Use of natural mucilage extracted from the *Stenocereus griseus* (Cardón Guajiro) plant as a coagulant in the treatment of domestic wastewater

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Arnulfo Antonio Tarón Dunoyer1*; Rafael Emilio González Cuello1; Fredy Colpas Castillo2

1Faculty of Engineering. Food Engineering Program. University of Cartagena, Street 30, n°48-152, 130014, Zaragocilla, Cartagena, Colombia. E-mail: rgonzalezc1@unicartagena.edu.co
2Exact and Natural Sciences Faculty. Chemistry program. University of Cartagena, Street 50, n°24120, 130014, Zaragocilla, Cartagena, Colombia. E-mail: fcolpasc1@unicartagena.edu.co

*Corresponding author. E-mail: atarond@unicartagena.edu.co

ABSTRACT

Coagulants can be extracted from vegetal material and applied in the treatment of wastewater. These coagulants are derived from seeds, leaves, bark, roots and fruits. This study focuses on the use of the mucilaginous extract of *Stenocereus griseus* (known as Cardón Guajiro) for removal of biochemical oxygen demand (BOD5), chemical oxygen demand (COD), total solids, turbidity and color in domestic wastewater from a pumping station in the city of Cartagena (Colombia). The optimal dose of *S. griseus* extract was determined by a pitcher test employing an E&Q F6-300 digital flocculator. All physicochemical tests were carried out following the specifications of the standard methods for wastewater (APHA). When 1400 mgL⁻¹ of natural coagulants were used in the sewage treatment, the turbidity obtained was 29.57 TNU, representing removal of 67.24%, considering the initial turbidity. This parameter decreases until 68.61 PCU, for a 72.12% removal at the same coagulant dosage regarding the color. It must be noted that significant statistical differences were found between all tested doses of the coagulant. The mucilaginous extract of *S. griseus* exhibited useful properties in the primary treatment of domestic wastewater.

Keywords: coagulation, color, removal, turbidity, water treatment.

Tratamento primário de águas residuais domésticas a partir da mucilagem natural extraída da fábrica de *Stenocereus griseus* (Cardón Guajiro) como coagulante

RESUMO

Os coagulantes podem ser extraídos de matéria vegetal e aplicados no tratamento de efluentes. Esses coagulantes são derivados de sementes, folhas, cascas, raízes e frutos. Este estudo enfoca o uso do extrato mucilaginoso de *Stenocereus griseus* (conhecido como Cardón Guajiro) para a remoção da demanda bioquímica de oxigênio (DBO5), demanda química de oxigênio (COD), sólidos totais, turbidez e cor em águas residuais domésticas de uma estátion de bombeamento na cidade de Cartagena (Colômbia). A dose ideal de extrato de *S. griseus* foi
determinada por um teste de jarro empregando um floculador digital E & Q F6-300. Todas as determinações físico-químicas foram realizadas seguindo as especificações dos métodos padrão para efluentes da APHA (Standard Methods for Water and Wastewater). Quando foram utilizados 1400 mgL\(^{-1}\) de coagulante natural no tratamento de esgoto, a turbidez obtida foi de 29,57 TNU, representando remoção de 67,24% considerando a turbidez inicial. Este parâmetro diminui até 68,61 PCU para uma remoção de 72,12% na mesma dosagem de coagulante em relação à cor. Deve-se notar que diferenças estatísticas significativas foram encontradas entre todas as doses testadas do coagulante. O extrato mucilaginoso de \(S.\) griseus, teve propriedades valiosas no tratamento primário de águas residuais domésticas.

