Efficiency of sugarcane bagasse-based sorbents for oil removal from engine washing wastewater

Viviane Vasques da Silva Guilharduci, Patrícia Benedini Martelli and Honória de Fátima Gorgulho

ABSTRACT

This work evaluates the efficiency of sugarcane bagasse-based sorbents in the sorption of oil from engine washing wastewater. The sorbents were obtained from sugarcane bagasse in the natural form (SB-N) and modified with either acetic anhydride (SB-Acet) or 3-aminopropyltriethoxysilane (SB-APTS). The results showed that the sorption capacity of these materials decreased in the following order: SB-APTS > SB-N > SB-Acet. The superior oil sorption capacity observed for SB-APTS was attributed to the polar amino end groups in the silane structure, which acted to increase the hydrophilic character of the fibers. However, all the sorbents obtained in this study were able to clean a real sample of wastewater from engine washing, leading to significant reductions in suspended matter, sediment, anionic surfactants, and turbidity.

Key words | engine washing wastewater, oil sorption, sugarcane bagasse

INTRODUCTION

The car wash industry is a major consumer of freshwater, despite the new technologies developed in this area (Mazumder & Mukherjee 2011). In the case of engine washing, the wastewater can contain a wide range of contaminants, one of the main components being used engine oil (Hamawand et al. 2013). The concentrations of oil and grease in vehicle washing water lie in the range from 20 to 400 mg L$^{-1}$, while the levels in engine washing water can reach around 4,000 mg L$^{-1}$ (Dominguez-Rosado & Pichtel 2003). In Brazil, the procedures most commonly used do not include effective effluent treatment or recycling of wastewater (Rosa et al. 2011). The main technique employed for the treatment of vehicle or engine washing water is its collection in an underground concrete tank (separation tank), with separation of the suspended solids, oil, and grease by gravity (Hu et al. 2013). However, this system is not completely efficient in removing dispersed oil (small oil droplets), emulsified oil, surfactants, and other residues that remain in suspension (Zhang et al. 2014). As an alternative, an adsorbent can be added to the final discharge from the oil/water tank separators in order to improve the water cleaning process. The sorption technique is one of the most effective methods for treatment of oil-contaminated water (Mazeikiene & Svediene 2010). The most desirable features of an adsorbent are low cost, efficiency, and no environmental impact. An inspection of the literature reveals that many types of biomaterials have been exploited for simple, effective, and inexpensive treatment of water containing oil (Lee et al. 2016). These sorbents are renewable and biodegradable, and once they have been used for oil sorption, they can be easily removed from the water and properly disposed of on land, or be recycled.

Sugarcane bagasse (SB), both in natura and chemically modified, has been reported as a potential renewable sorbent for wastewater treatment, due to its abundance, floatability, biodegradability, nontoxicity, and low cost (El-Gendya & Nassara 2016). The sugarcane industry is based mainly on the production of sugar and ethanol, which generates huge volumes of bagasse and trash. Brazil is currently the world’s largest producer of sugarcane. The Brazilian sugarcane agro-industry processed around 427×10$^6$ tons of crushed sugarcane in 2011 (Santos et al. 2012). After milling the sugarcane for juice extraction, bagasse is obtained as a residue, corresponding to about 25% of the total weight and consisting of approximately 40% cellulose, 24% hemicellulose, and 25% lignin (Resende et al. 2011). SB is usually burned for energy supply in sugar and ethanol
mills; as a result, this industry generates large volumes of SB ash waste worldwide (Pippo & Luengo 2013). The ash waste is a non-biodegradable solid material, and the difficulty of its disposal can lead to problems of environmental pollution.

Given the above background, the aim of this work was to investigate the efficiency of SB as a sorbent for the treatment of engine washing effluents. SB has been reported as a sorbent for the removal of pollutants including metal ions, dyes, and hydrocarbons from aqueous media, as well as for the capture of CO2 (Raymundo et al. 2010; Soliman et al. 2011; Boni et al. 2016; Luo et al. 2016). However, despite the importance of this issue in the industrial and environmental contexts, the oil sorption properties of SB have still not been effectively explored. There have been no published studies concerning the use of this biosorbent for the treatment of real effluents, including the wastewater from engine washing. This work evaluates the treatment of oily wastewater using sorption by SB in its natural form and after modification with acetic anhydride or 3-aminopropyltriethoxysilane. The preparation and characterization of the modified SB materials are described, together with the effects of the modifications on the sorption properties.

