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Assessment of treatability of the Tietê River through a process of coagulation-flocculation associated with hydrodynamic cavitation and ozonation

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Abstract: As it flows through the city of São Paulo, the Tietê River receives heavy discharges of industrial effluents and domestic sewage, resulting from the city's continuous urban expansion and the inadequacy of its sanitary sewage system. This study focused on an analysis of the efficiency of PGα21Ca and quaternary ammonium tannate, water purification products, based on coagulation-flocculation and sedimentation tests, followed by treatment with a hydrodynamic cavitation reactor associated with ozonation in the treatment of Tietê River water. The removal of turbidity, apparent color, and chemical oxygen demand (COD) were evaluated. Jar testing assays were conducted, and the best turbidity removal rates were obtained with a concentration of 300 mg L^{-1} for PGα21Ca and 150 mg L^{-1} for quaternary ammonium tannate. The coagulation-flocculation treatment removed approximately 93% of turbidity for both coagulants. After combining coagulation-flocculation with hydrodynamic cavitation with ozonation, the final COD removal rate applying PGα21Ca was 47.63% in 1 hour of reaction, while that of quaternary ammonium tannate was 40.13% in 2 hours of reaction. Although the results appear to indicate the superior performance of PGα21Ca, it should be noted that the treatment with quaternary ammonium tannate also provided good results in reducing turbidity, COD, and apparent color, using a smaller dose of this coagulant and that its use may be more advantageous from an environmental point of view, due to its natural composition.

Key words: γ-polyglutamic acid, quaternary ammonium tannate, coagulation-flocculation tests, hydrodynamic cavitation, ozonation, urban river.

INTRODUCTION

Brazil's national environmental agency, CONAMA – Conselho Nacional do Meio Ambiente, classifies the stretch of the Tietê River that flows through the metropolitan region of São Paulo as a class four waterway (Brasil 2005), i.e., its function is limited to navigation and landscape harmony. Since 1992, the São Paulo state government has been discussing the possible restoration of the river throughout the state, aiming to strongly improve basic sanitation services and to ban the discharge of untreated domestic and industrial sewage into the river. The Metropolitan Region of São Paulo (MRSP) is located in southeastern Brazil and is one of the world's largest urban agglomerations. Rapid economic development and intense urbanization throughout the country have led to serious problems in the MRSP, with a high demand for water supply, the need for more efficient sewage treatment, and significant losses in the environmental quality of its surface water bodies (Campos et al. 2019).

Urban rivers are strongly affected by land use and occupation, irregular discharge of domestic and industrial effluents, and leaching of agricultural compounds. These factors can rapidly lead to water eutrophication and changes in limnological variables (total phosphorus, dissolved oxygen, biochemical oxygen demand, thermotolerant coliforms, nitrite), resulting in loss of water quality (Rietzler et al. 2018, Azadi et al. 2019, Cardoso-Silva et al. 2021).

Several processes and unit operations, such as coagulation-flocculation, sedimentation, oxidation, disinfection, and others, are among the most used for water and wastewater treatment. Inorganic salts such as aluminum sulfate ($Al_2(SO_4)_3$), ferric chloride ($FeCl_3$), ferrous sulfate ($FeSO_4$), and polyaluminum chloride (PAC), whose molecular formula is $Al_n(OH)_mCl_{3n-m}$, are often used as coagulants for these purposes. However, the use of this type of reagent is associated with a large amount of sludge production (Nti et al. 2021). Additionally, due to concerns about non-degradability, and left-over residues, natural coagulants have been studied as a promising environmentally friendly alternative (Gautam & Saini 2020).

The main advantages of natural coagulants over inorganic and synthetic ones include the ready availability of raw material, which is often renewable; its low corrosiveness in water distribution systems; the fact that the volume of sludge generated in the process is up to five times lower; and their biodegradability, factor that mitigates the negative environmental impacts. In general, this type of coagulant poses no risks to human and animal health, and its development is related to environmentally sustainable technologies (Teixeira et al. 2017).

