Ambiente & Água - An Interdisciplinary Journal of Applied Science
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
E-mail: ambi.agua@gmail.com

Removal of turbidity and color in domestic wastewater using aqueous seed extract of *Cassia fistula*

ARTICLES doi:10.4136/ambi-agua.2803

Received: 04 Oct. 2021; Accepted: 09 Mar. 2022

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ABSTRACT

Many substances of plant origin are extracted for use in the primary treatment of domestic wastewater. In most cases, they are used as coagulating and flocculating agents and are derived from seeds, leaves, bark or sap, roots, and fruits of trees and plants. In this research, the use of *Cassia fistula* seed was evaluated for the removal of turbidity and color in domestic wastewater from a pumping station in the city of Cartagena (Colombia). The optimal dose of *C. fistula* seed powder was determined by jar test using an E&Q F6-300 digital flocculator. Physicochemical parameters such as turbidity and color were determined, following the recommendations of APHA (Standard Methods for Water and Wastewater), expressing the results in UNT (Total Nephelometric Units) for turbidity, and UPt-Co (Platinum-Cobalt Units) for the color. The results obtained show that with a dose of 160 mgL^{-1} of the coagulant extracted from the *C. fistula* seed, a value of 34.14 NTU is reached for removal of 62.18% with respect to the initial turbidity value. The color decreases reaching a minimum value of 88.59 UPC for removal of 64%, at a dose of 160 mgL^{-1} of natural coagulant. The seed *C. fistula* exhibited good coagulating properties at low doses and can be an important alternative for the removal of color and turbidity in wastewater.

Keywords: color, removal, turbidity, water treatment.

Remoção de turbidez e cor em efluentes domésticos usando extrato aquoso de sementes de *Cassia fistula*

RESUMO

Muitas substâncias de origem vegetal são extraídas para serem utilizadas no tratamento primário de águas residuais domésticas. Na maioria dos casos, elas são usadas como agentes coagulantes e floculantes e são derivadas de sementes, folhas, cascas ou seiva, raízes e frutos de árvores e plantas. Nesta pesquisa, avaliou-se o uso da semente de Cassia fístula para a remoção de turbidez e cor em águas residuais domésticas de uma estação de bombeamento na cidade de Cartagena (Colômbia). A dose ideal de pó de semente de C. fístula foi determinada por teste de jarro usando um floculador digital E&Q F6-300. Parâmetros físico-químicos como turbidez e cor foram determinados, seguindo as recomendações da APHA (Métodos Padrão para Água e Esgoto), expressando os resultados em UNT (Unidade Nefelométrica Total) para turbidez e UPt-Co (Unidade de Platina-Cobalto) para a cor. Os resultados obtidos mostram que com uma dose de 160 mgL^{-1} do coagulante extraído da semente de C. fístula, atinge-se um valor de 34,14 NTU para remoção de 62,18% em relação ao valor de turbidez inicial. A cor diminui atingindo um valor mínimo de 88,59 UPC para remoção de 64%, na dose de 160 mgL^{-1} de coagulante natural. A semente de C. fistula exibiu boas propriedades de coagulação em baixas doses e pode ser uma alternativa importante para a remoção de cor e turbidez em águas residuárias.

Palavras-chave: cor, remoção, tratamento de água, turbidez.

1. INTRODUCTION

The quality of both drinking and domestic wastewater is determined in terms of physical, chemical, and biological parameters and its monitoring is extremely important since it is known that the consumption of contaminated water accelerates the appearance of many health problems (Mirzabeygi *et al.*, 2017; Soleimani *et al.*, 2018). High concentrations of organic compounds and suspended particles in the water increase turbidity, serving as a medium for transmitting pathogenic organisms; therefore, the removal of turbidity is an important process in water treatment (Hameed *et al.*, 2018). The removal of turbidity and color in water treatment is basically achieved simply and inexpensively through processes such as coagulation and flocculation. The residual waters produced by domestic activities are usually contaminated by particles, many of which are suspended solids. Removal of these contaminants generally requires the use of coagulants.

Coagulation is one of the oldest processes, widely used in the treatment of drinking and wastewater. Coagulation is a process that removes impurities, especially suspended particles and colloids in water, by destabilizing and agglomerating the particles into larger aggregates. This allows the aggregates to settle quickly and can subsequently be easily separated from the water (Jiang, 2015).

