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1 Characteristics and oil sorption effectiveness of kapok fiber, sugarcane
2 bagasse and rice husks: Oil removal suitability matrix[†]

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24 **Abstract**

25

26 The characteristics and water/oil sorption effectiveness of kapok fiber, sugarcane bagasse and rice husks
27 have been compared. The three biomass types are subjected to field-emission scanning electron microscopy-
28 energy dispersive x-ray spectroscopy while the surface tension analyses for liquid-air and oil-water systems
29 have also been conducted. Both kapok fiber and sugarcane bagasse exhibit excellent oil sorption capabilities
30 for diesel, crude, new engine and used engine oils since all their oil sorption capacities exceed 10 g/g.
31 Synthetic sorbent exhibits oil sorption capacities comparable to sugarcane bagasse while rice husks exhibit
32 the lowest oil sorption capacities among all the sorbents. Kapok fiber shows overwhelmingly high oil-to-
33 water sorption (O/W) ratios ranging from 19.35 to 201.53 while sugarcane bagasse, rice husks and synthetic
34 sorbent have significantly lower O/W ratios (0.76 to 2.69). This suggests that kapok fiber is a highly-
35 effectual oil sorbent even in well-mixed oil-water media. An oil sorbent suitability matrix has been proposed
36 to aid relevant stakeholders for evaluation of customized oil removal usage of the natural sorbents.

37

38 **Keywords:** Kapok fiber; sugarcane bagasse; rice husk; oil sorption

39

40 **Introduction**

41

42 Rapid global industrialization coupled by consumer need for energy resources have driven huge demand
43 for fossil fuel for both industrial and end-user markets. This presents an environmental drawback in terms of
44 possible oil spill contamination that may arise during sea transportation of petroleum products. There have
45 been numerous cases highlighted in the mass media involving various offshore operations and tankers
46 accidentally spilling petroleum products or derivatives into the open sea; one of the most frequently
47 referenced being the infamous 1989 Exxon Valdez oil spill at Prince William Sound, Alaska. Presently, the
48 much-highlighted *Deepwater Horizon* (BP) oil spill that occurs in the Gulf of Mexico in April 2010 is now

49 considered as one of the largest offshore oil spill in United States history. The pressures exerted by the
50 United States government as well as the public on the accountable oil and gas conglomerate have provided a
51 significant impetus to compel other oil and gas industrial stakeholders to search for effective oil spill
52 management and remediation strategies.

53 In most cases, cost-effective sorbents are typically utilized to remove oil spills. Such sorbents can be
54 classified as either inorganic mineral, organic synthetic or organic vegetable products [1,2]. Examples of
55 mineral products include clayey materials and graphite while synthetic products are sorbents made of
56 polypropylene and polyurethane foam. The usage of natural organic-based sorbents derived from plant
57 sources represents a vital development in sustainable environmental technology since it emphasizes on the
58 biodegradability, reusability and cost-effectiveness aspects. There have been numerous reported studies
59 involving usage of natural plant-based sorbents for sorption of oil such as bark [3], kenaf [4], kapok [5],
60 milkweeds [4], rice husks [6] and sugarcane bagasse [7]. Many of these natural sorbents exhibit comparable
61 or even higher oil sorption capacities than synthetic sorbents, but they also sorb water as well, rendering
62 reduced oil sorption capacities. This presents a disadvantage when used in marine environments [8]. As such,
63 it is highly desirable to ensure that the natural sorbent is highly hydrophobic or lipophilic so that high oil
64 selectivity over water can be maintained. In this regards, it has been well-established that kapok fiber is an
65 excellent natural oil sorbent through comprehensive studies conducted by several research groups [5,9,10].
66 Lim and Huang [5] suggest that its superior oil removal capability is attributed to its waxy fiber surface and
67 large lumen that promote internal capillary oil movement. In the absence of kapok fiber, however, other
68 natural sorbents should also be considered. While the oil sorption capacities of the latter are lower than the
69 former, we surmise that given the right conditions, other natural sorbents can also be fully optimized for the
70 purpose of oil removal from oil-water medium. As such, a direct comparison of the characteristics and oil
71 sorption effectiveness of natural sorbents with regards to different oil types will greatly facilitate the end-user
72 in evaluating the suitability of each sorbent for specific oil removal tasks.

