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Restructuring in the flow of textile wastewater treatment and its relationship with water quality in Doce River, MG, Brazil

Reestruturação na forma do tratamento de efluentes têxteis: uma proposta embasada em fundamentos teóricos

Marluce Teixeira Andrade Queiroz[1]
Carolina Andrade Queiroz[2]
Lucas Barbosa Alvim[1]
Millor Godoy Sabará[3]
Mônica Maria Diniz Leão[4]
Camila Costa de Amorim[4]

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Abstract: Textile industries use large amounts of water in the processes of dyeing and processing of textile fibers, generating high volumes of wastewater containing dyes, surfactants, inorganic ions, wetting agents, among others. The main environmental impact of these effluents is related to the absorption of light into the water, which interferes with the photosynthesis of plants and algae. Therefore, it is relevant to have environmental planning aimed at the reuse of the water, increased removal of dyes, as well as reducing losses in the dyeing. In this work, studies were undertaken to propose control measures so as to introduce the concepts of Cleaner Production (CP) in the textile sector. Data was collected in a company located in the catchment area of the river Doce, in Minas Gerais, and established the association of the relative advantages of conventional coagulation/flocculation with the combined use of Advanced Oxidation Processes (AOP). The proposed measures entail a decrease in the volume and characteristics of the refractory sludge generated and the possibility of recirculation of treated effluent. The need to develop pilot-scale experiments was identified, including monitoring of the acute toxicity of treated effluents.

Keywords: Textile industries; Recalcitrant compounds; Advanced oxidation processes; Decontamination; Eco-efficiency.

Resumo: *As indústrias têxteis utilizam grandes quantidades de água nos processos de tingimento e beneficiamento das fibras, gerando volumes elevados de efluentes contendo corantes, surfactantes, íons inorgânicos, agentes umectantes, entre outros. O principal impacto ambiental desses efluentes está relacionado com a absorção de luz no meio aquático, o que interfere na fotossíntese de plantas e algas. Sendo assim, é relevante um planejamento ambiental propiciando o aumento da remoção dos corantes, redução das perdas no tingimento e reúso da água. Neste trabalho, foram realizados estudos visando à proposição de medidas de contenção dos riscos ambientais e contribuir para melhor aderência aos conceitos da ecoeficiência no setor têxtil através de um estudo de caso. Os dados foram coletados em uma empresa localizada na área de abrangência do Rio Doce, Minas Gerais, sendo proposta a inclusão do Processo Oxidativo Avançado (POA) e ultrafiltração associada ao tratamento convencional para diminuição do volume gerado e características refratárias, e dessa forma oportunizando o reúso da água. Identificou-se a necessidade do monitoramento da toxicidade do lodo gerado em função da presença de teores de*

[1]Centro Universitário do Leste de Minas Gerais – UNILESTE, Avenida Tancredo Neves, 3500, Bairro Universitário, CEP 35170-056, Coronel Fabriciano, MG, Brasil, e-mail: marluce.queiroz@bol.com.br; l.barbosa.alvim@gmail.com

[2]Tribunal de Contas do Rio de Janeiro, Praça da República, 70, CEP 20060-010, Rio de Janeiro, RJ, Brasil, e-mail: carolanq@yahoo.com.br

[3]Universidade do Estado de Minas Gerais – UEMG, Avenida Brasília, 1304, CEP 35930-314, João Monlevada, MG, Brasil, e-mail: mgsabara@uol.com.br

[4]Universidade Federal de Minas Gerais – UFMG, Avenida Presidente Antônio Carlos, 6627, Pampulha, CEP 31270-901, Belo Horizonte, MG, Brasil, e-mail: desa@ufmg.com.br

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metais tóxicos visando seu reaproveitamento, sendo sugerido estudo para incorporação da massa em argila para fabricação de blocos cerâmicos de vedação utilizados na construção civil.

Palavras-chave: *Indústria têxtil; Compostos recalcitrantes; Processos oxidativos avançados; Descontaminação; Ecoeficiência.*

1 Introduction

Brazil's water abundance is very significant, given that about 10% of the world's fresh water is concentrated in this country. However, heterogeneous conditions can be identified in this resource's distribution. In Brazil, water is, in many places, considered a limited resource and able to provide only the basic survival conditions for humans (Handl et al., 2008). An example of the water scarcity is found in the state of São Paulo, where one of the world's largest metropolis is found, in which rationing periods have occurred since the 80s, a situation that commonly happens in other parts of the national country (Gutiérrez, 2012).

Another important aspect that affects the availability of fresh water in the world is the process of degradation that has been submitted due to natural and anthropogenic pollution (Manenti et al., 2014). Among the factors that naturally affect the quality of the water we can mention the climate, vegetation, topography and soil geology. Anthropogenic pollution is mainly associated to inappropriate soil use, waste and sewage discharge into bodies of water, improper disposal of domestic waste and dead animals, pesticides and other pollutants (Queiroz et al., 2015).

The importance of surface water protection to the sustainability of the planet already is an incontestable fact, and the industries hold great responsibility for maintaining the effluent discharges within the environmental standards (Seiffert, 2007). Cavalcante et al. (2013) state that the various economic segments should fit the eco efficiency concept by progressively reducing the environmental impact and the natural resources consumption, and to provide goods / services at competitive prices that meet the human needs, contributing to the populations' life quality. Hirschler (2008) reinforces that the industries need to ensure the maintenance of the productive process with the application of modern technologies that can also contribute to reduce contaminant sources.

In this scenario, the textile segment occupies a prominent position. It is the manufacturing industry, which from the fibrous raw material attains the production of several types of tissues, associated with the fiber length. For example, long or short fibers originate respectively silk and cotton and thereby contribute positively to the economic balance of Brazil in the area of exports (BNDES, 2014).

However, that is an economic enterprise characterized by the generation of large amounts of wastewater containing dyes, surfactants, inorganic ions, wetting agents, etc., which are classified as recalcitrant and / or persistent compounds. These substances alter the physico-chemical parameters of surface water causing serious environmental dysfunctions (Hirschler et al., 2011).

