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Sustainability in Textile Industry Using Cyclodextrins to Improve the Properties of Textiles

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Abstract

Cyclodextrins are cyclic oligosaccharides with a truncated cone structure, a hydrophilic surface with hydroxyl groups, and a hydrophobic cavity that can combine with different substances to form reversible inclusion complexes. This study provides an overview of the general characteristics of β-cyclodextrin and its uses in the textile sector. Because β-cyclodextrin has so many uses, it is extremely important to the textile industry. The method of β-cyclodextrin attachment to the textile surface is one of the important elements.

In this research, many applications of cyclodextrin in the field of dyeing or printing simultaneous with finishing using different materials are reviewed. Cyclodextrins are used to give textiles properties including UV protection, slow release of fragrances, insecticide delivery, and antibacterial properties.

Keywords: cyclodextrin, host-guest complex, UV protection, dyeing, printing, finishing.

Introduction

Researchers have been quite interested in cyclodextrin ever since it first mentioned.[1] demonstrating the range of its use and the interest in research. Cyclodextrins have long been used in manufacturing textiles. Still, there is potential for creating novel goods based on cyclodextrins that have superior qualities.[2]Cyclodextrins (CDs) are important compounds that are utilized in a variety of sectors and applications, including textiles, filtration, pesticide formulations, medicine, and cosmetics.[3]

Cyclic oligosaccharides, or CDs, are created when the starch in foods like rice, potatoes, and corn is broken down by enzymes.[4] It is clean, biodegradable, environmentally sustainable, and consistent with biochemistry. [5] Figure 1 illustrates the three forms of α-cyclodextrin, β-cyclodextrin, and γ-cyclodextrin, which are made up of 6, 7, and 8 α-1,4-glycosidic linkages.[6] Nevertheless, β-CD is the most commonly used in cellulosic fabric alterations because of its affordability, ease of production, ease of attachment to textile surfaces, and large cavity size that allows it to accommodate a variety of guest molecules. [4, 6] The chemical composition of CDs includes a number of glucose units joined by α-1,4-glycosidic linkages to form a truncated cone. The unique arrangement of the hydroxyl groups on the outside of the cone provides a hydrophilic surface, while the interior provides a hydrophobic surface.[7]

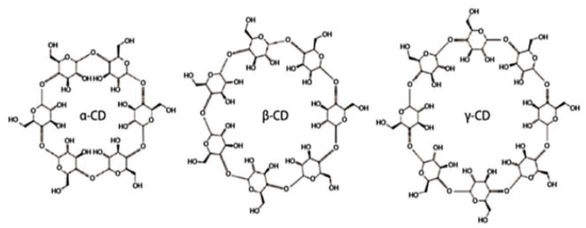

Fig 1: Chemical structure of Cyclodextrins

In textile chemical processing, B-cyclodextrin is commonly used for pre-treatment, dyeing, printing, and finishing procedures.[5] the removal of waxes and fats from the cotton fiber's cuticle layer can occur when b-cyclodextrin is added to the cuticle of cotton fibers containing hydrophobic waxes.[8] Polymers with a β-CD base are highly good at removing reactive and dispersing dyes from aqueous solutions. The adsorption capacity of composites will be improved by the addition of β-CD. [9]

B-cyclodextrin dyeing was carried out at a low temperature, resulting in better color intensity and about a 70% increase in dye diffusion into the polyester fiber.[10]

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Cyclodextrins are utilized to give textiles properties including UV protection, slow release of fragrances, insecticide delivery, and antibacterial properties.[11]

Properties of Cyclodextrins

The ability to form solid integration complexes with a broad range of solid, liquid, and gaseous chemicals by molecular complexity is one of cyclodextrin's most notable features. The process of developing CD inclusion compounds is a complex process that involves multiple components. Between the sizes of the host and guest molecules, complex creation fits. Molecular aggregates known as host-guest complexes are sustained through noncovalent bonding, such as hydrogen bonding, van der Waals, or hydrophobic contact, but never by fully covalent connections. One feature that sets host molecules apart is an interior cavity that allows the integration of a guest molecule. As a result, hosts function as metabolites, cofactors, and substrates for guests and receptors.[12]