73 The aim of this study is to compare the characteristics and water/oil sorption effectiveness of kapok fiber,
74 sugarcane bagasse and rice husks so that each biomass can be tailored for either water or oil sorption
75 applications. We evaluate four oil types for this study, namely, diesel, crude, new engine and used engine oils
76 so that our findings can have diverse implications and may aid future research in this regards. We propose an
77 oil sorbent suitability matrix subsequent to analyses of our findings to aid relevant stakeholders in deciding
78 the customized usage of such natural sorbents. We use the term ‘sorbent’ throughout the paper rather than
79 ‘absorbent’ or ‘adsorbent’ since we deem that there is always possibility of existence of both specific
80 mechanisms when it comes to sorption of oil or water using biomass. In chemical-based processes,
81 absorption is taken to mean the uptake of bulk fluid into the overall matrix of the sorbent while adsorption
82 refers to physico-chemical ‘attachment’ of fluid molecules on the micro/nano-sized porous surfaces of the
83 biomass. There are many instances of misuse of the terms ‘adsorbent’ and ‘absorbent’ in the open literature
84 and hence we prefer to avoid such misuse by utilizing a more generic term in this paper.

85

86 **Materials and methods**

87

88 *Collection, preparation and characterization of kapok fiber, sugarcane bagasse and rice husks samples*

89

90 Raw kapok fiber, sugarcane bagasse and rice husks were obtained from agricultural village settlements in
91 the state of Perak, Malaysia. All visible foreign impurities found in the samples were manually removed
92 before experimentation. The hard external sugarcane layer was removed from its stalk and the resultant
93 bagasse was washed with water to remove foreign materials. It was then dried in sunlight to remove
94 moisture. The bagasse was subsequently grounded to sizes less than 4 mm. A synthetic sorbent made of inert
95 polypropylene and polyester fibers was also included in the study so that a direct comparison between the oil
96 sorption effectiveness of commercial sorbent with that of natural biomass can be made. Figure 1 shows all
97 the natural and synthetic sorbents used in the study. Field emission scanning electron microscopy (FESEM)

98 (Zeiss Supra 55 PP) together with energy dispersive x-ray (EDX) spectroscopy (Oxford INCA) were used to
99 analyze the biomass' surface morphologies and elemental compositions, respectively. The average densities
100 of the natural sorbents were determined using Quantachrome Ultrapycnometer 1000 where 10 analysis runs
101 per sorbent were performed.

103 *Determination of liquid properties*

105 Densities of liquids were determined using Anton Paar DMA 35N Density Meter. The surface tension
106 data for liquid-air and oil-water were determined using Interfacial Tension Meter, IFT 700 (Vinci
107 Technologies, France) via the established pendant drop method. In this method, a liquid drop is produced
108 from the end of a capillary needle and put in contact with either air or liquid at a specified temperature. The
109 shape of the liquid drop was recorded using a camera and subsequently a software (Drop Analysis System)
110 analyzed and calculated the surface tension of the drop.

112 *Water and oil sorption experiments*

114 The water and oil sorption capacities of the biomass were determined using a standard method (F726-99)
115 stipulated by the American Society for Testing and Materials (ASTM) [11]. According to this method,
116 commercial sorbents in the form of rolls, films, sheets, pads, blankets or webs are categorized as Type I
117 sorbents while kapok fiber, sugarcane bagasse and rice husks are categorized as Type II sorbents since the
118 latter are unconsolidated and particulate-based. Diesel oil (PETRONAS Dynamic Diesel), crude oil (Tapis
119 crude oil), new engine oil (PETRONAS Mach 5 SL 10W-30) and used engine oil were employed to evaluate
120 the oil sorption capacity of the biomass. The sorption capacity was expressed as gram of liquid absorbed per
121 gram of dry sorbent (g/g).

123 **Results and discussion**

124 125 *Characteristics of kapok fiber, sugarcane bagasse and rice husks*

126
127 Figure 2 shows the micrographs of kapok fiber, sugarcane bagasse and rice husks. With the exception of
128 sugarcane bagasse which is subjected to minor size reduction, the kapok fiber and rice husks are relatively
129 unprocessed. Therefore, the micrographs illustrate the microstructures of the biomass which closely mirror
130 their as-received bulk condition. This is important in the context of their utilization as oil sorbents since it is
131 cost-effective to use them in their current form without incurring significant processing cost.

