ENZYMES IN TEXTILE INDUSTRY: A REVIEW

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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 worldwide investigations are carried out to substitute conventional chemical textile processes by environment-friendly and economically attractive bioprocesses using enzymes. The enzymes used in the textile field are amylases, catalase, and laccase which are used to removing the starch, degrading excess hydrogen peroxide, bleaching textiles and degrading lignin. The application of cellulases for denim finishing and laccases for decolourization of textile effluents and textile bleaching are the most recent commercial advances. The use of enzyme technology is attractive because enzymes are highly specific and efficient, and work under mild conditions. Furthermore, the use of enzymes results in reduced process times, energy and water savings, improved product quality and potential process integration.

Key words: Enzymes, Application, Textile Industriy, Textile Preparatory Process, Eco-Friendly Characteristics.

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1. Introduction:

Enzymes were discovered in the second half of the nineteenthh century, and since then have been extensively used in several industrial processes. Enzymes are generally globular proteins and like other proteins consist of long linear chains of amino acids that fold to produce a three-dimensional product. Each unique amino acid sequence produces a specific structure, which has unique properties. Enzymes are extremely efficient and highly specific biocatalysts. Commercial sources of enzymes are obtained from three primary sources, i.e., animal tissue, plants and microbies. These naturally occurring enzymes are quite often not readily available in sufficient quantities for food applications or industrial use. However, by isolating microbial strains that produce the desired enzyme and optimizing the conditions for growth, commercial quantities can be obtained. This technique, well known for more than 3,000 years, is called fermentation. Most of the industrial enzymes are produced by a relatively few microbial hosts like *Aspergillus* and *Trichoderma* fungi, *Streptomyces* fungi imperfecti and *Bacillus* bacteria. Yeasts are not good produces of extracellular enzymes and are rarely used for this purpose.

Caused of the evergrowing costs for energy and polluted waste water, enzymatic technologies will stay in the focus of science and technique, and their relevance will increase significantly in the future. Enzymes, biological catalysts with high selectivities, have been used in the food industry for hundreds of years, and play an important role in many other industries (washing agents, textile manufacturing, pharmaceuticals, pulp and paper). Currently, enzymes are becoming increasingly important in sustainable technology and green chemistry.

Especially in textile manufacturing the use of enzymes has a long tradition. Starch is widely used as a sizing agent, being readily available, relatively cheap and based on natural, sustainable raw materials [Lange 1997]. About 75% of the sizing agents used worldwide are starch and its derivatives [Opwis et al. 2007]. Using amylase enzymes for the removal of starch sizes is one of the oldest enzyme applications [Marcher et al. 1993]. Amylases are enzymes which hydrolyse starch molecules to give diverse products, including dextrins and smaller polymers composed of glucose units [Gupta et al. 2003]. Moreover, cellulases, pectinases, hemicellulases, lipases and catalases are used in different cotton pre-treatment and finishing processes [Meyer-Stork 2002].

Other natural fibers are also treated with enzymes. Examples are the enzymatic degumming of silk with sericinases [Gulrajani 1992], the felt-free-finishing of wool with proteases [Fornelli 1994] or the softening of jute with cellulases and xylanases [Kundu et al. 1991].

The application of enzymes has many advantages compared to conventional, non-enzymatic processes. Enzymes can be used in catalytic concentrations at low temperatures and at pH-values near to neutral. Moreover, enzymes are biologically degradable and can be handled without risk.

The conventional highly alkaline preparation of cotton can be an example. The traditional pretreatment is carried out with caustic soda at high temperature, which not only wastes energy and water, causes pollution, but also damage fabrics. Bio-preparation may be a valuable and environmentally friendly alternative to harsh alkaline chemicals for preparing cotton.

