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# Kapok in Technical Textiles

Review

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# Kapok v tehničnih tekstilijah

***Pregledni znanstveni članek***

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## Abstract

*Kapok (Ceiba pentandra) is a highly lignified organic seed fibre, containing 22–45% of cellulose, 22–45% of hemicelluloses, and 15–22% of lignin. In its primary cell wall kapok contains, in addition to waxes, a high percentage of inorganic substances, which, in combination with a high percentage of acetyl groups, imparts excellent hydrophobic properties to kapok even after removal of waxes. Low fibre density, i.e. 0,348 gcm$^{-3}$, is attributed to a wide lumen, which occupies approximately 74% of a kapok fibre. Due to such wide lumen, kapok has an exceptional capability of liquids retention. Kapok boasts with good anti-microbial properties. It is distinguished from other cellulosic fibres by its excellent thermal and acoustic insulating properties, high buoyancy, and good oil and other non-polar liquids absorbency. Kapok is mainly used in the form of stuffing and nonwovens; it is rarely used in yarns, mostly due to low cohesivity of its fibres and their resilience, brittleness, and low strength. New potentials of kapok have been opening in the field of technical textiles, yachts and boats furnishing, insulating materials in refrigeration systems, acoustic insulation, industrial wastewaters filtration, removal of spilled oil from water*

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## Izvleček

Kapok (Ceiba pentandra) je visoko ligninizirano naravno semensko vlakno iz 22–45 % celuloze, 22–45 % hemiceluloz in 15–22 % lignina. Poleg voskov vsebuje v primarni celični steni visok delež anorganskih snovi, ki skupaj z acetilnimi skupinami, katerih delež je prav tako visok, dajejo kapoku tudi po odstranitvi voska odlične hidrofobne lastnosti. Nizka gostota vlaken, 0,348 gcm$^{-3}$, je posledica širokega lumna, ki zajema okrog 74 % vlakna. Širok lumen omogoča izjemno sposobnost zadrževanja tekočin. Kapok ima protimikrobne lastnosti. Med celuloznimi vlakni izstopa tudi po odličnih toplotnih in zvočnoizolacijskih sposobnostih, plovnosti, odličnih sposobnostih absorpcije olj in drugih nepolarnih tekočin. Kapok uporabljajo predvsem v obliki polnila in vlaknovin, zelo malo v prejah, predvsem zaradi slabe kohezivnosti vlaken, togosti, krhkosti in nizke trdnosti. Raziskave kažejo nove potencialne možnosti uporabe kapoka za tehnične tekstilije, kot polnila za notranjo opremo jaht in čolnov, kot izolacijskega materiala v hladilnih sistemih, za zvočno izolacijo, za filtracijo odpadnih industrijskih vod, za zbiranje razlite nafte na vodnih površjih in za ojačitveno komponento v polimernih kompozitih. Kapok je fiziološko inerten. Uporabljajo ga tudi v prehrani za selektivno izločanje maščob.

Ključne besede: kapok, Ceiba pentandra, lignin, oljni absorberji, vlaknati kompoziti.

*surfaces, and reinforcement components in polymer composites. Kapok is physiologically inert. It is also used in nutrition for selective elimination of fats.*

*Key words: kapok, Ceiba pentandra, lignin, oil sorbents, fibre composites*

## 1 Introduction

*Kapok is a standardized common name for organic cellulosic fibres extracted from the seedpod of the kapok tree Ceiba pentandra (ceiba, kapok, kapok tree, silk cotton tree, silk cottonwood, vegetable down, vegetable silk, Java cotton) [1]. Kapok tree Ceiba pentandra L. with several varieties: Var. caribaea, Var. guineensis, Var. pentandra and Var. indica (DC) Bakh produces fibres of high quality. Kapok tree Var. pentandra is a natural hybrid between Var. caribaea and Var. guineensis [2].*

*Kapok trees grow in Mexico, Central America, Caribbean islands, in the northern part of South America and in the western part of Africa. In Java it has been cultivated since the 10th century. The annual world production of kapok is about 123 thousand tonnes [3]. The highest market share belongs to Java kapok. In the year 2001, Indonesia, Thailand, and the USA exported 2,775 tonnes of kapok. Major importers of kapok are Japan, China, and Hong Kong [4]. The price of kapok fibres is about 0.2 US$/kg.*

*Kapok has been traditionally used as a stuffing in mattresses, pillows, and upholstered furniture. Machine spinning of kapok is difficult due to brittleness and low cohesivity of its fibres, and is limited to coarse yarns only or to the yarns from blends with cotton. In the second half of the 20th century the use of kapok drastically dropped with the advent of synthetic stuffing materials, notaby polyurethane foam. During recent years kapok, as a recyclable and biodegradable fibre, has become interesting again. Oil filters and composites are new potentials of its use. Kapok can be found also in the Slovenian market, mostly as a stuffing in pillows.*

*The production technology of kapok is traditional as poor countries in which kapok is*

## 1 Uvod

Kapok je standardizirano rodovno ime za naravna celulozna vlakna iz semenske luščine plodu kapokovca *Ceiba pentandra* (angl. *ceiba*, *kapok*, *kapok tree*, *silk cotton tree*, *silk cottonwood*, *vegetable down*, *vegetable silk*, *Java cotton*) [1]. Kakovostna vlakna daje kapokovec *Ceiba pentandra L.* z več podvrstami: *Var. caribaea*, *Var. guineensis*, *Var. pentandra* in *Var. indica (DC) Bakh*. Kapokovec *Var. pentandra* je naravni hibrid med *Var. caribaea* in *Var. guineensis* [2].

Kapokovec uspeva v Mehiki, Srednji Ameriki, na Karibih, na severu Južne Amerike in v Zahodni Afriki. Na Javi ga gojijo od 10. stoletja dalje. Svetovna letna proizvodnja kapoka je okrog 123 tisoč ton [3]. Na trgu je največ javanskega kapoka. V letu 2001 je znašal izvoz kapoka iz Indonezije, s Tajske in iz ZDA 2.775 ton. Glavni uvozniki kapoka so Japonska, Kitajska in Hongong [4]. Cena vlaken je okrog 0,2 ameriškega dolarja za kilogram.

Tradicionalno uporabljajo kapok kot polnilo za žimnice, blazine in oblazinjeno pohištvo. Strojno predenje kapoka je zaradi krhkosti in slabe kohezivnosti vlaken zelo težko ter omejeno na grobe preje oziroma na preje iz mešanic z bombažem. V drugi polovici 20. stoletja se je uporaba kapoka močno zmanjšala, ker so ga izpodrinila sintetična polnila, predvsem poliuretanske pene. Zadnja leta postaja kapok kot obnovljivo in biorazgradljivo vlakno zopet zanimiv. Odpirajo se nove možnosti uporabe za oljne filtre in v kompozitih. Kapok najdemo tudi na slovenskem tržišču, in sicer največkrat kot polnilo v blazinah.

