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REMOVAL OF POLLUTANTS IN LAGUNA DE LAS ILUSIONES, TABASCO, USING NANOBIOADSORBENTS SYNTHESIZED WITH LIGNOCELLULOSIC RESIDUES.

POLLUTANTS REMOVAL AT LAGUNA DE LAS ILUSIONES, TABASCO USING NANOBIOADSORBENTS SYNTHESIZED WITH LIGNOCELLULOSIC WASTES

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Abstract - This experimental study developed and applied nanomaterials, i.e. materials at nanometer scale, with dimensions smaller than 100 nm, using lignocellulosic residues (residual biomass) as raw material for synthesis, therefore they are considered bionanomaterials, with adsorbent properties. The synthesis method used is based on a delignification process, promoted by chemical agents, we used NaOH and HCl, which generated activated or partially carbonized carbon depending on the experimental conditions, from pineapple crown and cocoa shell.

These properties confer them applications in removal or elimination of pollutants, in particular, we demonstrate it in liquid samples taken from Laguna de las Ilusiones de Mexico, considered a Natural Protected Area of our State, Tabasco, to prove the capacity of bioadsorbent nanomaterials synthesized contributing with efficient technologies, modern and low-cost technologies to reduce the environmental impact of our eutrophicated aqueous systems and generating in turn, a valorization alternative for an appropriate circular economy in waste management, since these contribute to the generation of Greenhouse Gases by microbial decomposition, when they reach the landfills.
Key words: bioadsorbent nanomaterials, environmental impact, waste management, removal, aqueous contaminants, lignocellulosic wastes.
Abstract - This study was developed and applied nanomaterials, that is, materials on a nanometer scale, with dimensions less than 100 nm, using lignocellulosic waste (residual biomass) as raw material for the synthesis, which is why they are considered bionanomaterials, with adsorbent properties. The synthesis method used is based on a delignification process, promoted by chemical agents, we used NaOH and HCl, which generated activated or partially carbonized carbon depending on the experimental conditions, from pineapple crown and Cocoa Pod Husk.

These properties give them applications in the removal or elimination of contaminants, in particular, we demonstrate it in liquid samples taken from Laguna de las Ilusiones from Mexico, considered a Protected Natural Area of our State, to test the capacity of synthesized bioadsorbent nanomaterials by contributing with efficient, modern and low-cost technologies to reduce the environmental impact of our eutrophicated aqueous systems and generating, in turn, a recovery alternative for an appropriate circular economy in waste management, since these contribute to the generation of Greenhouse Gases from microbial decomposition, when they reach landfills.

Keywords - bioadsorbent nanomaterials, environmental impact, waste management, removal, aqueous pollutants, lignocellulosic wastes.

INTRODUCTION

Currently, in many states of the Mexican Republic, particularly in Tabasco, there are eutrophicated lagoons and rivers, which means that freshwater loses its colorless, odorless and tasteless properties and, most importantly, its innocuousness, which means that it cannot be used as a source of water for human consumption [1-2]. In Tabasco we see characteristics of eutrophicated systems in Laguna de las Ilusiones, Laguna el Negro, and in the Grijalva River [3-4] (Figure 1).

Eutrophicated systems in Mexico are the result of discharges of domestic and/or industrial wastewater, without effective treatment or that were not previously treated, so they still have an excess of biodegradable and/or synthetic organic matter that causes this ecological disaster [1-2]. Current conventional wastewater treatments include physicochemical and biological treatments, i.e., primary (chemical), secondary (biological) and tertiary (disinfection) treatment, which have among their disadvantages that they are expensive, since they require operating consumables that must be supplied continuously 365 days a year, which can be difficult to provide; Examples of these operating consumables include coagulants, flocculants ($Al(SO_4)_3$, disinfectants (NaClO), synthetic ion exchange resins and strains of microorganisms [5-6].

Figure 1. *Wastewater discharged into La Laguna de las Ilusiones and greenish appearance of a water body characteristic of eutrophicated systems. Source: El Heraldo de Tabasco.*

In Mexico, as well as in various parts of the world, efficient technologies are not applied to eliminate pollutants from domestic wastewater called sewage, so that it can be discharged without impacting the environment, or even no treatment is applied to wastewater of any kind due to lack of coverage. In the development of the discussion of the State Development Plan 2019-2024, they detail that as a consequence of the uncontrolled growth of the main cities of the State such as: Villahermosa, Cárdenas, Huimanguillo, Comalcalco, Paraíso, as well as the metropolization of the municipality of Centro with Nacajuca, there have been problems such as, the saturation of the urban infrastructure, the appearance of irregular human settlements, the contamination of the environment, the lack of water quality and the lack of water treatment.
water bodies, the high concentration of population in unhealthy areas, among other social problems. This uncontrolled population growth complicates the situation because it requires sufficient resources to provide services to a large population, represents a huge challenge and a large investment of financial resources.
coupled with the high costs of wastewater treatment and potabilization [3] [4].

