EVALUATION OF A CATIONIC POLYSACCHARIDE COAGULANT FOR OPTIMIZING THE TREATMENT OF OILY EFFLUENTS FROM THE MANAUS REFINERY (REAM) – QQS COA S

AVALIAÇÃO DE COAGULANTE POLISSACARÍDICO CATIÔNICO PARA A OTIMIZAÇÃO DO TRATAMENTO DE EFLUENTES OLEOSOS DA REFINARIA DE MANAUS (REAM) – QQS COA S

EVALUACIÓN DE UN COAGULANTE POLISACÁRIDO CATIÓNICO PARA OPTIMIZAR EL TRATAMIENTO DE EFLUENTES OLEOSOS DE LA REFINERÍA DE MANAUS (REAM) – QQS COA S

https://doi.org/10.56238/sevened2026.008-159

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ABSTRACT

This technical-scientific report details the results of a treatability study conducted with effluents from the Manaus Refinery (REAM), focusing on the evaluation of a high-performance organic coagulant, QQS COA S, a starch-based polysaccharide modified with cationic groups. The main objective was to compare its efficiency with the conventional treatment of the refinery, which employs a tannin-based coagulant with a daily consumption of approximately 200 kg, aided by about 2 kg of a flocculant polymer. The assays, carried out in Jar Test equipment, simulated the coagulation and flocculation conditions, revealing that the QQS COA S, in dosages in the range of 10 to 30 ppm, promotes a clarification and phase separation (water/oil/solids) visually superior to that obtained with approximately 33,333 ppm of the tannin coagulant. This dose reduction, greater than 99% (or 1,000 times), is justified by the macromolecular structure of cationic starch and its mechanisms of action, which include charge neutralization and formation of interparticle bridges, efficient in breaking the oil-in-water emulsion. The study concludes that the replacement of tannin by cationic starch represents a strategic opportunity for REAM, with the potential for a drastic reduction of operating costs, logistics optimization, and a significant advance in environmental sustainability, aligning the practice with the fundamental theory of colloid and polymer chemistry and encouraging the local production of high value-added inputs.

Keywords: Effluent Treatment. Oil Refinery. Oily Water. Organic Coagulants. Cationic Starch.

RESUMO

Este relatório técnico-científico detalha os resultados de um estudo de tratabilidade conduzido com efluentes da Refinaria de Manaus (REAM), focando na avaliação de um coagulante orgânico de alta performance, o QQS COA S, um polissacarídeo à base de amido modificado com grupamentos catiônicos. O objetivo central foi comparar sua eficiência com o tratamento convencional da refinaria, que emprega um coagulante à base de tanino com um consumo diário de aproximadamente 200 kg, auxiliado por cerca de 2 kg de um polímero floculante. Os ensaios, realizados em equipamento Jar Test, simularam as condições de coagulação e floculação, revelando que o QQS COA S, em dosagens na faixa de 10 a 30 ppm, promove uma clarificação e separação de fases (água/óleo/sólidos) visualmente superior à obtida com aproximadamente 33.333 ppm do coagulante de tanino. Esta redução de dosagem, superior a 99% (ou 1.000 vezes), é justificada pela estrutura macromolecular do amido catiônico e seus mecanismos de ação, que incluem neutralização de carga e formação de pontes interpartículas, eficientes na quebra da emulsão óleo-em-água. O estudo conclui que a substituição do tanino pelo amido catiônico representa uma oportunidade estratégica para a REAM, com potencial para uma drástica redução de custos operacionais, otimização logística, e um avanço significativo em sustentabilidade ambiental, alinhando a prática com a teoria fundamental da química de coloides e polímeros e incentivando a produção local de insumos de alto valor agregado.

Palavras-chave: Tratamento de Efluentes. Refinaria de Petróleo. Água Oleosa. Coagulantes Orgânicos. Amido Catiônico.

RESUMEN

Este informe técnico-científico detalla los resultados de un estudio de tratabilidad realizado con efluentes de la Refinería de Manaus (REAM), centrado en la evaluación de un coagulante orgánico de alto rendimiento, QQS COA S, un polisacárido a base de almidón modificado con grupos catiónicos. El objetivo principal fue comparar su eficiencia con la del tratamiento convencional de la refinería, que emplea un coagulante a base de tanino con un consumo diario de aproximadamente 200 kg, asistido por aproximadamente 2 kg de un polímero floculante. Las pruebas, realizadas en un aparato de prueba de jarras, simularon las condiciones de coagulación y floculación, revelando que QQS COA S, en dosis de 10 a 30 ppm, promueve una clarificación y separación de fases (agua/aceite/sólidos) visualmente superior a la obtenida con aproximadamente 33.333 ppm del coagulante a base de tanino. Esta reducción de dosis, superior al 99% (o 1000 veces), se justifica por la estructura macromolecular del almidón catiónico y sus mecanismos de acción, que incluyen la neutralización de cargas y la formación de puentes interpartículas, eficientes para romper la emulsión de aceite en agua. El estudio concluye que la sustitución del tanino por almidón catiónico representa una oportunidad estratégica para REAM, con el potencial de una drástica reducción de costos operativos, optimización logística y un avance significativo en la sostenibilidad ambiental, alineando la práctica con la teoría fundamental de la química de coloides y polímeros e impulsando la producción local de insumos de alto valor añadido.

Palabras clave: Tratamiento de Aguas Residuales. Refinería de Petróleo. Aguas Aceitosas. Coagulantes Orgánicos. Almidón Catiónico.

1 INTRODUCTION

The treatment of effluents in oil refineries is a critical operation that aims to mitigate the environmental impact of the industry and ensure compliance with strict environmental regulations, such as CONAMA Resolution No. 430/2011 in Brazil [1]. These effluents, commonly referred to as oily waters, are complex oil-in-water (O/W) emulsions, stabilized by natural surfactants and process additives, and loaded with suspended solids, dissolved organic compounds (phenols, benzene, polyaromatic hydrocarbons - PAHs), and inorganic ions [2, 3]. The breakdown of this emulsion and the removal of the dispersed phase are the primary objectives of the physicochemical treatment, where the coagulation-flocculation step plays a central role [4].

The Manaus Refinery (REAM) currently uses a tannin-based organic coagulant. Although natural coagulants are preferable to inorganic metal salts (e.g., aluminum sulfate, ferric chloride) for reasons of sustainability and lower generation of toxic sludge [5], the application in REAM, as informed by the operation, represents a high daily consumption. Assuming the new flow rate of **150 m^3/h** (3,600 m^3/day), the tannin dosage (200 L/day, density ~1 kg/L) is approximately 56 ppm. Such dosing not only exponentially raises operating costs (OPEX), but also overloads the system with an additional organic load, complexifies logistics and product handling, and can negatively impact the management of the generated sludge [6].

