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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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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 (BOD_5), 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 (DBO_5), demanda química de oxigênio (COD), sólidos totais, turbidez e cor em águas residuais domésticas de uma estação 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.

Table 1. Physicochemical characterization of domestic wastewater.

Parameters	Value	Unit
Total alkalinity	218.0±1.00	mg $CaCO_3$ L^{-1}
Biochemical Oxygen Demand (BOD_5)	128.1±0.81	mgL^{-1}
Chemical Oxygen Demand (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}
Turbidity	90.28±1.00	NTU
Color	246.1±0.60	UPC
Total solids	610.0±0.22	mgL^{-1}

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.

$$Turbidity\ removal\ (\%) = \frac{T_0 - T_f}{T_0} * 100 \quad (1)$$

Where: T_o is the initial value of turbidity and y T_f is the final value of turbidity.

The percentage of color removal was determined using Equation 2.

$$color\ removal\ (\%) = \frac{Co - Cf}{Co} * 100 \quad (2)$$

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* (ME*S. g*). These removal percentages are lower than those found for (Al2(SO4)3 at all doses tested. At 1400, 1600 and 1800 mgL-1 of ME*S. 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 ME*S. 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.

Parametros	Dosages of mucilaginous extract of *S. griseus* [mgL^{-1}]							
	C_i	800	1000	1200	1400	1600	1800	Unidades
Total alkalinity	218.0±1.0[a]	222±05[b]	230±2[c]	237±2[d]	240±1[d]	241±09[d]	242±2[d]	mg $CaCO_3$ L^{-1}
BOD_5	128.1±0.81 [a]	114±02[b]	102.1±08[c]	96.8±01[d]	57.64±1[e]	59.8±08[e]	60.6±01[e]	mgL^{-1}
COD	219.4±0.76 [a]	137±07[b]	104.7±04[c]	100±09[d]	70.5±03[e]	82.6±1.5[f]	84.2±1.3[f]	mgL^{-1}
Total hardness	490.0±2.5 [a]	450±2.1[b]	445±1.1[c]	409±1.5[d]	400±1.0[e]	402±1.9[e]	406±1.8[d]	mg $CaCO_3$ L^{-1}
Conductivity	1210.2±1.3 [a]	1220±1[ab]	1226±1.2[b]	1252±3[c]	1250±4[c]	1251±2[c]	1260±3.1[d]	µScm^{-1}
Turbidity	90.28±1.00 [a]	54.7±05[b]	46.66±02[c]	33.8±01[d]	29.57±05[e]	32.4±02[e]	35.90±09[f]	NTU
Color	246.1±1.1 [a]	180±1[b]	115.2±2[c]	80.50±2[d]	68.61±09[f]	70.6±05[f]	72.30±1[g]	UPC
Total solids	610.0±1.5[a]	335±08[b]	261.2±01[c]	219.±02[d]	180.4±08[e]	204±0.3[f]	211,1±07[f]	mgL^{-1}
	Dosages of $Al_{2}(SO_4)_3$ [mgL^{-1}]							
	C_i	10	15	20	25	30	35	
Total alkalinity	218.0±1.0[a]	219±02[a]	226±1.2[b]	230±2.3[c]	233±1.1[c]	239±2.2[d]	240±1.9[d]	mg $CaCO_3$ L^{-1}
BOD_5	128.1±0.81 [a]	105±0.8[b]	91.2±1.2[c]	82.9±1.6[d]	44.30±05[e]	47.8±1.1[f]	50.05±0.9[f]	mgL^{-1}
COD	219.4±0.76 [a]	123±2[b]	96.5±1[c]	82.4±09[d]	60.27±03[e]	68.4±09[f]	70.9±1.3[f]	mgL^{-1}
Total hardness	490.0±2.5 [a]	431±2.5[b]	430±1.5[b]	394±1.1[c]	381±2.1[d]	383±1.9[d]	389±1.2[e]	mg $CaCO_3$ L^{-1}
Conductivity	1210.2±1.3 [a]	1213±4[a]	1220±2.3[c]	1239±2[d]	1248±3.1[c]	1252±1[c]	1256±2.5[c]	µScm^{-1}
Turbidity	90.28±1.0 [a]	42.4±09[b]	37.26±1[c]	28.7±09[d]	25.67±1.2[e]	26.9±1[ed]	27.5±1.1[d]	NTU
Color	246.1±1.1 [a]	150±1.3[b]	100.5±2.2[c]	62.4±1.8[d]	51.11±1-4[f]	55.4±09[g]	59.90±1.6[h]	UPC
Total solids	610.0±1.5[a]	290±2.1[b]	246.1±2.2[c]	201.±1.9[d]	152.8±1.3[e]	180±1.6[f]	183.4±1.9[f]	mgL^{-1}