MATERIALS AND METHODS

Reagents

Aminopropyltriethoxysilane (APTS, 98%, (H2NCH2CH2CH2)Si-(OCH2CH3)3) was purchased from Dow Corning and was used without further purification. The other analytical grade reagents were obtained from Merck (Brazil) and were used as received. The motor oil and engine cleaning wastewater effluent used in this study were obtained from Retífica del Rei (São João del Rei, MG, Brazil). The effluent was characterized following the methodology established by the American Public Health Association (Water Environment Federation & APHA 2005). The physicochemical parameters analyzed include chemical oxygen demand (COD), turbidity, oil and grease, anionic surfactants, total suspended solids and sediment.

Sorbent material

SB was supplied by Cachaça Coqueiro (Nazareno, MG, Brazil). The bagasse was washed repeatedly with distilled water to remove all the dirt particles. The washed fiber was then dried in an oven (Q314M, Quimis) at 60 °C for 24 h, under a flow of air. It was subsequently ground and sieved through 30 mesh sieves (TE648, Tecnal). The resulting natural fiber was designated SB-N and was used as the starting material to produce the other types of adsorbent, as described below.

SB-Acet

The acetylation of SB-N was based on previous reports (Sun et al. 2005). The SB-N was first submitted to a preliminary treatment in which the fiber was soaked in 10% NaOH solution (using a ratio of 1 g/1 mL) at 0 °C for 2 h. The bagasse was then washed with Milli-Q water until neutral pH and dried at 60 °C for 24 h. Following this procedure, 70 g of the cleaned bagasse was placed in a 1 L round-bottom flask containing 300 mL of acetic anhydride and 200 mL of acetic acid. The mixture was acidified by adding 1 mL of H2SO4 and maintained under agitation (NE4967, Nova Etica) for 24 h at 60 °C. At the end of this period, the solution was filtered and the product was rinsed first with ethanol and then with water until the pH reached around pH 7.0. After this procedure, the sample was dried at 60 °C for 24 h.

SB-APTS

Before the chemical modification, the fibers were washed with Milli-Q water at 60 °C until no color was observed in the wash water. After cleaning, the SB-N was mixed with APTS, using a 5/2 mass ratio of SB-N/APTS, and was then dispersed into 400 mL of acetone. The suspension was placed in a bottle with glass spheres and left on a roller-conveyor (TE500/1, Tecnal) for 24 h at 200 rpm. The excess of reagents was Soxhlet-extracted with acetone for 24 h. Subsequently, the fiber was dried in an oven at 60 °C for 24 h, under a flow of air.

Characterization

Fourier transform infrared (FTIR) spectra were obtained in the range 400–4,000 cm⁻¹, using a Perkin-Elmer 1720 FTIR spectrometer. The samples were mixed with KBr (Merck, spectroscopy grade) in an approximate ratio of 10/1. The resulting mixture was pressed into pellets and the spectra were acquired using 300 scans and a resolution of 4 cm⁻¹.

Thermogravimetric curves were obtained by thermogravimetric analysis/differential thermal analysis (TGA/DTA) (Model 2950, TA Instruments), in the range 30–1,000 °C, at a scanning rate of 5 °C min⁻¹, under a flow of nitrogen.
The specific surface area \( (A_{\text{BET}}) \) was determined by the Brunauer-Emmett-Teller (BET) nitrogen adsorption method, using an Autosorb-2 analyzer (Quantachrome, USA). The total pore volume \( (V_p) \) was determined at a relative pressure of 0.98. The samples were degassed for 180 min at 300 °C before analysis. All data analyses were performed using ASiQwin v.1.11 software (Quantachrome).

**Batch sorption experiments**

**Oil absorbance test**

This test was performed using a sample of used engine oil to obtain a synthetic oil/water mixture with an oil concentration of 10.0 g L\(^{-1}\). The used oil absorbance was determined by immersing 1.0 g of fiber in 100 mL of the oil/water mixture. After 24 h, the sorbent was removed from the mixture and dried for 24 h at room temperature. The oil sorption was calculated using the following equation:

\[
Q = \frac{(m_f - m_0) \times 1000}{m_0}
\]

where \( Q \) is the oil sorption capacity (g/g), \( m_0 \) is the total mass of dry sorbent (g), and \( m_f \) is the mass of sorbent before sorption (g).

