Enzymatic Biotechnology

- **Enzymes are biological catalysts.** The term ‘‘enzyme’’ was first used by Kühne in 1878 and is derived from the Greek word enzumé, meaning ‘‘in (en) yeast (zumé).
- **Chemically, enzymes are proteins of high molecular weight**: for example, that of enzyme a-amylase of Bacillus subtilis is about 100,000.
- **Enzymes are a sustainable alternative to the harsh toxic chemicals in the textile industry.**
- **As enzymes operate in moderate conditions of temperature and pH, with reduced energy consumption, there are fewer greenhouse gas emissions.**
- **The usage of enzymes minimizes both water consumption and waste generation during textile manufacturing as well.**
- **Moreover, enzymes generate minimum by-products and are fewer risks to humans, wildlife, and the environment, as enzymes are particular in their actions.**

Introduction to Enzymes in Textile Biotechnology:

Enzymes are proteins produced by living organisms that act as catalysts to accelerate chemical reactions without being consumed. In textile processing, enzymes have been successfully used to enhance processes such as de-sizing, scouring, bleaching, and finishing. The use of enzymes allows for reduced water and energy consumption, lower temperatures, and minimal environmental impact.

Key Properties of Enzymes Used in Textiles:

- **Specificity:** Enzymes target specific substrates, allowing for precision in textile processing without damaging fibers.
- **Biodegradability:** Enzymes are biodegradable, making them environmentally friendly.

- **Mild Reaction Conditions:** Enzymes work under moderate temperature and pH conditions, reducing the need for harsh chemicals.

Applications of Enzymes in Textile Processing:

a. Desizing with Amylases:

- **Process:** Desizing is the removal of size materials (typically starch) applied to yarns during weaving to protect them from damage.
- **Enzyme Used:** Amylases are the most common enzymes used for desizing, as they hydrolyze the starch into soluble sugars, which can then be easily washed away.
- **Advantages:**
    - Reduces water, chemical, and energy consumption compared to traditional desizing methods.
    - No fiber damage, as amylase targets starch specifically without affecting the cotton or synthetic fibers.

b. Bioscouring with Pectinases: (2022)

- **Process:** Scouring is the process of removing impurities such as waxes, oils, and pectin from cotton to make the fabric more absorbent.
- **Enzyme Used:** Pectinases break down pectin, a component of the primary cell wall in cotton fibers, without damaging the cellulose.
- **Advantages:**
    - Lower temperatures (50-60°C) are required compared to traditional alkaline scouring (which operates at 100°C or higher).
    - Reduces water and energy usage, as well as wastewater pollution.
    - Maintains fiber strength and enhances fabric softness.

c. Biobleaching with Laccases and Peroxidases:

- **Process:** Bleaching is used to whiten textiles by removing natural colorants such as lignin from cotton.

- **Enzymes Used:** Laccases and peroxidases can partially replace chemical bleaching agents. Laccases oxidize phenolic compounds, while peroxidases catalyze the degradation of lignin.

- **Advantages:**
    - Reduces the need for harsh oxidizing agents like hydrogen peroxide.
    - Operates under milder conditions, preserving the mechanical properties of fibers.
    - Produces less wastewater and toxic byproducts.

d. Bio-polishing with Cellulases:

- **Process:** Bio-polishing is the treatment of cellulosic fibers (like cotton) to remove surface fuzz and improve the fabric's smoothness and appearance.
- **Enzyme Used:** Cellulases break down the microfibrils on the surface of the fabric, resulting in a smoother finish.
- **Advantages:**
    - Enhances the softness and luster of fabrics.
    - Reduces pilling by removing loose fibers.
    - Environmentally friendly, as the process uses less water and energy than traditional mechanical polishing.

e. Bio-stoning with Cellulases:

- **Process:** Bio-stoning is used to achieve the "stone-washed" effect on denim fabrics. Traditionally, pumice stones were used to abrade the fabric.
- **Enzyme Used:** Cellulases degrade the cotton surface, creating a worn and faded look without the need for abrasive stones.
- **Advantages:**
    - Reduces mechanical damage to fabric, prolonging garment life.
    - Decreases water, energy, and pumice stone consumption, resulting in less damage to washing machines.
    - Generates less sludge, making the process more eco-friendly.

f. Degradation of Synthetic Fibers with Cutinases and Lipases:

- **Process:** Synthetic fibers like polyester can accumulate oil-based stains during wear. Enzymatic treatments can help remove these hydrophobic substances.
- **Enzymes Used:**
    - **Cutinases:** Break down cutin, a component of plant cell walls, but also target polyester's ester bonds.