In recent years, the paradigm in the treatment of drinking water and industrial wastewater has changed the culture of water operators, by adopting and implementing sustainable development in the operation. One of the realistic practices is to replace the chemicals used in the treatment process with "green" chemicals that cause less environmental impact in terms of production, consumption, and secondary waste management. In this context, natural coagulant seems to fit this picture and may be an option over conventional inorganic coagulants.

It is reported that natural coagulants are generally easily obtainable from plant raw material; produce less biodegradable sludge (potentially reducing the costs associated with its disposal) and are less affected by the pH of the water (Mohd-Salleh *et al.*, 2019; Saleem and Bachmann, 2019) Inorganic coagulants such as alum are widely used to remove turbidity from the water (Hussain *et al.*, 2019; Ramavandi, 2014). Currently, numerous substances extracted from plants with coagulant activity (natural coagulants) have been discovered. Natural coagulants have proven their clotting efficacy as reported in a substantial number of research articles. However, the widespread acceptance and application of natural coagulants in the water industry remain low.

A review is necessary to promote the use of natural coagulants, highlighting the current development and efforts to improve the capacity of natural coagulants (Ang and Mohammad, 2020; Tarón *et al.*, 2017). Several explanations have been suggested in the literature regarding the coagulant activity of the extracts of natural coagulants (Guzmán *et al.*, 2013).

Ndabigengesere *et al.* (1995) proposed that proteins with a molecular weight of 13 kDa present in plant extracts are active components for coagulation. The chemical composition of the extracts obtained from natural coagulants does not clearly explain the coagulation activity

(Bui *et al.*, 2016; Guzmán *et al.*, 2015; Šciban *et al.*, 2009). Some authors have suggested that the active components of coagulation in plant extracts are not proteins, but some type of organic polyelectrolyte (Sanghi *et al.*, 2002; Okuda *et al.*, 2001).

There are several natural plant extracts such as *Moringa oleifera*, *Jatropha curcas*, *Cyamopsis tetragonoloba*, *Strychnos potatorum*, *Hibiscus sabdariffa*, and *Clidemia angustifolia* that have been used in coagulation and water purification for many years. These coagulants, for the most part, are derived from seeds, leaves, bark or sap, roots and fruits of trees and plants, or can be extracted from microorganisms, animal or plant tissues (Yuan and Manh, 2015). The cañafistula, carao, or cañadonga is a natural tree of Central America and the coastal areas of the Antilles, belonging to the family Fabaceae genus Cassia. In Colombia, México, and probably other countries, it is also known as a *Cassia fistula* Golden-Shower (Tarón *et al.*, 2017).

Guzmán *et al.* (2015), reported in their study that *Cassia fistula* seed powder has excellent properties to be used in the primary treatment of drinking water. In this research, the coagulant power of the *Cassia fistula* seed and its effect on the removal of color and turbidity in domestic wastewater was evaluated.

2. MATERIAL AND METHODS

2.1. Domestic wastewater sample

Domestic wastewater from the domestic wastewater pumping station located in the "La Cuchilla" sector (10.405672, 75.521783) of the city of Cartagena de Indias - Colombia was used. The sample was collected between 9:00 and 10:00 a.m., since it is assumed that a maximum discharge peak passes through this pumping station at that time and contains high levels of turbidity and color.

2.2. Initial physicochemical characterization of wastewater

The domestic wastewater was characterized physicochemically, following the methodology proposed by APHA *et al.* (2012). Turbidity was determined by the nephelometric method (method 2130B); using a Turbiquant 300 IR turbidimeter which measures turbidity in nephelometric turbidity units (NTU) using a formalin polymer as a standard solution.

Table 1 shows the values of the physicochemical parameters of the residual effluent.

Table 1. Initial physicochemical characterization of domestic wastewater.

Parameter	Value	Unit
Total alkalinity	218.0±1.00	mg $CaCO_3$ L^{-1}
BOD	128.1±0.81	mgL^{-1}
COD	219.4±0.76	mgL^{-1}
Total hardness	490.0±0.57	mg $CaCO_3$ L^{-1}
Conductivity	1210.2±0.8	μScm^{-1}
Turbidness	90.28±1.00	NTU
Colour	246.1±0.60	UPC
Total solids	701.0±0.22	mgL^{-1}

Values represent the mean of three determinations (N = 3). Source: the authors and adapted from Tarón et al., (2017).