In this scenario, the search for more efficient and sustainable alternatives is imperative. This report presents an in-depth study on the application of QQS COA S, a cationic starch-based polysaccharide coagulant, as a high-performance solution for the treatment of REAM effluent. The central hypothesis is that the unique macromolecular structure of cationic starch, combined with its high charge density, allows for much more efficient colloidal destabilization and particle agglomeration, validating in practice what the theory of polymer and colloid chemistry predicts. The study aims not only to demonstrate the technical and economic superiority of cationic starch, but also to provide a robust scientific basis that justifies the technological transition and fosters the discussion about the strategic potential of local production of this high value-added input in the Amazon region.

2 THEORETICAL FOUNDATION

To understand the magnitude of the results obtained, it is essential to delve into the chemical and physical principles that govern the coagulation of oily effluents and the molecular structure of the coagulants in question.

2.1 CHEMISTRY OF ORGANIC COAGULANTS

2.1.1 Cationic Starch (QQS COA S)

Starch is a natural, abundant, biodegradable polysaccharide composed of D-glucose units. It consists of two macromolecules: amylose (linear chain) and amylopectin (branched chain). In its natural state, starch has no significant ionic charge, which makes it ineffective as a primary coagulant [7].

The transformation into a high-performance coagulant occurs through cationization, a chemical reaction that introduces positively charged functional groups into the starch structure. The most common process uses a reagent such as 3-chloro-2-hydroxypropyltrimethylammonium chloride (CHPTAC), which reacts with the hydroxyl (-OH) groups of starch in an alkaline medium [8, 9].
Starch Cationization Reaction:
Step 1: Formation of the Epoxide Reagent (EPTAC) CHPTAC, in the presence of an alkaline catalyst (NaOH), forms a more reactive Epoxide intermediate, 2,3-epoxypropyltrimethylammonium chloride (EPTAC).

ClCH2CH(OH)CH2N+(CH3)3 Cl- + NaOH→CH2(O)CH-CH2N+(CH3)3 Cl- + NaCl + H2O
(CHPTAC) → (EPTAC) (1)

Step 2: Starch Etherification The epoxide ring of the EPTAC is then opened by the nucleophilic attack of a hydroxyl group of the starch molecule, forming a stable ether bond and attaching the quaternary ammonium cationic group **$—N^{+}(CH_3)_3$** to the polymer chain.

Starch-OH + CH2(O)CH-CH2N+(CH3)3 Cl- → Starch-O-CH2CH(OH)CH2N+(CH3)3 Cl-
(Cationic Starch) (2)

The result is a high molecular weight macromolecule with multiple cationic sites, an ideal combination for coagulation and flocculation mechanisms

2.1.2 Tannin

Tannins are natural polyphenols of plant origin. Its structure is based on aromatic rings with multiple hydroxyl groups (-OH). To act as coagulants, tannins also need to be chemically modified to acquire cationic charge, usually through a Mannich reaction, which introduces amino groups into the structure [5, 10]. Although effective, tannins possess an intrinsically lower molecular weight compared to starch polymers, which may limit their ability to form efficient interparticle bridges, requiring higher dosages to achieve destabilization [6].

2.2 COAGULATION AND FLOCCULATION MECHANISMS IN OILY EFFLUENTS

The stability of an oil-in-water emulsion, such as REAM effluent, is maintained primarily by electrostatic repulsion between the oil droplets, which have a negative surface charge (negative zeta potential) [4]. The coagulation-flocculation process aims to break this stability through four main mechanisms [11]:

1. Electrical Double Layer Compression: The high concentration of coagulant positive ions in the aqueous medium compresses the diffuse electrical double layer around the oil droplets, reducing the repulsion barrier.
2. Adsorption and Load Neutralization: This is the primary mechanism for cationic coagulants. The **$—N^{+}(CH_3)_3$** groups of cationic starch adsorb directly to the negative surface of the oil droplets and suspended solids, neutralizing their charge. When the zeta potential approaches zero, the van der Waals force of attraction predominates, and the particles begin to aggregate.
3. Adsorption and Bridging: The long polymeric chains of cationic starch adsorb simultaneously on multiple particles (oil droplets, solids), forming physical "bridges" that bind them together into microflocs. This mechanism is particularly effective for high molecular weight polymers such as starch and explains why the QQS COA S demonstrated good flocculation even without an auxiliary flocculant on one of the test days.
4. Sweep Flocculation: This occurs when the coagulant is added in excess and precipitates as hydroxide. The colloidal particles are then "swept up" and entangled by this precipitated mass. This mechanism is most common with inorganic coagulants and is not the primary mode of action for organic polymers at optimal dosages.

2.3 CATIONIC STARCH AS A HIGH-PERFORMANCE AGENT

The theoretical superiority of cationic starch over tannin for this type of effluent lies in the synergistic combination of high molecular weight and high charge density. While both can neutralize fillers, starch's ability to form long, robust bonds is far superior, resulting in the formation of larger, stronger flakes with a much smaller amount of product. Practice, as demonstrated in the trials, confirmed the theory: the efficiency of the cationic starch bridging mechanism allowed a dose reduction of more than 99%, a feat that load neutralization alone, with a lower molecular weight coagulant such as tannin, cannot achieve.

