BIOFUNCTIONAL TEXTILE MATERIALS: Cosmetic textiles

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The latest trend in textile industry promotes products with added value that provide additional comfort to users and have a focus on health in terms of use. In that sense, biofunctional and intelligent textile products with different types of applications for improving the lifestyle of the modern consumer stand out. Cosmetic textile is a high-performance textile which represents a fusion of textile material with cosmetics. The main challenges in the manufacture of such products are the selection of products with a cosmetic effect for a particular purpose, storage of agents in the structure of the textile, the rate of release of the agent on the skin and the stability of the agent to the maintenance procedures of textiles and clothing. This paper provides an overview of cosmetic agents for application on textiles, methods of their storage and release and the techniques applicable on textile. Finally, a range of commercially available cosmetic textile products is presented.

Keywords: textile materials, essential oils, aromatherapy, microencapsulation, cyclodextrin

Introduction

In everyday life, people are surrounded by some kind of clothing throughout the day, which is why clothing is described as second human skin. The traditional purpose of clothing to protect the human body from external factors and provide comfort in terms of use has been expanded by aesthetic and health factors. Clothing shape and pattern should reflect the spirit of the times in which they are used, and more recently their role in cosmetic areas has been promoted. “Cosmetic textile” is a high-performance textile that is a fusion of textile material with cosmetic substances. These are functional fabrics, knitted and non-woven textiles finished with cosmetic ingredients that are released on the skin during wearing. “Cosmetic clothing” can provide a range of benefits some of which could be considered cosmetic, such as skin whitening, wrinkle reduction, hydration, increased energy, relaxation, refreshment and perfuming. A wide range of cosmetics with different effects is available in the form of creams, oils and powders, etc., but a textile as a medium for achieving a cosmetic effect on the skin is recommended for the following reasons: i) textiles cover a large part of the body most of the day which provides a unique opportunity to transfer cosmetics to body parts; ii) continuous release of small doses of cosmetics can be more effective than a single application of a large quantity of cosmetics. The rise of cosmetic textiles market opens a way for new resources in which consumers can assess their clothes, providing a new way for the development of both cosmetics manufacturers and clothing.

Beiersdorf represented skin-shaping shorts with micro-encapsulated coenzyme Q10, which is found in many Nivea creams for skin care. “Cosmetic giant L’oreal has teamed up with Roxy, a fashion sportswear brand, to develop a range of products under the Biotherm brand”. The first product, a neck warmer, which debuted at the end of 2015, helps in skin care when it is exposed to extreme conditions. The product contains microcapsules with anti-inflammatory extracts and vitamin E. Illuminage Beauty, a joint venture of Unilever Ventures and Syneron Medical, presented a pillow case containing fibers with built-in copper oxide. The product is claimed to reduce the appearance of wrinkles and smooth the skin within four weeks. Illuminage also offered a mask for rejuvenating the skin around the eyes, which contained patented technology with copper. In its shirt production, Under Armor used technology containing zeolites with antimicrobial properties to aid in controlling body odors [1]. The cosmetic textiles market, which is still in its infancy, is expected to flourish in the next few years, offering numerous opportunities to both clothing and cosmetics manufacturers and retailers selling cosmetics or apparel. Continuous integration of the innovative technologies in garments is accepted by today’s consumers who appreciate efficiency of the products [2].

The development and production of cosmetic textiles is not an easy and simple task. The main problems in making such a product with added value are the selection of agents with cosmetic effect for a specific purpose,
the storage of agents in the textile structure, the release rate of agents and the stability of agents in the washing process. Applying the techniques of microencapsulation opens up the possibility of producing new products with many advantages over the traditional products of the textile industry. The application of active substances in the form of microcapsules on garments gives completely new properties, such as the controlled release of the active substance and increased stability [3-5]. Although the microencapsulation has found application in other industries over the past few decades (such as food, cosmetic and pharmaceutical industries), commercial textile products comprising the microcapsules have begun to emerge in the 90s of the last century. Today, the use of microcapsules has been expanded to new areas of application, as shown in Figure 1 [6].

It is noted that the pharmacy and health care sectors have the highest level of application of microencapsulation, whereas the textile sector is in fourth place. Cosmetics or mixtures of products may be of natural or synthetic origin. In order for the textile to have a cosmetic effect, the applied product must be transferred from the textile to the skin during use [7].

Figure 1. Schematic representation of the statistical distribution of microencapsulation in different areas of application (drawn on the basis of data from ref. 6)

Cosmetic ingredients for textile finishing

The main cosmetic ingredients that bind to textile materials are synthetic and inorganic matters, animal and plant derivatives [8-10].

Various synthetic and inorganic compounds are used to provide cosmetic benefits to consumers. Oxides of iron, zinc and titanium, zinc nanoparticles and oxalic acid are used for protection against harmful UV radiation. For providing the deodorizing effect in textiles, glucosamine is used and copper-oxide gives the antimicrobial functionality to the fabric [8, 9].

Animal derivatives chitosan, squalene and sercin are used in cosmetic textiles. Chitosan is a natural product obtained from chitin. Chitosan is the name for chitin deacetylation products in which the degree of deacetylation is greater than 70%. It is used for blood clotting and wound healing; it improves skin texture, hydrates the skin, stimulates cell regeneration and has an antibacterial effect [11]. Squalene (Figure 2) is a fatty compound, a natural antioxidant and is found in the palm and olive oil, but is usually extracted from the shark liver, where it is present in high concentrations. In the human body, it is abundant in the skin, where it plays a very important function of maintaining the hydrolipid barrier. The cosmetic industry has researched it due to its beneficial effect on the skin, and the possibility of its use as an aid in the treatment of tumors is being investigated. Squalene is not susceptible to peroxidation and protects the skin from UV light as a quencher of singlet oxygen [12].