Tehnologija pridobivanja kapoka je še vedno tradicionalna, saj vanjo revne dežele, v katerih uspeva kapok, v preteklosti niso bile sposobne vlagati. Podobno kot druga rastlinska vlakna, razen bombaža, je bil tudi kapok v preteklih tridesetih letih zapostavljeno vlakno, nekonkurenčno sintetičnim materialom. Danes je kapok še vedno zelo nepoznano naravno celulozno vlakno s posebnimi lastnostmi, ki na področju tehničnih tekstilij še niso dovolj izkoriščene. V članku je podan pregled literature, od morfologije, kemičnih in fizikalnih lastnosti kapoka do uporabe v preteklosti in danes.

## 2 Pridobivanje in kakovost kapoka

Plodovi kapoka so 10–40 cm dolgi in 3–5 cm debeli. Na odraslem drevesu dozori 500–4000 plodov. Ko dozorijo, počijo, pri čemer se stisnjena vlakna široko razprostrejo. Plodove obirajo ročno, zaprte tolčejo z bambusovimi palicami, da razbijejo trdo lupino in pridejo do vlaken. Semena izločajo na preprostih, sitastim bobnom podobnih napravah. Sledi odstranjevanje ostankov plodov, posušenih listov in drugih nevlaknatih primesi. Ameriški patent [2] opisuje postopek strojnega čiščenja kapoka že na začetku 20. stoletja. Pred pakiranjem sušijo kapok na soncu v gostih mrežastih vrečah, da vlaken ne odpihne veter in da jih zaščitijo pred komarji. Za transport jih stiskajo v bale, težke 95–120 kg, zaščitene z jutovino *growing were not able to invest into it. In the last thirty years kapok was, just like other plant fibres, with the exception of cotton, ignored and unable to compete with synthetic materials. Even today, kapok is still an almost unknown organic cellulosic fibre with special properties, which are still not sufficiently exploited in the field of technical textiles. The paper gives a survey of the literature, from morphology, chemical and physical properties of kapok to its use in the past and today.*

## 2 Production and Quality of Kapok

*Kapok seedpods are 10–40 cm long and 3–5 cm thick. A grown-up kapok tree produces 500–4000 seedpods. When ripened, seedpods burst and the compressed fibres spread widely. Seedpods are harvested by hand and closed seedpods are beaten with bamboo sticks in order to break hard husk and to reach fibres. Seeds are separated on simple, sieve-like devices similar to drums and cleared from pod debris, dry leaves, and other non-fibrous impurities. The US patent [2] describes the method of kapok machine cleaning at the beginning of the 20th century. Prior to being packed, kapok is dried in the sun protected from wind and mosquitoes in dense net bags. For transport purposes kapok fibres are compressed into bales of weight 95–120 kg and protected with jute or polypropylene fabric. The compression must be moderate as kapok is very brittle and cannot withstand strong stresses.*

*The quality of kapok is evaluated on the basis of the percentage of lignin, diameter of fibres (kapok with more uniform diameter obtains higher value), buoyancy on the alcohol solution with*

ali tkanino iz polipropilena. Stiskanje vlaken v bale je omejeno zaradi krhkosti kapoka.

Kakovost kapoka ocenjujejo na podlagi vsebnosti lignina, premera vlaken, pri čemer doseže kapok z enakomernejšim premerom višjo vrednost, plovnosti na alkoholni raztopini z gostoto 0,928 gcm$^{-3}$ in relativne hitrosti omočenja ter potopitve vlaken.

Vsebnost lignina kvalitativno ocenjujejo z mikrokemijsko reakcijo z alkoholno raztopino fluoroglucinola in HCl. Pri segrevanju kapoka s HCl nastaja iz pentoz, ki so v vlaknu, furfural ($C_4H_3O{\cdot}CHO$), ta pa se ob prisotnosti fluoroglucinola ($C_6H_3(OH)_3$) obarva. Najboljši kapok ne da reakcije obarvanja, kapok slabše kakovosti se obarva rdečerjavo do magentardeče [5].

Najbolj kakovosten kapok prihaja na trg iz Afrike in z Jave. Slabša sta kapok s Cejlona in indijski kapok. Javanski kapok razvrščajo v tri razrede: super fini kapok – Super Fine Quality (AJK), fini kapok – Fine Quality (C-Min) in standardni kapok – Standard Quality (C-Off).

Kakovostna vlakna pridobijo le iz zrelih plodov (slika 1). Nezrela vlakna imajo slabo trdnost, slaba lesk in barvo ter ne prenesejo močnega stiskanja v bale. Nezrelemu kapoku lahko izboljšajo videz s fermentacijo na prostem, vendar se mehanske lastnosti pri tem postopku ne izboljšajo.

*Figure 1: Closed (top) and halved (bottom) kapok seedpod with fibres (foto: T. Rijavec)*

## 3 Morfološka struktura kapoka

Kapok je gladko, enocelično vlakno cilindrične oblike, brez zavojev. Ima tanko celično steno, ki jo prekriva debela plast voska. Širok lumen je zapolnjen z zrakom, ki se pri sušenju zrelih vlaken ne sesede kot pri bombažu. Sploščena so le nezrela ali mrtva vlakna. Po videzu in značilnih lastnostih je kapok zelo podoben vlaknom svilnic *Asclepias*, *Ceropegia* in *Calotropis* (angl. milkweed fibres), le da so slednja mnogo daljša.

V svetlobnem mikroskopu so vlakna videti prosojna, z značilnimi v lumnu zajetimi zračnimi mehurčki (slika 2). Koren vlakna je nekoliko razširjen (slika 3), z mrežasto zgoščeno celično steno (slika 4), proti vrhu se vlakna zožijo. Prečni prerez vlaken (slika 5) je ovalen do okrogel.

Struktura celične stene kapoka se razlikuje od drugih naravnih celuloznih vlaken. Primarna celična stena, ki je neposredno povezana *density 0.928 gcm$^{-3}$, and relative velocity of fibres wetting and submersion.*

*The percentage of lignin is qualitatively evaluated with the microchemical reaction with alcohol solution of fluoroglucinol and HCl. When kapok is heated with HCl, furfural ($C_4H_3O{\cdot}CHO$) is produced from pentoses present in the fibres, which becomes dyed in the presence of fluoroglucinol ($C_6H_3(OH)_3$). Kapok of the best quality does not undergo any dyeing, whilst kapok of inferior quality is dyed red-brown to magenta red [5].*

*Kapok of the highest quality comes from Africa and Java. The kapok from Ceylon and India is of lower quality. Java kapok is classified into three classes: Super Fine Quality (AJK), Fine Quality (C-Min) and Standard Quality (C-Off).*

*Qualitative fibres are produced only from ripened kapok seedpods (Fig. 1). Immature fibres have low strength, inferior lustre and colour, and do not withstand stress during compression into bales. The appearance of immature fibres can be improved by fermentation in the open air, however, mechanical properties are not improved with this process.*

## 3 Morphological Structure of Kapok

*Kapok is a smooth, unicellular, cylindrically shaped, twistless fibre. Its cell wall is thin and covered with a thick layer of wax. A wide lumen is filled with air and does not collapse like cotton. Only immature and dead fibres are flattened. In their appearance and characteristic properties kapok fibres are very similar to milkweed fibres produced by plants Asclepias, Ceropegia, and Calotropis, only that the latter are much longer.*

*Under the light microscope kapok fibres look transparent with characteristic air bubbles in the lumen (Fig. 2). Kapok fibres are slightly widened at their roots (Fig. 3) with a lattice-like condensed cell wall (Fig. 4) and are narrowing towards the top. The cross section of fibres (Fig. 5) is oval to round.*

*The kapok cell wall structure differs from other natural cellulosic fibres. A primary cell wall, which is directly related to superficial properties of fibres, consists of short microfibrils, which*

s površinskimi lastnostmi vlaken, sestoji iz kratkih mikrofibrilov, ki so orientirani pravokotno na površino vlaken [6]. V sekundarni celični steni potekajo mikrofibrili skoraj vzporedno z osjo vlakna [7].