The dyes, specifically, contribute to the increase in turbidity reducing the incidence of solar radiation in the water column interfering in biogeochemical cycles, affecting aquatic organisms mainly algae and consequently the fish that feed on them (Niebisch et al., 2014).

Corseuil et al. (2011) point out that the deposition of recalcitrant substances in river sediments also constitutes a rather unfavorable condition. Those substances can percolate through the soil and reach the water table affecting the health standard of groundwater. This situation represents a serious risk to public health, particularly of the rural community.

Therefore, the relevance of this study translates to produce results on the control measures of water pollution related to the line of treatment. Given that premise, measures directed to the decontamination of wastewaters through the association of conventional biological treatment methods with the Advanced Oxidation Processes (AOP) and ultrafiltration were suggested, based on the literature review. The disclosure of this study is understood as a positive catalyst mechanism for the insertion of the textile industry in line with sustainable development.

2 Theoretical foundations

2.1 Eco-efficiency: fundamental concepts and importance

Throughout its existence the textile industry has shown potential for growth and improvement of their technologies to meet the demand with maintenance of quality requirements (Correia et al., 2013). In this context, it is required that this production segment accede to the concepts of eco-efficiency. This is the most efficient use of natural resources in the processes and products in order to avoid waste and reduce the negative impacts. It is worth pointing out that the eco-efficiency covers key elements on the environmental scope, such as minimizing expenditure on materials, reducing the spread of toxic contaminants, encouraging recycling, extending the durability of the product, maximizing the tolerable use of natural resources, among others (Cortimiglia et al., 2015).

2.2 Textile industry: productive steps and effluent treatment

Niebisch et al. (2010) report that the per capita consumption of textile fiber in Brazil is estimated at 7.0 kg, being slightly higher than the world average. The country has three macro areas of production, namely South (Paraná, Santa Catarina and Rio Grande do Sul), Southeast (Minas Gerais, Rio de Janeiro and São Paulo) and Northeast (Ceará, Pernambuco, Bahia and Rio Grande do Norte), whereas the North and Midwest regions are less expressive (Reis & Revello, 2008).

The textile manufacturing process has five basic stages (Figure 1), the first being the spinning, through which the yarn is made from natural and / or manufactured fibers (Reis & Revello, 2008). Afterwards, the yarn can be sent to the pre-treatment or directly to weaving and knitting. The pre-treatment involves dyeing, sizing, twisting and special treatment. The weaving and / or knitting are stages by which are created fabrics that can be made through flat, circular or rectilinear knitting, based on customer requirements. The finishing treatment is the stage of preparation and finishing of woven, knitted or crocheted articles. In the stage of manufacturing, there is the application of diversified technologies for textiles, plus the adding of accessories in the products, such as buttons and varied adornments, based on the analysis of consumer trends and preferences (Niebisch et al., 2014).

The serious environmental problem is mainly related to the dyeing sector. Wesenberg et al. (2003) state that the textile fibers require dyes with peculiar and well defined characteristics, which may have high affinity, uniformity of color, fade resistance and economic viability. There are several ways to classify the colorants, for example, according to their chemical constitution, application, strength, kind of electronic excitation when exposed to light, among others (Toscan et al., 2017).

Robinson et al. (2001) point out the broad use of reactive dyes in the textile industries, especially those from the azo-dyes family. Such dyes are known to be recalcitrant and generate aromatic amines through reductive cleavage of azo bonds by bacteria, as discussed by Chagas & Durrant (2001). Pinheiro et al. (2000) also studied these dyes and state that they are compounds with carcinogenic and mutagenic character.

Ambrósio & Campos-Takaki (2004) analyzed the structure of the azo pigments and affirm that these compounds are characterized by presenting chromophore groups, with one or more groups (-N=N-) linked to aromatic structures, and are known to be recalcitrant, generating aromatic amines through reductive cleavage of the azo bonds by bacteria, which have carcinogenic and mutagenic character

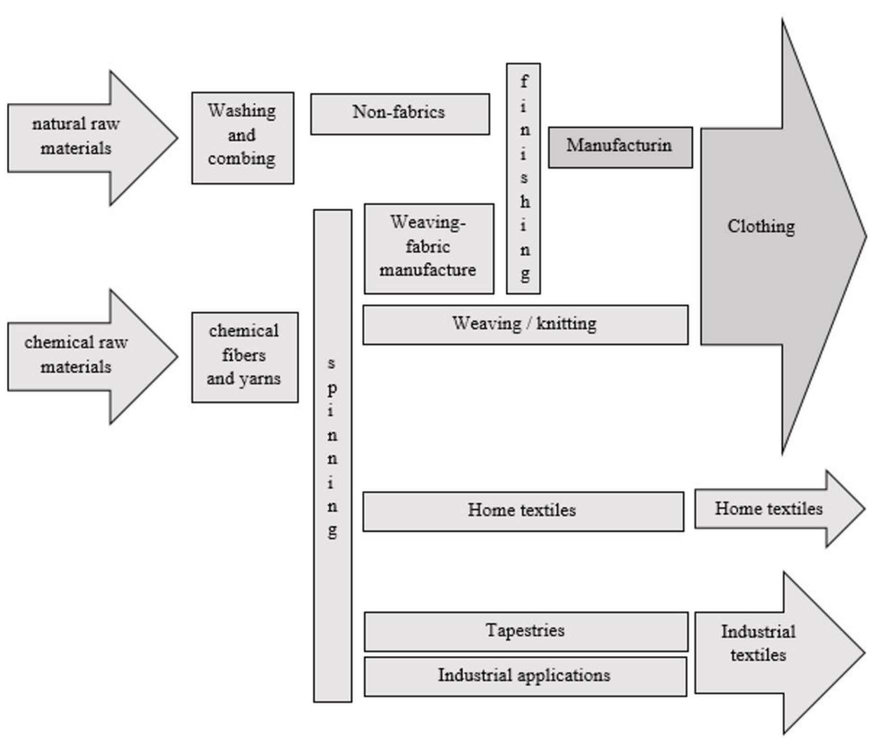

Figure 1. Production flow in the textile industry. Source: IEFP (2015).

