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Natural coagulation as an alternative to raw water treatment

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Abstract: The availability of drinking water is one of the several problems humans face, considering that its availability is reduced to 0.80% of the existing fresh water. Then, coagulation-flocculation is a stage of this treatment. It is a process that agglomerates the suspended particles in a larger (floc) that could be separated by sedimentation and filtration processes to make the water drinkable. So, this work aimed to evaluate the effect of the dose of coagulant of yam starch (*Dioscorea rotundata*) and the speed of agitation in the turbid water treatment process. For which the yam starch was extracted by implementing two methods which were NaOH and H_2O, using centrifugation at 1500 rpm for 10 min, and adjusting the pH with HCl and NaOH 0.20 M, for later determining the effect of agitation speed (rpm) and coagulant concentration (ppm) on the percentage of turbidity removal, pH, and colour, to be compared with a synthetic coagulant. A yield of 42.60% was found in the wet base. The natural coagulants extracted with NaOH presented better turbidity removal, with a percentage of 92.48% at an agitation speed of 40 rpm and a concentration of 250 ppm. It can be concluded that natural yam coagulant can be recommended for use in the coagulation stage in the raw water treatment process for subsequent conversion to drinking water.

Keywords: agitation speed, coagulant concentration, flocculation, turbid waters, yam

INTRODUCTION

One of the great problems faced by the world is the availability of fresh water, since this is vital for the survival of living beings, this because on the planet there is a limitation of the availability of 0.80% of the existing fresh water. However, the remaining 3% of surface water is not always suitable for human consumption, and it is necessary to remove impurities in order to adapt it to the potability standards [Fuentes Molina *et al.* 2016]. Wastewater treatment is a multi-stage process to restore water quality, where organic matter, solids, minerals, nutrients, disease causing organisms or other contaminants are reduced or removed from the wastewater.

Coagulation-flocculation is a stage of this treatment, it is a process that agglomerates the suspended particles in a larger (floc) that could be separated by sedimentation and filtration processes [Kaavessina *et al.* 2017]. The chemical coagulation-flocculation process consist in the elimination of suspended particles in the surface of water, with a size average of 5 to 200 nm, and it's determined by physicochemical parameters like ionic strength, point zero charge, pH, temperature, type and dose of coagulant material, type of distribution, concentration, type of pollutant and properties of organic materials and colloidal particles in suspension [Sohrabi *et al.* 2018]. Conventionally, in the process of coagulation-flocculation, polymeric flocculants and inorganic coagulating agents have been used extensively for the elimination of turbidity, dissolved and suspended solids, decrease in chemical oxygen demand in clarification and sedimentation processes [Teh *et al.* 2016]. These flocculants agents generally consist of metallic salts of synthetic origin, which affect the bodies of water if they are available without prior treatment, since their low stability and biodegradability are low [Wan Kamar *et al.* 2015]. Among the most used polymers are polyacrylamide, polyacrylic acid and various cationic polymers. However, their cost is high, they have low biodegradability in soil and water, and residual monomers have a high level of toxicity [TRUJILLO *et al.* 2014]. In contrast, natural polyelectrolytes are inexpensive, have low toxicity and good biodegradability [TIRADO *et al.* 2017]. Thus, there has been increasing interest in developing flocculants that are biodegradable and based on natural products. Some of these are: modified starch, cellulose, and bacterial polysaccharides [OLADOJA 2014].

In this sense, natural polymers of plant and animal origin are being developed in water treatment (clarification) to reduce the use of conventional flocculant coagulants. Natural coagulants of vegetable origin have been successfully evaluated in water clarification processes due to their ability to remove turbidity, colour, organic matter, colloidal particles, and microorganisms. Starches are polysaccharides present in plants, which are a source of high availability and low cost, and have many physicochemical properties like biocompatibility biodegradability, and non-toxicity [ARRIETA ALMARIO *et al.* 2019; YULIANA *et al.* 2012]. Several industrial applications have been found for starch such as pharmaceutical, food, biomedical, cosmetic and polymer [ARRIETA ALMARIO *et al.* 2019; RODRÍGUEZ-SOTO *et al.* 2019]. Currently, different investigators have found that starches can be used as flocculants due of their properties; thus could reduce cost involved in water treatment for discharges from food and beverages, mining, fermentation, dyes and textiles [SALEHIZADEH *et al.* 2018].

