ENZYMES IN TEXTILE CHEMICAL PROCESSING

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ABSTRACT

Among industrial enzymology's most rapidly growing fields is the use of enzymes in the textile industry. Enzymes are increasingly being used in textile chemical processing due to their non-toxic and environmentally friendly characteristics, and the growing requirements for textile manufacturers to reduce pollution in textile manufacturing. Enzymes have also been used to create unique patterns on textile surfaces. Amylases, catalases, and laccases are the most frequently used enzymes in textile production to remove starch, degrade hydrogen peroxide (H2O2) after bleaching, bleach textile materials, and dissolve lignin. It reduces solid waste and effluent. About 75 enzymes are commonly used in textile manufacturing processes, out of the 7000 known enzymes.

KEYWORDS: *Enzymes, textile industry, bleaching, eco-friendly, desizing, scouring.*

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1. INTRODUCTION:

The textile industry has become increasingly popular with enzyme treatments because of their stereo specificity, non-toxicity, environmental friendliness, and energy efficiency. A textile chemical process typically involves the use of enzymes at each step of the manufacturing process. A few important enzymes to mention in this category are amylases for textile designs, celluloses for washing denim and leather, and proteases for wool modification. Due to extreme pH and temperature conditions, enzymes have limited industrial acceptance despite lot potential.

2. ENZYMES USED IN TEXTILE PROCESSING:

2.1.THE ENZYME COMMISSION'S SYSTEM OF CLASSIFICATION OF ENZYMES AND ASSIGNING CODE NUMBERS:

Table 1. Enzyme Code Groups and Enzyme types

First digit of EC number (group)	Enzyme class	Type of reaction catalyst
1	Oxidoreductases	Oxidation/reduction reactions
2	Transferases	Transfer of an atom or group between two molecules
3	Hydrolases	Hydrolysis reaction
4	Lyases	Removal of a group from substrate (not by hydrolysis)
5	Isomerases	Isomerization reactions
6	Ligases	The synthetic joining of two molecules, coupled with the breakdown of pyrophosphate bond in a nucleoside triphosphate.

According to the Enzyme commission of the International Union of Biochemistry, enzymes can be categorized into six groups: oxidoreductases, transferases, hydrolases, lyases, isomerases, and ligases. Wet textile processing is predominantly carried out with enzymes from Group 3, hydrolases, which catalyse the hydrolysis of chemical bonds in substrates. Amylases, cellulases, pectinases, catalases, and proteases are part of this group and are used in many applications such as desizing, bio scouring, cleaning, and drying, and imparting shrink resistance to wool. Cellulase is one of the most popular enzymes used in textiles.

3. INDUSTRIAL TEXTILE BIOPROCESSING:

Conventional textile wet processing methods are characterized using high concentrations of chemicals, pH conditions that are alkaline or acidic, and high temperatures. These enzymes are active at mild temperatures, often at neutral pH levels, can accelerate a wide range of reactions, and can remain unchanged after the reactions have taken place. According to the life-cycle assessment (LCA) studies commissioned by Novozymes, it is possible to save up to 28% in water consumption, up to 80% in chemical consumption, and up to 25% in energy consumption by using enzymes in cotton textile production.

Biological laundry detergents are the greatest application of enzymes to the textile industry. Several different enzymes and complex enzyme systems are used in modern laundry detergent formulations in order to help solubilize and remove soils and stains from clothing at lower temperatures and with less surfactant. Specific proteases, amylases, lipases, pectinases, and mannanases have been identified and developed to remove protein, starch, fatty, fruit, and guar gum-related stains from detergent formulations and applications. Detergent formulations have also been created which contain cellulases to enhance the appearance of cotton garments by eliminating pills and rejuvenating their luster.

