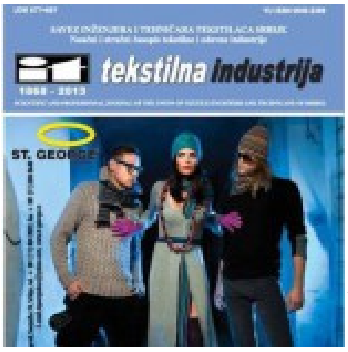

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BIOPOLISHING ENZYMES AND THEIR APPLICATIONS IN TEXTILES: A REVIEW

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Review Article

Abstract: Textile processing is a growing industry that traditionally has used a lot of water, energy and harsh chemicals. Due to the ever-growing costs for water and energy world wide investigations are carried out to substitute conventional chemical textile processes by environment-friendly and economically attractive bioprocesses using enzymes. Conventional chemical processes are generally severe and fibre damage may occur. However, enzymes are characterized by their ability to operate under mild conditions and as a result processes can be carried out without further damaging the fibers. Enzymes are also readily biodegradable and therefore potentially harmless and environmentally friendly. This work represents a review of various properties of enzymes and applications of biopolishing enzymes in textiles. Biopolish treatment is imparted to any fiber or fabric to improve its smoothness and shine on the fabric's surface by removing fiber-yarn ends projecting from it. Biopolishing enzymes used in biopolishing, offers a number of benefits such as improvement in pill resistance (a pill, colloquially known as a bobble, is a small ball of fibres that forms on a piece of cloth), superior colour brightness, softness and cooler feel.

Keywords: biopolishing enzymes, bio-polishing, eco-friendly characteristics, healthy environment, water and energy saving.

BIOPOLIRAČKE ENZIME I NJIHOVA PRIMENA U TEKSTILU: PREGLED

Apstrakt: Tekstilna obrada je rastuća industrija koja tradicionalno koristi dosta vode, energije i jake hemikalije. Zbog stalno rastuħih troškova za vode i energije širum svetu se sprovode istraživanja za zamenu konvencionalne hemijske tekstilne procese sa ekološke i ekonomske atraktivne bioprocese koje koriste enzime. Konvencionalne hemijske procese su generalno ozbiljna i mogu da oštete vlakana. Meђutim, enzime se odlikuju sa njihove sposobnosti da rade pod blagim uslovima i kao rezultat toga procesi mogu da se odvivaju bez dodatnog oštečenja vlakana. Enzimi su takoђe lako biorazgradive i stoga potencijalno bezopasne i ekološke. Ovaj rad predstavlja pregled različitih svojstava enzima i primjena biopoliračke enzime u tekstilu. Biopolirački tretman prenese bilo na vlakana ili tkanina da poboljša svoju glatkoħu i sjaj na površini tkanine sa uklanjanjem vlakana od krajeve prediva stvorene od njega. Biopoliračke enzime korišħene u biopoliranje, nude niz pogodnosti kao što su poboljšanje otpornosti formiranja male lopte od vlakana na tkanine, superiornog sjaja boje, mekoħe i hladniji oseħaju.

Ključne reči: biopoliračke enzime, biopoliranje, ekološke karakteristike, zdrava životna sredina, uštedu vode i energije.

1. INTRODUCTION

Textile processing industry has to face the significant challenges to maintain the eco standards, to save the environment as well as to survive for the fittest. So the application of eco friendly chemicals and auxiliaries will be the proven solution for future. Biotechnology is defined as application of biological organisms, systems and processes to manufacturing and processing industries. This is reflected in ability of enzymes to recognize other biological systems and to catalyse a vast range of specific chemical reactions under moderate and much more economic conditions.