132 Kapok fiber has a microstructure which is distinct from the other biomass in which hollow tubular
133 structures (or lumen) can be clearly seen. The diameters of the lumen are determined to be approximately
134 within the 5 – 10 μm range which are smaller than the lumen diameters range (19 – 12 μm) reported by Lim
135 and Huang [5]. The sugarcane bagasse exterior appears to be rough while the surface morphology of rice
136 husks exhibits extended and interconnected dome-shaped regions, an observation previously reported by
137 Markovska and Lyubchev [12].

138 Table 1 shows the elemental compositions (detected via EDX) and average densities of kapok fiber,
139 sugarcane bagasse and rice husks. Both kapok fiber and sugarcane bagasse contain carbon percentages higher
140 than 50% and this provides an initial indication of their high lignocellulosic content. The high percentage of
141 silica (> 20%) detected in rice husks is due to the presence of opaline silica (plant-based hydrated amorphous
142 form of silica) found predominantly in the outer epidermis of rice husks [13,14].

150 Table 2 shows the liquid densities as well as liquid-air and oil-water surface tension data at 25°C. The
151 liquid densities and liquid-air surface tension data are consistent with findings reported by Lim and Huang
152 [5]. The oil-air surface tension values for all four oil types are very similar to one another while water-air
153 surface tension is significantly higher (68.5 MN/m). There is a possibility that such high water-air surface
154 tension may, to an extent, inhibit penetration of water into the internal hollow biomass structures due to
155 presence of pore air [5]. This implies that adhesion forces between water molecules at the water-air interface
156 are considerably higher than that of oil molecules at the oil-air interface, rendering the relative inability of
157 water molecules to ‘wet’ the pore air.

161 Figure 3 shows the water and oil sorption capacities of kapok fiber, sugarcane bagasse, rice husks and
162 synthetic sorbent. It is observed that more than 50% of rice husks have sunk to the bottom of the container
163 during the water sorption experiment. According to the ASTM F 726-99 standard, rice husk is considered to
164 have failed this test since the percentage of settled (sunk) sorbent is more than 10%. This observation is
165 consistent with the density of rice husks showed in Table 1 which is higher than water density. The synthetic
166 sorbent has the highest water sorption capacity while it is conversely true for kapok fiber. In this case, the
167 observed relative hydrophobicity of kapok fiber and hydrophilicity of synthetic sorbent are apparent. The
168 sugarcane bagasse appears to exhibit comparable water sorbing capability since its water sorption capacity is
169 more than 5 g/g. The high water sorption capacity of the bagasse is also reported by Said et al. [7] where they
170 found that it ranges from 400 to 700 % water absorptivity. Therefore, it is envisioned that the bagasse can be
171 applied as an inexpensive bulk water removal material.

172 The usage of the four oil types is justifiable since they represent two broad classifications of oil which are
173 relevant in the context of our study, namely, light- (e.g. crude oil) and heavy-weight (engine oil) oils. As
174 such, it is believed that our study can provide findings which have universal applicability. Crude oil contains
175 low-boiling fractions that evaporate swiftly after a spill and often before substantial cleanup operations can
176 commence [15]. Such evaporative tendency is reflected by its relatively low density compared to engine oils.
177 Both kapok fiber and sugarcane bagasse exhibit excellent oil sorption capabilities for all oil types since all
178 their oil sorption capacities exceed 10 g/g. However, kapok fiber is evidently a more superior oil sorbent
179 compared to sugarcane bagasse especially in terms of sorption of engine oils where the new engine oil
180 sorption capacity is 200% more than for sugarcane bagasse. Synthetic sorbent exhibits oil sorption capacities
181 comparable to sugarcane bagasse while rice husks exhibit the lowest oil sorption capacities among all the
182 sorbents. Therefore, rice husks may be unsuitable as sorbent material for both water and oil, though it can
183 still be used as a decent sorbent for engine oils since its sorption capacities for such oils are higher than 5 g/g.
184 An apparent trend can be observed from Figure 3; all sorbents have substantially higher new and used engine
185 oils sorption capacities compared to diesel or crude oil. This phenomenon is also observed by Lim and
186 Huang [5] in which they postulate that the higher viscosity of engine oil is responsible for its higher sorption
187 in kapok fiber. Table 3 compares the oil sorption capacities of biomass in this study with other sorbents. It is
188 obvious that kapok, sugarcane bagasse and rice husks afford superior oil sorption capacities compared to
189 other reported media such as vermiculite and peat.