rows with different letters are significantly different ($p < 0.05$); mean ± standard deviation of 3 repetitions.

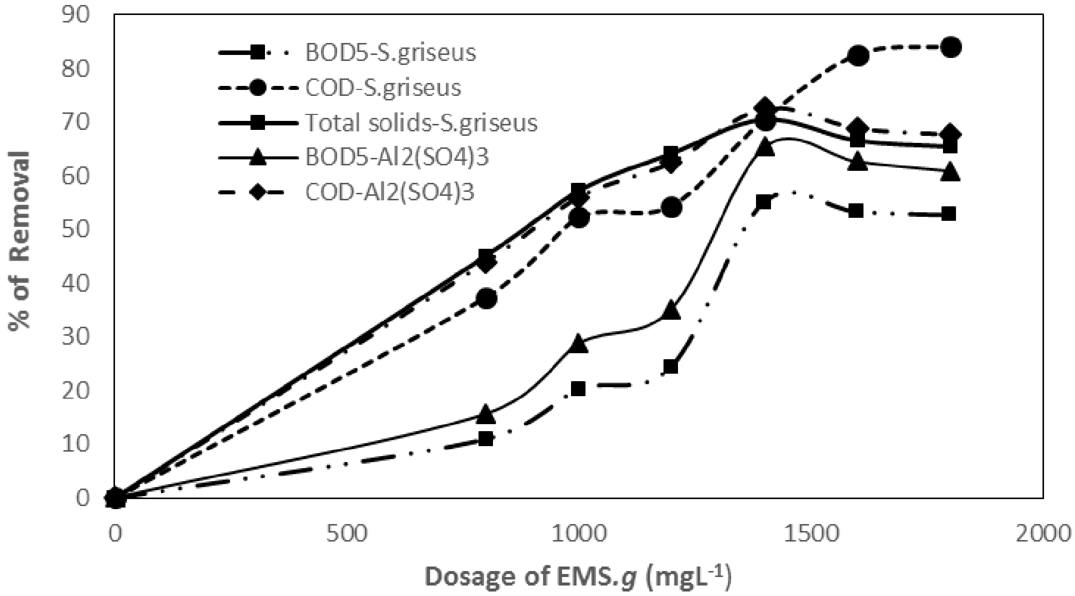

Figure 1. Removal of BOD_5, COD and total solids employing mucilaginous extract of *S. griseus* and the chemical coagulant $Al_2(SO_4)_3$. *Dosages of $Al_2(SO_4)_3$: 10, 15, 20, 25, 30 and 35 mgL^{-1}.

It is observed that $Al_2(SO_4)_3$ had better results than ME*S. g*. with respect to the removal of COD and BOD_5. When 25 mgL^{-1} of coagulant was used in the treatment, a BOD_5 removal of 65.41% was reached. However, it must be highlighted that the percentage of BOD_5 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 $Al_2(SO_4)_3$ presents better coagulation properties than natural coagulant (ME*S. g*). It can be concluded that ME*S. g* could be an effective alternative to decrease BOD_5 and COD values in domestic wastewater treatment; these results corroborate the studies of Tarón *et al*. (2017) and Guzmán *et al*. (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 *et al*., 2016).