Advantages of cyclodextrin

- improvement of very insoluble guests' solubility.
- protection of labile guests from heat, visible or UV radiation, and oxidation's destructive effects.
- control of sublimation and instability.
- physical isolation of substances that are incompatible.
- chromatographic separations.
- altering taste by disguising flavors and offensive odors.
- the controlled release of flavors and medicines.
- eliminating dyes and auxiliaries from dyeing wastewater.
- retarding the process of finishing and dying.
- protecting colors against unwanted adsorption and aggregation.[3]

Host-Guest Complex Formation

The ability of CDs to host different solid, liquid, and gaseous organic or inorganic compounds and form solid inclusion complexes (also known as "host-guest" complexes) with them is by far their most significant and practical feature. allowing for the subsequent controlled release of these active compounds. A necessary condition for the guest molecule to form a compound with the CD (host molecule) is that it must be suitable—either entirely or partially—within the cavity. Since no covalent bonds are created, the hydrophobic forces are the main force behind this phenomenon. Nonetheless, additional factors including dipole-dipole interactions and van der Waals might also play a role in the guest's binding. Typically, a single guest molecule complexes with a single CD molecule, with the exception of certain low molecular weight compounds, in which case the cavity may contain many guest molecules.

For the potential creation of a complex, selecting the right CD is so crucial. Because the guest molecule's volume and the CD cavity's size are compatible, it is simpler for tiny molecules to form stable complexes with α-CD and β-CD. In the case of γ-CD, the significantly greater cavity size makes the fit unfavorable if the guest molecule is too small. In general, inclusion complexes with ratios of 1:1, 1:2, 2:1, and 2:2 can form, depending on the size of the guest molecules and environmental factors. An equilibrium results from the interactions between the guest and host molecules.[7, 13]

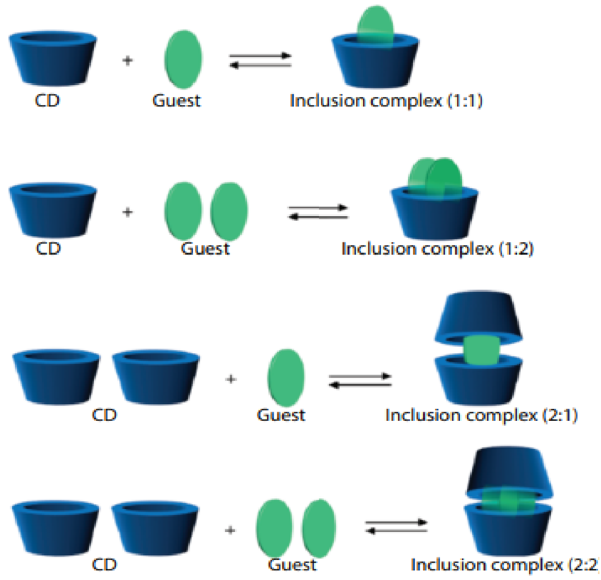

Fig 2: the different types of inclusion complexes [14]

For the preparation of CD-guest inclusion complexes, various techniques can be used. The kind of CD and the composition of the guest molecules determine which complex preparation is optimum. The most crucial techniques for creating cyclodextrin inclusion complexes are, in short, kneading (for guests that are poorly water soluble), co-precipitation (for guests that are not water soluble), heating in a sealed container (for volatiles that are thermostable), freeze-drying (for guests that are thermolabile or water soluble), and spray drying (for molecules that are thermostable). [15]

Methods for Attachment of β-CD on Textiles:

Since hydroxyl groups are the only functional groups found in cyclodextrins, there isn't a strong chemical connection between CDs and textile fibers in their original state. A number of techniques, such as using crosslinking agents, chemical modification of CDs, modification of the textile substrate, etc., have been proposed for the permanent fixing of CDs on textile fibers. The optimal technique for attaching CDs to a textile substrate is determined by a number of variables, including the final purpose and fiber type.[16]