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

1. INTRODUCTION

Domestic wastewater processes involve physicochemical treatment (coagulation and flocculation). Coagulation is defined as adding chemicals reagents to wastewater for agglutination of small particles into larger particles that can be removed by solids processes (Ang and Mohammad, 2020; Luo et al., 2020; Guzmán et al., 2013). A wide range of wastewater treatments has been developed over the last decades. These treatments can be classified into physical (sedimentation, filtration, adsorption and UV), chemical (coagulation, electrochemical, ion exchange, oxidation, catalytic reduction and disinfection) and biological (phytoremediation and biodegradation) (Kooijman et al., 2020; Ang and Mohammad, 2019; Hamzah et al., 2017; Kumar and Chowdhury, 2020; Hoong and Ismail, 2018).

Coagulation is an essential process for removing turbidity, color and organic matter in domestic and industrial wastewater. Some coagulants employed to remove impurities and colloidal particles from wastewater are ferric chlorides, aluminum sulfate, polyaluminum chloride, and calcium carbonate (Bergamasco et al., 2009). Nevertheless, there are some disadvantages related to the use of coagulants, such as cost, production of large volumes of sludge and pH modifications of the treated water (Olivero et al., 2014; Yin, 2010). Bergamasco et al., 2009). Several studies have reported the efficiency of some low-cost coagulants employed in wastewater treatments. For example, Jaafari et al. (2020) employed a magnetic chitosan to remove anionic dyes from polluted waters. Likewise, Naghipour et al. (2018) carried out studies to remove diclofenac from aqueous solutions using activated pine charcoal as adsorbent material.

Natural coagulants have been studied as an alternative to traditional chemical coagulants. Some natural coagulants studied are those obtained from vegetal species such as \(Moringa oleifera\) (Okuda et al., 1999; Caldera et al., 2007) from \(Cereus deficiens\) (commonly known as cactus or cardon lefaria) (Martínez et al., 2003) and from \(Opuntia cochinellifera\) (Almendárez de Quezada, 2004). The genus \(Stenocereus\) (Berger) Riccob Comprises a heterogeneous group of cacti distributed from southern Arizona to northern Colombia and Venezuela (Anderson, 2001; Terrazas et al., 2005). The "cardón guajiro" or "yosú" (in Wayúu language), \(Stenocereus griseus\) (Haw.) Buxb, is a columnar cactus that can reach up to 11 m in height. In Colombia, it is present in the departments of Guajira, Cesar and Magdalena. This vegetal species has not been studied previously as a coagulant of wastewater.

However, the active compounds of cardon guajiro, such as polysaccharides and proteins, can be a useful alternative to coagulation and flocculation processes of various pollutants. It is also a plant that grows easily on the north coast of Colombia; it has low cost and does not generate a negative environmental impact, which makes this plant a very attractive source of coagulant material for the industry. This work therefore focuses on evaluating the use of mucilage extracted from \(Stenocereus griseus\) as a natural coagulant in domestic wastewater.
2. MATERIALS AND METHODS

2.1. Wastewater sample

The wastewater was obtained from a pumping station located in Cartagena de Indias, Colombia. The water sample was collected in the morning because, at that time, there was maximum discharge volume and the wastewater presents high levels of turbidity. The plants of *S. griseus* were obtained from the northern region of Colombia, at San Juan del Cesar in Guajira.

2.2. Physicochemical characterization of wastewater.

The wastewater sample was characterized following the Standard Methods for Water and Wastewater (APHA *et al.*, 2012). For color determination, a colorimeter (Lovibond PFX 195) was employed using the 2120B method; the results were expressed as platinum-cobalt units (PCU). Turbidity was determined by the nephelometric method (Method 2130B) using a turbidity meter (Turbiquant 3000 IR). The pH was assessed by potentiometry with a digital potentiometer (Bench pH/Conductivity meter PC 510). Alkalinity was calculated by titration (expressed in mg of CaCO$_3$/L). Hardness was measured by titration using an EDTA solution as the titrating agent; this parameter was expressed in mg of CaCO$_3$/L. Table 1 shows the values obtained for the wastewater characterization.