Natural coagulants of vegetable origin have been used from *Moringa oleifera* [RODIÑO-ARGUELLO *et al.* 2015], starch of *Manihot esculenta* [ORTIZ ALCOCER *et al.* 2018], and *Opuntia cactus* [FUENTES MOLINA *et al.* 2016], which turn out to be biodegradable, economic, safe for their compatibility with the environment; thanks to the presence of soluble proteins that acts in the process as a natural cationic cationic polyelectrolyte. The performance of the final application of starch as a coagulant and flocculant, depends to the structure and the molecular weight, in addition to environmental parameters [WU *et al.* 2016]. Then, it is important to effectively build and exploit the structure-activity relationships which influence the selection and design of high-performance flocculants in decontamination, since colloids in water are negatively charged and have a negative floc. Cationic flocculant is suitable for charge neutralisation and favourable for flocculation [OLADOJA 2015; WANG *et al.* 2013]. Nevertheless, little has been studied on the effects of polymeric flocculant chain architectures that impact process performance due to the long chain of macromolecules [WU *et al.* 2016]. Therefore, in the present study, yam starch (*Dioscorea rotundata*) was used as a clarifier of turbid waters, evaluating the effect of the coagulant dose, agitation speed and pH in the process.

MATERIAL AND METHODS

RAW MATERIAL

For the development of the present research a random experimental design of central point type by blocks was followed, developed by the software STATGRAPHICS Centurion XVIII. The effect of agitation speed (rpm) and coagulant concentration (ppm) on turbidity removal percentage and pH was evaluated. A Thomson WGZ 400B turbidimeter was used to quantify the turbidity of the samples, a 900 Bante Instrument multiparameter to measure the pH of the solutions and a Lovibond PFX195 digital colorimeter to quantify the colour present in the samples. Bentonite, distilled water, NaOH and yam were used in the execution of the experiment.

STARCH EXTRACTION

Yam starch was extracted by two methods: NaOH and H_2O. To carry out these, a solution of NaOH 2.50% and H_2O, in a 1:2 weight-volume relation, was contacted with 500 g of yam previously prepared by peeling, washing, and grating. Later, the mixture was homogenised and left to cool for 24 h at 4°C. After that, they were liquefied, filtered to be centrifuged at 1500 rpm for 10 min; to the precipitate obtained in the centrifuge, 200 cm^3 of deionised water were added, and the pH was adjusted to neutrality using HCl and NaOH 0.20 M. Then, the precipitate was centrifuged again at the same conditions, and dried for 24 h at room temperature, for subsequent milling.

JAR TESTS

Synthetic turbid water was prepared dissolving 0.30 g of bentonite in deionised water, mixing this solution for 1 h at 200 rpm. Afterwards, the solution was left for 21 h for a hydration process. Each solution was then diluted in 1.90 dm^3, and mixed resulting in a turbid water of 32.30 NTU [CANEPA *et al.* 2004]. For the coagulation-flocculation tests, a jar test equipment was used, where the prepared turbid water solution was put in contact with the natural coagulant (yam starch).

Likewise, to compare the development of the natural coagulant, the prepared turbid water was put in contact with the synthetic coagulant $Al_2(SO_4)_3$, observing its effect on pH.

All test were made by triplicate.

STATISTICAL ANALYSIS

Statistical analysis was performed with the STATGRAPHICS Centurion XVIII program, where an analysis of variance (ANOVA) with a 95% confidence level (maximum permissible error 5%) was performed.