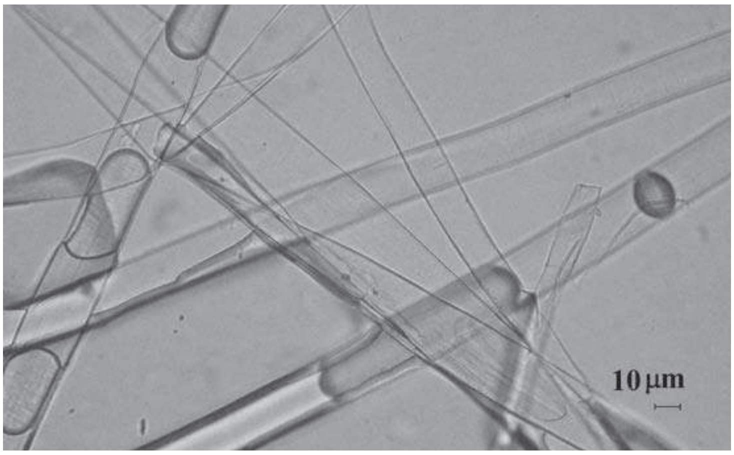


*Figure 2: Kapok fibres observed under optical microscope (foto: T. Rijavec)*

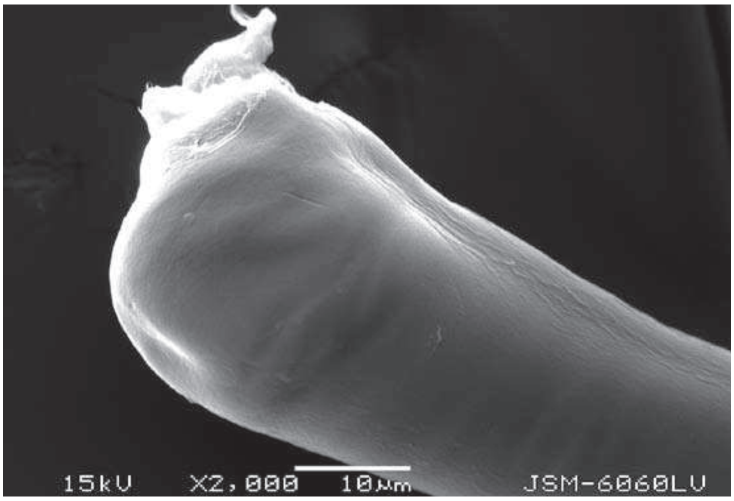


*Figure 3: Characteristic widened root of a kapok fibre (foto: M. Leskovšek)*

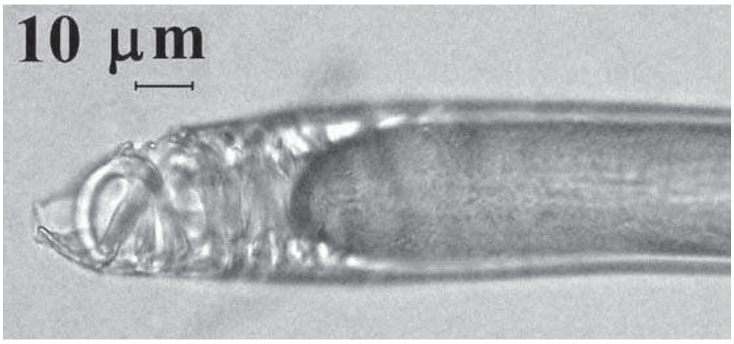


*Figure 4: Lattice-like end of a kapok fibre (foto: T. Rijavec)*

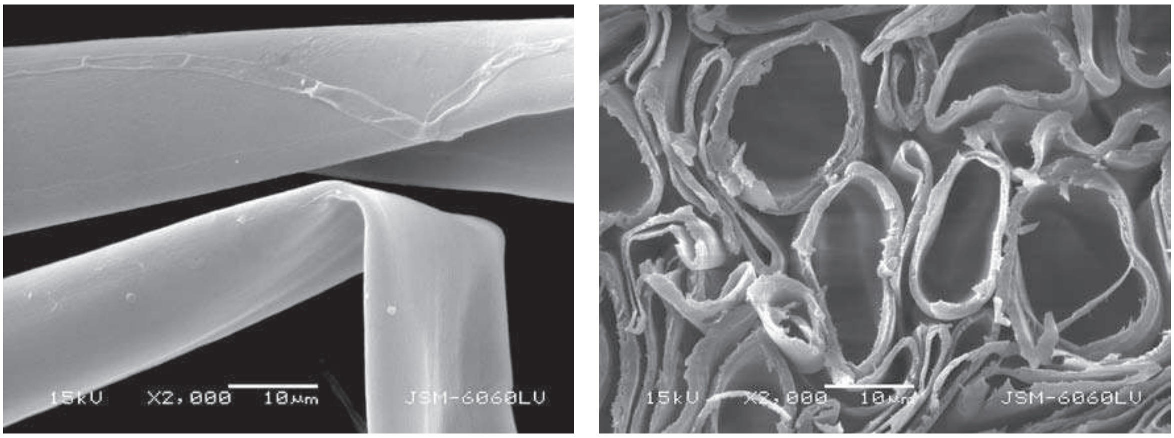


*Figure 5: Longitudinal (a) and cross section (b) view of kapok under scanning electronic microscope at 2000× magnification (foto: M. Leskovšek)*

*are oriented rectangular to the surface of fibres [6]. In the secondary cell wall microfibrils run almost parallel to the fibre axis [7].*

## 4 Properties of Kapok

*Likewise all natural cellulosic fibres, kapok contains mostly alpha cellulose (35–50%), hemicelluloses (22–45%), lignin (15–22%) [8, 9, 10], about 10–11% of moisture (commercial addition 10.9%), and to 2–3% of waxes. It also contains smaller quantities of starch, about 2.1% of proteins, and inorganic substances, notably iron (1.3–2.5%) [11].*

*The FT-IR spectra of kapok show typical absorption bands: at 2918 cm$^{-1}$ (corresponds to asymmetrical and symmetrical stretching of bonds in $CH_2$ and $CH_3$ that are presented in waxes), 1600, 1510, 1470, and 1425 cm$^{-1}$ (correspond to stretching of C–O bonds in lignin) [15].*

*Considering the content of alpha cellulose, kapok is liker to wood than flax and other plant fibres. The average degree of cellulose polymerisation in kapok is 6600 glucose residue [8] which is comparable with cotton and other natural cellulosic fibres.*

*Lignin, which is chemically very complex aliphatic and aromatic hydrocarbon, has a role of a joining incrust between cellulose and highly ramified hemicelluloses. Kapok contains lignin, which is chemically very similar to lignin in hardwood in its elementary composition and metoxi groups ($CH_3O$–) content. A relatively high content of*

## 4 Lastnosti kapoka

Kapok – podobno kot vsa naravna celulozna vlakna – vsebuje predvsem alfa celulozo (35–50 %) in hemiceluloze (22–45 %), lignin (15–22 %) [8, 9, 10], okrog 10–11 % vlage (trgovski dodatek 10,9 %) in največ 2–3 % voskov. V manjših količinah vsebuje tudi škrob, okrog 2,1 % beljakovin in anorganske snovi, predvsem železo (1,3–2,5 %) [11].

