

# **HIBISCUS ASPER(RAMAN KOGI) FIBRE USE AS A SORBENT FOR OIL SPILL CLEAN IN WATER BODY**

## **ABSTRACT**

This research aimed at investigating the possibility of using *Imperata cylindrical* fibre as a sorbent for oil spill clean-up. The acetylation was carried out in a free solvent system under mild conditions using acetic anhydride, in the presence of calcium chloride as a catalyst, at a temperature of 100°C for 3 hour. The crude oil and the *Hibiscus asper* sorbent were characterized, the sorption behaviors studied were found to increase with increase in weight per gain percent (WPG%). The WPG% and oil sorption capacity indicated the success of acetylation. Fourier transform infrared spectroscopy (FT-IR) was used for the analysis of unmodified and modified *Hibiscus asper* sorbent to further examine the success of acetylation. In the spectra of FT-IR of the acetylated *Hibiscus asper* material evidence of acetylation is clearly proven by, the enhancement of 1755 cm<sup>-1</sup>, as 1755.31-1715.97 cm<sup>-1</sup> which are carbonyl C=O stretching of esters, the enhancement of 1494.97 -1403.35 cm<sup>-1</sup> of (C-H bond in – O(C=O)-CH<sub>3</sub> and the appearance of 1154.69- 1154.43 cm<sup>-1</sup> which is a C=O stretching of acetyl group. The values for correlation coefficient (R<sup>2</sup>) showed that the model fitted the Langmuir isotherm (R<sup>2</sup> *Hibiscus asper* 0.99) better than the Freundlich isotherm, indicating that the adsorption process was monolayer. The higher oil sorption capacity shown by the modified *Hibiscus asper* sorbent compared to the lower oil sorption capacity of unmodified, indicated that the modified *Hibiscus asper* sorbent can substitute for synthetic fibres and recommended for oils spill clean-up in contaminated environments.

**Key words:** Adsorption, oil spill, sorbents, *Hibiscus asper*, fibre, Langmuir isotherm.

## **INTRODUCTION**

The world major source of energy is fossil fuel which is been transported by ships and pipelines across ocean and land, hence oil spill occurrence accidentally becomes inevitable. As the production of petroleum products is at the increase from 50 to 2500 million tons from mid-1950's to 1990's which results in the massive transportation and associated oil spills (Nwilo and Badeje, 2007). Oil spills are common occurrences today because of the many uses of oil in the society. Oil spills from vessels or land based facilities can pose serious threats to shorelines, banks and other sensitive habitats. In Nigeria oil spill is a common event (Baird, 2002) and occur due to a number of causes, including corrosion of pipelines and tankers (accounting for 50% of all spills), Sabotage (28%) Oil production operators (21%) inadequate or non-functional production equipment (1%) (Nwilo and Badeje, 2001).

36 It is known that commercially available synthetic sorbent are very costly due to the facts that a lot had  
37 been spent in the production unlike the natural plant sorbents which are abundantly available and  
38 cheap. Agricultural waste sorbent is abundantly available around the world and several different  
39 methods of development with or without catalyst have been developed. A number of natural sorbents  
40 have been modified and studied for use on oil cleanup. They were observed to be excellent oil  
41 sorbents because of their hydrophobic and oleophilic character, for example; cotton (Johnson *et al.*,  
42 1973; Choi *et al.*, 1993, Choi, 1996), wool (Radetic *et al.*, 2003), bark (Haussardet *et al.*, 2003), barley  
43 straw ( Hussein *et al.*, 2008), Kenef (Lee *et al.*, 1999) and corn-cobs (Diya'udeen *et al.*, 2008).

44 The English name of the plant is River hemp or water hemp, the plant belongs to the family  
45 *Malvaceae* and the botanical name is *Hibiscus asper*, the Hausa name is Ramar-raafii or Ramarruwa  
46 but the common name is *Hibiscus asper* . The Fulani people called it follere (plural pole) Roger  
47 Blench and MallamDendo (2006). It grows along the river bank, the bark is used as ropes and the  
48 leaves is used as a vegetable in some West African delicacy soup.

