Chapter

Auxiliary Strategies for Water Management in Industries: Minimization of Water Use and Possibility of Recycling and/or Reuse of Effluent

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Abstract

Water management in industry by minimizing water consumption and effluent generation, reusing and/or recycling as a possibility the economy and conservation of water, energy and economic resources. The characterization of the final effluent allows evaluating how much the treatment is adequate to meet the requirements of the regulations of different countries for recycling and/or reuse and evaluated the possibility of reuse, as well as the choice of effluent treatment methods. In this case, technical, environmental and economic criteria, with a view to complying with industrial reuse regulations, should be evaluated, and a multicriteria analysis (MCA) can be adopted to classify the treatment systems applied in different reuse scenarios, made possible by the combination of multiple processes, with the use of tertiary treatment techniques. It should be noted that the potential for recycling and/or reuse of effluents generated in industry increases when effluents are separated into groups (principle of segregation of effluent streams). As a way of promoting a more sustainable model, the use of reuse systems is promising to reduce consumption, as well as reducing operating costs when treating effluents.

Keywords: industrial reuse, multicriteria analysis, segregation of effluents, use of effluents, water management

1. Introduction

Environmental pollution and the preservation of natural resources are subjects of constant presence in the world political and socioeconomic guidelines, especially the discussions related to water pollution. These debates are fueled by issues such as water scarcity [1–3], climate change pressures, disordered urban development and increased domestic waste production and industrial [4, 5].

To minimize some of these impacts, especially water scarcity, the implementation of effluent reuse programs provides direct and indirect benefits, such as the integration and sustainable use of water resources; reduction of excessive abstraction of surface and groundwater; reduction of energy consumption and environmental protection, reinforced by the restoration of rivers, marshes and lagoons [5]. With advances in effluent treatment technologies [6] and the possibility of [7, 8], water reuse presents itself as a potential source for different sectors of society, especially for the industrial sector.

The industry has also sought to improve processes in terms of sustainability, such as measures to reduce waste and effluent production, to meet international and national market requirements, and to adapt to the new scarcity scenario water resources. A number of countries practice industrial water reuse [9] the United States, Japan, and Australia have projects with a high percentage of effluent reuse from commercial and residential water and sanitation facilities [5, 10].

The establishment of targets for reuse, expressed in terms of the percentage of municipal effluents, which are treated to obtain a high quality, for an advantageous reuse have been adopted by different countries. Australia, which reused about 8% of the treated effluent in 2012, set the goal of increasing this quantity to 30% by 2030. In the case of Saudi Arabia, about 16% of the effluent was reused in of expansion to 65% by the end of 2016. Singapore, reuse 30% of the effluent and has a plan to reduce its dependence on external sources. Israel has achieved 70% reuse of domestic effluents [8].

In the case of the fish processing industry, where water is used in abundance in the various stages of production (an average of 11 m^3 ton of processed fish and 15 m^3 tons in the case of shrimp processing). The adoption of measures to reduce waste and effluent production are needed [11–14]. Under these circumstances, the use of reuse and recycling systems is promising to achieve these objectives and is important for achieving sustainable management [8]. In this industry, the large amount used leads to an increase in the volume of effluents generated, which, if not treated properly, lead to different impacts [7, 11–13, 15].

Evaluating alternatives for treatment of effluents capable of meeting technical, environmental and economic criteria implies the feasibility of reducing effluents and improving quality. The adoption of technologies and procedures that reduce the amount of water used. As well as the increase in reuse can characterize the implantation of cleaner production technologies in the industries, which not only confers the reduction of the direct and indirect costs of the process through the management of the consumption of water, energy and raw material used, as well as the efficiency of the enterprise.

2. Quality and requirements established for the practice of industrial reuse

As for the water consumption in the fish processing industries, it is known that the greater use is concentrated in the washing and cleaning steps. However, volumes used for the storage and refrigeration of fishery products should be considered for reuse [16], both before and during processing, as an important lubricant in the various stages of fish handling [16, 17]. As well as in waste management, which consists of scales, meat, bones, cartilage and viscera [11] and of the effluents characterized by high organic load and salts, which result in higher volumes of total suspended solids, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) [11, 16, 18, 19] reducing the quality of these effluents. They are still rich in nitrogen and phosphorus, which when discharged can lead to eutrophication [12].