    - **Lipases:** Hydrolyze triglycerides into fatty acids and glycerol, which can remove oil-based stains from synthetic fibers.
- **Advantages:**
    - Improves cleanliness and stain removal without damaging the fabric.
    - Reduces the need for harsh solvents or surfactants, making the cleaning process more sustainable.

Environmental and Economic Benefits:

a. Reduced Chemical Use:

- Enzymes provide a safer alternative to harmful chemicals used in textile processing, reducing the environmental impact of effluent discharge and lowering the risk of occupational hazards.

b. Lower Water and Energy Consumption:

- Enzyme-based processes often operate at lower temperatures and under neutral pH conditions, which decreases energy consumption and minimizes water usage.
- For example, bioscouring and biobleaching require less water than traditional alkaline scouring and peroxide bleaching.

c. Biodegradability and Eco-friendliness:

- Unlike synthetic chemicals, enzymes are biodegradable, which minimizes their environmental footprint. This is particularly important in achieving sustainability goals in the textile industry.

Challenges and Future Prospects: (2019)

a. Cost of Enzymes:

- Although the cost of enzymes has been decreasing with advancements in biotechnology, it can still be a limiting factor in widespread adoption, especially for smaller textile manufacturers.

b. Enzyme Inactivation:

- Enzymes can lose activity due to exposure to extreme conditions (e.g., high temperatures, strong chemicals), which limits their application in some textile processes. Advances in enzyme stabilization and genetic engineering are addressing these challenges.

c. Integration with Existing Machinery:

- Integrating enzyme-based processes into existing textile machinery requires technological upgrades and adjustments. However, industry trends are moving towards the development of equipment tailored for enzyme applications.

The advantages of using Enzymes (2021)

- The reaction rate is accelerated by lowering the activation energy of the reaction. The enzyme remains intact at the end of the reaction by acting as a catalyst.
- Remarkable chemical precision is due to far greater reaction specificity, even without functional group protection. Enzyme engineering can further improve their stability and specific activity.
- Processes are easy to control as the enzyme activity depends upon operating conditions.
- Enzymes are biodegradable and eco-friendly.

- Applicable under milder conditions of temperature (below 100 _C), pressure (atmospheric), and pH (around neutral). However, high-temperature–stable enzymes are also available nowadays for faster reactions.
- Lower energy input leads to lower costs and lower emissions of greenhouse gases to the environment.
- Enzymatic reactions are several orders of magnitude faster.
- Rarely are by-products generated.
- Fewer wastes are generated, and disposal problems are minimized.
- Safe to handle and non-corrosive.
- It reduces pollution loads due to the easy biodegradability of enzymes.
- Safely dischargeable after use, sometimes after inactivation by changing pH or temperature.
- It reduces global warming, saving in acidification, and nutrient enrichment.

The Problems and Challenges of Enzyme Application

- Enzyme recovery and reuse.
- Scale-up in an industrial environment.
- Higher process time.
- It may not always be economically feasible.

Precautions to be strictly followed are:

- Live steam should not be used.
- Chemicals should be added in pre-diluted form.
- Compatible ionic surfactants should be used.
- Non-ionic wetting agents with appropriate cloud points are preferred
- The temperature, pH, and heavy metal contamination should be closely monitored.
- The enzymes should be carefully stored under prescribed conditions.

Sources of Enzyme:

- ✓ **Vegetable source:** Malt extract is made from germinated barley. These are mainly used in desizing.
- ✓ **Bacterial source:** Enzymes can be commercially produced by growing cultures of certain microorganisms, e.g., protease, catalase, amylase.
- ✓ **Animal source:** These enzymes are obtained from slaughterhouse wastes such as pancreas, cattle blood lever, etc.

Types of Enzyme	Application
Amylase	Amylase enzyme is used in desizing that hydrolyses and reduces the molecular weight of amylose and amylopectin molecules in starch, rendering it water soluble enough to be washed off the fabric.
Cellulase	Cellulase enzymes are used in cotton bio-polishing, which selectively act on the loose fibers protruding from the fabric or yarn surface. This enzyme can also be used in the bio-stoning of jeans.
Pectinase	Pectinase enzyme is used in the bio-scouring of cotton to remove hydrophobic (oils, fats) and other non-cellulosic components (dust, dirt).
Catalase	After bleaching with hydrogen peroxide (H_2O_2), the Catalase enzyme is used in the subsequent process to catalyze the decomposition of hydrogen peroxide to water and oxygen.
Protease	Protease enzyme is used in scouring animal fibers, degumming of silk, and modification of wool fiber properties.

