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Evaluation of the use of plantain starch as a natural coagulant for the removal of colour and turbidity in water for human consumption

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Abstract

Aim. To evaluate the effect on pH, removal of turbidity and colour, using plantain starch as a natural coagulant, extracted by wet and basic route, in a sample of synthetic water. **Materials and methods.** The starch was extracted by placing the pre-treated biomass in contact with water or a NaOH solution for 20 h at 18 ° C, and then separating by filtration. The efficiency in the removal of turbidity and colour was carried out using a jug test, varying the initial concentration of coagulant and the stirring rate. **Results.** It was found that the starch obtained by the wet route presented a higher level of turbidity reduction compared to that obtained with NaOH, reaching an efficiency of 94.6%; using 150 mg/L of coagulant and 40 rpm, and having a better performance than the synthetic coagulant aluminium sulphate ($Al_2(SO_4)_3$). **Conclusions.** The variable evaluated with the highest linear influence is the combination of stirring rate and coagulant concentration. The use of plantain starch extracted by wet route is recommended for use in water treatment for human consumption, highlighting its nature as an advantage over $Al_2(SO_4)_3$.

Keywords: Colour, pH, Turbidity, Stirring rate, Natural coagulant.

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Evaluación del uso de almidón de plátano como coagulante natural para la remoción de color y turbidez en agua para consumo humano

Resumen

Objetivo: Evaluar el efecto sobre el pH, remoción de turbidez y color, usando almidón de plátano como coagulante natural, extraído por vía húmeda y básica, en una muestra de agua sintética. **Materiales y métodos:** El almidón se extrajo colocando la biomasa pre-tratada en contacto con agua y/o una solución de NaOH durante 20 h a 18 °C, y luego separando por filtración. La eficiencia en la remoción de turbidez y color, se realizó mediante prueba de jarras variando la concentración inicial de coagulante y la velocidad de agitación. **Resultados:** Se encontró que el almidón obtenido por vía húmeda presentó un nivel de reducción de turbidez más elevado respecto al obtenido con NaOH, alcanzándose una eficiencia del 94.6%; usando 150 mg/L de coagulante y 40 rpm, y teniendo un mejor comportamiento que el coagulante sintético sulfato de aluminio ($Al_2(SO_4)_3$). **Conclusiones:** La variable evaluada con la mayor influencia lineal es la combinación de la velocidad de agitación y concentración de coagulante. Se recomienda el uso de almidón de plátano extraído por vía húmeda para su uso en tratamiento de aguas para consumo humano, resaltando como ventaja su naturaleza frente al $Al_2(SO_4)_3$.

Palabras Clave: Color, pH, Turbidez, Velocidad de agitación, Coagulante natural.

Avaliação do uso de amido de banana como coagulante natural para remoção de cor e turbidez na água para consumo humano

Resumo

Objetivo. Alvo. Avaliar o efeito no pH, remoção de turbidez e cor, utilizando amido de banana como coagulante natural, extraído por via úmida e básica, em uma amostra de água sintética. **Materiais e métodos.** O amido foi extraído colocando a biomassa pré-tratada em contato com água ou uma solução de NaOH por 20 h a 18 ° C e depois separando por filtração. A eficiência na remoção de turbidez e cor foi realizada utilizando um teste de jarro, variando a concentração inicial de coagulante e a taxa de agitação. **Resultados.** Verificou-se que o amido obtido pela via úmida apresentou maior nível de redução de turbidez em relação ao obtido com NaOH, atingindo uma eficiência de 94,6%; utilizando 150 mg/L de coagulante e 40 rpm e com melhor desempenho que o sulfato de alumínio coagulante sintético ($Al_2(SO_4)_3$). **Conclusões.** A variável avaliada com a maior influência linear é a combinação da taxa de agitação e da concentração de coagulante. Recomenda-se o uso de amido de banana extraído por via úmida no tratamento da água para consumo humano, destacando sua natureza como vantagem sobre o $Al_2(SO_4)_3$.

Palavras chave: Cor, pH, Turbidez, Taxa de agitação, Coagulante natural.