190 Figure 4 shows the oil-to-water (O/W) sorbency ratios (oil sorption capacity/water sorption capacity) of
191 kapok fiber, sugarcane bagasse, rice husks and synthetic sorbent. The result affords quantification on the
192 relative oil/water selectivity of the sorbents whereby high O/W ratio indicates that the sorbent has high
193 affinity for oil and *vice versa*. Quite clearly, kapok fiber exhibits overwhelmingly high O/W ratios ranging
194 from 19.35 to 201.53 while sugarcane bagasse, rice husks and synthetic sorbent have considerably lower
195 O/W ratios (0.76 to 2.69). This implies that kapok fiber can be effectively used as an oil sorbent even in the
196 presence of significant amount of water. For rice husks and synthetic sorbent which exhibit O/W ratios lower

197 than 1 for diesel and crude oils, the presence of water may complicate the oil sorption process since water
198 may also interfere by saturating the sorbents before its intended oil sorption usage can be fully realized.

199 For the convenience of relevant stakeholders, a suitability matrix for usage of kapok fiber, sugarcane
200 bagasse, rice husks and synthetic sorbent for oil removal has been constructed (Table 4). To the best of our
201 knowledge, such matrix has not been previously created by any research groups. This matrix is constructed
202 based on the perceived oil sorption suitability *vis-à-vis* the potential interference caused by concurrent water
203 sorption. In highly-agitated oil spill waters (which may be due to wave action and strong ocean current),
204 sorbents that show good water sorption capacities are not effective oil sorbents due to the aforesaid reason.
205 Nonetheless, such sorbents may be relatively effective for removal of oil from clearly stratified oil/water
206 layers in still seawaters. In any case, the best biomass sorbent for oil removal is kapok fiber due to its
207 exceptionally superior oil sorption capacity. However, the other biomass may be suitable in certain
208 circumstances (based on the suitability matrix) should the fiber be unavailable for oil removal.

210 **Conclusions**

211
212 Kapok fiber and sugarcane bagasse exhibit superior oil sorption capabilities for all four oil types since all
213 their oil sorption capacities exceed 10 g/g while rice husks exhibit the lowest oil sorption capacities among
214 all the sorbents. Kapok fiber shows overwhelmingly high O/W ratios (19.35-201.53) while sugarcane
215 bagasse, rice husks and synthetic sorbent have significantly lower O/W ratios (0.76-2.69). The oil sorbent
216 suitability matrix can be utilized by pertinent stakeholders for rapid evaluation of oil removal usage of the
217 natural sorbents. The method used for creation of suitability matrix can also be tailored for future studies
218 involving other natural sorbents.

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222

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226 **References**

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228 [1] J. Wardley-Smith, *The Control of Oil Pollution*, Graham and Trotman Publication, London, 1983.

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230 [2] C. Teas, S. Kalligeros, F. Zankos, S. Stournas, E. Lois, and G. Anastopoulos, *Investigation of the*
231 *effectiveness of absorbent materials in oil spills clean up*, *Desalination* 140 (2001), pp. 259-264.

232

233 [3] M. Haussard, I. Gaballah, P. De Donato, O. Barrès, and A. Mourey, *Use of treated bark for the removal*
234 *of lipids from water*, *J. Air Waste Manag. Assoc.* 52 (2003), pp. 76-83.

235

236 [4] H.M. Choi, and R.M. Cloud, *Natural sorbents in oil spill cleanup*, *Environ. Sci. Technol.* 26 (1992), pp.
237 772-776.

238

239 [5] T.T. Lim, and X. Huang, *Evaluation of kapok (Ceiba pentandra (L.) Gaertn.) as a natural hollow*
240 *hydrophobic–oleophilic fibrous sorbent for oil spill cleanup*, *Chemosphere* 66 (2007), pp. 955-963.

241

242 [6] E. Khan, W. Virojnagud, and T. Ratpukdi, *Use of biomass sorbents for oil removal from gas station*
243 *runoff*, *Chemosphere* 57 (2004), pp. 681-689.

