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Almidón de yuca (Manihot esculenta Crantz) como coadyuvante en la coagulación floculación de aguas residuales domésticas

Cassava Starch (Manihot esculenta Crantz) As a coadyuvant in the coagulation flocculation of domestic wastewater

Amido de mandioca (Manihot esculenta Crantz) como coadjuvante na coagulação da floculação doméstica de efluentes

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Resumen

La coagulación floculación se ha empleado en el tratamiento de aguas residuales utilizando sales metálicas y polímeros con el fin de remover sólidos en suspensión, entre otros contaminantes. La turbiedad y el color son indicadores de sólidos suspendidos en el agua residual, y como parámetros de control es esencial determinarlos debido a que representan pruebas rápidas para precisar la reducción de los sólidos (suspendidos y disueltos). En tal sentido, en este estudio se evaluó la eficiencia de remoción de dichos parámetros de un agua residual doméstica, en la cual se aplicó un tratamiento de coagulación-floculación agregando el polímero natural almidón de yuca (*Manihot esculenta Crantz*) y combinando coagulantes floculantes como $Al_2(SO_4)_3$, $FeCl_3$ y $Ca(OH)_2$, de modo que se pudieran hallar las dosis óptimas de polímero y coagulantes para ofrecer la mejor remoción de turbiedad y color. En total, se analizaron 216 muestras de agua residual doméstica: 54 para determinar la dosis óptimas de los coagulantes y 162 de las mezclas. La combinación que presentó la mayor eficiencia fue la combinación de 250 mgL^{-1} de $Al_2(SO_4)_3$ y 750 mgL^{-1} del almidón, con turbiedad inicial de 24 NTU y color inicial de 958 CU. Esta logró remover 75 % de la turbiedad y 78 % del color, y obtuvo una turbiedad final de 6 NTU y color final de 210 CU. La segunda mezcla fue 250 mgL^{-1} de $Ca(OH)_2$ y 250 mgL^{-1} de almidón, con turbiedad inicial de 23.9 NTU y color inicial de 1430 CU. Esta combinación removió 34.3 % de turbiedad y 67.6 % del color, es decir, se redujo la turbiedad hasta 15.7 NTU y el color hasta 453 CU. El ahorro en el consumo de sulfato de aluminio para este tipo de agua residual fue de 16.7 %, ya que la dosis del reactivo fue de 300 mgL^{-1}, mientras que para el hidróxido de calcio el ahorro en el reactivo fue de 37.5 %, debido a que la dosis óptima de este estuvo en 400 mgL^{-1}.

Palabras clave: almidón de yuca, coagulación-floculación, prueba de jarras, sulfato de aluminio.

Abstract

Flocculation coagulation has been used in the treatment of wastewater using metal salts and polymers in order to remove solids in suspension among other contaminants present. The Turbidity and color are indicators of suspended solids in the wastewater and as control parameters for being rapid tests to determine the reduction of solids (suspended and dissolved). This study evaluated the removal efficiency of these parameters of domestic wastewater, where a coagulation-flocculation treatment was applied adding cassava starch (*Manihot esculenta Crantz*) a natural polymer, combined flocculants coagulants such as $Al_2(SO_4)_3$, $FeCl_3$ and $Ca(OH)_2$, to find the optimal dose of polymer and coagulants that will exhibit the best removal turbidity and color. A total of 216 samples of domestic wastewater were analyzed, 54 to determine the optimal dose of coagulants and 162 of the mixtures. The combination that presented the highest efficiency was the combination of 250 mgL^{-1} of $Al_2(SO_4)_3$ and 750 mgL^{-1} of the starch, with initial turbidity of 24 NTU and initial color of 958 CU, it was possible to remove 75% of the turbidity and 78% of the color, obtaining a final turbidity of 6 NTU and final color of 210 CU. The second mixture was 250 mgL^{-1} of $Ca(OH)_2$ and 250 mgL^{-1} of starch, with initial turbidity of 23.9 NTU and initial color of 1430 CU, this combination removed 34.3% turbidity and 67.6% of the color, that is, the turbidity was reduced to 15.7 NTU and the color to 453 CU, These combinations yielded significant figures for the removal of contaminants. The saving in consumption of aluminum sulphate for this type of wastewater was 16.7% since the dose of the reagent was 300 mgL^{-1}, while for calcium hydroxide the saving in the reagent was 37.5%, since the dose optimal of this was in 400 mgL^{-1}.

Keywords: Cassava starch, coagulation-flocculation, jar test and aluminum sulfate.

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Resumo

A coagulação por floculação tem sido utilizada no tratamento de águas residuárias utilizando sais metálicos e polímeros para remoção de sólidos em suspensão, entre outros poluentes. Turvação e cor são indicadores de sólidos suspensos nas águas residuais, e que os parâmetros de controlo é essencial porque eles representam determinar testes rápidos para sólidos de redução precisos (suspenso e dissolvido). A este respeito, neste estudo, a eficiência de remoção dos ditos parâmetros de um esgoto doméstico em que o tratamento de coagulação-floculação foi aplicado através da adição do amido de mandioca polímero natural (Manihot esculenta Crantz) e combinando floculante coagulante, tal como avaliado Al2 (SO4) 3, FeCl 3 e Ca (OH) 2, de modo que poderia encontrar doses óptimas de polímero coagulante e para oferecer a melhor cor e turvação remoção. No total, foram analisadas 216 amostras de efluentes domésticos: 54 para determinar a dose ótima dos coagulantes e 162 das misturas. A combinação tinha a mais alta eficiência foi a combinação de 250 mg L-1 de Al2 (SO4) 3 e 750 mg L-1 de amido, com turbidez inicial de 24 NTU e cor inicial de 958 CU. Isso conseguiu remover 75% da turbidez e 78% da cor, e obteve uma turvação final de 6 NTU e cor final de 210 CU. A segunda mistura foi de 250 mgL -1 de Ca (OH) 2 e 250 mgL -1 de amido, com turvação inicial de 23,9 NTU e cor inicial de 1430 UQ. Essa combinação removeu 34,3% de turbidez e 67,6% de cor, ou seja, a turbidez foi reduzida para 15,7 NTU e cor para 453 UQ. As poupanças no consumo de sulfato de alumínio para este tipo de águas residuais foi de 16,7%, e a dose de reagente foi 300 mgL-1, enquanto que a poupança de hidróxido de cálcio em reagente foi de 37,5%, porque a dose ideal era de 400 mgL-1.