Our environmental solution is aligned with the 17 Sustainable Development Goals (SDGs), proposed in the 2030 Agenda Goals, especially Goal 6: Water and Sanitation which states "ensure availability and sustainable management of water and sanitation". There is a global concern about the water challenge and it is reflected in specific actions of the United Nations Organization (UN) [7]. It is a sad reality that Domestic Wastewater in most developing countries, such as ours, is generally directly discharged without treatment, being a high percentage, of the total generated at State and National Level, as stated, the same State Development Plan 2019-2024 (PLED), as well as in the Sectoral Program for Environment and Natural Resources 2020-2024 issued by the Ministry of Environment and Natural Resources (SEMARNAT)[3,8]. Therefore, the provision of adequate Water and Sanitation services is essential to achieve the SDGs, requiring WWTPs operating at 100% coverage, in the State and in the Country. Fresh water is essential for the development of human life and all living beings on the planet, so currently access to safe fresh water, sanitation and hygiene is a priority, but this process is linked to the provision of adequate water treatment and sanitation, essential to achieve SDG 6 [9].

The removal of contaminants to colloidal size is carried out in the Wastewater Treatment Plants (WWTP), in the coagulator/flocculator phase, but requires very expensive operating consumables such as $Al(SO_4)_3$, synthetic resins, for the process of thickening/clarification of sewage. In addition, these substances must be supplied continuously 365 days a year, which can be difficult due to the economic situation of our state, a scenario that has resulted in 35 to 40% of sewage reaching rivers and streams [9-10]. However, this research group, which has previously worked with methods to generate bioadsorbent nanomaterials, has been successful in generating optimal surface properties for the removal or elimination of pollutants. In particular, we were able to remove or eliminate methylene blue with a 90% removal rate, using alkali-treated lignocellulosic biomass at pH 6, close to neutral, at a temperature of 35 °C [11].
The Drinking Water System in Tabasco according to the PNED 2019-2024, has 20 water treatment plants, 355 wells, 527 subsystems, and 16 pumping cisterns; similarly, the Sewage System is composed of 201 subsystems, 84 pumping stations (cárcamos), finally the Sanitation System, has 76 Wastewater Treatment Plants. However, it is a fact that in the State the population has had to suffer the poor quality and scarcity of water, due to the fact that 68% of the water has not been treated correctly in the last few years; a situation that has resulted

in approximately 32% of the sewage reaching rivers, lagoons and streams without proper treatment. This discharge of domestic wastewater from household sewage drains is a threat to aquatic ecosystems, endangering endemic species such as the manatee and the frigatebird, and endangering freshwater reserves for future generations [12].

In developing countries, about 90% of wastewater is discharged untreated into various freshwater bodies and approximately two million tons of industrial, domestic and agricultural wastes are disposed of in the same way [7].

In the Sector Program for the Environment and Natural Resources issued by the Ministry of the Environment and Natural Resources (SEMARNAT) of our country, it mentions this problem "in the case of water pollution, a large part of the basins in the territory receive significant volumes of untreated wastewater from urban and industrial areas, as well as those that run off from agricultural areas loaded with agrochemicals, affecting biodiversity and reducing the availability of the liquid, which means that the national wastewater treatment capacity is still insufficient, since it covers only 63% of the water collected in the sewage systems" [8].

Therefore, to contribute to reduce this problem, we implemented a low-cost treatment based on lignocellulosic waste (free raw material that is discarded in open dumps), which has the potential to be used as an operating consumable to replace conventional materials used in Wastewater Treatment Plants (WWTP) in the stage of thickening of sewage. This technology proposed by our group aims to improve the performance in continuous operation and cost/benefit ratio of the process; or, even in new WWTPs, with the advantage of its low cost and high efficiency in removal or elimination of pollutants. These lignocellulosic wastes are the raw material of the so-called bioadsorbents and from methods of synthesis of nanomaterials, we generate the ideal textural and structural properties to remove Biodegradable Organic Matter.
In particular, we tested bioadsorbent nanomaterials in a Natural Protected Area of our country.
State the "Laguna de las Ilusiones" Ecological Reserve. The application of efficient wastewater treatment methods represents a benefit for Mexico and the rest of the world, by reducing the environmental impact suffered by our freshwater bodies.