49 Chemical modification of plant or wood materials to improve their dimensional stability has been the  
50 subject of research for many years. A wide variety of chemicals have been studied including  
51 anhydrides, acid chlorides, carboxylic acids isocyanates, acetals, esters, acetyl chloride, B-  
52 propiolactone, acrylonitrile and exosides. Cellulose sorbents have been chemically treated (Sun *et*  
53 *al.*, 2004) and research into the use of their modified products as absorbents for the removal of crude  
54 oil from aqueous solutions have been on the increase. A lot of research is being carried out to develop  
55 natural plants materials for oil spill cleanup. Modified natural plants have shown very high capacity to  
56 sorbs oil from sites, Rice Husks ( Nwankwera, et al, 2011), Barley Straw ( Hussein, et al, 2008).

57 The aim of this research work is to investigate the possibility of using *Hibiscus asper* fibre as a sorbent  
58 for oil spill clean-up due to fact its abundantly availability and cheap.

59

## 60 MATERIALS AND METHODS

### 61 Sample Collection and Preparation

62 The plant sample *Hibiscus asper*(Figure 1), was collected from a farm land located in Girei Local  
63 Government Area, Adamawa State, Nigeria and identified by a Botanist from ModibboAdama  
64 University of Technology, Yola .

65 The sample obtained was cut from the stem with a knife, the bark was removed, washed with distilled  
66 water and was spread on a clean polyethene and allowed to dry in the laboratory for one week at room  
67 temperature. It was crushed using piston and mortar and then sieved using improvise mesh(0.841 mm  
68 in size) and left to dried at 65°C in the oven which was stored in a labeled polyethene bags. The crude  
69 oil sample was collected in a sample bottle from Port-Harcourt Refinery in River State, Nigeria ( the  
70 chemical composition of the crude oil is shown in Table 2)

71



72

73 Figure 1: Picture of *Hibiscus asper* (Raman Kogi) plant at sample location in Girei Local  
74 Government area of Adamawa State

75 **Extraction Procedure**

76 5g of the bark *Hibiscus asper* was extracted with the mixture of ethanol-toulene (2:1 v/v) for 3hours.  
77 After extraction the samples was rinsed with ethanol followed by hot water and oven dried at 105°C  
78 for 24 hours to reach a constant weight. The extractible content was calculated as a percentage of  
79 oven dried test samples. Akylation is the process of transferring an alkyl group from one molecule to  
80 another. alkyl substituent is an alkane which have one missing hydrogen atom. is basically the process  
81 of introducing hydrocarbon into chemicals. Synthetic fibre are manmade fibres that can absorbed up  
82 to seventy times their weight in oil.eg plastic like fibres are design to absorb oil into their surface  
83 while rubber fibres and some polymers absorbed liquid unto their molecular structure and swell  
84 (USEPA,2011). Catalyst is substances which increase rate of chemical reaction without its self  
85 undergoing any change. The catalyst used was calcium chloride not only speed the rate OH-group  
86 bond breaking by chemically mediated analysis, but also its an advantage of removing hemicelluloses  
87 component of the organic material which is highly responsible for the sorbent hydrophilicity its  
88 significant sorbtion process.

89 **Chemical Modification**

90 The acetylation was carried out in mild conditions in the presence of calcium chloride using acetic  
91 anhydride by Sun *et al* (2004) in a free solvent system. 5g of sample was placed in a 500ml flat  
92 bottom flask containing 300cm<sup>3</sup> of the acetic anhydride and 30g of calcium chloride. The flask was

93 placed into a thermostatic water bath set at 100°C under atmospheric pressure, with a reflux condenser  
94 fitted, the flask was removed from the water bath and the hot reagent was decanted off. The sample  
95 material was thoroughly washed with ethanol and acetone to removed unreacted acetic acid by-  
96 product. The new product was oven dried at 60°C for 8 hours. The dried modified *Hibiscus asper* fibre  
97 was re-weighed to determine the weight gain on the basis of initial oven dry measurement, weight  
98 percent gain % (WPG) of the *Hibiscus asper* fibre due to acetylation was calculated from the formula:  
99 
$$\text{WPG (\%)} = [(W_{\text{mod}} - W_{\text{unmod}}) / W_{\text{unmod}}] \times 100$$

100 Where  $W_{\text{mod}}$  is the oven dried weight of the modified *Hibiscus asper* and  $W_{\text{unmod}}$  is the weight of the  
101 *Hibiscus asper* prior to reaction.