Palavras-chave: fécula de mandioca, floculação por coagulação, teste de jar, sulfato de alumínio.

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Introduction

Domestic and industrial wastewater have increasingly complex pollutants to eliminate with conventional biological treatments. This has led to the use of coagulation flocculation, a process that uses metal salts as pretreatment or secondary treatment of toxic waters and difficult degradation, which cause damage to dispose in receiving bodies without prior treatment (Ismail, Fawzy, Adbel-Monem, Mahmoud and El-Halwany, 2012).

However, to reduce the use of these metal salts, different synthetic or natural polyelectrolytes can be used (Amuda and Alade, 2006). The former are organic compounds obtained chemically from coal and petroleum derivatives, while the latter are generated by natural biochemical reactions, either in plants or animals, and can be proteins, carbohydrates and polysaccharides (Arboleda, 2000). In this sense, currently natural polymers of vegetable and animal origin are being developed in the treatment of water (clarification) to reduce the use of conventional flocculating coagulants. For example, lefari cactus with methanol and ethyl acetate have been used in the treatment of synthetic waters with turbidity from 20 NTU to 150 NTU, which has achieved between 80% and 90% removal of this parameter with a cactus dose of 10 mgL-1 (Martínez, Chávez, Díaz, Chacín and Fernández, 2003). Also, banana starch has proved to be a good flocculant, but with slow sedimentation in the clarification and with initial turbidity of 150 NTU, which has reached its best removal efficiency at pH 5, with a mixture of 50% aluminum sulphate and 50% starch in percent by weight, with a final concentration of 3.9 NTU to 4.09 NTU (Trujillo et al., 2014). Likewise, it has been tested with Moringa oleifera in waters with turbidity of 75 NTU and 150 NTU. The optimal coagulant concentrations have been 500 mgL -1 and 400 mgL -1, respectively, with removal rates between 80.1% and 94.3% for these concentrations (Caldera, Mendoza, Briceño, García y Fuentes, 2007).

On the other hand, and with regard to those of animal origin, bovine bones have been used in waters of 50 NTU and 90 NTU, with removal efficiencies of 71% to 81% with an optimum dose of 22 mgL-1 to 38 mgL- 1 of the bovine bone (Fuentes, Aguilar, Caldera and Mendoza, 2014).

These results serve to demonstrate that it is necessary to know the potential of wastewater treatment with new natural polymers, since these (in comparison with synthetic ones) are less toxic, have better biodegradability, are more economical and generate lower volumes of sludge (Duran , Morales and Yusti, 2005, Kirchmer, Arboleda and Castro, 1975).

In this regard, the objective of this research is to offer an alternative to the physical-chemical treatment systems of domestic wastewater that use metallic salts to reduce their consumption, since some dose between 2000 mgL-1 and 4000 mgL-1 of Al2 (SO4) 3 and Ca (OH) 2 (López et al., 2014), which also allows to reduce trace concentrations of said compounds in the treated waters that are discharged to the receiving bodies (Ministry of the Navy and Natural Resources [Semarnat], nineteen ninety six).

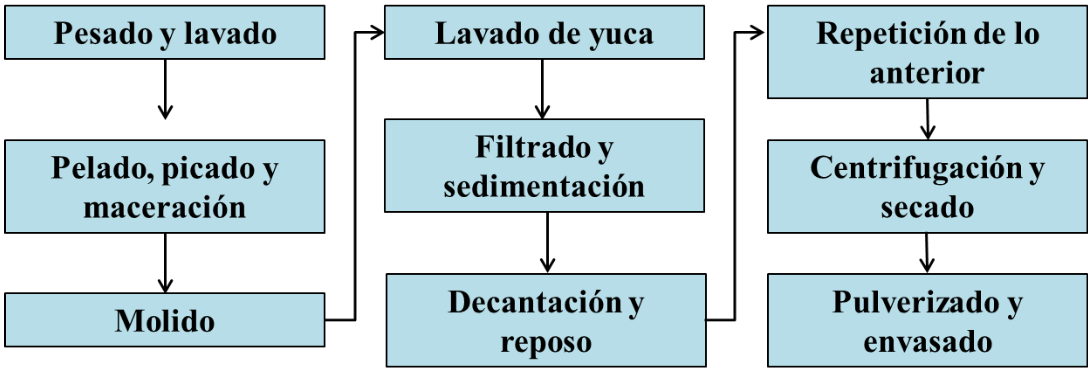
For this, treatability tests were carried out (coagulation-flocculation) that allowed to obtain the optimal dose of Al2 (SO4) 3, FeCl3, Ca (OH) 2 and an organic polymer of cassava (Manihot esculenta Crantz), with the best removal of Turbidity and color in domestic wastewater, in addition to measuring and observing the behavior of parameters such as temperature, pH and electrical conductivity, which are of immediate determination for the control and operation of plants.

Materials and methods

First activity: obtaining cassava starch

Cassava starch (Manihot esculenta Crantz) was extracted using the modified methodology of Aparicio (2003), with cassava tubers purchased in a public market in Centro, Tabasco (Mexico). The extraction is described in figure 1.

Figura 1. Esquema de la obtención de almidón de yuca



Fuente: Elaboración propia

To obtain the starch, 10 kg of cassava were weighed and washed. The peel was removed and they were split in approximate portions of 2 cm x 2 cm x 1.2 cm, which were deposited in a container with water at 40 ° C (the volume of water weighed 6 times the weight of the tuber). These portions were subsequently ground in an impact proof blender until their complete disintegration was achieved. The result of this process was washed three times with the same water of soaking on a sieve number 100. The material that passed through the sieve was allowed to settle for a period of 3 hours (the material that was retained in the sieve was removed). After the resting time by decantation, the supernatant was separated, and the obtained sediment was left to rest in the refrigerator overnight. The next day the operation was repeated to remove the supernatant and, subsequently, the pellet was centrifuged at 850 r. p. m. during 15 minutes. The paste obtained was dried in an oven at 40 ° C for 24 hours, and then pulverized in a mortar with pistil in quantities of 5 g. Finally, it was packed in plastic containers (PET).