(Oliveira et al., 2014). Pinheiro et al. (2000) complement saying that the presence of this kind of bond in its chromophore group, as well as of sulfonate groups, demonstrates the renitent character of this kind of complex molecular structure (Figure 2).

The dyes used must be carefully selected based on certain characteristics, such as high affinity with the raw material, uniformity of color, fade resistance and economic viability (Niebisch et al., 2014). Thus, in order to meet the demand, there are about 10,000 (ten thousand) dyes and pigments available to the textile industry and it is estimated that world production is around 8,105 tons per year, of which 10-15% become available through the effluent (Niebisch et al., 2014).

Colorants are identified as the most troublesome compound in the textile effluents due to its high solubility in water and low degradability (Niebisch et al., 2014). Among these, reactive dyes, especially the family of azo-dyes are the most used today, because they have advantages such as the stability in the light conditions, pH and temperature. Also, they ensure a wider range of colors and economic viability (Gusmão et al., 2014).

Fixation of reactive dyes in the tissues occurs through the electrophilic group, which is capable of forming covalent bond with hydroxyl groups of the cellulosic fibers or with amino, hydroxyl and thiol of the protein fibers as well as with amino groups of the polyamides (Kunz et al., 2002). However, the formation of the covalent bond is not sufficient to prevent dye loss on the production line. For that reason, high volumes of effluents with strong staining are generated due to the presence of pigments that are not properly fixed to the fibers (Ledakowicz et al., 2001).

Reis & Revello (2008) reported losses ranging from 10 to 20% of dyes during the washing step, causing the strong color of the final effluent. Moreover, organic compounds such as amines, dextrins, size material, greases, pectins, alcohols, acetic acid, soaps and detergents and inorganic compounds such as sodium hydroxide, carbonate, sulfate and chloride are also present in the wastewater. Those compounds cause the textile effluents to present high Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), suspended solids and low concentrations of Dissolved Oxygen (DO) (Table 1) (López Cisneros et al., 2002).

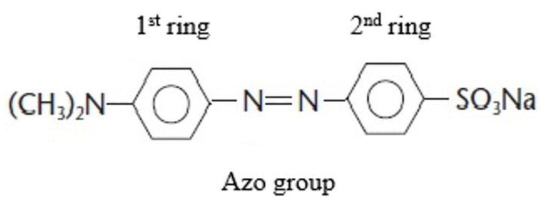

Figure 2. Example of azo-dye. Source: Brasil Escola (2015).

Among the physicochemical parameters, special attention has been given to the coloring (Table 1), as this interferes immediately in photosynthetic activity of aquatic biota to which the effluent is inserted (Kunz et al, 2002).

Thus, considering the varied aspects mentioned, the effluent from the textile industry presents very high toxicity (Table 1). Part of this toxicity (acute toxicity) can be reduced by biological processes, mainly represented by activated sludge (Montalvao et al., 2007).

The process of activated sludge is widely used worldwide in different variations, and its efficiency largely defined by the content of organic matter (OM), availability of microorganisms and oxygen, the way of feeding the reactors and biomass retention time (Foco & Téran, 2007).

In the biological treatment, the organic matter is converted into carbon dioxide (CO_2) and water; or carbon dioxide (CO_2) and methane (CH_4), by the action of aerobic and anaerobic microorganisms respectively. The main advantages are the low cost and efficiency in relation to various organic compounds. However, it has limitations regarding the presence of recalcitrant substances being inefficient regarding the removal of color, even favoring, in many cases, the formation of high concentrations of heavy metals

Table 1. Main physicochemical parameters of the textile effluent.

Textile Industry Effluent	
Parameter	**Characteristic**
Chemical Composition	Amines, colorants, dextrines, size, greases, pectins, alcohols, acetic acid, soaps and detergents and inorganic compounds such as sodium hydroxide, carbonate, sulfate and chloride
Color	High concentration
Colorant	Incomplete fixation generating losses ranging from 10 to 20%
BOD	High concentration
COD	High concentration
Heavy metals	Formed from the colorant degradation
OD	Low concentration
Suspended solids	Low concentration
Toxicity	High concentration (recalcitrant compounds)
Biological treatment with activated sludges	Partial removal of color and toxicity

Source: Adapted from López Cisneros et al. (2002) and Zanoni & Carneiro (2001).

(Santoro et al., 2014). It is noteworthy that the heavy metals are substances capable of accumulating in aquatic plants and consequently passing through the food chain, contaminating other organisms, resulting in severe disabling injuries such as neuropathies and cancer (Baird & Cann, 2011).

Regarding the decontamination of wastewater, the textile effluent stands out for its complexity, requiring the use of methodologies to ensure the necessary efficiency in the degradation of recalcitrant pollutants, without the formation of toxic intermediates, and within an economic feasibility perspective (Fu & Viraraghavan, 2001). The statement shows the importance of this topic in the integrated management perspective in order to maintain biodiversity.

In this context, the so-called Advanced Oxidation Processes (AOPs) have received great attention for being able to convert refractory pollutants into harmless chemical species (Alaton et al., 2002).

The AOPs are considered clean technology, because there is no sludge formation and phase transfer of pollutants, and the end products, carbon dioxide, water, inorganic ions and by-products are less toxic. These processes can also be used for the degradation of organic compounds in aqueous phase or adsorbed onto a solid matrix (Molinari et al., 2002; Queiroz et al., 2011).

When the degradation of pollutant species occurs in a single stage it is classified as homogeneous, such as Fenton, photo-Fenton, UV / H_2O_2 and ozonation; and called heterogeneous when it makes use of a photocatalyst such as systems UV / TiO_2 and UV / ZnO (Arslan & Balcioglu, 1999; Queiroz et al., 2011).