| Parameters                      | Value        | Unit       |
|---------------------------------|--------------|------------|
| Total alkalinity                | 218.0±1.00   | mg CaCO$_3$/L |
| Biochemical Oxygen Demand (BOD$_5$) | 128.1±0.81 | mg/L       |
| Chemical Oxygen Demand (COD)    | 219.4±0.76   | mg/L       |
| Total hardness                  | 490.0±0.57   | mg CaCO$_3$/L |
| Conductivity                    | 1210.2±0.8   | μScm$^{-1}$ |
| Turbidity                       | 90.28±1.00   | NTU        |
| Color                           | 246.1±0.60   | UPC        |
| Total solids                    | 610.0±0.22   | mg/L       |

2.3. Preparation of the coagulant

The mucilage (coagulant) was extracted from plants of *S. griseus*, especially the section between the bark and the woody tubular medulla (stem pulp). The epidermis was removed from fragments of *S. griseus* stems and the parenchymatous tissue. This parenchyma was liquefied for one (1) minute. Then, the solid phase was separated from the aqueous phase and the aqueous phase mass was determined by gravimetry. Finally, distilled water was added to obtain a mucilaginous heterogeneous mixture (Fuentes *et al.*, 2011).

2.4. Coagulation process

The standard jar test described by Satterfield (2005) was used to determine the optimum coagulant dosage. The mucilaginous mixture described in Section 2.3 500 mL of coagulant-wastewater solutions at different concentrations (800, 1000, 1200, 1400 and 1600 mg L$^{-1}$) was prepared employing wastewater without coagulant and another containing Al$_2$(SO$_4$)$_3$ as control. Then, both wastewaters (with and without coagulant) were subjected to agitation at 100 rpm during 1 minute, followed by slow agitation at 40 rpm for 30 minutes. Finally, all samples were left for 60 minutes to allow sedimentation (Tarón *et al.*, 2017). The assays were performed at room temperature in an E&Q F6-300 Digital Flocculator.

The turbidity removal percentage was determined using Equation 1.
\[
Turbidity\ removal\ (\%) = \frac{T_0 - T_f}{T_0} \times 100
\]

Where: \(T_0\) is the initial value of turbidity and \(T_f\) is the final value of turbidity.

The percentage of color removal was determined using Equation 2.

\[
color\ removal\ (\%) = \frac{C_o - C_f}{C_o} \times 100
\]

Where, \(C_o\) is the initial value of color and \(C_f\) is the final value of color.

2.5. Statistical analysis

The results were analyzed by means of ANOVA (one way) to determine statistically significant differences (P<0.05) among the samples. The software SPSS (Version 17.0 for Windows) was used. All tests were done in triplicate.

3. RESULTS AND DISCUSSION

3.1. Physicochemical characterization of the effluent after treatment with coagulants

Table 2 shows the physicochemical parameters evaluated in wastewater subjected to coagulant at different dosages. Statistical differences can be seen (P<0.05) between initial and final values of alkalinity at doses 800, 100 and 1200 mgL\(^{-1}\) of the mucilaginous extract of \(S. \) griseus (MES. g). These removal percentages are lower than those found for (Al\(_2\)(SO\(_4\))\(_3\) at all doses tested. At 1400, 1600 and 1800 mgL\(^{-1}\) of MES. g, no significant differences (P>0.05) were found. The results are similar to those reported by Dearmas Duarte and Ramírez Hernández (2015), that achieve efficient nutrient removal through the use of natural and chemical coagulants in a wastewater treatment plant.

As doses of MES. g increase, the percentages of total solids removed also increase. The highest percentage of removal was 70.49%, which was reached employing a coagulant dosage of 1400 mgL\(^{-1}\). When high doses (>1600mgL\(^{-1}\)) of coagulant were used, a slight increase in solid content was observed due to the load that can produce a re-stabilization of the system. This behavior also could be associated with the increase of coagulant requirement when the suspended solids rise, since the polymers can present an optimum coagulant concentration that depends on the molecular weight and ion concentration solids in suspension (Sánchez and Untiveros, 2004).