Second activity: preparation of solutions for mixtures

In the wastewater treatment of this project, mixtures were carried out between the organic polymer (cassava starch) and the metal salts, as shown below: Al2 (SO4) 3-cassava, FeCl3-cassava and Ca (OH) 2-yucca. The solutions were prepared as follows:

1. On an analytical balance, 10 g of cassava (Manihot esculenta Crantz) were weighed, which were diluted in 1 liter of distilled water in a 1000 ml flask. This mixture was subsequently refrigerated in a glass jar.
2. On an analytical balance, 10 g of Al2 (SO4) were weighed, which were diluted in 1 liter of distilled water in a 1000 ml flask.
3. On an analytical balance, 10 g of Ca (OH) 2 were weighed, which were diluted in 1 liter of distilled water in a 1000 ml flask.
4. On an analytical balance, 10 g of FeCl3 were weighed, which were diluted in 1 liter of distilled water in a 1000 ml flask. Once prepared, the mixtures were refrigerated in glass jars.

Third activity: obtaining residual water samples

Wastewater for the treatability tests was collected from the wastewater treatment plant (PTAR) station of the Universidad Juárez Autónoma de Tabasco (UJAT), Academic Division of Biological Sciences (DACBiol). The sampling area is located at the following coordinates: N 17º59'28.15 ", O 98º58'25.85", with an elevation of 12 m. The volume of the sample by treatability test was 20 liters, which were collected in a jug with that capacity. Then it was cooled to a temperature of 4 ° C (NMX-AA-003-SCFI-2000). Finally, treatability tests were carried out. 60 liters were required for the flocculant coagulant tests with their three repetitions, and 60 liters for each combination of coagulant with the polymer. In total there were 240 liters of wastewater.

Fourth activity: doses of the coagulant mixtures used in the research

Before starting the treatments of the mixtures it was necessary to determine the optimal doses for the best turbidity and color removal using only the flocculant coagulants Al2 (SO4) 3, FeCl3 and Ca (OH) 2. In the treatability tests with the mixtures were included the inorganic metal salts and the organic polymer, that is, the cassava starch (Manihot esculenta Crantz). Next, Table 1 shows the specific dosages used:

Tabla 1. Dosificación del hidróxido de calcio-yuca, cloruro férrico-yuca y sulfato de aluminio-yuca

$Ca(OH)_2$ (HCAL) mgL^{-1}	$ClFe_3$ (CLF) mgL^{-1}	$Al_2(SO_4)_3$ (SUL) mgL^{-1}	Almidón de yuca (AY) mgL^{-1}		
0	0	0	250	500	750
50	50	50	250	500	750
100	100	100	250	500	750
150	150	150	250	500	750
200	200	200	250	500	750
250	250	250	250	500	750

Fuente: Elaboración propia

Fifth activity: treatability tests

Before carrying out the treatability tests, the water taken as a sample was characterized in the station of the physical-chemical PTAR of the UJAT-DACBiol. The treatability test (coagulation-flocculation) used was based on the pitcher test method, according to the Pan American Health Organization and the Pan American Center for Sanitary Engineering Studies (PAHO / CEPIS) (1992), as well as what was established by Barrenechea (2004), as follows:

1. It was verified that the equipment of jars (Phipps and Bird, series PB-900) -which has six vessels with agitators and automated programming system- will work in excellent conditions to carry out the treatability tests.
2. 1000 ml of the collected wastewater of the 20 liters (4 ° C) was placed in each of the vessels of the equipment. Then the light switches went on to observe the process.
3. In the first treatability test, cassava starch (Manihot esculenta Crantz) was added with a concentration of 250 mgL-1 in each of the vessels, except the glass that was taken as a control. After adding the cassava starch, the aluminum sulphate was dosed at concentrations of 0, 50, 100, 150, 200 and 250 mgL-1 taking except for cup 1 (control of the treatability test). After adding both cassava starch and aluminum sulfate, the

equipment was programmed to agitate the samples at 100 r. p. m. for two minutes; this for the purpose of destabilizing the surface charges of the particles present in the wastewater sample. After two minutes it was re-programmed for a slow mix at 30 r. p. m. for 15 minutes, in order to promote the formation of flocs. Subsequently, each of the glasses was allowed to settle for 30 minutes.

4. At the end of the sedimentation time, 50 ml of treated water from each of the vessels was collected in beakers to determine the parameters of pH, color, turbidity, temperature and electrical conductivity (CE).
5. The turbidity and color parameters were determined with the La Motte TC3000we 1969-EPA equipment, while the parameters of temperature, electrical conductivity and pH were measured with HANNA HI 9828 multiparameter equipment.
6. This same procedure was carried out in triplicate, and then the whole process was repeated for the dosages of cassava starch of 500 mgL-1 and 750 mgL-1 in different treatability tests. In this way the sulphate test with cassava starch was terminated. The whole process described (from 1 to 6) was also carried out with ferric chloride and calcium hydroxide. In total, 54 samples were analyzed to determine the optimum doses of the salts [Al2 (SO4) 3, FeCl3 and Ca (OH) 2] and 162 samples to obtain the optimum dose in the combination of the salts with cassava starch.
7. At the end of each of the treatability tests, the jars test equipment was cleaned.

Sixth activity: data analysis

From the data obtained from turbidity and color, the removal efficiency of the treatments was calculated, expressed as percentage of removal for each observed variable (Chung, Wu, Tam and Wong, 2008). For this, the equation R = Ce - Cs / Ce * 100 was used:

Where

R = remoción (%)

Ce = concentración de entrada/inicial de agua residual

Cs = concentración de salida/final del agua residual tratada.

