



Study of oil sorption behavior of filled and structured fiber assemblies made from polypropylene, kapok and milkweed fibers

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ABSTRACT

This article reports on oil sorption behavior of fiber assemblies made up of single natural and synthetic fibers as well as blend of natural and synthetic fibers when tested with high density oil and diesel oil. A series of filled fiber assemblies were prepared from 100% polypropylene, kapok, and milkweed fibers and another series of bonded structured fiber assemblies were prepared from a 70/30 blend of kapok and polypropylene fibers and a 70/30 blend of milkweed and polypropylene fibers. It was observed that the porosity of the fiber assemblies played a very important role in determining its oil sorption capacity. The polypropylene fiber assembly exhibited the highest sorption capacity (g/g) followed by the kapok and milkweed fiber assemblies at porosity <0.98. At higher porosities (above 0.98), polypropylene filled fiber assembly has poor sorption capacity due to large sized inter fiber pore. The kapok and milkweed fibers have intra fiber porosities of 0.81 and 0.83, respectively. All the fiber assemblies showed higher oil sorption capacity with the high density oil as compared to the diesel oil. As the kapok and milkweed fiber have low cellulose content, hence their slow degradation is an advantage in fresh and marine water applications. The good sorption capacity of kapok and milkweed fiber assemblies along with their biodegradable nature offer great scope for structuring them into fiber assemblies with large porosity and uniform pores to have efficient oil sorbents.

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1. Introduction

Oil is known to be one of the most important sources of energy in the modern industrial world. It is also used as a raw material for many chemicals and synthetic polymers worldwide [1–3]. It is a naturally occurring substance. The organic residues from the decay of plants and animals are converted by heat and pressure into petroleum, migrating upwards, sometimes over extensive areas, either to reach the surface or be occasionally trapped in what are to become oil reservoirs [4]. During production, transportation, storage, and usage of oil there is always a risk of oil spillage. Oil spill occurs over the seas, water bodies and land surfaces due to tanker disasters, wars, operation failures, equipment breaking down, accidents, and natural disasters. Oil spills into land, river or ocean impose a major problem on the environment [2,5–10]. The impact of marine oil spills to coastal environments and marine resources has over the past decades created increased public and government awareness and concern to preserve and protect the marine environment [11]. When oil comes in contact with water, it forms oil-in-water emulsion or floating film that needs to be

removed before it is discharged into the environment. Even very low concentrations of oils can be toxic to microorganisms responsible for biodegradation in conventional sewage processes [12]. The volatile components evaporate quickly. Some of the medium-sized polycyclic aromatic hydrocarbons are slightly soluble. Some of the products, which are degraded by sun and microorganisms, are highly soluble. The polycyclic aromatic hydrocarbons are known to affect a variety of biological processes and can be potent cell mutagens and carcinogens [3]. It is therefore necessary to clean the water or land immediately after the oil spill. The removal of crude oil and petroleum products that are spilled at sea is a serious problem of the last few decades. There are some oil spill remediation products available including but not limiting to dispersants, absorbents, bioremediation agents and other miscellaneous products like surface cleaners, gelling agents, demulsifiers, solidifiers, etc. that can be used to clean up oil spill. Of them, the polypropylene fiber based oil sorbent products have been found to be mostly used to clean up oil spill. Polypropylene is however not biodegradable, hence possess environmental problems. Instead the natural fiber based oil sorbents could be an interesting alternative to the synthetic oil sorbents.

Abdullah et al. studied the physicochemical and sorption characteristics of Malaysian kapok with diesel and engine oil. Kapok exhibited high hydrophobic–oleophilic characteristics, attributed to hollow lumen and its waxy surfaces. Kapok also found to have

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high oil retention and re-usability [13]. Milkweed floss has been reported to have hollow structure that provides large interspatial area to trap and retain oil [14]. Kapok fibers typically comprise of 64% cellulose, 13% lignin [15] and milk weed fiber comprise of 55% cellulose, 18% lignin [16]. Besides these constituents, they also contain waxy cutin on the fiber surface which makes them water repellent notwithstanding they are mainly composed of cellulose. Suni et al. have studied the oil sorption characteristics of cotton grass fiber. Cotton grass fibers and mats exhibited high sorption capacity of different oils than synthetic sorbent. Because of slow bio-degradability of these fibers, it would be easy to dispose the used sorbent either by composting or burning [17]. In this work, an attempt has been made to develop fiber assemblies with different porosities made up of single natural (Kapok and Milkweed) and synthetic fibers (Polypropylene) as well as blends of natural and synthetic fibers to study the influence of porosity and types of fibers and oils on oil sorption behavior.