Figure 2. Chemical structure of squalene

Sericin and fibroin, together with very small amounts of waxy substances, mineral salts and dyes, are the main ingredients of the natural silk. Sericin is rich in serine (about 32%), aspartic acid (16.8%) and glycine (8.8%), which is why it has a high concentration of hydroxyl groups [13]. In industrial practice, most of the sericin is removed during the degumming process and discharged as an effluent that causes water pollution. However, it is scientifically proven that the sericin is a biomolecule of great importance and it has antibacterial, antioxidant and hydrating properties. Separation and reuse of sericin from wastewater after degumming or from discarded cocoons can reduce environmental pollution, also regenerated sericin can be used for various cosmetic purposes and cosmetic textiles [14]. The amino acid components of sericin provide excellent retention of moisture on the skin, so it can be used as an addition to high-quality cosmetics. The molecular weight of sericin directly affects the types of cosmetic application, i.e. besides skin hydration, the sericin can be used for the hair care and repair [15]. Sericin when incorporated in cosmetics like lotions, creams and ointments increases skin elasticity, reduces wrinkles and signs of aging. Also, nail cosmetics containing 0.02-20% of sericin can prevent cracking and brittle nails [16].

The various herbal products can be used for the preparation of cosmetic textiles, and the choice depends on the effect wanted to be achieved on the skin. Aloe vera is a subtropical plant from the lily family. There are 250 species of this plant and the most important of them is Aloe vera Barbadosensis Miller. Aloe leaf contains more than 75 nutrients and 200 active components, including 20 minerals, 18 amino acids and 12 vitamins. Aloe vera is used to obtain the wound healing effect, antibacterial, antiviral and anti-inflammatory effects. The textile treated by it is pleasant to wear and provides a feeling of well-being. Green tea is reasonably one of the most desirable trends in the world of skin care. Green tea polyphenols can provide photo protection, increase microcirculation and improve skin properties [17]. Polyphenols are derivatives of epicatechin and act as catchers of free radicals that accelerate skin aging, i.e. they have antioxidant, anti-inflammatory and anti-cancer properties. The main and most chemo-preventive ingredient of green tea re-
sponsible for biochemical or pharmacological effects is epigallocatechin-3-gallate (EGCG) [18]. In vitro and in vivo clinical studies on animals and humans suggest that green tea polyphenols are photoprotective in nature and can be used as pharmacological agents to prevent UV-induced skin disorders, including photoaging, melanoma, and nonmelanoma human skin cancer. EGCG is at least 100 times more effective than vitamin C and 25 times better than vitamin E in protecting the cells and their genetic material [19]. The Journal of the American Medical Association of Dermatology has noticed that “green teas have anti-inflammatory and anti-cancer potential, which can be used against various skin disorders” [20]. The researchers have further stated that “adding green tea to skin care products can have a profound effect on various skin disorders in the years to come”, such as maintaining youthful skin structure and firmness, stimulating hair growth, acne treating, and lightening blackheads, treatment of puffy eyes and dark circles and the fight against signs of premature aging such as liver spots and wrinkles [20].

Aromatherapy (aroma - the smell, therapy - treatment) is the use of natural essential (etherial) oils of specified origin. Aromatherapy involves the use of high quality essential oils entering the body through the respiratory tract or skin [21]. Essential oils are volatile, colorless or light-yellow substances with an intense scents and greasy consistency, soluble in fat, alcohol, ether or chloroform. Essential oils are obtained from the raw parts of plants (flowers, leaves, roots, stems, barks, branches, seeds, fruits) using conventional or advanced methods (Figure 3) [22].

![Figure 3. Extraction methods of essential oils](image)

The biological activity and the scents of oils are conditioned by their chemical composition. The composition of the oil depends on a number of factors, including the origin of the raw materials or the growing conditions of the plants. Essential oils are not chemically homogeneous. In most cases, they are a mixture of several organic compounds (terpene hydrocarbons and their derivatives with oxygen, alcohol, aldehydes, ketones, organic acids, esters and ethers). In general, one substance prevails in a certain oil (Table 1) [21], and a variety of the following substances is present in minor amounts.

**Table 1. Dominant ingredients in some aromatic plants (drawn on the basis of data from ref. 21)**

<table>
<thead>
<tr>
<th>Main ingredient</th>
<th>Aromatic plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>limonene</td>
<td>mint, hyssop, lavender, marjoram, oregano, thyme, vervain</td>
</tr>
<tr>
<td>β-pinene</td>
<td>parsley, basil, caraway, fennel, marjoram, oregano, sage</td>
</tr>
<tr>
<td>carvone</td>
<td>dill, coriander</td>
</tr>
<tr>
<td>camphor</td>
<td>balm, basil, dill, lavender, marjoram, sage</td>
</tr>
<tr>
<td>thymol</td>
<td>marjoram, oregano, thyme, balm</td>
</tr>
<tr>
<td>α-thujene</td>
<td>dill, balm, caraway, lavender, marjoram, oregano, sage</td>
</tr>
</tbody>
</table>

Beatović et al. have studied the chemical composition and antioxidant and antimicrobial activity of basil oil (Ocimum sanctum L.). Essential oil from dried basil herb (Ocimum sanctum L.) was processed by hydrodistillation. A total of 41 components were identified in the tested essential oil. The most represented chemical group was sesquiterpene hydrocarbons with 80.47%. Other groups were less represented: oxidized monoterpenes 5.82%, oxidized sesquiterpenes 4.1%, monoterpenes hydrocarbons 2.28% and phenylpropanoids 7.33% [23]. The structure of essential oils and their solubility in fats make them compatible with human proteins and allow the body to easily recognize and accept them. Table 2 shows the properties of chemical components of the essential oils [24].