2.3. Obtaining the coagulant

The natural coagulant was obtained according to the scheme proposed by Yin (2010). The seeds of *C. fistula* were collected manually, the seeds damaged by insects were discarded. Later they were subjected to sun exposure, for approximately 8 days. Immediately upon drying, these were mechanically ground, using a Pulvex Model 95 helical mill; the powder obtained was passed through a 40 mesh sieve. The coagulant solution was prepared by dissolving 25 g of seed powder in 100 mL of distilled water.

2.4. Jar Test

The standard jar test described by Satterfield (2005) was used in this investigation. This consisted of preparing seven solutions with 500 mL of residual water obtained from the pumping station, using one as a control; the remaining six were dosed with *C. fistula* seed extracts at concentrations of 120, 140, 150, 160, 180, and 200 mg / L respectively. The residual water and that mixed with the coagulating agent were initially stirred at 100 rpm for 1 minute, followed by slow stirring at a speed of 40 rpm for 30 minutes; subsequently, the samples were allowed to stand for 60 minutes (sedimentation time). For this, an E&Q F6-300 digital flocculator was used. After the sedimentation time, samples of the supernatant liquid are taken for analysis.

The percentage turbidity removal was determined using Equation 1.

$$percent\ turbidity\ removal = \frac{T_o - T_f}{T_o} * 100 \quad (1)$$

Where; T_o is the initial turbidity value and T_f is the final turbidity value, for each dose of coagulant.

The color was measured by visual comparison of the sample using a Lovibond PFX 195 colorimeter applying the 2120B method and the results of the color evaluation were expressed in platinum-cobalt units (UPC).

The percentage of color removal was determined using Equation 2.

$$percent\ color\ removal = \frac{C_o - C_f}{C_o} * 100 \quad (2)$$

Where C_o is the initial value of the color and C_f is the final value, for each dose of coagulant.

2.5. Statistical analysis

The percentage of removal of turbidity and color was used as response variables. These data were analyzed using the analysis of variance (one-way ANOVA) in order to determine statistically significant differences ($p < 0.05$) between the samples. SPSS software (Version 17.0 for Windows) and Tukey's multiple comparison test were used. All tests were done in triplicate.

3. RESULTS AND DISCUSSION

Table 2 shows the values of the physicochemical parameters of domestic wastewater before and after the coagulation process, using a dose of 160 mgL^{-1}. The results show that the coagulant presents excellent coagulation conditions, which shows a decrease in the levels of the analyzed physicochemical parameters, finding significant differences at $p < 0.05$. When comparing the results with some coagulants used, there is correspondence between them, such as the case of Aluminum Sulfate (Al_2SO_4), which presents similar removal percentages, but using a dose of 20 mgL^{-1}. Prakash *et al.* (2014), reported similar results, but using Moringa oleifera seeds as coagulant.

Table 2. Physicochemical characterization of the domestic residual effluent after the coagulation process with *C. fistula* seed at a dose of 160 mgL^{-1}.

Parameter	Residual effluent (Ci)	Aqueous extract of Seed of *C. fistula*	$(Al_2SO_4)^*$	Unid
Total alkalinity	218.0±1.00[a]	261.1±08[b]	290.0	mg $CaCO_3$ L^{-1}
Biochemical Oxygen Demand (BOD_5)	128.1±0.81[a]	52.38±20[b]	31.92	mgL^{-1}
Chemical Oxygen Demand (COD)	219.4±0.76[a]	211.1±10[a]	245.0	mgL^{-1}
Total hardness	490.0±0.57[a]	401.3±00[b]	331.5	mg $CaCO_3$ L^{-1}
Conductivity	1210.2±0.8[a]	1346.1±1[b]	1330	μScm^{-1}
Turbidness	90.28±1.00[a]	34.14±17[b]	9.500	NTU
Colour	246.1±0.60[a]	88.59±23[b]	42.00	UPC
Total solids	701.0±0.22[a]	230.2±05[b]	149.4	mgL^{-1}

* taken from Tarón *et al.* (2017), (Al_2SO_4) * at a dose of 20 mgL^{-1}. Different letters in each row show statistically significant differences at $p < 0.05$. C_i: Initial conditions.
Source: the authors.

