Tatjana Rijavec
[1] Oddelek za tekstilstvo, Naravoslovnotehniška fakulteta, Univerza v Ljubljani

Influence of Kapok Hollowness on Its Liquid Retention Capacity

Original Scientific Paper

Received *October 2009* • Accepted *November 2009*

Vpliv votlosti kapoka na sposobnost zadrževanja tekočin

Izvirni znanstveni članek

Poslano *oktober 2009* • Sprejeto *november 2009*

Abstract

Kapok (Ceiba pentandra) is a natural cellulose fibre with an extraordinary lumen and round-to-oval cross-section. It is one of the most efficient fibres for oil absorbers where it even outperforms synthetic fibres. The mechanism of oil sorption into kapok fibres has not been entirely researched yet. Excellent sorption capacities are attributed to the retention of oils in the kapok fibre lumen. The paper is going to present the results of measurements of the kapok fibres hollowness, and the capacity of kapok fibers to retain liquids after having been soaked for 3 hours and centrifuged, as well as the mechanism of water and oil surface adsorption. Geometrical indices of raw kapok were measured or calculated based on the measured parameters of the raw fibres cross-sections: thickness of the cell wall 1.01 μm, the lumen diameter to fibre diameter ratio (d/D) 0.85, percentage of the hollowness 73.08%, volume of the raw kapok lumen 2.1 cm³g, density of fibres 0.3968 g/cm³, specific surface area per volume unit 0.2324 μm/μm² and per weight unit 0.6678 m²/g resp. It has been noticed that at contact of dry kapok fibres with liquid, water is spreading slowly over the surface of fibres where-

Vodilni avtor/corresponding author:
dr. Tatjana Rijavec
tel.: +386 1 200 32 24
e-mail: tatjana.rijavec@ntf.uni-lj.si

Izvleček

Kapok (*Ceiba pentandra*) je naravno celulozno vlakno z izrazitim lumnom in okroglim do ovalnim prečnim prerezom. Je eno najučinkovitejših vlaken za oljne absorberje, kjer prekaša sintetična vlakna. Mehanizem sorpcije olj v kapokova vlakna ni popolnoma proučen. Odlične sorpcijske sposobnosti pripisujejo zadrževanju tekočin v lumnu vlaken. V članku so predstavljeni izsledki raziskave votlosti kapoka in sposobnosti zadrževanja tekočin po triurnem namakanju in centrifugiranju vlaken ter mehanizem površinske adsorpcije vode in olja. Geometrijski indeksi surovega kapoka so bili izmerjeni in izračunani na podlagi izmerjenih parametrov prečnega prereza surovih vlaken: debelina celične stene 1,01 μm, razmerje med premerom lumna in premerom vlakna (d/D) 0,85, votlost 73,08-odstotna, gostota vlaken je 0,3968 g/cm³, zunanja specifična površina 0,2324 μm /μm² oziroma 0,6678 m²/g. Ob stiku suhih vlaken kapoka s tekočino je bilo opaženo počasno širjenje vode po površju vlaken, olje pa se je razširilo zelo hitro. Voda že takoj ob stiku s kapokovimi vlakni začne prodirati v lumen vlaken. Olje počasneje prodira v lumen vlaken kot voda. Zelo malo olja je prodrlo v lumen kapoka v začetnih minutah, po daljšem času namakanja pa je olje dobro zapolnilo lumen kapoka. Povprečni volumen lumna kapoka je 2,1 cm³ na gram absolutno suhih vlaken, kar pomeni kapaciteto vlaken za zadrževanje tekočine v lumnu. Izmerjene količine zadržane vode po triurnem namakanju in centrifugiranju so bile 1,03 g za vodo, za jedilno olje 1,32 g in za parafinsko olje 1,07 g na gram absolutno suhih vlaken. Količina zadržanega olja, ki ostane v kapoku po centrifugiranju, je manjša od kapacitete lumna in pomeni le nekaj odstotkov celotne količine vsebovanega olja v namakanih vlaknih pred centrifugiranjem. Centrifugiranje omogoča *as oil spreads very quickly. Water starts to penetrate into the fibre lumen as soon as it comes into contact with kapok fibres. Oil penetrates into the fibre lumen at a slower rate than water. In the first few minutes only a very low amount of oil penetrated into the kapok fibre lumen, however, after a longer period of time, oil filled the kapok fibre lumen very well. The mean volume of a kapok fibre lumen is 2.1 cm^3 per 1 gram of absolutely dry fibres, which represents the capacity of fibres to retain liquid in their lumen. The measured mean amount of the retained liquid in kapok fibres after the fibres have been soaked for 3 hours and centrifuged was 1.03 g in the case of water, 1.32 g in the case of cooking oil and 1.07 g in the case of paraffin oil per 1 g of absolutely dry fibres. The quantity of oil retentioned in kapok after centrifugation was lower than capacity of fibres lumen which presents only few percentages of the whole quantity of retentioned oil in kapok fibres before centrifugation. Centrifugation process enables a highly percentage of oil regeneration and reusage of kapok filters.*

Keywords: kapok, fibre hollowness, geometrical indices of hollow fibres, amount of retained liquid

1 INTRODUCTION

Hollow fibres belong to heterophyllic fibres of the sheat/core type with the core representing a hollow part of the fibre which is usually filled with air [1]. They are characterized by geometrical parameters among which the size of the hollow part as well as the external and internal surfaces are the most important [2, 3]. The hollowness of fibres has a significant influence on physical properties of fibres and end products, such as density, thermal and acoustic insulation and liquid retention capacity.

Man-made melt-spun hollow fibres are mostly used as the stuffing for winter clothes, fake fur and upholstery. The fineness of these fibres, which are typically made of polyester and polypropylene, is about 6 dtex for pillows stuffing, about 15 dtex for upholstery, and 40 dtex for filtration [4]. Solution-spun hollow fibres have porous semi-permeable wall and are mostly used for liquid and gas filtration, e.g. seawa-

visok odstotek regeneriranja olj iz kapokovih filtrov in njihovo ponovno uporabo.

Ključne besede: kapok, votlost vlaken, geometrijski indeksi votlih vlaken, količina zadrževane tekočine.

1 Uvod

Votla vlakna so heterofilna vlakna tipa plašč/jedro, kjer je jedro votli del vlakna, ponavadi zapolnjen z zrakom [1]. Karakterizirajo jih geometrijski parametri, med katerimi so najpomembnejši velikost votlega dela vlaken ter zunanja in notranja površina [2, 3]. Votlost vlaken vpliva na fizikalne lastnosti vlaken in končnih izdelkov, kot so gostota, toplotna in zvočna izolacija ter sposobnost zadrževanja tekočin.

Kemična votla vlakna, spredena iz taline, največkrat uporabljajo za polnila za zimska oblačila, umetno krzno in notranjo opremo. Ta so najpogosteje iz poliestra in polipropilena, finoča je okrog 6 dtex za blazine, okrog 15 dtex za pohištvo in 40 dtex za filtracijo [4]. Votla vlakna, spredena iz raztopine, imajo porozno polprepustno steno. Največ jih namenjajo za filtracijo tekočin in plinov, npr. za razsoljevanje morske vode, farmacevtsko in biotehniško separacijo ter za detoksinacijo krvi [5]. Takšen primer so tudi votla bakrova vlakna (CUP), ki jih uporabljajo za dializne membrane [6].

Rastlinska elementarna vlakna so ostanki prozenhimatskih, v vzdolžni osi podaljšanih rastlinskih celic. Protoplazma, ki je v osrednjem delu rastlinske celice, se pri odmrtju celice posuši in pusti za seboj z zrakom napolnjen votli del, t. i. lumen. Ta poteka vzdolž vlakna in se pri nekaterih vlaknih (npr. pri surovem bombažu) sesede, ko na celično steno ne pritiska več protoplazma. Velikost in oblika lumna sta pri različnih vrstah rastlinskih vlaken zelo različni [7]. Odvisni sta od razvitosti sekundarne celične stene in tudi od napetosti, ki delujejo v vlaknih med odmiranjem rastlinskih celic, ko se protoplazma suši.