**Effect of adsorbent dose**

Different amounts of adsorbent (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, and 5.0 g) were added to a series of 100 mL volumes of wastewater, followed by shaking (10 rpm) the bottles for 24 h in a shaker (TE-140, Tecnal). The oil sorption was obtained following the same procedure described above.

**Effect of contact time**

The sorption capacity at different times was studied by conducting batch sorption experiments using 15 portions (3.0 g) of adsorbent placed in separate beakers together with 100 mL of real wastewater. The samples were then shaken for different periods (10, 30, 60, 90, 120, 150, 180, 240, 300, 360, 480, 600, 720, 1,440, and 2,880 min). After each sorption time, the material was removed from the mixture and dried for 24 h at room temperature. The oil sorption was determined following the same procedure described above.

### RESULTS AND DISCUSSION

**Characterization of the natural and modified adsorbents**

Table 1 summarizes the bagasse-based sorbents and their textural characteristics. CO\(_2\) adsorption/desorption isotherms were used to obtain information about the specific surface areas and pore volumes of the samples, including their microporosity (Chung et al. 2011). The values obtained for the specific surface area ranged from 7.0 to 11 m\(^2\) g\(^{-1}\). The surface area of natural cellulosic fiber is usually reported to be below 1 m\(^2\) g\(^{-1}\), although the values are obtained using adsorption isotherms for nitrogen, which is unable to access small pores. The greater specific surface area for SB-Acet was in agreement with other reports (Sun et al. 2003; Chung et al. 2011). A possible explanation for this behavior was the NaOH treatment, which caused a broadening of the lamellar structure and collapse of the fibers, resulting in increased roughness, as expected for a greater specific surface area.

FTIR spectroscopy was employed to evaluate the bagasse fiber surfaces before and after the modifications. The acetylation of the bagasse was confirmed by comparing the FTIR spectra obtained for SB-Acet and SB-N (Figure 1(a)). For both samples, there was a weak broad band centered at 3,650 cm\(^{-1}\), usually attributed to the stretching vibration of free hydroxyl groups. The broad absorption band observed at around 3,210 cm\(^{-1}\) was characteristic of hydrogen bonding in hydroxyl groups (Vázquez and García 2010). The acetylation reaction of cellulose fibers has been widely reported in the literature, and the acetylation of SB cellulose has been described in several studies (Sun et al. 2003; Chung et al. 2011). The main evidence of acetylation is the appearance and/or enhancement of three ester bands, the first centered at around 1,746 cm\(^{-1}\), attributed to carbonyl (C = O) stretching vibration, the second at 1,373 cm\(^{-1}\), related to the C-H

<table>
<thead>
<tr>
<th>Sample</th>
<th>Characteristics</th>
<th>Specific surface area (m(^2) g(^{-1}))</th>
<th>Total pore volume (cm(^3) g(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB-N</td>
<td>Natural fiber</td>
<td>9.6</td>
<td>0.01</td>
</tr>
<tr>
<td>SB-Acet</td>
<td>SB-N after acetylation</td>
<td>11</td>
<td>0.02</td>
</tr>
<tr>
<td>SB-APTS</td>
<td>SB-N modified with APTS</td>
<td>9.3</td>
<td>0.01</td>
</tr>
</tbody>
</table>
bond in -(C=O)-CH$_3$, and the last at 1,240 cm$^{-1}$, associated with the C-O stretching of acetyl groups. The strong band at 1,040 cm$^{-1}$ could be attributed to C-O stretching in C-O-C linkages of cellulose, hemicellulose, and lignin. The small band observed at around 900 cm$^{-1}$ corresponded to C-H glycosidic deformation associated with the $\beta$-glycosidic linkages between the anhydroglucose units of the cellulose in all the fibers. This band is also known as the amorphous band.