244

- 245 [7] A.E.-A.A. Said, A.G. Ludwick, and H.A. Aglan, *Usefulness of raw bagasse for oil absorption: A*
246 *comparison of raw and acylated bagasse and their components*, *Biores. Technol.* 100 (2009), pp. 2219-
247 2222.
- 248
- 249 [8] Q.F. Wei, R.R. Mather, A.F. Fotheringham, and R.D. Yang, *Evaluation of nonwoven polypropylene oil*
250 *sorbents in marine oil-spill recovery*, *Marine Poll. Bull.* 46 (2003), pp. 780-783.
- 251
- 252 [9] K. Hori, M.E. Flavier, S. Kuga, T.B.T. Lam, and K. Iiyama, *Excellent oil absorbent kapok [Ceiba*
253 *pentandra (L.) Gaertn.] fiber: Fiber structure, chemical characteristics, and application*, *J. Wood Sci.* 46
254 (2000), pp. 401-404.
- 255
- 256 [10] M.A. Abdullah, A.U. Rahmah, and Z. Man, *Physicochemical and sorption characteristics of Malaysian*
257 *Ceiba pentandra (L.) Gaertn. as a natural oil sorbent*, *J. Hazard. Mater.* 177 (2010), pp. 683–691.
- 258
- 259 [11] ASTM, F726-99: *Standard Test Method for Sorbent Performance of Adsorbents*, in: *Annual Book of*
260 *ASTM Standards*, ASTM Committee on Standards, West Conshohocken, PA, 1998.
- 261
- 262 [12] I.G. Markovska, and L.A. Lyubchev, *A study on the thermal destruction of rice husk in air and nitrogen*
263 *atmosphere*, *J. Therm. Anal. Calorimet.* 89 (2007), pp. 809-814.
- 264
- 265 [13] R.V. Krishnarao, and M.M. Godkhindi, *Distribution of silica in rice husks and its effect on the*
266 *formation of silicon carbide*, *Ceram. Int.* 18 (1992), pp. 243-249.
- 267
- 268 [14] S.-E. Ryu, T.-N. Kim, and T.-K. Kang, *Pulverization of rice husks and the changes of husk densities*, *J.*
269 *Mater. Sci.* 32 (1997), pp. 6639-6643.

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[15] R.F. Johnson, and T.G. Manjrekar, *Removal of oil from water surfaces by sorption on unstructured fibers*, *Env. Sci. Technol.* 7 (1973), pp. 439-443.

[16] G.N. Mathavan, and T. Viraraghavan, *Treatment of oily waters using peat*, *Water Poll. Res. J. Canada* 25 (1990), pp. 73–90.

[17] A. Srinivasan, and T. Viraraghavan, *Removal of oil by walnut shell media*, *Biores. Technol.* 99 (2008), pp. 8217–8220.

[18] D. Mysore, T. Viraraghavan, and Y.C. Jin, *Removal of oil by vermiculite*, *Fresenius Environ. Bull.* 13 (2004), pp. 560–567.

295 **Table 1**

296 Elemental compositions and average densities of kapok fiber, sugarcane bagasse and rice husks.

	C (%)	O (%)	Si (%)	Average density (g/cm ³)
Kapok fiber	53.79	46.21	-	0.7358
Sugarcane bagasse	50.92	49.08	-	0.9866
Rice husks	24.01	51.03	24.94	1.1575

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310 **Table 2**

311 Properties of liquids at 25°C.

	Density at 25°C (g/cm ³)	Liquid-air surface tension at 25°C (MN/m)	Oil-water surface tension at 25°C (MN/m)
Water	1.00	68.50	-
Diesel oil	0.83	26.77	18.85
Crude oil	0.84	27.72	15.35
New engine oil	0.85	28.25	17.60
Used engine oil	0.93	27.35	7.52

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321 **Table 3**

322 Comparison of oil sorption capacities of biomass in this study with other sorbents.

Sorbent	Type of oil	Sorption capacity (g/g)	Reference
Canadian peat	Standard mineral oil	7.85	[16]
Walnut shell	Standard mineral oil	0.30	[17]
Walnut shell	Canola oil	0.51	[17]
Vermiculite	Standard mineral oil	2.53	[18]
Vermiculite	Canola oil	2.57	[18]
Kapok fiber	Diesel oil	19.35	This study
Sugarcane bagasse	Diesel oil	10.51	This study
Rice husks	Diesel oil	2.60	This study

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337 **Table 4**

338 Suitability matrix for usage of kapok fiber, sugarcane bagasse, rice husks and synthetic sorbent for oil
 339 removal.