Gamma-polyglutamic acid (γ-PGA) is a water-soluble, biodegradable, biocompatible, and non-toxic anionic biopolymer obtained from bacteria of the genus *Bacillus* through fermentative processes (Sung et al. 2005, Bajaj & Singhal 2011, Campos et al. 2020, 2021). γ-PGA has been used in water treatment because it increases its flocculation activity, among other properties (Shih & Van 2001, Campos et al. 2016, 2019). Kunioka (2004) demonstrated that combining polyaluminum chloride and γ-PGA effectively removes turbidity. Wu & Ye (2007) developed a biopolymer with flocculation activity in which γ-PGA is one of the main components. Campos et al. (2023) synthesized Fe_3O_4 magnetic nanoparticles coated with γ-polyglutamic acid to remove metoprolol from water.

Quaternary ammonium tannate (QAT) is an extract of vegetable origin, recommended for the treatment of water and effluents. Chemically speaking, vegetable tannin is a phenolic polymer, whose monomer structure is flavin-3-ol. Cationic organic polymers are made through the mechanism proposed by Mannich (Beltran-Heredia et al. 2010, Reed & Finck 1997, Mangrich et al. 2014).

In terms of oxidation, hydrodynamic cavitation (HC) has been used as a promising alternative in the treatment and disinfection of complex organic effluents, chemical products, and refractory organic compounds. Oxidation is caused by bubble collapse generated by a Venturi tube, with both chemical and mechanical effects that contribute to the degradation of contaminants. The geometric shape of this tube generates micro or nanobubbles, whose collapse generates hydroxyl radicals due to the reaction between aqueous compounds and oxygen (Fedorov et al. 2021, Gągol et al. 2018, Gogate 2002). Among the different techniques for producing cavitation, HC has been demonstrated to offer maximum active zones within the entire capacity and higher energy efficiency. In addition, it is easier to construct the configuration including the constrictions or the cavitating devices such as Venturi and orifice plates (Thanekar et al. 2018, Thanekar & Gogate 2019, Mohod et al. 2023).

Additionally, ozone (O_3) is a chemical reagent with high oxidative potential (2.07 V), its use is associated with the formation of hydroxyl radicals, leading to the oxidation of organic compounds when applied in solution. There is no sludge formation and any excess reagent is decomposed into oxygen and water (Wang et al. 2022). The application of O_3 as an oxidant is considered a convenient and eco-friendly technology, due to its low initial investment, minimal space requirement, and low operational costs. However, limitations of this technology include its short mid-life and issues with mass transfer (Wang et al. 2020). One alternative to address the mass transfer problem is to increase the turbulent zone, thereby enhancing the contact between the reagent and the pollutant particles (Fu et al. 2024). In this context, the association of HC with the O_3 (HC+O_3), is described as a synergistic process for the removal of refractory pollutants, combining two oxidative processes while mitigating the limitations with the gaseous reagent, such as selectivity and low solubility in water (Wang et al. 2022).

The demand for technology combinations in water and wastewater treatment, such as coagulation-flocculation paired with additional steps like advanced oxidation, has increased due to stricter regulations regarding pollutant concentrations in natural waters (Chen et al. 2021). The combination of coagulation-flocculation with HC+O_3 has been studied in works such as those by Qiao et al. (2023) and Domingos et al. (2023) for leachate treatment, and by Saputra et al. (2021) for textile wastewater treatment. These studies emphasize that the coagulation-flocculation pre-treatment aims to enhance the efficiency of the HC+O_3 reaction as the primary treatment method.

Given the promising potential of natural products to act as coagulants, this work focuses on evaluating the efficiency of the action of a hybrid coagulant and an organic one in removing apparent color and turbidity as a pre-treatment from raw water from the Tietê River, sampled in the city of São Paulo. Subsequently, the sequence of the coagulation-flocculation process followed by the treatment with HC+O_3 was evaluated in terms of COD reduction, aiming to verify the applicability of combining these processes.