**Table 2. Properties of the essential oil ingredients (drawn on the basis of data from ref. 24)**

<table>
<thead>
<tr>
<th>Compound properties</th>
<th>hydrocarbons</th>
<th>sesquiterpene alcohols</th>
<th>phenols</th>
<th>aldehydes</th>
<th>cyclic aldehydes</th>
<th>ketones</th>
<th>esters</th>
<th>oxides</th>
<th>coumarins</th>
<th>sesquiterpenes</th>
<th>phenylpropanes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>stimulant, decongestant, antiviral, antitumor</td>
<td>antimicrobial, anti-inflammatory, anti-allergic</td>
<td>anti-microbial, irritant, immune stimulating</td>
<td>spasmodic, sedative, anti-viral</td>
<td>spasmodic</td>
<td>mucolytic, cell-regenerating, neurotoxic</td>
<td>spasmodic, sedative, anti-fungal</td>
<td>expectorant, stimulant</td>
<td>UV sensitising, antimicrobria</td>
<td>anti-inflammatory, anti-viral, immune stimulating</td>
<td>carminative, anesthetic</td>
</tr>
</tbody>
</table>

The effects of essential oils are multidirectional (Table 3) and strongly depend on the properties of the dominant ingredient [25]. Also, the action of essential oil may be the result of synergistic or antagonistic action of some ingredients [26].

In the cosmetic aromatherapy, certain essential oils are used for skin, hair and nails in order to cleanse, smell or protect them, and in order to maintain good condition, change their appearance and control body odors. Transport of matter through the skins occurs as a two-way process: absorption and excretion. Small non-polar molecules of essential oils pass through hair follicles that contain sebum, an oily liquid to which essential oils have an affinity. From here, the oils diffuse into the bloodstream or are taken up by lymph or interstitial fluid (fluid that surrounds all body cells) into other parts of the body [27].
Essential oils, as well as their isolated compounds, are widely used in cosmetic products and offer various benefits. In a recently published paper, Montenegro et al. have found that gels containing lipid nanoparticles filled with rosemary oil showed a significant increase in skin hydration and elasticity compared to gels containing free essential oil [28]. It has been clinically proven that a combination of aromatherapy massage and inhalation aromatherapy reduces anxiety and pain in burn patients [29]. Due to their useful properties, essential oils of various plants [30, 31] are increasingly used for integration into textile products [32].

### Table 3. Possible use of some essential oils (drawn on the basis of data from ref. 21, 25)

<table>
<thead>
<tr>
<th>Effect on mood and mental status</th>
<th>Effect on skin</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>fatigue</strong>: Angelica archangelica, Citrus aurantium, Coriandrum sativum, Cymbopogon nardus, Eucalyptus radiata, Juniperus communis, Mentha spicata, Pelargonium graveolens, Pinus sylvestris, Rosmarinus officinalis, Salvia scarea, Zingiber officinalis</td>
<td>antibacterial activity: Melaleuca alternifolia, Leptospermum scoparium, Rosmarinus officinalis, Lavandula officinalis</td>
</tr>
<tr>
<td><strong>insomnia</strong>: Angelica archangelica, Cananga odorata, Citrus aurantium, Cistus ladaniferus, Citrus bergamia, Citrus limon, Citrus reticulata, Citrus sinensis, Cuminum cyminum, Juniperus communis, Lavandula angustifolia, Litsea cubeba, Melissa officinalis, Myrtus communis, Ocimum basilicum, Origanum majorana, Valeriana officinalis</td>
<td>antifungal activity: Melaleuca ericifolia, Melaleuca armitii, Melaleuca leucadendron, Melaleuca styphelioides, Mentha piperita, Brassica nigra, Angelica archangelica, Cymbopogon nardus, Skimmia laeolca, Artemisia siberi, Cuminum cyminum</td>
</tr>
<tr>
<td><strong>anxiety, agitation, stress</strong>: Angelica archangelica, Cistus ladaniferus, Citrus aurantium, Cymbopogon martini, Eucalyptus staigeriana, Lavandula angustifolia, Litsea cubeba, Ocimum basilicum, Origanum majorana, Pelargonium graveolens, Pugatoemon patchouli, Valeriana officinalis</td>
<td>anti-inflammatory action: Melaleuca alternifolia, Citrus limon, Lavandula officinalis, Pogostemon patchouli, Rosmarinus officinalis, Santalum album</td>
</tr>
<tr>
<td><strong>mental exhaustion, burnout</strong>: Mentha piperita, Ocimum basilicum, Helichrysum angustifolium</td>
<td>strengthening vascular walls: Pelargonium graveolens, Citrus amara, Rosmarinus officinalis, Rosa damascena</td>
</tr>
<tr>
<td><strong>memory loss</strong>: Litsea cubeba, Mentha piperita, Rosmarinus officinalis</td>
<td>delaying skin ageing: Citrus limon, Citrus amara, Rosa damascena</td>
</tr>
<tr>
<td><strong>pains of various origins, including bone and joint pains</strong>: Rosmarinus officinalis, Juniperus communis, Cinnamomum zeylanicum, Zingiber officinalis, Lavandula angustifolia, Matricaria recutita, Leptospermum scoparium, Origanum majorana, Pinus mugo</td>
<td>removal of metabolic wastes, improvement of lymph circulation, anti-cellulite action: Citrus limon, Juniperus communis, Pelargonium graveolens, Cupressus sempervirens, Rosmarinus officinalis, Santalum album, Citrus paradisi</td>
</tr>
<tr>
<td><strong>memory and concentration</strong>: Basil, Cypress, Black Pepper, Lemon, Hysop, Rosemary, Peppermint</td>
<td></td>
</tr>
</tbody>
</table>
ficinalis) has anti-bacterial, antioxidant and anti-inflammatory properties, and its regular use provides a medical treatment, alleviation and protection against eczema. Marigold is also used in some medicinal cosmetic ointments with antiseptic properties, its extracts contribute to the alleviation and recovery of skull skin damage and the regeneration of hair roots and hairs, and can be used to alleviate scalp irritations and recover dry hair. It is useful for hydrating human skin, especially in winter, and its anti-inflammatory properties are especially useful in cases of tissue degeneration, such as hard-to-heal wounds, acne, ulcers, bed sores, varicose veins, bruises, rashes and eczema [37]. Therapeutic uses of marigold are similar to those of Aloe Vera and its extract can be applied to textile by the technique of microencapsulation.