For the permanent fixing of CDs on various textile fibers, crosslinking agents such as citric acid (CA), dimethylol dihydroxy ethylene urea (DMDHEU), and 1,2,3,4-butane tetra carboxylic acid (BTCA) can be utilized. The effects of β-CD crosslinking on spacer polyester fabric utilizing DMDHEU, CA, and BTCA were compared. After ten washing cycles, it was discovered that BTCA was the most effective crosslinking agent in terms of the CD's durability of polyester fibers.[17]

CD molecules can covalently attach to wool and cotton fibers with the use of crosslinking agents such as CA and BTCA. These fibers' polymeric structures contain hydroxyl groups, which allow for the possibility of an esterification reaction between the hydroxyl groups of the fiber and the carboxyl groups of the cross-linkers. Cyclodextrin's hydroxyl groups have the ability to bond the CD to the fiber and take part in the esterification step. [18, 19]

There are two steps in the esterification reaction between BTCA (or other polycarboxylic acids) and cotton cellulose or cyclodextrin. A cyclic anhydride forms in the first stage between two nearby carboxylic acid groups. The second stage includes the formation of ester bonds by an esterification reaction between the hydroxyl groups of cyclodextrin and cellulose macromolecules and the previously formed acid anhydrides.

The crosslinking of cyclodextrins to polyester, polyamide, and polypropylene can also be accomplished with polycarboxylic acids.[7] For instance, grafted β-CD on knitted PP fabric using citric acid, and enhanced the cloth's dyeability with reactive, acid, and dispersion dyes.[20]

Application of Cyclodextrins in the Textile Area:

Reliability testing has dispelled reservations regarding the toxicity of CDs and their derivatives, and numerous experiments have been successful in producing them. Since their introduction into textile-related studies in the 1990s, CDs have become increasingly relevant. They highlight the critical role that CDs play in textile processing and innovation, and their use offers immediate opportunities for the development of eco-textiles and other environmentally friendly products. Additionally, CDs have a wide range of potential applications. The textile industry has registered cyclodextrins for use in spinning, pretreatment, dyeing, finishing, and dye removal; among these, dyeing, finishing, and water treatment are the most applicable applications to date.[13]

The textile fibers can absorb more dye molecules by the attachment of β-CD and its derivatives, which can be achieved through hydrogen bonding, inclusion complex, or contact with the side groups of the crosslinking agent (e.g., the free carboxylic acid groups of BTCA).Numerous experiments have been conducted to enhance the textile substrates' dyeability and printability using a range of synthetic and natural dyes.[7]

One of the most promising agents in the textile processing industry for high added value textiles is a biocompatible cyclodextrin biopolymer. Cyclodextrins have the ability to create compounds for inclusion by serving as hosts for various small molecules. Cyclodextrin is a promising fabric finishing reagent because of this property. It improves both appearance and functionality. The surface of CD-finished textiles will exhibit UV resistance, anti-bacteria, odor absorption, and fragrance releases. Since CDs and textile fibers cannot create a covalent bond, CDs are grafted to the textile fiber using polycarbonate acids or other binding agents. [5]

Using CDs on cotton fabric

Simultaneous Dyeing and Fragrance Finishing:

The pad-dry-cure method has led to the development of a newer technique for simultaneous dyeing and finishing. It involves the use of a limited aqueous solution of reactive dye, citric acid, and suitable fragrance chemical microencapsulated in beta-cyclodextrin solubilized in water along with Citric acid and Sodium hypophosphite as catalyst applied on cotton fabric. Spectrophotometer analysis of combined dyed and finished cotton fabric shows a deeper color yield and good aroma finishing using monochlorotriazine reactive dye along with jasmine oil microencapsulated in beta cyclodextrin in the presence of citric acid and sodium hypophosphite applied on cotton fabric. For comparative purposes, beta cyclodextrin encapsulated aroma finish was also applied after dyeing cotton fabric with the same monochlorotriazine reactive dye. In comparison to the two-stage standard method, simultaneous reactive dyeing and aroma finishing with beta cyclodextrin and citric acid yields cotton fabric with higher color value, appropriate wrinkle resistance, and good tensile strength retention property. The effective formation of ester crosslinks between the carboxyl group of citric acids and the hydroxyl groups of cellulose and beta cyclodextrin is confirmed by FTIR spectra. Additionally, jasmine oil was applied to cotton using the standard pad-dry-cure process without beta cyclodextrin and with beta cyclodextrin using the micro encapsulation technique. When jasmine oil is applied with beta cyclodextrin via microencapsulation, it retains more aroma intensity when dyeing and finishing simultaneously than when using two-stage conventional procedures.[21]