Spektri FT-IR kažejo značilne absorpcijske trakove kapoka: pri 2918 cm$^{-1}$ (kar ustreza asimetričnemu in simetričnemu raztezanju vezi v $CH_2$ in $CH_3$, ki so prisotnostne v voskih) ter pri 1600, 1510, 1470 in 1425 cm$^{-1}$ (ustrezajo raztezanju C–O vezi v ligninu) [15].

Po vsebnosti alfa celuloze se kapok bolj približa lesu kot lanu in drugim rastlinskim vlaknom. Povprečna stopnja polimerizacije celuloze v kapoku znaša 6.600 glukoznih ostankov [8], kar je primerljivo z bombažem in drugimi naravnimi celuloznimi vlakni.

Lignin, ki je kemično zelo zapleten alifatsko-aromatski ogljikovodik, ima vlogo povezujočega inkrusta med celulozo in močno razvejano hemicelulozo. Kapok vsebuje lignin, ki je kemično zelo podoben ligninu v trdem lesu – po elementarni sestavi in vsebnosti metoksi skupin ($CH_3O$–). Relativno visok delež lignina v kapoku se raztopi pri kislih obdelavah. Lignin je dobro obstojen pri visokih temperaturah, a občutljiv za UV-žarke. Primarna celična stena kapoka vsebuje manj lignina in več polisaharidov kot sekundarna celična stena. Visoka vsebnost lignina v kapoku, ki je dobro odporen na bakterije, povečuje protimikrobne sposobnosti izdelkov iz kapoka. Kapok je odporen proti običajnim celuloznim bakterijam. Napadajo in razgrajujejo ga lesne mikroplesni in bakterije, ki povzročajo površinsko erozijo (skoraj anaerobne bakterije) in luknjičavost (bakterije, ki potrebujejo veliko kisika) kapoka, podobno kot v lesu [12, 13].

*lignin in kapok dissolves during acid treatments. Lignin is well resistant at high temperatures but is sensitive to UV rays. A high content of lignin in kapok enhances its antimicrobial properties. The primary cell wall of kapok contains less lignin and more polysaccharides than the secondary cell wall. A high content of lignin imparts good antibacterial resistance to kapok. Kapok is resistant to usual bacteria, which digest cellulose. It is attacked and degraded by wood micromildew, erosion bacteria (almost anaerobic bacteria), and tunnelling bacteria (bacteria which need high amount of oxygen) in the same way as wood [12, 13].*

*Hemicelluloses are polycholocelluloses with a lower degree of polymerisation than alpha cellulose. Kapok contains especially xyloses (about 23%) and 4-0-methyil-glucuronic acid (about 5.9%). Hemicelluloses are fast biodegradable. Alpha cellulose and hemicelluloses are more sensitive to thermal degradation than lignin but more resistant to UV degradation than lignin.*

*Iron and other minerals are concentrated mostly in the primary cell wall in which they might represent even a 20% share. Due to a high content of inorganic substances in the primary cell, kapok fibres have lower capability of water absorption and higher resilience.*

*Since kapok contains about 13% of acetyl ($CH_3CO$–) groups, it preserves the hydrophobic properties even after the removal of waxes, which means the reduced capability of the fibres surface to form hydrogen bonds [8]. Raw fibres are extremely hydrophobic (oleophyllic) with a high capacity of absorbing non-polar liquids.*

*The colour of raw kapok is yellow to brownish, or whitish. Pure white colour is rare. Fibres are free of odour, non-toxic, and non-allergic. They have very soft touch, are fluffy, and extremely light (approximately six times lighter than cotton). Kapok contains 70–80% of air and provides excellent thermal and acoustic insulation. The absolute density of a kapok cell wall is 1.474 gcm$^{-3}$, whilst the density of fibres by considering about 74% of lumen is only 0.384 gcm$^{-3}$ [14]. Kapok boasts with excellent buoyancy on water. When compressed, kapok fibres can support up to 36 times their own mass on water. They are five times more buoyant than*

Hemiceluloze so poliholoceluloze z nižjo stopnjo polimerizacije kot alfa celuloza. V kapoku so prisotne predvsem ksiloze (okrog 23 %) in 4-0-metil-glukuronska kislina (okrog 5,9 %). Hemiceluloze so hitro biorazgradljive. Alfa celuloza in hemiceluloze so občutljivejše za termično razgradnjo kot lignin, vendar manj nagnjene k UV-degradaciji kot lignin.

Železo in drugi minerali se nahajajo večinoma v primarni celični steni, v kateri predstavljajo skupno tudi do 20 % delež. Visoka vsebnost anorganskih snovi v primarni celični steni ima za posledico manjšo sposobnost vezanja vode in povečano togost vlaken.

Kapok vsebuje okrog 13 % acetilnih ($CH_3CO$–) skupin, zaradi česar ima tudi po odstranitvi površinskih voskov hidrofobne lastnosti, to je zmanjšano sposobnost površja vlaken za tvorjenje vodikovih vezi [8]. Surova vlakna so izredno hidrofobna (oleofilna) in imajo visoko kapaciteto absorpcije nepolarnih tekočin.

Barva surovega kapoka je rumenkasta, rjavkasta ali belkasta. Popolnoma bela barva je redka. Vlakna so brez vonja, netoksična in ne povzročajo alergij. So zelo mehkega otipa, puhasta in zelo lahka (približno šestkrat lažja od bombaža). Kapok vsebuje 70–80 % zraka ter je zato odličen toplotni in zvočni izolator. Absolutna gostota celične stene kapoka je 1,474 gcm$^{-3}$, gostota vlakna z upoštevanjem približno 74 % lumna pa le 0,384 gcm$^{-3}$ [14]. Kapok dobro plava na vodi. V stisnjeni obliki zdržijo vlakna na vodi do 36-kratno svojo težo. So 5-krat bolj plovna kot plutovina in se sušijo hitreje od nje. Plovnost ohranijo vlakna tudi po odstranitvi voskov [5].

Kapok je naravno votlo vlakno z odličnimi oleofilnimi lastnostmi, z visoko sposobnostjo vezanja raznih olj. Kapok olja absorbira, adsorbira in kapilarno vsrkava. Oleofilne lastnosti pripisujejo voskastemu površju vlaken in visoki vsebnosti acetilnih skupin, velika kapaciteta absorpcije olj pa je posledica širokega lumna vlaken. Opazili so, da olje prodre skozi celično steno v lumen vlakna, voda pa ne. Še vedno ni popolnoma razjasnjen hiter in učinkovit mehanizem absorpcije olja v kapokova vlakna [21].