In AOP, the oxidation process depends on the formation of the hydroxyl radical ($^{\bullet}OH$) in a sufficient amount to act as a primary oxidizing agent (Ledakowicz et al., 2001). These radicals are highly oxidizing species ($E^0 = 2.8V$) and nonselective that attack most of the organic molecules (López Cisneros et al., 2002). The low selectivity of attack of the hydroxyl radical is an important characteristic for the use of the AOP in wastewater treatment (Andreozzi et al., 1999; Queiroz et al., 2011).

The organic compounds are oxidized by the hydroxyl radical ($^{\bullet}OH$) mainly by the abstraction of hydrogen (Equation 1). This reaction generates organic radicals and the addition of molecular oxygen to carbon centered radicals, producing the peroxyl radical (Equation 2). These intermediates initiate reactions in oxidative degradation chain, leading ultimately to carbon dioxide, water and inorganic salts (Daneshvar et al., 2004).

$$RH + HO\bullet \rightarrow H_2O + R\bullet \quad (1)$$

$$R\bullet + O_2 \rightarrow RO_2\bullet \quad (2)$$

Besides hydrogen abstraction, the transfer of electrons to the hydroxyl radical (Equation 3) and electrophilic addition (Equation 4) are the other reactions of the hydroxyl radical with organic compounds (Daneshvar et al., 2004).

$$RH + HO\bullet \rightarrow RX\bullet + OH^- \quad (3)$$

$$PhX + HO\bullet \rightarrow HOPh\bullet \quad (4)$$

X = halogen; Ph = phenyl of naphthyl group.

The efficiency of AOP depends on the concentration of the polluting charge, usually expressed as Chemical Oxygen Demand (COD), which can be treated in an economically viable manner, therefore decreases with the increase of organic matter (OM), requiring the consumption of larger quantities of expensive reagents; such as hydrogen peroxide, ozone and/or titanium dioxide. Andreozzi et al. (1999) suggest that the maximum COD to obtain the best efficiency of AOP corresponds to 5.000 $mgO_2.L^{-1}$.

Oliveira & Leão (2009) emphasize that, even in not so high concentrations of COD, the AOP are uneconomical for large volumes of effluents, so there is need for their association with other types of physical, chemical or biological treatments and / or treatment of part of the raw effluent, i.e., only the fraction actually concentrated, bio-recalcitrant and toxic.

Therefore, the potential of the AOP to degrade recalcitrant or toxic compounds should, on the other hand, be explored by integrated use with biological treatments (cheaper and more compatible with the environment) (Santoro et al., 2014), either as pre-treatment, to increase the biodegradability of these compounds, forming intermediaries that will act as substrates for microorganisms in a subsequent biological step, or as a post-treatment for the destruction of compounds that were not degraded in the treatment by activated sludge (Sarria et al., 2002).

Bergamasco et al. (2011) state that only a combination of different treatments makes it possible to remove various organic compounds in an industrial effluent (natural organic matter, micropollutants, trihalomethane precursors and compounds that cause odor and taste), it is important to include ultrafiltration to ensure the reuse of water.

Rodrigues et al. (2003) report that conventional filtration processes do not allow the retention of smaller particles, such as dyes. Therefore, the particle size to be retained becomes a factor for exclusion from traditional technology. In general, this type of treatment suits to the retention material with diameters of 10^5 Angstroms or greater than 10 Microns, being more suitable for removal of cell suspensions (Rodrigues et al., 2003).

Pinilla et al. (2017) punctuate that the introduction of membrane separation processes in wastewater treatment systems enable a very different level of quality compared to traditional methods, especially in relation to disinfection, due to the reduction in the consumption of chemicals.

In membrane technology, membranes represent a selective barrier, which under the action of a motive force is able to promote the separation of constituents of a solution or suspension. The motive force may be a gradient of concentration, pressure, temperature or electrical potential (in the case of ionic species) (Viana, 2004).

In the systems called ultrafiltration pore size ranges from 1 to 100 nm. The configuration of ultrafiltration modules can be done in two ways: in a pressurized system in pressure vessel or immersed system. Selecting the most suitable system will depend on the physicochemical characteristics of the effluent, decontamination level to be achieved and the availability of financial resources (Brites et al., 2016).

3 Materials and methods

This study consisted of a review of the specialized literature, conducted between February 2011 and August 2014, period in which a consultation of books and papers available in the libraries of the Minas Gerais Federal University was conducted. Scientific papers were also selected through search in the Scielo database by using terminology relevant to the descriptors in engineering and technology. The following keywords were used: textile effluent, advanced oxidation process and recalcitrant compounds.

The criteria of inclusion were the oxidative process approach with the use of ultra-violet irradiation, and comparative studies between this and other kinds of wastewater treatment. The works that regarded the use of other types of treatment focused on the removal of pollutants were excluded.

The researches were directed to a textile industry company located in the catchment area of the river Doce, whose treated effluent was released in Peixe's river before flowing into Santo Antonio River, MG, which is the disposal site of the effluent treated in the receiving body. It's worth highlighting that the water body flows through the municipalities of Alvinópolis, Dom Silvério and Rio Doce, receiving their sewage. Moreover, it presents an elongated and well drained basin, with the occurrence of flooding in the lower parts, which is the result of changes in the hydrological behavior, consequence of human action adversely affecting municipalities that interface with the water source (Mello et al., 2010).

The investigation of the productive process consisted in gathering data related to the operational steps, identifying the points in which there's wastewater generation, relating to the main physical and chemical indicators, dissolved aluminum levels, true color, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, Sedimentable Solids (SS) and Total Suspended Solids (TSS), which were obtained by the analytical methods of the American Public Health Association (APHA, 1998) to the input and output of the Wastewater Treatment Plant (WWTP).

The monitoring's findings provided by the company were analyzed according to the Resolution n.º 357/2005 of the National Council of the Environment (CONAMA 357/2005) (Brasil, 2005), which establishes, for the lotic ecosystems, the usage of Water Classes according to their main uses. It was verified that the Peixe river was used for fishing activities, animal watering, irrigation of tree crops and forages, among others. These activities are included in Class 2 (two), which incorporates all of the primary and secondary human actions of primary and secondary contact with the water body (CBH-Rio Doce, 2006).