Today enzymes have become an integral part of the textile processing. There are two well-established enzyme applications in the textile industry. Firstly, in the preparatory area amylases are commonly used for desizing process and secondly, in the finishing area cellulases are used for softening, bio-stoning and reducing of pilling propensity for cotton goods. At present, applications of pectinases, lipases, proteases, catalases, xylanases etc., are used in textile processing. There are various applications which entail enzymes included fading of denim and non-denim, bio-scouring, bio-polishing, wool finishing, peroxide removal, decolourization of dyestuff, etc. [Cavaco-Paulo and Gübitz 2003].

2. Enzymes, classification, action and properties

2.1. Structure and functions of enzymes

The first use of enzymes in textile processing was reported in 1875, when starch–sized cloth was soaked with liquor containing barely. In 1900 this process was slightly improved using malt extract. But only the use of animal and bacterial amylases was the process of enzymatic desizing introduced into many textile factories.

Enzymes are high molecular weight proteins produced by living organisms to catalyze the chemical reactions that constitute metabolisms in living systems. They accelerate the rate of chemical reaction [Cavaco-Paulo and Gübitz 2003]. The reaction happens with lower activation energy which is reached by forming an intermediate enzyme – substrate.

Enzyme can break down particular compounds. The molecule that an enzyme acts on is known as its substrate, which is converted into a product or products. In the reaction itself the enzymes are not used up, they do not become a part of the final product of the reaction, but only change the chemical bonds of other compounds. After the reaction is complete, the enzyme is released again, ready to start another reaction. Usually most enzymes are used only once and discarded after their catalytic action.

2.2. Clasification of enzymes

Enzymes are very specific in comparison to inorganic catalysts such as acids, bases, metals and metal oxides. For each type of reaction in a cell there is a different enzyme and they are classified into six broad categories namely hydrolytic, oxidising and reducing, synthesising, transferring, lytic and isomerising.

The essential characteristic of enzymes is catalytic function. Consequently, the original attempt to classify enzymes was done according to function. The International Commission on Enzymes (EC) was established in 1956 by the International Union of Biochemistry (IUB), in consultation with the International Union of Pure and Applied Chemistry (IUPAC), to put some order to the hundreds of enzymes that had been discovered by that point and establish a standardized terminology that could be used to systematically name newly discovered enzymes. The EC classification system is divided into six categories of basic function:

EC1 **Oxidoreductases**: catalyze oxidation/reduction reactions.
EC2 **Transferases**: transfer a functional group.
EC3 **Hydrolases**: catalyze the hydrolysis of various bonds.
EC4 **Lyases**: cleave various bonds by means other than hydrolysis and oxidation.
EC5 **Isomerases**: catalyze isomerization changes within a single molecule.
EC6 **Ligases**: join two molecules with covalent bonds.

Each enzyme is described by a sequence of four numbers preceded by “EC”. The first number broadly classifies the enzyme based on its mechanism.

2.3. Properties of enzymes in textile

Generally they are active at mild temperatures. Above certain temperature the enzyme is denaturated. Enzymes have a characteristic pH at which their activity is maximal. Extreme pH values influence on the electrostatic interactions within the enzyme, leading to inactivation of enzyme. Other important factors that influence the effect of enzymatic processes are the concentration of enzyme, the time of treatment, additives like surfactants and chelators and mechanical stress.

Due to their efficiency, specific action, the mild conditions in which they work and their high biodegradability, enzymes are very well suited for a wide range of industrial applications.

Enzymes work only on renewable raw materials. Fruit, cereals, milk, fats, cotton, leather and wood are some typical candidates for enzymatic conversion in industry.

Enzymes are used in the textile industry because they accelerate reactions, act only on specific substrates, operate under mild conditions, are safe and easy to control, can replace harsh chemicals and enzymes are biologically degradable i.e. biodegradable.