Enzymes are biological catalysts. A catalyst is any substance which makes a chemical reaction go faster, without itself being changed. All enzymes are made of protein and because they are sensitive to heat, pH and heavy metal ions. Unlike ordinary catalysts, they are specific to one chemical reaction. An ordinary catalyst may be used for several different chemical reactions, but an enzyme only works for one specific reaction. Enzymes must have the correct shape to do their job. Enzymes change their shape if the temperature or pH changes, so they have to have the right conditions. In the conventional textile processing, the grey fabric has to undergo a series of chemical treatments before it turns into a finished fabric. The chemicals used for all these steps are quite toxic. The consumption of energy and raw-materials, as well as increased awareness of environmental concerns related to the use and disposal of chemicals into landfills, water or release into the air during chemical processing of textiles are the principal reasons for the application of enzymes in finishing of textile materials [1].

Biopolishing is an important finishing treatment carried out on cellulosic fabrics using acid cellulases to achieve improvement in gloss, luminosity of colours and resistance to pilling, cooler feel and clear surface [2, 3]. Cellulases are inducible enzymes synthesized by a large diversity of microorganisms including both fungi and bacteria during their growth on cellulosic materials [4]. These microorganisms can be aerobic, anaerobic, mesophilic or thermophilic. Among them, the genera of Clostridium, Cellulomonas, Thermomonospora, Trichoderma, and Aspergillus are the most extensively studied cellulase producer [5, 6].

2. LITERATURE REVIEW

2.1 COTTON FIBRE AND HIS STRUCTURE

Cotton, the seed hair of plants of the genus Gossypium, is the purest form of cellulose readily available in nature. It has many desirable fibre properties making it an important fibre for textile applications. Cotton is the most important of the raw materials for the textile industry. The cotton fibre is a single biological cell with a multilayer structure. The layers in the cell structure are, from the outside of the fiber to the inside, cuticle, primary wall, secondary wall, and lumen. These layers are different structurally and chemically [7, 8]. The primary and secondary walls have different degrees of crystallinity, as well as different molecular chain orientations. The cuticle, composed of wax, proteins, and pectins, is 2.5% of the fiber weight and is amorphous. The primary wall is 2.5% of the fiber weight, has a crystallinity index of 30%, and is composed of cellulose. The secondary wall is 91.5% of the fiber weight, has a crystallinity index of 70%, and is composed of cellulose. The lumen is composed of protoplasmic residues [9]. Cotton fibres have a fibrillar structure. The whole cotton fibre contains 88 to 96.5% of cellulose, the rest are noncellulosic polysaccharides constituting up to 10% of the total fibre weight [10]. The layers consist of densely packed elementary fibrils, organized into microfibrils and macrofibrils. They are held together by strong hydrogen bonds. The lumen forms the centre of the fibres. Cotton is composed almost entirely of the polysaccharide cellulose. Cotton cellulose consists of crystalline fibrils varying in complexity and length and connected by less organized amorphous regions with an average ratio of about two-thirds crystalline and one-third non-crystalline material, depending on the method of determination [11]. The chemical composition of cellulose is simple, consisting of anhydroglucose units joined by β-1,4-glucosidic bonds to form linear polymeric chains.

2.2 WOOL FIBRE AND HIS STRUCTURE

Wool, a complex natural fibre composed mainly of proteins (97%) and lipids (1%), is an ideal substrate for several enzyme classes, such as proteases and lipases. Wool fibre consists of two major morphological parts: the cuticle and the cortex. The cuticle is subdivided into two main layers, exocuticle and endocuticle, and has an outermost is membrane called the epicuticle [12]. The cortex comprises spindle-shaped cortex cells that are separated from each other by a cell membrane complex. An important component of the cuticle is 18-methyleicosanoic acid. This fatty acid is bound to a protein matrix, forming a layer, that can be removed by treatment with alcoholic alkaline or chlorine solutions. Crosslinking is a major cuticle characteristic. Thirty-five percent of the exocuticle is made up of cysteine residues, and the cuticle is crosslinked by isodipeptide bonds [12]. The diffusion barrier is mostly due to the hydrophobic character of the exocuticle layer, caused by the large amount of disulphide crosslinks and the bound lipid material. Consequently, fibre pretreatment processes primarily modify the composition and morphology of the wool surface [12].