Based on this classification, we realized a comparative analysis of the monitoring results with the dispositions of the Normative Deliberation nº 01/2008 of the State Environmental Policy Council (COPAM, 2008) and the State of Minais Gerais's Council for Water Resources (MG-CERH). In consonance with that legislation, whenever the measured parameters were not included in the compulsory goals, we used CONAMA 357/2005 quality standards.

4 Results and discussion

It was found that the steps of dyeing, printing, sizing, toilets and cafeterias generated effluents that were transferred to an equalization tank (Figure 3). In the Wastewater Treatment Plant (WWTP) the effluents were first subjected to biological degradation (Figure 3) using the activated sludge technique with supply of atmospheric oxygen.

In the biological treatment, the organic matter (OM) removal was carried out by bacteria, producing carbon dioxide, water and organic flakethat would grow in the aeration tank and form the biomass to be sedimented in the decanter (Foco & Téran, 2007).

Then primard secondary decantation occurred (Figure 3), with the addition of aluminum sulphate ($Al_2(SO_4)_3$) in the second phase, enabling the formation of aluminum hydroxide ($Al(OH)_3$) (Equation 5), favoring the coagulation / flocculation phenomenon.

In this step, an important control parameter was the alkalinity (Bergamasco et al., 2011), therefore calcium hydroxide ($Ca(OH)_2$) 1mol.L^{-1} was added to the secondary sedimentation tank (when necessary), (Konradt-Moraes et al., 2008).

$$Al_2\left(SO_4\right)_{3(aq)} + 6OH^-{}_{(aq)} \rightarrow 2Al\left(OH\right)_{3(s)} \downarrow + 3SO_4{}^{-2}{}_{(aq)} \quad (5)$$

The strict control of pH was necessary due to the amphoteric character of aluminum. Shriver et al. (2008) report that at pH lower than 9.5, the solubility of aluminum in the form of ion $[Al(OH)_4]^-$ abruptly decreases, producing the $Al(OH)_3$ gel. However, the researchers report that at pH lower than 4, hydroxide dissolves forming a solution of complex ions $[Al(H_2O)_6]^{3+}$ (Equation 6) damaging the coagulation/flocculation (Shriver et al., 2008).

$$\left[Al(OH)_4\right]^- \leftrightarrow Al(OH)_3 \leftrightarrow \left[Al(OH)_6\right]^{3+}\ pH > 9.5) \quad acid\ solution\ (pH < 4) \tag{6}$$

The secondary decanted sludge was returned by pumping (Figure 3) to the aeration tank to increase the system efficiency (Foco & Téran, 2007). It was found that the operating cost was quite high due to energy consumption for moving the equipment. In addition to that, the company also had expenses for the treatment of the generated sludge, which would go through the incineration process after the discharge by filter press (Figure 3). Finally the treated wastewater was released into the Peixe river thus contributing to groundwater recharge.

Analyzing the concentration of contaminants to the input and output of the Wastewater Treatment Plant (WWTP), it was identified that there is need for improvement of the treatment system in order to maximize the environmental benefits. The dissolved aluminum content increased from 0,19 $mg.L^{-1}$ to 2,75 $mg.L^{-1}$ (Table 2), which corresponds to an increase of 1447.37% suggesting relationship with the excess of aluminum sulfate ($Al_2(SO_4)_3$).

Besides, the Peixe river waters belong to Class 2 and according to the Resolution of the National Environment Council (CONAMA) No 375/2005 the Maximum Permitted Value (MPV) of dissolved aluminum corresponds to 0,1 $mg.L^{-1}$ (Table 2) and can be used for subsistence agriculture, food production for livestock and herd watering (Mello et al., 2010).

The aluminum-containing effluents tend to have higher concentrations in depth, in which are also identified the lowest pH values. In this condition anaerobiosis and mild stratification may occur, allowing the decay of metal concentration along the body of water, notably in the dry season. In contrast, increasing precipitation leads to an escalation in the aluminum content and augmented turbidity. Another important aspect of the metal chemistry relates to its dissolution in the soil due to the acid-base reaction, neutralizing the acid rain. This way, the metal becomes bioavailable being extremely toxic to vegetation and it may affect the entire catchment by surface runoff, affecting fish reproduction, adult specimens, primary producers (algae) and primary consumers (Alves et al., 2014).