DEVELOPMENT

Methodology

A) Synthesis of Nanomaterials

The synthesis method was carried out at the Research Laboratory I, which is part of the Nanotechnology Area at the National Technological Institute of Mexico, specifically at the Technological Institute of Villahermosa, located at km 3.5 of the Villahermosa-Frontera highway.

Relevant information in the scientific literature was gathered and reviewed to understand the preparation methods and parameters that most significantly affect the structural and textural properties of biomass-based nanoadsorbent materials. There are several techniques, including immersion in acidic and/or alkaline chemical solutions, as well as thermal, ultrasonic, microwave treatments, among others.

For the synthesis of the nanomaterial, we chose residues of agro-industrial products of great economic impact in our State of Tabasco and in the South-Southeast Region, derived from cocoa and pineapple. For the preparation process, a preliminary step was performed, which included dehydration and pulverization, both for the cocoa shell and the pineapple crown.

The preliminary step for the cocoa shell included removing the pericarp and endocarp to keep only the mesocarp and exocarp. With this process the cocoa shell was exposed from its pod, these residues were obtained from a local producer, who sells at retail, dry beans for the preparation of pozol in the municipality of Nacajuca, Tabasco.

The cocoa pod shells were reduced in size by cutting them into pieces for efficient washing and so that, at the time of drying, heat transfer would be as homogeneous as possible. The washing was done in three stages, the first with purified water, the second with distilled water, and the third with deionized water at 40°C. After washing, it was dried by forced convection to remove surface water from the pod. After the removal of the surface water, the sample was weighed and
was dried in an oven at 100°C for a period of 24 hours.

For the pineapple waste, we collected the raw material, in particular a part that is discarded called crown. These materials were obtained from Walmart City Center, address Boulevard Adolfo Ruiz Cortines 1450, Atasta de Serra, 86100 Villahermosa, Tab. Repeated visits were made to obtain the mass quantity of raw material necessary to carry out all the necessary experiments. Subsequently, a preliminary washing, size reduction and dehydration step was also applied.

The delignification process for the synthesis of nanomaterials was carried out with the immersion procedure in alkaline and acid solutions. The alkaline and/or acid treatment was carried out using a ratio of 1/10 (lignocellulosic residue: acid or alkaline solution w/v) at room temperature for 12 h, 2 different concentration levels are proposed. Oven-dried cocoa husk or pineapple crown powders were subsequently immersed in a respective sodium hydroxide or hydrochloric acid solution (solid-liquid ratio of 100 g/l) at room temperature for 12 h. The suspension was filtered under vacuum and filtered in a vacuum and then dried. The suspension was filtered under vacuum and washed thoroughly with deionized water until a neutral pH of the filtrate was obtained and then the material was washed with acetone. It was dried in an oven at 80 °C until constant weight was reached, a prudent time of 24 h was considered.

Table 1. *Lignocellulosic residues occupied in the study along with their applied synthesis treatment.*

Method	Treatment occupied	Occupied lignocellulosic waste
Alkaline-Cocoa	White	Cocoa Husk
	Treated with 0.1 M NaOH	Cocoa Husk
	Treated with 5M NaOH	Cocoa Husk
Acid-Pineapple	White	Pineapple Crown
	Treated with $H_2SO_{(4)\,0.}5M$	Pineapple Crown
	Treated with H_2SO_4at 5M	Pineapple Crown
	Treated with H_2SO_4at 10M	Pineapple Crown

B) Characterization of the synthesized nanomaterials by Scanning Electron Microscopy and Infrared Spectrophotometry.

Scanning Electron Microscopy (SEM) is an imaging technique widely used in materials research due to its high resolution and capabilities to analyze morphological, structural and chemical characteristics of the samples under study. SEM studies were carried out using a Scanning Electron Microscope (Hitachi S-3000N model) at an electron accelerating voltage of 20 kV. This analysis was carried out by the Centro de Investigación de Ciencia y Tecnología Aplicada de Tabasco of the División Académica de Ciencias Básicas of the Universidad Juárez Autónoma de Tabasco, as well as the collaboration of Benemérita Universidad Autónoma de Puebla (BUAP), in the Chemical Sciences faculty at the Laboratorio de Pruebas Analíticas no destructivas, with the support of Dr. Gerardo Enrique Córdova Pérez.