3 METHODOLOGY

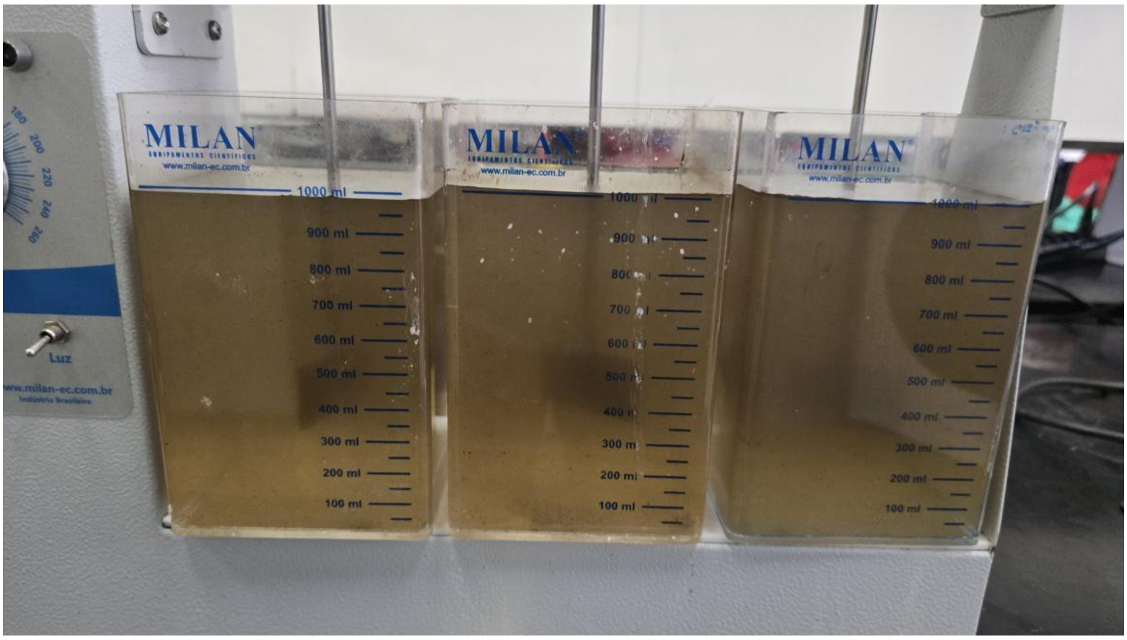
The treatability tests were conducted on a benchtop, following a standard jar test protocol (Jar Test), which is the most widespread methodology to simulate and optimize coagulation and flocculation processes on a laboratory scale.

3.1 MATERIALS AND EQUIPMENT

- Jar Test Equipment: Jar Test Milan Scientific Equipment (JTC), with multi-jar capability and stirring speed control.
- Jugs: Acrylic beakers with a capacity of 1000 mL.
- Dosing Instruments: Syringes for dosing chemical reagents.
- Sample: Raw effluent from the Manaus Refinery (REAM).
- Chemical Reagents:
  - Organic Coagulant: QQS COA S (CATIONIC STARCH), supplied by QQS Chemicals Trade.
  - Auxiliary Flocculant: QQS FLOC (cationic polymer already in emulsion and with open chain).

Figure 1

Products evaluated in the assay: QQS COA S Coagulant and QQS FLOC Flocculant



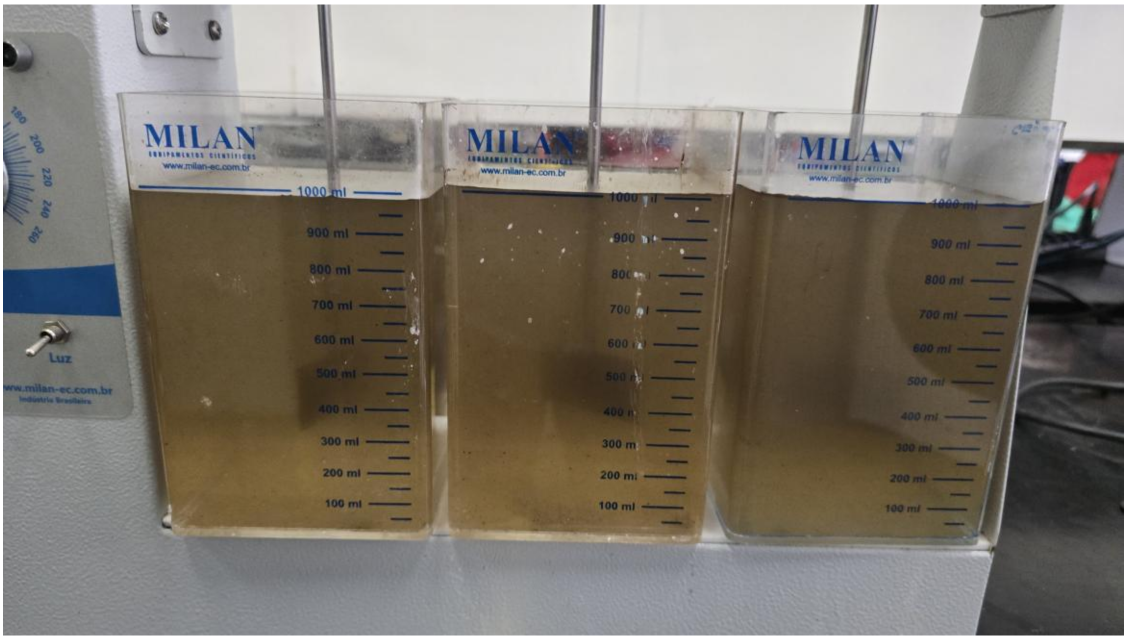
Source: Personal Archive (2026).

3.2 SAMPLE

A sample of raw effluent collected directly from one of the points of the treatment process of the REAM Refinery was used. The sample presented typical characteristics of refinery effluent, with yellowish color, visible presence of oils and greases on the surface and in emulsion, and high turbidity.

Figure 2

Sample of the raw effluent from the REAM Refinery in the test jars before the start of treatment



Source: Personal Archive (2026).

3.3 EXPERIMENTAL PROCEDURE (JAR TEST)

The procedure followed best practices for coagulation/flocculation assays:

1. Preparation: The 1000 mL jugs were filled with the raw effluent sample.
2. Coagulant Addition: QQS COA S coagulant was dosed in each jar at different concentrations (5 to 50 ppm).
3. Rapid Mixing (Coagulation): 260 RPM agitation for 1 minute for coagulant dispersion and destabilization of colloidal loads.
4. Slow Mixing (Flocculation): The speed has been reduced to 120-130 RPM for 5 minutes. QQS FLOC 2030 auxiliary flocculant was added (0.5 to 4.0 ppm) to promote flake growth.
5. Resting (Sedimentation/Flotation): Resting for 10-15 minutes for separation of the flakes.
6. Evaluation: The efficiency was evaluated visually (clarified water quality, separation speed, flake size).

4 RESULTS AND DISCUSSION

4.1 CRITICAL ANALYSIS OF THE CURRENT TREATMENT (TANNIN)

The daily consumption of 200 L of tannin and 2 kg of polymer is the starting point for the analysis. At a flow rate of 150 m^3/h (3,600 m^3/day), this translates into dosages of ~56 ppm tannin and ~0.56 ppm polymer. This massive dosage suggests that the predominant coagulation mechanism may be "sweep" flocculation, where excess coagulant precipitates, dragging contaminants. This is not an efficient mechanism and generates an excessive volume of sludge, with high associated costs [12].