RESULTS AND DISCUSSION

STARCH YIELD

After following the starch extraction methodology with H_2O and NaOH, the initial 500 g of hawthorn yam 213 g of bagasse and 287 g of starch on a wet basis were obtained, reaching a yield of 42.60%. Subsequently, the starch was dried, obtaining 78.20 and 81.30 g of starch by extraction methods with NaOH and H_2O, respectively. Therefore, it can be said that the hydration method is more efficient to extract starch from yam.

Previously, it was reported the extraction of starch from different fonts with yields around 0.5% [CARRASQUERO *et al.* 2017], and 1.5% [HERNÁNDEZ-CARMONA *et al.* 2017] using the extraction with water. Therefore, the percentages of starch extracted are optimal since they exceed the percentages reported, with yam starch being the highest percentage with 16.26%.

pH EFFECT

It was found all the water samples reached a pH between 6 and 8 (Fig. 1), being within the range considered suitable for the use of raw water according to Colombian standard defined by Decree 1575 [2007]; comprising what was found by [Saritha *et al.* 2017], who determined the same optimal pH range for the removal of turbidity through chitin as a natural coagulant. Likewise, the behaviour of the pH in relation to the coagulant dose and agitation rate during the jar test is inversely proportional to the concentration of the coagulant and the agitation rate does not clearly affect the pH of the samples. This behaviour could be explained for the fact that with an increase in pH, the zeta potential of the starches is more negatively charged by the presence of the carboxyl (COOH) and hydroxyl (OH) groups of the proteins [Choy *et al.* 2016].

Table 1. Results of turbidity and colour removal tests using yam starches

Starch	Speed (rpm)	Colour removal (Pt-Cb)			Turbidity removal (NTU)		
		coagulant concentration (mg·dm^3)					
		125	187.5	250	125	187.5	250
NaOH	30	10	10	0	8.3	7.1	3.3
	40	10	10	0	5.8	4.0	2.4
H_2O	30	10	10	0	12.7	11.8	8.1
	40	10	10	0	9.0	8.9	5.8

Source: own study.

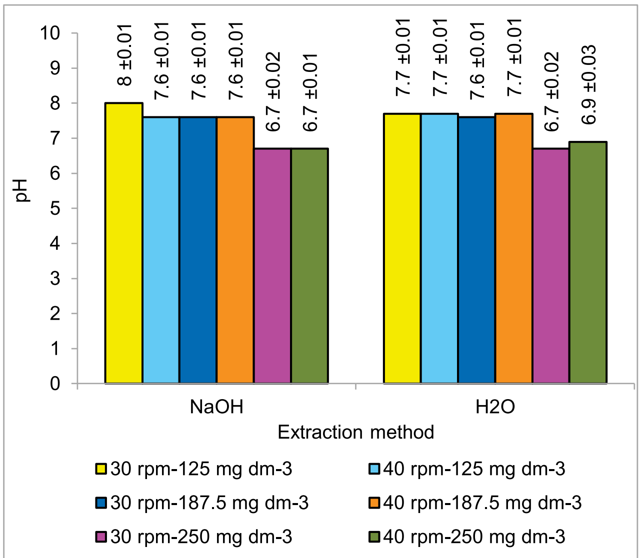

Fig. 1. pH as a function of speed and coagulant concentration of yam starches; source: own study