Using (β-CD-MCT) and sandalwood oil derivative for aroma finishing:

A surface modification called β-CD-MCT (β-cyclodextrin modified with monochlorotriazine) formed and applied to cotton textiles. Research has been done on the possibility of entrapping sandalwood oil as an aroma-finishing agent. Tensile testing and the FTIR were employed to look into the treatment's effects. It was discovered that β-CD-MCT may be fastened to cotton fabrics at high temperatures (150◦C) using the pad-dry-cure process. There was a noticeable improvement in the treated materials' tensile strength. When untreated cotton was kept at room temperature (30◦C) for 8 days, the scent vanished. In cotton garments treated with β-CD-MCT, the smell persisted for 21 days under identical settings.[22]

Multifunctional finishing using β-C GRAFTED Chitosan and lemongrass oil

Textiles with multifunctional finishing contribute desirable biological and functional features that increase the products' value. This study set out to extract the essential oil from lemongrass and apply it as a finishing agent to conventional cotton fabric. Cotton fabric was scented using the pad-dry technique with a finishing composition that included chitosan grafted with βcyclodextrin and lemongrass oil. Through FTIR spectroscopy, the ester bond formation between cellulose and β-cyclodextrin-grafted chitosan was verified. Using UV-visible spectroscopy, the scent release rate was assessed after finishing.

Because cationic chitosan was available and citral was present in lemongrass oil, the resulting fabric had high antibacterial action. The chitosan finished fabric with β-CD grafting showed enhanced tensile strength, increased drape coefficient, and somewhat decreased air permeability, without substantially affecting the fabric's physical characteristics. In conclusion, lemongrass oil could be applied to traditional clothing as a finishing touch to give it a scent. Furthermore, the use of βCD-grafted chitosan in clothing and textile finishing for home furnishings opens up new possibilities for distinctive textile goods. [23]

Antimicrobial finishing with β-C and butane tetracarboxylic acid

Using butane tetracarboxylic acid crosslinking in the presence of sodium hypophosphite monohydrate as a catalyst, cyclodextrin was grafted onto cotton fabric. Octenidine dihydrochloride, an antibacterial, was loaded into this completed cotton fabric. The Diffusion Disk Method was used to assess the antibacterial activity of cyclodextrin-grafted cotton fabrics against two species of bacteria (Gram positive and Gram negative) and two types of fungus, both before and after loading with octenidine dihydrochloride. To test the antimicrobial finishing's durability against repeated washings, the antimicrobial cotton fabric was put through a number of washing cycles. Following each cycle, the antimicrobial activity was determined. According to the measurements, after 20 washing cycles, the resulting cotton fabrics still have an acceptable level of their antibacterial activity. The ability of the cavities found in cyclodextrin moieties to host and progressively release the antimicrobial agent molecules is responsible for this antibacterial activity's persistence.[24]

Using Natural and Sulfated β-C Inclusion Complexes of Silver Nanoparticles in anti-microbial finishing

it was looked into and compared the impacts on cotton fabric of the β-cyclodextrin (β-CD) complex and its derivative, the S-β-CD complex, with silver nanoparticles. Cotton samples were subjected to five different treatments: β-CD + AgNPs; S-β-CD + AgNPs; β-CD + AgNPs + EDTA; and S-β-CD + AgNPs + EDTA. The results of the antibacterial test indicated that S-β-CD + AgNPs + EDTA was the most successful therapy. It was also stable for 10 washing cycles, showing 79% efficacy against S. aureus bacteria and 77% efficacy against E. coli bacteria.