The Infrared Spectrophotometry method, also known as IR, was selected. It is based on the interaction of infrared radiation with matter by absorption, emission or reflection. Thus, infrared (IR) spectrophotometers are widely used to identify chemicals with specific functional groups. This analysis was carried out in the specialized laboratory of process engineering, located in the Academic Division of Agricultural Sciences of the UJAT, with the collaboration of Dr. Pedro García Alamilla.

C) Contaminant removal experiments in liquid samples taken at Laguna de las Ilusiones

The ideal site for sampling was identified, in this case Vaso Cencali, since it is considered the most contaminated area of the Laguna de las Ilusiones. The sampling procedure was based on Standard NMX-AA-003-1980 Wastewater-Sampling. For the sampling process, nitrile gloves, mouth covers and a clean gown were used. The sampling container was rinsed 10 times before sampling, the rinsing was done by completely filling the container and submerging it completely.

The sampling container was attached to a PVC tube, which provided a sampling depth of 30 cm, the sampling was performed with gloves on each hand and mouth covers, approximately 1 liter was extracted. The sample was labeled to be correctly identified at any time, and was placed in a cooler at 277K (4°C) for transport to the site of the adsorption or contaminant removal experiments.

For our problem solution, 15 mL of water sample taken from the Laguna de las Ilusiones was measured and was volumetrized with 135 mL of deionized water, shaken and the pH of this sample was measured, being the pH reached with these conditions 6.6 g of specific bioadsorbent nanomaterial (activated nanocarbon from cocoa shell biomass or pineapple crown) and 150 mL of the problem solution at pH 6 were added to a heating grid with magnetic stirring, regulating the stirring speed at a constant 250 rpm and the temperature at 35°C. The process time was 180 min. Samples were taken every half hour and at zero time. Prior analysis, these were filtered to avoid the presence of bionanoadsorbent residues and then deposited in eppendorf tubes, wrapped with light insulating paper and stored in a refrigerator for later analysis. Chemical Oxygen Demand was then measured using Hanna high range vials from 0 to 15000 mg/L, with a Hanna iris visible spectrophotometer model HI801-01 of 115 V.

DISCUSSION AND ANALYSIS OF RESULTS

A) Characterization of the synthesized nanomaterials by Scanning Electron Microscopy and Infrared Spectrophotometry.

The morphological and textural properties of cocoa pod husk biomass under acid and alkaline hydrolysis chemical treatments were investigated by Scanning Electron Microscopy (SEM). Figure 1, shows the SEM micrographs of a sample area randomly taken from the

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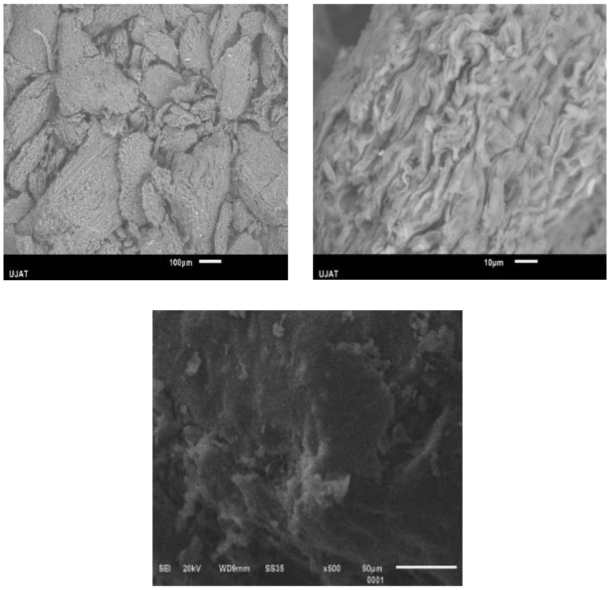
Cocoa Husk, dehydrated and pulverized without alkaline and/or acid treatment. The lignocellulosic structure presents amorphous crystals, possibly due to the presence of hemicellulose, pectin, lignin [13-14]. The surface is smooth, without high porosity.



Micrographs of dehydrated and pulverized Cocoa Shell (CC) without treatment with alkaline chemical agent.

Figure 2 shows the SEM micrographs of an area of the sample taken randomly from the Cocoa Husk, dehydrated and pulverized with 0.1 M alkaline treatment. The lignocellulosic structure shows amorphous crystals even after treatment, possibly due to the presence of hemicellulose, pectin, lignin (Iyabode-Akinjokun et al., 2021), in addition to low porosity. This indicates that this concentration does not promote efficient hydrolysis in the residual cocoa biomass.