### 102 **Characterization of the sorbents**

103 The moisture content was determined according to the method of Rengarajet *et al.*, (2000). Ash content  
104 was determined using the methods employed by Aloko & Adebayo (2007). The Volatile content was  
105 determined according to the method of Fapetu (2000). The fixed carbon was determined as adopted  
106 by Fapetu (2000). The method described by Ekpete and Horsfall (2011) was adopted. Porosity was  
107 determined by the method adopted by Ekpete and Horsfall (2011). Specific gravity was determined  
108 by the method adopted by Ekpete and Horsfall (2011). Swellability (S) and Anti- swelling efficiency  
109 (ASE) tests were determined as adopted by Termiz (2006)

### 110 **Characterization of Crude Oil Sample**

111 The following physico-chemical properties were used to characterize the crude oil sample from Port-  
112 Harcourt.

113 The density of the crude oil was determined using a specific gravity bottle as adopted by Nwankwere  
114 (2011). The viscosity of the crude oil was obtained using a viscometer at 25°C. The specific gravity  
115 (s.g) of the crude oil was calculated using the result obtained for density. The specific gravity being a  
116 more standard measurement was obtained by multiplying the density obtained with the density of  
117 water 0.998g/dm<sup>3</sup>. The American Petroleum Institute (API) was obtained using the method describe  
118 by Nwankwere (2011)

### 119 **Crude oil sample weathering**

120 The crude oil contains low boiling fractions that evaporates after a spill and is often before significant  
121 cleanup operations can take place. Therefore in order to simulate the situation of the oil spill and to  
122 minimize experimental variation, the crude oil samples was placed in beakers in a laboratory at room  
123 temperature for one day in an open air to released volatile hydrocarbons contents.

### 124 **Oil sorption studies**

125 Oil sample 20ml was suspended in 150ml of water in a 250ml beaker, different weights of the  
126 absorbent was spread on the surface of the mixture, the procedure was repeated at room temperature,  
127 after 20 minutes the absorbent was collected with a net and left to drained by hanging the net  
128 suspended by retort and clamp over the beaker for 15 minutes. The entire procedure was carried out at

129 various conditions to test the effect of sorbent weight, reusability and time of acetylation. The oil  
130 sorption capacity was calculated from the formula:

131 Sorption capacity = new weight gain/ original weight x100

### 132 **Determination of the amount of water sorption**

133 The water content of the sorbent was determined in the laboratory using the method of centrifuge  
134 technique as carried out by Hussein *et al* (2008). The **absorbent** was subjected to pressing to desorb  
135 the crude oil. During the pressing stage petroleum ether (10-20ml) was added to help **extract** the oil in  
136 the sorbent, the extracted liquid was collected in a centrifuge tube. The centrifuge tube was put in a  
137 water bath to break emulsion present and then centrifuge for 20 minutes. The amount of water sorbed  
138 was weighed and recorded.

### 139 **Fourier Transform Infrared Spectroscopy Analysis (FT-IR)**

140 The modified and unmodified properties of *Hibiscus asper* samples were characterized using FT-IR,  
141 Perkin-ELMER-8000S Spectrophotometer. Samples were run using the KBr pellet technique at the  
142 National Research Institute for Chemical Technology (NARICT), Zaria, Kaduna-Nigeria.

### 143 **Statistical data analysis**

144 The data obtained was analyzed using the method for calculating mean and standard deviation  
145 expressed as estimate standard deviation S of a finite set of experimental data (N< 30) at 95%  
146 confidence level **and two degrees of freedom.**

147 
$$SD = \frac{\sqrt{\sum(\bar{x}-x)^2}}{N-1}$$

## 148 **RESULTS AND DISCUSSIONS**

149 The resultType equation here.s of the physical properties of the unmodified and modified plant  
150 materials shown that during the course of the modification the ash contents which is the reflection of  
151 the inorganic composition is within the range of the general ash content ( 1%-20%) of the fibrous raw  
152 material. After modification ***Hibiscus asper*** has the ash content of 13%, moisture content reduced by  
153 11%, hence the plant materials will have low water intake and become more hydrophobic. The  
154 swellability was decreased from 680%-407%, making the plant materials a better sorbent for oil  
155 retention as swellability influences competition between oil and water for sorption sites in the sorbent.  
156 The oil sorption capacity also increases from 320%- 449%, this shows that the acetylation of the plant  
157 materials makes it a possible sorbent for oil spill application Nwankere et al. (2010). The  
158 improvement and changes in the physical properties of the plant materials after acetylation is an  
159 indication of a successful acetylation, the WPG of *Hibiscus asper* was 224%.