4. DEVELOPMENTS IN APPLICATION OF ENZYMES FOR TEXTILE PROCESSING:

4.1 IMMOBILIZATION OF ENZYMES:

By improving the properties of commercially available enzymes, protein engineering has revolutionized the process of developing industrial catalysts. An enzyme is attached to the support material, resulting in a reduced or lost mobility while retaining its catalytic activity and can be used repeatedly.

Fig.1 Support materials and its factors to be considered

4.2 IMMOBILIZATION SUPPORT:

The material plays an important role in determining the performance of the immobilized enzyme.

4.2.1 ADVANTAGES:

- Recovery & rescue of catalyst.
- Continuous operation possible.
- Easy handling.
- Easier product separation
- Potential of enzyme stabilization.

4.2.2 DISADVANTAGES:

- Loss of reduction in enzyme activity.
- Diffusion limitations.
- Additional cost of support & technique.

4.3 METHODS OF IMMOBILIZATION:

There are three basic categories of enzyme methods.

- Carrier/Surface Attachments.
- Encapsulation.
- Cross-linking.

Fig.2 Enzyme methods

4.4 ENZYMES IN TEXTILE CHEMICAL PROCESSING:

All manufacturing steps of chemical processing can be carried out by enzymes, as well as effluent treatment. Enzymes have a variety of applications in the textile industry, such as Hydrolases and oxidoreductases. In other words, microbial enzymes are often more useful than plant or animal enzymes. In addition, the enzymes from microbes are more stable than their corresponding enzymes from plants and animals, and their production is more convenient and safer.

4.5 DEVELOPMENTS IN THE APPLICATIONS OF ENZYMES FOR COTTON TEXTILE PROCESSING:

Enzyme technology has been used extensively in textile chemical processing, and research is active in this area. The development of enzymatic textile processing is systematically and independently discussed.

- Economical & Industrial-viable Enzymes/process.
- Supplementary enzymatic assistance.
- Combined enzymatic pre-treatment.
- Immobilization of enzymes.

4.6 IN TEXTILE PROCESSING, ENZYMES HAVE THE FOLLOWING POTENTIAL APPLICATIONS:

- Anti-shrinkable wool.
- Bleach clean-up.
- Synthetic fibre modification.
- Biological polymer synthesis & functionalization.
- Utilization of immobilized enzymes for textile functionalization.

5. BIO DESIZING:

Table 2 Enzymes, its application and mechanism

Name	Nomenclature	Textile application	Mechanism
Oxidoreductase	EC 1	Dyeing	Catalyses the transfer of electrons from one molecule, also called the hydrogen or electron acceptor.
Laccases	EC 1.10.3.2	Discoloration of textile effluent. Bleaching of lignin contained fibres and indigo in denim fabric.	Degrade a wide range of recalcitrant (unruly) organic compounds including lignin.
Catalases	EC 1.11.1.6	Removal of hydrogen peroxide after bleaching.	In situ peroxide decomposition.
Lipases	EC 3.1.1.3	Make polyester hydrophilic, a substitute for alkaline hydrolysis. Detergent additive.	Split fats and oils into glycerol and fatty acids Remove most difficult lipid stains during washing.
Amylase	EC 3.2.1	Starch designing	Spilt starch (amylase) into dextrin and sugars.
Cellulases	EC 3.2.1.4	Stone washing Bio finishing for handle modification. Carbonization of wool	Degrade cellulose into soluble products.
Xylanase	EC 3.2.1.8	Bleaching	Degrade hemicellulose by breaking linear polysaccharide beta-1, 4-xylan into xylose.
Pectinases	EC 3.2.1.15	Bio sourcing substituting caustic soda boil.	Degrade pectin.
Proteases	EC 3.4	Removal of protein stains during scouring.	Split proteins into soluble polypeptides and amino acids.

In textiles, starch and starch derivatives are most commonly used as a size.