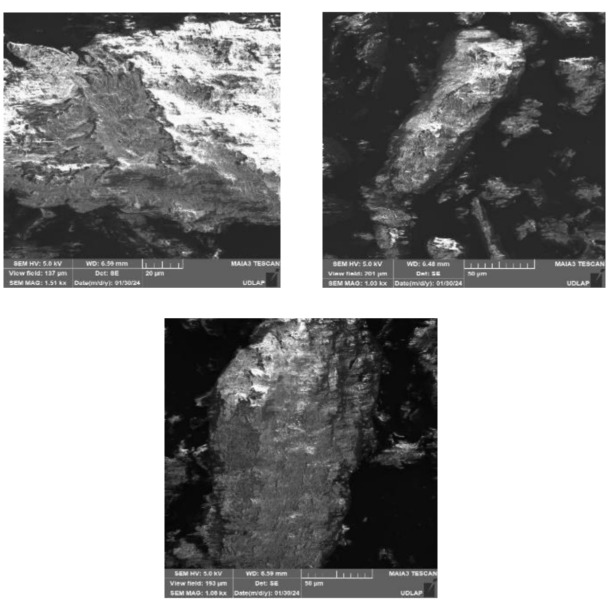


***Figure 2.** Micrographs of Cocoa Shell (CC) treated with 0.1M NaOH agent.*

Figure 3 shows the SEM micrographs of an area of the sample taken randomly from the Cocoa Husk, dehydrated and pulverized with 5 M alkaline treatment. The lignocellulosic structure shows amorphous crystals even after treatment, possibly due to the presence of hemicellulose, pectin, lignin [14], but it still shows some periodicity as well as more porosity. Individual elongated fiber, rod and spherical structures are observed in the nanocrystals that can be seen, due to the agglomeration and the amorphous crystals, in some areas it is not possible to clearly appreciate the structure that they acquire. This indicates that this concentration promotes a partial hydrolysis in the residual cocoa biomass and generates a polycrystalline material [13].

Figure 4 shows the SEM micrographs of an area of the sample taken at random from the pineapple crown, dehydrated and pulverized with 0.5 M acid treatment. The lignocellulosic structure shows amorphous crystals even after treatment, possibly due to the presence of hemicellulose, pectin, lignin [14], but it also shows areas with periodicity and high porosity. Elongated individual nanofiber-like structures are observed in the nanocrystals that can be seen. Due to the agglomeration and amorphous crystals, in some areas it is not possible to clearly appreciate the structure they acquire. This indicates that this concentration promotes a partial hydrolysis in the residual cocoa biomass [13].

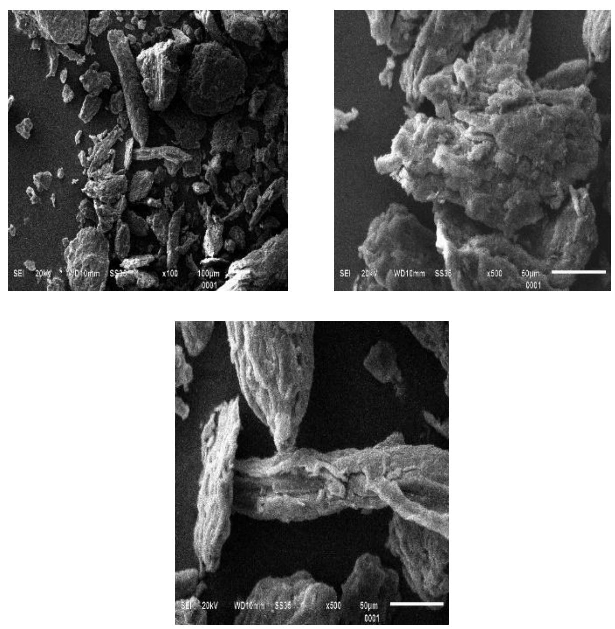


***Figure 3.** Micrographs of cocoa shell (CC) treated with 5 M NaOH agent.*

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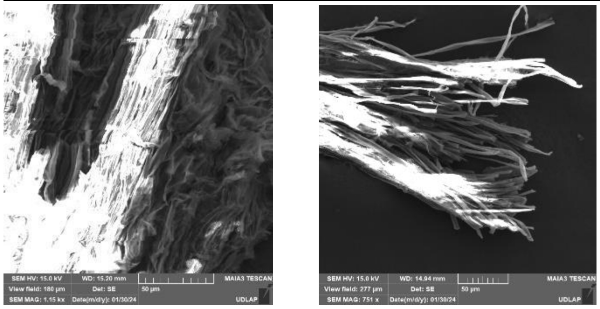

Micrographs of pineapple crown (PC) treated with 0.5 M H_2SO_4agent.