The outcomes of the physical tests demonstrated that the treatments increased the samples' weight, stiffness, tensile strength, and yellowness values. Relatively speaking, samples treated with S-β-CD showed larger alterations in physical test results than the other samples. The distinction between the chemical structures of the β-CD and S-β-CD was confirmed by FTIR analysis. The sample treated with S-β-CD + AgNPs + EDTA had the largest amount of silver nanoparticles, according to EDX analysis. The most advantageous approach for biological applications was thus determined to be treating the S-β-CD complex with AgNPs and crosslinking this complex to a cotton sample using EDTA.[25]

Using CDs on wool:

using plasma treatment and grafting of β-cyclodextrin on color properties

Using natural dye derived from shrimp shell, the effects of low temperature plasma (LTP) treatment and beta-cyclodextrin (β-CD) grafting on the dyeing and fastness qualities of wool fabrics were assessed. Following the pre-mordanting procedure, samples were dyed using aluminum sulfate, iron sulfate, tin chloride, copper sulfate, and sodium dichromate as mordants. The morphological and chemical alterations of the fibers were investigated using Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM). Additionally, using the AATCC 100-1993 test method, the antibacterial capabilities of fabrics were quantitatively assessed against S. aureus.

Results have shown that after dyeing substances, a green hue may be achieved by utilizing sodium dichromate as a mordant. Increasing the concentration of β-CD and sodium dichromate throughout the post-treatment process resulted in an improvement in the color strength and difference between the samples. The antimicrobial results of the samples showed that the colored and β-CD-grafted sample had a considerable reduction in the number of germs, but the LTP-treated fabric showed no antibacterial action. In addition, the samples treated with β-CD exhibited very good to excellent light and washing fastness characteristics.[26]

monochloro-triazine -cyclodextrin for enhancing printability and functionality

The structure of the wool fabric was successfully altered by using monochloro-triazine-cyclodextrin (MCT-CD). The enhanced post-printing capabilities of the modified wool, together with its exceptional antibacterial properties, were likely attributed to the grafted CD moieties' exceptional ability to form guest-host inclusion complexes and the beneficial influence of the wool's active sites. It was looked into whether Ag-NP's colloid or triclosan derivatives may be used as an after-treatment after the pre-modification and post-printing steps. The degree of pre-modification, the kind of dye and degree of fixing, the type of antibacterial agent, its method of interaction, and the amount of loading onto the modified printed wool determine the level of improved qualities. More than 75% of the antibacterial properties that were imparted remained intact even after 15 washing cycles.[27]

Using CDs on polyester

improving inkjet printing performance

B-cyclodextrin and citric acid were used to modify the surface of polyester fabrics in order to increase their sharpness and color yield while employing water-based pigment inkjet printing. The fabrics were treated with a 100g/L solution of b-cyclodextrin and 100g/L of citric acid. When comparing the modified polyester fabric to the control, the printed patterns' line width and image area—which are used to assess printing performances—were smaller. The K/S value indicated a 47% improvement in color yield. (SEM) verified that following surface alteration, there was an increase in surface roughness. The printed patterns' microscope photos amply demonstrated the increased color yield and clarity. Therefore, the alteration of b-cyclodextrin provided a possible method for polyester pretreatment for pigment inkjet printing.[28]

Using B-CD and chitosan in Hydrophilic Finishing for Wash Resistance Improvement

Sodium periodate oxidized β-CD to produce oligosaccharides with more than two aldehyde groups. Initially, O-β-CD, which is a hydrophilic finishing agent and cross-linker, was employed in conjunction with CTS to finish PET fabrics by the immersion-padding technique. Following finishing, a cross-linking network between the amino groups in CTS and the aldehyde groups in O-β-CD developed on the PET fiber surface. As a result, the final PET fabrics showed superior wash resistance in addition to increased hydrophilicity.