In the case of fiber modification with APTS, it was difficult to differentiate the characteristic FTIR bands from those in the SB-N spectrum (Figure 1(b)), due to the presence of several overlapping bands with weak intensities. However, increased intensity of the broad band at 950–1,100 cm$^{-1}$ was observed, suggesting the presence of Si-O-C bonds in the treated fiber. There was also a well-defined absorption band at 1,200 cm$^{-1}$, associated with the Si-O-C bonds (Valadez-Gonzalez et al. 1999; Eng et al. 2014). The peaks observed in the FTIR spectrum for SB-APTS were in agreement with those reported in other studies of natural fibers modified with silane coupling agents. The increased intensity of -OH stretching vibration at around 3,190 cm$^{-1}$ was indicative of intensified hydrogen bonding.

The TGA results for the natural and modified fibers are shown in Figure 2. The curves were mainly characterized by three distinct events, as observed for other lignocellulosic materials (Mortari et al. 2010). The initial mass loss was due to the volatilization of adsorbed moisture present in the fibers. Substantial mass loss was observed in the second step between 100 and 350 °C, mainly attributed to cellulose and hemicellulose degradation. Several reports have demonstrated that most of the volatile content of the biomass is generated from the decomposition of hemicellulose and cellulose. Lignin decomposes more slowly over a wider temperature range (200–900 °C), due to its structural complexity, and is responsible for char formation. Silane

![Figure 1](https://iwaponline.com/wst/article-pdf/75/1/173/456401/wst075010173.pdf)
grafting of SB-N increased the temperature for the third step of mass loss, between 375 and 718 °C, as observed in the TG curve for SB-APTS. This indicated that silane grafting improved the thermal stability of the fiber, in agreement with previous reports (Mortari et al. 2010; Tee et al. 2013). For SB-Acet, in the third step, from 374 to 545 °C, there was complete degradation of the sample, in agreement with other studies showing that the thermal stability of SB decreases after acetylation (Sun et al. 2005; Chung et al. 2011). The process of acetylation leads to the disintegration of intramolecular interactions, with breaking of the hydrogen bonds between the hydroxyl groups present in cellulose macromolecules.

Oil removal by the bagasse-based sorbents

Given that the wastewater from car engine washing is mainly contaminated with used engine oil, the bagasse-based sorbent efficiency was first investigated for a synthetic used engine oil/water mixture (10.0 g L⁻¹). As the presence of surfactants in motor wash effluent can affect the oil sorption, the experiments were also carried out in solutions containing surfactants. For this study an anionic surfactant, sodium dodecylbenzenesulfonate, and a nonionic surfactant, TritonX-100 (C₁₄H₂₂O(C₂H₄O)ₙ), were utilized. The results are shown in Figure 3, and the oil sorption capacity (g oil/g fiber) obtained in pure aqueous medium is described in Table 2. After 24 h of contact between the fiber and the mixture, the sorbent was removed. Visual inspection revealed no obvious swelling or increase in volume, suggesting that the removal process was mainly controlled by adsorption, rather than absorption. In addition, the low specific surface areas and porosities of the bagasse fibers indicated that the key factor differentiating the behaviors of these samples was the chemical nature of the surface. The hydrophobic and hydrophilic sites of the fibers attracted the adsorbate, which became trapped in the structures of the surfaces and pores. The different surface treatments of the bagasse affected its sorption capacity, with the bagasse modified with silane coupling agents (SB-APTS) presenting a substantial increase in oil sorption capacity, compared with the other samples. The presence of polar amino end groups (NH₂) in the silane structure leads to increased hydrophilicity of natural fibers, which should favor interaction with the constituents of the used engine oil. In contrast, the acetylation of SB acted to increase the acetyl groups, resulting in greater hydrophobicity and a consequent decrease in the adsorption capacity.

Some research has demonstrated that the acetylation of natural fiber improves crude oil sorption capacity (Ngaini...
et al. 2014; Behnood et al. 2016; Utomo et al. 2016). The modification with acetic anhydride places some relatively hydrophobic chains on the raw bagasse structure, resulting in increased hydrophobicity. The crude oil consists essentially of a mixture of hydrocarbons, which promotes its hydrophobic character. Similarly, the fresh motor oil composition is based on a mixture of hydrocarbons, and hence present affinity for hydrophobic sorbent (Litvishkova et al. 1974; Al-Zahrani & Putra 2013; Mohammed et al. 2015; Yang et al. 2016). However, after use, the oil changes its composition through thermal degradation and contamination from generated waste in the engine. This process leads to the formation of low molecular weight compounds and oxidation products. Therefore, it is expected that the affinity for hydrophobic solvent will decrease, and the oil removal observed to SB-Acet should be lower than that obtained in other studies.