	Kapok fiber	Sugarcane bagasse	Rice husks	Synthetic sorbent
Removal of diesel or crude oil from oil-water mixture	<ul style="list-style-type: none"> Highly recommended. 	<ul style="list-style-type: none"> Moderately suitable. Reduced capacity due to water sorption. 	<ul style="list-style-type: none"> Not suitable. O/W ratio < 1. 	<ul style="list-style-type: none"> Not suitable. O/W ratio < 1.
Removal of engine oil from oil-water mixture	<ul style="list-style-type: none"> Highly recommended. 	<ul style="list-style-type: none"> Moderately suitable. Reduced capacity due to water sorption. 	<ul style="list-style-type: none"> Moderately suitable. Reduced capacity due to water sorption. 	<ul style="list-style-type: none"> Moderately suitable. Reduced capacity due to water sorption.
Removal of diesel or crude oil from clearly stratified oil/water layers	<ul style="list-style-type: none"> Highly recommended. 	<ul style="list-style-type: none"> Suitable for relatively stagnant oil layer. 	<ul style="list-style-type: none"> Not suitable. Diesel/crude oil sorption capacity < 5 g/g. 	<ul style="list-style-type: none"> Suitable for relatively stagnant oil layer.
Removal of engine oil from clearly stratified oil/water layers	<ul style="list-style-type: none"> Highly recommended. 	<ul style="list-style-type: none"> Very suitable for relatively stagnant oil layer. O/W ratio > 2. Engine oil sorption capacity > 10 g/g. 	<ul style="list-style-type: none"> Suitable for relatively stagnant oil layer. 	<ul style="list-style-type: none"> Suitable for relatively stagnant oil layer.

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343 **Figure Captions**

344 **Figure 1.** Kapok fiber, sugarcane bagasse, rice husks and polypropylene.

345 **Figure 2.** Micrographs of (a) kapok fiber, (b) sugarcane bagasse; and (c) rice husks.

346 **Figure 3.** Water and oil sorption capacities of kapok fiber, sugarcane bagasse, rice husks and synthetic
347 sorbent.

348 **Figure 4.** Oil-to-water sorbency ratios of kapok fiber, sugarcane bagasse, rice husks and synthetic sorbent.

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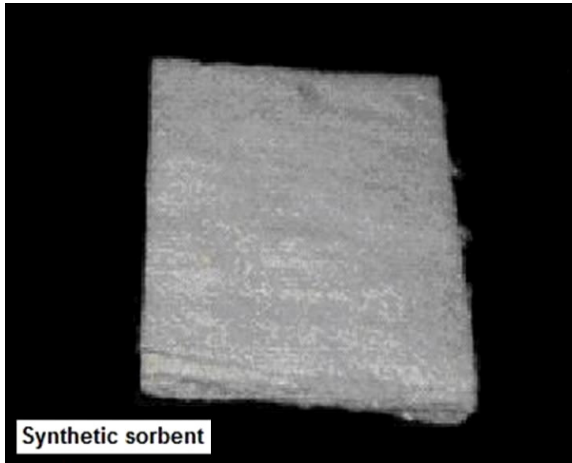
Kapok fiber



Sugarcane bagasse



Rice husks



Synthetic sorbent

Figure 1. Kapok fiber, sugarcane bagasse, rice husks and polypropylene.