Vitamin E is used in cosmetics as a powerful antioxidant in an attempt to reduce the negative impact of UV radiation and prolong the youthful appearance of the skin. Vitamin E is the collective name for a group of fat-soluble compounds with recognizable antioxidant action. Natural vitamin E exists in eight chemical forms that have different levels of biological activity. The most active form of vitamin E is α-tocopherol (Figure 4) [38].

![Figure 4. Chemical structure of vitamin E (α-tocopherol)](image)

In the recent years, the possibility of implantation of vitamin E in cosmetic textile by microencapsulation, impregnation or by complexing has been investigated. Antioxidants are very susceptible to environmental factors such as light, oxygen and heat. When antioxidants get into the air, they disappear quickly, so this desired effect remains limited. The transfer of vitamin E from textiles to the skin provides security in protecting the skin from UV radiation. Fabric enriched with vitamin E can be used as a value-added product that will meet people's expectations. Lately, several content works have been dedicated to the incorporation of α-tocopherols in textile materials. In a recently published paper, Ghaheh et al. have treated cotton fabrics with protein-based nanoparticles that contain vitamin E [38]. After processing, the antioxidant activity of treated fabrics and the release of nanoparticles from the fabric surface and their transfer to other substrates have been examined. The test for antioxidant capacity has shown the ability of functionally processed fabrics to reduce the amount of free ABTS (12,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)) radicals in solution. The impregnated fabric was kept in 95% ethanol in order to determine the release of vitamin E. The abrasion, sweat, and the presence of proteases are variable factors whose influence on the release of vitamin E was examined. The rate of transition of the vitamin E was largest at the beginning of the reaction and the highest values of released vitamin E were registered in the fabric samples with the maximum filling of vitamin E. Also, the higher the concentration of vitamin E on the cotton cloth means greater antioxidant capacity [38]. Determination of anti-oxidant capacity of cotton fabrics treated by microcapsules containing α-tocopherol was the objective of this paper done by this group of authors [39]. Antioxidant capacity of fabrics was determined by the method of free radical removal, 1,1-diphenyl-2-picrylhydrazyl (DPPH). The samples treated with microcapsules had the ability to neutralize DPPH in the amount of 57.4%, and the activity of α-tocopherol of 61.73 μg. After one wash with fabric finishing, 35.73% of the amount of α-tocopherol was removed, due to which the ability to neutralize DPPH was reduced to 32.6% and the activity was 35.02 μg. However, even after 20 washing cycles, it was found that most of the microcapsules which remained in the gaps of fibers and fabric, had an activity of 15.1 μg and exhibited a significant antioxidant capacity [39]. In a recently published paper, Matijević et al. used three methods to isolate α-tocopherol from cotton cosmetic textiles [40]. Cotton fabrics have been pre-treated with cosmetic substances based on α-tocopherol and cyclodextrin. Then, insulation of α-tocopherol from cosmetic cotton fabric was performed by means of three different techniques: mixing, Soxhlet extraction and microwave extraction. Solvent extraction was methanol. The concentration of α-tocopherol in methanol was determined by HPLC method. The amounts of isolated α-tocopherol from the identical surface of cotton fabric were approximately the same in all methods and amounted to about 190 μg/ml, which indicated that the chosen techniques were applicable for the isolation of α-tocopherol from cotton cosmetic textiles. After 5 washing cycles, α-tocopherol is still present on cotton in different amounts depending on the method of isolation, namely: microwave extraction (23%), Soxhlet (13.8%) and mixing (10.2%) [40]. Elsairi et al. have investigated the antibacterial efficiency, and UV protection (UPF) of cotton/PES mixtures which are functionally finished by natural products, vitamin E oil and jojoba oil [41]. The mixture of cotton/PES was functionally finished in such a way that firstly, the process was carried out with monochloro-triazine-β-cyclodextrin, dimethyl dihydroxy ethylene urea and MgCl₂ as a catalyst. In the second step, one group of samples was treated with jojoba oil and the other group with vitamin E oil. Antibacterial efficacy was tested and UPF factor was determined on functionalized samples. The original fabrics did not have antibacterial properties and the UPF protection factor was low. The samples finished with natural products had the ability to inhibit the growth of the tested strains of bacteria, and the UPF factor was significantly increased after processing, in proportion to the concentration of the natural product. The authors have stated in the conclusion that the applied ecological final process can be applied in industrial conditions to achieve value-added textile products [41]. Formation and categoriza-
tion of a functionalized polypropylene non-woven textile after impregnation with vitamin E for potential use as a sleeping mask is the aim of a recently published paper [42]. In the experiment, a polypropylene non-woven textile was impregnated with vitamin E in three forms: microcapsules, micro-emulsions and solid lipid nanoparticles, in order to determine the effect of various systems for the release of vitamin E from the textile material. The release of vitamin E from textiles was examined in vitro in ethanol for 12 h. The amount of vitamin E in ethanol was determined by HPLC method. It was concluded that the form of the vitamin E carrier affected its release from textiles, because vitamin E in the form of microcapsules had the highest release rate whereas vitamin E in solid lipid nanoparticles had the lowest one [42].