In comparison to the traditional desizing process, the biodesizing process generates less waste water and contains fewer toxic chemicals, making it a more environmentally friendly alternative. Enzymatic desizing produces nontoxic sugars and dextrin as their end products. As a result, they raise the biochemical oxygen demand (BOD) of the waste water. This process can be performed in a continuous manner, which consists of three steps:

• The impregnation takes place at temperatures above 70 °C using a buffered calcium solution (Ca). In an alternative method, fabric may be soaked with an enzyme solution at its optimum temperature before incubation (at a lower temperature) is carried out.

• Depending on the temperature, pH, size, and nature of the fabric, the enzyme is incubated anywhere from 2-16 hours.

• Washing with a neutral liquor after a wash above 80 °C in an alkaline liquid.

The desizing process may be carried out by enzymes called amylases in modern textile industries. The a-amylase is produced with microbes through submerged fermentation (SMF) or solid state fermentation (SSF), which employs waste products from other processes. The SMF is specialized for the extraction of secondary metabolites in liquid form.

Amylases are of two types:

1) Dextrionogenic, a-amylases (EC 3.2.1.1)
2) Saccharogenic, b-amylases (EC 3.2.1.2)

They both hydrolyze glucosidic linkages within the starch molecules, but they function at different points in the reaction. A-amylase acts randomly on the substrate, so it is typically faster-acting than b-amylase, which is why it is commonly used for textiles desizing. The pH of a regular amylase may range from 5.5 to 7.0, and the temperature may range from 25 to 55 ° C. Medium temperature desizing with amylases can be done at 50-95 °C, whereas high temperature stable amylase can be used for desizing above 95 °C in the exhaust bath and also by the pad-steam process.

Table 3 Enzymes used in different processes

Process	Enzymes
Designing	Amylase, lipase
Scouring	Pectinase, cellulose, cutinase
Bleaching	Oxidoreductase, xylanase
Dyeing	Oxidoreductase
Finishing	Cellulose, oxidoreductase, lipase
Composting of textile waste	Laccases, cellulose, protease, nylonase, polyesterase

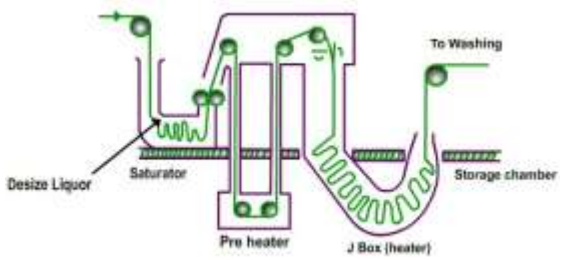

Fig. 3 Desizing Procedure Inwards Stuff Industry

6. BIO SCOURING:

For wettability, pectinase is the only enzyme required, while other enzymes may have beneficial effects. Optimal scouring temperature is 50-65 °C and pH is 7.5-9.0, respectively. There are many advantages to bio scouring over traditional alkaline scouring, including neutral pH, reduced water consumption, and a reduction in weight and strength loss as well as maintaining the natural softness of the cotton fibre. As compared to alkali-boil scouring, bio scouring has a much lower temperature (40-60 °C). While bio scouring can provide the desired hydrophilicity in the cotton fabric, it leaves sufficient wax residues on the fabric surface so fewer softeners are needed during the finishing process.

Pectin degrading enzymes fall into three major categories, including:

- Pectin esterases (PEs),
- Polygalacturonases (PGs), and
- Polygalacturonate lyases (PGLs).

It has been discovered that pectin esterases are naturally produced in plants such as bananas, citrus fruits, and tomatoes, in addition to the fact that bacteria and fungi can also produce them [1]. An important benefit of such enzymes in bio preparation is that they do not destroy cotton fibers cellulose. The enzyme catalyzes the hydrolysis of the salts of polygalacturonic acids (pectin) in the primary wall matrix very rapidly. The pectinase enzyme hydrolyzes the pectin found in cotton, which is a noncellulosic impurity. Some kinds of pectinases can function under slightly alkaline conditions even when chelating agents are present- alkaline pectinases.