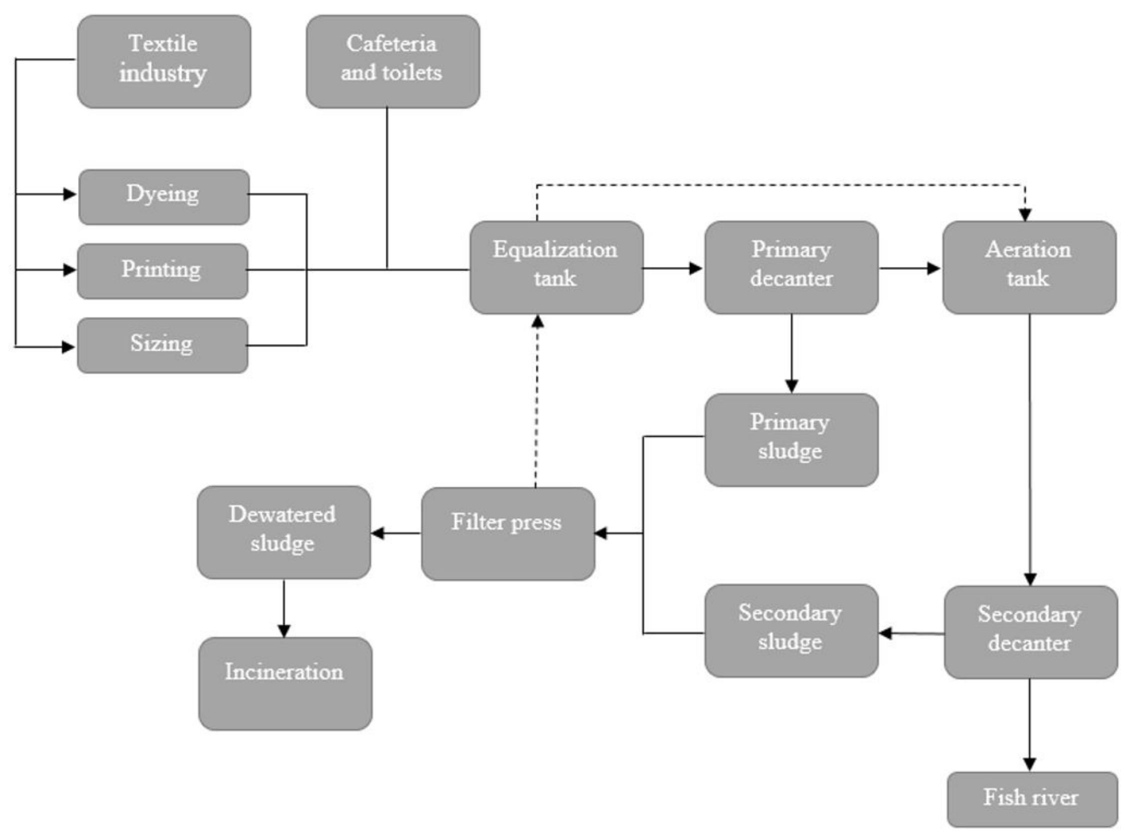

Figure 3. Generation and treatment of effluents in the researched textile industry.

Table 2. Physicochemical parameters of the effluent at input and output of the Wastewater Treatment Plant.

Parameter	Un.	WWTP Input	WWTP Output	η (%)	COPAM 01/2008	CONAMA 357/2005
Al	$mg.L^{-1}$	0.19	2.75	-	-	0.1
True Color	$mg.Pt.L^{-1}$	2158	83	-	-	75
BOD	$mgO_2.L^{-1}$	660	90	86,36	60 - 75%	
COD	$mgO_2.L^{-1}$	1769	283	84,00	70 -75%	
pH	-	5.30	7,50	-	6 - 9	
SS	$mL.L^{-1}$	<0.1	<0.1	-	1.0	
TSS	$mg.L^{-1}$	184	28	-	100	
Surfactant Substance	$mg.L^{-1}$	1.98	6.15	-	2.0	

Source: Company (September, 2011).

In relation to man, the main via of non-occupational exposure to aluminum is by ingestion of food and water. It is worth noting that the Ministry of Health, through the Decree 518/04 (Brasil, 2004), establishes a maximum allowed aluminum concentration of 0.2 mg/L as acceptance standard for water intended for human consumption. The results indicated an elevation of the costs related to the treatment of water meant for public supply (CETESB, 2006).

Therefore, the elimination or reduction of aluminum concentration in the surface waters is a condition to ensure the populations' health (Queiroz, 2017). Thus, it was inferred that the textile effluent released into the Peixe river requires planning of mitigation actions aiming to the preservation of the ecosystems.

Regarding the color, it was found that the applied treatment allowed a reduction from 2.158 $mg.L^{-1}$ to 83 $mg.Pt.L^{-1}$ (Table 2), resulting in quite significant removal (≅96.15%). However, it still presented an elevated content of adsorbed pigments, suggesting acute toxicity due to the recalcitrant compounds.

Thus, the problem related to the sludge accumulation arises, given that this kind of residue can be characterized as dangerous and belongs to Class I (ABNT, 2004). The incineration of this sludge implied a hazardous condition due to the probability of toxic compounds emissions (dioxins and furans) demanding, in general, temperatures above 850 °C and the installation of filter systems able to reduce the emission levels to the environmental standards (Trujillo et al., 2006). It can be inferred that the higher the pollution load, the greater the difficulties to ensure an effective pollutants retention.

It is worth pointing out that this mixture has a quite variable composition, which, in general, presents high levels of organic matter, nitrogen, phosphorus, micro-nutrients, pathogens and heavy metals prevenient from certain types of dyes (Hirschler et al., 2011). Its application in agriculture, either as a nutrient source for plants or as soil corrective, depending on the sludge's chemical composition, has proven itself a viable green alternative targeting its final destination (Hirschler et al., 2011). In this context, application of toxicity tests in order to define the real conditions for the reuse of the generated sludge reveals to be important.

It was also verified that the company met the requirements established by COPAM No. 01/2008 regarding the reduction of the Biochemical Oxygen Demand (BOD) and the Chemical Oxygen Demand (COD) set, respectively, between 60 to 75%; and 70 to 75% (Table 2). The treatment achieved a removal of 86.36% for the COD and 84.00% for the BOD in comparison with the contamination level at the input of the WWTP (Table 2).

However, this condition did not entail environmental quality, being only a palliative condition. The COPAM norm # 1/2008 determines that those parameters' efficiency of removal must be measured in percentage terms, when the industry fails to reach the minimum of 60 and 250 $mg.L^{-1}$ for BOD and COD, respectively. It was observed that in the WWTP output, the BOD was 90 $mg.L^{-1}$, while the COD reached 283 $mg.L^{-1}$ (Table 2).

Moreover, the emission of surfactants was 6,15 $mg.L^{-}$ (Table 2), those being contaminants capable of reducing viscosity and superficial tension of water, implying serious environmental dysfunctions.

Once again, the need for improvement in the treatment developed by the company was attested, demanding the implementation of measures capable of guaranteeing the protection of the water body according to the principles of CP aiming for environmental sustainability.

In this context, it is suggested the use of rainwater by collecting it in cisterns from the roofs of the industrial building and the administrative areas (Sinditêxtil, 2014). The rainwater collection will reverberate positively in the reduction of flood peaks caused by torrential downpours, a usual situation in the region of the study.