4.2 CATIONIC STARCH PERFORMANCE EVALUATION (QQS COA S)

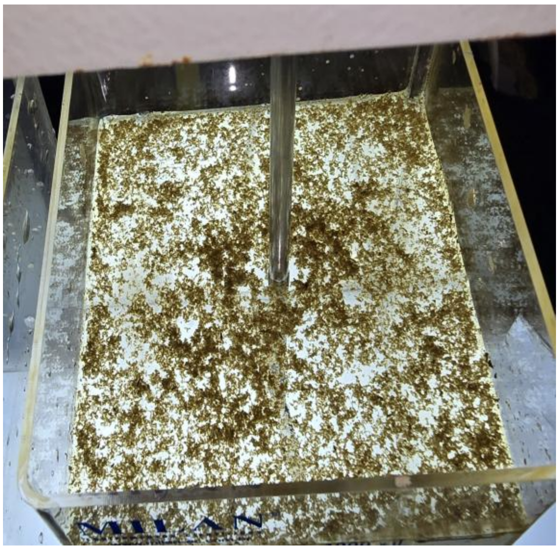
Tests with the QQS COA S have demonstrated outstanding efficiency.

4.2.1 Efficiency of QQS COA S Coagulant (Without Flocculant)

The most notable result was the performance of the QQS COA S performing alone on one of the days. At the dosage of 30 ppm, the coagulant promoted an almost complete phase separation, with large and well-defined flocs flotating rapidly. This result validates the hypothesis that the high molecular weight of cationic starch promotes an efficient bridging mechanism, acting both as a coagulant and as a flocculant.

Figure 3

Top view of the jug with 30 ppm of QQS COA S, showing the layer of flotated flakes and the clarified water below



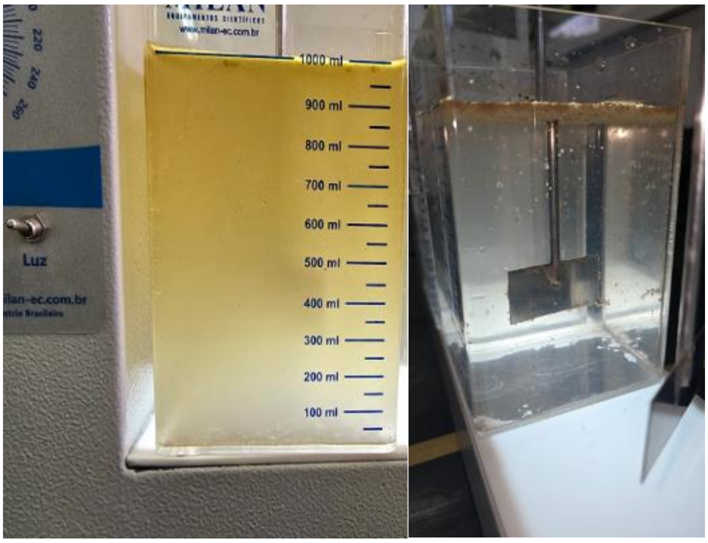
Source: Personal Archive (2026).

4.2.2 Efficiency of Coagulant + Flocculant Combination

The combination of 10 ppm of QQS COA S with 1.0 to 2.0 ppm of QQS FLOC proved to be the optimal range, producing superior visual quality water. The use of the auxiliary flocculant allows reducing the dosage of the primary coagulant and confers greater mechanical resistance to the flocs, desirable for continuous systems.

Figure 4

Visual comparison: raw effluent (left) and treated with 10 ppm QQS COA S + 2.0 ppm QQS FLOC (right)



Source: Personal Archive (2026).

4.3 COMPARATIVE ANALYSIS AND THEORETICAL VALIDATION

Table 1 summarizes the direct comparison, where the superiority of cationic starch is evident in all aspects evaluated.

Table 1

Comparative analysis between coagulants

Feature	Current Treatment (Tannin)	Proposed Treatment (QQS COA S)	Advantage of QQS COA S
Coagulant Dosage	60 to 120 ppm	10 - 30 ppm	
Main Engine	Probably "Sweep Flocculation"	Load Neutralization + Bridging	More efficient and specific
Visual Efficiency	Bottom	Superior	Improved water quality
Sludge Generation	High	Low	Lower disposal cost
Operating Cost	Elevated	Drastically Reduced	Direct savings
Logistics and Handling	Complex	Simplified	Operational optimization

Source: The author (2026).

5 DOSING TABLES FOR OPTIMIZATION

The following are the tables with the consolidated results of the tests, which serve as a basis for optimization on a pilot and industrial scale.

Table 2

Assay Results - QQS COA S Coagulant Only

Coagulant Dosage (ppm)	Visual Result
5	Initial formation of microflocs
10	Good flake formation
20	Larger flakes, good separation
30	Great, fast separation and clear water
40	Good, but no gain over 30 ppm
50	Onset of redissolve/overflow

Source: The author (2026).

Table 3

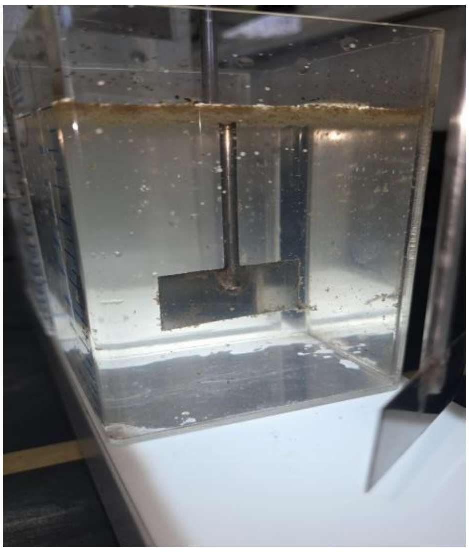
Assay Results – QQS COA S Coagulant + QQS FLOC 2030 Flocculant

Coagulant Dosage (ppm)	Flocculant Dosage (ppm)	Visual Result
5	0.5	Insufficient
5	1.0	Opaque
5	1.5	Fair
5	2.0	Fair
5	4.0	Good
10	1.0	Good
10	1.5	Very good
10	2.0	Excellent
15	4.0	Excellent
20	0.5	Good
30	2.0	Excellent (very fast separation)

Source: The author (2026).