In relation to the statistical analysis, once the experimental data complied with the postulates of the parametric statistics (normality and homoscedasticity), an ANOVA variance analysis (one way) was carried out to determine if there were significant statistical differences in the treatments. Likewise, a means test was performed by the Tukey method.

The results obtained were examined with the Statgraphics 7.0 program, and each generated graph was interpreted. The referred P value corresponds to 100% reliability of the analysis at 5% error, which expressed as quotient is equal to 0.05. When the value of P is lower than this figure, there are significant differences between the treatments compared (otherwise, there are no differences). Therefore, when representing the value of P a 5% error, it has a degree of reliability of 95% in the analysis. All the analyzes were considered as one-way, since the response variables (turbidity, color, pH and electrical conductivity) only depended on the treatment applied to the samples.

Results

Wastewater during the August-December 2015 period showed a minimum expenditure (Qmin) of 0.14 Ls-1, the average expenditure (Qmed) of 0.41 Ls-1, and the maximum instantaneous expense (Qmax.Inst) of 0.51 Ls- 1 (the behavior of the expenditure in hourly average is presented in figure 2). On average, the residual water presented a color of 1114.25 ± 373.7 UC, CE of 1098.65 ± 114.9 μScm-1, the pH of 7.6 ± 0.2 UpH, the average of the other parameters is shown in Table 2.

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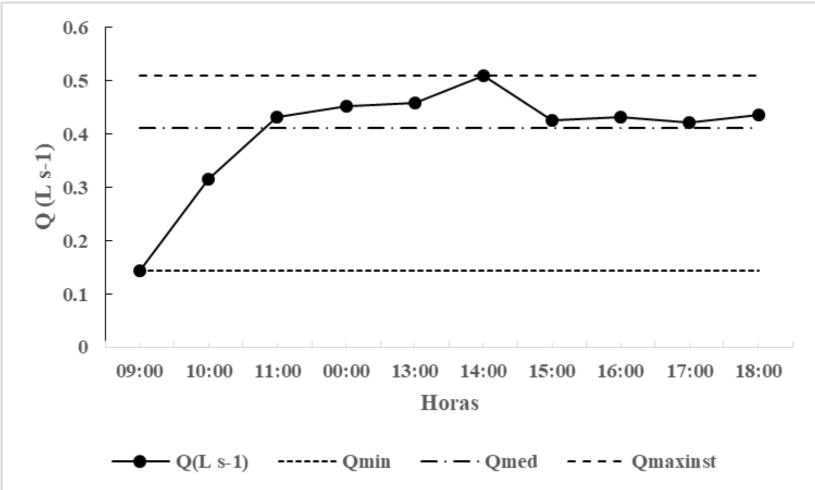
Figura 2. Descarga de aguas residuales en el cárcamo de la UJAT-DACBiol



Fuente: Elaboración propia

Tabla 2. Características fisicoquímicas del agua residual a tratar

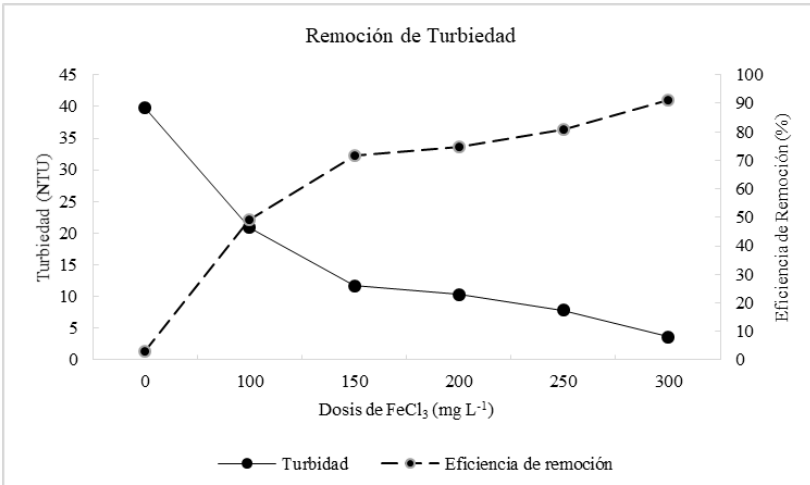
Parámetro	Unidad	Promedio	Desviación (±)
T. Agua	°C	24.99	2.3
Turbiedad	NTU	18.97	6.5
Color	UC	1114.25	373.7
OD	mgL^{-1}	5.68	1.1
pH	U pH	7.66	0.2
Presión	mbar	1016.32	9.2
Resistividad	MΩ. Cm	0.00091	0.0
CE	μScm^{-1}	1098.65	114.9
SDT	mgL^{-1}	551.70	56.4
Salinidad	psu	0.54	0.1
Pot. Oxi. Red.	ORP	-390.44	397.7

Fuente: Elaboración propia

Optimal doses using conventional flocculating coagulants

The behavior of FeCl3 in the removal of turbidity of wastewater shows that a dosage of 300 mgL-1 is required to remove 91.2% of the turbidity, that is, the final concentration is 3.6 ± 0.4 NTU when there is an initial concentration of 41 NTU (figure 3).

Figura 3. Remoción de turbiedad con el coagulante floculante $FeCl_3$



Fuente: Elaboración propia

The behavior of Ca (OH) 2 in the removal of turbidity of wastewater shows that a dosage of 400 mgL-1 is required to remove 87.9% of the turbidity, that is, the final concentration is 5.4 ± 0.5 NTU when you have initial concentration of 44.7 NTU (figure 4).