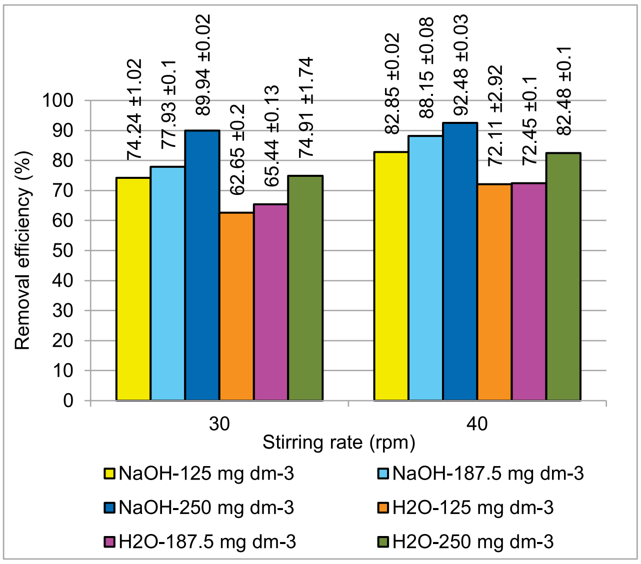

Fig. 2. Effect of the agitation speed (rpm), coagulant dose (ppm) and type of extraction on the percentage of turbidity removal; source: own study

The pH can change the superficial charge of coagulants and pollutants; thus, it is a critical variable involve in coagulation-flocculation processes [Kukić *et al.* 2015]. In this sense, it has been reported pH dependence when using acorn and nut of horse chestnut from common oak used like natural coagulants [Antov *et al.* 2018], the opposite happened with bean seed extracts [Kukić *et al.* 2015], and plantain peel powder [Daverey *et al.* 2019]. This implies that the natural coagulants obtained in this investigation are highly stable over a wide pH range, which is an influential criteria for choosing a coagulants for its use in treatment of wastewater [Paredes *et al.* 2018].

EVALUATION OF TURBIDITY AND COLOUR REDUCTION

The results of removal of colour and turbidity after the jar test show that all colour values are in the value of 10 cobalt-platinum, this indicates that they are in an acceptable range according to Decree 1575 of 2007 for potable waters (Tab. 1).

The Figure 2 shows the behaviour of turbidity in relation to the coagulant dose and the agitation speed during the jar test. It is observed that when the coagulant dose of 250 ppm is added, it is where the highest percentage of turbidity removal is achieved in comparison with the other coagulants and speeds at which the work was performed. In this same figure it is observed that the percentage of reduction of turbidity is directly proportional to the agitation speed and to the concentration of the coagulant, in the same way these affect in a notorious way the reduction in the process of coagulation-flocculation, coincide with what was reported by [dos Santos *et al.* 2018], who observed in the coagulation/flocculation tests evaluated a rapid decrease in values of colour and turbidity of the starch effluent for the different concentrations evaluated.

STATISTICAL ANALYSIS

Table 2 shows the results obtained from the analysis of variance over the pH of the extracted yam starches to determine the effects of the tested factors, finding that the yam starch extracted with NaOH had a significant effect on the concentration ($p < 0.05$). On the other hand, cassava starch extracted with H_2O had no significant effect ($p > 0.05$) on the agitation speed or on the concentration of the coagulant. In the percentage of turbidity removal with starch extracted by the two methods tested NaOH and H_2O from yam, ANOVA results gave a p-value less than 0.05

Table 2. ANOVA for obtained yam starches

Parameter	NaOH			H_2O		
	sum of squares	*F*-value	*p*	sum of squares	*F*-value	*p*-value
A factor	0.045	0.39	0.578	0.020	0.17	0.705
B factor	1.265	10.83	0.046	0.893	7.55	0.071
Total error	0.350			0.354		
Error (corr.)	1.661			1.268		

Explanations: A = stirring rate, B = coagulant concentration.
Source: own study.

in both effects (agitation speed and coagulant concentration) in the two extraction methods which indicates that these effects had a significant influence on the removal of turbidity.

COMPARISON OF SYNTHESISED STARCH WITH A SYNTHETIC COAGULANT

The Figure 3 shows the results obtained from a pH measurement of raw water samples after a jug test using the synthetic coagulant $Al_2(SO_4)_3$. Comparing the results of Figures 1 and 3, it was found that the presented residual pH values of the natural coagulants extracted from yam are closer to the ranges stipulated by the current Colombian norm than those found with the synthetic coagulant, opposite case with that reported by Ortiz Alcocer *et al.* [2018], where the pH values were between 6.9–7.8, for the coagulant of cassava starch and synthetic coagulant $Al_2(SO_4)_3$.