MATERIALS AND METHODS

Jar tests were carried out using a jar test apparatus (PoliControl Instr. Anal.) equipped with six 2-liter jars with maximum agitation of 300 rpm. The raw and treated water parameters were assessed using the following equipment: turbidity was measured employing a Hach Tu5200 turbidimeter; pH was measured by the potentiometric method using a Thermo Scientific Orion DUAL STAR meter under normal temperature conditions; zeta potential and conductivity were measured using a Malvern Zetasizer Nano – ZS90 zeta potential analyzer; and COD was determined using a spectrophotometer HACH DR 5000. The analysis of turbidity, apparent color, and COD were performed in triplicate. The tests were conducted following the procedures of the Standard Methods for the Examination of Water and Wastewater (APHA 2012).

Raw water cations were determined using inductively coupled plasma optical emission spectroscopy (ICP-OES), with a Perkin Elmer Optima 7300 DV ICP-OES Spectrometer. Anions were determined simultaneously by high-performance liquid chromatography (HPLC), employing a Perkin-Elmer model 430D chromatograph.

The PGa21Ca powder came from Nippon Poly-Glu Co. Ltd., recommended for use of 50 to 100 mg L^{-1}. The product’s typical flocculation time, whose initial turbidity of 100 NTU is 15 minutes, results in a final turbidity of <1 NTU. The coagulant was added directly to the jars, as recommended by the manufacturer, to prevent reactions with other components of the formulation, such as calcium and aluminum sulfates, forming insoluble polyglutamate (Campos et al. 2019).

The second commercial coagulant, TANFLOC® SG, is a cationic organic polymer of essentially vegetable origin, produced from *Acacia mearnsii*, commonly known as black wattle. This coagulant has a low molecular weight, and according to the manufacturer, it does not alter the pH because it does not consume the alkalinity of the medium (Tanac 2003).

The HC+O_3 treatment was performed in a 35-liter acrylic storage tank coupled to a WEG pump (0.25 HP/3480-3500 rpm) to recirculate the fluid (batch system). All the connections used here were made of ¾" white PVC, ¾" crystal pipe, and ¾" Venturi intake tube, in addition to a 10 mm diameter conical concentric orifice plate, as described by Bis et al. (2015), operating under a pressure of 0.5 bar or 0.51 kgf cm^{-2}, with O_3 production by an Oxclen generator, with nominal flux of 3g h^{-1}.

RESULTS AND DISCUSSION

The Tietê River flows solely through the state of São Paulo (Figure 1), starting at its source in the Serra do Mar Mountain range in the municipality

