industry.

Since fish processing industry consumes large amounts of water and the demand for manufactured fish goods increases, the implementation of techniques of water management and wastewater reuse must be recognized and stimulated. Industrial wastewater reuse is a great alternative to the preservation of fresh drinking water.

REFERENCES

Afonso, M.D.; Bórquez, R (2002). Review of the treatment of seafood processing wastewaters and recovery of proteins therein by membrane separation processes – prospects of the ultrafiltration of wastewaters from the fish meal industry. *Desalination*, 142(1), 29-45.

APHA - American Public Health Association (2012). *Standard Methods for the Examination of Water and Wastewater*. 22 ed. Washington, DC.

Brazil, Ministério da Saúde (2011). Portaria nº 2.914, de 12 de dezembro de 2011. Dispõe sobre os procedimentos de controle e de vigilância da qualidade da água para consumo humano e seu padrão de potabilidade. *Diário Oficial da República Federativa do Brasil*, Brasília, DF, 12 de Dezembro de 2011.

Brazil (1997). NBR 13969. *Tanque sépticos*: Unidades de tratamento complementar e disposição final dos efluentes- Projeto, construção e operação. ABNT (Associação Brasileira de Normas Técnicas). Rio de Janeiro.

CAC (Codex Alimentarius Commission) (1999). Codex Alimentarius Commission: Codex Committee on Food Hygiene. *Discussion Paper on Proposed Draft Guidelines for the Hygienic Reuse of Processing Water in Food Plants*. Joint FAO/WHO Food Standards Programme, 32nd Session, Washington, DC, USA.

CAC (Codex Alimentarius Commission) (2001). *Proposed Draft Guidelines for the Hygienic Reuse of Processing Water in Food Plants*; CX/FH 01/9. Joint FAO/WHO Food Standards Programme, 34th Session, Bangkok, Thailand.

CAC (Codex Alimentarius Commission) (2007). *Report of the Thirty-Eighth Session of the Codex Committee on Food Hygiene*. Alinorm 07/30/13. Joint FAO/WHO Food Standards Programme, 38th Session, Rome, Italy.

Casani, S.; Rouhany, M.; Knøchel, S (2005). A discussion paper on challenges and limitations to

water reuse and hygiene in the food industry. *Water Research*, 39(6), 1134-1146.
Chowdhury, P.; Viraraghavan, T.; Srinivasan, A (2010). Biological treatment processes for fish processing wastewater – A review.” *Bioresource Technology*, 101, 439-449.
Cristóvão, R. O.; Botelho, C. M.; Martins, R. J. E.; Loureiro, J. M.; Boaventura, R. A. R. (2015). Fish canning industry wastewater treatment for water reuse e a case study. *Journal of Cleaner Production* 87, 603-612.
Dietrich, A.M., & Burlingame, G.A. (2015). Critical Review and Rethinking of USEPA Secondary Standards for Maintaining Organoleptic Quality of Drinking Water. *Environ. Sci. Technol*., 49(2), 708–720.
EPA - United States Environmental Protection Agency (2004). *Guidelines for Water Reuse*. EPA 625/R-04/108. Environmental Protection Agency. Washington, D.C.
EPA - United States Environmental Protection Agency (2012). *Guidelines for Water Reuse*. EPA/600/R-12/618. Environmental Protection Agency. Washington, D.C.
European Union (1998). Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. *Off. J. Eur. Commun*., L330, 32–53.
Greece (2011). Joint Ministerial Decree (JMD) 145116/2011: Definition of measures, conditions and procedure for wastewater reuse. *Greek Government Gazette*, 354B, 8/3/2011.
Gonzalez, J.F. (1996). Wastewater Treatment in the Fishery Industry. FAO Fisheries Technical Paper (FAO), No. 355/FAO, Rome (Italy), Fisheries Dept. Available in: <http://www.fao.org/docrep/003/V9922E/V9922E00.HTM#Contents> Access: 13/04/2016.
José H. J., Moreira R. F. P. M., Luiz D. B., Virmond E., Genena A. K., Andersen S. L. F., Sena R. F. and Schröder H. Fr. (2013). Water and Wastewater Management and Biomass to Energy Conversion in a Meat Processing Plant in Brazil – A Case Study. In: Muzzalupo, I. (Ed.) *Food Industry*. cap. 30, 702-733.
Luiz, D. B., José, H. J. & Moreira, R. F. P. M (2012). A Discussion Paper on Challenges and Proposals for Advanced Treatments for Potabilization of Wastewater in the Food Industry. In: Valdez, B. (Ed.). *Scientific, Health and Social Aspects of the Food Industry*.
Mavrov, V.; Bélières, E. (2000) Reduction of water consumption and wastewater quantities in the food industry by water recycling using membrane processes. *Desalination*, 131, 75–86.
Niekerk, H. V.; Silberbauer, M. J.; Maluleke, M. (2014). Geographical differences in the relationship between total dissolved solids and electrical conductivity in South African rivers. *Water SA.* 40(1), 133–138.
Spain (2007). Real Decreto 1620/2007 de 7 Diciembre, por el que se establece el regímen jurídico de la reutilización de las aguas depuradas. *BOE* num 294. Pp. 50639-50661. Madrid, 8 de Diciembre 2007.
WHO - World Health Organization (2011). *Guidelines for drinking-water quality*. 4th ed. Geneva.