1. Introduction

Access to water with sanitary conditions for human consumption is essential for the health of consumers, and their final characteristics will depend on its origin (groundwater or surface water) and the potabilization treatment. Coagulation is a physical-chemical process to reduce the repulsive potential of the electric double layer of colloids using coagulants as metallic, polyelectrolytes and polymers. As a result, colloidal particles begin to develop and then agglomerate into larger particles or flocs (Sillanpää *et al.*, 2018). The potabilization process consists of treating water for human consumption, which implies low costs, with easily operable installations. Generally, the system has a desander, flocculator, flocculator-sedimentador, filters and storage reserves (Pantoja-Espinosa *et al.*, 2015).

There are different types of coagulants such as metallic salts, natural coagulants from plants rich in polysaccharides, proteins (Shamsnejati *et al.*, 2015) and polyelectrolytes (Donato et al., 2006) (Salehizadeh *et al.*, 2018). Normally, polymeric flocculants and inorganic coagulants have been used; these are are expensive, and generally consist of metal salts of synthetic origin, which affects the bodies of water due sludges are arranged without prior treatment (Kamar, Abdul Aziz and Ramli, *et al.*, 2015). Despite, its effectiveness it has been found large amounts of inorganic ions on effluents, which fall the shelf life-time of the equipment owing to corrosion, fouling and clogging (Gao *et al.*, 2009).

In this sense, starch is a natural coagulant alternative to minimise the harmful impacts caused by traditional coagulants. Starch has a low cost, renewable nature and environmentally friendly (Choy, Prasad and Wu *et al.*, 2016). Gelatinised starch increases the viscosity of aqueous solutions, and it promotes the elimination of turbidity (Zhu, 2015).

Starch and its derivatives have been shown to be very useful for flocculation of ultrafine mineral particles and iron metals (Trujillo *et al.*, 2014). Several researchers have used natural coagulants from alum and rice starch (Teh *et al.*, 2014), calcium alginate (Arcila y Peralta, 2016), modified starches (López-Vidal *et al.*, 2014), starch with alum and poly-aluminium chloride (Choy, Prasad and Wu *et al.*, 2016). They found that the use of coagulants of natural origin is a viable alternative for their use in the clarification of surface waters, which represents a sustainable option for water treatment managers as opposed to inorganic coagulants. Therefore, the objective of the present study was to use plantain starch as a natural coagulant, in order to remove turbidity and colour present in a water sample by varying the agitation rate and concentration of the coagulant.

2. Materials and Methods

2.1. Experimental design

The present investigation used an experimental design of response-surface of central composite type. Two independent variables were evaluated (agitation rate (rpm) and coagulant concentration (mg/L)) with two variation levels (30 and 40 rpm). The dependent variables were pH, colour (Platinum-Cobalt Scale [Pt/Co]) and turbidity (Nephelometric turbidity units [NTU]), and the intervening variables were centrifugation time (min), centrifugation rate (1500 rpm), cooling time (20 h) and sample concentration (0.5 Kg/L). During the experimentation, Merck brand analytical grade reagents were used.

2.2. Starch extraction

The starch extraction was done using 1000 g of plantain, it were peeled and sliced for subsequent washing with distilled water to eliminate impurities. Then 500 g were immersed in a solution of 0.25% NaOH by weight and 500 g in water; both mixtures were cooled to 4 ºC for 20 h, and then liquefied for 1min. After the maceration process, starch-rich products were obtained and filtered separately. The filtrates were centrifuged at 1500 rpm for 10 min. The centrifuged material was adjusted to neutral pH using a 2M HCl solution and centrifuged again at the same conditions. Finally, the starch was dried and ground (Maniglia and Tapia, 2016).

2.3. Turbid water preparation

The synthetic turbid water was elaborated by dispersion of 0.3 g of bentonite in 800 mL of deionised water. This solution was mixed for 1 h at 200 rpm, and subsequently was left 21 h at rest for a hydration process. Then, it was diluted in 1.9 L of deionised water, and resulting dispersion has a turbidity of 32.3 NTU (Canepa *et al.*, 2004; López-Vidal *et al.*, 2014).

2.4. Turbidity removal test

The tests to remove turbidity and colour were performed by putting in contact the turbid water sample with the starch extracted in the jar test equipment at 200 rpm for 1-2 min. The agitation rate was reduced to 20-40 rpm for 15 min, the mixture was left to repose, and an aliquot was taken to measure turbidity (NTU), colour (Pt/Co) and pH of the solution.