The results in Figure 3 show that the surfactant dissolved in the mixture oil/water reduces the sorption capacity for all sorbents. It has been known that surfactants can contribute to decreased water/sorbent tension, leading to increased wettabillity of sugarcane-based sorbent. In order to better evaluate this process, the water retention in the sorption process for each fiber was determined (g water/g fiber). For the conditions of pure water, solution of sodium dodecylbenzenesulfonate and solution of Triton X-100, the sorbents SB-N, SB-Acet and SB-APTS exhibited the following values (g/g): 0.04, 0.05, 0.06; 0.01, 0.01, 0.03; 0.07, 0.09, 0.08, respectively. These values are not large enough to justify the decrease in oil sorption capacity. Based on these results, it is possible to suggest that in the oil/water/surfactant system there is competition by the sorbent, and the surfactant was preferentially absorbed by the fiber, reducing the amount of oil removed.

There are rare studies involving used engine oil sorption by natural fibers, especially in aqueous environments. Table 2 summarizes some values of engine oil sorption capacity obtained for other sorbents, which can be compared with the results of this work. Compared with some vegetal fibers, the bagasse-based sorbents exhibit higher capacity in removing engine oil from water. In contrast, their efficiency is lower than that observed for waste of leather (chrome shaving) and esterified sago bark. However, considering its abundance, good buoyancy, low cost and biodegradability, SB has potential to be applied as a sorbent for removing oil from water.

In order to test the sorption capacity of the bagasse fibers for cleaning the effluents from engine washing, the sorbent dose according to wastewater volume was evaluated for a real effluent sample in which the oil concentration was estimated to be 1,800 mg L⁻¹. The sorbent mass/effluent volume ratio can affect the efficiency of oil removal, due to saturation of the sorbent. At a certain fiber/oil ratio, sorbent aggregation can occur, decreasing the available area and blocking diffusion routes, so that the sorption sites become saturated (Sun et al. 2003). The SB-APTS sorbent reached the highest sorption capacity at a sorbent mass/effluent volume ratio of around 35 (Figure 4). In contrast, the SB-Acet sorbent exhibited low efficiency, without reaching saturation (for the concentration range studied). The SB-N material showed intermediate behavior, compared to the other sorbents, reaching a maximum sorption capacity at a sorbent mass/effluent volume ratio of around 30.

### Table 2 | Oil sorption capacity of some natural sorbents

<table>
<thead>
<tr>
<th>Sorbent</th>
<th>Sorbent treatment</th>
<th>Water/oil mixture</th>
<th>Sorption capacity (g/g)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chrome shaving</td>
<td>Without modification</td>
<td>Used engine oil (15 g L⁻¹)</td>
<td>2.5</td>
<td>Gammoun et al. (2007)</td>
</tr>
<tr>
<td>Yellow horn shell residues</td>
<td>Treated with ionic liquid</td>
<td>Engine oil (100 g L⁻¹)</td>
<td>0.34</td>
<td>Li et al. (2015)</td>
</tr>
<tr>
<td>Agricultural waste from palm</td>
<td></td>
<td>Engine oil (40 mL oil/500 mL water)</td>
<td>0.5</td>
<td>Idris et al. (2014)</td>
</tr>
<tr>
<td>Sago bark</td>
<td>Raw fiber</td>
<td>Used engine oil (15 mL oil/250 mL water)</td>
<td>0.24</td>
<td>Peng et al. (2013)</td>
</tr>
<tr>
<td>Sago bark</td>
<td>Modified with stearic acid</td>
<td></td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>SB-N</td>
<td>Raw fiber</td>
<td>Used engine oil (10 g L⁻¹)</td>
<td>0.38 ± 0.01</td>
<td>Present study</td>
</tr>
<tr>
<td>SB-Acet</td>
<td>Modified with acetic anhydride</td>
<td></td>
<td>0.75 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>SB-APTS</td>
<td>Modified with APTS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The effect of contact time on the sorption kinetics for the bagasse-based sorbents was investigated using a sorbent mass/effluent volume ratio of 30 g L$^{-1}$. The curve of sorption according to time (Figure 5) indicated a gradual sorption process that reached equilibrium very slowly. After 10 h of contact, no further substantial change was observed in the sorption capacity, with no further sorption occurring within 24 h.