The use of vitamin C (ascorbic acid) is also being studied in the development of cosmetic textiles. Vitamin C is a water-soluble and recognized antioxidant that is involved in important metabolic functions and is vital for the growth and maintenance of healthy bones, teeth, gums and blood vessels. As a branded antioxidant, it is also used in cosmetic industry because vitamin C accelerates collagen synthesis and slows down the decomposition of collagen. It is also effective in preventing the formation of wrinkles on the skin. Ascorbic acid is a very unstable vitamin, it easily oxidizes and therefore it is very important in which form is stored in the textile, so that the stable form is released onto the skin [43]. Carriers, such as micro- and nanoparticles, are being intensively researched as vitamin C delivery systems to enhance its beneficial effects in skin healing. One published study examined the possibility of producing polyamide microcapsules containing vitamin C for cosmetic applications [44]. The experiment was designed so that the yield of microcapsules of about 80% was achieved by interface polymerization and the size of microcapsules ranges from 13-36 μm [44]. Cheng et al. prepared gelatin microcapsules with vitamin C, using the emulsion solidification technique, and successfully incorporated them into cotton fabric for the development of cosmetic textiles [45]. The action of a small amount of water or sweat causes the capsule shell to burst and vitamin C to be released, which is directly absorbed by the skin [45].

Gallic acid has recently been recommended as an active component for the production of cosmetic textiles [46]. Alonso et al. have finished polyamid knitted fabric and tested the antioxidant effect of cosmetic textiles on the skin by gallic acid in the form of microspheres prepared from e-poly-ε-caprolactone [47]. The test is based on determining the degree of inhibition of lipid peroxidation in the stratum corneum after the application of gallic acid. When gallic acid in the form of a microsphere is applied to the skin via cosmetic textiles, the degree of inhibition of lipid peroxidation in the stratum corneum was 11%, which led the authors to conclude that the inclusion of antioxidants in cosmetic textiles improves the skin's photoprotection ability [47]. Vitamin E, C and gallic acid could be included in cosmetic related functional “add-ons” for high performance textile.

A recently published paper investigated the possibility of using aromatic oils of lemongrass and citronella oil for aromatherapy and the durability of the aroma of treated fabrics [48]. Fabric samples were kept in an alcoholic solution of oil of a certain concentration for 24 h, squeezed and air-dried. Based on the change in the mass of the samples, it was determined that wool absorbed the most oil and cotton fabric the least. The aroma durability was assessed during 30 days and 6 washes. Samples of woolen fabric had the highest aroma intensity after the last evaluation, and samples of cotton fabric had the lowest, and it can be said that woolen and silk fabrics are more suitable for final aromatherapy finishing compared to cotton fabrics [48].

Finishing of textiles with cosmetic products

Depending on the type of cosmetic product, the desired effect and the method of transfer to the skin, there are different ways of final finishing and binding the cosmetic agent to textiles.

Synthetic and inorganic substances, such as copper oxide, may be attached to the textile material by impregnation from a solution, as well as adding to the molten mass of the synthetic polymer. Impregnated cotton and synthetic fabrics with copper oxide show powerful biological effects and can be used for the production of socks to prevent fungal infection *Tinea pedis* - athlete’s foot [49]. Copper is an essential element in traces that is involved in many physiological and metabolic processes of humans, including the creation and rehabilitation of skin wounds [50]. The adults need 0.9 mg of copper daily [51]. Borkow and Gabbay have examined the bactericidal and antifungal operations of fabrics comprising fibers impregnated with copper [52]. The number of bacteria (*E. coli* and *S. aureus*) was decreased by more than 100 times within 2 h after being exposed to cotton fabrics containing copper, and after 60 minutes there was a complete inhibition of the fungus (C. albicans). The cotton socks produced from a material comprising 10% of cotton fibers, impregnated with copper within 2-6 days, remove all the symptoms of athlete's foot [52]. Copper plays a key role in several processes of formation and regeneration of the skin, which was the reason behind the testing of the textiles with the content of copper oxide on the possibility of reducing the depth of wrinkles on skin face [53, 54]. A study on volunteers aged 40-60 was conducted using pillowcases made of PES/cotton mixture with 0.4% copper oxide for 4 weeks [53]. The dermatologists’ assessment has established that sleeping on the pillowcase with copper oxide after 2 and 4 weeks led to a significant reduction in wrinkles and the improvement of facial skin [53]. In another study, polyester pillowcases with 1% copper oxide were used [54]. Changes on the facial skin were analyzed by means of software for a 3D image analysis after 4 and 8 weeks. Sleeping on pillowcases for 1 month resulted in a reduction of the depth of facial wrinkles for about 9%, which
was explained by the possibility of absorption of copper ions by the skin, due to the effects of moisture located between the face and the pillowcase. The use of pillowcases containing copper oxide did not cause any side effects such as skin irritation, itching or inflammation [54].

Hostinek et al. have studied the penetration of copper in the stratum corneum of human skin in vivo for 72 h [59]. The obtained results showed that copper penetrates during 72 h through the stratum corneum and reaches the granulosa layer (stratum granulosum). The amount of copper in the stratum corneum after 72 h was about 2.5 times higher than the initial value [55].