2.3 CELLULOSE AND CELLULASES

Cellulose is considered as one of the most important sources of carbon on this planet. Agriculture wastes contain a high proportion of cellulosic matter which is easily decomposed by a combination of physical, chemical and biological processes. The major components of these are cellulose and hemicellulose (75-80%) while lignin constitutes only 14%. Biological degradation, for both economic and ecological reasons, has become an increasingly popular alternative for the treatment of agricultural, industrial, organic as well as toxic waste. These wastes have been insufficiently disposed leading to environmental pollution.

Recycling of agricultural residue can be achieved naturally and artificially by microorganisms. Aerobic organisms such as fungi, bacteria, and some anaerobic organisms have been shown to be able to degrade some constituents of these residues.

Cellulases are important enzymes not only for their potent applications in different industries, like industries of food processing, animal feed production, pulp and paper production , and in detergent and textile industry, but also for the significant role in bioconversion of agriculture wastes in to sugar and bioethanol. Cellulases are hydrolytic enzymes that catalyse the breakdown of cellulose to smaller oligosaccharides and finally glucose. Cellulases are enzymes which hydrolyze the β-1,4-glycosidic linkage of cellulose and synthesized by microorganisms during their growth on cellulosic materials [4, 13]. The commercially available cellulases are a mixture of enzymes: endogluconases, exogluconases and cellobiases. The application of cellulases in textile processing started in the late 1980s with denim finishing. Currently, in addition to biostoning, cellulases are also used to process cotton and other cellulose-based fibres. Cellulases are usually classified by the pH range in which they are more effective and, accordingly, acid cellulase, neutral cellulase and alkaline cellulase. Acid cellulases are class of enzymes that act at pH 3.8-5.8 and in the temperature range of 30-60 ^{o}C. Besides these, acid cellulases extract substantial amount of dyestuff from the fabric, particularly indigo dyes (this property is exploited in denim washing) which may in turn deposit on the white portion of the fabric. This phenomenon is known as back staining. Cellulase enzymes which act at pH 6.0-7.0 and in the temperature range of 40-55 ^{o}C are termed as neutral cellulases. They are less reactive and therefore require longer treatment time compared to the former class. Alkali stable cellulase can be incorporated in household detergent formulations for effective stain removal. Cellulases are inducible enzymes which are synthesized by microorganisms during their growth on cellulosic materials [4].

2.4 BIOPOLISHING ENZYMES AND BIOPOLISING

Cellulases were introduced in textile and laundry only a decade ago, they have now become the third largest group of enzymes used in these applications [14]. Microbial cellulases find applications in textile industries as biostoning of jeans, biopolishing of textile fibers, improved fabrics quality, improved absorbance property of fibers, softening of garments, improved stability of cellulosic fabrics, removal of excess dye from fabrics, restoration of colour brightness etc. Bio-stoning and bio-polishing are the best-known current textile applications of cellulases. In Table 1 are given the applications of cellulases in the textile industry.

Denim stonewash enzymes or denim enzymatic treatments has replaced traditionally used pumice stones since it is more environmentally friendly and reduces overall damage to the denim while still producing the “stone washed” which is still very popular today [15, 16]. Traditional stonewashing of jeans involves amylase-mediated removal of starch coating (desizing) and treatment (abrasion) of jeans with pumice stone (1-2 kg/pair of jeans) in large washing machines. Stonewash enzymes degrade the cellulose from the denim and transforms in into sugar. Since the jeans indigo dye is attached to the cellulose, the dye is also removed. It is this random removal of single day molecules that makes the jeans appear as though they have been worn naturally. The advantages in the replacement of pumice stones by a cellulose-based treatment include less damage of fibers, increased productivity of the machines, and less work-intensive and environment benign [6, 17]. Biopolishing (de-pilling enzymes) is a biological process in which the cellulose acts on the surface of the fabric. The enzyme molecule is more than a thousand times larger than a water molecule and is therefore too large to penetrate the interior of a cotton fiber.