Color and turbidity are descending functions of ME*S. g* 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^{-1}. 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*S. g*). On the contrary, the use of high doses of ME*S. g* 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 $Al_2(SO_4)_3$, 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^{-1} of $Al_2(SO_4)_3$. 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 *et al.* (2017) in aqueous extract of Cassia fistula seed in the primary treatment of domestic wastewater (Figure 2).

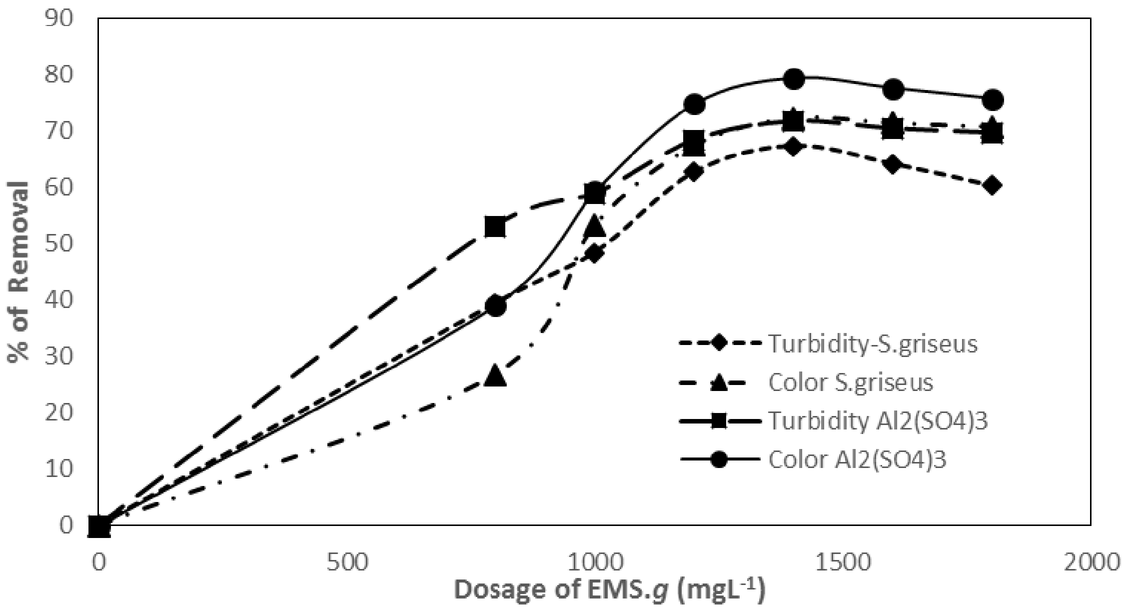

Figure 2. Turbidity and color removal using mucilaginous extract of *S. griseus* (ME*S. g*) and $Al_2(SO_4)_3$. *Dosages of $Al_2(SO_4)_3$: 10,15,20,25,30 y 35 mgL^{-1}.

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* (ME*S. g*) can be used as a coagulant in domestic wastewater treatment due to its properties to remove color, turbidity, BOD_5, 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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6. REFERENCES

ALMENDÁREZ DE QUEZADA, N. Comprobación de la efectividad del coagulante (Cochifloc) en aguas del lago de Managua Piedras Azules. **Revista Iberoamericana de Polímeros,** v. 5, n. 1, p. 46-54, 2004.

ANDERSON, E. **The cactus family**. Portland: Timber Press, 2001.

ANG, W. L.; MOHAMMAD, A. W. Integrated and Hybrid Process Technology. **Sustainable Water and Wastewater Processing**, v. 9, p. 279-329, 2019. https://doi.org/10.1016/b978-0-12-816170-8.00009-0

ANG, W. L.; MOHAMMAD, A. W. State of the art and sustainability of natural coagulants in water and wastewater treatment. **Journal of Cleaner Production**, v. 262, n. 121267, 2020. https://doi.org/10.1016/j.jclepro.2020.121267

APHA; AWWA; WEF. **Standard Methods for the examination of water and wastewater**. 22nd ed. Washington, 2012. 1496 p.