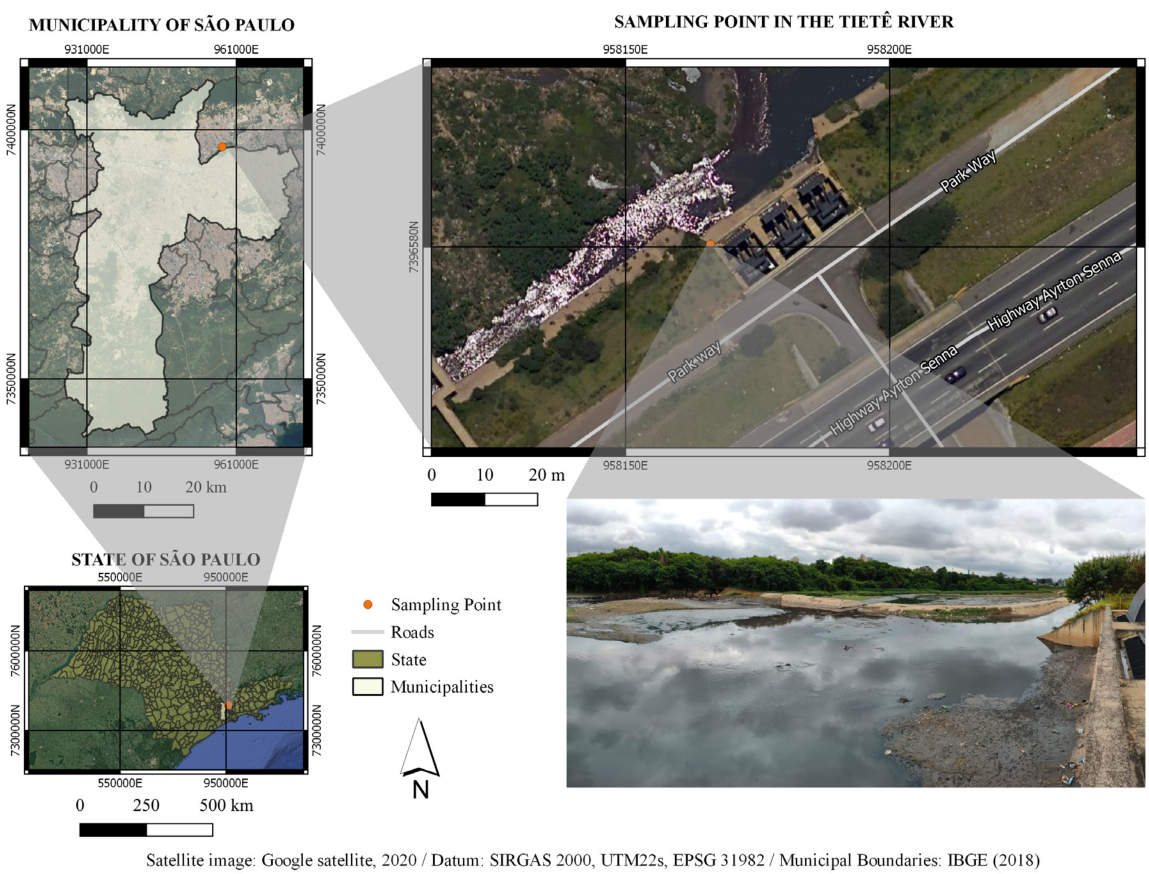

Figure 1. Location of the sampling point on the Tietê River, in the city of São Paulo, where the dam is located in Tietê Ecological Park. At this point, the dark water gives off a fetid smell and is home to a large bird population. The site also contains large amounts of solid waste, including PET bottles and other objects.

of Salesópolis. Its course follows a southeast-northwest direction for more than 1000km, until it flows into the Paraná River, in the municipality of Itapura, bordering a total of 62 municipalities. The Tietê River is divided into three stretches: the Upper, Middle, and Lower Tietê. This division is based on the physiography of the state of São Paulo, as described by Ab'Saber & Bernardes (1958). The basin of the Upper Tietê covers an area of 5,720 km² (Keck & Jacobi 2003), extending from the river's headwaters in Salesópolis to the municipality of Pirapora do Bom Jesus, passing through the metropolitan region of São Paulo (MRSP) (FUSP 2008). In the Upper Tietê basin, the river undergoes significant impacts along its 200 km length, with the discharge of enormous loads of industrial and domestic waste into this stretch, much of it untreated (Campos 2008).

This work verified the optimal concentration of chemical hybrid (PGα21Ca) and natural coagulants (TAQ) for turbidity and apparent color. The experiments were carried out employing jar tests. The jar test assays were carried out in a completely randomized design. An analysis of variance (ANOVA) was performed and the mean turbidity removal rates were compared using the Tukey test. After determining the best conditions for each reagent, new series were performed associating the coagulation-flocculation with the HC+O_3 process, verifying the COD value reductions.

Table I describes the physicochemical parameters of the raw and treated water from the Tietê River in the dry season, comparing them with the guidelines and legal limits established by CONAMA, Brazil's National

Table I. Physicochemical parameters of raw water from the Tietê River in the dry season.