Other factors to be considered in production that will influence the effluent characteristics are the types of fish to be processed, the water supply system used

Concentration limits	Application	Country
Fecal coliform <200 NPM/100 mL pH between 6 and 8 Turbidity <5 NTU Free residual chlorine between 0.5 and 1.5 mg/L	Class 1 water: used for car washing, direct contact of users with water, aerosol aspiration	Brazil
Fecal coliform <500 NPM/100 mL Turbidity <5 NTU Free residual chlorine >0.5 mg/L	Class 2 water: used for washing floors and pavements, watering gardens, maintaining lakes and canals for landscape purposes, except fountains	
Fecal coliform <500 NPM/100 mL	Class 3 water: used for flushing toilets	
Fecal coliform <500 NPM/100 mL Turbidity <10 NTU Dissolved oxygen >2 mg/L	Class 4 water: reuse in orchards, cereal, fodder, cattle pastures and other crops through surface drainage or specific irrigation systems.	
TSS: 35 mg/L Turbidity: 15 NTU *Escherichia coli*: 10^4 UFC/100 mL *Legionella* spp.:100 UFC/L	Cleaning process, but not for the food industry	Spain
TSS: 35 mg/L *Escherichia coli*: 10^3 UFC/100 mL Nematode eggs: 1 eggs/10 mL *Legionella* spp.: 100 UFC/L	Processing and washing water in the food industry	
TSS: 5 mg/L Turbidity: 1 NTU *Escherichia coli*: 0 UFC/100 mL Nematode eggs: 1 eggs/10 mL	Cooling towers and evaporative condensers	
BOD ≤30 mg/L Thermotolerant coliforms ≤200/100 mL pH between 6 and 9 TSS ≤30 mg/L Minimum residual chlorine 1 mg/L	Cooling without recirculation	USA
BOD ≤30 mg/L Thermotolerant coliforms ≤200/100 mL pH between 6 and 9 TSS ≤30 mg/L Minimum residual chlorine 1 mg/L	Cooling towers (variables depend on the rate of recirculation)	
Escherichia coli ≤200 UFC/100 mL (average)	Cooling water	Greece
pH between 6 and 8.5 BOD: ≤10 mg/L (in 80% of samples) TSS: ≤10 mg/L (in 80% of samples) Turbidity ≤2 NTU *Escherichia coli*: ≤5 UFC/100 mL (80% of samples), ≤50 (in 95% of samples)	Use of single reticulated cooling water, cooling water for boilers, process water.	

TSS, total suspended solids; BOD, biochemical oxygen demand; NTU, turbidity unit; UFC, colony formation unit. Brazilian NBR Technical Standards 13969: 1997 [24], European Standards: Spain, Royal Decree 1620, [25] and Greece, Ministerial Decree [26], American Guidelines [8].

Table 1.
Reuse and recycling quality requirements established by standards and regulations for industrial reuse.

and the volume of effluent generated [16, 18, 20]. The occurrence of these variables in the operational conditions makes it difficult to plan a single treatment unit capable of meeting the necessary requirements for all types of effluents produced in this type of industry.

When it is intended to employ water reuse systems in meat product industries, account should be taken of the limitation imposed by the regulations. 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 whom it is handled. There are also other barriers to the large-scale operationalization of these systems, such as insufficient policies to support the reuse of reclaimed water; lack of public awareness and acceptance; failures in risk management systems, among others [6, 8]. However, each industrial plant is unique, with size and quality of different effluents, therefore, generalizations about the use and effluent characteristics are difficult to measure, making treatment complex.