Dolžina kapoka je 10–35 mm, premer vlaken 20–43 μm. Debelina celične stene je okrog 1–3 μm. Razmerje med dolžino in premerom vlaken (aspektno razmerje) je okrog 720. Izmerjena natezna trdnost kapoka je 8,4 cNtex$^{-1}$ (93,3 MPa), Youngov modul 4 GPa in pretržni raztezek 1,2 % [3].

## 5 Uporaba kapoka

Najstarejši patenti za predelavo kapoka segajo v začetek prejšnjega stoletja ter obravnavajo postopek predenja kapoka [16] in dodajanje kapoka papirni masi za izboljšanje leska zidnih tapet [17]. Kapok še danes najpogosteje uporabljajo kot polnilo zaradi njegovih dobrih toplotnoizolacijskih lastnosti, za zvočno izolacijo ter zaradi odlične plovnosti za rešilne jopiče in obroče. V sodobnosti kapok sega na področje tehničnih tekstilij za filtracijo nepolarnih snovi in na področje kompozitov.

*cork and dry more quickly than cork. They preserve buoyancy even after the removal of waxes [5].*

*Kapok fibres are 10–35 mm long, their diameter is 20–43 μm. The cell wall thickness is about 1–3 μm. The length-to-diameter ratio (aspect ratio) is about 720. The measured tensile strength of kapok is 0.84 cNdtex$^{-1}$ (93.3 MPa), Young's module 4 GPa, and breaking elongation 1.2% [3].*

## 5 Use of Kapok

*The oldest patents dealing with the processing of kapok go back to the beginning of the last century and describe the method of kapok spinning [16] and its adding to the paper mass to improve the lustre of wallpapers [17]. Due to its good thermal insulating properties, kapok is still today mostly used as a stuffing and for insulation of sound, and due to its excellent buoyancy, for life jackets and lifebelts. Modern use of kapok is spreading into the field of technical textiles for filtration of non-polar substances and into composites.*

### 5.1 Thermal and Acoustic Insulation

*Kapok, which is used for stuffing, must be cleaned, dried and cut. It can be prepared on the same machinery as cotton. Raw fibres are carded by using air because mechanical carding is not recommended due to breaking of brittle fibres and formation of large quantities of dust. Seeds and dust are removed by suction.*

*Kapok is used as a stuffing for high quality toys. Already in 1879 Margarete Steiff began to sew pincushions in the form of elephants, and developed them later into velvet and fleece toys stuffed with kapok, cotton, or fine wool [18]. A kapok stuffing is by about 50% lighter than a cotton stuffing and by about 30% lighter than a wool stuffing.*

*Kapok had been widely used as a stuffing in quilts, pillows, and upholstery until approximately 1950 when it was substituted by hollow manmade fibres and today very expensive polyurethane foams which were much simpler for manufacture and less flammable than kapok. Since kapok is an excellent thermal insulator, extremely light, and does not cause allergies, it is practically irreplaceable for the people who*

### 5.1 Toplotna in zvočna izolacija

Kapok za polnilo očistijo, posušijo in narežejo. Lahko ga pripravijo na isti strojni opremi kot bombaž. Surova vlakna mikajo z uporabo zraka, saj mehansko mikanje ni priporočljivo zaradi lomljenja krhkih vlaken in nastajanja velikih količin prahu. Semena in nastali prah odstranjujejo z odsesavanjem.

Kapok uporabljajo za polnilo visokokakovostnih igrač. Že leta 1879 je Margarete Steiff začela šivati blazinice za bucike v obliki slončkov, ki jih je pozneje razvila v igrače iz žameta in pliša, napolnjene s kapokom, bombažem ali fino volno [18]. Polnila iz kapoka so za okrog 50 % lažja od bombažnih in za okrog 30 % lažja od volnenih polnil.

Približno do leta 1950 so kapok veliko uporabljali kot polnilo za odeje, blazine in pohištvo, pozneje so ga v veliki meri nadomestila votla kemična vlakna in danes izjemno drage poliuretanske pene, ki so bolj preproste za proizvodnjo in niso tako hitro vnetljive kot kapok. Zaradi odličnih toplotnoizolacijskih sposobnosti, lahkosti in nealergenosti je nenadomestljiv za ljudi, ki ne prenašajo dobro sintetičnih materialov. Danes se uporaba kapoka ponovno povečuje, in sicer za notranjo opremo jaht in čolnov ter kot polnilo blazin za vrtno pohištvo. Kapok skupaj z drugimi celuloznimi vlakni v obliki vlaknovine za polnila v notranji opremi omogoča dobro uravnavanje vlage in naravno protibakterijsko zaščito brez uporabe kemikalij [19].

Zaradi odlične toplotnoizolacijske sposobnosti uporabljajo kapok kot izolacijski material manjših hladilnih sistemov. Uporabljajo ga tudi za podloge spalnih vreč, rokavice za ravnanje s suhim ledom ipd. V preteklosti so ga uporabljali tudi za toplotno izolacijo vodovodnih cevi.

V oblačilih ga uporabljajo kot polnilo za podloge, v katerih zaradi dobre toplotne izolacije in nealergenosti nadomešča perje, puh in sintetiko.

Kapok uporabljajo tudi za zvočno izolacijo bivalnih prostorov.

### 5.2 Plovnost

Kapok je cenjen kot polnilo za rešilne jopiče, rešilne pasove in prenosne pontone za zaščito pred utopitvijo. Nestisnjen javanski kapok lahko nosi 20–30-kratno lastno maso, indijski kapok pa le 10–15-kratno lastno maso, da se ne potopi. Če javanski kapok potopijo v vodo, izgublja plovnost zelo počasi. 30-dnevni test je pokazal le 10 % izgubo plovnosti. Plovnost kapoka pred uporabo za rešilne obroče oziroma jopiče za neplavalce vedno preizkušajo. Vlakna dajo v mrežo iz žice ali kletko s kovinskimi ojačanimi robovi ter jo potopijo v svežo vodo 30 cm pod gladino za 48 ur. Po 48 urah določijo plovnost vlaken, tako da stehtajo vlakna in njihovo maso primerjajo z maso vlaken pred testiranjem. Če vsebnost vode v kapoku ne ustreza predpisom, vlaken ne uporabijo za rešilne jopiče [20].