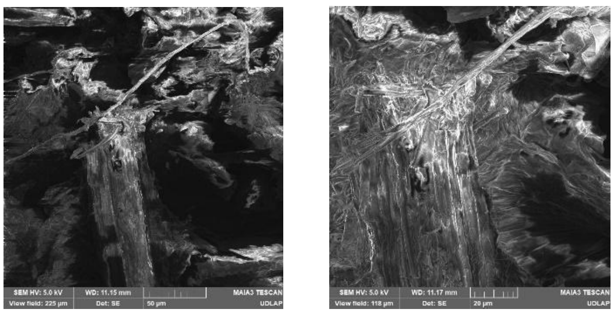

Figure 5. *Micrographs of pineapple crown (PC) treated with 5 M H_2SO_4agent.*

With this analysis it was observed that alkaline and acid treatments improve the nano crystalline structure of the material, including the surface or texture, since it uncovered more cavities in the watermelon rind and pineapple crown, compared to white, favoring the development of openings with greater depth. These pits are scattered, heterogeneous and amorphous. These morphological changes could be attributed to the partial destruction of cellulose, hemicellulose and lignin by hydroxide and sulfuric acid treatment, these changes being more severe at 5M concentrations than at 0.1M for cocoa peel.

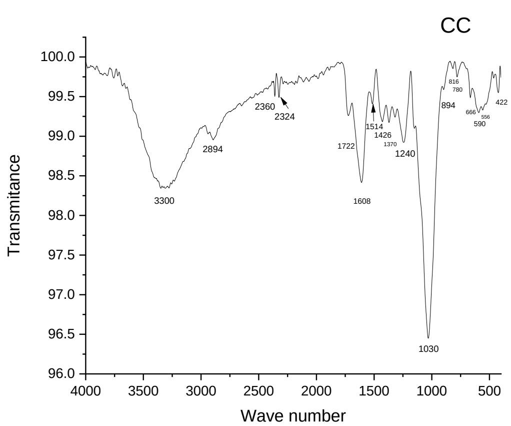

Figure 6. *Fourier Transform Infrared Spectrum of dehydrated and pulverized, untreated DC.*

The results of Fourier Transform Infrared Spectroscopy Analysis for Cocoa Husk samples alkaline treated with Sodium Hydroxide solutions varying in concentration from 0.1 to 5M are presented in Figures 6-8.

Figure 7, a band at 1722 $cm^{-1}$is observed which is attributed to the stretching vibration of the acetyl and uronic ester groups in pectin, while the carboxylic acids of hemicelluloses or the ester bond of the carboxylic group of ferulic and p-coumaric acids of lignin, is associated 1515 $cm^{(-1)}$ [13-15]. The band at 1515 $cm^{-1}$and 1244cm^{-1}in the spectrum of Figure 7, of dehydrated and pulverized Cocoa Husk alkaline treated at 0.1 M is attributed to C=C in planar aromatic vibrations due to the presence of lignin and C-O-C ether extending from the ether bond found in lignin. The presence of these bands in the spectrum, although with reduced intensity, shows that alkaline treatment at this concentration did not effectively remove the lignin in this material. The presence of lignin in the fiber after the alkaline hydrolysis chemical treatment could be responsible for the low crystallinity obtained from future XRD calculations. The peaks at 2, 985 and 702 $cm^{-1}$are due to C-H stretching and bending vibrations in the cellulose chains. The broad peak with a maximum of 3,316 cm^{-1}corresponding to the vibration of the OH group resulting from the inter and intramolecular bonds of polymeric compounds such as carboxylic acids and alcohols, as well as the adsorbed water molecule, for the Cocoa Husk nanomaterial alkaline treated with 0.1 M Sodium Hydroxide solutions.

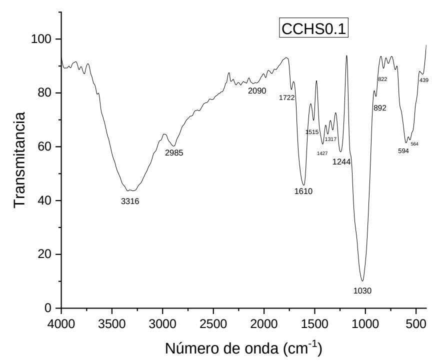

Figure 7. *Fourier Transform Infrared Spectrum of DC alkaline treated with 0.1M sodium hydroxide solution.*

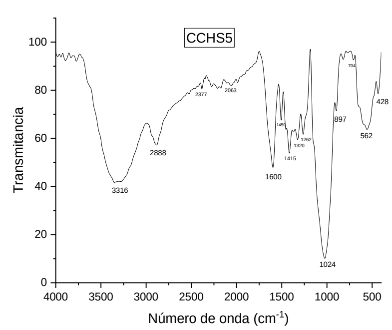

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Figure 8. Fourier Transform Infrared Spectrum of DC alkaline treated with 5M Sodium Hydroxide solution.