Another barrier is the environmental regulations, which focus on the discharge of effluents into the water bodies, not being considered, in most of these documents, the necessary criteria for reuse and recycling [21]. However, there are efforts by several countries. In Europe, the countries with more specific reuse regulations are Greece, Spain and Portugal, and have applied in different reuse modalities. Italian regulations also describe urban, agricultural and industrial uses, but industrial use is permitted if there is no direct contact with food [5]. In the United States, regulations are developed according to the criteria of each state. In the case of Australia, government agencies initiated a reform in water management in 1994, when measures were adopted to use alternative water sources and the development of guidelines for obtaining recycled drinking water [22, 23]. In number of reuse projects, Japan leads, with approximately 1800; followed by Australia with more than 450; then Europe, with about 200; the Middle East, with more than 100; Latin America, over 50, and Sub-Saharan Africa, with just over 20 [5].

Despite the legal limitations of reuse, countries have been regulating the practice (**Table 1**). In these places, reuse water is mainly applied to urban uses and agricultural irrigation. Although effluent reuse is a widespread and widely applied practice, it is necessary to remember that the accomplishment of treatment to suit the requirements of the next use or to the related regulations is indispensable.

3. Analysis of potential effluent reuse and recycling

The industrial sector has adopted water reuse programs (**Table 2**), as a tool for the economy, for sustainability, and for the preservation of water resources. In order to comply with the regulations for industrial reuse and potability, joint systems of treatments are required. However, conventional effluent treatment is not suitable for the application of the effluent treatment, since the use of a less expensive technology for the treatment of effluents when the reuse option adopted is less restrictive [8, 24]. As well as the reuse and/or recycle systems when it comes to the food industry, since it is necessary to meet the specific criteria [16, 27, 28]. Advanced treatment techniques capable of removing high levels of pollutants should be used [29].

The choice of treatment technologies that best fits the reality of each industry does not depend exclusively on the level of removal to be achieved, since other technical, economic and environmental criteria also influence decision-making. In order to establish which treatment levels are adequate, tools capable of evaluating the technologies for applications in reuse projects can be employed. Compensatory models are an example; since they allow achieving results closer to what would be the ideal result, because they are more demanding in assessing the advantages and disadvantages of each attribute, which characterizes a multicriteria analysis (MCA). These models can be divided into three subgroups: (i) scoring models (such as simple additive weighting); (ii) compromise models (such as TOPSIS); and (iii) concordance models (such as ELECTRE and PROMETHEE) [35].

Product or stage of processing	Type of water	Subsequent use	Reference
Beef processing			
Beef processing	Shower water from chiller	Reuse as warm water for cleaning and as water of constitution of boiler	[30]
Beef processing			
	Final effluent	Reuse in operation that does not require low concentration Total solid suspended (SST) and turbidity	[31]
Poultry processing			
Poultry processing	Pre-chiller water, effluent from gutter gutter; cooling chamber water and thawing; filter washing water	Recycle	[32]
Fish processing			
Processing of crustaceans	Cooling water from crustaceans after cooking	Direct reuse in the crustacean cleaning step before cooking	[33]
Fish processing	Process water from: vacuum or centrifugal pumping, evaporation (film evaporator or conventional) and drying (direct flame or steam)	Recycling, protein separation and subsequent incorporation into the processing	[34]

TSS, total suspended solids.

Table 2.
Industrial recycling and reuse of treated effluents in food processors.

The PROMETHEE is a non-parametric method of classification, which uses the principle of superior classification to formulate a ranking of alternatives, suitable for problems in which a finite number of alternatives must be classified in relation to several, sometimes-contradictory criteria [36]. The PROMETHEE approach has the advantage of being easier to use and less complex than the ELECTRE approach, although they are part of the same principles of agreement. For this reason, its application in solving environmental problems is increasing [3, 35].

For the implementation of PROMETHEE, it is necessary to define the weights of the criteria adopted and the preference functions of the decision maker when comparing the contribution of the alternatives in terms of each separate criterion. ELECTRE is a method of overcoming based on the agreement analysis. The main advantage is that it takes account of uncertainties and inaccuracies.

By optimizing the way in which the industries treat the effluents, a reduction of the operational costs of the plant can be obtained, besides minimizing the generation and the volume of effluents, without sacrificing the value or quality of the product [37]. The multicriteria analysis can subsidize the choice of the technology that satisfies the most possible criteria (objective and subjective), considering aspects competing in the decision of the managers of these types of establishments. Among the alternatives of effluent treatment systems for the fish processing industry, it is possible to choose the technologies that have the highest levels of removal (**Table 3**), capable of producing reuse waters with higher quality, or by better meeting the criteria of greater relevance [38].