### 5.3 Sorpcijske sposobnosti

Kapok je primeren za filtracijo oljnih suspenzij. Danes so oljni filtri za filtracijo odpadnih voda kovinske, prehrambene, tekstilne, *do not stand synthetic materials well. Today, kapok has been increasing used for upholstery in yachts, boats and garden furniture. The use of kapok in combination with other cellulosic fibres in the form of nonwovens for furnishings enables good regulation of moisture and natural antibacterial protection without using any chemicals [19].*

*Due to its excellent thermal insulating properties, kapok is used as an insulating material in smaller refrigerating systems. It is used as a lining in sleeping bags, gloves for dry ice handling, etc. In the past it was also used for thermal insulation of conduit pipes.*

*As it provides good thermal insulation and does not cause allergies, kapok is used as a filling of the clothing linings instead of feathers, down, and synthetic materials.*

*Kapok is also used for acoustic insulation of dwelling rooms.*

### 5.2 Buoyancy

*Kapok is highly appreciated as a stuffing in lifejackets, lifebelts, and mobile pontoons to provide protection from drowning. The non-compressed Java kapok can support, on water, a mass which exceeds its own mass by as much as 20–30 times, whilst Indian kapok can support only a mass which exceeds its own mass by 10–15 times until submersion. If Java kapok is immersed into water, it looses its buoyancy very slowly. A 30-day test has shown only a 10% loss of buoyancy. Prior to using kapok for lifebelts and lifejackets for non-swimmers buoyancy of kapok is always tested. Fibres are put into a wire mesh or a cage with metal reinforced edges, and immersed into fresh water 30 cm under the surface for 48 hours. After 48 hours the buoyancy of fibres is determined by weighing fibres and by comparing the mass with the mass of fibres prior to testing. If the content of water in kapok differs from the prescribed one, fibres are not used for lifejackets [20].*

### 5.3 Sorptivity of non-padar liquids

*Kapok is a natural hollow fibre, which has excellent oleophyllic properties with a high capability of absorbing, desorbing, and capillary imbibing of various oils. Oleophyllic properties are attributed to the waxy surface of fibres and to*

usnjarske, petrokemične in druge industrije iz sintetičnih vlaken, kot so polipropilenska, poliestrska ali poliamidna vlakna. Naravna celulozna vlakna vpijejo več olj kot sintetična vlakna, so učinkovitejša kot oljni filtri in poleg tega tudi biorazgradljiva. Surov, neobdelan kapok zadržuje olje dlje časa kot kapok, ekstrahiran v etanolu ali kloroformu. Kapok iz sladke ali morske vode selektivno absorbira okrog 40 g olja na gram vlaken [21]. Pri gostoti zlaganja vlaken 0,02 gcm$^{-3}$ je kapaciteta absorpcije dizelskega goriva 36 gramov olja na gram vlaken, pri večji gostoti zlaganja vlaken, 0,09 gcm$^{-3}$, pa kapaciteta absorpcije dizelskega goriva znaša le 7,9 gramov olja na gram vlaken [15]. S stiskanjem izločijo olja, zadrževana v filtru, še učinkovitejše pa je centrifugiranje, s katerim je mogoče pridobiti tudi nad 83 % olja, ki ga lahko ponovno uporabijo [22].

Praktično je kapok uporaben tudi za manjše, prenosne separatorje za olje/vodo [22]. Prav tako je primeren za predfiltracijo voda, ki ji sledi membranska filtracija [15]. Učinkovito ga lahko uporabijo za zbiranje razlite nafte v rekah in morju [23].

Popolnoma biorazgradljive oljne absorberje nepolarnih snovi lahko izdelajo iz 100 % kapoka brez aditivov (lepil) po postopku segrevanja materiala na temperaturo steklastega prehoda vsebujočih hemiceluloz (ta je odvisna od stopnje hidriranja hemiceluloz in se zniža z omočenjem) in stiskanja segretega materiala. Med segrevanjem pri 90–120 °C preidejo hemiceluloze v gel, med stiskanjem kratek čas pri temperaturi 170–190 °C pa se vlakna povežejo med seboj [24]. Na ta način povečajo trdnost končnega izdelka. Temperature nad 220 °C povzročijo oksidacijsko degradacijo vlaken. Dodatek največ 3–10 % tujih ojačitvenih vlaken je še sprejemljiv, ker ob povečani natezni trdnosti ne zmanjša sorpcijske kapacitete kapoka.

Absorberji iz kapoka v obliki filtrov, gob ali blaga so primerni za izločanje mazalnih in motornih olj, barv, herbicidov, fungicidov in pesticidov, aromatskih snovi, gorljivih in radioaktivnih snovi ter podobnih snovi iz plinastih (zraka) in tekočih (vode) medijev ali za čiščenje tal.

V raziskavi sorpcije zdravju škodljivih policikličnih aromatskih ogljikovodikov (PAHs), ki nastajajo pri nepopolnem gorenju in prehajajo iz zraka v vodo, so ugotovili slabšo sposobnost kapoka za vezanje PAHs iz vode v primerjavi s poliestrskimi in rogozovimi vlakni [25].

Kapok uporabljajo v medicini kot absorpcijski material, ki nadomešča bombaž. Lahko vpije tudi do 30-krat večjo maso vode od lastne mase. V tropskih predelih so ga zato uporabljali za kirurška oblačila.

## 5.4 Kapok v kompozitih

Rastlinska vlakna (lan, konopljo, juto, sisal in kokos) vse več uporabljajo za ojačitev polimernih kompozitov. Ojačitev polimerne matrice je odvisna od dobre adhezije med vlakni in matrico, ki jo izboljšajo z odstranitvijo površinskih voskov in kemično modifi-

*the high content of acetyl groups, whilst high capability of oil absorption is attributed to a wide lumen of fibres. It has been noticed that oil penetrates through the fibre cell wall into its lumen, which is not the case with water. However, quick and efficient mechanism of oil absorption has not been completely explained yet [21].*

*Kapok is suitable for filtration of oil suspensions. Oil filters for filtration of wastewaters discharged by metal, food, textile, leather, petrochemical, and other industries are today made of synthetic fibres, such as polypropylene, polyester, or polyamide fibres. In comparison with synthetic fibres, natural cellulosic fibres absorb higher quantities of oils, are better oil filters, and are also biodegradable. Raw, untreated kapok retains oil longer than kapok extracted in ethanol or chloroform. Kapok selectively absorbs about 40 g of oil per gram of fibres from freshwater or seawater [21]. When the density of fibres arrangement is 0.02 gcm$^{-3}$, the capability of Diesel fuel absorption is 36 g of oil per gram of fibres. At a higher density of fibres arrangement, i.e. 0.09 gcm$^{-3}$, the capacity of Diesel fuel absorption is only 7.9 g of oil per gram of fibres [15]. Oils, which are retained in a filter, can be extracted either by squeezing or more efficiently by centrifuging where even more than 83% of oil can be extracted; the extracted oil can be reused [22].*

*Kapok is also very suitable for smaller, mobile water/oil separators [22]. Another field of use is for pre-filtration of waters, which is followed by membrane filtration [15]. It can be efficiently used for collecting spilled oil on the surface of rivers and seas [23].*

*Fully biodegradable oil sorbents of non-polar substances can be manufactured from 100% kapok without additives (glues) by heating the material to the glass transition temperature of the contained hemicelluloses (it depends on the degree of hydration of these hemicelluloses, and it decreases by wetting) and by compressing the heated material. During heating at 90–120 °C hemicelluloses pass over into gel, and during compressing at the temperture 170–190 °C for a short time interlinking of fibres occurs. [24] In this way, the strength of the end product is increased. Temperatures above 220 °C induce oxidative degradation of fibres. The addition of no*

kacijo vlaken, predvsem z alkaliziranjem ali acetiliranjem [31, 32]. Alkaliziranje kapoka vpliva na topografske spremembe površja vlaken in na izboljšanje kristalne strukture. 8 % raztopina NaOH ne povzroči vidnih sprememb na površju kapoka, 40 % raztopina NaOH pa povzroči razbrazdanje površja in povečanje specifične površine kapoka [33], kar je posledica odstranitve hemiceluloz in lignina. Visoke koncentracije alkalij lahko poslabšajo termično odpornost kapoka. Acetiliranje hidroksilnih skupin zmanjša polarnost kapoka in poveča adhezivnost s hidrofobno polimerno matrico. Kemična reaktivnost je zaradi visoke vsebnosti hemiceluloz in lignina ter nižje kristaliničnosti, s katero je povezana dostopnost hidroksilnih skupin na površju in v amorfnih predelih vlaken, učinkovitejša pri kapoku kot pri konoplji, sisalu in juti.