For instance, in 2009, a significant portion of Alvinópolis population was subjected to precarious conditions, such as property loss and waterborne diseases, due to the phenomenon. In 2011, the situation happened again, forcing the municipal public authorities to issue a preliminary notification of disaster (Nopred), seeking support from the State of Minas Gerais (Gazeta Online, 2011).

The stored rainwater contains pollutants originated from atmospheric contamination and when it flows through the roofs it drags along coarse material (leaves, twigs, stones, among others), biological agents (bacteria and parasites present in the feces of birds, cats and rodents) and many other materials. The stored volume might be utilized for less noble uses, such as cleaning, toilets and fire hydrants, helping to reduce the consumption of potable water.

The measure contributes to reduce the consumption of natural resources, chemicals, electric energy and financial expenses related to water usage charges (Sinditêxtil, 2014).

Regarding the industrial processing, two important measures may contribute to the rational use of water: - acquisition of a more modern machinery that allows to work with smaller bath ratios, diminishing the consumption of water, energy and other reactives; and - reduction of current facilities, with the reuse of dye baths as many times as possible, as long as it does not negatively affect the final quality of the product (Rosa et al., 2016).

Nevertheless, we found that the company used mainly direct dyes. Silva et al. (2014) reinforce that the reuse of dyeing baths with this kind of dye is the most difficult one, due to the final product's desired quality. Therefore, it is important to conduct experiments on a pilot-scale in order to verify the real possibilities of application for this strategy (Silva et al., 2011).

It was also indicated the running of tests on the hydraulic system to detect physical losses, through the use of appropriate instrumentation, to avoid destructive interventions. The study must cover all company facilities, involving moisturizers, toilets, cafeteria, and equipment, among others. A hydraulic system lacking proper maintenance can lose 15 to 20% of the water captured by the industrial installation. In general, there is a positive balance between the maintenance cost and the financial return because of the reduction of the water usage fees (Ferreira et al., 2016).

Another important aspect is pointed out by Peralta-Zamora et al. (2016) and involves the introduction of properly sized and operated treatment systems. Such measure contributes positively to minimize the textile industry environmental impact. The researcher highlights the importance of the Advanced Oxidation Processes introduction to generate less pollutant effluents.

In this context, it was suggested that adjustments in the company's treatment system were made. The effluents originated from the dyeing and printing steps would be submitted to the Advanced Oxidation Process (AOP) as a pretreatment to increase these compounds' biodegradability, thus optimizing the subsequent biological treatment (Sarria et al., 2002).

It was recommended the use of the homogeneous Fenton, which has already been explored by several researchers, achieving very satisfactory levels of degradation to the direct dyes, especially compared to Congo Red (VC). Based on the results achieved by Peralta-Zamora et. al. (2016), Queiroz et al. (2011) among others, it is possible to infer that its inclusion in the textile industry shall lead to the improvement of the effluents treatment process.

The homogeneous Fenton, a kind of AOP, presents standardized procedures that can easily fit in the production line. The efficiency of the Fenton oxidation process depends on many factors, such as temperature, pH, amount of organic matter, concentration of hydrogen peroxide and iron II (Bautista et al., 2008), and the use of effluent contamination level indicators, such as the BOD and COD, is important. Besides, it is worth pointing out that tests, on a pilot-scale, with the raw effluent must be implemented so as to provide greater safety to its effective installation.

The first step is oxidation, in which the effluents derived from dyeing and printing must be mixed with hydrogen peroxide (H_2O_2) (oxidizing agent), ferrous sulphate heptahydrate ($FeSO_4.7H_2O$) (catalyst) and the pH adjusting agent (sulfuric acid) (Figure 4). Afterwards, the neutralization must be carried out through the addition of the alkaline agent (sodium hydroxide), occurring the degradation of the residual hydrogen peroxide (Figure 4) (Bautista et al., 2008).

Thereafter, the dyeing and stamping effluents subjected to pre-treatment with homogeneous Fenton shall be transported to the equalization tank, along with the effluents from the cafeteria, bathrooms and sizing (Figure 4) that had already presented high biodegradability characteristics, being perfectly adequate to the biological treatment.

The proposition has also included the possibility of improving the decanted water characteristics through the addition of polyelectrolytes or polymers as coagulation auxiliaries (Figure 4), according to Sabogal-Paz et al. (2015), the association implies the reduction of the decantation time due to the size of the resulting flake, which is bulkier in comparison with those obtained by the use of the metallic coagulant.

Guilherme (2009) affirms that, in general, by the use of the polyelectrolyte, the sludge volume is reduced to around 50%, allowing, in many situations,