160 The results of the physical properties of the unmodified and modified plant materials were reported as  
161 seen in the Table 1.

162 Table 1Characterization properties of *Hibiscus asper*

163 Characterizing properties	unmodified	modified
164 Ash Content (%)	6.00±0.01	13.00±0.01

165	Moisture content (%)	4.00±0.01	11.00±0.03
166	Volatile content (%)	98.00±0.05	50.00±0.01
167	Bulk Density (g/cm <sup>3</sup> )	1.24±0.01	1.14±0.01
168	Fixed Carbon (%)	4.00±0.01	37.00±0.01
169	Specific Gravity (g/cm <sup>3</sup> )	0.017±0.01	0.018±0.01
170	Sweallability (Absorption)	608±0.01	407±0.02
171	Oil Sorption Capacity (%)	320±0.01	449±0.02

172

173 The properties of the crude oil characterized were the density, specific density, API gravity, viscosity  
 174 and the ash content. The results obtained are shown in Table 2.

175 The results of the characterized oil show its lightness in the recorded density of less than 1 and  
 176 specific gravity which makes a promising sorbent, the viscosity at 30°C is 3.06 mpa.s, these properties  
 177 tend to affect the way oil samples are being absorbed by the sorbents.

178

179 Table 2.Characterization of the crude oil sample

180	Parameters	Values
181	Density (g/cm <sup>3</sup> )	0.91±0.01
182	Specific gravity (g/cm <sup>3</sup> )	0.85±0.02
183	*API (30°C)	35.07±0.01
184	Viscosity (30°C, mpa.s)	3.06±0.01
185	Ash content (%) @ 700°C	11.80±0.01

186 \*API – American Petroleum Institute, PHCO-Port-Harcourt crude oils

187

188 In this research the weight per gain (WPG) increased as the temperature increases which are an  
 189 indication of effective Acetylation. The relationship between the temperature of acetylation of  
 190 Hibiscus asperand the weight per gain is illustrated in Table 3. This result agreed with the work done  
 191 by Nwankwere (2010), where acetylated rice husk showed increased in weight per gain with increased  
 192 temperature during modification.

193

194 Table 3.Effect of Temperature and time on the natural plant sorbents

195	Temperature (°C)				
196	10°C	20°C	30°C	40°C	60°C
197					
198					
199					
200	Time (min)	(Weight Per Gram) %			

201	10	1.7	2.0	2.3	2.5	2.7
202	20	1.9	2.1	2.5	2.7	2.9
203	30	2.0	2.4	2.7	3.0	3.6
204	40	2.4	2.6	3.0	3.2	3.9
205	50	2.8	2.9	3.2	3.5	4.1
206	60	3.0	3.3	3.5	3.9	4.5
207	80	2.7	2.9	3.0	3.6	3.9
208	100	2.5	2.7	2.8	3.4	3.7
209	120	2.2	2.5	2.1	3.2	3.5

210

211 The oil/water sorption ability of the natural plant materials was examined in order to understand the  
 212 sorption capacity of the sorbents Table 4. There was an increase in sorption capacity for oil/water with  
 213 increase in sorbent weight for the natural plant materials. The modified plant materials showed higher  
 214 sorption capacity than the unmodified. The oil/water sorption by unmodified *Hibiscus asper* increased  
 215 from 10.62g/g to 34.20g/g,

216

217 Table 4. Oil and water sorbed by unmodified and modified *Hibiscus asper*

218	Weight			
219	Of Sorbent	Sorption time	Oil and water sorbed	Oil and water sorbed
220	(g)	(mins)	(Unmodified) (g/g)	(Modified) (g/g)
221	0.5	60	10.62	14.4
222	1.0	60	16.26	18.06
223	1.5	60	18.78	21.96
224	2.0	60	27.24	31.68
225	2.5	60	34.20	36.42

226

227 The oil sorption capacity recorded by the natural plant materials as shown in Table 5. The unmodified  
 228 oil sorption of *Hibiscus asper* was 13.14g/g and it increased to 24.09g/g. The higher oil sorption  
 229 capacity shown by modified plant materials is an evidence of successful replacement of the water  
 230 attracting hydroxyl group by acetic anhydride, thus chemical modification has improved water  
 231 absorption due to acetylation.