BERGAMASCO, R.; BOUCHARD, C.; VIEIRA DA SILVA, F.; HESPANHOLD, M.; REIS, M.; FAGUNDES, M.R. An application of chitosan as a coagulant/flocculant in a microfiltration process of natural water. **Desalination**, v. 245, p. 205-213, 2009. https://doi.org/10.1016/j.desal.2008.04.049

CALDERA, Y.; MENDOZA, I.; BRICEÑO, L.; GARCÍA, J., FUENTES, L. Eficiencia de las semillas de *Moringa oleifera* como coagulante alternativo en la potabilización del agua. **Boletín del Centro de Investigaciones Biológicas**, v. 41, n. 2, p. 244-254, 2007.

DEARMAS DUARTE, D.; RAMÍREZ HERNÁNDEZ, L. F. Remoción de nutrientes mediante coagulantes naturales y químicos en planta de tratamiento de aguas residuales, Valledupar Colombia. **Revista De Investigación Agraria Y Ambiental**, v. 6, n. 2, 183–196, 2015. https://doi.org/10.22490/21456453.1415

FUENTES, L.; MENDOZA, IVÁN.; LÓPEZ, A.; CASTRO, M.; URDANETA, C. Efectividad de un coagulante extraído de *Stenocereus griseus* (Haw.) Buxb. en la potabilización del agua. **Revista Técnica de la Facultad de Ingemiería Unividad del Zulia**, v.34. n. 1, p. 39-47, 2011.

GARDINER, D.; PETER, F.; CARR, Y. Cactus extract increases water infiltration rates in two soils. **Communications in Soil Science and Plant Analysis,** n. 30, p. 1713-1719, 1999. https://doi.org/10.1080/00103629909370323

GUZMÁN, J.; VILLABONA, A.; TEJADA, C.; GARCÍA, R. Reduction of water turbidity using natural coagulants: a review. **Revista UDCA Actualidad & Divulgación Científica**, v. 16, n. 1, p. 253–262, 2013. https://doi.org/10.31910/rudca.v16.n1.2013.881

HAMZAH, A.; MANIKAN, V.; ABD AZIZ, N.A.F. Biodegradation of tapis crude oil using consortium of bacteria and fungi: optimization of crude oil concentration and duration of incubation by response surface methodology. **Sains Malaysiana**, v. 46. n. 1, p. 43-50, 2017. https://doi.org/10.17576/jsm-2017-4601-06

HENRÍQUEZ, M.; MONTERO, F.; RODRÍGUEZ, O.; HERNÁNDEZ, A. Efecto de diferentes suspensiones de cardón dato, cactus lefaria, tuna española y PAM sobre algunas propiedades físicas de un suelo de Quibor-Lara. **Revista de la Faculdad de Agronomia,** v. 17, p. 295-306, 2000.

HOONG, H. N. J.; ISMAIL, N. Removal of dye in wastewater by adsorption coagulation combined system with Hibiscus sabdariffa as the coagulant. **MATEC Web of Conferences**, v. 152. n. 01008, p. 1-14, 2018. https://doi.org/10.1051/matecconf/201815201008

JAAFARI, J.; BARZANOUNI, H.; MAZLOOMI, S.; ABADI FARAHANI, N.; SHARAFI, K.; SOLEIMANI, P.; HAGHIGHAT, G. Effective adsorptive removal of reactive dyes by magnetic chitosan nanoparticles: Kinetic, isothermal studies and response surface methodology**. International Journal of Biological Macromolecules,** v. 164, p. 344–355, 2020. https://doi.org/10.1016/j.ijbiomac.2020.07.042