Figure 8 for the activated nanocarbon treated with a higher concentration of 5M Sodium Hydroxide, the band at 1722 cm^{-1}that was seen in the nanocarbon activated at 0.1 M Sodium Hydroxide is not present. The disappearance of this band showed that all the ester bonds of the hemicelluloses were cleaved by the alkaline treatment. However, this treatment does not affect the ether bonds between lignin and hemicelluloses. The disappearance of this band, according to Outtara et al., 2023 justifies the cleavage of all ester bonds of hemicelluloses after alkaline treatment, the changes in this region are attributed to the C=O stretching vibration with the benzene ring (lignin) and the carbonyl and acetyl groups in the xylan component of hemicelluloses.

It is observed in Figure 8 that the bands at 1317 cm^{-1}, 1515 cm^{-1}, 790 cm^{-1}, 594 cm^{-1}disappear completely and 1244cm^{-1}decreases in intensity, therefore, in the materials alkaline treated at 5 M, the lignin removal was more effective. An intense band of 1024 and 1030 $cm^{-1}$was identified in both materials alkaline prepared at 0.1 and 5M, it is due to C-O-C pyranose stretching the skeletal vibration, which confirms the presence of cellulose. It can be observed that the intensity of this band increases with the progressive intensity of the chemical treatments, which could indicate an increase in the crystallinity of the samples. The peaks at 2.888 and 704 $cm^{-1}$are due to C-H stretching and bending vibrations in the cellulose chains.

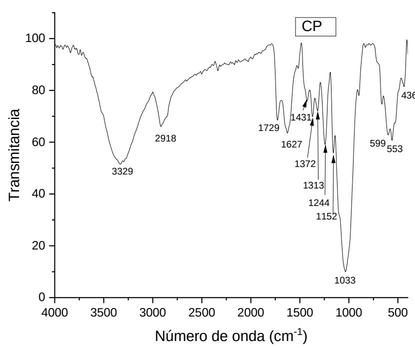

Figure 9. Fourier Transform Infrared Spectrum of dehydrated and pulverized, untreated pineapple crown (CP).

The results of Fourier Transform Infrared Spectroscopy Analysis for Pineapple Core (PC) samples acid-treated with Sulfuric Acid (SA) solutions varying in concentration from 0.1 to 5M are presented in Figures 9-11.

Figure 10. Fourier Transform Infrared spectrum of CP treated with 0.5 M H_2SO_4agent.

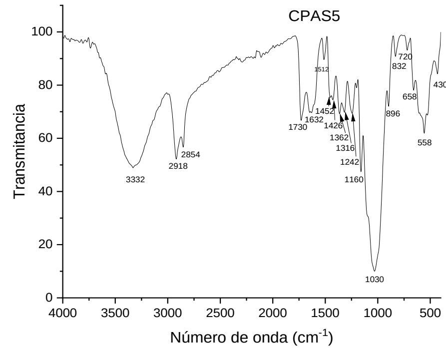

Figure 11. Fourier Transform Infrared spectra of CP treated with 0.5 M H_2SO_4agent.

The Infrared spectrum of acid-treated CP showed an intense and broad band from 3300 to 3335 cm^{-1}due to the vibration of the hydrogen bonded hydroxyl group in the cellulosic structure of CP. A strong and sharp band around 2910 $cm^{-1}$is attributed to the vibration of the C-H stretching bond due to the cellulose and hemicellulose groups. The peak around 1735 $cm^{-1}$is due to C-O stretching of carbonyl groups (C=O) in hemicellulose. The peaks around 1420 and 1230 cm^{-1}indicate the existence of lignin and hemicellulose structures. From the IR spectra, it cannot be concluded that the acid treatment has efficiently removed hemicellulose and lignin, as well as surface and specific functional groups are not clear [16].

C) Contaminant removal experiments in liquid samples taken at Laguna de las Ilusiones

The parameter Chemical Oxygen Demand was used in this study to determine the efficiency in the removal treatments of contaminants present in a complex matrix of a liquid sample taken from Laguna de las Ilusiones, in the Cencali Vessel, in the city of Villahermosa, Tabasco, Mexico.