2. Materials and methods

2.1. Materials

In this work, three different fibers namely kapok, milkweed and polypropylene were used. The oils used were high density oil and diesel oil. The density of the high density oil and diesel oil was 0.9 g cm^{-3} and 0.82 g cm^{-3} , respectively. The surface tension of the high density oil and diesel oil was $3.1 \times 10^{-2} \text{ cN cm}^{-1}$ and $2.5 \times 10^{-2} \text{ cN cm}^{-1}$, respectively. The viscosity of the high density oil and diesel oil was $1.17 \times 10^{-3} \text{ cN s cm}^{-2}$ and $1.64 \times 10^{-5} \text{ cN s cm}^{-2}$ at 20°C temperature. The kapok fiber was collected from the Salem region of India. Milkweed fiber was collected from the northern part of India. The polypropylene fibers (2.2 denier and 40 mm length) were supplied by Zenith Fibers Ltd., India. The fibers are coated with spin finish (details are not disclosed by the supplier) for easy processing. The spin finish usually contain: lubricant, anti-static agent, anti-oxidizing agent, etc.

2.2. Development of filled fiber assembly

A series of filled fiber assemblies were developed by using 100% kapok, milkweed and polypropylene fibers. A known weight of fibers was filled inside a circular PVC tube (20 mm inner diameter; 25 mm length) so as to obtain a specific porosity of fiber assembly inside this tube. The fiber volume fraction was varied from 0.01 to 0.09 so that the porosity was varied from 0.91 to 0.99. A large number of holes were drilled on the wall of this tube so as to facilitate the easy flow of oil during testing.

2.3. Development of bonded structured fiber assembly

A series of bonded fiber assemblies were prepared by mixing kapok and polypropylene fibers in 70:30 blend ratio and milkweed and polypropylene fibers in 70:30 blend ratios. This was done in two steps. In the first step, the fibers were processed through a miniature carding machine to form a fibrous web. It was observed that the fibrous web coming out of the doffer was not strong enough to withstand gravity forces between the doffer and the web collecting drum. Hence a web doffing conveyer was fabricated and placed between the doffer and the collecting drum so as to provide the web a support on its way from the doffer to the web collecting drum. In the second step, the fibers in the web were thermally bonded by the application of heat and pressure. The temperature was maintained at 200°C and the time was kept at 36 s. The pressure was varied as 10, 20, 30, 40 and 50 bar.

2.4. Testing of fibers

The kapok, milkweed, and polypropylene fibers were tested for their physical and chemical structures. The scanning electron microscopic images of the fibers were taken by using Zeiss EVO 50 scanning electron microscope. The images were analyzed by using a measuring toolbar as made available in the SEM computer program package. The Fourier transform infra-red (FTIR) spectroscopy of the kapok and milkweed fibers was carried out by using a Perkin Elmer FTIR spectroscopy. The crystallinity of the fibers was tested by using Philip's Analytical Instrument from 10 to 80° two theta ranges using an X-ray generator with 40 kV voltages and 30 mA current.

2.5. Determination of contact angle

The angle of contact between fiber and liquid (oil and water) was determined by using a Krüss Processor Tensiometer K100 in combination with Krüss LabDesk software in adsorption mode. For this, the fibers were packed randomly inside a probe that is cylinder having perforations at the bottom. Based on the modified Washburn's equation [18], the capillary constant of the packed fiber assembly was determined using n-hexane:

$$\cos \theta = \frac{m^2}{t} \frac{\eta}{\rho \gamma_{lv} C} \quad (1)$$

where θ is the angle of contact between fiber and liquid, m is the weight of liquid adsorbed in time t , η is the kinematic viscosity of the liquid, ρ is the density of the liquid, γ_{lv} is the surface tension of the liquid, and C is known to be capillary constant for a given material. When Washburn's experiment is performed with a liquid (n-hexane) which is known to have a contact angle of $\theta=0^\circ$ ($\cos \theta=1$) on the fiber, then the capillary constant C can be determined from the m^2 versus t data. Further, n-hexane is typically used as the liquid for determining the capillary constant, because of its low surface tension (18.4 mN m^{-1}). Once the capillary constant C was determined for a particular material, a second sample of the same fibers was tested for its wettability by other liquid (oil and water). The value of the material constant C determined by the n-hexane test was used in the Washburn's equation (equation 1), in combination with m^2 versus t data obtained during testing with the other liquids (Diesel, HD oil and water) to obtain the angle of contact between fiber and liquid.

2.6. Determination of porosity of fiber assembly [18]

A sample of known volume was cut from the fiber assembly. The mass of dry sample was measured. It was then immersed in n-decane till saturation was achieved. The mass of the wet sample was measured. The difference in the mass of the wet and dry sample gave the mass of n-decane absorbed. The quotient of this mass to the density of n-decane resulted in the volume of n-decane absorbed. The quotient of the volume of n-decane to the volume of the sample resulted in porosity of the sample.