From the removal rate obtained by the different treatment systems, multicriteria analysis (AMC) can be employed to support the decision on the choice of

Treatment	Parameters	Removal	Reference
Coagulation/Flocculation with $FeCl_3$	SST BOD COD Oils and greases	95.4% 89.3% 87.5% 92%	[39]
Rotary bioreactor	COD	98%	[40]
Discontinuous mixed reactor and compact filter reactor	Ntotal Dissolved organic carbon	99.9% 88%	[41]
Bioreactor and ultrafiltration by membranes	COD	92%	[42]
Bioreactor; coagulation/flocculation/sedimentation; microfiltration by membranes	COD Dissolved solids Ntotal Ptotal	100% 100% 93% 100%	[15]
Sedimentation/flotation; coagulation/flocculation; biological treatment by activated sludge process; sand filter filtration; reverse osmosis and UV disinfection	Dissolved organic carbon Oils and greases SST Anions and cations heterotrophic bacteria	99.9% 99.8% 98.4% 96% 100%	[13]

TSS, total suspended solids; BOD, biochemical oxygen demand; COD, chemical oxygen demand; Ntotal, total nitrogen; Ptotal, total phosphorus; UV, ultra violet. Source: [43].

Table 3.
Advanced treatment techniques for removal of high levels of pollutants.

wastewater treatment systems for reuse, considering the economic, technological and environmental criteria.

The AMC tool was employed to determine the best wastewater treatment technology from fish processing industries. The Visual PROMETHEE 1.4 program (implementation software of both the PROMETHEE method and the GAIA method) was used.

Economic [construction cost (CC) and operation and maintenance cost (CO&M)], technological [pollutant removal capacity (CRP), system complexity (COMP) and specialized MO (MOE)] and environmental (potability) aspects were adopted. [(PO), energy consumption (EC) and odors (OD)] [38].

It was postulated that the best system comprises efficient and low cost treatment and it was admitted that the economic and environmental criteria have importance and greater weight in the analysis. When considering obtaining a wastewater for potable reuse, deployment costs and removal efficiency were prioritized. While operation and maintenance costs were of intermediate importance, followed by the other criteria in order of importance. If potable reuse was not necessary, its weight was redistributed, prioritizing cost and removal efficiency criteria.

To analyze effluent compliance for reuse, the following standards and regulations were adopted (**Table 1**): Brazilian NBR Technical Standards 13969: 1997 [24], European Standards: Spain, Royal Decree 1620, [25] and Greece, Ministerial Decree [26], American Guidelines [8].

When the intended reuse was drinking, the Brazilian Ministry of Health (MS Ordinance No. 2914 [64]) was used, as well as to evaluate the potential for reuse of effluents in the most restrictive activities, such as preparation, handling and disposal fish packaging in processing industries.

For the use of potable reuse, from the effluent generated in the facilities of fish processing industries, the potability criterion (PO) was considered to be of greater relative importance, with a higher weight valuation than the others, given the restrictions imposed by the use itself and by rules and regulations.

Among the alternatives of effluent treatment systems for the fish processing industry, the technologies that presented the highest levels of pollutant removal were chosen (**Table 3**).

After processing the data by the AMC program used, it can be verified that the alternative that best meets the criteria listed for the importance weighting adopted was the effluent treatment system composed by the following technologies: bioreactor; coagulation/flocculation/sedimentation; microfiltration by membranes (Bio + Coag/floc/sed + Memb) [15], followed by sedimentation/flotation systems; coagulation/flocculation; biological treatment by activated sludge process; sand filter filtration; reverse osmosis and UV disinfection (Sed/Flot + Coag/floc + Sludge + Filtr + OsmRev + UV) [13].

It is noteworthy that the alternative Bio + Coag/floc/sed + Memb presented better overall performance, by better meeting the most relevant criteria adopted for drinking reuse. The criteria that most influenced the decision axes (**Figure 1**) were pollutant removal efficiency (CRP) and potability (PO).