Figure 5

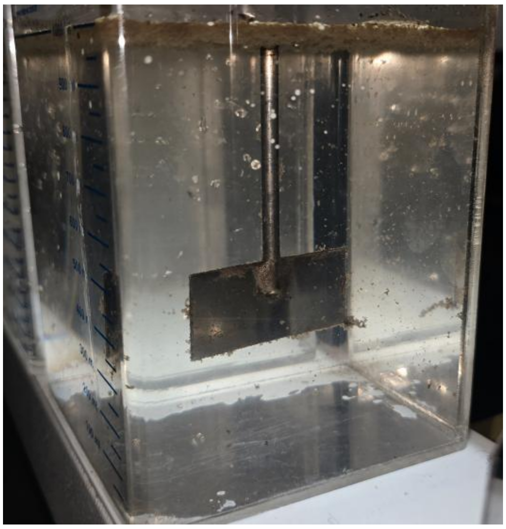
Side view of the jug after treatment with QQS COA S. Clarified water with flotated flakes on the surface



Source: Personal Archive (2026).

Figure 6

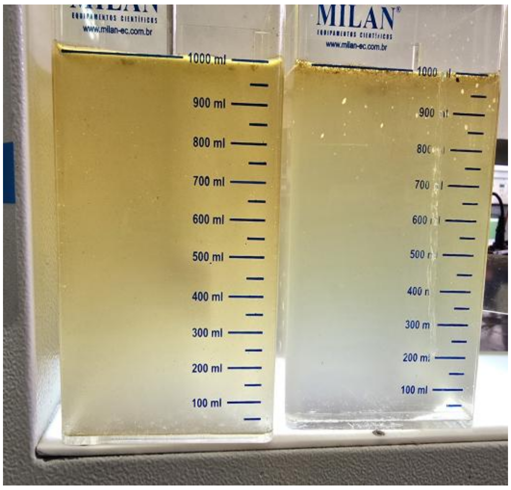
Front view of the jar after treatment with QQS COA S, showing the transparency of the treated water



Source: Personal Archive (2026).

Figure 7

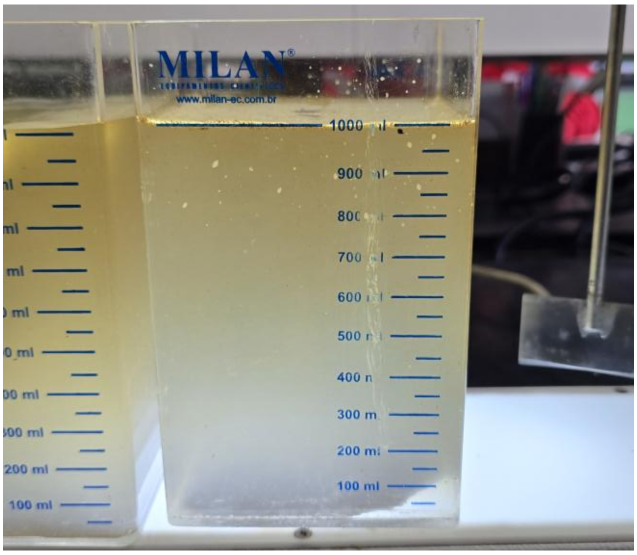
Detail of the clarification obtained with the coagulant QQS COA S, with well-defined flakes on the surface



Source: Personal Archive (2026).

Figure 8

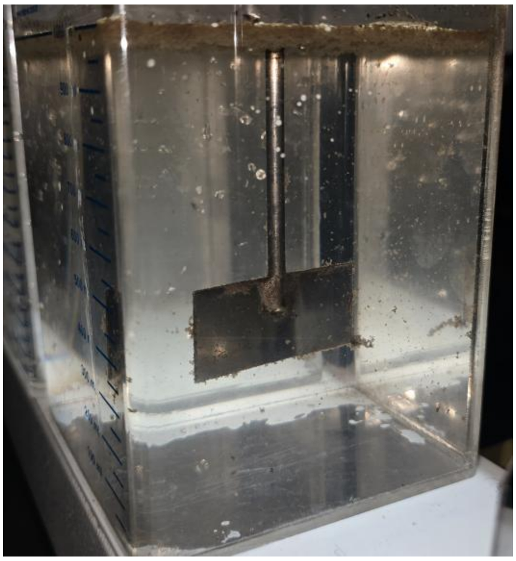
Side-by-side comparison: effluent with lower dosage (left, still turbid) and effluent treated with optimized dosage (beginning of flotation)



Source: Personal Archive (2026).

Figure 9

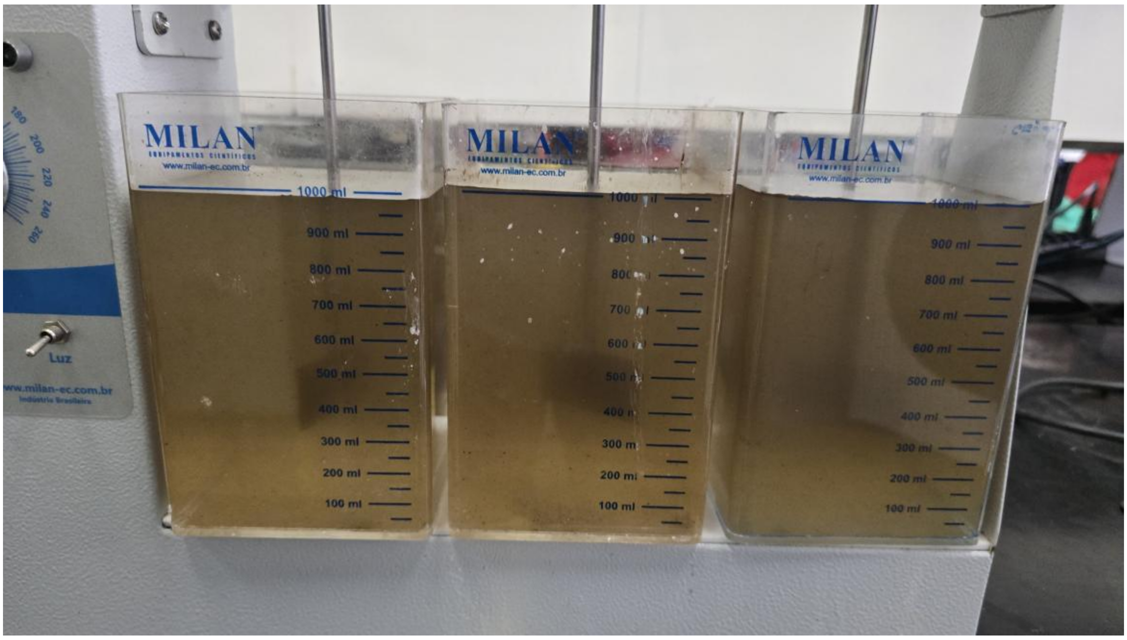
Test jar in intermediate stage of sedimentation, showing the progression of clarification



Source: Personal Archive (2026).