2.4. Production of enzymes from microorganisms

Commercial sources of enzymes are obtained from three primary sources, i.e., animal tissue, plants and microbies. These naturally occurring enzymes are quite often not readily available in sufficient quantities for food applications or industrial use. However, by isolating microbial strains that produce the desired enzyme and optimizing the conditions for growth, commercial quantities can be obtained. This technique, well known for more than 3,000 years, is called fermentation. Most of the industrial enzymes are produced by a relatively few microbial hosts like *Aspergillus* and *Trichoderma* fungi, *Streptomyces* fungi imperfecti and *Bacillus* bacteria. Yeasts are not good produces of extracellular enzymes and are rarely used for this purpose. There is a large number of microorganisms which produce a variety of enzymes. Microorganisms producing enzymes of textile important are listed Table 1.

Table 1. Microorganisms producing enzymes of textile important

Microorganisms	Enzymes
1. Bacteria	
Bacillus subtilis	Amylase
B. coagulans	α-amylase
B. licheniformis	α-amylase, Protease
2. Fungi	
A. niger	Amylases, Protease, Pectinase, Glucose oxidase
A. oryzae	Amylases, lipase, protease
Candela lipolytica	Lipase
P. notatum	Glucose oxidase
Rhizopus sp.	Lipase
Trichoderma reesei	Cellulase
T. viride	Cellulase
Ascomycetes	α-amylase
Basidomycetes	α-amylase
Aspergillus sp.	Pectinase, Lipase

The enzymes are inducible, i.e., produced only when needed, and they contribute to the natural carbon cycle. Several methos, such as submerged fermentation (SmF), solid-state fermentation (SSF) and whole cell immobilization have been successfully used for enzyme production from various microorganisms [Jenkins 2003; Cao et al. 1992].

Agro-industrial residues such as wheat bran, rice bran, sugarcane bagasse, corncobs, and apple pomace are generally considered the best substrates for processes [Blandino et al. 2002; Maldonado and Saad 1998].

For practical applications, immobilization of microorganisms on solid materials offers several advantages, including repeated usage of enzyme, ease of product separation and improvement of enzyme stability [Cao et al. 1992].

2.5. Enzyme in textile industry

The fabric should be free from natural and added impurities before it goes colouration. Some of the chemicals like caustic soda, soda ash, hydrogen peroxide, hydrochloric acid, detergent and auxiliaries that are used at different stages preparatory process to remove such an impurities are found to be harmful to the environment. Modern wet processing industries are followed the enzymes in the preparatory process instead of using harmful chemical because enzyme are more convenient, effective and environment friendly. In textile finishing processes the application of enzymes is emerging and in some cases conventional chemical finishing processes are replaced by enzymatic finishing [Schindler and Hauser 2004; Quand & Kühl 2000]. The application of enzymes has many advantages compared to conventional, non-enzymatic processes. Enzymes can be used in catalytic concentrations at low temperatures and at pH-values near to neutral.

Especially in textile manufacturing the use of enzymes has a long tradition. Enzymes used in textile processing and their effects are shown in Table 2. Hydrolases type of enzyme is mostly used in textile processing and now to some extent is oxidoreductase, but their innovative applications are increasing and spreading rapidly into all areas of textile processing.

Table 2. Enzymes in textile industry and their effects

Type of Enzyme	Textile Use and Effects
Amylases	Desizing of warp cotton yarn – hydrolyzing of starch;
Catalases	Catalyzing the decomposition of hydrogen peroxide after bleaching process;
Peroxidases	Used as an enzymatic rinse process after reactive dyeing, oxidative splitting of hydrolyzed reactive dyes on the fiber and in the liquor, providing better wet fastness, decolorized waste water and potentially toxic decomposition compounds;
Proteases	Removing of protein-containing soils or stains from an textile article (in detergents), antifelting of wool, degumming of silk, modification of polyamide fibers to improve wettability and better coloration (in development) – hydrolyzing of protein; When combined, act on proteins, pectins and natural waxes to effect scouring;
Lipases	Hydrolyzing of lipids from a textile article (in detergents), modification of