Kapok (*Ceiba pentandra*) je votlo semensko enocelično vlakno, ki ima tanko, vendar togo sekundarno celično steno. Ta se pri sušenju protoplazme ne sesede. Zato večina vlaken obdrži cevasto obliko. Na površju vlaken so številne mehanske poškodbe, upogibi, kinki ipd. [8]. Po morfoloških lastnostih je primerljiv s svilnico (*Asclepias syriaca*), ki spada med invazivne rastline na območju Slovenije.

Kapok je izjemno učinkovito vlakno za biorazgradljive oljne absorbente [9]. V zadnjem desetletju je bilo opravljenih več raziskav za uporabo kapoka za oljne filtre in za odstranjevanje naftnih madežev pri razlitju v rekah, morjih in oceanih. Pri proučevanju filtracijskih sposobnosti kapoka v 5-, 10- in 15-odstotni vodni emulziji dizelskega in hidravličnega olja so ugotovili več kot 99-odstotno odstranitev olja [10]. Iz oljne suspenzije s sladko ali morsko vodo absorbira kapok tudi več kot 40 g olja na gram vlaken [9].

ter desalination, pharmaceutical and biotechnical separation, and blood detoxination [5]. The example of such fibres are cupro fibres (CUP) used for dialysis membranes [6].

Vegetable elementary fibres are the remains of prosenchymatous, in the longitudinal axis extended plant cells. When a cell dies out, protoplasm, which is located in the central part of the plant cell, dries up and leaves an air-filled hollow space, the so-called lumen. Lumen runs alongside fibre; in some kinds of fibres (e.g. cotton fibres) it collapses when the pressure of protoplasm on the cell wall slackens. The size and shape of lumen highly differ from one type of vegetable fibre to another [7]. They depend on the development degree of a secondary cell wall as well as on tensions acting inside fibres during the plant cells dying out when protoplasm is drying.

Kapok (Ceiba pentandra) is a hollow seed monocellular fibre. It has thin but rigid secondary wall, which does not collapse during drying of protoplasm. This is why most kapok fibres keep tubular shape which is prone to deformations, such as flexures, kinks, etc. [8]. The morphological properties of kapok can be compared with those of milkweed (Asclepias syriaca), which belongs to invasive plants in the territory of Slovenia.

Kapok is an extremely effective fibre for biodegradable absorbents [9]. In the last decade several researches have been carried out about possible use of kapok for oil filters and for removal of oil spills from the surface of rivers, seas and oceans. Investigations of the kapok's filtration capacity in a 5, 10 and 15% water emulsion of Diesel and hydraulic oil have shown that more than 99% of oil has been removed [10]. Kapok is capable of absorbing even more than 40 g of oil per 1 gram of fibres from the oil suspension with fresh or seawater [9].

A high content of inorganic substances (1–2.5%) and acetyl groups in a primary cell wall and a waxy surface of raw kapok have a significant impact on high wetting capacity of kapok fibres with oils. Lim and Huang [11] have found that after the extraction of raw kapok with chloroform when superficial waxes and substances soluble in organic solvents were removed, kapok still remained water unwettable and highly oleophyllic fibre. A contact angle between extract and oil was 117°. The outstanding wettability of

Visoka vsebnost anorganskih snovi (1–2,5 %) in acetilnih skupin v primarni celični steni poleg voskaste površine surovega kapoka vplivata na veliko sposobnost omočenja kapokovih vlaken z olji. Lim in Huang [11] sta ugotovila, da je kapok po ekstrakciji surovega kapoka s kloroformom, pri čemer so se odstranili površinski vosek in v organskih topilih topne snovi, še vedno ostal z vodo neomočljivo in močno oleofilno vlakno. Stični kot med ekstraktom in oljem je bil 117°. Odlična omočljivost kapoka omogoča površinsko zadrževanje velikih količin olja, ki se pri ožemanju vlaken ali centrifugiranju zelo hitro odstranijo.

Na hitrost absorpcije tekočin in količino kemično vezane tekočine vplivata molekulska in nadmolekulska struktura celične stene rastlinskih vlaken. Morfološka in nadmolekulska struktura kapoka je bila natančno obrazložena šele v zadnjem času [12]. Molekulska struktura kapoka je dobro proučena. Kapok vsebuje 19–20 % lignina in 22–28 % ksilana. Oleofilne absorpcijske sposobnosti celične stene kapoka so posledica kar 12–13 % acetilnih skupin, vezanih na neceluloznih molekulah, predvsem na ligninu, ki so porazdeljene znotraj nizkokristaline alfaceluloze tipa II, katere delež v surovem kapoku je od 35- do 43-odstoten [9, 13].

Prodiranje olja v kapokova vlakna po kapilarnem mehanizmu opisujeta Choi in Moreau [14], ki sta ta mehanizem proučevala s scanning elektronskim mikroskopom v sobnih razmerah. Ugotovila sta, da je „olje na površini kapokovega vlakna po določenem času izginilo s površja vlakna, verjetno zaradi sorpcije po kapilarnem mehanizmu zaradi votlega lumna". Obnašanje lumna pri navzemanju tekočin je različno, odvisno od vrste rastlinskega vlakna. V surovem suhem bombažnem vlaknu je lumen seseden. V vodni raztopini NaOH (pri mercerizaciji) prihaja do nabrekanja sekundarne celične stene bombaža proti sredini vlakna zaradi prepočasnega nabrekanja primarne celične stene, kar vodi v zmanjšanje lumna. V kapoku se lumen zapolni s tekočinami. Glede na to, da o prodiranju olj skozi celično steno in o nabrekanju celične stene kapoka ni znanih podatkov v literaturi, vpliv olja na velikost lumna ni poznana. Ker je kapok rastlinsko vlakno z zelo kompaktno primarno celično steno [12], predvidevamo, da je sposobnost nabrekanja primarne celične stene tako v olju kot v vodi omejena.

Hori [9], ki je raziskoval absorpcijo surovih vlaken kapoka v suspenziji dizelsko olje/voda, je v optičnem mikroskopu opazil prisotnost predvsem obarvanega dizelskega olja v lumnu kapokovih vlaken. Ocenil je, da voda ne more prodreti v kapokova vlakna zaradi visoke površinske napetosti kapoka proti zraku, ki je zajet v vlaknih ($7{,}2 \times 10^{-4}$ N/cm pri 20 °C).

Pore v vlaknih so prav tako območja zadrževanja tekočin, ki dodatno povečujejo količino absorbiranih tekočin. Poroznost kapokovih vlaken ni raziskana.

Namen naše raziskave je bil proučiti geometrijsko votlost kapoka in oceniti vpliv lumna na sposobnost zadrževanja vode in olja.

kapok enables that high amounts of oils are retained on the surface of fibres. They are quickly removed during squeezing or centrifuging fibres. The liquid absorption rate and the amount of chemically bound liquid are dependent on molecular and supramolecular structure of the vegetable fibres cell wall. The morphological and supramolecular structure of kapok has not been explained in detail until recently [12]. The molecular structure of kapok has been well researched. Kapok contains 19–20% of lignin and 22–28% of xylan. Oleophyllic absorption capacities of a kapok cell wall are the result of even 12–13% of acetyl groups bound on non-cellulose molecules, particularly to lignin, which are distributed inside low-crystalline cellulose of type II the content of which in raw kapok is 35–43% [9, 13]. Penetration of oil in kapok fibres by capillarity is described by Choi and Moreau [14] who investigated this mechanism with a scanning electron microscope at room conditions. They found out that »oil on kapok fibre surface disappeared from the surface after a certain period of time, probably due to sorption by capillary action because of hollow lumen«. The behaviour of lumen during liquid absorption differs in dependence of the type of vegetable fibres. A dry raw cotton fibre has a collapsed lumen. In water solution of NaOH (at mercerisation) a secondary cell wall of cotton swells inwards as a result of too slow swelling of a primary cell wall which

2 Metode raziskav

V raziskavi smo uporabili surov javanski kapok s povprečno dolžino 18,8 mm in finočo 1,02 dtex.