The BOD_5 value decreases considerably with respect to the initial value, finding statistically significant differences at $p < 0.05$, obtaining a maximum value in removal of 57.02%, using a coagulant dose of 160 mgL^{-1}, these results correspond to those reported for Aluminum Sulfate (Al_2SO_4), which achieved a decrease in the biochemical oxygen demand of 75.08% (Tarón *et al.*, 2017).

Regarding the chemical oxygen demand (COD), no statistically significant differences were found at $p > 0.05$ at a dose of 160 mgL^{-1} of coagulant; it may be feasible, possibly due to the action of various compounds of an organic nature and not biodegradable by conventional methods and refractory to biological oxidation.

Alkalinity, unlike the other physicochemical parameters, increased its concentration level; this behavior can be explained, supported by the possible restoration of the system by the dissolution of the flocs formed (Guzmán *et al.*, 2015).

The domestic wastewater sample initially contained a fairly high level of turbidity (90.28 ± 1.00), characteristic for this type of effluent; the doses of coagulants used in the coagulation process decreased the levels of turbidity in the effluent, at different doses. In Table 3, the results of the turbidity levels in the domestic wastewater can be seen, taking into account the concentrations used in the aqueous extract of *C. fistula* seed.

According to Equation 1, raised in Section 2.4 of this manuscript, removal percentages of 47.09, 54.13, 50.60 and 54.00% are achieved, when using doses of 120, 140, 180 and 200 mgL^{-1} of coagulant, respectively, highlighting that the maximum removal occurs when using a dose of 160 mgL^{-1} of aqueous extract of *C. fistula* seed, in which a removal of 62.18% is achieved, these results are in accordance with those reported in the literature, using other natural coagulants, such as those of *M. oleifera* and chemical coagulants such as Aluminum Sulfate, which present a coagulation capacity greater than that of *C. fistula* seed.

Table 3. Behavior of turbidity and color in domestic waste effluent

Parameters *	Coagulant dose (mgL^{-1})				
	120	140	160	180	200
Turbidity	47.76±1[a]	41.41±82[b]	34.14±17[c]	44.59±40[d]	41.52±15[d]
Colour	169.34±06[a]	117.14±21[b]	88.59±23[c]	99.42±28[d]	98.19±17[d]

***** *different letters in each row show statistically significant differences at $p < 0.05$*.
Source: the authors.

An important aspect to highlight is the fact that after reaching the peak of maximum removal, this percentage (%) decreases, when increasing the coagulant dose from 160 mgL^{-1} to 180 and 200 mgL^{-1} (Figure 1). What would be expected would be that the removal would have a variation directly with the coagulant concentration; the fact that the turbidity level experiences an increase may be caused by an increase in the concentration of total solids, due to the restoration of the system by the dissolution of the flocs formed (Guzmán *et al.*, 2015).

The analysis of variance (ANOVA) shows that there is no statistically significant difference at p> 0,05, between the effluent turbidity levels, when a dose of 180 mgL^{-1} is used with that of 200 mgL^{-1}. According to the results, the aqueous extract of *C. fistula* seed has good coagulant properties that allow it to remove turbidity in waters with high content of solids and organic matter, although these percentages are lower than those presented by sulfate. aluminum, which is one of the most widely used coagulants in the primary treatment of raw and wastewater.