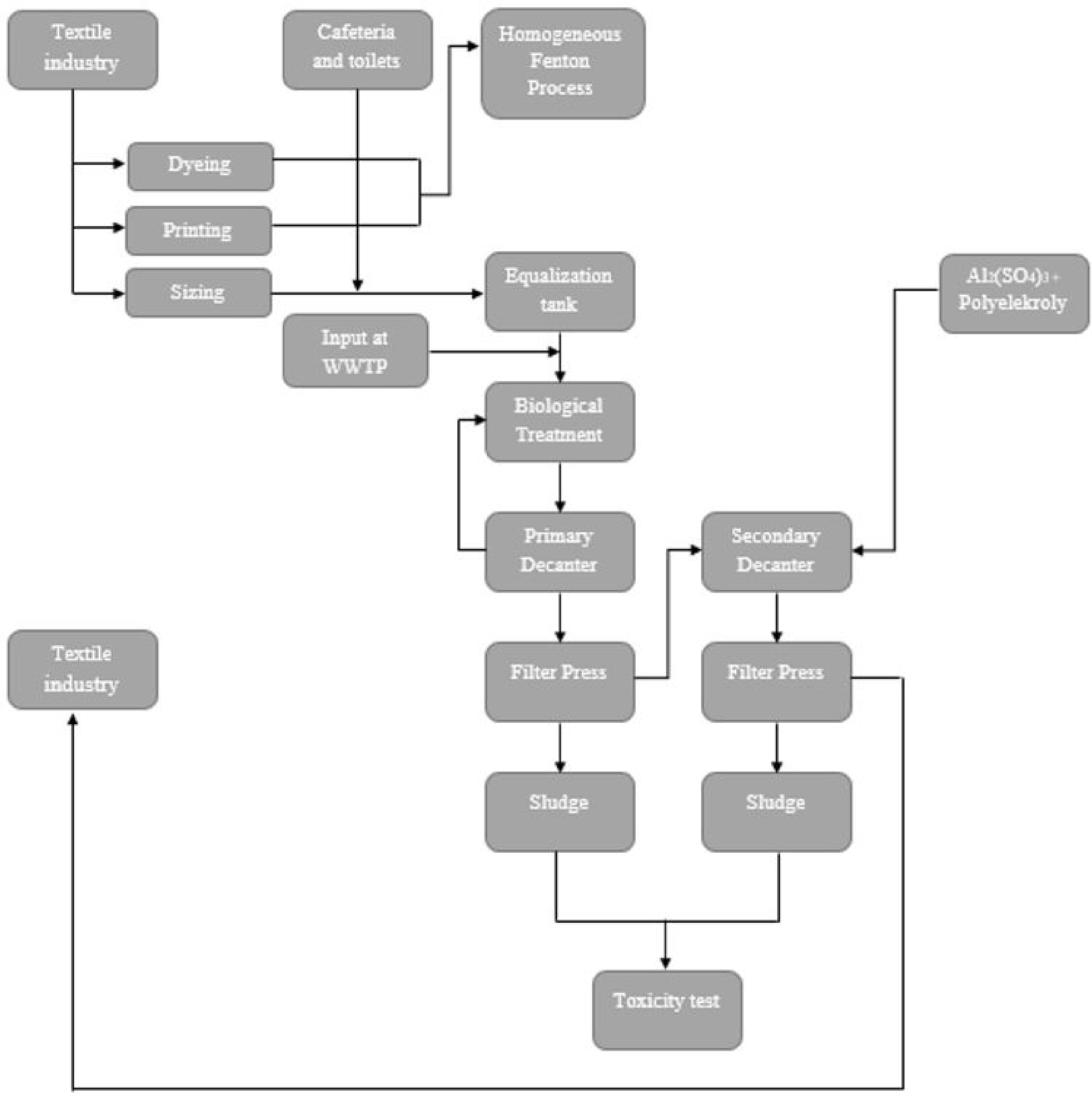

Figure 4. Proposition of adaptation in the textile effluent treatment.

the elimination of the alkalizing agents ($Ca(OH)_2$) to regulate the pH.

Another relevant aspect is related to the decrease of the consumption of coagulant ($Al_2(SO_4)_3$), which reaches the cost of R$ 25,60.kg^{-1} (twenty-five reais and sixty cents per kilo) (Quimibrás, 2011), significantly encumbering the coagulation / flocculation step. Guilherme (2009) also affirms that the decrease in the aluminum salt consumption increases the treatment's economic viability, even with the inclusion of the polyelectrolyte's price. It is noteworthy that there might be also a reduction in the investment destined for the incineration of the generated sludge.

Besides, it is also a mechanism that favors the reduction of dissolved aluminum concentrations in the treated effluent, enabling the adjustment to the MPV established in Resolution CONOMA # 357/2005.

The company must incorporate the culture of continuous improvement. Therefore, it is also proposed the adjustment of the treated effluent parameters to the needs of the productive process aiming for its recirculation.

Silva et al. (2011) report that the reuse of industrial water can be achieved by the use of ultrafiltration membranes. Such measure is widely justified by the scarcity of fresh water caused by the deterioration of water sources (Mierzwa et al., 2008).

Mierzwa et al. (2008) highlight that the cost-benefit ratio is favorable regarding the use of ultrafiltration, considering the expenses related to water usage charges. The toxicity of the generated sludge must also be tested. Studies concerning the implementation of a system that incorporates low cost and good response were recommended. It was referred to the test of *Escherichia coli* growth inibition systematized by Jardim et al. (1990), in 24 h cultures with five serial dilutions (1:1) in a period of 8 h of exposure. In case the effective mineralization is achieved, other possibilities regarding the sludge handling, instead of incineration, may arise, including its use in the fertilization of eucalyptus plantations held by the company in order to meet the demand for cellulose fibers.

5 Conclusions

Based on the results of this study, it was found that the treatment of the textile industry's effluents required the adoption of more adequate practices in order to be inserted within the eco efficiency parameters aiming for sustainable development.

With respect to the water consumption reduction, specifically, it's suggested the installation of cisterns for rainwater reuse for less noble purposes, thus contributing to diminish the likelihood of flooding in the area where the company is installed.

In order to improve the quality of the treated effluent, it was indicated the application of homogeneous Fenton process as a pre-treatment for wastewater prevenient from the dyeing and printing processes, which is also a factor that aggregates value to the optimization of the biological process with activated sludge.

The utilization of polyelectrolytes as coagulation auxiliaries was recommended. Such substances may allow an even more significative removal of color and turbidity, enabling the emission of the treated effluent with dissolved aluminum content within the Maximum Permitted Value (MPV) established by the CONAMA Resolution # 357/2005, which corresponds to 0,1 $mg.L^{-1}$. As advantages, the reduction of the generated sludge volume, and consequently, the decrease in the financial outlay related to its final disposal were pointed out. It was also reassured that the sludge toxicity evaluation through the test with *Escherichia coli* is of great importance. The effective evidence of the mineralization of the byproduct may allow its application, including as a fertilizer.

It was identified that the adoption of the proposition demands further investigations and conduction of trials on a pilot scale, including the possibility of water reuse through the utilization of ultra-filtration membranes. Finally, it is worth highlighting that the suggested adjustments fit with the environmental management perspective, inserting the segment in the eco-efficiency concepts, thus increasing their competitiveness in national and international markets.

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