2.1 Geometrijski indeksi kapoka

Geometrijske indekse kapoka smo proučili na podlagi meritev prečnega prereza vlaken, ki smo ga posneli na vrstičnem elektronskem mikroskopu JSM-2 JEOL pri 2000-kratni povečavi, pospeševalni napetosti 10 kV, naklonu vzorca 45° in delovni razdalji 12 mm. Snop vlaken smo na tesno potisnili skozi luknjico v ploščatem nosilcu in štrleče konce odrezali. Zaradi takšnega načina priprave preparata so se vlakna večinoma deformirala iz okrogle v ovalno oziroma elipsasto obliko po prečnem prerezu (slika 1). Vlakna smo pred snemanjem naparili s plastjo ogljika (C) in plastjo zlitine zlato/paladij (Au/Pd). Na digitalnih posnetkih prečnih prerezov vlaken (slika 1, levo) smo s pomočjo računalniškega programa [15] odčitali debelino celične stene (d_{st}) ter veliko ($2a_{vl}$; $2a_{lu}$) in malo ($2b_{vl}$; $2b_{lu}$) os zunanje in notranje elipse prereza vlaken (slika 1, desno). Opravili smo meritve na 100 vlaknih.

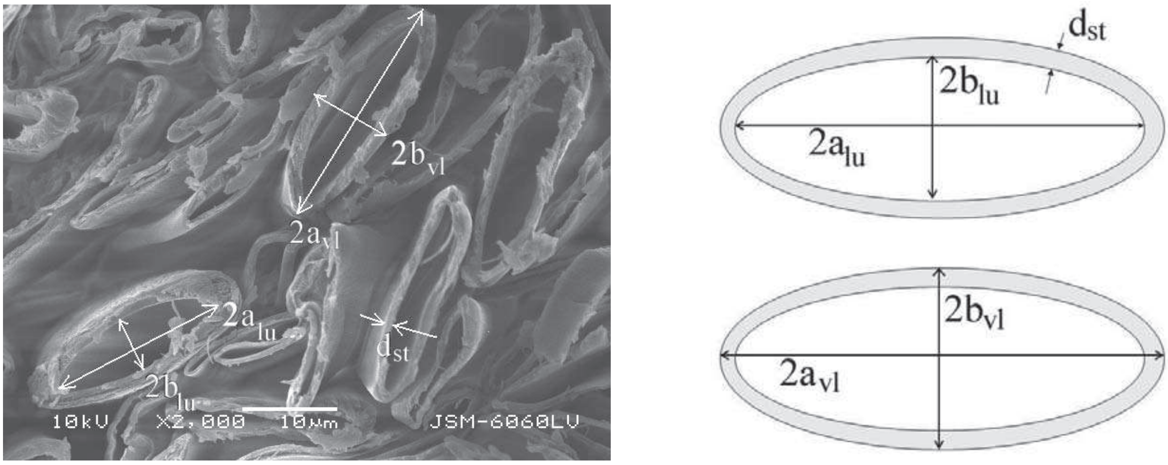

Figure 1: Left: Kapok fibre cross-section scanned on SEM microscope at 2000× magnification with presented read parameters. (Author Mrs. M. Leskovšek.) Right: Method of reading fibres cross-section dimensions. Index vl designates the external ellipse, and index lu the internal ellipse; 2a – large axis, 2b – small axis

Debelino celične stene kapokovih vlaken (d_{st}) lahko izračunamo tudi po enačbi 1:

$$d_{st} = \frac{a_{vl} - a_{lu}}{2} \quad \text{ali} \quad d_{st} = \frac{b_{vl} - b_{lu}}{2} \tag{1}$$

Odčitane vrednosti velike in male osi elipse smo uporabili za izračun obsega prečnega prereza vlakna (o_{vl}) in lumna (o_{lu}) kapoka po Hudsonovih enačbah 2 in 3 za elipso [16]:

$$o \approx \frac{\pi}{4}(a+b)\left[3(1+L) + \frac{1}{1-L}\right] \tag{2}$$

leads to the decrease of lumen. A kapok lumen is filled with liquids. Since there is no information available in literature about penetration of oils through a cell wall and about kapok cell wall swelling, the effect of oil on the size of lumen is not known. As kapok is a vegetable fibre with a very compact primary cell wall [12], we assume that the capacity of a primary cell wall to swell in oil and water is limited.

Hori [9] who investigated the absorption of raw kapok fibres in a suspension of Diesel oil and water noticed under optical microscope that it was dyed Diesel oil which was mainly present in the kapok fibres lumen. He estimated that water could not penetrate into kapok fibres due to high surface tension between kapok and air captured in the fibres (7.2 × 10⁻⁴ N/cm at 20°C).

Since pores in fibres are also considered the zones of liquids retention, the amount of absorbed liquids is additionally increased. Porosity of kapok fibres has not been researched yet.

The purpose of our research was to investigate the geometrical hollowness of kapok and to evaluate the capacity of kapok fibres to retain water and oils in their lumen.

2 Research methods

The Java kapok of mean length 18.8 mm and fineness 1.02 dtex was used in the research.

2.1 Geometrical indices of kapok

Geometrical indices of kapok were investigated based on measurements of the fibre cross-section which was scanned on the JSM-2 JEOL scanning electron microscope at 2000× magnification, acceleration voltage 10 kV, specimen inclination 45° and work distance 12 mm. A fibre wad was tightly pushed through a hole in the flat holder, and protruding fibre ends cut off. As a result of such method of preparation of the specimen, fibres mostly underwent deformation from round to oval or ellipsoidal shape (Fig. 1). Prior to scanning, fibres were steamed with a layer of carbon (C) and a layer of the gold/palladium (Au/Pd) alloy. On digital images of fibres cross-sections the thickness of the cell wall (d_{st}) as well as the large ($2a_{vl}$; $2a_{lu}$) and small ($2b_{vl}$; $2b_{lu}$) axis of the fibres external and internal ellipse cross-section (Fig. 1, right) were read

$$L = \frac{(a+b)^2}{[2\ (a+b)]^2} \tag{3}$$

Iz obsega prečnega prereza kapoka smo izračunali premer kapokovih vlaken z okroglim prečnim prerezom (D) (en. 4) in premer pripadajočega lumna (d) (en. 5). Zunanji in notranji premer sta osnovna parametra, ki definirata votla vlakna. Čim večje je razmerje med njima, (d/D), bolj votla so vlakna, tem manjša je gostota vlaken, večja sposobnost vsrkavanja tekočin, večja toplotna izolativnost in manjša mehanska togost vlaken.

$$D = \frac{o_{vl}}{\pi} \tag{4}$$

$$d = \frac{o_{lu}}{\pi} \tag{5}$$

Zunanjo (P_z) in notranjo (P_n) površino na dolžino (l) enega metra votlih vlaken smo izračunali po enačbah 6 in 7:

$$P_z = o_z \cdot l \cdot 10^6 \ \ (\mu m^2) \tag{6}$$

$$P_n = o_n \cdot l \cdot 10^6 \ \ (\mu m^2) \tag{7}$$

Volumen vlakna (V_{vl}), lumna (V_{lu}) in celične stene (V_{st}) smo izračunali po enačbah 8, 9 in 10 za cevasto nesesedeno vlakno z okroglim prečnim prerezom na dolžino (l) enega metra vlakna.