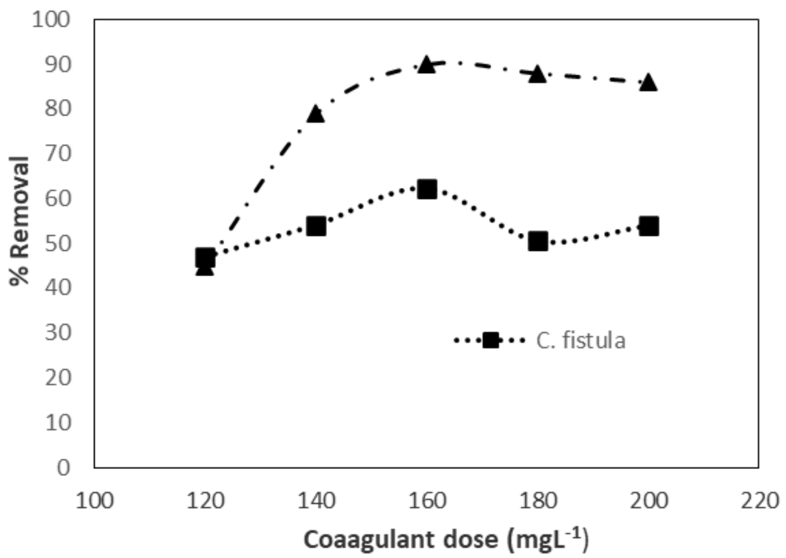

Figure 1. Turbidity removal percentage vs. dose of coagulant applied.
Tarón et al., 2017; doses of Aluminum sulfate [10, 15, 20, 25 and 30 mgL^{-1}].

In Figure 2, the behavior of the color in the effluent is shown, for a dose of 120 mgL^{-1} of coagulant, a removal of 31.19% is achieved, which supposes, being a low percentage of removal, is a promising result, taking into account that, in primary wastewater treatments, higher doses of these are used. These results correspond to those found by Barreto *et al.* (2018), but using avocado seeds (*Persea gratissima* Goerin).

The most efficient dose, in the removal of color, is obtained by using a coagulant concentration of 160 mg L^{-1}, achieving 64% of the total color removal, finding significant statistical differences at p> 0.05 when compared with the percentages obtained with other doses of coagulant. For doses of 180 and 200 mg L^{-1}, no statistical differences were found at p> 0.05.

It must be taken into account that, when using high doses of coagulant, above 160 mgL^{-1}, a re-stabilization of the dispersion can occur, which results in an increase in the turbidity and color values (Guzmán *et al.*, 2015).

The coagulant effect and the ability to remove color in domestic wastewater from the aqueous extract of the *C. fistula* seed is lower than that of aluminum sulfate (Al_2SO_4); however, this can be an advantage, when used in the treatment primary water and thus reduce the amounts used of inorganic polyelectrolytes (chemical coagulants).

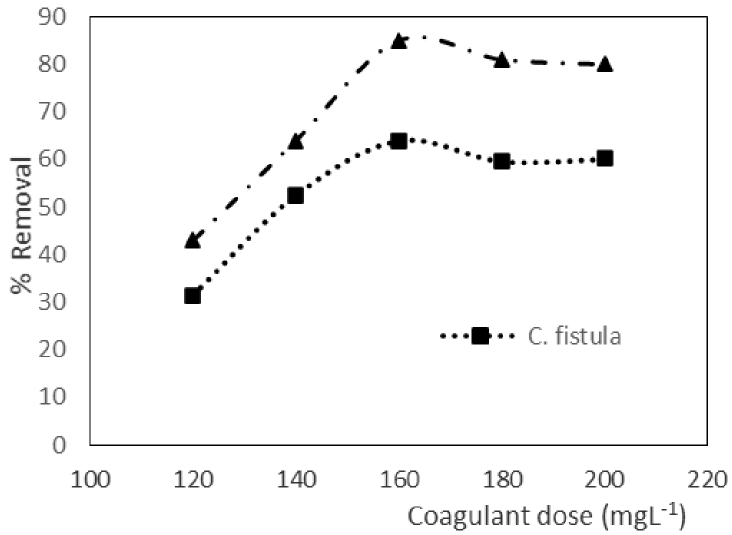

Figure 2. Percentage of color removal vs. dose of coagulant applied.
Tarón et al. (2017); doses of Aluminum sulfate [10, 15, 20, 25 and 30 mgL^{-1}].

4. CONCLUSIONS

The aqueous extract of the *C. fistula* seed powder has interesting qualities to be used in practice as an alternative natural coagulant in the primary treatment of domestic wastewater using dosages close to 160 mg L^{-1}. In this investigation, it was found that the coagulating power and the ability to remove color, turbidity, total solids, and BOD_5 from the aqueous extract of the seed of *C. fistula* is lower than that of aluminum sulfate, which indicates that further investigation is necessary regarding its feasibility for use as a secondary coagulant.

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