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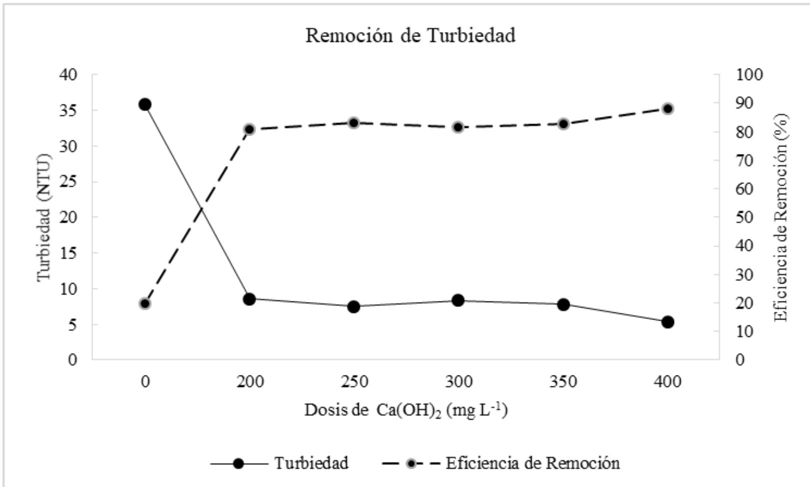
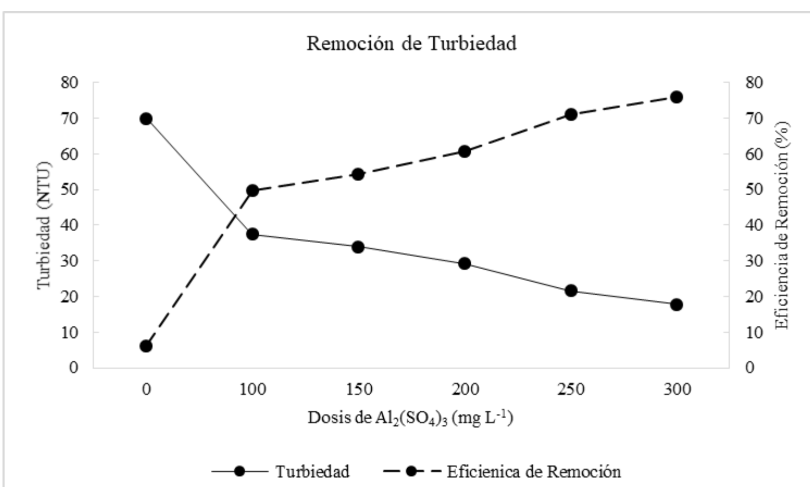
Figura 4. Remoción de turbiedad con el coagulante floculante $Ca(OH)_2$



Fuente: Elaboración propia

Finally, the behavior of Al2 (SO4) 3 in the turbidity removal of wastewater shows that a dosage of 300 mgL-1 is required to achieve a 76.1% removal of turbidity, that is, the final concentration is 17.8 ± 0.1 NTU when there is an initial concentration of 74.6 NTU (figure 5).

Figura 5. Remoción de turbiedad con el coagulante floculante $Al_2(SO_4)_3$



Fuente: Elaboración propia

Characteristics of the best treatments

Next, Table 3 shows the characteristics of the best treatments with the different doses of cassava starch.

Tabla 3. Características fisicoquímicas del agua residual con los mejores tratamientos

Tratamiento	pH (UpH)	T. Agua (°C)	CE (μs/cm)	Turbiedad (NTU)	Color (UC)	ER Turb. (%)	ER Color (%)
SUL25/25AY	7.7	24.4	1221	10.8	270	36.5	58.9
	6.9	24.4	594	12.6	294	46.4	61.2
	7.3	24.7	1011	11.6	278	51.7	71.0
CLF25/25AY	7.7	24.8	1368	26.0	738	18.5	48.3
	7.6	25	1472	19.3	554	33.9	66.2
	7.5	25.2	1246	13.6	370	52.3	77.5
HCAL25/25AY	9.8	25.6	968	15.7	463	53.7	67.6
	9.8	25.7	1128	12.9	591	50.8	58.5
	9.8	25.6	1048	19.3	527	43.1	63.1
SUL25/50AY	7.8	23.9	1289	11.8	383	30.6	41.7
	7.0	22.9	822	19.9	357	15.3	52.8
	7.7	23.2	980	15.5	428	35.4	55.3
CLF25/50AY	7.7	24.0	1354	27.0	797	15.4	44.2
	7.6	25.9	1311	20.1	571	31.2	65.2
	7.5	23.9	1249	13.2	337	53.7	79.5
HCAL25/50AY	9.8	23.9	998	19.3	538	43.1	62.4
	9.9	24.1	1097	19.7	527	24.8	63.0
	9.9	24.2	1060	19.6	510	42.2	64.3
SUL25/75AY	7.7	22.7	1156	9.3	171	45.3	74.0
	7.1	22.1	573	8.5	196	63.8	74.1
	7.7	22.3	992	6	210	75.0	78.1
CLF25/75AY	7.7	23.3	1295	22.3	618	30.1	56.7
	7.6	23.2	1270	16.2	467	44.5	71.5
	7.5	23.2	1241	10.2	350	64.2	78.7
HCAL25/75AY	9.6	22.8	961	18.9	580	44.2	59.4
	10.1	23.1	1020	18.3	552	30.2	61.3
	9.8	22.9	990	19.1	565	43.7	60.5

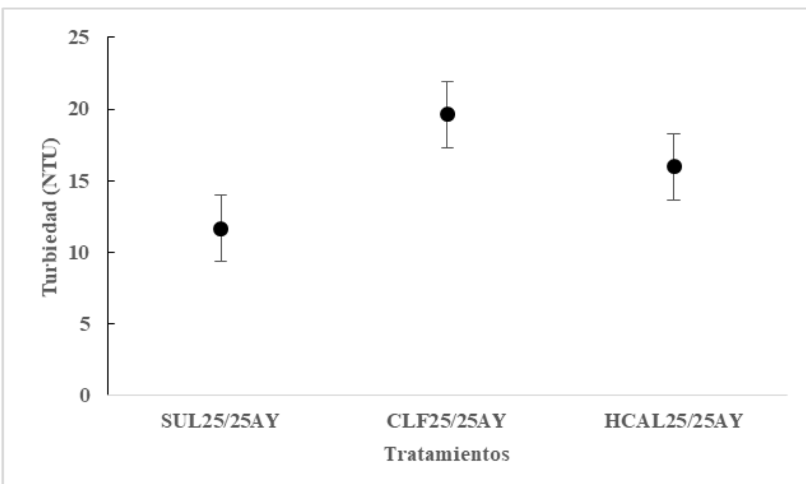
Nomenclatura: SUL25/25AY = mezcla de 250 mgL^{-1} de sulfato de aluminio con 250 mgL^{-1} de almidón de yuca