$$V_{vl} = \frac{\pi D^2}{4} \cdot l \tag{8}$$

$$V_{lu} = \frac{\pi d^2}{4} \cdot l \tag{9}$$

$$V_{st} = V_{vl} - V_{lu} \tag{10}$$

Votlost kapoka (r_{vl}) smo podali kot razmerje med volumnom lumna (V_{lu}) in volumnom celotnega vlakna (V_{vl}) in je enako razmerju med površino prečnega prereza lumna (A_{lu}) in površino prečnega prereza celotnega vlakna (A_{vl}) oziroma razmerju njunih premerov (en. 11):

$$r_{vl} = \frac{V_{lu}}{V_{vl}} \cdot 100 = \frac{A_{lu}}{A_{vl}} \cdot 100 = \frac{d^2}{D^2} \cdot 100 \tag{11}$$

Volumska specifična površina vlakna ($P_{z/V}$) je razmerje med zunanjo površino (P_z) in celotnim volumnom vlakna (V_{vl}) (en. 12):

$$P_{z/V} = \frac{P_z}{V_{vl}} = \frac{4}{D} \tag{12}$$

Maso vlakna smo izračunali iz volumna (V_{st}) in gostote celične stene (ρ_{st} = 1,474 g/cm³ [17]) po enačbi 13. Gostoto vlaken smo izračunali iz mase vlakna (m_{vl}) na celoten volumen vlakna (enačbi 14).

$$m_{vl} = \frac{V_{st}}{\rho_{st}} \tag{13}$$

by means of a computer program. The measurements were carried out on 100 fibres.
The thickness of the kapok fibres cell wall (d_{st}) can also be calculated by using Equation 1.
The read values of the ellipse large and small axes were used to calculate the circumference of the fibre cross-section (o_{vl}) and the lumen (o_{lu})

$$\rho_{vl} = \frac{m_{vl}}{V_{vl}} \quad (14)$$

Utežno specifično površino ($P_{z/m}$) smo izračunali iz razmerja med zunanjo površino (P_z) in maso vlakna (m_{vl}) po enačbi 15:

$$P_{z/m} = \frac{P_z}{m_{vl}} = \frac{4}{\rho_{vl} \cdot D} \quad (15)$$

Table 1: Assembly of geometrical hollow fibre indices

Geometrijski indeksi za votla vlakna z okroglim prečnim prerezom	Geometrical indices of hollow fibres with round cross-section	Simbol/ Symbol
debelina stene vlakna	*Thickness of the kapok fibres cell wall*	d_{st}
mala notranja os	*Small internal axis of elipse*	$2b_{lu}$
mala zunanja os	*Small external axis of elipse*	$2b_{vl}$
velika notranja os	*Large internal axis of elipse*	$2a_{lu}$
velika zunanja os	*Large external axis of elipse*	$2a_{vl}$
notranji obseg vlakna	*Fibre internal (lumen) circumference*	o_{lu}
zunanji obseg vlakna	*Fibre external circumference*	o_{vl}
premer lumna	*Lumen diameter*	d
premer vlakna	*Fibre diameter*	D
zunanja površina vlakna	*Fibre external surface area per unit length*	P_z
notranja površina vlakna	*Fibre internal surface area per unit length*	P_n
volumen celične stene	*Cell wall volume*	V_{st}
volumen lumna	*Lumen volume*	V_{lu}
volumen vlakna	*Fibre volume*	V_{vl}
votlost	*Hollowness*	r_{vl}
površina prečnega prereza lumna	*Lumen cross-section surface area*	A_{lu}
površina prečnega prereza vlakna	*Fibre cross-section surface area*	A_{vl}
volumska specifična površina vlakna	*Fibre specific surface area per unit of volume*	$P_{z/V}$
gostota vlakna	*Fibre density*	ρ_{vl}
utežna specifična površina vlakna	*Fibre specific surface area per unit of weight*	$P_{z/m}$
razmerje med premerom lumna in vlakna	*Lumen diameter to fibre diameter ratio*	d/D
razmerje med zunanjo in notranjo specifično površino	*External to internal specific surface area ratio*	P_z/P_n

of kapok by using Hudson's Equations 2 and 3 for ellipse [16].

From the kapok fibre cross-section circumference the diameter of kapok fibres with round cross-section (D) (Eq. 4) and the diameter of the related lumen (d) (Eq. 5) were calculated. The external and internal diameter are basic parameters which define hollow fibres. Higher is the ratio between them (d/D), hollower are the fibres, lower is the fibres density, higher is the liquid absorbing capacity, better are the thermal insulation properties and lower is the mechanical rigidity of fibres.

External (P_z) and internal (P_n) surface areas per unit length (l) of 1 metre of hollow fibres have been calculated by using Equations 6 and 7.

The volume of fibre (V_{vl}), lumen (V_{lu}) and cell wall (V_{st}) for tubular non-collapsed fibre with round cross-section per length (l) of 1 metre of fibres has been calculated by using Equations 8, 9 and 10.

The hollowness of a kapok fibre (r_{vl}) has been expressed as the ratio of the volume of lumen (V_{lu}) to the volume of entire fibre (V_{vl}); it equals the ratio of the lumen cross-section surface area (A_{lu}) to the entire fibre cross-section surface area (A_{vl}) or the ratio between their diameters (Eq. 11).Fibre specific surface area per unit volume ($P_{z/V}$) is the ratio of external surface (P_z) to total fibre volume (V_{vl}) (Eq. 12).

Fibre mass has been calculated from the volume (V_{st}) and cell wall density (ρ_{st} = 1.474 g/cm^3 [17]) by using Eq. 13. Fibre density has been calculated from the fibre mass (m_{vl}) per total fibre volume (Eq. 14).

Specific surface area per unit mass ($P_{z/m}$) has been calculated from the ratio of external surface (P_z) to fibre mass (m_{vl}) by using Equation 15.

In a Table 1 the meanings of symbols for hollow fibres with round cross-section are assembled.

2.2 Liquids sorption mechanism and amount of retained liquid

The water and oils sorption mechanism was investigated by using the Olympus CX2 optical microscope, on which fibres were photographed by using the Olympus SP-350 digital compact camera, fixed on the third microscope ocular.

The amount of retained liquid (KZT) was determined according to DIN 53 814 standard

V preglednici 1 so zbrani simboli in njihov pomen za geometrijske indekse votlih vlaken z okroglim prečnim prerezom.

2.2 Mehanizem sorpcije tekočin in količina zadrževane tekočine

Mehanizem sorpcije vode in olj smo proučevali v optičnem mikroskopu Olympus CX2, na katerem smo vlakna tudi fotografirali s pomočjo digitalne kompaktne kamere Olympus SP-350, pritrjene na tretjem okularju mikroskopa.

Količino zadržane tekočine (KZT) smo določili po standardu DIN 53 814 [18]. Proučevali smo sposobnost zadrževanja destilirane vode, jedilnega in parafinskega olja surovega kapoka, surovega bombaža (finoče 1,8 dtex) in viskoznih vlaken (1,7 dtex). Vzorec mase 0,4 g smo tri ure namakali v 150 ml destilirane vode oziroma olja v erlenmajerici z brušenim zamaškom. Za surov kapok smo morali zatehto vlaken zmanjšati na 0,2 g vlaken, da smo jih po namakanju v olju lahko vložili v epruvete, saj so surova vlakna kapoka navzela zelo veliko količino olja. Nato smo vlakna odsesali in za pet minut obtežili s kilogramsko utežjo. Vlakna smo nato kvantitativno prenesli v steklene epruvete, kot jih predpisuje standard, le-te pa v kovinske epruvete centrifuge. Centrifugirali smo 30 minut pri 3000 vrtljajih na minuto. Po centrifugiranju smo vlakna takoj stehtali. S centrifugiranjem smo odstranili površinsko adsorbirano tekočino in ugotavljali zadrževanje tekočine v notranjosti vlaken. Količino zadržane tekočine smo izračunali po enačbi 16:

$$KZT = \frac{m_2 - m_1}{m_1} \times 100 \qquad (16),$$

kjer je m_1 masa suhih vlaken, m_2 masa vlaken po centrifugiranju in KZT količina zadrževane tekočine, izražena v odstotkih.