232

233 Table 5. Oil sorbed by unmodified and modified *Hibiscus asper*

234	Weight of	Sorption time	oil sorbed	oil sorbed
235	Sorbent (g/)	(mins)	unmodified(g/g)	modified (g/g)
236	0.5	60	13.14	18.96

237	1.0	60	17.88	23.82
238	1.5	60	19.29	25.32
239	2.0	60	22.02	28.23
240	2.5	60	24.09	31.08

241

242 Water sorption capacity of *Hibiscus asper* was examined to understand the water sorption ability of the  
 243 sorbent (Table 6). The unmodified plant materials showed higher water uptake at 60 minutes  
 244 compared to water uptake by the modified.

245 Water uptake by unmodified *Hibiscus asper* was 6.33g/g and it increased to 18.39g/g. Modification  
 246 was achieved by acetylation which resulted in less water uptake by the modified plant materials.

247 Table 6. water uptake capacity by unmodified and modified *Hibiscus asper*

248	Weight of	Sorption time	water uptake	water uptake
249	Sorbent (g)	(mins)	unmodified (g/g)	modified (g/g)
250	0.5	60	6.33	3.33
251	1.0	60	9.06	6.99
252	1.5	60	12.99	10.02
253	2.0	60	16.23	13.59
254	2.5	60	18.39	16.03

255

256 The effect of reusability of *Hibiscus asper* was carried on crude oil as shown in Tab OS (MOD) (g/g)  
 257 showed that the acetylated *Hibiscus asper* was reused three times before it reached 50% of the original  
 258 sorption capacity. This could be due to the irreversible deformation of the natural plant materials as a  
 259 result of tearing, crushing and other deterioration during squeezing. It's evident that the acetylated  
 260 sorbents could be efficient in recycling as seen practically in its stable floatability with much cycles  
 261 carried out.

262

263

264

265 Table 7. Effect of 1g acetylated reusability of *Hibiscus asper*

Weight	No. of	Sorption time(min)	Oil sorbed (g/g)
of sorbent (g)	Cycles		
1	1	60	11.25
1	2	60	11.70
1	3	60	12.60
1	4	60	12.30

1                      5                      60                      12.00

266

267 The results of the acetylation of the natural plant materials using different concentrations of acetic  
 268 anhydride and catalyst are shown in Table 8. The solid to liquid ratio of *Hibiscus asper* observed at  
 269 1.20 and 1.60 of sorbent to acetic anhydride mixture resulted to the increased of WPG from 3.67±  
 270 0.01 to 7.61±0.01 respectively. The structural modification by introducing the acetyl groups in place of  
 271 the hydrogen of the hydroxyl group is evident with increased in the WPG. The catalyst (Calcium  
 272 Chloride) dosage from 1-3% have shown efficient Acetylation and the use of catalyst in Acetylation  
 273 does not only speed the rate of hydroxyl group bond breaking by chlorinating mediated analysis, but  
 274 also its an advantage of removing hemicelluloses components of the organic material, which is highly  
 275 responsible for the sorbent hydrophilicity is significant. This work unfolded a new modified fibre  
 276 product that could have sorbent oleophilicity needed for cleaning of an environment contaminated.

277

278 Table 8. Effect of acetic anhydride and catalyst on *Hibiscus asper*

Solid/liquid	Temperature (°C)	Reaction time (1hours)	Catalyst (%)	WPG(%)
1.20	60	11.0	3.67	
1.30	60	1	1.5	4.81
1.40	60	1	2.0	5.77
1.50	60	1	2.5	6.05
1.60	60	1	3.0	7.61

285

286 The sorption studies obtained for the sorbents in water, oil and both oil and water indicated increased  
 287 sorption with increased weight of the sorbent as reported similarly by Hussein, *et al.*, (2008), there  
 288 was low water pick up by the modified natural plant materials as compared to the unmodified  
 289 samples.