Fuente: Elaboración propia

Comparison between treatments with metal salts

Comparing the treatment of the dose of 250 mgL-1 of each coagulant with 250 mgL-1 of cassava starch, it can be seen that the one-way analysis of variance indicates that there are highly significant differences (P <0.001) between the mean values of the variable turbidity of the different coagulant treatments (CLF25 / 25AY, HCAL25 / 25AY, SUL25 / 25AY) with 95% reliability. The coagulant with the best turbidity removal was SUL25 / 25AY with an average of 11.6 ± 0.9 NTU, followed by coagulant HCAL25 / 25AY with an average of 15.9 ± 6.2. The highest average values of turbidity CLF25 / 25AY were presented in the coagulant with an average of 19.6 ± 3.2, respectively (Figure 6). The Tukey test means showed statistically significant differences between treatments.

Figura 6. Valores promedios de la variable *turbiedad* (NTU) ± intervalos de confianza de LSD de los tipos de tratamiento (CLF25/25AY, HCAL25/25AY, SUL25/25AY)



Fuente: Elaboración propia

The one-way analysis of variance indicates that there are highly significant differences (P <0.001) between the mean values of the color variable of the different coagulant treatments (CLF25 / 25AY, HCAL25 / 25AY, SUL25 / 25AY) with 95% reliability . The coagulant with the best color removal was SUL25 / 25AY with an average of 280.6 ± 12.2, followed by coagulant HCAL25 / 25AY with an average of 527.0 ± 64.0. The highest

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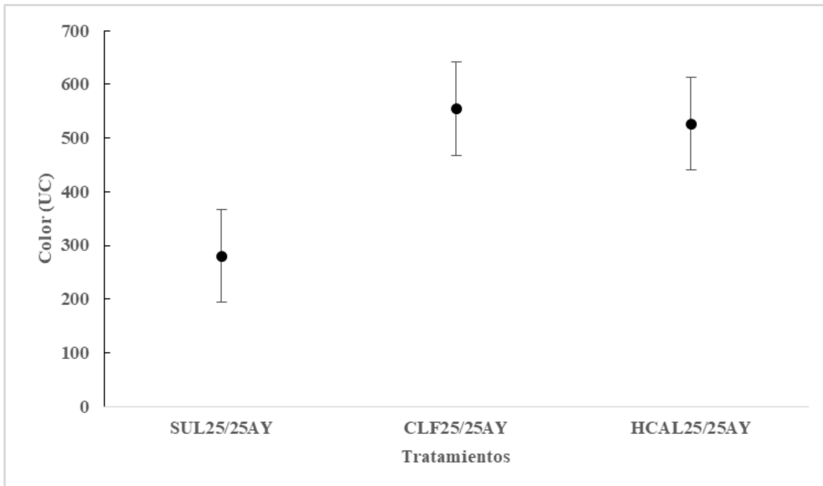
average color values were presented in the coagulant CLF25 / 25AY with an average of 554.0 ± 184.0, respectively (figure 7).

Figura 7. Valores promedios de la variable *color* (CU) ± intervalos de confianza de LSD de los tipos de tratamiento (CLF25/25AY, HCAL25/25AY, SUL25/25AY)



Fuente: Elaboración propia

From the dose of 250 mgL-1 of each coagulant with 500 mgL-1 of cassava starch, it can be seen that the one-way analysis of variance indicates that there are highly significant differences ($P < 0.05$) between the mean values of the variable turbidity of the different coagulant treatments (CLF25 / 50AY, HCAL25 / 50AY, SUL25 / 50AY) with 95% reliability. The coagulant with the best turbidity removal was SUL25 / 50AY with an average of 15.7 ± 4.05, followed by coagulant HCAL25 / 50AY with an average of 19.5 ± 0.2. The highest average values of turbidity were presented in the coagulant CLF25 / 50AY with an average of 20.1 ± 6.1, respectively (figure 8).

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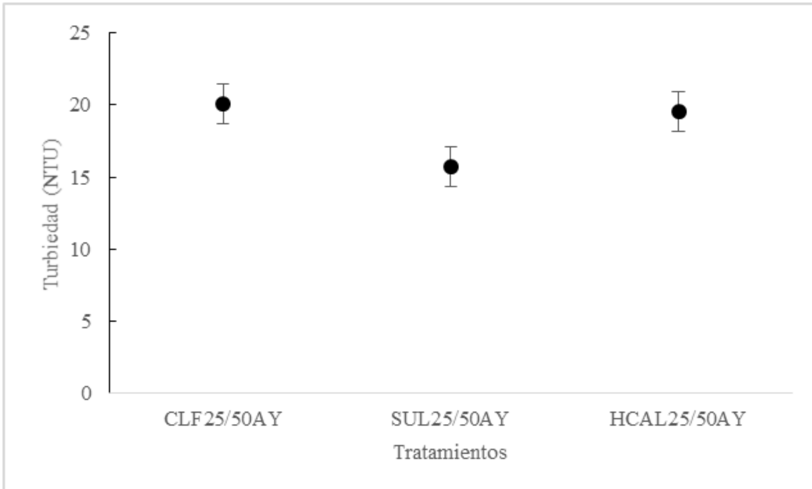
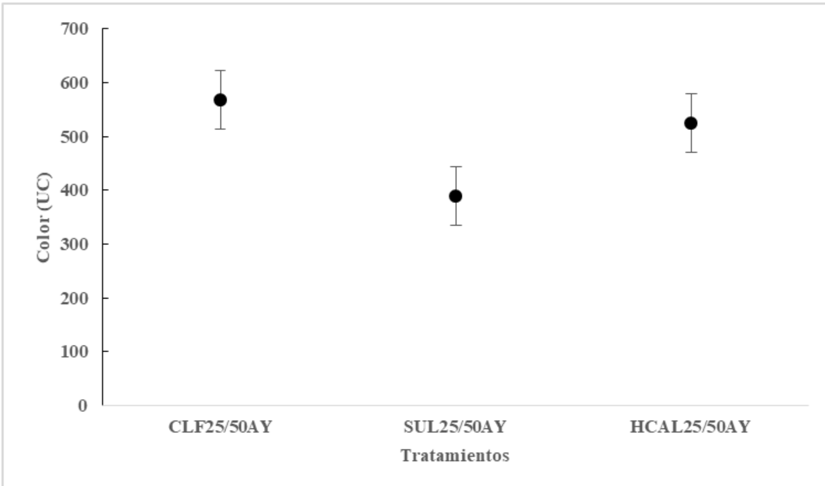
Figura 8. Valores promedios de la variable *turbiedad* (NTU) ± intervalos de confianza de LSD de los tipos de tratamientos (CLF25/50AY, HCAL25/50AY, SUL25/50AY)