Uporabili smo parafinsko olje proizvajalca S Pharmachem Sušnik Jože, s.p. (gostota 0,865 g/cm^3, viskoznost 186 mPas pri 20 °C) in jedilno rafinirano 100-odstotno sončnično olje Sončni cvet proizvajalca Gea, d.d. (gostote 0,950 g/cm^3 pri 20 °C).

3 Rezultati z razpravo

3.1 Geometrijski indeksi kapoka

V preglednici 2 so zbrani izmerjeni geometrijski indeksi prečnega prereza kapoka, v preglednici 3 pa izračunani geometrijski indeksi po enačbah 1–15.

Izračunani premer vlaken kapoka z okroglim prečnim prerezom je 16,81 µm. Povprečna izmerjena debelina celične stene je 1,01 µm, minimalna debelina 0,70 µm, maksimalna debelina 1,73 µm. Po geometrijskih karakteristikah kapok izstopa v primerjavi z votlimi sintetičnimi vlakni za polnila, kjer npr. na trgu dostopna votla vlakna okroglega prečnega prereza dosegajo premere več kot 250 µm ob debelini stene okrog 13 µm in manj.

Table 2: Measured geometrical indices of kapok fibres with ellipsoidal cross-section

Geometrical indices of kapok fibres with ellipsoidal cross-section	Mean value (µm)	Standard deviation (µm)	Coefficient of variation (%)
Large external axis ($2a_{vl}$)	24.61	4.29	17.42
Small external axis ($2b_{vl}$)	5.95	2.05	34.43
Large internal axis ($2a_{lu}$)	21.38	4.19	19.59
Small internal axis ($2b_{lu}$)	3.91	1.87	47.84
Thickness of fibre wall (d_{st})	1.01	0.22	21.45

Table 3: Calculated geometrical indices of kapok fibres with round cross-section

Geometrical Index	D (µm)	d (µm)	d/D	o_z (µm)	o_n (µm)	V_{vl} (µm^3)	V_{lu} (µm^3)	V_{st} (µm^3)	ρ (g/cm^3)
Value	16.81	14.31	0.85	52.78	44.93	227 110	165 970	61 140	0.3968

Geometrical Index	A_{vl} (µm^2)	A_{lu} (µm^2)	r_{vl} (%)	P_z (µm^2)	P_n (µm^2)	P_z/P_n	$P_{z,V}$ (µm / µm^2)	$P_{z,m}$ (m^2/g)
Value	227.11	165.97	73.08	52 780	44 930	1.17	0.2324	0.6678

[18]. We investigated the retention capacity for distilled water, cooking oil and paraffin oil of raw kapok, raw cotton (fineness 1.8 dtex) and viscose fibres (1.7 dtex). The specimen with the mass of 0.4 g was soaked for 3 hours in 150 ml of distilled water or oil in the Erlenmeyer flask fitted with ground joint. In case of raw kapok the mass of fibres had to be reduced to 0.2 g in order to be inserted into test tubes after having been soaked in oil because raw kapok fibres absorbed a very large amount of oil. After that fibres were gently squeezed and loaded with a 1 kg weight for 5 minutes. Fibres were then transmitted into glass test tubes in the quantities prescribed by the standard. Test tubes were placed into metal test tubes of centrifuge. The process of centrifuging was carried out 30 minutes at 3000 rpm. Immediately after the process of centrifuging process has stopped, fibres were weighted. By the centrifugation process the surface adsorbed liquid was eliminated and the quantity of retained liquid in the fibres was measured. The amount of the retained liq-

Lumen pomeni povprečno kar 73,1 odstotka kapokovega vlakna. Po votlosti dosega kapok zelo visoke vrednosti, saj imajo kemična vlakna za polnila ponavadi votlost pod 50 odstotki [19]. Pri povprečni gostoti kapoka 0,348 g/cm^3 in votlosti 73,08 odstotka je notranji volumen kapoka (volumen lumna) 2,1 cm^3 (2,1 ml) na gram vlaken. Kapok se odlikuje tudi z izjemno veliko specifično površino, ki je pomembna za površinsko adsorpcijo tekočin. Njegova zunanja specifična površina je 0,6678 m^2/g vlaken. Primerjava kapoka s sintetičnimi mikrovlakni, ki jih npr. uporabljajo za t. i. „čudežne" čistilne krpe v gospodinjstvih, pokaže za polovico nižjo specifično površino (0,3291 m^2/g) pri PA 6 mikrovlaknih okroglega prečnega prereza s premerom 10,6 µm [20].

3.2 Mehanizem sorpcije tekočin

V primerjavi z votlimi kemičnimi vlakni, ki imajo v notranjosti eno ali več kapilar z odprtinami na obeh straneh vlaken, so kapokova vlakna na vrhu zožene, zaprte cevke (slika 2a) z ozko odprtino (slika 2b) le na mestu, kjer so bila prirasla na semena.
Pri mikroskopskem opazovanju prodiranja tekočin v lumen kapokovih vlaken smo vlakna narezali na dolžino 1–2 mm, da smo omogočili prodiranje tekočine v vlakna. Pripravili smo suhe preparate in opazovali širjenje kapljice tekočine po površju vlaken. Ob stiku suhih vlaken z vodo se je le-ta počasi širila po površju

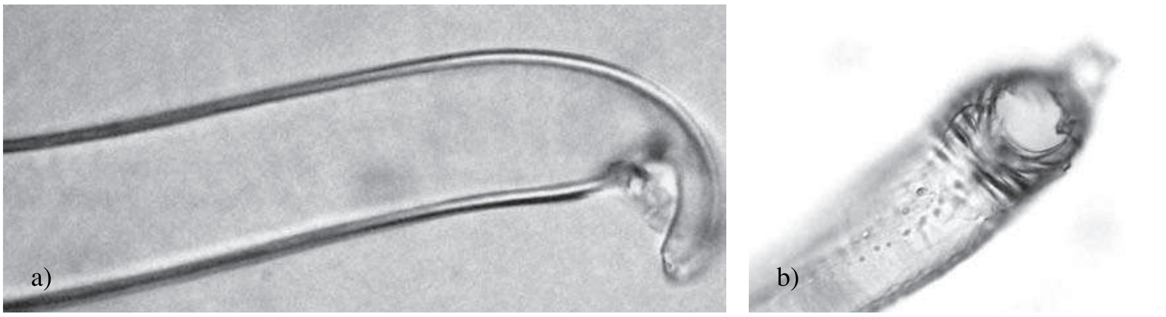

Figure 2: Thinned top end of kapok fibre (a) and its bottom end (b), which was attached to the seed, with a well visible opening. (200x magnification (Fig. a), 400x magnification (Fig. b). Scanned on Olympus optical microscope. Author: Mrs.T. Rijavec).

uid has been calculated by using Equation 16, where m_1 is the mass of dry fibres, m_2 the mass of fibres after centrifuging, and KZT the quantity of the retained liquid expressed in percentages.

The amount of the retained water was investigated on the fibres of raw kapok, raw cotton, and viscose fibres. In addition to distilled water, paraffin oil produced by S Pharmachem Sušnik Jože s.p. (density 0.865 g/cm^3, viscosity 186 mPas at 20 °C), and 100% cooking oil Sončni cvet produced by Gea d.d. (density 0.950 g/cm^3 at 20 °C) were used.

vlaken, ob stiku z oljem pa se je le-to zelo hitro razširilo po površju kapoka. Razlog za takšno obnašanje je oleofilno površje kapokovih vlaken, ki omogoča dobro adhezijo z olji in slabo adhezijo z vodo. To obnašanje je dobrodošlo z vidika uporabe kapoka za oljne filtre, kjer se mora olje hitro in pred vodo adsorbirati na kapokova vlakna.