Figure 10

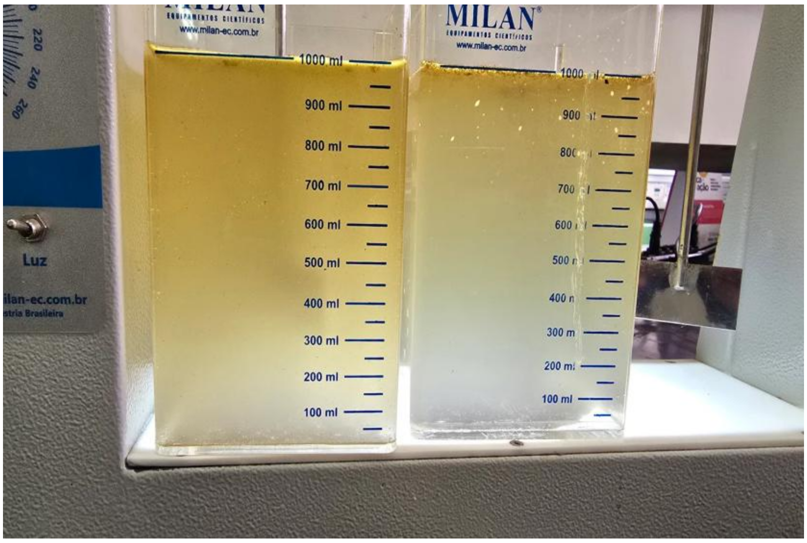
Final result of treatment with QQS COA S and QQS FLOC 2030 - repeatability



Source: Personal Archive (2026).

Figure 11

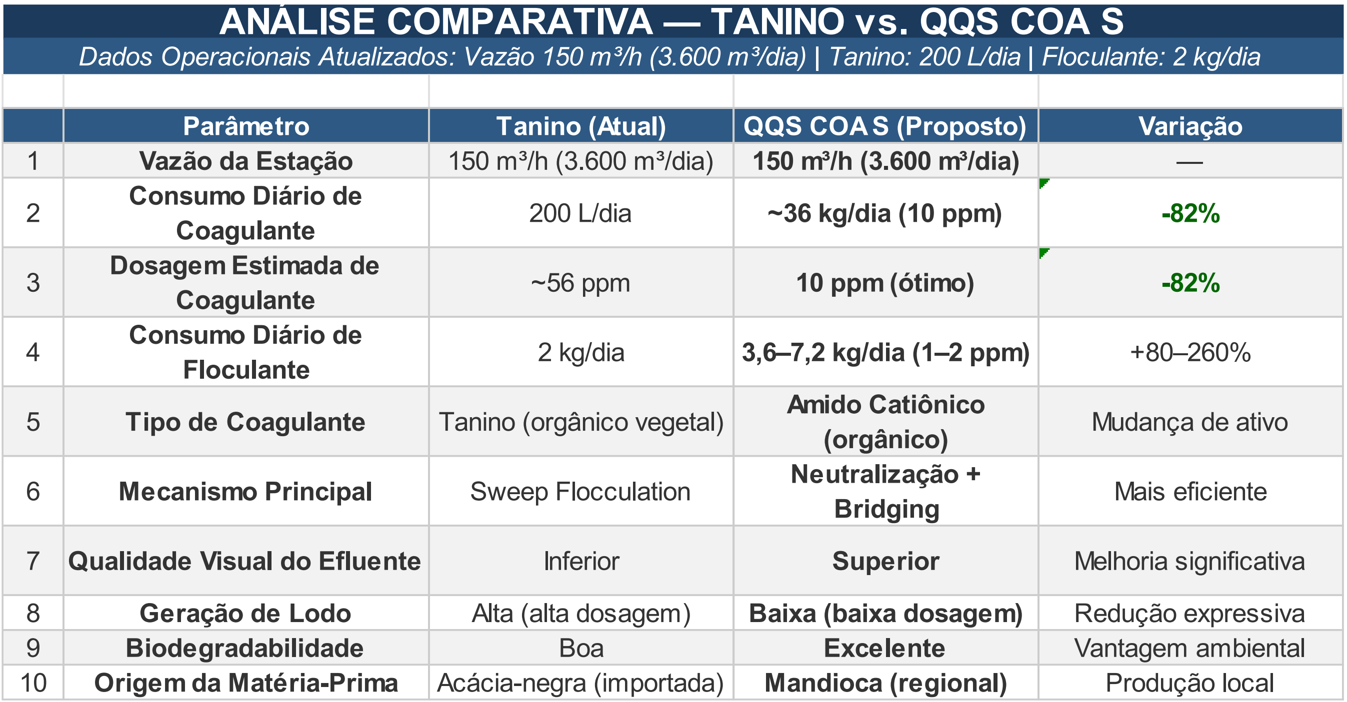
Effluents from the second day of testing



Source: Personal Archive (2026).

Table 4

Complete Table for Pilot Scale Filling—QQS COA S Coagulant Dosages (5 to 25 ppm) with QQS FLOC 2030 Flocculant Variations (0.5 to 5.0 ppm)



ANÁLISE COMPARATIVA — TANINO vs. QQS COA S

Dados Operacionais Atualizados: Vazão 150 m³/h (3.600 m³/dia) | Tanino: 200 L/dia | Floculante: 2 kg/dia

	Parâmetro	Tanino (Atual)	QQS COA S (Proposto)	Variação
1	**Vazão da Estação**	150 m³/h (3.600 m³/dia)	**150 m³/h (3.600 m³/dia)**	—
2	**Consumo Diário de Coagulante**	200 L/dia	**~36 kg/dia (10 ppm)**	**-82%**
3	**Dosagem Estimada de Coagulante**	~56 ppm	**10 ppm (ótimo)**	**-82%**
4	**Consumo Diário de Floculante**	2 kg/dia	**3,6–7,2 kg/dia (1–2 ppm)**	+80–260%
5	**Tipo de Coagulante**	Tanino (orgânico vegetal)	**Amido Catiônico (orgânico)**	Mudança de ativo
6	**Mecanismo Principal**	Sweep Flocculation	**Neutralização + Bridging**	Mais eficiente
7	**Qualidade Visual do Efluente**	Inferior	**Superior**	Melhoria significativa
8	**Geração de Lodo**	Alta (alta dosagem)	**Baixa (baixa dosagem)**	Redução expressiva
9	**Biodegradabilidade**	Boa	**Excelente**	Vantagem ambiental
10	**Origem da Matéria-Prima**	Acácia-negra (importada)	**Mandioca (regional)**	Produção local

Source: The author (2026).