290 The effect of WPG on oil absorptivity of the sorbent showed that because of the small hydroxyl  
 291 groups are substituted with larger acetyl groups, the sorbent will remain in a permanently swollen  
 292 state and thus become heavier. A higher WPG showed a higher degree of Acetylation, because the  
 293 acetyl groups added are responsible for increased oil sorption by the acetylated sorbent, therefore it is  
 294 expected that the WPG increases, the sorption capacity of the sorbent would increase simultaneously.

295 Sorption qualities of barley strands, both revealed increased time with increased sorption time. Table  
 296 9 showed that the oil sorbed by *Hibiscus asper* increased from 4.12g/g to 5.90g/g,

297

298 Table 9. Effect of sorption time on 1g of *Hibiscus asper*

WOS (g)	Time (min)	Oil Sorbed (g/g)
---------	------------	------------------

1	20	4.12
1	30	4.93
1	40	5.11
1	50	5.54
1	60	5.9

299

300 Correlation coefficient ( $R^2$ ) is an important indicator to determine which isotherm fit the system and  
 301 the highest ( $R^2$ ) will fit the system The Freundlich value for *Hibiscus asper* was  $k = 2.52$ ,  $n = 1.28$   
 302 and  $R^2$  was 0.27. For Langmuir value  $a = 0.02$ ,  $b = 0.02$  and  $R^2 = 0.99$ . These results (Table 12)  
 303 showed that acetylated plant materials fitted Langmuir model isotherm for it has the highest  $R^2$  value  
 304 the adsorption can be described as monolayer. The values of  $R^2$  for the plant material sorbents  
 305 indicated that it is an excellent sorbents to clean-up oil spilled in a contaminated area.