In order to make a broader process discussion, we first tested the adsorbent nanomaterials synthesized with alkaline treated Cocoa Husk, to make a comparative study in a forthcoming publication, of the efficiency with the thermally synthesized nanomaterials and those treated with chemical agents.

Table 2 shows the COD values of initial concentration of 5,000 mg/l and different COD values taken every 30 min, until reaching a total process time of 180 min. For the experiment with the blank material, i.e., CP, only dehydrated and pulverized, after 30 min it reached 8% removal, and after 180 min it obtained a value of 58%. For the removal kinetics using the 5M acid-treated CP, after 30 min, it reached an average value between the original and replicate experiments of 98% COD removal, and after 180 min it obtained an average value of 100%,

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but the mass balance was reached at approximately 90 min of the process.

Results of Chemical Oxygen Demand and % pollutant removal in Laguna de las Ilusiones, Tabasco, Mexico, using activated nanocarbon derived from CP.

Experiments	T (time in min)	COD	COD removal (%)
White Experiment	0	5,000	**0**
	30	4,600	**8**
	90	4,200	**16**
	150	3,100	**38**
	180	2,100	**58**
Experiment 1 (powder with H_2SO_4 solution at 5M)	0	5,000	**0**
	30	**100**	**98**
	90	**0**	**100**
	150	**0**	**100**
	180	**0**	**100**
Experiment 1 Replica (powder with H_2SO_4 solution at 5M)	0	5,000	**0**
	30	**100**	**98**
	90	**0**	**100**
	150	**100**	**98**
	180	**0**	**100**

Table 3 shows the COD values of initial concentration of 2,000 mg/l and different COD values taken every 30 min, until reaching a total process time of 180 min. For the experiment with the white material, i.e., Cocoa Husk, only dehydrated and pulverized, after 30 min it reached 5% removal, and after 180 min it obtained a value of 60%. For the removal kinetics using the 5M alkaline treated Cocoa Husk, after 30 min, it reached an average value between the original and replicate experiments of 50% COD removal, and after 180 min it obtained an average value of 73%, but the mass balance was reached at approximately 150 min of process.

Results of Chemical Oxygen Demand and % removal of pollutants in Laguna de las Ilusiones, Tabasco, Mexico, using activated nanocarbon derived from CC.

Experiments	T (time in min)	COD	COD removal (%)
White Experiment	0	2000	**0**
	30	1900	5
	90	1400	30
	150	1200	40
	180	**800**	**60**
Experiment 1 (powder treated with NaOH solution at 5M)	0	2000	**0**
	30	1000	50
	90	1000	50
	150	1000	50
	180	**600**	**70**
Experiment 1 Replica (powder with NaOH solution at 5M)	0	2000	0
	30	1000	50
	90	600	70
	150	600	70
	180	**500**	**75**

CONCLUSIONS

This innovative low-cost technology using lignocellulosic waste is technically feasible and has demonstrated high efficiency in the removal of contaminants derived from sanitary activities, i.e. organic compounds that are oxidizable, such as biodegradable organic matter: feces, urine (urea) and food remains (proteins (meat), carbohydrates (bread, tortilla), lipids (fats)).

Particularly at a slightly acidic pH 6 during adsorption experiments, the acid-treated pineapple crown showed more than outstanding values. The cocoa pod reached 70 to 75% after 180 min of adsorption. In addition, it should be noted that at 90 min the pineapple crown had already reached its mass balance, improving the process times, as it was left in less time. Although in both cases, the results of transparency and crystallinity were not achieved with the naked eye.

However, quantitatively speaking it is an optimal and desired result in wastewater treatment, as it indicates that the treated water meets the required quality standards and can be discharged into the environment without posing risks to public health or the surrounding ecosystem.

It is important to note that achieving 100% removal of contaminants with nanobiadsorbents may depend on the nature of the contaminants present in the water and the specific characteristics of the treatment process. Therefore, it is necessary to perform continuous monitoring and adjust operating conditions as needed to maintain treatment efficiency and effectiveness over time. This project will seek to improve the economic feasibility of the removal process now working with Cocoa Husks thermally treated with nitrogen flux at calcination temperatures of 500 and 700 °C.

This research work provides a guideline for the study of other contaminated matrices, including industrial effluents with a high load of organic and inorganic compounds from the state of Tabasco.

Likewise, the design and optimization of filtration systems based on this material would be pertinent, with the objective of offering accessible and efficient solutions for water treatment in communities with limited resources.

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