2.7. Testing of sorption capacity

The testing of sorption behavior of the fibrous assemblies was done by using oil alone and a mixture of oil and water. The oil sorption test without water was performed as follows. A 400 ml of oil was taken in a 1000 ml beaker. The filled fiber assembly inside tube was immersed horizontally in the oil and allowed for 10 min to absorb oil. In the case of structured fiber assembly, 1 g of web was put in the oil. Then the assembly was taken out and allowed to drain to remove the loosely attached oils on the tube surface. The sorption capacity was then calculated by dividing the difference in mass

of the sample after and before sorption by the mass of the sample before sorption [19]. Another, sorption test was performed over oil floating on water. For this, a 50 ml of oil was poured over 400 ml of water. During testing oil got separated from the water and was floating.

2.8. Testing of retention capacity

The fiber assembly after removal from the beaker (as described in Section 2.7) was allowed to drain out the oil for 300 s. The retention capacity was calculated by dividing the difference in the masses of the wet and dry samples by the mass of the dry sample.

2.9. Theoretical determination of average hydraulic diameter of pores between fibers

The fiber assemblies (both filled and structured web) used in this study had fibers arranged randomly, for which the determination of hydraulic pore diameter was difficult. However a model to determine the hydraulic pore diameter for a parallel fiber assembly was developed which can be used to compare the filled fiber assemblies made of solid fibers (polypropylene) and hollow fibers (kapok and milkweed). Let us assume that d_i and d_o are the inner and outer diameters of the hollow fiber, N_f is the number of fibers in the fiber assembly, ε is the porosity of the fiber assembly, A_f is the cross-sectional area of a fiber, A_p is the cross-sectional area of all the pores (intra and inter pores), A_{po} is the cross-sectional area of all the inter fiber pores, A_{pi} is the cross-sectional area of an intra pore, and D_h is the hydraulic diameter of an inter fiber pore. It is then possible to write the following expression for hydraulic pore diameter

$$D_h = \frac{4A_{po}}{\pi N_f d_o} \quad (2)$$

The expression for the cross-sectional area of a fiber can be written as follows

$$A_f = \frac{\pi}{4}(d_o^2 - d_i^2) \quad (3)$$

And the expression for the cross-sectional area of an intra pore can be written as follows

$$A_{pi} = \frac{\pi}{4}d_i^2 \quad (4)$$

For a unit cross-sectional area of the fiber assembly, it can be considered that the total cross-sectional area equals to one, that is, $A_T = 1$. Then, the following expressions are valid to write

$$N_f A_f + N_f A_{pi} + A_{po} = 1 \quad (5)$$

$$A_p = A_{po} + N_f A_{pi} = \varepsilon \quad (6)$$

$$A_{pi} = A_f \left[\frac{d_i^2}{d_o^2 - d_i^2} \right] \quad (7)$$

By combining the above expressions, it can be proved that for a hollow fiber assembly,

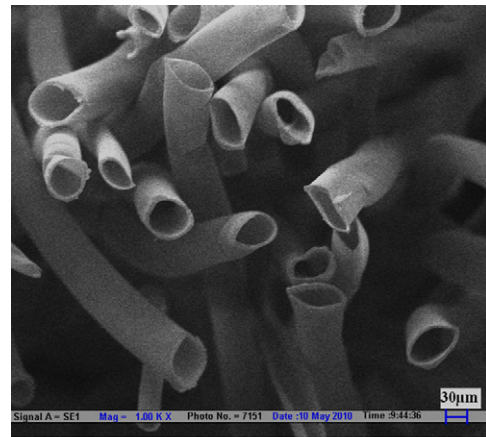
$$N_f = \frac{4(1 - \varepsilon)}{\pi(d_o^2 - d_i^2)} \quad (8)$$

$$D_h = \frac{1}{d_o(1 - \varepsilon)}(\varepsilon d_o^2 - d_i^2) \quad (9)$$

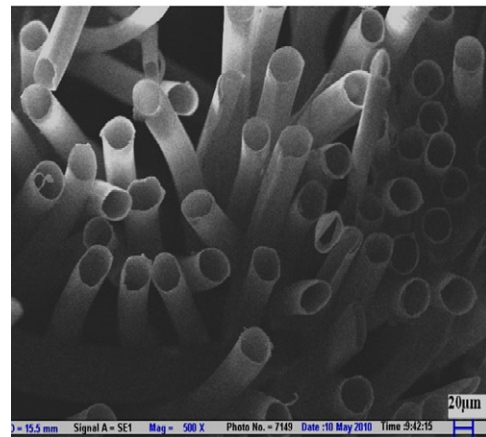
For a solid fiber, $d_i = 0$ and $d_o = d$. Then