For the reuse of non-potable water in less restrictive activities associated with the fish processing industry, such as use in water sanitation facilities, floor washing, garden irrigation and cooling and heating systems, potability requirements were not considered. Therefore, the valuation of the weights presented a redistribution of importance, prioritizing the criteria construction cost (CC), operation and maintenance cost (CO&M) and pollutant removal capacity (CRP).

As alternatives for effluent treatment systems, the same technologies were adopted when considering potability. For this case, the alternative that best meets the listed criteria for the importance weighting adopted was the effluent treatment system proposed by Fahim et al. [39]: coagulation/flocculation with $FeCl_3$ (Coag/Floc), followed by the systems proposed by Artiga et al. [42]: bioreactor and ultrafiltration by membranes (Bio + Memb).

The reason for the alternative proposed by Fahim et al. [39] presented the best overall performance, by meeting the most relevant criteria adopted: construction cost (CC) and operation and maintenance cost (CO&M) and pollutant removal capacity (CRP). For and Artiga et al. [42] were the COMP, CC and EC criteria (**Figure 2**).

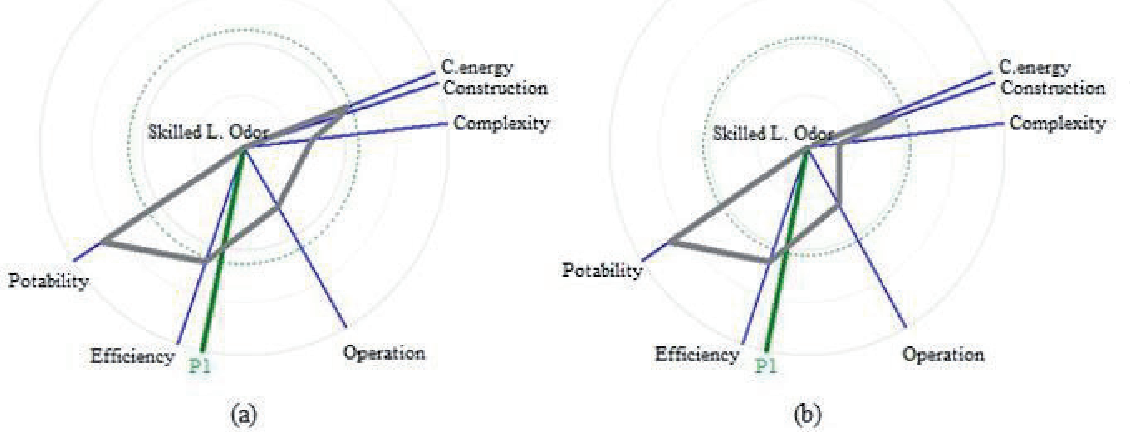

Figure 1.
Behavior of treatment alternatives proposed by Queiroz et al. [15], (a) bioreactor; coagulation/flocculation/sedimentation; microfiltration by membranes (Bio + Coag/floc/sed + Memb), followed by the systems proposed by Cristóvão et al. [13]: sedimentation/flotation; coagulation/flocculation; biological treatment by activated sludge process; sand filter filtration; reverse osmosis and UV disinfection (Sed/Flot + Coag/floc + Sludge + Filter + OsmRev + UV).