Additionally, the methods used to treat PET fabrics hydrophilically with CTS/O-β-CD and oxidize β-CD periodate were environmentally friendly. PET fabrics could be hydrophilic finished without the need for pretreatment or chemical cross-linking agent. The by-product of the oxidation reaction, sodium iodate, was obtained by precipitating it with calcium chloride. Through laundry cycle tests, the wash resistance of the CTS/O-β-CD finished PET fabrics—which had a relatively high moisture recapture and reduced water drop wetting time—was examined. Following 25 washing cycles, it was demonstrated that the PET fabric treated with CTS and O-β-CD had enhanced hydrophilicity and hydrophilic durability.[29]

Using CDs on blended fabrics

dyeing of polyester/cotton blended fabric with cationic dyes via b-CD

Based on b-CD modification, polyester/cotton fabric one-bath one-step dyeing was achieved by using cationic dyes to color polyester fabric at low temperatures. By using CA to crosslink the polyester fabric, b-CD was deposited on it. Following b-CD/CA modification, the modified polyester fabric's hydrophilicity was considerably enhanced. Because of the development of cationic dye/b-CD inclusion complexes and ionic interaction between COO free end groups (CA) and cationic dyes, the modified polyester fabrics effectively dyed with cationic dyes at 70C, demonstrating a better level of dyeing performance than the unmodified polyester fabrics. Among the several crosslinking agents, the polyester fabric treated with b-CD/CA exhibited the strongest color retention and the best level of dyeing quality.

The b-CD modified polyester/cotton fabric demonstrated a greater color depth when dyed with cationic dyes, indicating a noticeable improvement in the dyeing capabilities of the modified polyester. When cured at 180°C, the b-CD modified polyester/cotton fabrics' washing, rubbing, sweating, and light fastness scores were all above grade 3-5, indicating that b-CD modification can enable one-bath, one-step dyeing of polyester/cotton fabrics.[30]

improving disperse dyeing and UV-protection of cotton-blended fabrics using MCT-b-CD

The primary objective was to modify cotton cellulose-containing fabrics to increase the substantivity of disperse dyes by using mono chlorotriazine-b-CD (MCT-b-CD), which has hydrophobic cavities and the extraordinary ability to form inclusion complexes with organic materials through host-guest interactions. Optimum conditions were given for grafting MCT-b-CD onto and/or within cotton and cotton/PET (50/50) blend fabrics, as well as for simultaneous alkaline-disperse dyeing at 100 ˚C for 60 min.

through interaction between the host and guests, increasing the degree of interaction and fixation—deeper shade depth, in other words. Cotton fabrics and cotton/polyester blend fabrics with deep dyes exhibit superior UV protection against damaging UV-B rays. The degree of disperse dyeing and the ensuing improvement in UV-blocking are largely dependent on the type of substrate, the degree of MCT-b-CD grafting, the type of disperse dye, and the conditions of the "all-in" bath.[31]

disperse printing and UV-protecting of wool/polyester blend using b-CD

In order to modify the wool component so that it might form "host-guest" inclusion complexes with disperse dyes during the subsequent disperse printing stage, which would result in union disperse printing, pretreatment of wool/polyester blend fabric with monochlorotriazinyl b-CD was performed. the best treatment sequence and conditions were padding the blend fabric with an aqueous formulation made of citric acid (5 g/L), monochlorotriazinyl b-CD (60 g/L), wet-pickup (70%), thermo-fixing at 120 C/5 min, comprehensive washing, drying, post-printing with disperse dyes, and lastly steaming at 140 C for 30 min. According to experimental results, the structure of the wool component was modified by fixing the used monochlorotriazinyl b-CD onto and/or within it. This increased ability to pick up, adsorb, and retain the guest disperse dye vapors into its grafted hydrophobic cavities led to the achievement of union-disperse printing with deeper shades and remarkable fastness properties. The resulting prints show outstanding UV-protective properties due to inclusions.[32]

Conclusion

Sustainability is becoming a more significant issue in today's globe. the apparel and garment sector is one of the most polluting in the world. The demands of the green climate have surpassed the necessity for sustainable textiles. The apparel and textile industries switch from unsafe to efficient production methods.

In this context, researchers continuously investigate and promote the use of cyclodextrins (CDs) in textile manufacture.