Parameters	Unit	This study	CONAMA 357/2005 Class 3
Cl^-	mg L^{-1}	144	250
NO_3^-	mg L^{-1}	8.7	10
HCO_3^-	mg L^{-1}	95	0.15
SO_4^{2-}	mg L^{-1}	82	250
P_{total}	mg L^{-1}	5.6	0.15
Na^+	mg L^{-1}	152	*
K^+	mg L^{-1}	25.3	*
Ca^{2+}	mg L^{-1}	26.4	*
Mg^{2+}	mg L^{-1}	18.7	0.5
pH	-	7.4	6.0 – 9.0
Electrical conductivity	µS cm^{-1}	1653	*
Dissolved oxygen	mg L^{-1}	2.63	≥ 4
Thermotolerant Coliform	NMP/100 mL	2.1 x 10^7	2500
Turbidity	NTU	110.7±4.4	100
Chemical Oxygen Demand (COD)	Mg O_2 L^{-1}	145.5±1,9	*
Apparent color	mg Pt Co L^{-1}	64.1±0.9	75
TDS	mg L^{-1}	1057	*

***limit not specified.**

Environmental Agency, under its Resolution No. 357/2005 for Class 4 surface waters, and USEPA Surface Quality Criteria for Class 2 and Class 4 waters (USEPA 2018). The poor quality of Tietê River water is indicated by its high turbidity and intense odor of gases such as CH_4 and H_2S.

In the first test conducted with PGα21Ca, concentrations of 50 to 100 mg L^{-1} were used, as proposed by Campos et al. (2016). Removal was partial, with visibly insufficient formation of flocs, and the water after sedimentation was still turbid. The results indicated that the values of turbidity of the decanted water samples were more than 40 NTU, with a maximum removal rate of approximately 65%. Therefore, larger concentrations, more specifically from 100 to 600 mg L^{-1} of PGα21Ca, were used in subsequent assays, visually showing better efficient flocculation in the range of 400 to 600 mg L^{-1}. Table II describes the results of these assays.

In the tests with QAT reagent, four concentrations were used: 50, 100, 150, and 200 mg L^{-1}, as described in the works of Guibal & Roussy (2007), Beltrán-Heredia et al. (2010) and Flores et al. (2023). The turbidity removal of the decanted water was visually satisfying, especially for the concentrations above 150 mg L^{-1}, however, the floc formation appeared to be slower and was more dependent on decantation time than in samples treated with more than 400 mg L^{-1} of PGα21Ca. Table III describes the results of these tests. All the assays were carried out in triplicate, and the two reagents showed little change in terms of pH level, reaching pH 7.0 in the treatment with 600 mg L^{-1} of PGα21Ca and pH 6.9 in that with 200 mg L^{-1} of QAT.

The maximum average turbidity removal rate was achieved with 400 mg L^{-1} of PGα21Ca, which provided a 97.44% reduction in turbidity. The best average removal rate, 95.08%, was achieved with 200 mg L^{-1} of QAT. For comparison, Carvajal-Zarrabal et al. (2012) obtained a turbidity reduction of 70% during the treatment of ethanol distillation wastewater with 250 to 300 mg L^{-1} of PGα21Ca. Meanwhile, Alves et al. (2022) obtained a reduction of 98% in turbidity

Table II. Residual turbidity levels reached in treatments with PGα21Ca.

Treatment	Concentration of PGα21Ca (mg L^{-1})	Residual turbidity (NTU)/Repetition				Mean turbidity removal (%)
		1	2	3	Mean	
T_1	100	41.4	39.6	34.5	38.5 ± 3.57	65.23
T_2	200	22.2	17.9	12.4	17.5 ± 4.91	88.80
T_3	300	7.63	4.39	8.33	6.78 ± 2.10	93.88
T_4	400	3.29	2.71	2.51	2.83 ± 0.40	97.44
T_5	500	4.18	2.56	2.39	3.04 ± 0.98	97.25
T_6	600	3.23	4.23	3.18	3.54 ± 0.59	96.80

Table III. Residual turbidity levels reached in treatments with QAT.