306

307 Table 10. Langmuir isotherm of *Hibiscus asper*

Ce/Qe	Ce
0.03	0.5
0.04	1.0
0.06	1.5
0.07	2.0
0.08	2.5

314

315

316 Table 11. Freundlich isotherm of *Hibiscus asper*

Log Ce	log Qe
- 0.03	1.28
1.00	1.38
0.18	1.40
0.30	1.45
0.40	1.50

323

324

325 Table 12: Langmuir and Freundlich isotherms model constant

326 Langmuir model

Freundlich model

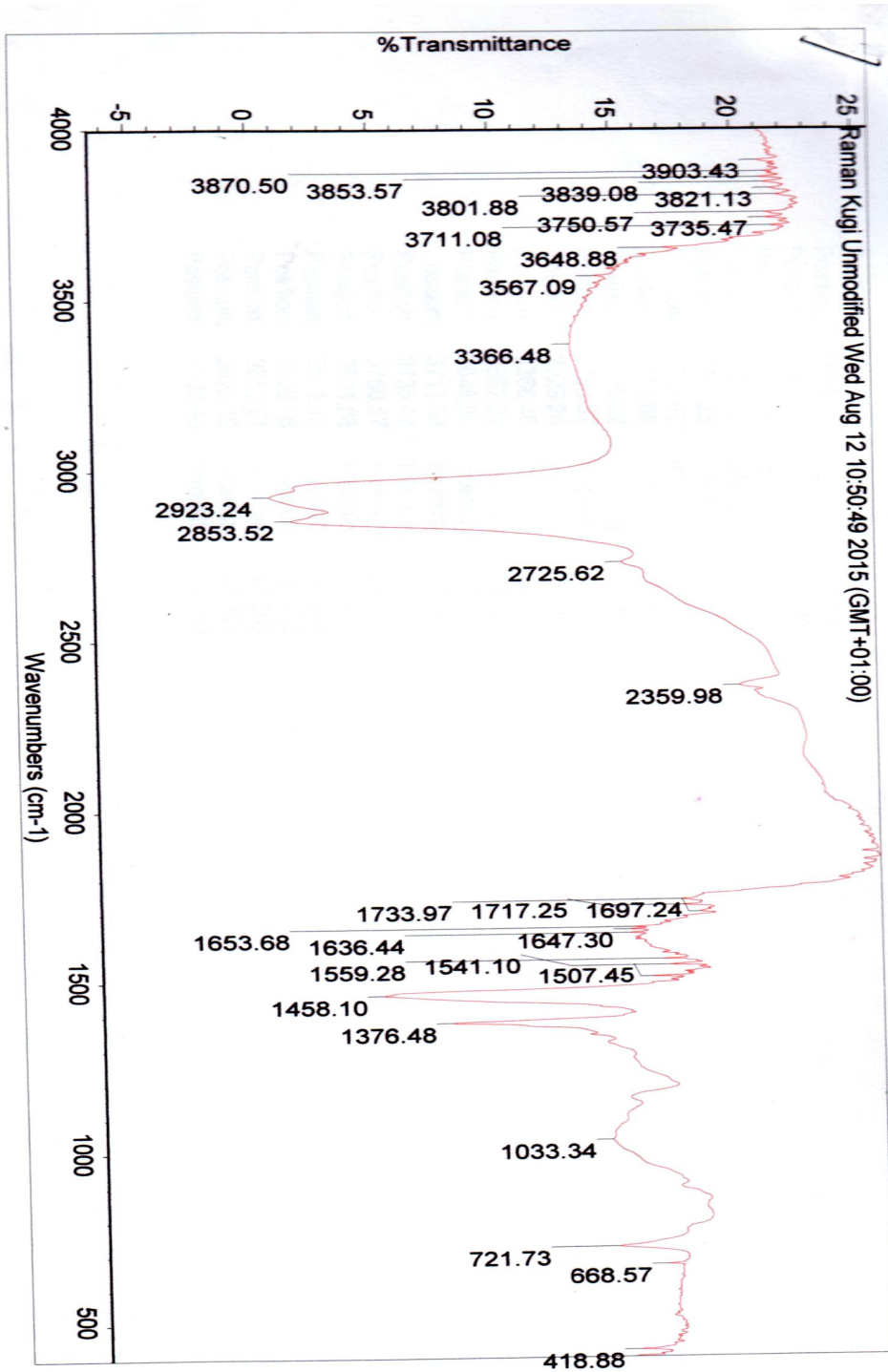
	a	b	R <sup>2</sup>	k	n	R <sup>2</sup>
328	<i>Hibiscus asper</i>	0.02	0.02	0.99	2.52	1.280.27

329

330 The characteristics of a particular functional group in a molecule in general are shown by the  
 331 vibrational frequencies. A distinct O-H stretching in the region of 3390.62 cm<sup>-1</sup> to 3175.99 cm<sup>-1</sup> and  
 332 C-H stretching in methyl and methylene groups (2923.23 cm<sup>-1</sup>) and absorptions in the region from  
 333 1030.22cm<sup>-1</sup> to 1755.31cm<sup>-1</sup> (Owen and Thomas, 1989) are characteristics of these plant  
 334 materials. The most dominant functional group present that react and selectively attached the pollutant  
 335 to the sorbent for its removal is O-H (3748.05-3176.02 cm<sup>-1</sup>).

336 Structural units that undergo various changes are the functional groups located on the glucose  
 337 monomer in the cellulose as observed in the FTIR spectra (Bodirlau and Teaca, 2009). The peaks  
 338 observed at 418.88, 418.25, 721.48 and 1031.22 cm<sup>-1</sup> are associated with the unmodified plant  
 339 materials while those absorbed at 3755.78, 3353.64, 3673.61 and 3626.76 cm<sup>-1</sup> in the spectra of the  
 340 acetylated plant materials provided some evidence of Acetylation in the modified plant materials.