Cyclodextrins have the ability to create compounds for inclusion by serving as hosts for various small molecules. Cyclodextrin is a promising fabric finishing reagent because of this property. The process improves appearance and performance in areas such as wastewater treatment, flame-retardant finishing, UV protection, and antibacterial qualities.

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Conflict of Interest

There is no conflict of interest in the publication of this article.

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References

1. Szente, L. and Szejtli, J. Highly soluble cyclodextrin derivatives: Chemistry, properties, and trends in development, *Advanced drug delivery reviews*, **36**(1) 17-28 (1999).
2. Singh, M., Sharma, R. and Banerjee, U.C. Biotechnological applications of cyclodextrins, *Biotechnology advances*, **20**(5-6) 341-359 (2002).
3. Voncina, B. and Vivod, V. Cyclodextrins in textile finishing, *Eco-friendly textile dyeing and finishing*, 53-75 (2013).
4. Eid, B.M. and Ibrahim, N.A. Recent developments in sustainable finishing of cellulosic textiles employing biotechnology, *J. Clean. Produc.*, **284** 124701 (2021).
5. El-Sayed, E., A Othman, H. and Hassabo, A.G. Cyclodextrin usage in textile industry, *Journal of Textiles, Coloration and Polymer Science*, **18**(2) 111-119 (2021).
6. Bhaskara-Amrit, U.R., Agrawal, P.B. and Warmoeskerken, M.M.C.G. Applications of b-cyclodextrins in textiles, *AUTEX research journal*, **11**(4) 94-101 (2011).
7. Haji, A. Functional finishing of textiles with β-cyclodextrin, *Frontiers of Textile Materials: Polymers, Nanomaterials, Enzymes, and Advanced Modification Techniques*, 87-116 (2020).
8. Setthayanond, J., Sodsangchan, C., Suwanruji, P., Tooptompong, P. and Avinc, O. Influence of mct-β-cyclodextrin treatment on strength, reactive dyeing and third-hand cigarette smoke odor release properties of cotton fabric, *Cellulose*, **24** 5233-5250 (2017).
9. Yadav, S., Asthana, A., Chakraborty, R., Jain, B., Singh, A.K., Carabineiro, S.A.C. and Susan, M.A.B.H. Cationic dye removal using novel magnetic/activated charcoal/β-cyclodextrin/alginate polymer nanocomposite, *Nanomaterials*, **10**(1) 170 (2020).
10. Bezerra, F.M., Lis, M.J., Firmino, H.B., Dias da Silva, J.G., Curto Valle, R.d.C.S., Borges Valle, J.A., Scacchetti, F.A.P. and Tessaro, A.L. The role of β-cyclodextrin in the textile industry, *Molecules*, **25**(16) 3624 (2020).
11. Cabrales, L., Abidi, N., Hammond, A. and Hamood, A. Cotton fabric functionalization with cyclodextrins, *surfaces*, **6**(8) (2012).

12. Gonzalez Pereira, A., Carpena, M., García Oliveira, P., Mejuto, J.C., Prieto, M.A. and Simal Gandara, J. Main applications of cyclodextrins in the food industry as the compounds of choice to form host–guest complexes, *International Journal of Molecular Sciences*, **22**(3) 1339 (2021).

13. Lis Arias, M.J. Beta-cyclodextrines in textile industry, (2020).

14. Topuz, F. and Uyar, T. Electrospinning of cyclodextrin functional nanofibers for drug delivery applications, *Pharmaceutics*, **11**(1) 6 (2018).

15. Cheirsilp, B. and Rakmai, J. Inclusion complex formation of cyclodextrin with its guest and their applications, *Biol Eng Med*, **2**(1) 1-6 (2016).

16. Agrawal, P.B. and Warmoeskerken, M. Permanent fixation of β- cyclodextrin on cotton surface—an assessment between innovative and established approaches, *Journal of applied polymer science*, **124**(5) 4090-4097 (2012).

17. Montazer, M. and Jolaei, M.M. Β- cyclodextrin stabilized on three- dimensional polyester fabric with different crosslinking agents, *Journal of applied polymer science*, **116**(1) 210-217 (2010).