Fuente: Elaboración propia

The one-way analysis of variance indicates that there are highly significant differences (P <0.001) between the mean values of the color variable of the different coagulant treatments (CLF25 / 50AY, HCAL25 / 50AY, SUL25 / 50AY) with 95% reliability . The coagulant with the best color removal was SUL25 / 50AY with an average of 389.3 ± 35.9, followed by the coagulant HCAL25 / 50AY with an average of 525.0 ± 14.1. The highest average color values were presented in the coagulant CLF25 / 50AY with an average of 568.3 ± 230, respectively (figure 9).

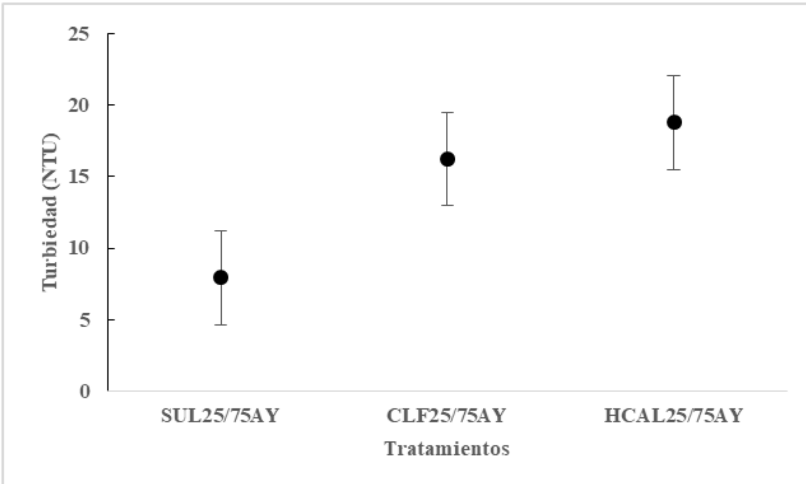
Figura 9. Valores promedios de la variable *color* (CU) ± intervalos de confianza de LSD de los tipos de tratamientos (CLF25/50AY, HCAL25/50AY, SUL25/50AY)



Fuente: Elaboración propia

Comparing the treatment of the dose of 250 mgL-1 of each coagulant with 750 mgL-1 of cassava starch, it can be observed that the best removal of contaminants with the one-way analysis of variance indicates that there are highly significant differences ($P < 0.001$) between the mean values of the variable turbidity of the different coagulant treatments (CLF25 / 75AY, HCAL25 / 75AY, SUL25 / 75AY) with 95% reliability. The coagulant with the best turbidity removal was SUL25 / 75AY with an average of 7.9 ± 1.7, followed by coagulant CLF25 / 75AY with an average of 16.2 ± 6.05. The highest average values of turbidity were presented in the coagulant HCAL25 / 75AY with an average of 18.76 ± 0.4, respectively (figure 10).

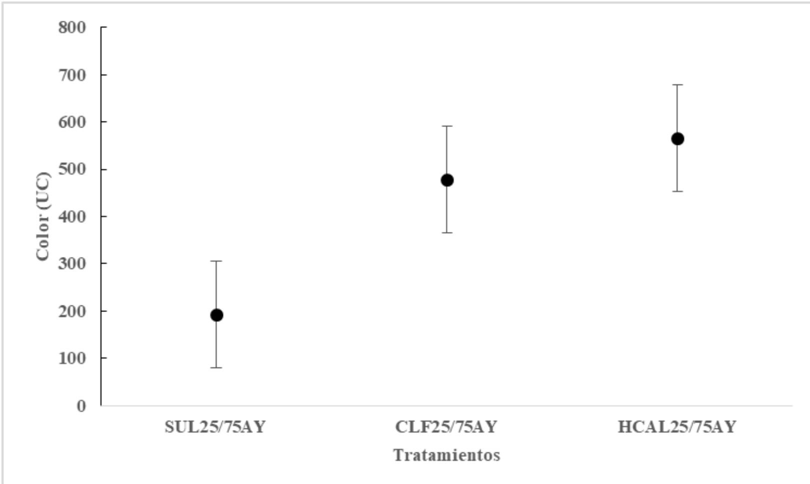
Figura 10. Valores promedios de la variable *turbiedad* (NTU) ± intervalos de confianza de LSD de los tipos de tratamientos (CLF25/75AY, HCAL25/75AY, SUL25/75AY)



Fuente: Elaboración propia

The one-way analysis of variance indicates that there are highly significant differences (P <0.001) between the mean values of the turbidity variable of the different coagulant treatments (CLF25 / 75AY, HCAL25 / 75AY, SUL25 / 75AY) with 95% reliability . The coagulant with the best color removal was SUL25 / 75AY with an average of 192.3 ± 19.7, followed by coagulant CLF25 / 75AY with an average of 478.7 ± 134.3. The highest average color values were presented in the coagulant HCAL25 / 75AY with an average of 565.6 ± 14.0, respectively (figure 11).