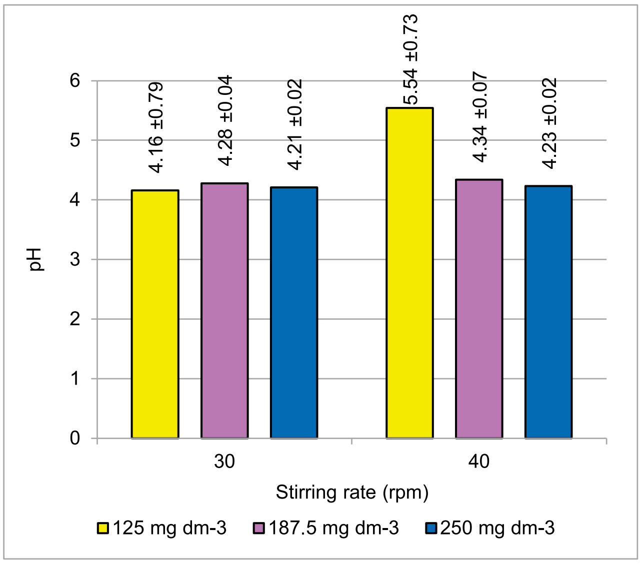

Fig. 3. Effect of coagulant concentration, type of extraction and speed of agitation on pH; source: own study

In the Table 3 are shown the results obtained from a colour measurement of raw water samples after a jar test using $Al_2(SO_4)_3$ as a synthetic coagulant. When comparing the results obtained for the synthetic coagulant with those of the natural coagulant (Tab. 1), the colour values for both the natural coagulants extracted from the yam and the synthetic coagulants had the same value. Likewise, the residual turbidity values obtained with the natural coagulants extracted from yam did not reach the minimum value required by the normative of Colombia, different from the data presented by Molina *et al.* [2016], who obtained the best turbidity values in natural coagulants as a substitute for $Al_2(SO_4)_3$. However, the results are satisfactory considering the conclusion of Rodiño-Arguello *et al.* [2015], which indicated that a complementary sedimentation and filtration process can be used as an alternative coagulation-flocculation water treatment system valid for small scale or rural areas. These results could be attached to the quickly formation of flocs with good characteristics, whose contributed to the appropriate sedimentation because of the consistency and weight of the particles; thus, according to the results obtained by Paredes *et al.* [2018].

Table 3. Removal of colour and turbidity using the commercial synthetic coagulant $Al_2(SO_4)_3$.

Speed (rpm)	Colour removal (Pt-Cb)			Turbidity removal (NTU)		
	coagulant concentration ($mg \cdot dm^3$)					
	125.0	187.5	250.0	125.0	187.5	250.0
30	10	10	10	3.5	3.9	2.5
40	10	10	10	2.2	2.3	2.5

Source: own study.

CONCLUSIONS

The obtaining of the coagulant in powder from yam using NaOH and H_2O was satisfactory, getting the best results of turbidity removal with the starch extracted by alkaline route, with a starch synthesis yield of 42.60% in wet base. The synthesised coagulant did not add odour, flavour, or colour to the raw water. Also, it was highlighted because the pH was maintained in the range of current Colombian regulations. It was found that using starch extracted with sodium hydroxide, agitation speed of 40 rpm, and coagulant concentration of 250 ppm, a removal percentage higher than 92% was reached. From the obtained results when using the natural coagulant respect $Al_2(SO_4)_3$, it could be said that a complementary sedimentation and filtration process can be used as an alternative coagulation-flocculation water treatment system valid for small-scale or rural areas. So the use of natural coagulant from yam can be recommended for use in the coagulation stage in raw water treatment process for subsequent potabilisation.

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