$$N_f = \frac{4(1 - \varepsilon)}{\pi d^2} \quad (10)$$

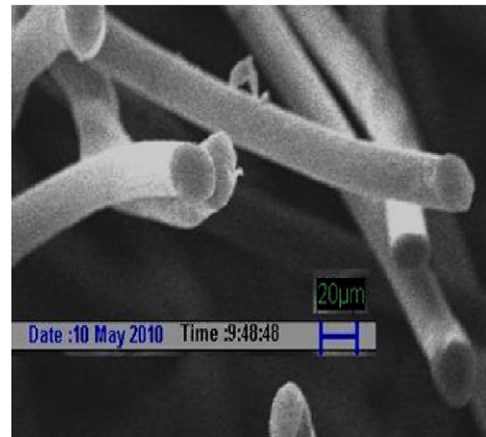
$$D_h = \frac{\varepsilon d}{(1 - \varepsilon)} \quad (11)$$



Kapok



Milkweed



Polypropylene

Fig. 1. SEM Images of fibers.

3. Results and discussion

3.1. Fiber structure

The scanning electron microscopic images of the cross-section of kapok, milkweed, and polypropylene fibers are shown in Fig. 1. It can be observed that the kapok and milkweed fibers are hollow fibers. Similar observations were made earlier [20,21]. The inner and outer diameters of the kapok fiber were measured as 20.7 μm and 23 μm , respectively. The same for the milkweed fiber were measured as 26.5 μm and 29 μm , respectively. The diameter

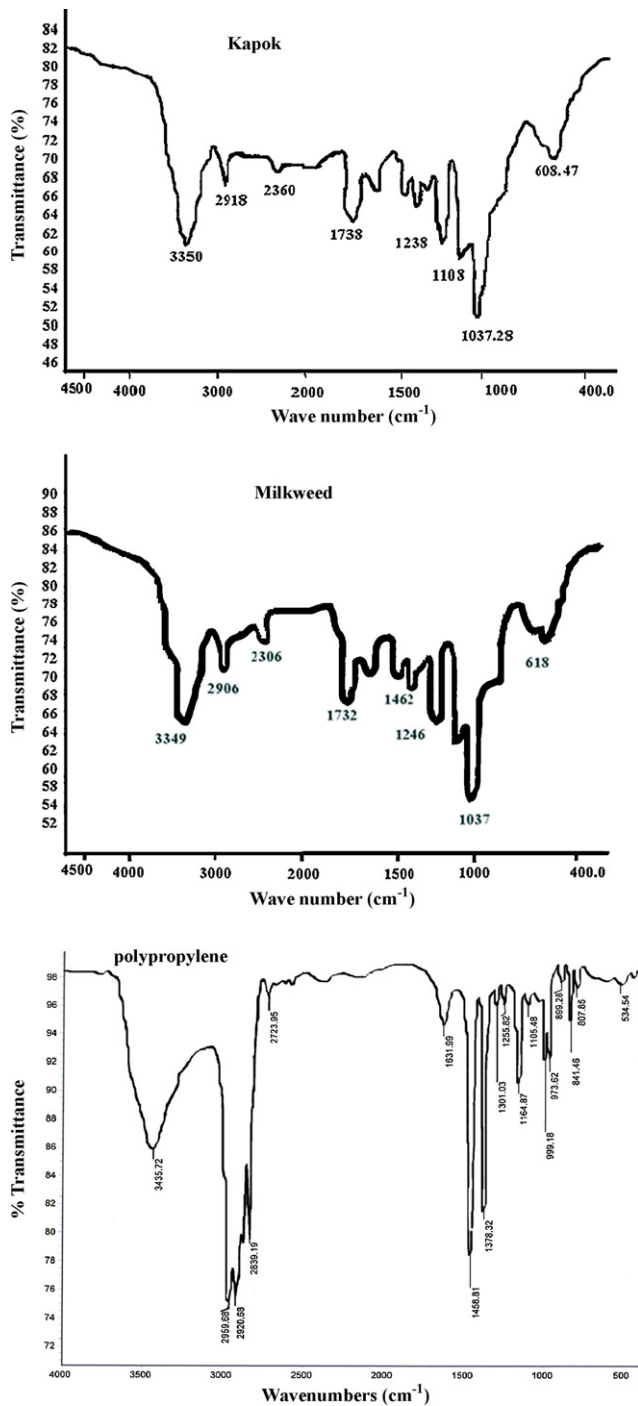


Fig. 2. FTIR spectra of kapok, milkweed and polypropylene fibers.