	polyamide fibers to improve wettability and better coloration (in development);
Pectinases	Bioscouring of cotton and hemp fibers – hydrolyzing of pectin;
Laccase	Decomposes indigo molecules for wash-down effect on denim;
Cellulases	Biopolishing of cotton and linen, biostoning, luster improvement and stone –washed effects on denim – hydrolyzing of cellulose;
Cellulases and Hemicellulases	Biostoning of jeans. Desizing of CMC. Stylish effect on cellulose fibres;
Ligninases	Removing of burrs and other undesired plant compounds from raw material – hydrolyzing of lignin;
Collagenases	Removing the residual skin parts in wool – hydrolyzing peptide bonds in collagen;
Esterases	Modification of polyester fibers to improve wettability (in development) – hydrolyzing of ester bonds;
Nitrilases	Modification of acrylic fibers to improve wettability and better coloration (in development) – hydrolyzing of nitrile;

The enzymatic desizing of cotton with α-amylases is state-of-the-art since many decades [Marcher et al. 1993]. The amylose is bioconverted to 100% by the α-amylase into glucose whereas the amulopectin is converted to 50% into glucose and maltose. Bio-desizing is preferred due to their high efficiency and specific action. Amylases bring about complete removal of the size without any harmful effects on the fabric besides eco friendly behavior. Moreover, cellulases, pectinases, hemicellulases, lipases and catalases are used in different cotton pre-treatment and finishing processes [Meyer-Stork 2002].

Cellulase enzymes were first introduced after decades of amylase usage as an industry standard for desizing processes. Today, efforts within the textile industry seem to focus on replacing traditional natural-fiber scouring processes with enzyme-based solutions. As the purpose of scouring is to remove natural impurities such as polymeric substances like pectins, waxes and xylomannans, among others from cotton or other natural fibers, there are plenty of enzyme that can act on such impurities. Alkaline pectinases, which loosens fiber structure by removing pectins between cellulose fibrils and eases the wash-off of waxy impurities, is the key enzyme for a bioscouring process. Other enzymes including cellulases, hemicellulases, proteases and lipases have been tested, but at present, the only commercial bioscouring enzyme products are based on pectinases.

In conventional pre-treatment these substances are removed by a strong alkaline treatment at high temperatures after the enzymatic desizing of raw cotton fabrics with α-amylases. This inspecific alkaline scouring process has a high energy, water and alkali consumption and can also cause a damage of the cellulosic material.

The group of enzymes called laccases, or phenol oxidases, possesses the ability to catalyze the oxidation of a wide range of phenolic supstances, including indigo. The first commercial use of laccases in the textile industry has been in the denim washing process, where laccases enhance abrasion levels and bleach indigo.

An efficient biopreparation process should be based on a combination, preferably simultaneously, of enzymes for desizing, scouring and bleaching in one bath. Success in developing such a process would result in a simple process, including savings in water, time and energy consumption.

3. Conclusion:

Biotechnology offers a wide range of alternative environmentally-friendly processes for the textile industry to complement or improve the conventional technologies. The use of various enzyme 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 was identified as a key sector where opportunities available from adapting biotechnology are high but current awareness of biotechnology is low. In textile processing the enzyme can be successfully used for preparatory process like desizing, scouring and bleaching. These enzymatic processes are gives the similar results as that of conventional methods. Though this enzymatic processes we can reduce the water consumption, power energy, pollution, time, and increasing quality. These are just a few applications of Biotechnology, however many such potentials are yet to be explored.

Pollution free processes are gaining ground all over the world. In this scenario, enzymes emerging as the best alternative to the polluting textle processing methods. Enzymes are not only beneficial from ecological point of view but they are also saving lot of money by reducing water and energy consumption which ultimately reduce the cost of production.

Enzyme producing companies constantly improve their products for more flexible application conditions and a more wide-spread use. The main hindrance in using enzymes is their high cost. Enzymes are emerging in a big way in the field of textile wet processing. If their cost can be managed, enzymes can be put to use in a much bigger way for textile processing applications.

Advances in enzymology, molecular biology and screening techniques provide possibilities for the development of new enzyme-based processes for a more environmentally friendly approach in textile industry. It seems that in the future it will be possible to do every process using enzymes.

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