Table 5

PROTOCOLO DE ENSAIO				
Etapa	**Tempo**	**Rotação (RPM)**	**Objetivo**	
Mistura Rápida	1 minuto	260	Coagulação (desestabilização coloidal)	
Mistura Lenta	5 minutos	120–130	Floculação (formação de flocos)	
Repouso	2–10 minutos	—	Sedimentação / Flotação	

TESTE 1: APENAS COAGULANTE (SEM FLOCULANTE) — Dia 2				
#	**QQS COA S (ppm)**	**QQS FLOC 2030 (ppm)**	**Resultado Visual**	**Observação**
1	5	0	OK	Clarificação parcial
2	10	0	OK	Clarificação parcial
3	20	0	+/−	Resultado intermediário
4	30	0	**ÓTIMO**	Excelente clarificação — melhor resultado
5	40	0	OK	Boa clarificação
6	50	0	—	Dosagem excessiva

TESTE 2: COAGULANTE + FLOCULANTE				
#	**QQS COA S (ppm)**	**QQS FLOC 2030 (ppm)**	**Resultado Visual**	**Observação**
1	5	0,5	~0	Sem resultado significativo
2	5	1	Opaco	Sem clarificação
3	5	1,5	~6	Resultado parcial
4	5	2	~6	Resultado parcial
5	10	0,5	Bom	Clarificação visível
6	10	1	Bom	Boa clarificação
7	10	1,5	Bom	Boa clarificação
8	10	2	Bom	Boa clarificação
9	20	0,5	Bom	Clarificação visível
10	30	2	**SEPAROU**	Excelente — separação total de flocos
Legenda:	*Melhor resultado*	*Bom resultado*	*Resultado parcial*	*Sem resultado*

Source: The author (2026).

Table 6

Analytical results

QQS COA S = 10 ppm

#	QQS FLOC 2030 (ppm)	Turbidez Inicial (NTU)	Turbidez Final (NTU)	% Remoção Turbidez	Resultado Visual	Observações
1	**0,5**	289,0	**134,8**	**53,4%**	**Fraco**	Necessita otimização de dosagem
2	**1,0**	289,0	**121,4**	**58,0%**	**Fraco**	Faixa ótima de custo-benefício (dado experimental)
3	**1,5**	289,0	**112,9**	**60,9%**	**Fraco**	Faixa ótima de custo-benefício (dado experimental)
4	**2,0**	289,0	**106,3**	**63,2%**	**Fraco**	Faixa ótima de custo-benefício (dado experimental)
5	**2,5**	289,0	**105,8**	**63,4%**	**Fraco**	Necessita otimização de dosagem
6	**3,0**	289,0	**90,9**	**68,5%**	**Fraco**	Necessita otimização de dosagem
7	**3,5**	289,0	**84,2**	**70,9%**	**Regular**	Formação de flocos moderada
8	**4,0**	289,0	**87,5**	**69,7%**	**Fraco**	Necessita otimização de dosagem
9	**4,5**	289,0	**86,4**	**70,1%**	**Regular**	Possível início de reestabilização por excesso de polímero
10	**5,0**	289,0	**86,6**	**70,0%**	**Regular**	Possível início de reestabilização por excesso de polímero

QQS COA S = 5 ppm

#	QQS FLOC 2030 (ppm)	Turbidez Inicial (NTU)	Turbidez Final (NTU)	% Remoção Turbidez	Resultado Visual	Observações
1	**0,5**	289,0	**225,8**	**21,9%**	**Sem Resultado**	Dosagem de coagulante insuficiente para neutralização de carga efetiva
2	**1,0**	289,0	**216,1**	**25,2%**	**Sem Resultado**	Dosagem de coagulante insuficiente para neutralização de carga efetiva
3	**1,5**	289,0	**229,9**	**20,4%**	**Sem Resultado**	Necessita otimização de dosagem
4	**2,0**	289,0	**200,1**	**30,8%**	**Insuficiente**	Necessita otimização de dosagem
5	**2,5**	289,0	**199,2**	**31,1%**	**Insuficiente**	Necessita otimização de dosagem
6	**3,0**	289,0	**197,1**	**31,8%**	**Insuficiente**	Floculante compensa parcialmente a baixa dosagem de coagulante
7	**3,5**	289,0	**201,2**	**30,4%**	**Insuficiente**	Floculante compensa parcialmente a baixa dosagem de coagulante
8	**4,0**	289,0	**191,9**	**33,6%**	**Insuficiente**	Floculante compensa parcialmente a baixa dosagem de coagulante
9	**4,5**	289,0	**185,3**	**35,9%**	**Insuficiente**	Floculante compensa parcialmente a baixa dosagem de coagulante; Possível início de reestabilização por excesso de polímero
10	**5,0**	289,0	**202,3**	**30,0%**	**Sem Resultado**	Floculante compensa parcialmente a baixa dosagem de coagulante; Possível início de reestabilização por excesso de polímero

Source: The author (2026).

Table 7

Beginning of extraordinary results

QQS COA S = 15 ppm						
#	**QQS FLOC 2030 (ppm)**	**Turbidez Inicial (NTU)**	**Turbidez Final (NTU)**	**% Remoção Turbidez**	**Resultado Visual**	**Observações**
1	**0,5**	289,0	**53,9**	**81,3%**	**Regular**	Formação de flocos moderada
2	**1,0**	289,0	**48,8**	**83,1%**	**Regular**	Formação de flocos moderada
3	**1,5**	289,0	**44,2**	**84,7%**	**Regular**	Formação de flocos moderada
4	**2,0**	289,0	**41,0**	**85,8%**	**Bom**	Formação de flocos moderada
5	**2,5**	289,0	**37,1**	**87,2%**	**Bom**	Formação de flocos moderada
6	**3,0**	289,0	**34,8**	**88,0%**	**Bom**	Formação de flocos moderada
7	**3,5**	289,0	**30,4**	**89,5%**	**Bom**	Formação de flocos moderada
8	**4,0**	289,0	**29,2**	**89,9%**	**Bom**	Formação de flocos moderada
9	**4,5**	289,0	**29,7**	**89,7%**	**Bom**	Possível início de reestabilização por excesso de polímero
10	**5,0**	289,0	**29,4**	**89,8%**	**Bom**	Possível início de reestabilização por excesso de polímero