of the polypropylene fiber was measured as $19\ \mu\text{m}$. The density of the kapok, milkweed, and polypropylene fibers were taken as $1320\ \text{kg m}^{-3}$, $1480\ \text{kg m}^{-3}$ and $920\ \text{kg m}^{-3}$, respectively [9,22]. The FTIR spectra of kapok, milkweed and polypropylene fibers are shown in Fig. 2. In case of kapok fibers, a well-defined peak is observed at $3350\ \text{cm}^{-1}$ wave number that suggests the presence of hydroxyl ($-\text{OH}$) group. The peak around $2918\ \text{cm}^{-1}$ is suggested due to the CH stretching of aliphatic ($=\text{CH}_2$ and $-\text{CH}_3$) groups. This can be associated with the presence of plant wax, which generally consists of n-alkanes, smaller portion of alcohols, fatty acids, aldehydes, ketones, and n-alkyl esters [9]. The peaks around $1738\ \text{cm}^{-1}$ and $1238\ \text{cm}^{-1}$ are due to the presence

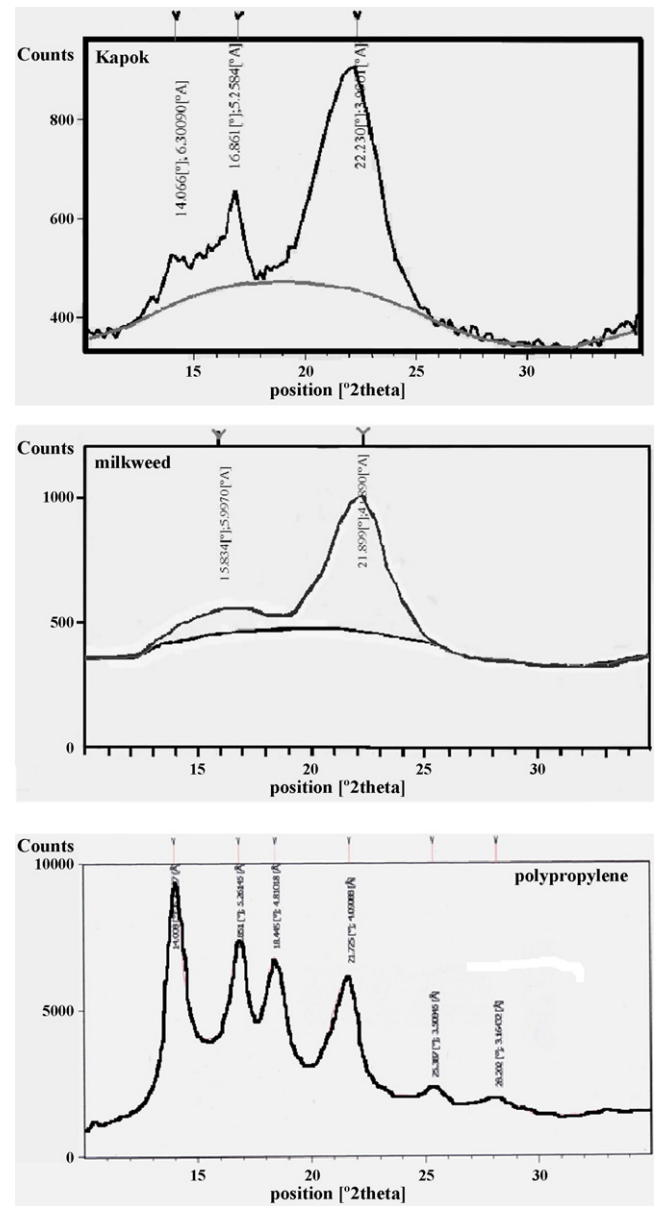


Fig. 3. X-ray diffraction patterns of kapok, milkweed and polypropylene fibers.

of carbonyl ($\text{C}=\text{O}$) group stretching of ester and $\text{C}-\text{O}$ stretching of acetyl group associated with the presence of plant wax, and the peak at $1037\ \text{cm}^{-1}$ wave number is associated with $\text{C}-\text{O}$ stretching due to the presence of cellulose, hemicellulose, and lignin [23]. A set of similar peaks are observed in the FTIR spectra of milkweed and kapok fibers that suggest the presence of similar groups in milkweed and kapok fibers. In the case of polypropylene, the peaks $2959\ \text{cm}^{-1}$ and $2920\ \text{cm}^{-1}$, $1458\ \text{cm}^{-1}$ and $1378\ \text{cm}^{-1}$ indicate the presence of CH , CH_2 and CH_3 groups in the fiber and confirm its chemical structure. The presence of other peaks corresponding to the chemical composition of the spin finish applied onto the polypropylene. The peak $3435\ \text{cm}^{-1}$ might be due to NH , OH or CO groups.

The X-ray diffraction patterns of kapok and milkweed fibers are shown in Fig. 3. The kapok fiber showed 59% crystalline region and 41% amorphous region, and the milkweed fiber exhibited 56% crystalline region and 44% amorphous region. The polypropylene fiber showed 64% crystalline region.