Pri pripravi termostabilnih poliestrskih kompozitov, ojačanih s tkanino iz kapoka in bombaža (KP/CO), so za izboljšanje adhezije vlaken s poliestrom tkanino najprej mercerizirali v 5 % NaOH, pri čemer so odstranili voske in pektin [34]. Natezna trdnost oziroma modul sta se s povečevanjem količine vlaken poslabšala, izboljšala pa sta se upogibna trdnost in upogibni modul. Uporaba teh kompozitov za poceni silose za žito, za šolske zgradbe in ohišja je še posebej smotrna v revnih deželah, v katerih ta vlakna tudi pridobivajo.

Tkanine iz KP/CO so primerne za ojačitev izotaktičnega polipropilena v kompozitih z nižjo mehansko trdnostjo [35]. Alkaliziranje in acetiliranje tkanine iz KP/CO sta zaradi znižanja deleža kristaline faze vplivali na znižanje natezne trdnosti kompozita v primerjavi s kemično neobdelano tkanino.

## 5.5 Kapok v prehrani

Zaradi odličnega vezanja olj so kapok uporabili tudi za selektivno izločanje nasičenih maščob iz človeškega telesa. Kapok ne veže vode, zato ima prednost pred konvencionalnimi rastlinskimi vlakni. Kapok zmeljejo v prah in ga dodajo kruhu, piškotom ter podobnim prehrambenim izdelkom. Kot oljni absorber kapokov prah lahko učinkuje zdravilno. Dodan živilom (npr. kruhu) ali stisnjen v tabletah v telesu veže odvečna olja (nasičene maščobne kisline) [36].

Na Tajskem so opravili uspešne raziskave predelave kapoka v mikrokristalino celulozo, ki v zadnjih letih prodira na področje prehrane in farmacije kot polnilo, zgostilo ali stabilizator zaradi svoje fiziološke inertnosti, varnosti in stabilnosti [37].

## 5.6 Predenje kapoka

Kapok le redko predejo, saj so vlakna krhka ter zato zdržijo nizke natezne in torzijske sile. Vlakna imajo zaradi gladkega površja in visoke vsebnosti voskov slabo kohezivnost. Zato kapok vedno predejo v mešanicah z drugimi vlakni, predvsem z bombažem. Sredi prejšnjega stoletja so ga predelovali le v grobe preje do 125 tex, v mešanicah z bombažem pa do 50 tex. Pred predenjem so kapok obdelali z alkoholom, etrom ali drugimi topili, s katerimi so odstranili voske in dosegli bolj hrapavo površje. Prejo iz kapoka so *more than 3–10% of foreign reinforcing fibres is still acceptable, as such percentage does not deteriorate the sorptivity of kapok.*

*Sorbents made of kapok in the form of filters, sponges, or fabrics are suitable for separation of lubricant oils and motor oils, dyestuffs, herbicides, fungicides and pesticides, aromatic substances, flammable and radioactive materials, and similar substances from gaseous (air) and liquid (water) media or for floor cleaning, etc.*

*The results of the researches of sorptivity of health hazardous polycyclic aromatic hydrocarbons (PAHs), which are generated during incomplete combustion and which pass from the air into the water, show that the kapok's capability of absorbing PAHs from water is lower than that of polyester and reed fibres [25].*

*Kapok is also used in medicine as absorbing material instead of cotton. It is capable of absorbing a mass of water, which is even to 30 times higher than its own mass. In tropical areas, kapok was used for surgeon clothing.*

### 5.4 Kapok in Composites

*Plant fibres (such as hemp, jute, flax, sisal, and coconut fibres) are increasingly used for reinforcement of polymer composites. Reinforcement of a polymer matrix is dependent on good adhesion between the fibres and the matrix, which can be improved by removing superficial waxes and by chemical modification of fibres, notably by alkalisation and acethylation [31, 32]. Alkalisation of kapok induces topographic changes of the fibres surface and improves the crystalline structure of fibres. The 8% solution of NaOH does not induce any visible changes on the surface of kapok, whereas the 40% solution of NaOH makes the surface furrowed and enlarges the specific surface of kapok [33], which is the result of the removal of hemicelluloses and lignin. High concentrations of alkalis can deteriorate the thermal stability of kapok. Acethylation of hydroxyl groups decreases the polarity of kapok and increases its adhesivity with a hydrophobic polymer matrix. Since kapok contains a high percentage of hemicelluloses and lignin and has also lower crystallinity to which accessibility of hydroxyl groups on the surface and in*

uporabljali za pliše in trakove, pri katerih je prišel do izraza kapokov lesk [26].

Angleški patent iz leta 1940 opisuje metodo proizvodnje čiste kapokove preje iz kapokovih vlaken [27]. Ameriški patent iz leta 1942 [16] opisuje izdelavo oplaščene preje z jedrom iz bombaža, volne ali svile in plaščem iz kapokovih vlaken. Kapokova vlakna so prilepili na jedro preje s pritiskanjem in brez vitja vlaken. Posamezne preje so med seboj vili v niti za pletenje ali tkanje. V pletivu so bile preje prečno prepletene z ojačevalno nitjo, da kapok ni izpadal. Te niti so bile primerne za izdelavo odej, oblačil, izolacijskih podlog za letala, hladilnike ipd. Pri sami predelavi oplaščenih prej so se morali izogibati prevelikemu zvijanju vlaken in preje.

Izboljšanje predilnosti in mehanske trdnosti so poskušali doseči z obdelavo kapoka v emulzijah silikona, akrilonitrila, melamina, formaldehida, sečnine in vinilnih monomerov [28]. Pri nanašanju sintetičnih premazov je pomembno preprečiti prodiranje emulzije v lumen vlaken. Obdelana vlakna dobijo grobo, neenakomerno valovito površje, ki izboljša predilne in elastične lastnosti ter poveča vodoneprepustnost.

Japonski patent iz leta 2001 obravnava preje v mešanicah z do 20 % kapoka in blago iz takšnih prej, ki dosega dobro svetlobno obstojnost, belino, nizko težo, izboljšane toplotnoizolacijske lastnosti, higroskopičnost in dobro obarvljivost [29].