2.5. Statistical analysis

The data analysis was carried out by software STATGRAPHICS centurion XVI, through an analysis of variance ANOVA that allowed separating the variations of the diverse factors that affect a dependent variable with a degree of effect 1.

3. Results and Discussion

3.1. Turbidity Removal Tests

Two samples of starch were obtained from the extraction using NaOH and water. The dry weight of the samples was 38 and 35.5 g respectively. Subsequently, jar tests were performed, and the effect of the coagulant dose and agitation rate on the pH of the raw water samples was evaluated.

The pH was inversely proportional to the concentration of the coagulant, and the agitation rate does not significantly affect the pH of the samples (**Figure 1**).

It can be seen that the samples treated at 40 rpm reveal a similar tendency in pH from the beginning (7.67-7.69) until the end (6.84-6.81), for the coagulant extracted with water and NaOH, respectively. On the other hand, the coagulant extracted with water at 30 rpm had a pH from 7.76 to 6.81. At last, the coagulant extracted with NaOH at 30 rpm has the highest initial pH (7.96), and their final pH was similar to the others (6.89). The pH is a main parameter in coagulation-flocculation process, due it can change the surface charge of the coagulant and/or contaminant; then, the starch obtained in the present study and used as natural coagulant is stable over a wide pH range and its use in real waters samples is recomended (Daverey, Tiwari and Dutta *et al.*, 2018; Paredes *et al.*, 2018).

Regarding the colour reduction of plantain starches, the colour value was 10 on the Platinum-Cobalt scale (**Table 1**) for all the samples. Plantain starch did not affect the colour of water solutions. This result can be considered positive. Starch does not add colour to the raw water sample after the test. These results are within the pH range of 6.0-8.5 established by Shamsnejati *et al.*, (2015) where the effected of pH on colour is not significant for the removal of dye from a textile wastewater model.

TABLE 1. TESTS OF COLOUR ON THE PLATINUM-COBALT SCALE

Starch	Agitation (rpm)	Coagulant concentration (mg/L)		
		125	187.5	250
Plantain NaOH	30	10	10	10
	40	10	10	10
Plantain H_2O	30	10	10	10
	40	10	10	10

The behaviour of turbidity concerning the coagulant dose and agitation rate during the jar test using plantain starch extracted with NaOH and water (**Figure 2**) were evaluated.

The coagulant concentration has a significantly positive effect on the removal of turbidity. Starch extracted with water (30 and 40 rpm) exhibits the best results. Turbidity was reduced more effectively, reaching a removal rate of 94.6% using 250 mg/L coagulant concentration and 40 rpm. This behaviour can be explained by the presence of amylopectin in the starch structure due to its electrolytic nature, which is a branched distribution of the proteins that compose it, and would trap in its structure, as was reported in literature (Trujillo *et al.*, 2014).

Figure 1. Effect of coagulant concentration and agitation rate on pH

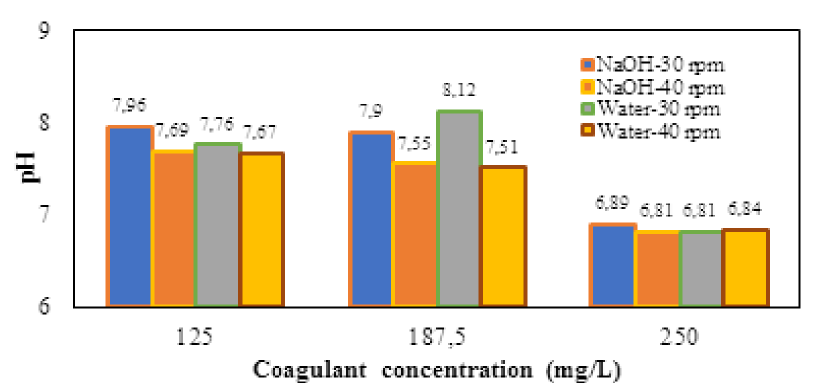


Figure 2. Effect of the agitation rate and concentration of coagulant on the removal of turbidity using plantain starch as coagulant