Figura 11. Valores promedios de la variable *color* (CU) ± intervalos de confianza de LSD de los tipos de tratamientos (CLF25/25AY, HCAL25/25AY, SUL25/25AY)



Fuente: Elaboración propia

Discussion

This type of waste water generally consumes concentrations of flocculating coagulants such as Al2 (SO4) 3 and Ca (OH) 2 ranges of 1000 mgL-1 to 5000 mgL-1 of concentration of both reagents (Aguilar) on the recommendation of manufacturers or patents of physicochemical plants. , Sáez, Llorens, Soler and Ortuño, 2002, Andía, 2000, López et al., 2014).

In the particular case of domestic wastewater from this study, removals with aluminum sulfate and ferric chloride were obtained with a dose of 300 mgL-1 and 400 mgL-1 with calcium hydroxide. Likewise, although starches of organic origin have been used for the removal of turbidity and color, they have been more used in superficial and synthetic waters (Almendárez, 2004, Martínez et al., 2003), in comparison with wastewater with domestic characteristics of this investigation. The difference of surface and synthetic waters reported for treatment with other organic polymers is that they contain turbidity of 50 NTU to 120 NTU and color <300 UC (Almendárez, 2004), while those reported in this study show initial turbidity of <50 NTU and color greater than 1000 CU, that is, have more organic material than surface water.

A study that evaluated cassava starch (Manihot esculenta Crantz) in the treatment of river water started with color concentrations of 85 UC, turbidity of 70 NTU, achieving the greatest color reduction (94% efficiency) with a dose of 2 mgL-1 of cassava plus 28 mgL-1 of aluminum sulfate (Solís, Laines and Hernández, 2012). On the other hand, in our research the best dose with 250 mgL-1 of aluminum sulphate and 750 mgL-1 of cassava starch achieved a removal of 61.4% turbidity and 75.4% color.

Also, in this study, the dosage treatment of 250 mgL-1 of coagulant and 250 mgL-1 of cassava starch (treatment SUL25 / 25AY) decreased the turbidity to 11.7 NTU, with a removal of 44.8%, while the color was reduced to 280 UC (63.7%). The second best treatment (HCAL25 / 25AY) decreased the turbidity 16 NTU, with a removal of 49.2%, while the color was reduced to 527 UC (63.1%). Likewise, with the CLF25 / 25AY treatment the turbidity was reduced 19.6 NTU, with a removal of 34.9%, while the color was reduced to 554 UC (64%).

In the dosing treatment of 250 mgL-1 of coagulant and 500 mgL-1 of cassava starch, the SUL25 / 50AY treatment decreased the turbidity to 15.7 NTU, with a removal of 27.1%, while the color was reduced to 389 UC (fifty %). The second best treatment (HCAL25 / 50AY) decreased the turbidity 19.5 NTU, with a removal of 36.7%, while the color was reduced to 525 UC (63%). With the CLF25 / 50AY treatment the turbidity was reduced 18.8 NTU, with a removal of 39.4%, while the color was reduced to 565 UC (60.4%).

Finally, in the dosing treatment of 250 mgL-1 of coagulant and 750 mgL-1 of cassava starch, the SUL25 / 75AY treatment decreased the turbidity to 7.9 NTU, with a removal of 61.4%, while the color was reduced to 192 UC (75.4%). The second best treatment (CLF25 / 75AY) decreased the turbidity 16.2 NTU, with a removal of 46.3%, while the color was reduced to 478 UC (69%). With the HCAL25 / 75AY treatment, the turbidity was reduced 20.1 UNT, with a removal of 33.4%, while the color was reduced to 568 UC (63%).

In all the experimental runs aluminum sulfate was better removing turbidity and color, while calcium hydroxide is the second best when used with concentrations of 250 mgL-1 and 500 mgL-1, respectively.

Now, and regarding the studies reported, Carpinteyro (2011) evaluated the treatment of municipal wastewater using three biopolymers: guar gum, mesquite and cactus mucilage. For a residual water with color of 2010 UC and turbidity of 537 NTU, the highest removal of turbidity (74%) was presented by guar gum with a dose of 50 mgL-1, followed by mesquite (73.09%) with 25 mgL- 1, and the cactus mucilage (72.5%) with 75 mgL-1. It is worth noting that the aforementioned biopolymers were not combined with any coagulant, unlike this research, where mixtures were made, of which the best were SUL25 / 75AY (61.5% turbidity and 75.4% color), CLF25 / 75AY (46.3% turbidity and 69.0% color) and HCAL25 / 25AY (49.2% turbidity and 63.1% color). Likewise, it should be noted that the color parameter can not be compared because in Carpinteyro's study (2011) that answer variable was not taken. Therefore, it is important to carry out studies with starches as the sole coagulation products to determine if under these conditions the effectiveness in the removal of color and turbidity in the wastewater treatment processes increases or decreases.

Conclusions

Based on the results obtained in this study, it can be affirmed that the mixture of the aluminum sulfate-cassava coagulant was more effective than the mixture of calcium hydroxide-cassava. This is of vital importance, since it was found that cassava starch decreased the concentration of the coagulant in the treatment of wastewater, which allows to establish the following conclusions:

1. The most efficient mixture was the combination of aluminum sulfate-cassava starch, since the turbidity and color levels were reduced in a significant amount.
2. The mixture of calcium hydroxide-cassava starch was the second best combination to reduce turbidity and color. This means that cassava starch is a coadjuvant in wastewater treatment processes, since it participates directly in the entrainment of ionic particles and organic matter.
3. It was observed that the dosages of metal salts and organic polymer depend on the turbidity and color of the initial sample. In other words, the previous characterization

of the water is essential to graduate the reagents, so that no quantities are released that can generate an increase in the measurements of the parameters to be analyzed.

4. These blends of coagulants can be implemented in the treatment of wastewater, surface, industrial and even leachate.
5. The saving of aluminum sulphate for this type of wastewater is 16.67%, since the reagent dose was 300 mgL-1, while for calcium hydroxide the saving in the reagent is 37.5%, since the dose of this was 400 mgL^{-1}.

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