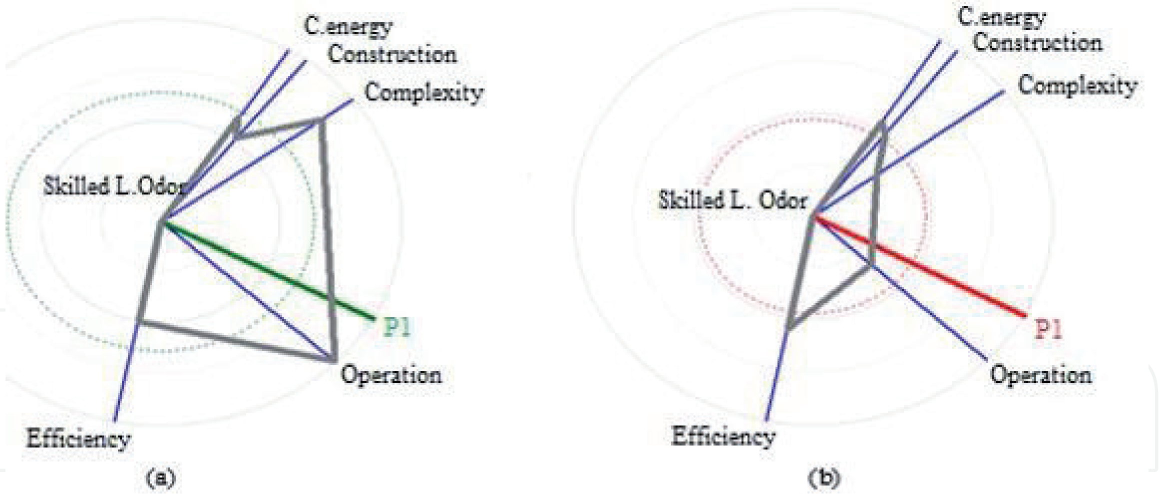

Figure 2.
Behavior of Fahim et al. [39] (a) coagulation/flocculation with $FeCl_3$ (Coag/Floc), Artiga et al. [42] (b), Queiroz et al. [15] bioreactor and ultrafiltration by membranes (Bio + Memb) and their decision axes.

Technician employed	% Theoretical adopted	References
Total solids		
Screen	31% a 60%	[46, 53]
Linked screen with fil	40% a 70%	[50]
and catchment area	100%	[54]
Sieving conjugated with microfiltration, ultrafiltration, nanofiltration and reverse osmosis	80% a 90%	[49]
Organic matter		
Screens	25% a 60%	[29]
Rotary filter	15%	[45]
Rotary sieve	25%	[45]
Nanofiltration conjugated prefiltration	56%.	[54]
Ultrafiltration	36%	[54]
Nanofiltration	60% a 80%	[54]
Dissolved air flotation	30% a 90%	[29, 55]
Coagulation-flotation	90%	[56]
Reverse osmosis	97,50%	[54]
Oils and greases		
Membrane filtration associated with electrocoagulation	65%	[57]
Ceramic membrane and electrocoagulation	50%	[57]
Ceramic membrane	2%	[57]
Dynamic membrane	10%	[57]
Flotation	37% e 63%	[49]
Screen	10% a 20%	[49]

Source: [58].

Table 4.
Segregation techniques and removal percentages achieved.

Even if the desired level of pollutant removal is reached, the use of clean technologies, which promote green innovation, together with the production process, should favor the sustainability of product transformation [44, 45]. Complex or simple technological investments, such as segregation of effluent, in processing contribute to cleaner production [44, 46, 47]. Segregation facilitates the treatment of the generated effluents [17] and can occur in the processing, through optimizations added to the production line.

In the case of the fish processing industry, several alternatives can be adopted such as alteration in the cutting machine; adjustment in the mechanized filleting machine; inclusion of waste separation ramp; [48] (**Table 4**). Allied operations are considered the minimization of waste generation, such as sieving; filtration; [49, 50] which reduce between 30% and 80% of the solid residues originated during fish processing [51, 52].

Studies of the valuation of by-products of fish processing indicate that these can be used in the elaboration of new products, with low raw material and production costs, increasing the industry profit and reducing the environmental impact caused [17]. Among the alternatives for the reuse of waste generated by fish processing are the use for animal and human consumption and for biodiesel generation, which may contribute to the establishment of a sector committed to environmental issues [59–63].

4. Conclusions

The precise characterization of the effluents, including the daily volumes, 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 assessment of the quality of the effluents to be treated.

The choice of the treatment system to be used with a view to reuse, capable of guaranteeing the project's profitability and sustainability, is not a simple decision process, depending on the number of possible alternatives and criteria to be evaluated (such as economic, technical, environmental and social). In order to choose the most appropriate technologies for the treatment of effluents, it is necessary to define the intended destination, either for discharge into the water sources or for the application in reuse and/or recycling systems. Based on related regulations, the available technologies can be related to the levels of removal required.

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Conflict of interest

The authors declare no conflict of interest.

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