Naša opazovanja surovega kapoka v optičnem mikroskopu so pokazala, da voda že takoj ob stiku s kapokovimi vlakni začne prodirati v lumen vlaken. V začetni fazi prodiranja smo opazili številne zračne mehurčke v vlaknih, ki so nastali zaradi izpodrivanja zraka iz vlaken (slika 3a). Polzaprta oblika vlaken vpliva na slabšo sposobnost navzemanja tekočin, ker zrak, ki ga pred seboj izpodriva tekočina, ki po kapilarnem mehanizmu pronica v lumen vla-

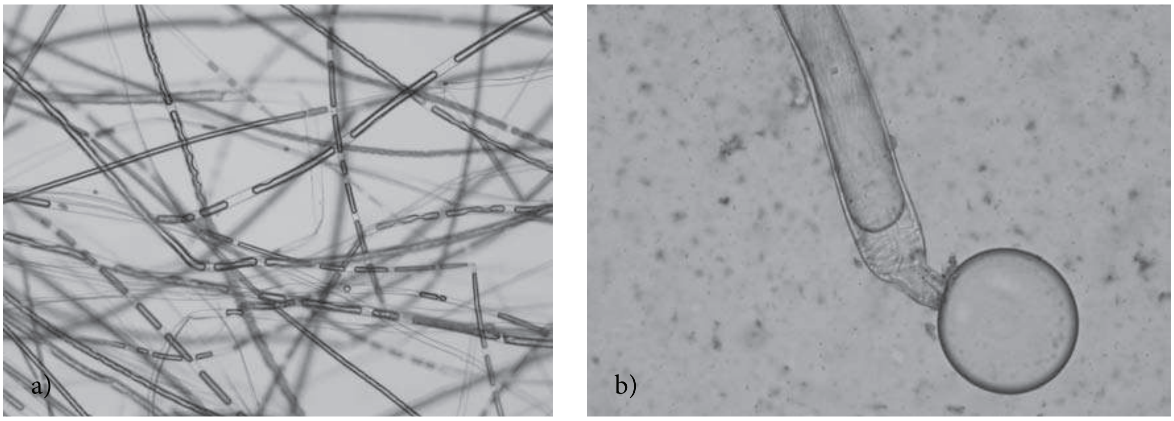

Figure 3: Scans of lengthwise appearance of kapok fibres after few minutes of soaking in water (a). Formation of air bubbles at the fibre top end of kapok fibre (b). (Scanned on Olympus optical microscope at 100x magnification (a). and at 400x magnification (b). Author: Mrs.T. Rijavec)

3 Results with discussion

3.1 Geometrical indices of kapok

The measured geometrical indices of the kapok fibre cross-section are presented in Table 2,

ken (slika 3b), lahko izstopa iz vlakna le na poškodovanih mestih celične stene.

V nasprotju z vodo olje počasneje prodira v lumen vlaken. Zelo malo olja prodre v lumen kapoka v začetnih minutah omakanja. Na sliki 4a, posneti nekaj minut po vložitvi vlaken v olje, vidimo,

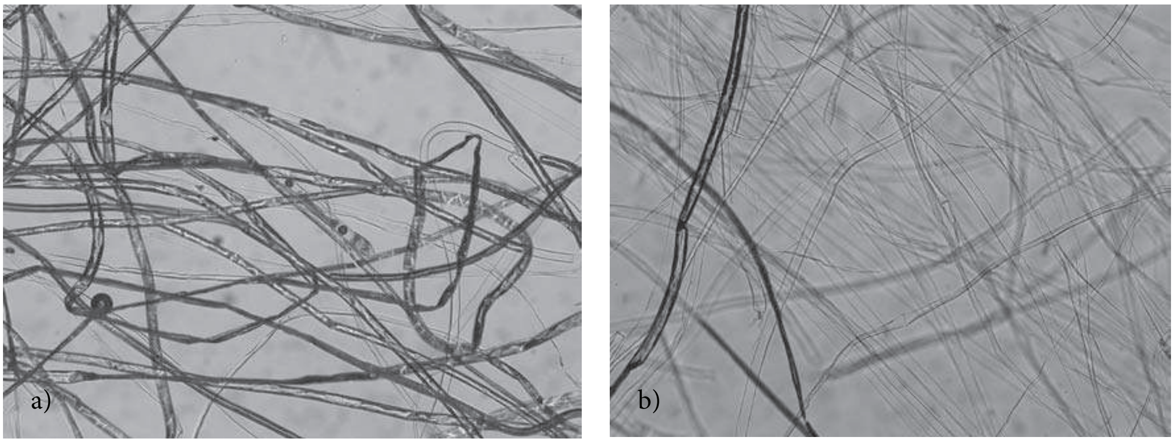

Figure 4: Scans of lengthwise appearance of kapok fibres after few minutes of soaking in paraffin oil (a) and after 48 hours of soaking in paraffin oil (b). (Scanned on Olympus optical microscope at 100x magnification. Author: Mrs. T. Rijavec.)

and the calculated geometrical indices by using Equations 1–15 are presented in Table 3.
The calculated diameter of a kapok fibre with round cros-section is 16.81 μm. The mean measured thickness of the cell wall is 1.01 μm, the minimum thickness is 0.70 μm, the maximum thickness is 1.73 μm. By considering geometrical indices kapok fibres surpass substantially hollow synthetic fibres used as stuffing materials; namely, commercially available hollow fibres with round cross-section have diamaters larger than 250 μm with the wall thickness about 13 μm and less.

da je večina vlaken kapoka še vedno zapolnjena z zrakom (neprosojnih). Na sliki 4b, posneti po 48 urah namakanja kapoka v olju, je olje zapolnilo lumen pri skoraj vseh vlaknih kapoka, ki so zato videti prosojna.

3.3 Količina zadrževane tekočine

Glede na izračunano velikost lumna v kapoku 2,1 cm^3 na gram vlaken je kapaciteta zadrževanja tekočine v lumnu enega grama absolutno suhih vlaken 2,1 g vode, 2,0 g jedilnega olja in 1,8 g parafinskega olja, ob predpostavki da tekočina ne povzroča nabrekanja celične stene in s tem ne vpliva na velikost lumna.
Po triurnem namakanju vlaken v vodi in oljih smo s centrifugiranjem odstranili površinsko vezano tekočino. Vrednosti KZT (pre-

Table 4: Amount of retained liquid (KZT) at room temperature on raw kapok (KP_{raw}), raw cotton (CO_{raw}) and viscose (CV) fibres

Liquid	Statistical value	Amount of retained liquid, KZT (wt. %)		
		KP_{raw}	CO_{raw}	CV
Distilled water	$\overline{x}$ (%)	103.47	41.00	75.91
	s (%)	8.64	3.27	2.04
	CV (%)	8.35	7.98	2.69
Cooking oil	$\overline{x}$ (%)	131.57	24.27	16.16
	s (%)	5.59	2.32	2.48
	CV (%)	4.25	9.38	15.34
Paraffin oil	$\overline{x}$ (%)	107.21	29.65	23.64
	s (%)	3.10	6.63	6.97
	CV (%)	2.89	22.35	29.47

On average, the lumen represents even 73.1% of a kapok fibre. Kapok has very high values of hollowness if it is considered that the hollowness of man-made fibres used for stuffing is usually under 50% [19]. With mean density of a kapok fibre 0.348 g/cm^3 and hollowness 73.08% the internal volume of a kapok fibre (volume of lumen) is 2.1 cm^3 (2.1 ml) per 1 gram of fibres.