341

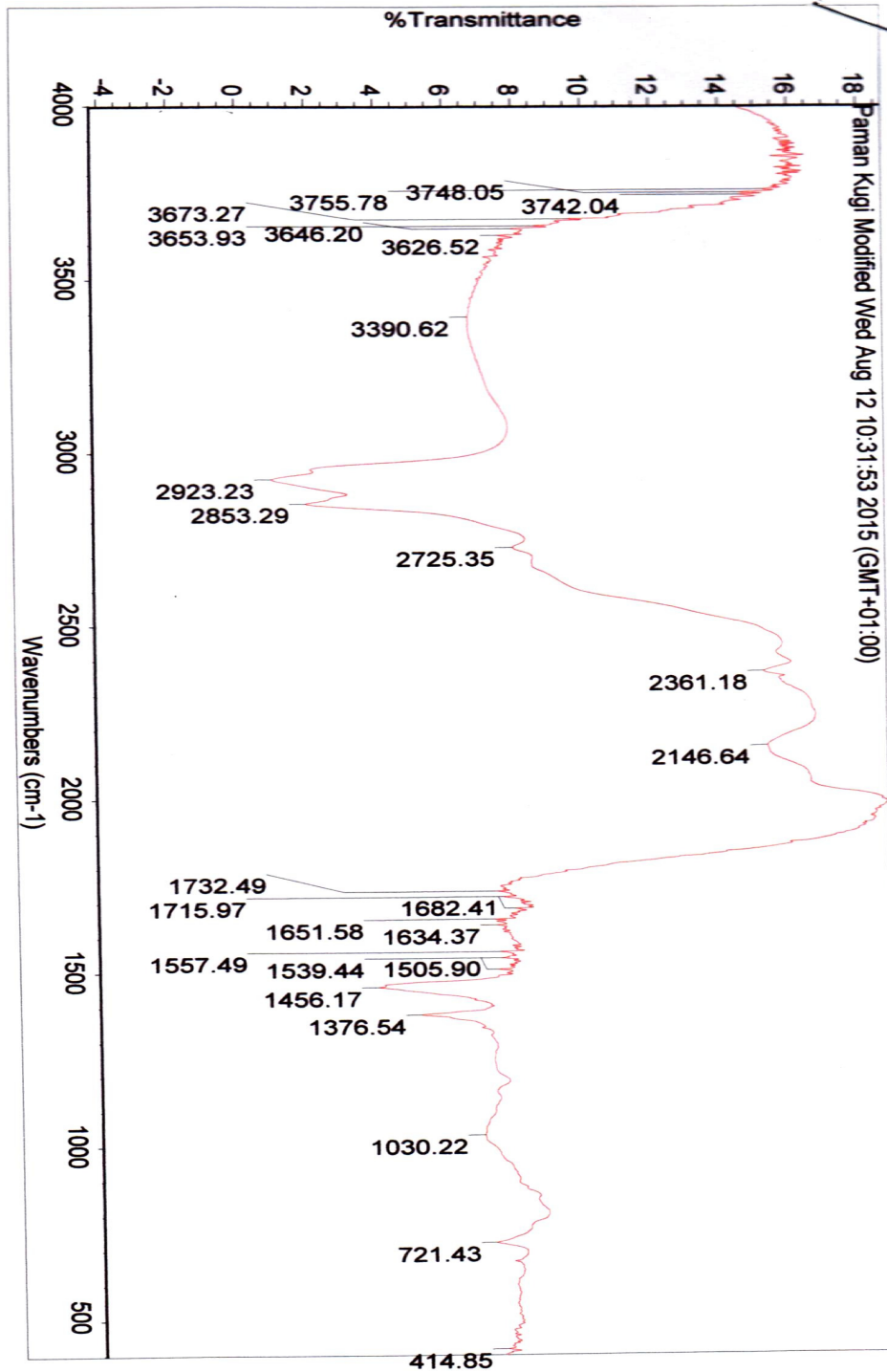


342

343

Figure 2. FT IR spectra of unmodified *Hibiscus asper*

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345

346

Figure 3. FT IR spectra of modified *Hibiscus asper*

347

348

349 **CONCLUSION**

350 In this research work the use of acetylated natural plant materials (*Hibiscus asper*), as sorbents for  
351 eliminating spilled oil from water bodies has been studied, the sorption behavior of the acetylated  
352 natural plant materials has indicated the hydrophobic status of the modified sample. Acetylation of the  
353 natural plant materials in the presence acetic anhydride using calcium chloride as catalyst in a solvent  
354 free system has proven to be successful.

355 The sorbents fitted the Langmuir model best the isotherms produced the highest correlation  
356 coefficient ( $R^2$ ). That means the model assumed monolayer coverage of the oil over the acetylated  
357 plant materials. The quick uptake and high absorption capacity makes the acetylated natural plant  
358 materials a good alternative sorbent for crude oil spill clean-up.

359

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