In the last 25 years, the application of microcapsules in the textile industry has been investigated intensively. The technology of microencapsulation was used by NASA in the early 1980s with the aim of controlling the thermal properties of clothing in the manufacture of space suits, using materials with phase change of state [56]. After that, the use of this technology has spread to more areas of textile refining: dyeing and printing, finishing against flammability, antimicrobial finishing, in the technology of color change (chromism), softening and finishing with fragrance products [57]. The most difficult task in the preparation of aromatherapy textiles is how to prolong the life of the fragrance, because the gradual release of small amounts of a cosmetic product is more efficient than one application of a cosmetic product in a large amount. The requirements for cosmetics on textiles are multiple, and they are reflected in the contribution to the feeling of comfort, transfer to the skin during the wearing of textiles, minimal damage during processing, durability during washing and stability during storage. The biggest technical challenge is the fastness to washing and the property of controlled release [58]. Microencapsulation could be an effective technique for solving this problem. Microcapsules are small particles of a size between 1 and 1000 μm which contain the active agent surrounded by a natural or synthetic polymeric membrane (a cover, shell and wall). Microcapsules consist of two parts, the core and the shell. The core (the inner part) has an active agent (a substance in the solid or liquid state), while the shell (the outer part-natural, semi-synthetic or a synthetic polymer) protects the core from the external environment. Encapsulation systems can be classified according to the five main types of morphology shown in Figure 5 [59].

The goal of encapsulation is to store the core material in a protective shell that will give unique properties in terms of controlled release, solubility or resistance of microcapsules to moisture, pH and oxidation. The main reasons for encapsulation are the following: separation of incompatible components; conversion of liquid into solids; increased stability (protection of closed materials from oxidation or deactivation due to reaction with the environment); concealment of odors, tastes and activities of encapsulated materials; protection of the immediate environment; controlled release of active compounds (slow or sustained release); targeted release of the encapsulated materials [60].

The choice of microencapsulation procedure for value-added textile applications depends on the desired characteristics and the use of the product. For example, the size and shape of the microcapsule, the coating material, the active substance, the release mechanism, the method of application and the compatibility with the other components must be adapted to the requirements of the textile processing conditions and the purpose of the product. There are three types of technology that can encapsulate the active substance in the capsules of micro and nano-size, which are shown in Figure 6 [61].

![Figure 6. Classification of the most important encapsulation techniques (drawn on the basis of data from ref. 61)](image-url)

Most frequently, microcapsules for use in the textile industry are prepared by the following techniques:
- **Interfacial polymerization:** In this technique, the capsule shell is formed by polymerization of two monomers in contact with two liquids that do not mix in the oil/water emulsion. The organic phase contains one monomer, which initiates the polymerization of the second monomer, whereby the amine is added to the continuous aqueous phase. A rapid polymerization reaction occurs at the phase border when the capsule shell is formed [61].
- **In situ polymerization** is one of the chemical processes of microencapsulation where the coating is formed by polymerization of monomers that are added together to a continuous aqueous phase. Polymerization occurs exclusively in the continuous phase and with polymer growth, it is deposited on the surface of the spread core which should be encapsulated. The results are smooth spherical microcapsules with a pressure sensitive cover [62].
- Coacervation processes (e.g. gelatin-gum Arabic microcapsule shell) occur in colloidal systems, where coacervate-rich macromolecular droplets surround the
scattered microcapsule nuclei and form a viscous microcapsule shell, which is fixed by crosslinking agents [62].

- Drying with dispersing serves as a microencapsulation technique when the active material is soluble or suspended in the melt or the polymer solution and it remains trapped in the dried particle. In this process, the dried solid is formed by spraying an aqueous solution of the core material and the film-forming material as fine droplets in warm air. The water then evaporates and the dried solid is usually separated by air separation. This method is used to encapsulate labile materials due to the short contact time in the dryer [63].

During the final finishing of textiles with microcapsules, the color and tactile properties of the textile product must not be changed. Solution formulation for processing contains agents for crosslinking, which to a large extent determine the quality and durability of the microencapsulated ingredient in the wash. Typical binders for this purpose include: water-soluble polymers (polyvinyl alcohol, carboxymethyl cellulose, modified starches and alginates); synthetic latexes (polyacrylate latexes, styrene-butadiene, polyvinyl acetate and ethylene-vinyl acetate copolymers); synthetic resins (urea - and melamine - formaldehyde resins, dimethylol dihydroxy dimethylol ethylene urea, dimethylol propylene urea, polyurethane and epoxy resins and vinyl acetate resins) and silicones. Various techniques and devices of discontinuous and continuous actions can be used for final finishing of textile materials with microcapsules. By the method of exhaustion, microcapsules are applied in an autoclave or jigger. The continuous process (Figure 7) includes impregnation with a solution of microcapsules and binders, drying and condensation at 150-160 °C [62].

The mechanisms of releasing the contents of the microcapsule core vary depending on the choice of wall material and, more importantly, its specific end use. Table 4 shows the relationship between the end use of functional textiles and the core release mechanism [64]. The content in the core can be released by a friction, pressure, changing the temperature, by diffusion through the polymeric wall, the dissolution of the polymer wall, by the enzyme action and the biodegradation [65].