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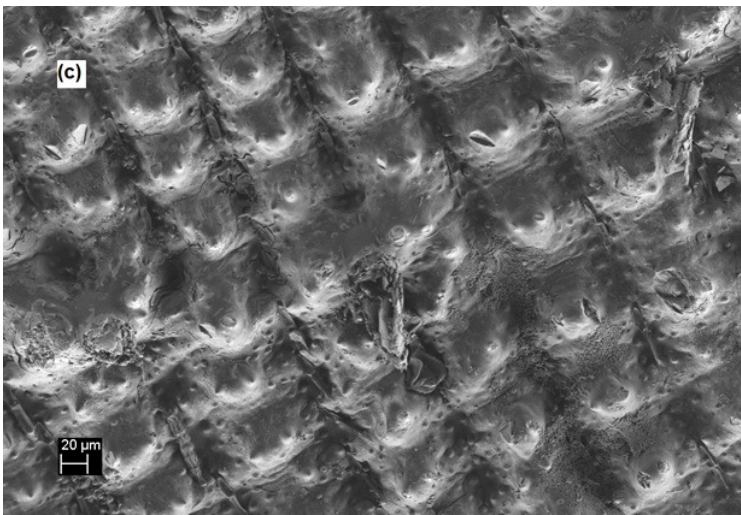
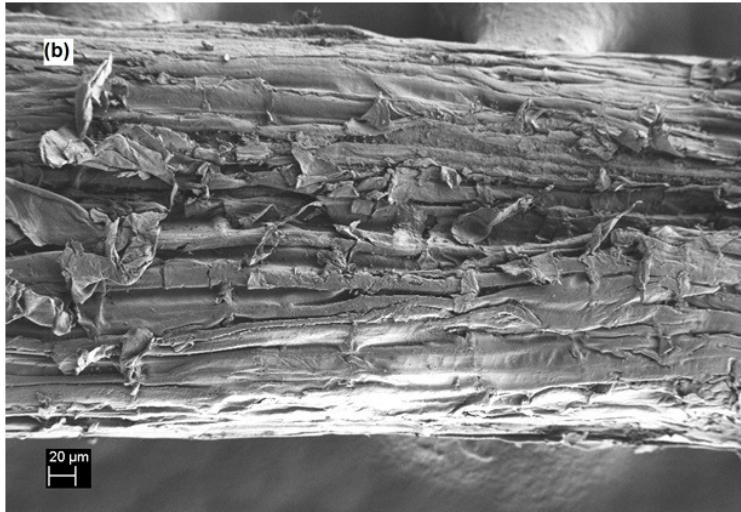
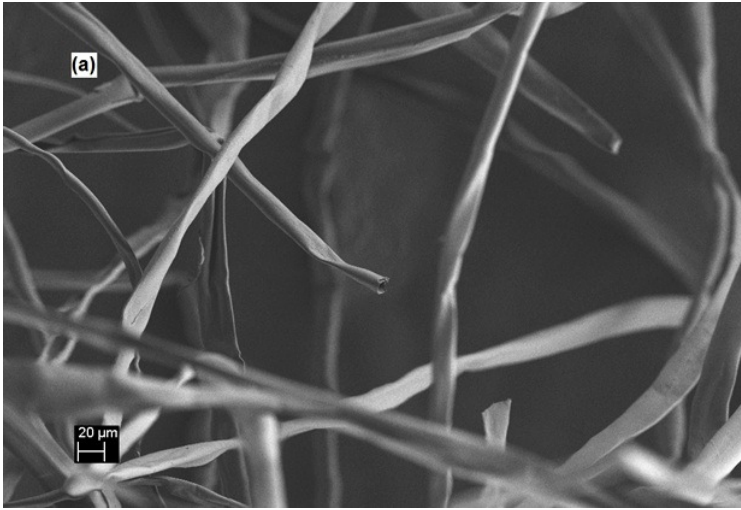
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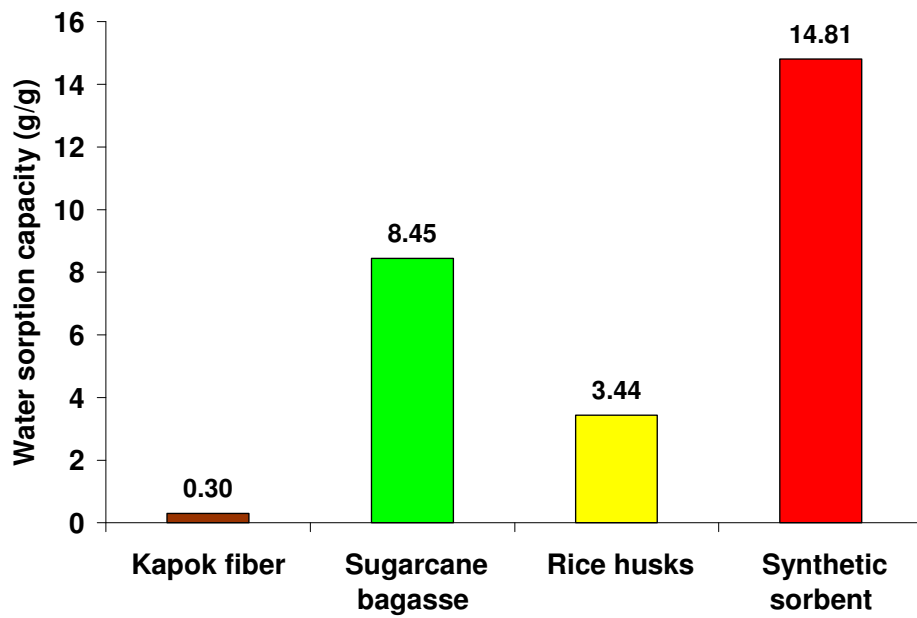
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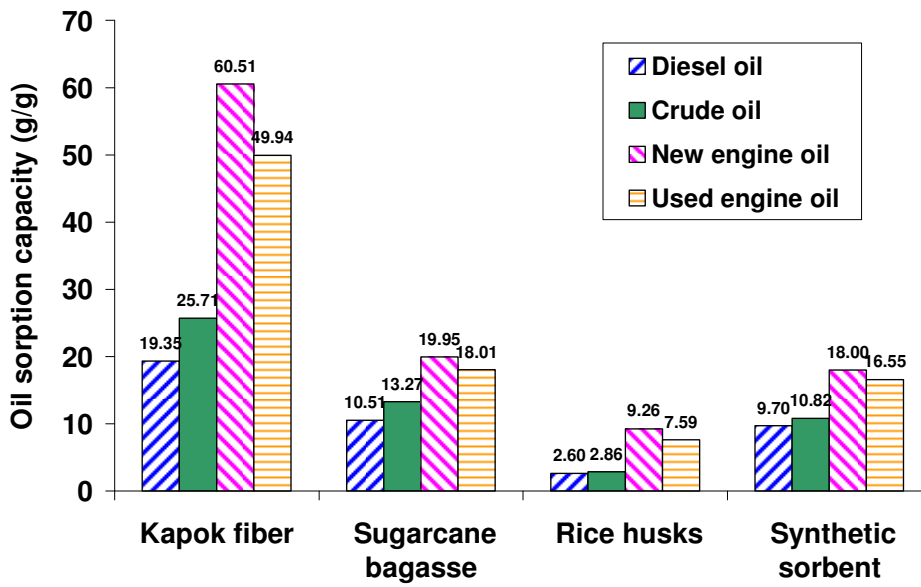
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Figure 2. Micrographs of (a) kapok fiber, (b) sugarcane bagasse; and (c) rice husks.