As mentioned previously, engine oil is not the only component of wastewater from engine washing. Furthermore, during engine operation there are changes in the composition of the oil due to the accumulation of solid contaminants and chemical conversion of the additives, resulting in soluble products of aging such as resins and heavy metal ions (Hamawand et al. 2013). These features provide an explanation for the results summarized in Figures 3 and 4, suggesting that the sorption of oily residues from engine washing was enhanced by the presence of polar groups on the sorbent surface.

An additional consideration is that the water employed to wash engines also contains additives to enhance cleaning, especially surfactants. Environmental problems may therefore be caused by the surfactants in the effluent, as well as turbidity and the presence of solids. The presence of these pollutants leads to an increase in the organic matter concentration, which can result in serious environmental problems. The performance of the bagasse-based sorbents in terms of these parameters was tested using the real effluent, employing the optimized sorbent mass/effluent volume ratio of 30 g L$^{-1}$ and an equilibrium time of 24 h. The values of all the parameters decreased after treatment of the wastewater using the SB fibers (Table 3). As a result of organic matter removal, there is a decrease of approximately 70% in the COD value. It is noticed that the best performance is obtained using SB-APTS, which leads to a reduction of 77% of COD and 99% of suspended solids. Most of the suspended solids found in water are electrostatically charged and could be adsorbed by the sorbent, resulting in reduced turbidity.

Table 3 | Characteristics of the raw effluent and effects of treatment with the bagasse-based sorbents

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Raw effluent</th>
<th>Percentage removal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SB-N</td>
</tr>
<tr>
<td>Suspended matter</td>
<td>4,200 mg L$^{-1}$</td>
<td>95</td>
</tr>
<tr>
<td>Sediment</td>
<td>32 mg L$^{-1}$</td>
<td>62</td>
</tr>
<tr>
<td>Turbidity</td>
<td>155 NTU</td>
<td>68</td>
</tr>
<tr>
<td>Oil and grease</td>
<td>1,800 mg L$^{-1}$</td>
<td>65</td>
</tr>
<tr>
<td>Anionic surfactants</td>
<td>5.6 mg L$^{-1}$</td>
<td>48</td>
</tr>
<tr>
<td>Chemical oxygen demand (COD)</td>
<td>4,180 mg L$^{-1}$</td>
<td>71</td>
</tr>
</tbody>
</table>

NTU, nephelometric turbidity units.
already discussed, the SB-APTS material was hydrophilic, which could improve the interaction with charged particles dispersed in the water, hence improving their adsorption.

The surfactant concentration was strongly reduced after treatment with all the sorbents, with the most substantial decreases achieved using SB-Acet and SB-APTS. These results are consistent with the hypothesis that surfactants should have high fiber affinity. The adsorption of anionic surfactants can involve ion exchange, physical adsorption, and hydrophobic bonding (Paria & Khilar 2004). The hydrophobic character of SB-Acet assisted interaction with the surfactant nonpolar groups, transferring the surfactant mol–phobic character of SB-Acet assisted interaction with the suspended matter, sediment, anionic surfactants, and turbidity. Similarly, the hydrophilic nature of SB-APTS enabled the material to be wetted, with the formation of a surface water film and promotion of interactions with the surfactant involving electrostatic attraction, adsorption by dispersion forces, and hydrogen bonding.

**CONCLUSIONS**

The sorption of oil from engine washing wastewater was evaluated using SB fibers in their natural state or following surface modification with acetic anhydride or APTS. The APTS functionalization inserted amino groups (NH₂) in the SB surface, which caused an increase in hydrophilicity. Sorption experiments indicated that this modification led to a higher oil sorption capacity of SB-APTS, compared with the SB-N and SB-Acet materials. In contrast, the acetylation of SB led to increased hydrophobicity, resulting in a reduced oil sorption capacity of SB-Acet. Nonetheless, all the bagasse-based sorbents tested in this study were able to clean a real sample of engine washing wastewater, leading to significant decreases in suspended matter, sediment, anionic surfactants, and turbidity.

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