Leta 2007 sta Ensheng Li in Longquan Xia (Kitajska) patentirala postopek prstanskega predenja kapoka. Izhodna surovina je mešanica kapoka (20–80 ut. %) z bombažem ali drugimi vlakni. Mešanico vlaken dvakrat mikajo, sledi dvakratno raztezanje in predenje. Preja 25,36 tex je dosegla pretržno silo 275 cN in specifično pretržno napetost 10,8 $cNtex^{-1}$ ter pretržni raztezek 6,6 % [30].

## 6 Zaključek

Kapok je biorazgradljivo naravno vlakno, danes tudi cenovno konkurenčno sintetičnim materialom. Zaradi dobrih toplotnoizolacijskih lastnosti je primerno za polnilo blazin, oblačil, igrač ipd., zaradi dobre plovnosti na vodi za zaščitne jopiče, blazine ipd. ter zaradi dobrih sorpcijskih in protibakterijskih lastnosti za medicinske namene. Visoka vsebnost voskov, anorganskih snovi in acetilnih skupin v primarni celični steni daje vlaknu hidrofoben značaj, ki se kaže v nizkem stičnem kotu z različnimi olji in visokem stičnem kotu z vodo. Uporaba kapoka za oljne absorberje je mogoča brez predhodne kemične obdelave vlaken. Oljni absorberji iz kapoka so poceni alternativa sintetičnim absorberjem. Širok lumen (okrog 74 % vlakna) omogoča zadrževanje velike količine olj, ki jih lahko ponovno uporabijo.

Kapok lahko belimo in se dobro obarva. Nizka trdnost, gladko površje vlaken in premajhna dolžina vlaken so vzrok za slabe predilne sposobnosti kapoka, ki na splošno ne zadoščajo zahtevam za uspešno predelavo kapoka po konvencionalnih predilnih postop-

*the amorphous regions of fibres is related, its chemical reactivity is more efficient than that of hemp, sisal, or jute.*

*In the case of thermally stable polyester composites reinforced with a kapok/cotton fabric, the adhesivity of fibres with a polyester fabric was improved by first mercerising the fabric in 5% NaOH to remove waxes and pectin [34]. The tensile strength/module deteriorated with the increase of the quantity of fibres, whereas flexing strength/module improved. The use of these composites for cheaper corn silos, school buildings, and casings is reasonable in poor countries in which these fibres are produced.*

*Fabrics made of kapok/cotton blends are suitable for reinforcement of isotactic polypropylene for composites with lower mechanical strength [35]. The decrease of the tensile strength of composites in comparison with chemically untreated fabrics is the result of alkalisation and acethylation of kapok/cotton fabrics by which the content of a crystalline phase is decreased.*

### 5.5 Kapok in Nutrition

*Due to excellent absorption of oils, kapok was also used for selective elimination of saturated fats from a human body. Since kapok does not absorb water, it has advantage over conventional plant fibres. Kapok is ground into powder and added to bread, biscuits and similar alimentary products. As oil sorbent, kapok can have a healing effect. Added to alimentary products (e.g. bread) or compressed into pills, kapok absorbs excessive oils (saturated fatty acids) [36].*

*In Thailand, successful researches were carried out about kapok processing into microcrystalline cellulose which has been recently penetrating into the food and pharmaceutical industry as a filling agent, thickener, or stabilizer due to its physiologic inertness, safety and stability [37].*

### 5.6 Spinning of Kapok

*Since kapok fibres are very brittle and can withstand only low tensile and torsional forces, kapok is rarely spun. Due to the smooth surface and a high content of waxes, kapok fibres have low cohesivity. For that reason kapok is always spun in blends with other fibres, mostly*

kih. Specialne tehnologije za predelavo kapoka ni na voljo. Poleg hitre vnetljivosti, krhkosti in neelastičnosti sta majhna dolžina vlaken in slaba kohezivnost osnovni oviri večje razširjenosti kapoka na področju oblačil.

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*cotton. In the middle of the last century kapok was processed only into coarse yarns up to 25 tex, and in blends with cotton up to 50 tex. Prior to spinning kapok was treated with alcohol, ether or other solvents in order to remove waxes and to achieve a coarse surface. Kapok yarn was used for fleeces and ribbons to which it imparted a typical lustre [26].*

*The United Kingdom patent from 1940 describes the method of producing pure kapok yarn from kapok fibres [27]. The US patent from 1942 [16] describes the manufacture of wrapped yarn containing a cotton, wool, or silk core and a kapok wrapping. Kapok fibres were stuck to the yarn core by pressing and without twisting. Then, individual yarns were intertwisted into the threads for knitting or weaving. Yarns in knitwear were crossly interlaced with a reinforcing thread in order to prevent kapok from falling out. These kapok yarns were suitable for manufacture of beddings, clothing, insulating linings for airplanes, refrigerators, etc. During processing of such wrapped yarns excessive twisting of fibres and yarn had to be avoided.*

*There were trials to improve the spinnability and mechanical strength of kapok by treating it in emulsions of silicone, acrylonitrile, melamine, formaldehyde, urea, and vinyl monomers [28]. When applying synthetic coatings, it is important that penetration of the emulsion into the fibre lumen is prevented. The treated fibres obtain coarse, unequal wavelike surface, which improves the spinning properties, elasticity, and water-resistance of kapok fibres.*

*The Japanese patent from 2001 deals with the yarns in blends containing up to 20% of kapok, and the fabrics made from such yarns, which exhibit good fastness to light, whiteness, low weight, better thermal insulating properties, hygroscopicity, and good dyeability [29].*

*In 2007 Ensheng Li and Longquan Xia (Kitajska) took out a patent for the kapok ring spinning method. The initial raw material is the blend of kapok (20–80 wt.%) with cotton or other fibres. The fibre blend is carded two times, after that it is drawn two times and spun. The breaking force of the yarn 25.36 tex was 275 cN, its tenacity 10.7 cNdtex$^{-1}$, and its breaking elongation 6.6% [30].*


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## 6 Conclusion

*Kapok is a biodegradable organic fibre, which can compete with synthetic materials also in terms of price. Its good thermal insulating properties make kapok suitable for stuffing pillows, clothing, toys, etc., its good buoyancy on water makes it suitable for lifejackets, mattresses, and other water-safety equipment, and its good sorptivity and antimicrobial properties make it suitable for medical purposes. A high content of waxes, inorganic substances and acethyl groups in the primary cell wall imparts to kapok fibres hydrophobic properties, which are exhibited in a low contact angle with various oils and a high contact angle with water. The use of kapok for oil sorbents is possible without previous chemical treatment of fibres. Oil sorbents made of kapok are a price effective alternative to synthetic sorbents. A wide lumen (about 74% of a fibre) enables retention of high amounts of oils, which can be reused.*

*Kapok can be bleached and dyed. However, due to low strength, smooth surface, and too short length of its fibres, kapok has a low spinnability, and cannot be, in general, spun by using conventional spinning methods. No special technology for kapok processing is available. In addition to high flammability, brittleness, and lack of elasticity, it is also too short length and low cohesivity of fibres, which impedes wider use of kapok in the field of clothing.*


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