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386 **Figure 3.** Water and oil sorption capacities of kapok fiber, sugarcane bagasse, rice husks and synthetic
 387 sorbent.

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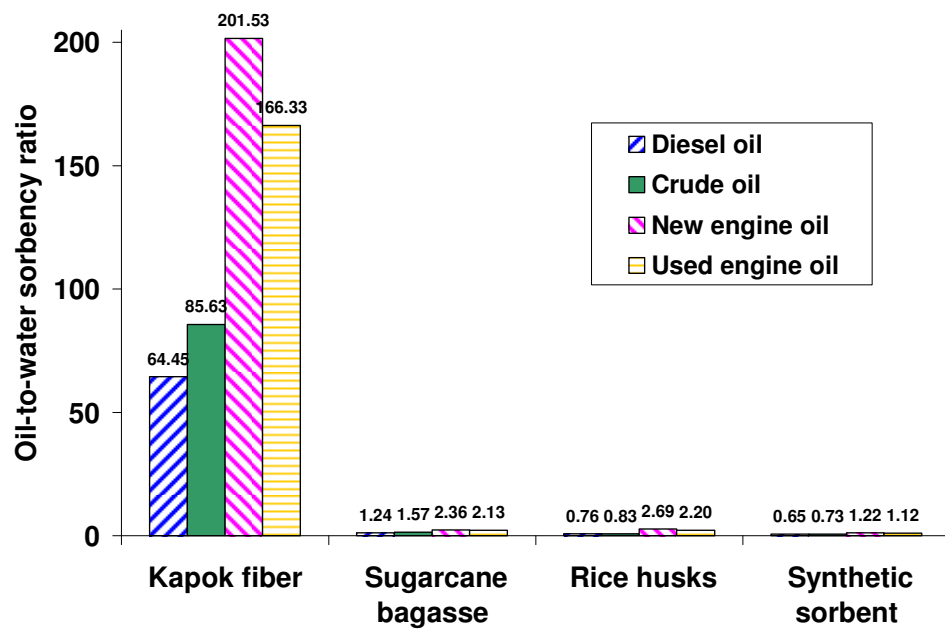


Figure 4. Oil-to-water sorbency ratios of kapok fiber, sugarcane bagasse, rice husks and synthetic sorbent.