Table 1. - Cellulases in textile industry

Enzyme	Function	Application	Reference
Cellulase, preferably neutral and endoglucanase rich	Removal of excess dye from denim fabrics; soften the cotton fabrics without damaging the fibre	Bio-stoning of denim fabrics; production of high quality and environmentally friendly washing powders	Galante et al., 1998 [19]; Godfrey, 1996 [20]; Uhlig, 1998 [17]
Cellulase, preferably acid and endoglucanase rich	Removal of excess microfibrils from the surface of cotton and non-denim fabrics	Bio-polishing of cotton and non-denim fabrics	Galante et al., 1998 [19]; Godfrey, 1996 [20]; Kumar et al.,1994 [21]
Cellulase, preferably endoglucanase rich	Restoration of softness and colour brightness of cotton fabrics	Production of high quality fabrics	Galante et al., 1998 [19]; Godfrey, 1996 [20]; Kumar et al., 1994 [21]

The objective of the process is elimination of micro fibrils of cotton through the action of cellulase enzyme. The acidic cellulases, when used in biopolishing, offers a number of benefits such as improve softness and water absorbance property of fibres, strongly reduce the tendency for pill formation, and provide a cleaner surface structure with less fuzz [18].

Biopolishing treatment for wool involves two steps. First, an activated peroxide bleach is used to whiten the wool fibers and remove the protective lipid barrier that surrounds them at lower temperatures and in half the time as conventional techniques. The peroxide treatment also the fibers more receptive to dye. The second step is what makes machine-washable wool a reality.

Lyocel has a unique property to fibrillate. Fibrillation is the longitudinal splitting of a single wet fibre into microfibers, caused by mechanical stress. Wet processes such as desizing, dyeing and laundering will produce fibrillation. After the primary fibrillation, the fabric or garment can be enzymatically defibrillated (biopolished) using a cellulase.

3. FUTURE DIRECTIONS

The progress in biotechnology of cellulases and related enzymes is truly remarkable and attracting worldwide attention. These developments together with improved scientific knowledge are expected to pave the way for a remarkable success in the biotechnology of cellulases and related enzymes in the 21st century. The possibility of leveraging innovations over industries could lead to new opportunities for biobased textile processes. Enzymes can be used in order to develop environmentally friendly alternatives to chemical processes in almost all steps of textile fibre processing. New enzymes with high specific activity, increased reaction speed, and tolerance to more extreme temperatures and pH could result in development of continuous processes.

The use of enzymes not only make the process less toxic (by substituting enzymatic treatments for harmful chemical treatments) and eco-friendly, they reduce costs associated with the production process, and consumption of natural resources (water, electricity, fuels), while also improving the quality of the final textile product. There is still considerable potential for new and improved enzyme applications in future textile processing. It seems that in the future it will be possible to do every process using enzymes.

4. CONCLUSION

The use of various enzymes is in the early stages of development but their innovative applications are increasing and spreading rapidly into all areas of textile processing. The textile industry can greatly benefit from the expanded use of these enzymes as non-toxic, environmentally friendly compounds. Textile processing industry is characterized by high consumption of energy and resources and time consuming processes.

Enzymes are a sustainable alternative to the use of harsh chemicals in industry and reduce energy and water consumption, and chemical waste production during manufacturing processes. Cellulases are being commercially produced by several industries globally and are widely being used in food, animal feed, fermentation, agriculture, pulp and paper, and textile applications. With modern biotechnology tools, especially in the area of microbial genetics, novel enzymes and new enzyme applications will become available for the various industries. Biopolishing employs basically the same cellulose action to remove fine surface fuzz and fibrils from cotton and viscose fabrics. The polishing action thus achieved helps to eliminate pilling and provides better print definition, colour brightness, surface texture, drapeability, and softness without any loss of absorbency.

Also, been developed the use of protease enzymes for a range of wool finishing treatments aimed at increased comfort (reduced prickle, greater softness) as well as improved surface appearance and pilling performance. The improved enzyme treatments will allow more selective removal of parts of the wool cuticle, without degradation or weakening of the wool fibre as a whole and without the need for environmentally damaging pre-chlorination treatment.

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