Treatment	Concentration of QAT (mg L^{-1})	Residual turbidity (NTU) / Repetition				Mean turbidity removal (%)
		1	2	3	Mean	
T_1	50	42.5	34.2	39.4	38.7 ± 4.19	65.05
T_2	100	12.3	13.9	18.8	15.1 ± 3.38	86.46
T_3	150	4.34	9.81	8.4	7.52 ± 2.84	93.21
T_4	200	3.19	8.75	4.4	5.45 ± 2.91	95.08

during the treatment of the grain processing sector, using 200 mg L^{-1} of QAT associated with a cationic hemicelluloses coagulant.

As observed in Tables II and III, both coagulants initially caused an increase in turbidity removal in response to increasing concentration of these reagents, until the curve leveled out. The results were interpreted based on statistical analysis of variance (ANOVA) and Tukey's test to determine the differences in performance as a function of the concentration of coagulant. ANOVA with a *p*-value of less than 0.05 indicates that the residual turbidity was significantly affected by the treatments. The mean results of the treatments were then compared by the Tukey test, which revealed their significant differences. Figures 2 and 3 depict the means of the treatments determined by the Tukey test, where different letters indicate a significant difference of 5% between the means.

As can be seen, in the treatment with PGα21Ca, the smallest dose without a significant contrast with the best removal rate was 300 mg L^{-1}, while, for the treatment with QAT, the lowest dose without significant difference with other turbidity means was 150 mg L^{-1}. These concentrations were therefore used in the subsequent steps. The coagulation-flocculation step was carried out on new samples of raw water under the same aforementioned conditions. The supernatant resulting from the coagulation-flocculation of each batch with its respective coagulant was then placed in the HC+O_3 reactor, for the tertiary treatment stage. As the main variable, the COD was measured in 1 and 2 hours of reaction. The final COD and the percentual reduction for both associations of technologies are expressed in Table IV.

It is possible to note, by the results expressed in Table IV, that treatment with HC+O_3, for the samples pre-treated with PGα21Ca, resulted in almost the same reduction of COD for both the duration of 1 and 2 hours, from 47.63 to 49.00% (2.87% of increase), therefore, there were no apparent benefits from more than 1 hours of reaction. On the other hand, the reduction of COD increased from 29.48% to 40.13% (36.12%) from 1 to 2 hours of reaction, showing that, for this association, the duration of 2 hours improved the COD reduction. In terms of the comparison of the two processes, the *t*-test was used to compare the residual COD of the treatment with

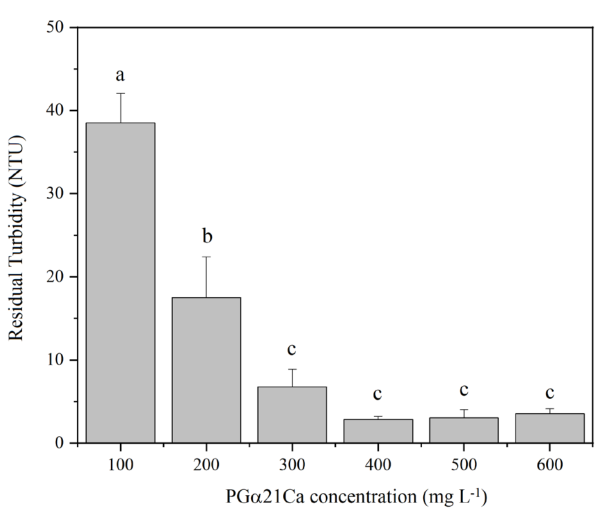

Figure 2. Block chart indicating the residual turbidity achieved with PGα21Ca, and comparison of means by Tukey's test at 5% significance.