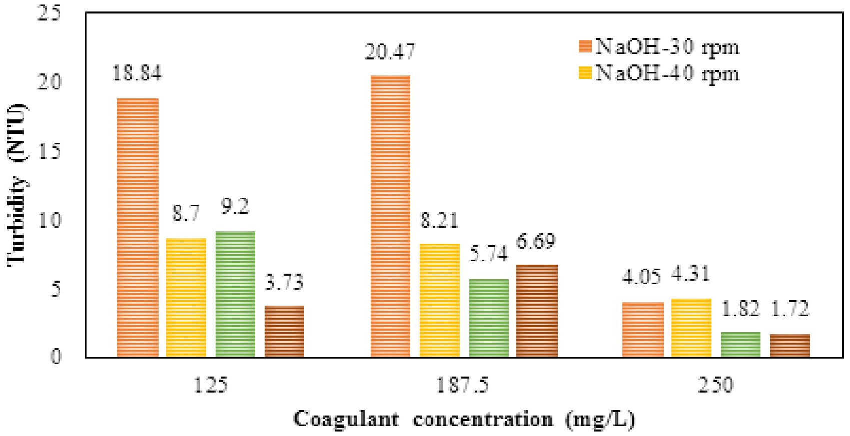


Figure 3. Effect of coagulant concentration and agitation rate on the pH of $Al_2(SO_4)_3$

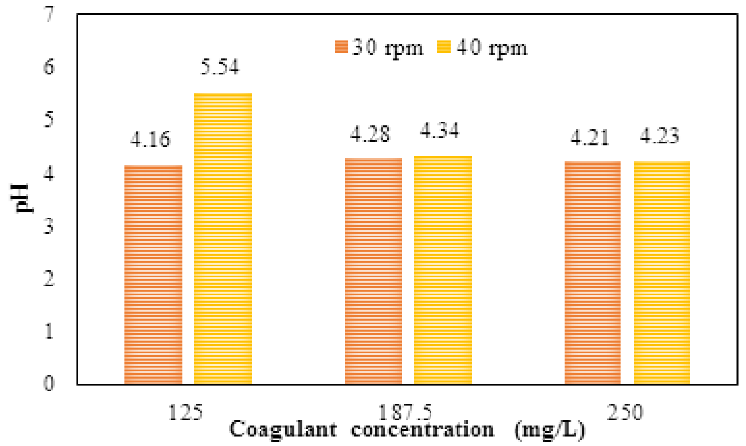
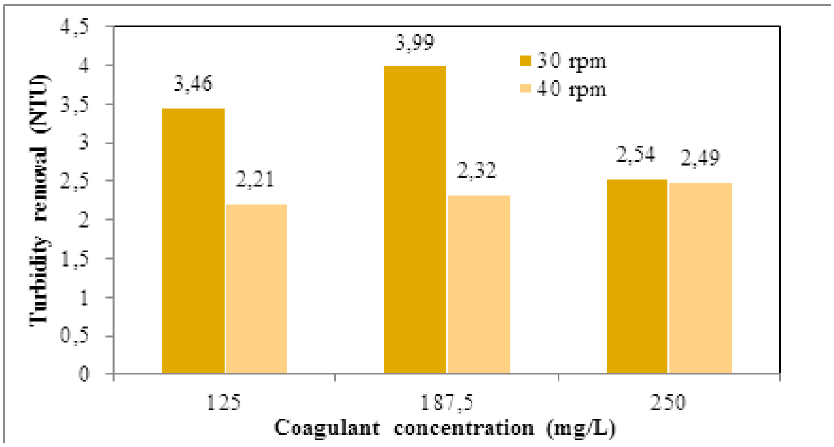


Figure 4. Effect of coagulant dose and agitation speed on turbidity removal using $Al_2(SO_4)_3$



$Al_2(SO_4)_3$ was used as a synthetic coagulant to compare with the plantain starch extracted with NaOH and water. **Figure 4** shows the results obtained from the turbidity measurement of raw water samples after a jug test using aluminium sulphate ($Al_2(SO_4)_3$) as a coagulant.

Comparing the obtained results (**Figure 1**, **Figure 3** and **Figure 4**), the residual pH values obtained with the natural coagulants extracted from the plantain were higher than those obtained with the synthetic coagulant. These results are like those reported by Ganjidoust *et al.*, (1997), a natural coagulant (chitosan) had the better effect than synthetic coagulants (HE and PEL) eliminating up to 90% of the colour and 70% of organic carbon. This phenomenon can be explained due to the high rate of formation of flocs of excellent characteristics during the process, by the electrolytic nature of the natural coagulant tested, which contributes to the appropriate and rapid sedimentation by the consistency and weight of the flocculated particles (Paredes *et al.*, 2018).