Table 1
Data of contact angles.

Fiber	Contact angle (°)		
	Diesel	HD	Water ^a
Polypropylene	70	78	≈90
Kapok	34	44	≈90
Milkweed	32	42	≈90

^a Approximate values.

3.2. Contact angle

The values of the angle of contact between the fibers and the fluids are listed in Table 1. The polypropylene fiber showed remarkably higher angle of contact with oil than the kapok and milkweed fibers, however, the kapok fiber exhibited slightly higher angle of contact with oil than the milkweed fiber. The presence of spin finishes on the polypropylene fiber might be responsible for high contact angles with oils. The diesel oil showed lower contact angle than the HD oil for all the fibers studied. The contact angle between fibers and water was difficult to determine precisely when it was close to ninety degree, since sorption was negligible to determine the slope, m^2/t .

The product of surface tension of oil and cosine of contact angle at the fiber–oil interface along with the radius of capillary are major factor in deciding the capillary pressure to imbibe oil into the pores as evidenced from Laplace equation:

$$\Delta P = \frac{2\gamma_{lv} \cos \theta}{r} \quad (12)$$

where r is the radius of the capillary.

It is evident from the equation that low contact angle at the fiber–oil interface and small pore are essential to exert high capillary forces on the oil and hence to achieve high oil sorption capacity.

3.3. Hydraulic diameter of inter-fiber pore

The hydraulic pore diameter of inter-fiber pore using the Eqs. (11) (for polypropylene) and (9) (for kapok and milkweed) for various porosity of unidirectional fiber assembly are given in Fig. 4. The inter fiber pore diameter is zero when porosity of kapok and milkweed fiber assemblies are 0.81 and 0.834, respectively, corresponding to the porosity of individual fibers themselves. This indicates that these fibers cannot be packed as fiber assembly with porosity lower than these values without compressing the fibers or collapsing the hollow lumen of the fibers. The intra pore diameters of the kapok and milkweed fibers are 20.7 μm and 26.5 μm ,

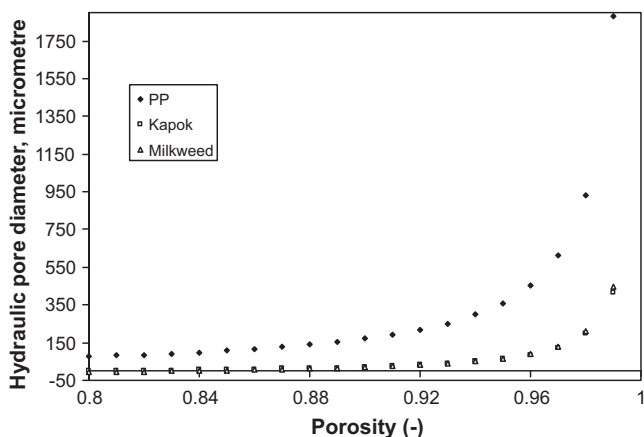


Fig. 4. Porosity and average hydraulic diameter of an inter-fiber pore for fibers aligned along the direction of liquid flow.

Table 2
Sorption capacity of filled fiber assembly (mass liquid/mass of fibers).

Porosity	HD oil			Diesel		
	PP	Kapok	Milkweed	PP	Kapok	Milkweed
0.91	10	6.8	4.8	9.1	6.3	4.6
0.92	11.3	7.8	6.2	10.4	7.1	5.1
0.93	13.1	9.0	6.8	11.5	7.4	5.8
0.94	15.5	10.7	9.3	12.4	8.2	6.3
0.95	18.8	12.6	10.8	17.1	11.8	7.9
0.96	23.5	13.4	11.1	20.8	13.3	10.3
0.97	32.0	19.8	15.6	23.8	18.6	13.5
0.98	40.4	33.4	27.2	38.8	25.6	20.1
0.99	84.6	61.6	44.3	45.4	52.7	37.0

respectively. The hydraulic diameters of inter fiber pore in PP, kapok and milkweed fiber assemblies are 192 μm , 26 μm and 24 μm at 0.91 porosity and 1880 μm , 414 μm and 449 μm at 0.99 porosity. The size of intra-fiber pores are smaller than the inter fiber-pores even at low porosity of 0.91. Oil penetration into larger capillaries depends on the balance between the capillary forces and retarding forces due to the weights of the oil in the capillaries. A very large inter fiber pore may not be favorable to obtain high sorption capacity, if the capillary forces are not sufficient to counteract the gravitational forces. In this case, the PP fiber with 19 μm diameter seems unfavorable. To get inter fiber pore diameter of around 450 μm at 0.99 porosity (as the case with kapok and milkweed), PP fibers with 4.5 μm diameter are preferred.