Kapok also boasts outstandingly high specific surface area, which is important for surface adsorption of liquids. Its external specific surface area is 0.6678 m^2/g of fibres. The comparison of kapok with synthetic microfibres, which are used for the so-called "magic"cleaning wipes for households, reveals that PA 6 microfibres having round cross-section with diameter 10,6 µm have by 50% lower specific surface area (0.3291 m^2/g) [20].

3.2 Liquids sorption mechanism

In comparison with hollow man-made fibres, which have in their interior one or more capillaries with openings on both sides of fibres, kapok fibres are closed tubes, thinned on the top end (Fig. 2 a) and with a narrow opening (Fig. 2b) only on the points on which they were attached to the seeds.

For the purposes of microscopic observation of liquids penetration into the kapok fibres lumen we cut fibres to the length of 1–2 mm to enable penetration of the liquid into fibres. We prepared dry specimen and observed spreading of a liquid droplet over the surface of fibres. At contact of dry fibres with water, water spread slowly over the surface of fibres, but at contact with oil, oil spread very quickly over the kapok surface. Such behaviour is the result of the kapok fibres oleophyllic surface, which imparts good adhesion with oils and poor adhesion with water to the fibres. Such behaviour is advantageous when kapok fibres are used for oil filters where oil must be absorbed by kapok fibres quickly and prior to water.

Our observations of raw kapok under optical microscope have revealed that on contact with fibres, water immediately starts to penetrate into the fibres capillaries. During the initial stage of penetration the formation of lots of air bubbles in the fibres can be noticed, which is the result of displacement of the air from fibres (Fig.

glednica 4) prikazujejo skupno količino kemično vezane tekočine v vlaknih in fizikalno zadrževane tekočine v lumnu in porah vlaken.

Izmerjena količina zadržanega olja po centrifugiranju v surovih kapokovih vlaknih je bila največja za jedilno olje, in sicer 131,6 odstotka, kar pomeni 1,32 g jedilnega olja na gram absolutno suhih vlaken. Ta količina je majhna v primerjavi s kapaciteto rastlinskih vlaken, ki skupaj v vlaknih in na površju zadržijo več kot 30 g olja/g vlaken [14], in kapaciteto surovega kapoka, ki zadrži skupaj tudi 36–45g dizelskega olja na gram vlaken [11]. Količina v kapokovih vlaknih absorbiranega jedilnega olja pomeni le nekaj odstotkov skupne količine zadržanega olja pred centrifugiranjem.

Razlika v količini zadržanega jedilnega in parafinskega olja je poleg razlike v gostoti olj posledica njune različne površinske napetosti.

Surovi bombaž ima od 3- do 5-krat slabšo sposobnost zadrževanja olj kot kapok. Površje surovega bombaža je prekrito z 0,4–1,0 ut. % voskov na maso suhih vlaken [21], kar omogoča površinsko adhezivnost do olja in preprečuje prodiranje vode v surova vlakna. Še manjša je bila izmerjena količina zadržanih olj v viskoznih vlaknih, kjer se olje le fizikalno veže samo na strukturirani žlebičasti površini in v površinskih porah. Bolj viskozno parafinsko olje se je zadržalo na bombažu in viskoznih vlaknih v večji količini kot manj viskozno jedilno olje.

Kapok je izrazito ligninocelulozno vakno s porazdeljenim hidrofobnim ligninom tudi v notranjosti celične stene vlaken. Skupaj z voskastim hidrofobnim površjem notranja struktura kapoka ovira prodiranje vode skozi celično steno. Na podlagi mikroskopskih opazovanj smo ugotovili, da voda hitro prodira v lumen kapoka skozi odprtine v vlaknih. Izmerjena količina 1,03 g vode/g suhih vlaken je manjša od kapacitete lumna v kapokovih vlaknih.

Surovi bombaž v vodi nabreka, pore in lumen se mu zapolnijo z vodo. Izmerjena količina zadržane vode v surovem bombažu je bila 0,41 g vode/gram suhih vlaken, kar je zelo blizu količine z vodo nasičenih bombažnih vlaken, ki znaša od 0,43 do 0,52 g vode na gram suhih vlaken [21].

Izmerjena količina zadržane vode v viskoznih vlaknih je bila večja kot v bombažu. Viskozna vlakna so zelo vodovpojna zaradi nizke kristaliničnosti in orientacije ter porozne strukture.

4 Sklepi

Po finoči vlaken lahko kapok opredelimo kot naravno mikrovlakno. Zunanji premer proučevanih vlaken kapoka je bil povprečno 16 µm. Povprečna izmerjena debelina celične stene je bila 1,0 µm. Lumen je pomenil kar 73 odstotkov vlakna.

Izjemno velika specifična površina kapokovih vlaken 0,6678 m^2/g in njena oleofilna narava sta glavna vzroka velike sposobnosti surovega kapoka za površinsko adsorpcijo olj.

3a). The semi-closed shape of fibres degrade their liquid absorption capacity, because the air which is displaced by the liquid penetrating into the fibre lumen by capillarity (Fig. 3b) can leave the fibre only through the points of mechanical damage in a cell wall.

Oil penetrates into the fibres lumen at a slower rate than water. Very small amount of oil penetrates into the kapok fibres capillaries in the first minutes of wetting. It is also evident in Figure 4a where most kapok fibres are still filled with air (opaque). In Figure 4b, taken after 48 hours of soaking in oil, it is seen that oil has filled almost all capillaries so that the fibres look transparent.

3.3 Amount of retained liquid

Based on the calculated size of the kapok lumen, i.e. 2.1 cm^3 *per 1 gram of fibres, the capacity of liquid retention in the lumen of 1 gram of absolutely dry fibres is 2.1 g of water, 2.0 g of cooking oil and 1.8 g of paraffin oil by assuming that liquid does not induce swelling of a cell wall and has therefore no impact on the size of lumen.*

After soaking fibres in water and oils for 3 hours, we removed the surface bound liquid by centrifuging. KZT values (Table 4) show total amount of chemically bound liquid in the fibres and physically retained liquid in the fibres lumen and pores.

The measured amount of retained oil in raw kapok fibres after centrifuging was the highest for cooking oil, i.e. 131.6%, which means 1.32 g of cooking oil per 1 gram of absolutely dry fibres. This amount is low if compared with vegetable fibres which are capable of retaining more than 30 g of oil per 1 gram of fibres inside fibres and on the surface altogether [14] as well as if compared with raw kapok, which is capable of retaining a total amount of even 36–45 g of Diesel oil per 1 gram of fibres [11]. The amount of cooking oil absorbed in kapok fibres represents only few percents of the total amount of retained oil prior to centrifugation.

The differences in the amount of retained cooking and paraffin oils are attributed to different surface tensions as well as different densities of both oils.

Raw cotton has 3–5 times lower oil retention capacity than kapok. Since raw cotton is covered with 0.4–1.0% by weight of waxes per dry

Absorbirane tekočine, ki ostanejo po centrifugiranju kapoka, se zadržujejo kemično vezane v amorfnih predelih celične stene in fizikalno vezane v porah in lumnu vlaken.

Po količini zadrževane vode kapok presega rastlinska in regenerirana celulozna vlakna. Kljub hidrofobnemu površju in slabi omočljivosti je kapok po treh urah namakanja v vodi zadržal po centrifugiranju kar 104 odstotke vode glede na maso suhih vlaken. Pretežno se je voda zadržala v lumnu vlaken.

Surovi kapok je izrazito oleofilno vlakno. Olja veže predvsem s površinsko adsorpcijo in v lumnu vlaken, kamor lahko prodre skozi odprtine na koncu vlakna ali na mestih mehanskih poškodb. Surovi kapok je po namakanju in centrifugiranju zadržal 132 ut. % jedilnega olja in 107 ut. % parafinskega olja, medtem ko je surovi bombaž zadržal le 24 ut. % jedilnega oz. 29,7 ut. % parafinskega olja, viskozna vlakna pa le 16 ut. % jedilnega in 24 % parafinskega olja pri sobni temperaturi.