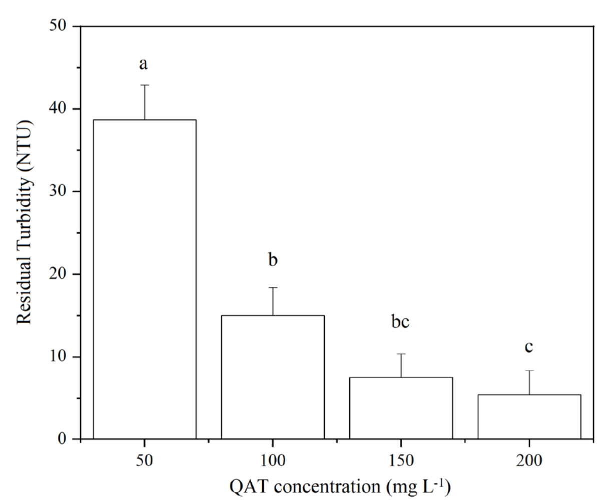

Figure 3. Block chart indicating the residual turbidity achieved with QAT, and comparison of means by Tukey's test at 5% significance.

PGα21Ca coagulation followed by one hour of HC+O_3, and the coagulation using QAT followed by two hours of HC+O_3. The results showed that, with a significance of 5%, the sequence of PGα21Ca coagulation-flocculation followed by the HC+O_3 reaction for 1 hour resulted in lower final COD.

When observed alone the percentage of COD reduction, of 47,63% and 40,13% for the PGα21Ca coagulation-flocculation followed by 1 hour of HC+O_3 and QAT pre-treatment followed by 2 hours of HC+O_3 respectively, it may appear relatively low compared to other studies. However, it is crucial to note that different initial conditions for water and wastewater in terms of COD can lead to misinterpretation. For instance, Abilaji et al. (2023), achieved a reduction of up to 90% while treating textile wastewater with a photo-electrochemical process followed by biodegradation, however, the initial COD was 4150 mg O_2 L^{-1} that resulted in the final COD of around 500 mg O_2 L^{-1}, still significantly higher than the observed in this work. Similarly, Kalia et al. (2023) treated a textile effluent with an initial COD of 1920 mg O_2 L^{-1} by the association of electrocoagulation, laccase treatment, and activated charcoal, with a percentual reduction of 86,5%, obtaining a final COD of 260 mg O_2 L^{-1}, again higher than the initial COD of the Tietê River raw water. As examples of studies that dealt with lower final COD, Nugroho et al. (2019) obtained a 60% COD reduction in artificially contaminated river water treatment through electrocoagulation, and a minimum value of 108 mg O_2 L^{-1}, and Shi et al. (2023) referenced the treatment of coking water by adsorption and oxidation, which was not satisfactory in reaching a final COD lower than 80 mg O_2 L^{-1}, thus, not satisfying the Chinese regulation for coking chemistry disposal. It is observed, then, that lower values of COD are related to a lower percentage of reduction due to non-degradable behavior.

The term “hard COD” is employed to refer to non-biodegradable COD or refractory COD, and studies in this field reinforce that advanced efficient treatments are becoming increasingly important and demanded (Feng et al. 2023). Among the works that obtained final COD lower than 100 mg O_2 L^{-1}, Sun et al. (2020), observed a decrease from 118.5 to 61.5 mg O_2 L^{-1} of COD with a treatment based on coagulation-flocculation followed by synchronized adsorption and oxidation; Shi et al. (2023) reduced the COD of pre-treated coking wastewater from 180 to 63 mg O_2 L^{-1} using catalytic ozonation; and Wang et al. (2020) obtained a 36% reduction using HC+O_3 during 30 minutes, treating wastewater with initial COD between 56-68 mg O_2 L^{-1}, resulting in a treated sample with around 40 mg O_2 L^{-1} COD. While the work of Sun et al. (2020) presents a satisfactory application of coagulation-flocculation as

Table IV. COD values reached after the water treatment with coagulation-flocculation with PGα21Ca and QAT followed by HC+O_3 reactor.