3.4. Sorption behavior of filled fiber assemblies

The oil sorption behavior of filled assemblies made up of single polypropylene, kapok, and milkweed fibers for the diesel oil and the high density oil are given in Table 2. It can be observed that the oil sorption capacity was increased with the increase in porosity. This was obvious, because a more porous fiber assembly could offer more free space for the oil to be absorbed inside the assembly. The polypropylene fiber assembly showed the highest oil sorption capacity followed by kapok and milkweed fiber assemblies, due to the former has low fiber density. This was true for both the oils; the only exception was with diesel at a very high porosity of 0.99. This will be discussed later. All the fiber assemblies showed higher sorption capacity for high density oil as compared to the diesel oil. This was obviously attributed to the fact that the high density oil was heavier than the diesel oil. The densities of the high density oil and diesel are: 0.9 and 0.82 g cm^{-3} , respectively. Similar observations were reported earlier [13]. It was interesting to note that the polypropylene fiber assembly with porosity as high as 0.99 exhibited sorption capacity as high as 84.6 g/g of fiber for the high density oil. The kapok and milkweed fiber assemblies with the same value of porosity (0.99) displayed oil sorption capacity of 61.6 g/g and 44.3 g/g for the same oil.

The sorption capacity expressed in terms of mass ratio is influenced by the density of fibers and liquids used. In order to normalize the effect of different density of fibers, sorption capacity in terms of volumetric ratio of oil and fibers and % volumes of pores filled are calculated and are given in Tables 3 and 4. The sorption capacity is less at high porosity of 0.98 and 0.99. This is due to large pores are not filled with liquid. PP and kapok has very high sorption capacity (~100%) up to a porosity of 0.92. The sorption capacities of PP and kapok fibers assemblies are more or less the same for both HD oil and diesel and are higher than the milkweed fiber assembly. There are variations in the % volume of pores filled by liquid with respect to porosity, due non-uniform hand filling of fibers inside the tube. This results in large localized variation in the inter fiber pore diameters. The very large pores are not filled with liquids. The variations in sorption capacity are much larger with milkweed

Table 3
Sorption capacities in terms of volume of liquid to fibers and % volumes of pores filled for HD oil.

ε	V_p/V_f	PP		Kapok		Milkweed	
		V_L/V_f	% volume of pores filled	V_L/V_f	% volume of pores filled	V_L/V_f	% volume of pores filled
0.91	10.1	10.1	100.0	9.9	97.9	7.9	77.9
0.92	11.5	11.5	99.8	11.5	99.9	10.2	88.7
0.93	13.3	13.2	99.7	13.2	99.6	11.2	84.0
0.94	15.7	15.6	99.8	15.7	100.0	15.3	97.9
0.95	19.0	19.0	100.0	18.5	97.3	17.8	93.8
0.96	24.0	23.8	99.2	19.6	81.6	18.2	75.9
0.97	32.3	32.3	100.0	29.0	89.7	25.7	79.4
0.98	49.0	40.9	83.4	48.9	99.8	44.7	91.2
0.99	99.0	85.5	86.4	90.4	91.3	72.9	73.6

V_p/V_f = ratio of volumes of pores and fibers; V_L/V_f = ratio of volumes of liquid and fibers; % volume of pores filled = $100 \times V_L/V_p$.

Table 4
Sorption capacities in terms of volume of liquid to fibers and % volumes of pores filled for diesel.

ε	V_p/V_f	PP		Kapok		Milkweed	
		V_L/V_f	% volume of pores filled	V_L/V_f	% volume of pores filled	V_L/V_f	% volume of pores filled
0.91	10.1	10.1	100.0	10.1	100.0	8.3	82.1
0.92	11.5	11.5	100.0	11.5	100.0	9.2	80.2
0.93	13.3	12.7	95.9	12.0	90.1	10.4	78.1
0.94	15.7	13.8	88.1	13.2	84.3	11.3	72.2
0.95	19.0	19.0	100.0	19.0	100.0	14.2	74.9
0.96	24.0	23.1	96.3	21.4	89.1	18.5	77.2
0.97	32.3	26.4	81.8	30.0	92.8	24.3	75.1
0.98	49.0	43.1	87.9	41.2	84.1	36.2	73.9
0.99	99.0	50.4	50.9	84.8	85.7	66.8	67.5

fiber assembly followed by kapok and the least for the PP fiber assembly.

It is observed that sorption capacity of all fiber assemblies with HD oil are mostly higher than with diesel. The HD oil being more viscous could not drain out easily from the pores and hence, higher sorption capacity is observed with HD oil. This is clearly evident when comparing the sorption capacity at highest porosity, 0.99. With largest pore size at this porosity, the low viscous diesel could drain out easily.