Regarding the chemical coagulant employed (Al\(_2\)(SO\(_4\))\(_3\), a similar behavior was seen. However, it must be noted that solids-removal levels are higher using low doses of coagulant (25 mgL\(^{-1}\)). The highest percentage of solid removal was 74.95; this is in accordance with the observations of Dearmas Duarte and Ramírez Hernández (2015). Statistical differences were appreciated among the percentages of solids removal using different dosages of coagulant. Presently, no investigations have been conducted pertaining to the use of coagulants extracted from \(S. \) griseus for water purification. Nevertheless, the effect of various suspensions of \(Stenocereus \) griseus, \(Cereus \) deficiens, \(Opuntia \) ficus-indica and polyacrylamide on physical properties of the soil of Quibor (Lara State, Venezuela) has been evaluated, with \(Stenocereus \) griseus being considered the best flocculants (Henríquez et al., 2000).

The findings seen in Table 2 demonstrate that mucilaginous extract of \(S. \) griseus can be employed to decrease levels of biological and chemical degradation of organic matter. A higher percentage of chemical degradation of organic matter was reached when 1400 mgL\(^{-1}\) of dosage of coagulant was used in the process. Statistical differences were observed among all coagulant dosages. Similar behavior was found for BOD\(_5\); the best degradation result is obtained when high doses of coagulant (>1400 mgL\(^{-1}\)) are used. Statistical differences were noted between all values of BOD\(_5\) obtained, as can be seen in Figure 1.
Table 2. Physicochemical characterization of domestic wastewater using different dosages of coagulants.

| Parameters                       | Dosages of mucilaginous extract of *S. griseus* [mgL⁻¹] | Dosages of Al₂(SO₄)₃ [mgL⁻¹] |
|---------------------------------|----------------------------------------------------------|-------------------------------|
|                                 | C₀  800  1000  1200  1400  1600  1800  Unidades        | C₀  10  15  20  25  30  35   |
| Total alkalinity                | 218.0±1.0ᵃ  222±05ᵇ  230±2ᶜ  237±2ᵈ  240±1ᵈ  241±09ᵈ  242±2ᵈ  mg CaCO₃ L⁻¹ |
| BOD₅                            | 128.1±0.81ᵃ  114±02ᵇ  102.1±08ᶜ  96.8±01ᵈ  57.6±1ᵉ  59.8±08ᵉ  60.6±01ᵉ  mgL⁻¹ |
| COD                             | 219.4±0.76ᵃ  137±07ᵇ  104.7±04ᶜ  100±09ᵈ  70.5±03ᵉ  82.6±1.5ᶠ  84.2±1.3ᶠ  mgL⁻¹ |
| Total hardness                  | 490.0±2.5ᵃ  450±2.1ᵇ  445±1.1ᶜ  409±1.5ᵈ  400±1.0ᵉ  402±1.9ᶠ  406±1.8ᶠ  mg CaCO₃ L⁻¹ |
| Conductivity                    | 1210.2±1.3ᵃ  1220±1ᵇ  1226±1.2ᵇ  1252±3ᶜ  1250±4ᵈ  1251±2ᵉ  1260±3.1ᵈ  μScm⁻¹ |
| Turbidity                       | 90.28±1.00ᵃ  54.7±05ᵇ  46.66±02ᶜ  33.8±01ᵈ  29.57±05ᵉ  32.4±02ᵉ  35.90±09ᶠ  NTU   |
| Color                           | 246.1±1.1ᵃ  180±1ᵇ  115.2±2ᶜ  80.50±2ᵈ  68.61±09ᵉ  70.6±05ᶠ  72.30±1ᶠ  UPC    |
| Total solids                    | 610.0±1.5ᵃ  335±08ᵇ  261.2±01ᶜ  219±02ᵈ  180.4±08ᵉ  204±0.3ᵉ  211,1±07ᶠ  mgL⁻¹  |