18. Bezerra, F.M., Carmona, Ó.G., Carmona, C.G., Plath, A.M.S. and Lis, M. Biofunctional wool using β-cyclodextrins as vehiculizer of citronella oil, *Process biochemistry*, **77** 151-158 (2019).

19. Gawish, S.M., Ramadan, A.M., Abo El-Ola, S.M. and Abou El-Kheir, A.A. Citric acid used as a cross-linking agent for grafting β-cyclodextrin onto wool fabric, *Polymer-Plastics Technology and Engineering*, **48**(7) 701-710 (2009).

20. Ghoul, Y.E., Martel, B., Achari, A.E., Campagne, C., Razafimahefa, L. and Vroman, I. Improved dyeability of polypropylene fabrics finished with β-cyclodextrin–citric acid polymer, *Polymer J.*, **42**(10) 804-811 (2010).

21. Samanta, A.K., Hossain, A., Bagchi, A. and Bhattacharya, K. Simultaneous dyeing and fragrance finishing of cotton fabric, *Journal of Materials Sciences and Applications*, **2**(4) 25-34 (2016).

22. Sricharussin, W., Sopajaree, C., Maneerung, T. and Sangsuriya, N. Modification of cotton fabrics with β-cyclodextrin derivative for aroma finishing, *The journal of the Textile Institute*, **100**(8) 682-687 (2009).

23. Singh, N., Ratnapandian, S. and Sheikh, J. Durable multifunctional finishing of cotton using β-cyclodextrin-grafted chitosan and lemongrass (cymbopogon citratus) oil, *Cellulose Chem Technol*, **55** 177-184 (2021).

24. Abdel-Halim, E.S., Al-Deyab, S.S. and Alfaifi, A.Y.A. Cotton fabric finished with β-cyclodextrin: Inclusion ability toward antimicrobial agent, *Carbohydrate polymers*, **102** 550-556 (2014).

25. Cagla, S. and Buket, A. Cotton fabrics finished by natural and sulfated β-cyclodextrin inclusion complexes of silver nanoparticles for biomedical applications, *Textile and Apparel*, **33**(4) 375-387.

26. Molakarimi, M., Khajeh Mehrizi, M. and Haji, A. Effect of plasma treatment and grafting of β-cyclodextrin on color properties of wool fabric dyed with shrimp shell extract, *The Journal of The Textile Institute*, **107**(10) 1314-1321 (2016).

27. Ibrahim, N.A., Abdalla, W.A., El-Zairy, E.M.R. and Khalil, H.M. Utilization of monochloro-triazine β-cyclodextrin for enhancing printability and functionality of wool, *Carbohydrate polymers*, **92**(2) 1520-1529 (2013).

28. Chen, L., Wang, C., Tian, A. and Wu, M. An attempt of improving polyester inkjet printing performance by surface modification using β- cyclodextrin, *Surface and interface analysis*, **44**(10) 1324-1330 (2012).

29. Lou, C., Yin, Y., Tian, X., Deng, H., Wang, Y. and Jiang, X. Hydrophilic finishing of pet fabrics by applying chitosan and the periodate oxidized β-cyclodextrin for wash resistance improvement, *Fibers and Polymers*, **21** 73-81 (2020).

30. Zhang, W., Ji, X., Wang, C. and Yin, Y. One-bath one-step low-temperature dyeing of polyester/cotton blended fabric with cationic dyes via β-cyclodextrin modification, *Textile research journal*, **89**(9) 1699-1711 (2019).

31. Ibrahim, N.A., E-Zairy, W.R. and Eid, B.M. Novel approach for improving disperse dyeing and uv-protective function of cotton-containing fabrics using mct-β-cd, *Carbohydrate Polymers*, **79**(4) 839-846 (2010).

32. Ibrahim, N.A. and El-Zairy, E.M.R. Union disperse printing and uv-protecting of wool/polyester blend using a reactive β-cyclodextrin, *Carbohydrate Polymers*, **76**(2) 244-249 (2009).