Table 4. Textile use and release mechanisms (drawn on the basis of data from ref. 64)

<table>
<thead>
<tr>
<th>End uses</th>
<th>Release mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmetics textiles (on contact with skin)</td>
<td>friction, pressure, biodegradation</td>
</tr>
<tr>
<td>Aromatherapy &amp; Fragrance textiles</td>
<td>friction, diffusion through polymer wall</td>
</tr>
<tr>
<td>Phase change material (thermoregulation)</td>
<td>temperature</td>
</tr>
<tr>
<td>Thermochromic &amp; Photochromic</td>
<td>temperature, ultra-violet light</td>
</tr>
<tr>
<td>Flame retardant textiles</td>
<td>flame, high temperature</td>
</tr>
</tbody>
</table>

Cyclodextrins are cyclic oligosaccharides that are formed by enzymatic degradation of starch and, more recently, they have been studied as a mean for production of a functional textile. The ability of cyclodextrins to form inclusion complexes can be used to store molecules in their hydrophobic cavities according to a host-guest mechanism. Pre-treatment of cellulose material in NaOH solution and of microwave radiation causes better binding of β-cyclodextrin and fastness to washing [66]. For the preparation of the new functionality of textiles with the use of cyclodextrin as a basis for binding of the aromatic agent, mechanisms of complexing and encapsulation are usually used. Depending on the number of glucopyranose units, interconnected by α-(1,4)-glycosidic bonds, there are α, β and γ cyclodextrins, which have 6, 7 and 8 units, respectively (Figure 8) [67]. The greatest application in the textile finishing industry has β-cyclodextrin, because of the simple production, safety for the human body, biodegradability and easy binding to the textile surface.

The inner diameter of β-cyclodextrin is in range from 600 to 680 pm which is sufficient to store aromatic compounds such as volatile fragrance and drugs. The new concept of modifying textile surfaces is based on the installation of compounds, such as β-cyclodextrin, which cannot form a direct covalent bond with the textile fiber because of the structure. The derivatives of cyclodextrin with a long alkyl chains establish Van der Waals interaction with the hydrophobic groups on the surface of the polymer (Figure 9a), while the cyclodextrin derivatives with a reactive group, e.g. monochlorotriazine, are covalently fixed to hydroxyl groups of cellulose fibers (Figure 9b) [68].
Installation of β-cyclodextrin in the textile can be accomplished in several ways, namely by spraying, impregnation, surface coating, ink-jet printing, and by grafting and the sol-gel technique [69]. Polycarboxylic acids (1,2,3,4-butane tetracarboxylic acid (BTCA), citric acid and polyacrylic acid) can be used as binding agents for grafting of cyclodextrin on natural fibers. The conditions of grafting of cyclodextrin on cotton and wool have been tested by the method of pad-dry-cure, depending on the concentration of dextrin (0-150 g/dm$^3$), polycarboxylic acids (0-100 g/dm$^3$) and the phosphorus catalysts (0-60 g/dm$^3$), as well as the time and temperature of condensation [70, 71]. Due to the presence of hydroxyl groups in the polymer structure of these fibers, an esterification reaction is possible between the carboxyl groups of the crosslinking agents and the hydroxyl group of the fibers. Also, the hydroxyl groups of cyclodextrin react with polycarboxylic acids by an esterification reaction, in which case the polycarboxylic acids act as binding compounds in the bonding of the fibers and cyclodextrin, as shown in Figure 10 [72].

Aromatherapy cotton textile was developed by forming inclusion compounds between β-cyclodextrin and microcapsules of various aromatic oils which have a sedative effect [74]. Different rates of fragrance release of different perfume microcapsules were related to the nature of the fragrant oils themselves. Microencapsulation can effectively control the rate of release of fragrant oil, if necessary, ensuring the presence of tested fragrances for over 30 days. Fabrics of cotton, and mixtures of cotton/PES were modified by sol-gel technique, and finished by β-cyclodextrin [75]. On the finished fabrics, the essential oils of eucalyptus, lavender and lemon were applied, in the form of spray and inclusion complex with β-cyclodextrin was produced. After 6 washes for 6 weeks, it was found that all samples had a certain intensity of odor. Fabric from the mixture has a higher intensity of odor compared to the cotton fabric as a result of higher volumes of a bound β-cyclodextrin containing the larger amount of oil in hydrophobic cavities [75]. In a recent publication, microcapsules, whose layer was obtained by polycondensation of β-cyclodextrin and 4,4'-methylenbis(phenyl isocyanate), were synthetized [76]. The nucleus of the microcapsule was filled with the perfume of nerolin (2-ethoxynaphthalene). The polyamide knitted fabric was impregnated with a suspension of microcapsules in the presence of a crosslinking agent. After drying at 100 °C, the microcapsules were fixed at 120 °C for 5 minutes. Examination of washing resistance of the impregnated fabric showed that the deposited microcapsules were effective even after 35 washes, because the loss of nerolin after 5 washing cycles was 20%, and after 30 washes was 68% [76].
age and control of the release of bioactive compounds, using the techniques of microencapsulation and surface coating in order to expand the scope of application of the cosmetic textiles. Microencapsulation technology offers many possibilities for improving the properties of textiles or it improves them by features of added value. Many companies in the field of textile chemistry have conducted research in this area and developed various microencapsulation treatments aimed at improving skin care [64, 77, 78].

Cognis, a textile chemical company based in Germany, has developed Skintex® technology that uses microencapsulation as a method to incorporate active ingredients into cosmetic textiles. The active ingredients are encapsulated inside the microcapsules and firmly bound to the fibers inside the fabric without affecting the touch and visual appearance of the textile. Chitosan is encapsulated to prevent heating, drying and cold and helps protect the skin from dehydration and maintains its flexibility and velvety soft touch. Useful ingredients are released either due to friction during wearing clothes or the chitosan layer is slowly reduced over time by the action of the carrier enzyme [78].

Clinically proven and patented fabric design from the Italian company Solidea has provided an assortment of shorts and socks on the market for reducing cellulite using micro-massage of body parts. The manufacturer claims that Micro Massage Magic clothing helps to smooth and reshape the buttocks and legs, improving the health and appearance of the legs and thighs. This patented design by Solidea combines compression with massage through daily movement [77].