At highest porosity (0.99), the sorption capacity of PP fiber assembly is lower than the kapok fiber assembly. This might be due to the very large hydraulic diameter of inter fiber pores with PP whose capillary pressure to fill themselves with liquids would be insufficient. Fine fibers would be required to enhance the sorption capacity, especially with high porosity of fiber assembly as evidenced from Washburn equation (13). When the liquid rises inside a circular pore of radius r , the gravitational forces balance the capillary forces and the liquid ceases to rise beyond the equilibrium wicking height h^* ,

$$h^* = \frac{2\gamma_{lv} \cos \theta}{\rho g r} \quad (13)$$

where g is the acceleration due to gravity.

Throughout the sorption process, milkweed fiber assembly exhibited air bubbles coming out. This problem was very severe at high packing of fibers (low porosity). The same phenomenon was observed with Kapok with lesser magnitude. This problem could be as a result of filling of lumen (intra fiber pore) which are much

smaller than the inter fiber pores for the porosity range considered in our experiments. Fiber folding must have resulted in collapsing of lumen in the plane of fiber folds. The liquids rising into the lumen from the two ends of a fiber must have encountered resistance of displaced air due to back pressure. This is the main reason that can be attributed to the low sorption observed with Milkweed fiber assembly packed inside the tube. The bending rigidity of fibers depends both on second moment of inertia and elastic modulus of fiber. The milkweed fibers are thicker than the kapok fibers and hence have higher area moment of inertia than the later. We could not test the modulus of rigidity of these fibers.

The filled fiber assemblies made up of 100% polypropylene, kapok, and milkweed fibers with porosity as high as 0.95 were examined for their sorption capacity when they were tested with oil and a mixture of oil and water. The results are presented in Table 5. It can be seen that the sorption capacity of all fiber assemblies when tested with oil was higher than that with the mixture of oil and water. It was observed that polypropylene fiber assembly sunk in the mixture of oil and water just after three minutes of placement of it in the bath. But, this did not happen with the kapok and milkweed fiber assemblies. In fact, these fiber assemblies showed very good buoyancy in the mixture of oil and water. This is probably due to the high wax content present on the surface of kapok and milkweed fibers that was indicated by the FTIR spectra of these fibers. The sinking of the polypropylene fiber assembly was probably due to the fact that the polypropylene fiber assembly imbibed water along with oil inside its structure. We are not sure about the presence of some hydrophilic finishes on the surface of PP fibers.

Table 5
Sorption capacity of different fiber assemblies with oil and oil–water mixture.

Fiber	Sorption capacity (g/g)			
	HD oil	Mixture of HD oil and water	Diesel oil	Mixture of diesel oil and water
Polypropylene	18.8	16.5	17.1	16.2
Kapok	12.6	12.0	11.8	10.6
Milkweed	10.8	9.7	7.9	7.3

Table 6
Sorption and retention of thermo-bonded blended structured fiber assembly with HD oil and diesel.

Porosity	HD oil		Diesel			
	Kapok-70%/PP-30%		Kapok-70%/PP-30%		Milkweed-70%/PP-30%	
	S	R	S	R	S	R
0.91	–	–	9.6	8.5	–	–
0.92	10.2	9.1	–	–	–	–
0.93	15.1	13.9	–	–	10	9.3
0.94	–	–	10.4	8.8	16.4	15
0.95	17.5	15.3	–	–	–	–
0.96	26	23	–	–	–	–

Note: S, sorption (g/g) and R, retention (g/g).

3.5. Sorption and retention of thermo-bonded blended structured fiber assembly

The oil sorption and retention behaviors of the thermo-bonded kapok-polypropylene and milkweed-polypropylene blended fiber assembly with high density oil and diesel oil are given in Table 6. It can be observed that the oil sorption capacity of the fiber assembly increased with the increase in porosity of the assembly. We could not produce uniform webs having a range of porosity and also webs with higher porosities. Hence, oil sorption and retention study could not be carried out for Kapok-PP with diesel and also the blends (Kapok-PP and Milkweed-PP) at certain porosities with both HD oil and diesel.

4. Conclusions

The fiber assemblies made from kapok and milkweed have good oil sorption capacity but lower compared to that of polypropylene. Due to low cellulose content in these natural fibers, they might be interesting sorbent for marine and freshwater applications as they cannot easily degraded by cellulose degrading microbes. The porosity of a fiber assembly played a very important role in determining its oil sorption capacity. The higher is the porosity the higher is the oil sorption capacity. By suitably structuring the fiber assembly, sorbent with high porosity could be achieved to obtain high oil sorption capacity. However, with very large porosities (>0.98), some of the pores become too large, capillary forces become insufficient to overcome the gravitational forces of the oil in these pores, and hence, the sorption capacity might be lowered. All the filled fiber assemblies showed higher oil sorption capacity with the high density oil as compared to the diesel oil.

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