*rows with different letters are significantly different (p < 0.05); mean ± standard deviation of 3 repetitions.
It is observed that Al<span>2</span>(SO<sub>4</sub>)<sub>3</sub> had better results than ME. <i>g</i>, with respect to the removal of COD and BOD<sub>5</sub>. When 25 mgL<sup>-1</sup> of coagulant was used in the treatment, a BOD<sub>5</sub> removal of 65.41% was reached. However, it must be highlighted that the percentage of BOD<sub>5</sub> removal decreased at higher dosages, likely due to system restabilization. Regarding chemical oxygen demand, a similar behavior was obtained. Its mean, the highest removal percentage was 67.86, which was significantly different from the other values obtained with various coagulants. These findings are similar to those reported by Dearmas Duarte and Ramírez Hernández (2015), who reduced wastewater BOD to 62.63%.

As shown in Figure 1, chemical coagulant Al<span>2</span>(SO<sub>4</sub>)<sub>3</sub> presents better coagulation properties than natural coagulant (ME. <i>g</i>). It can be concluded that ME. <i>g</i> could be an effective alternative to decrease BOD<sub>5</sub> and COD values in domestic wastewater treatment; these results corroborate the studies of Tarón <i>et al</i>. (2017) and Guzmán <i>et al</i>. (2013). It is important to mention that both industrial and domestic wastewater have key characteristics regarding the composition and structure of organic matter. Hence, a better understanding of organic matter's characteristics is important to improve treatment (Liu <i>et al</i>., 2016).

Color and turbidity are descending functions of ME. <i>g</i> concentration; the highest values of color and turbidity were 72.12 and 67.24%, respectively. These values were obtained using a coagulant concentration of 1400 mgL<sup>-1</sup>. Similar findings were published by Dearmas Duarte and Ramírez Hernández (2015). At low doses of natural coagulant, the removal of color and turbidity was not significant, possibly due to the slowness of the coagulation process, a product of the low doses (ME. <i>g</i>). On the contrary, the use of high doses of ME. <i>g</i> is not adequate, since the system restabilizes and presents a stationary behavior, where there is little variation in color and turbidity removal.

In the case of Al<span>2</span>(SO<sub>4</sub>)<sub>3</sub>, the higher removal percentage was obtained for both turbidity (71.56%) and color (79.23%); these values were obtained using a concentration of 25 mgL<sup>-1</sup> of Al<span>2</span>(SO<sub>4</sub>)<sub>3</sub>. Comparing the turbidity removal percentages, significant statistical differences at p<0.05 between the two coagulants studied were observed. These results of BOD and COD are lower than those published by Tarón <i>et al</i>. (2017) in aqueous extract of Cassia fistula seed in the primary treatment of domestic wastewater (Figure 2).
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Although the coagulation mechanism of mucilage of *S. griseus* in wastewater is unknown, it is presumed that pectins (mucilage) act as coagulant-flocculants. Mucilage is a polymer with high molecular weight, which can remain long and flexible, adsorbing various particles (Sánchez and Untiveros, 2004). Likewise, Gardiner et al. (1999) indicate no clear hypothesis for the mechanism of action of cactus extracts. However, these authors suggest that the mucilage synthesized are polysaccharides structured with functional groups such as –NH₂, –COOH and –OH, which leave charges that promote hydrogen bond formation.

4. CONCLUSIONS

The mucilaginous extract of *S. griseus* (MES. g) can be used as a coagulant in domestic wastewater treatment due to its properties to remove color, turbidity, BOD₅, COD and total solids. These properties are similar to some coagulants employed in primary treatment of domestic wastewater. The percentages of removal of both turbidity and color are promising and the dosages of inorganic chemical coagulants could be reduced. The highest removal percentages (70.42% for total solids, 72.12% color, 67.24% turbidity, 55% BOD₅, and 67.86% COD) were obtained using a dosage of 1400 mgL⁻¹ of coagulant. These findings therefore could have interesting implications in the industry for the reduction of effluent contaminants.

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