The UK-based chemical company Specialty Textile Product also uses microencapsulation technology to develop its bioactive products called Bio Cap. The active ingredients are those that are widely used in the cosmetics industry, including vitamins A, D, E and aloe vera, which provide various benefits for skin care and promote a sense of well-being [64].

The company Woolmark Development International Ltd has developed a new microcapsulation treatment for textile products called sensory perception technology (SPT). It is a system for delivering the active ingredients of the fragrance capsule core that are encapsulated and then released when there is direct contact with the skin. Microcapsules provide various skin benefits, such as moisturizing the skin, repelling insects, antibacterial and antifungal abilities, and reducing cellulite [64].

Lytess, a French company, is offering its customers not only a particular kind of collant that can drain and slim legs, but also many other textile products (e.g. jeans, pants and t-shirts) that are able to release other cosmetic substances. To produce and sell cosmetic textile products, Lytess combines its competencies with Sederma, a French company which produces active compounds for the cosmetic industry and has encapsulation technology skills for microcapsule fabrication [78]. Clariant (a global specialist in chemicals for the textile industry) and Lipotec (a creator of cosmetic ingredients) developed a new technology called Quiospheres® based on microcapsules which react with natural skin enzymes to release and deliver their cosmetics ingredients, and a homogeneous, durable application of these capsules to knitted, woven, and non-woven textiles. Quiospheres® technology can be applied to any textile fabric, such as cotton and nylon. Quiospheres® microcapsules are protected and are unaffected by the impact of handling, mechanical stress and high temperature throughout the textile production process. Garments can be made up, pressed, ironed and steamed at warm temperatures up to 120 °C (for 1 minute). Quiospheres® microcapsules are based on high technology actives or peptides and actually work with the layers of the skin. They are designed to work continuously over an extended period of time through gradual release [79]. Several selected types of cosmetic textile materials with a brief characterization are shown in Table 5 [80].

<table>
<thead>
<tr>
<th>Brand name and Manufacturer</th>
<th>Cosmetic ingredients</th>
<th>Product Form</th>
<th>Cosmetic Efficacy</th>
</tr>
</thead>
</table>
| Amino Veil, Ajinomoto with Muzo Corp, Japan | Arginine amino acid | Tennis and golf clothes | - Skin hydration  
- Maintain skin pH level  
- Skin rejuvenation  
- Skin hydration and cooling  
- Skin energizing and relaxing  
- Anti-heavy legs  
- Mosquito repellent properties  
- Skin moisturizing  
- Body cooling effect  
- Body thermal-regulating treatment |
| Skintex, Cognis Oleochemicals Corp, Germany | Essential oils from fruits and leaves | Clothes, innerwear | |
| Bio cap, CPC International Inc, UK | Vitamin A, D, E and aloe vera | Bedding, underwear, T-shirts, stockings and socks | |
| MenY5 Hyalurenan, Nyxstar, Spain Solavel™ ST-100, Croda, UK | Hyaluronic acid | Innerwear | - Promote skin elasticity, softness and firmness  
- UV protection  
- Skin anti-aging |
| SkinUp, SkinUp Lab, France | Phyto-marine actives and sallow grass seed oil | UV suit | |
| Lytess, Lytess, France | Caffeine and Shea butter | Clothing, slippers, underwear | |
| Matricole, Billerbeck, Germany | Collagen peptides | Leggings | - Anti-cellulite  
- Skin anti-aging  
- Skin hydration  
- Skin rejuvenation |
| Hydrofina Blue Dressing, US | Methylen Blue | Facial mask | |

Table 5. Commercial cosmetic textile products (drawn on the basis of data from ref. 80)
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Conclusion

Cosmetics textile is a new kind of innovative textile products, which provide consumers with additional functionality focused on skin care, protection from UV radiation and perfuming. For this purpose, the range of products, whose cosmetic effect is being tested, is constantly increasing. Essential oils have a noticeable biological activity, because they are mixtures of many organic compounds. The effects of essential oils are numerous and depend on the properties of the dominant ingredient. Certain synthetic and inorganic substances, as well as compounds of animal origin, also show a significant biological effect. The storage of cosmetics in the form of microcapsules, either by complexing with cyclodextrin or incorporation into the melt of the synthesized polymer, provides stability in relation to possible reactions with the environment and enables cosmetic effect for a longer period. The future development of cosmetic textiles requires a continuous effort of pharmacists and textile technologists to optimize products.

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Izvodi

**BIOFUNKCIONALNI TEKSTILNI MATERIJALI: Kozmetički tekstil**

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**Ključne reči:** tekstilni materijali, esencijska ulja, aromaterapija, mikroinkapsulacija, ciklodekstrin

Najnoviji trend u tekstilnoj industriji promoviše proizvode sa dodatnom vrednošću koji obezbeđuju dodatni komfor korisniku i imaju akcenat na očuvanje zdravlja u uslovima korišćenja. U tom smislu ističu se biofunkcionalni i inteligentni tekstilni proizvodi sa različitim vrstama aplikacija za unapređenje stila života savremenog potrošača. Kozmetički tekstil je tekstil visokih performansi koji predstavlja fuziju tekstilnog materijala sa kozmetičkim sredstvima. Glavni izazovi pri izradi ovakvih proizvoda su odabir sredstva sa kozmetičkim učinkom za određenu namenu, uskladištenje sredstva u strukturu tekstila, brzina otpuštanja sredstva na kožu i postojanost sredstva na postupke održavanja tekstila i odeće. U ovom radu je dat pregled kozmetičkih sredstava za aplikacije na tekstilu, načini njihovog uskladištenja i otpuštanja i tehnike nanosnja na tekstil. Na kraju je prikazan asortiman komercijalno dostupnih kozmetičkih tekstilnih proizvoda.