For scouring cotton fabrics, cellulases are especially effective. Cellulase can be found in some pectinase enzyme preparations. The impurities are then removed by subsequent washing. The combined action of both types results in more weight loss and strength loss as compared to the individual actions of pectinase and lipase. In order to obtain scoured yarn with lasting tensile strength, cotton fibers or their blends with other fibers can be treated for 18 hours at 40 °C with aqueous solutions containing protopectinases. Pectinases and cellulases are more effective than proteases and lipases. A change in cotton's water absorbency is rapidly induced by pectinases, cellulases, or a mixture thereof. Pectinases can destroy the cuticle structure in cotton by digesting the inner layer of pectins. The cellulase digests the cellulose lying under the cuticle structure of cotton, thus destroying its cuticle structure. Cellulases and pectinases break the linkages from the cuticle side and the cellulose side, respectively. The synergism results in more efficient scouring in terms of the speed and uniformity of treatment. Scanning electron microscopy (SEM) images revealed the destruction of cotton's cuticle during enzymatic scouring [2].

Das and Ramaswamy (2006) investigated the physical, chemical, and structural properties of wool fibers and specialty hair fibers upon enzyme treatment (savinase, resinase, xylanase, and pectinase). It was observed that the efficiency of xylanase and pectinase treatments was as good as conventional soap scouring. The tenacity, diameter, and SEM images of the fibers further demonstrated that neither of these enzymes caused physical damage at these concentrations.

The cellulases may help to open up the fragments for chemical attack. A chelating agent, such as EDTA, can hydrolyze seed coat fragments much faster than cotton fabric.

With bio scouring, both biological oxygen demand (BOD) and chemical oxygen demand (COD) are reduced. Compared to alkaline scouring (100%), the BOD and COD levels of enzymatic scouring are between 20%- 45%. A scouring process involving enzymes produces a total dissolved solid (TDS) that is between 20%-50 % lower than one involving an alkaline acid.

Scouring with enzymes is non-polluting, economical, and environment-friendly. It minimizes health risks, and the operators aren't exposed to aggressive chemicals [3].

Cold pad-store method makes the fabrics soak in enzyme solution for one hour, then they are stored for 4-12 hours and this is a lengthy process not suitable for industrial applications. Researchers have demonstrated that bio scouring cotton fabrics by repeated rubbing (5-15 times, at lower temperature) can greatly shorten enzyme scouring times and can be a useful means of improving enzymatic efficiency [4].

Fig. 4 Biosynthetic Fibers

7. BIOFINISHING:

Cellulases are used to soften cotton by removing projected fibers from its surface. The bio polishing process prevents the formation of pills [5]. Hydrolysis of the micro fibrils (hairs or fuzz) on the yarn or fabric surface is performed by cellulases.

The fabric presents much lower pilling tendency after bio polishing. The most popular method of fuzz removal is gas singeing.

Various effects of cellulase can be observed on man-made cellulosic fabrics such as lyocell (Tencel), viscose, and cellulose acetate. Using cellulase on viscose and lyocell alters the handle, drapeability, and removes surface fuzz. Cellulase can also reduce the tendency of viscose to pill and the fibrillation of lyocell, but it tends to have less of an effect on cellulose acetate. Enzymatic hydrolysis of linen is the most effective method of hydrolysis, followed by viscose, cotton, and lyocell.

The cellulase used in bio finishing is

(1) Acid cellulases with the strongest activity are those with a pH between 4.5 and 5.5, at 45 to 55 °C
(2) For neutral cellulases, pH should range from 5.5-8.0 at 50-60 °C

Cellulases used for bio finishing contain three or more enzyme systems

(1) Endo-b-(1, 4)-gluconases (EG) hydrolyze cellulose chains internally.
(2) Cellobiose is produced when exo-b-(1, 4)-gluconases hydrolyze cellulose chain ends. In this way, exo-cellulases perhaps assist in disintegrating crystalline regions so that they can be hydrolyzed by endo-cellulases more easily.
(3) Cellobiose and other small oligomers are hydrolyzed by b-(1, 4)-glucosidase into glucose.