Količina zadržanega olja, ki ostane v kapoku po centrifugiranju, je zelo majhna (1,07–1,32 g/g vlaken) in pomeni le nekaj odstotkov od celotne količine olja na vlaknih pred centrifugiranjem, ki je več kot 30 g olja na gram suhih vlaken. Centrifugiranje kapokovih filtrov omogoča visok odstotek regeneriranja olj in ponovno uporabnost filtrov.

5 Literatura

1. JAFFE, M. in EAST J.A. Polyester fibers. V: *Handbook of Fiber Chemistry. Third Edition*. Edited by Menachem Lewin. Boca Raton, London, New York: CRC Press, Taylor & Fracis Group, 2007, p. 24.
2. PETRULIS, D. Theoretical investigation of hollow fibres structure: relations between fibre inner diameter, wall thickness, and conventional indices. *Material Science (Medžiagotyra)*, vol. 9, 2003, no. 4, p. 423–427.
3. PETRULIS, D. Fundamental study of the effect of the fiber wall thickness and inner diameter on the structure of polyamide and polypropylene hollow fibers. *Journal of Applied Polymer Science*, vol. 92, 2004, p. 2017–2022.
4. GUPTA, D.K. The mechanics of tubular fiber: theoretical analysis. *Journal of Applied Polymer Science*, vol. 28, 1983, p. 3573–3584.
5. BEYREUTHER, R. in HOFMANN, H. Melt spinning of hollow fibers. *Chemical Fibers International*, vol. 47, 1997, p. 54–58.
6. KOTEK, R. Regenerated cellulose fibers. V: *Handbook of fiber chemistry. Third edition*. Uredil M. Lewin. Boca Raton, London, New York: CRC, Taylor & Francis. 2007, p. 709.
7. *Identification of textile materials. Seventh edition*. Manchester: The Textile Institute, 1975, p. 74, 77 in 78.
8. FENGEL, D. in WENZKOWSKI, M. Studies on kapok. 1. Elec-

fibres mass [21], its surface is adhesive for oils and impermeable for water. Even lower was the measured amount of retained oils in viscose fibres where oil was only physically bound to the structured grooved surface and in superficial pores. More viscous paraffin oil was retained on cotton and viscose fibres in a higher amount than less viscous cooking oil.

Kapok is a distinctively ligninocellulose fibre with hydrophobic lignin distributed also in the interior of a fibre cell wall. The kapok inner structure together with a waxy hydrophobic surface impedes the penetration of water through a cell wall. Based on microscopic observations we have found that water penetrates quickly into the kapok lumen through the openings in fibres. The measured amount of 1.03 g of water per 1 gram of dry fibres is lower than the capacity of the kapok fibres lumen.

Raw cotton swells in water, its pores and lumen get filled with water. The measured amount of retained water in raw cotton was 0.41 g of water per 1 gram of dry fibres, which is very close to that of water saturated cotton fibres, which is between 0.43 and 0.52 g of water per 1 gram of dry fibres [21].

The measured amount of retained water in viscose fibres was higher than that in cotton fibres. Viscose fibres are highly water absorbent due to low crystallinity and orientation as well as porous structure.

4 Conclusions

If fineness of fibres is considered, kapok can be defined as a natural microfibre. The external diameter of the investigated kapok fibres was about 16 μm and the cell wall thickness was only about 1.0 μm. Lumen represents even 73% of fibre.

Extraordinary large specific surface area of kapok fibres, i.e. 0.6678 m^2/g, and its oleophyllic nature are the main reasons or high capacity of raw kapok for oil surface adsorption.

Absorbed liquids, which remain in kapok fibres after centrifuging, are retained chemically bound in amorphous zones of a cell wall and physically bound in the fibres pores and lumen.

In the amount of retained water kapok outperforms vegetable and regenerated cellulose fi-

tron microscopic observations. *Holzforschung*, vol. 40, 1986, p. 137–141.

9. HORI, K. et al. Excellent oil absorbent kapok (Ceiba petandra L.) fiber: fiber structure, chemical characteristics, and application. *Journal of Wood Science*, vol. 46, 2000, p. 401–404.
10. HUANG, X. in LIM, TT. Performance and mechanism of hydrophobic-oleophilic kapok filter for oil/water separation. *Desalination*, vol. 190, 2006, p. 295–307.
11. LIM, TT. in HUANG, X. Evaluation of kapok (Ceiba pentandra (L.) Gaertn.) as a natural hollow hydrophobic-oleophilic fibrous sorbent for oil spill cleanup. *Chemosphere*, vol. 66, 2007, p. 955–963.
12. MEIWU, S., HONG, X. in WEIDONG, Y. The fine structure of the kapok fiber. *Tex. Res. J.*, 04. sept. 2009. [Dostopno na svetovnem spletu.] http://trj.sagepub.com/cgi/rapidpdf/0040517508095594v1.pdf [10.11.2009]
13. FENGEL, D. in PRZYKLENK, M. Studies on kapok. 2. Chemical Investigation. *Holzforschung*, vol. 40, 1986, p. 325–330.
14. CHOI, HM. in MOREAU, JP. Oil sorption behavior of various sorbents studied by sorption capacity measurement and environmental scanning electron microscopy. *Microscopy Research and Technique*, vol. 25 (2005) no. 5-6, p. 447–455.
15. Računalniški program SEM Control User Interface Version 6.55 JEOL Technics Ltd.
16. Obseg. Dostopno na svetovnem spletu: http://si.wikipedia.org/wiki/Obseg (23.07.2009)
17. MWAIKAMBO, LY. in ANSELL, MP. The determination of porosity and cellulose content of plant fibers by density methods. *Journal of Material Science Letters*, vol. 20, 2001, p. 2095–2096.
18. *DIN 53 814 – 1974: Prüfung von Textilien; Bestimmung des Wasserrückhaltevermögens von Fasern und Fadenabschnitten.*
19. MURASE, Y. et all. Improved polyester fibres. *GB patent 1369851(A)*, 09. 10. 1974.
20. RIJAVEC, T. *Laboratorijsko oblikovanje in analiza poliamidnih 6 mikrofilamentnih prej. Disertacija.* Ljubljana: Univerza v Ljubljani, Fakulteta za naravoslovje in tehnologijo, Oddelek za tekstilno tehnologijo, 1995, str. 85.
21. WAKELYN PJ. Et al. Cotton fibers. V: *Handbook of fiber chemistry. Third edition*. Uredil M. Lewin. Boca Raton, London, New York: CRC, Taylor & Francis. 2007, p. 587.

bres. Despite hydrophobic surface and inferior wettability, kapok retained even 104% of water with regard to the mass of dry fibres after having been soaked in water for 3 hours and centrifuged. Water was mostly retained in the lumen.
Raw kapok is distinctively oleophyllic fibre. It binds oils particularly by surface adsorption and in the lumen into which it can penetrate through the openings at the end of fibres or at the points of mechanical damage. Raw kapok retained 132% by weight of cooking oil and 107% by weight of paraffin oil after soaking and centrifuging, raw cotton retained only 24% by weight of cooking oil and 29.7% by weight of paraffin oil, and viscose fibres even less, i.e. 16 % by weight of cooking oil and 24% of paraffin oil at room temperature.
The amount of retained oil, which remains in kapok after centrifuging, is very low (1.07–1.32 g of oil per 1 g of fibres) and represents only few percents of the total amount of oils on fibres prior to centrifugation, which is higher than 30 g of oil per 1 g of dry fibres. Centrifugation of kapok fibres creates the opportunity for a high percentage of oils regeneration and for reuse of filters.