KOOIJMAN, G.; DE KREUK, M. K.; HOUTMAN, C.; VAN LIER, J. B. (2020). Perspectives of coagulation/flocculation for the removal of pharmaceuticals from domestic wastewater: A critical view at experimental procedures. **Journal of Water Process Engineering**, v. 34, p. 101161, 2020. https://doi.org/10.1016/j.jwpe.2020.101161

KUMAR, K.; CHOWDHURY, A. Use of Novel Nanostructured Photocatalysts for the Environmental Sustainability of Wastewater Treatments, Reference Module in Mater. **Encyclopedia of Renewable and Sustainable Materials**, v. 1, p. 949-964, 2020. https://doi.org/10.1016/b978-0-12-803581-8.11149-x

LIU, X.; CHEN, Q.; ZHU, L. Improving biodegradation potential of domestic wastewater by manipulating the size distribution of organic matter. **Journal of Environmental Sciences,** v. 47, p. 174–182, 2016. https://doi.org/10.1016/j.jes.2016.02.004

LUO, X.; SHE, M.; HUANG, Z.; CHEN, Z.; CHEN, Z.; LIN, B.; CUI, L. Efficient removal of Pb(II) through recycled biochar-mineral composite from the coagulation sludge of swine wastewater. **Environmental Research**, v. 190, n. 110014, 2020. https://doi.org/10.1016/j.envres.2020.110014

MARTÍNEZ, D.; CHÁVEZ, M.; DÍAZ, A.; CHACÍN, E.; FERNÁNDEZ, N. Eficiencia del cactus lefaria para su uso como coagulante en la clarificación de las aguas. **Revista Técnica de la Facultad de Ingeniería, Universidad del Zulia,** v. 26. n. 1, p. 27-33, 2003.

NAGHIPOUR, D.; HOSEINZADEH, L.; TAGHAVI, T.; JAAFARI, J. Characterization, kinetic, thermodynamic and isotherm data for diclofenac removal from aqueous solution by activated carbon derived from pine tree. **Data in Brief,** v. 8, p. 1082–1087, 2018. https://doi.org/10.1016/j.dib.2018.03.068

OKUDA, T.; BAES, A.; NISHIJIMA, W.; OKADA, M. Improvement of extraction method of coagulation active components from *Moringa oleifera* seed. **Water Research**, v. 33, n. 15, p. 3373-3378, 1999. https://doi.org/10.1016/S0043-1354(99)00046-9

OLIVERO, R.; AGUAS, Y.; MERCADO, I.; CASAS, D.; MONTES, L. Utilización de Tuna (*Opuntia ficus-indica*) como coagulante natural en la clarificación de aguas crudas. **AVANCES Investigación en Ingeniería,** v. 11, n. 1, p. 70-76, 2014. https://doi.org/10.18041/1794-4953/avances.1.302

SÁNCHEZ, S.; UNTIVEROS, G. Determinación de la actividad floculante de la pectina en soluciones de hierro (III) y cromo (III). **Revista de la Sociedad Química del Perú**, v. 70. n. 4, p. 201-208, 2004.

SATTERFIELD, Z. Jar testing. **Tech Brief**, v. 5, n. 1, p. 1-4, 2005.

TARÓN, A.; GUZMAN, L.; PORTNOY, I. Evaluación de la *Cassia fistula* como coagulante natural en el tratamiento primario de aguas residuales. **Revista Orinoquia**, v. 21, n. 1, p. 73-78, 2017. https://doi.org/10.22579/20112629.396

TERRAZAS, T.; LOZA, S.E.; ARREOLA, H. J. Anatomía caulinar de las especies del género Stenocereus (Cactaceae). **Acta Botánica Venezuellica**, v. 28. n. 2, p. 321-336, 2005.

YIN, C-Y. Emerging usage of plant-based coagulants for water and wastewater treatment. **Process Biochem**, v.45, p.1437-144, 2010. https://doi.org/10.1016/j.procbio.2010.05.030