Surface properties can be optimized through controlled finishing with cellsulase enzyme, but the tensile strength of a fabric is reduced. Weight loss up to 3%-6% and strength loss up to 10% are acceptable commercially. It has also been found that cellulase is more active in mercerized cotton than in 100% untreated cotton and cotton/polyester blends [6].

During cellulases finishing, in addition to rotating-drum washing machines and jets, some means of mechanical agitation of the fabric are also used. The dissociation of bound enzymes increases with an increase in mechanical action [7]. In practice, pad-batch machines, winch machines, and jet systems use different levels of agitation. Additionally, increasing levels of agitation reduce enzyme adsorption, increase the number of free sites for enzyme hydrolysis, and under extreme mechanical movements, and decrease cellulase specificity.

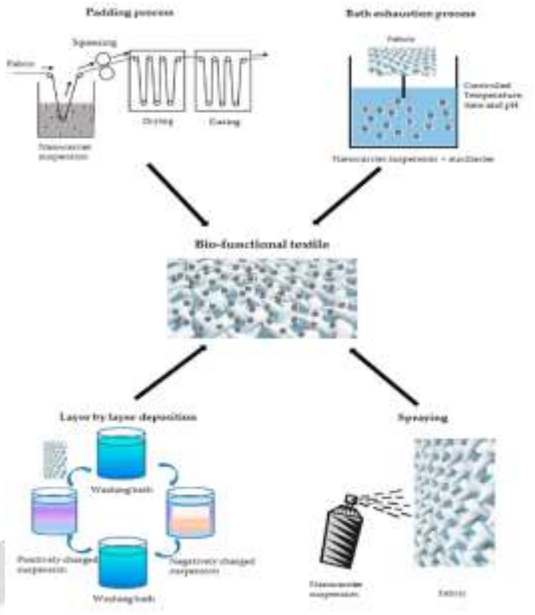

Fig. 5 Finishing techniques for bio-functional textile production

8. ENZYMES IN TEXTILE INDUSTRY-ENVIRONMENTALLY FRIENDLY APPROACH:

Enzymes have many advantages in the textile industry, including replacing harsh chemicals, speeding up reactions, acting only on specific substrates, operating under mild conditions, and being biodegradable and safe. Hence, cellulases loosen the indigo film on yarn surfaces by breaking the fibres. By mechanical abrasion, dye can be easily removed. With this principle, cellulase can be used to modify the surface and properties of cellulosic fibres and fabrics in order to produce a desired hand and surface. This process is called as bio-polishing.

Traditionally, cotton textiles are produced through a process of converting fiber to fabric. A grey fabric or yarn is converted into a wettable, bleachable, dye able form by utilizing several wet processes, including desizing, scouring, and a bleaching.

Scouring requires the use of high concentrations of sodium hydroxide and high temperatures to effectively remove impurities, allowing for dyeing of the fabric.

Laccase is one of the enzymes that can decolorize indigo. It is very important when it comes to treating and finishing denim fabrics. Textile industry uses peroxide bleaching since it is less toxic than chlorine bleaching. Consequently, the catalase operates in cold water and conserves a significant amount of energy. To remove the excess of the reducing agent, 30 – 40 liters of water per kilogram of fabric is usually needed for rinsing.

A protease is used to dissolve the gum layers of stiff raw silk to improve its luster and softness. Wool and silk fibers can be altered by a protease treatment to produce new and unique finishes. During degumming, sericin is removed from raw silk. The enzyme degumming process involves proteolytic breakdown of sericin with the help of an enzyme without any effect on fibroin.