Coagulant	**QAT**		**PGα21Ca**	
Duration of HC+O_3 (hours)	1	2	1	2
Final COD (mg O_2 L^{-1})	103.4	86.9	75.3	74.3
	102.8	87.5	76.3	74.6
	101.6	87.0	77.0	73.7
Mean	102.6 ± 0.91	87.1 ± 0.32	76.2 ± 0.85	74.2 ± 0.46
Decrease in COD (%)	29.48	40.13	47.63	49.00

pre-treatment, both Wang et al. (2020) and Shi et al. (2023) observed efficient treatment with improved ozonation, through catalysis and the association with HC. Wang et al. (2020) also described that the HC+O_3 process resulted in up to six times higher mineralization of pollutants compounds, while Shi et al. (2023) observed a reduction of COD of 38% when employing O_3 exclusively, in comparison with a reduction of 65% in the catalytic ozonation, exemplifying the advantage of combining O_3 in synergistic processes.

Finally, Table V presents the Tietê River raw water parameters, in comparison with the treated water parameters, for both possibilities of associations studied. The COD obtained for both technologies is close to the limit for reuse water Class 4 in Brazilian normative, for values lower than 75 mg O_2 L^{-1}, which allows its use for non-potable purposes. As for the other parameters, the treated water for both associations of technologies resulted in values already under the limit for reuse water for non-potable purposes in the state of São Palo, with turbidity lower than 5 NTU, and apparent color lower than 30 mg Pt Co L^{-1} (São Paulo 2020, ABNT 1997).

CONCLUSIONS

The development of new coagulants based on natural biodegradable raw materials has been steadily gaining momentum at research centers, representing an environmentally sustainable technology that follows the concept of using eco-friendly materials. Given the promising potential of natural products as sources of biocompounds, this study tested the use of a hybrid soy-based coagulant and a second coagulant extracted from the bark of the black wattle tree. Another major concern is that rivers flowing through large urban centers are exposed to the discharge of highly pollutant loads, causing them to lose more and more of their social significance. In this context, PGα21Ca and quaternary ammonium tannins are used as coagulants for wastewater treatment. Raw water samples from the Tietê River were subjected to the coagulation-flocculation process, resulting in a turbidity removal rate of 93.88% when using 300 mg L^{-1} of PGα21Ca and 93.21% when using 150 mg L^{-1} of QAT. The combination of coagulation-flocculation using the two coagulants and HC+O_3 resulted in a COD removal rate of 47.63% with PGα21Ca and 40.13% with QAT. The final COD values achieved highlight the combination of coagulation as pre-treatment with both coagulants, followed by oxidation through HC+O_3, as a potential alternative for reducing COD to values lower than 90 mg O_2 L^{-1}. The overall turbidity and COD indicated that PGα21Ca combined with HC+O_3 for 1 hour resulted in a better performance. However, it should be noted that treatment with QAT also provided interesting results, indicating that its use is potentially feasible depending on the intended use of water treated with it. In addition, the concentration of QAT that provided satisfactory results was lower than the concentration of PGα21Ca, and since QAT is a biopolymer obtained from natural

Table V. Physicochemical parameters Tietê River raw water and treated water through treatments with QAT e 2 hours of HC+O_3, and with PGα21Ca and one hour of HC+O_3.

Parameter	Raw water	PGα21Ca + 1h HC+O_3	QAT + 2h HC+O_3
COD (mg O_2 L^{-1})	145.5 ± 1.91	76.2 ± 0.85	87.1 ± 0.32
Turbidity (NTU)	110.75 ± 4.43	0.87 ± 0.015	4.08 ± 0.03
Apparent color (mg Pt Co L^{-1})	64.10 ± 0.94	17.4 ± 0.2	17.1 ± 0.11

sources, its use may be more environmentally friendly than that of the hybrid coagulant.

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All the authors of this article participated in collecting water samples from the Tietê River in São Paulo. Valquíria Campos guided and oversaw the fieldwork and created the dummy manuscript. Diego Gouveia Marques and Janaína M.F. Domingos and Marcelo Antunes Nolasco conducted the chemical tests. Diego G. Marques also carried out the statistical treatment of the data. Leandro Cardoso de Morais participated in the chemical tests, and in the creation of Table I. All the authors took part in the composition of the manuscript and in the discussion section, whose content they were in agreement with.