QQS COA S = 20 ppm						
#	**QQS FLOC 2030 (ppm)**	**Turbidez Inicial (NTU)**	**Turbidez Final (NTU)**	**% Remoção Turbidez**	**Resultado Visual**	**Observações**
1	**0,5**	289,0	**23,4**	**91,9%**	**Bom**	Formação de flocos moderada
2	**1,0**	289,0	**20,0**	**93,1%**	**Muito Bom**	Boa formação de flocos e separação de fases
3	**1,5**	289,0	**17,7**	**93,9%**	**Muito Bom**	Sinergia coagulante-floculante otimizada
4	**2,0**	289,0	**15,2**	**94,7%**	**Muito Bom**	Sinergia coagulante-floculante otimizada
5	**2,5**	289,0	**14,4**	**95,0%**	**Muito Bom**	Sinergia coagulante-floculante otimizada; Resultado compatível com padrão CONAMA 430/2011
6	**3,0**	289,0	**13,7**	**95,3%**	**Muito Bom**	Sinergia coagulante-floculante otimizada; Resultado compatível com padrão CONAMA 430/2011
7	**3,5**	289,0	**12,3**	**95,7%**	**Muito Bom**	Sinergia coagulante-floculante otimizada; Resultado compatível com padrão CONAMA 430/2011
8	**4,0**	289,0	**11,4**	**96,1%**	**Muito Bom**	Sinergia coagulante-floculante otimizada; Resultado compatível com padrão CONAMA 430/2011
9	**4,5**	289,0	**11,0**	**96,2%**	**Muito Bom**	Sinergia coagulante-floculante otimizada; Resultado compatível com padrão CONAMA 430/2011
10	**5,0**	289,0	**11,5**	**96,0%**	**Muito Bom**	Sinergia coagulante-floculante otimizada; Resultado compatível com padrão CONAMA 430/2011

QQS COA S = 25 ppm						
#	**QQS FLOC 2030 (ppm)**	**Turbidez Inicial (NTU)**	**Turbidez Final (NTU)**	**% Remoção Turbidez**	**Resultado Visual**	**Observações**
1	**0,5**	289,0	**14,6**	**94,9%**	**Muito Bom**	Alta dosagem de coagulante compensa baixa de floculante
2	**1,0**	289,0	**11,5**	**96,0%**	**Muito Bom**	Alta dosagem de coagulante compensa baixa de floculante; Resultado compatível com padrão CONAMA 430/2011
3	**1,5**	289,0	**10,4**	**96,4%**	**Muito Bom**	Sinergia coagulante-floculante otimizada; Resultado compatível com padrão CONAMA 430/2011
4	**2,0**	289,0	**9,4**	**96,7%**	**Muito Bom**	Sinergia coagulante-floculante otimizada; Resultado compatível com padrão CONAMA 430/2011
5	**2,5**	289,0	**8,3**	**97,1%**	**Excelente**	Sinergia coagulante-floculante otimizada; Resultado compatível com padrão CONAMA 430/2011
6	**0,0**	289,0	**7,9**	**97,3%**	**Excelente**	Repetibilidade
7	**0,0**	289,0	**7,0**	**97,6%**	**Excelente**	Repetibilidade
8	**0,0**	289,0	**6,3**	**97,8%**	**Excelente**	Repetibilidade
9	**0,0**	289,0	**6,0**	**97,9%**	**Excelente**	Repetibilidade
10	**0,0**	289,0	**6,2**	**97,9%**	**Excelente**	Repetibilidade

Source: The author (2026).

Table 8

LEGENDA DE CORES:	
🟩	Excelente (≥97% remoção)
🟩	Muito Bom (93-97% remoção)
🟨	Bom (85-93% remoção)
🟧	Regular (70-85% remoção)
🟥	Fraco (50-70% remoção)
🟥	Insuficiente (30-50% remoção)
⬜	Sem Resultado (<30% remoção)

Source: The author (2026).

6 CONCLUSION AND STRATEGIC RECOMMENDATIONS

The benchtop treatability assays not only validated the initial hypothesis, but exceeded expectations, conclusively and unequivocally demonstrating the technical, economic and environmental superiority of the cationic starch-based coagulant (QQS COA S) over the tannin coagulant currently in use at the Manaus Refinery (REAM).

6.1 SUMMARY OF RESULTS

The replacement of tannin by QQS COA S allows a superior dosage reduction, going from a consumption of 200 to 400 L/day of tannin (~200 kg/day) to an estimated consumption of 36 to 100 kg/day of QQS COA S (considering the optimal dosage in the new flow rate of 3,600 m³/day), of course we know that the flow rates are fluctuating in this context as well, an 82% reduction in primary coagulant intake. But even on the condition that both are matched in dosage, the cost of the QQS COA S is 30 to 40% without considering the freight. This drastic optimization is a direct reflection of the adequacy of the macromolecular structure of cationic starch, whose high molecular weight and charge density optimize the mechanisms of charge neutralization and, crucially, bridging, resulting in a noticeably superior emulsion breakdown and oil effluent clarification.

6.2 ECONOMIC AND OPERATIONAL IMPACT

The implications of this discovery are transformative for the operation of the wastewater treatment plant:

- Direct OPEX Reduction: The reduction translates into substantial and immediate financial savings.
- Logistics Optimization: The need to transport, store, and handle massive volumes of chemical is eliminated, simplifying the operation and reducing associated risks and costs.

- Sludge Management: The lower dosage of a biodegradable product results in a smaller volume of sludge, with better dewatering characteristics, which significantly reduces the costs of its management and final disposal, one of the largest cost components of a WWTP.

6.3 OPPORTUNITY FOR LOCAL PRODUCTION

But perhaps the most strategic conclusion of this study is the opportunity it reveals. Starch, the raw material for QQS COA S, is a renewable and abundant natural resource in the Amazon, with cassava being one of its richest sources. The proof that a high-tech starch derivative can solve a critical problem for a local industry (the refinery) with such significant advantages creates a powerful argument for encouraging the local production of this input.

1. Generate a high value-added bioeconomy, transforming a local agricultural resource into a high-performance industrial chemical.
2. Reduce dependence on external inputs, strengthening the regional industry's supply chain.
3. Create qualified jobs and foster research and development in green chemistry in the Amazon.

Therefore, it is recommended not only to carry out a test on an industrial scale to validate the results and make the coagulant change official, but also to present this study as a success case that demonstrates the feasibility of combining industrial performance, environmental sustainability and regional economic development through science and technology.

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