An enzymatic treatment improves silk’s affinity for reactive dyes, reducing the environmental impact. Wool has felting properties due to its surface structure, which has a scale-like appearance. Many chemical processes have been adapted, but the most common is the usage of polymers and active chlorine-based chemicals. As a result of using chlorine, AOX-charges can be found in wastewater.

The carbonization of wool is like the scouring of cotton, which involves removing contaminating material from the proteins before dyeing, since wool and cellulosic materials behave differently in dyeing.

Wool fabric is placed in a solution of sulphuric acid and heated. Polyethylene terephthalate (PET) is a hydrophobic fibre, and alkaline hydrolysis is an effective way to improve its wettability. The enzyme reaction requires 10 minutes at 25 °C and does not affect the strength. Lipase has also demonstrated effectiveness on sulphonated and micro denier polyester fabrics.

9. FUTURE TRENDS:

Enzymes are proteins and biodegradable. Since enzymes are extremely specific for particular or targeted textile finishing, enzyme-based bioprocessing can help prevent the adverse effects of fibre damage. By using enzyme bioprocessing, water and energy can be conserved and chemical quantities reduced, but the resulting textiles can also perform and be of better quality. Biotechnology based on enzymes could be one of the environmentally friendly processes employed in textiles to contribute to sustainability. Researchers have explored the application of enzymes to textiles over the past two decades. There are many industrial bioprocesses available, including bio scouring, bio stone washing, bleach clean-up, and bio polishing. Recent years have seen an increasing focus on laccases and peroxidases as means of removing color or polymerizing to generate color. Moreover, these enzymes can provide enhanced bleaching and fibre separation in the bast fibre processing.

Cotton, wool, and silk were important natural fibres in the development of sustainable textiles. This requires extensive cleaning processes that require a great deal of time, energy, and chemicals. Wet processes can damage fibres during these extensive processes. The wet processing of fibres and fabrics can be improved by using enzymes to improve efficiency, resulting in reduced environmental impact and improved product quality. In recent years, textile waste recycling processes have gained increasing importance since it has beneficial ecological, social, and economic effects from diverting textile waste from landfills and from placing pressure on raw resources. It would be interesting to explore the use of enzymes in reusing and recycling textile fibres and fabrics.

10. CONCLUSION:

In textile chemical processing, biocatalysts have proven to be an efficient and reliable tool, and native enzymes are used in an array of processes. The immobilization of enzymes is one of the most promising techniques for highly efficient and economically competent biotechnological process. Hence, there should be extensive research conducted on the immobilization techniques of various enzymes, related to textile chemical processing, in order to expand their horizons for use in textiles.

REFERENCES:

1. Shen, J., & Smith, E. (2015). Enzymatic treatments for sustainable textile processing. Sustainable Apparel, 119-133.

2. Li, Y., & Hardin, I. R. (1998). Enzymatic Scouring of Cotton-Surfactants, Agitation, and Selection of Enzymes. Textile Chemist & Colorist, 30(9).

3. Pawar, S. B., Shah, H. D., & Andhorikar, G. R. (2002). Enzymatic Processing of Cotton: A Bio-Technical Approach. MAN MADE TEXTILES IN INDIA, 45(4), 133-138.

4. Wu, S. Z., Liu, J. Y., & Dou, C. Y. (2017). Study on Ecoshine of wool with chlorine-free shrink-proof. Wool Textile Journal, 1, 25-28.

5. Lenin, V., Kandasamy, N., Karthick, S., & Kanipriya, M. (2009). Enzymes in Textile Finishing. Man-made Textiles in India, 52(1).

6. Aly, A. S., Moustafa, A. B., & Hebeish, A. (2004). Bio-technological treatment of cellulosic textiles. Journal of Cleaner Production, 12(7), 697-705.

7. Cortez, J., Bonner, P. L., & Griffin, M. (2004). Application of transglutaminases in the modification of wool textiles. Enzyme and Microbial Technology, 34(1), 64-72.