Table 2 shows the colour values on Platinum-Cobalt scale using $Al_2(SO_4)_3$ as a coagulant. In all treatment at different concentrations and agitation rates, the colour was constant (10 units). Same results were obtained with the starch. According to Colombian regulation for drinking water, obtained results are admissible because the colour should be lesser than 15 units when a coagulant dosage of 250 mg/L is used (Resolution 2115, 2007).

TABLE 2. TEST OF COLOUR ON PLATINUM-COBALT SCALE USING $AL_2(SO_4)_3$ AS COAGULANT

Agitation (rpm)	Coagulant concentration (mg/L)		
	125	187.5	250
30	10	10	10
40	10	10	10
Range required by Resolution 2115 of 2007	<15		

3.2. Statistical analysis

Statistical analysis was performed using an ANOVA analysis of variance, as shown in **Table 3**, which indicates that the coagulant concentration has a confidence level of 95.0 being significantly influential on the process.

TABLE 3. ANALYSIS OF VARIANCE FOR PH

	Extracted with NaOH					*Extracted with water*				
Source	*Sum of squares*	D.F.	*Middle Square*	*F- Reason*	*P-value*	*Sum of squares*	D.F.	*Middle Square*	*F- Reason*	*P-value*
A: Stirring rate	0.0816	1	0.0816	1.12	0.368	0.019	1	0.0192	0.32	0.611
B: Coagulant Concentration	0.950	1	0.950	13.00	0.0366	1.22	1	1.221	20.27	0.0205
Total error	0.219	3	0.0731			0.180	3	0.060		
Total (corr.)	1.251	5				1.421	5			

TABLE 4. ANALYSIS OF VARIANCE FOR PERCENTAGE OF TURBIDITY REMOVAL OF POSTHARVEST PLANTAIN STARCH

	Extracted with NaOH					*Extracted with water*				
Source	*Sum of squares*	D.F.	*Middle Square*	*F- Reason*	*P-value*	*Sum of squares*	D.F.	*Middle Square*	*F- Reason*	*P-value*
A: Stirring rate	41.343	1	41.343	0.72	0.457	77.688	1	77.688	8.34	0.063
B: Coagulant Concentration	7.263	1	7.263	0.13	0.745	1.625	1	1.625	0.17	0.7043
Total error	171.358	3	57.119			27.953	3	9.3178		
Total (corr.)	219.965	5				107.267	5			

For the analysis of pH variance, it was obtained that the concentration of coagulants extracted with water and NaOH had a P-value lower than 0.05. This fact indicates that this variable affects the pH, on the contrary to the agitation rate (P-value higher than 0.05) in both forms of extraction. The Durbin-Watson statistic (DW) showed that there was no serial autocorrelation since the P-value was higher than 0.05.

Table 4 shows the ANOVA analysis for the percentage of turbidity removal, finding that none of the effects has a P-value less than 0.05 indicating that these variables and their correlations are not statistically incident on the process.

As for the variance of the turbidity percentage, the two variables (agitation rate and coagulant concentration) and the extraction with NaOH had a P-value greater than 0.05. It indicates that none of these effects has an incidence on the turbidity percentage. On the other hand, the agitation rate obtained a P-value lesser than 0.05 for the coagulant extracted with water. The Durbin-Watson statistic (DW) proved that there was no serial autocorrelation since the P-value was higher than 0.05.

4. Conclusion

The plantain starch tested did not contribute odour, flavour and colour to the raw water, it was also highlighted because the pH was maintained in the acceptable range so that the coagulation-flocculation process was given satisfactorily. Under the conditions established when performing the jar test, the percentages of turbidity removal most of the cases were higher than 70%, using doses of coagulants similar to conventional synthetic coagulants. Starch extracted with water being the most efficient for the removal of turbidity, the variable with the highest linear influence being the combination of agitation rate and concentration of coagulant, it is showing better behaviour regarding turbidity removal than the commercial aluminium sulphate coagulant.

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