Action of Enzyme

Enzymes are large molecular complexes and can't penetrate the interior of the fabric. Hence, enzyme action takes place preferentially on the surface. The polypeptide chain of the enzyme is folded so that a small three-dimensional pocket is called an active site.

The active site is a perfect fit for a specific substrate, and once the substrate binds to the enzyme, no further modification is necessary. The active site of enzyme catalysis operates first to form an enzyme-substrate complex (ES), which finally breaks into a product and regenerates the enzyme through a bio-reaction mechanism explained in formula-1 and shown in Figure 1. The process continues until conditions in the processing bath deactivate the enzyme.

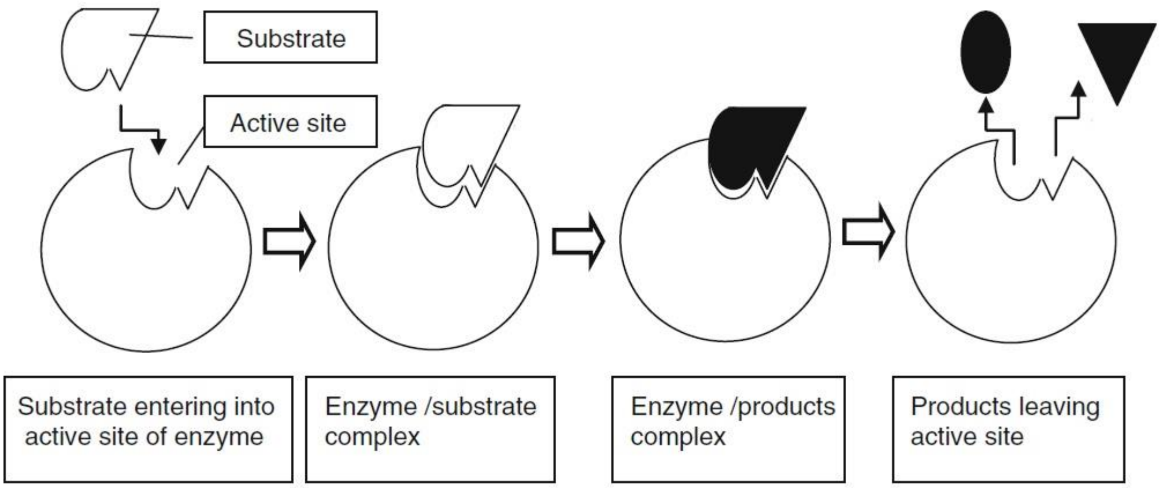


Figure 1: Lock and Key Model of Enzyme Action

$$\mathbf{E} + \mathbf{S} \rightarrow \mathbf{ES} \rightarrow \mathbf{E} + \mathbf{P}$$

Enzymatic Desizing

Enzymatic desizing is carried out, using a pad-batch process, on an accurate weight of the starch-sized cotton fabric. The fabrics were wet in the saturator, containing the enzyme solution and 1 g/L non-ionic surfactant with a pH (of 5.5–7.5). Then, the fabric was passed through a nip roller to get a controlled wet pick up (60%–120%) and then kept in the oven for the desired time (4–24 hr) and temperature (30°C–60°C). After the enzymatic treatment, the fabrics were washed with hot water (at 90°C) for 10 min to deactivate the enzymes, then washed with cold water several times. Finally, the treated cotton fabrics were oven-dried for 1 hr at 105°C–110°C.

Table 1: Optimum Conditions of Enzymatic Desizing

Type of Enzyme	Enzyme conc. (g/l)	Temperature (°C)	pH range
Pancreatic	1-3	50-60	6.5-7.5
Malt extract	3-20	50-60	6-7.5
Bacterial	0.5-1	60-80	5.5-7.5

Tentative recipe for Enzymatic Desizing:

Bactasol (amylase enzyme)	: 0.5 g/l
Non-ionic detergent	: 0.5-1.0 g/l
Temperature	: 70°C
pH	: 6
Dwell period	: 4-24 hours

The action of Amylase Enzyme in Enzymatic Desizing:

- Amylase enzymes are used in enzymatic desizing that consists of two parts, **α-amylase** and **β-amylase**. **α -amylase attacks the starch chain randomly** so that the degree of polymerization of starch is rapidly reduced and transferred into **glucose and water molecules. β- Amylase successively removes the terminal maltose unit** so the polymeric chain can gradually shorten.

Advantages of enzymatic desizing over conventional desizing

- There is no risk of mildew formation on fabric in enzymatic desizing, which can be observed in rot or acid desizing.
- There is no risk of hydro-cellulose formation in fabric, but that is observed in acid desizing.

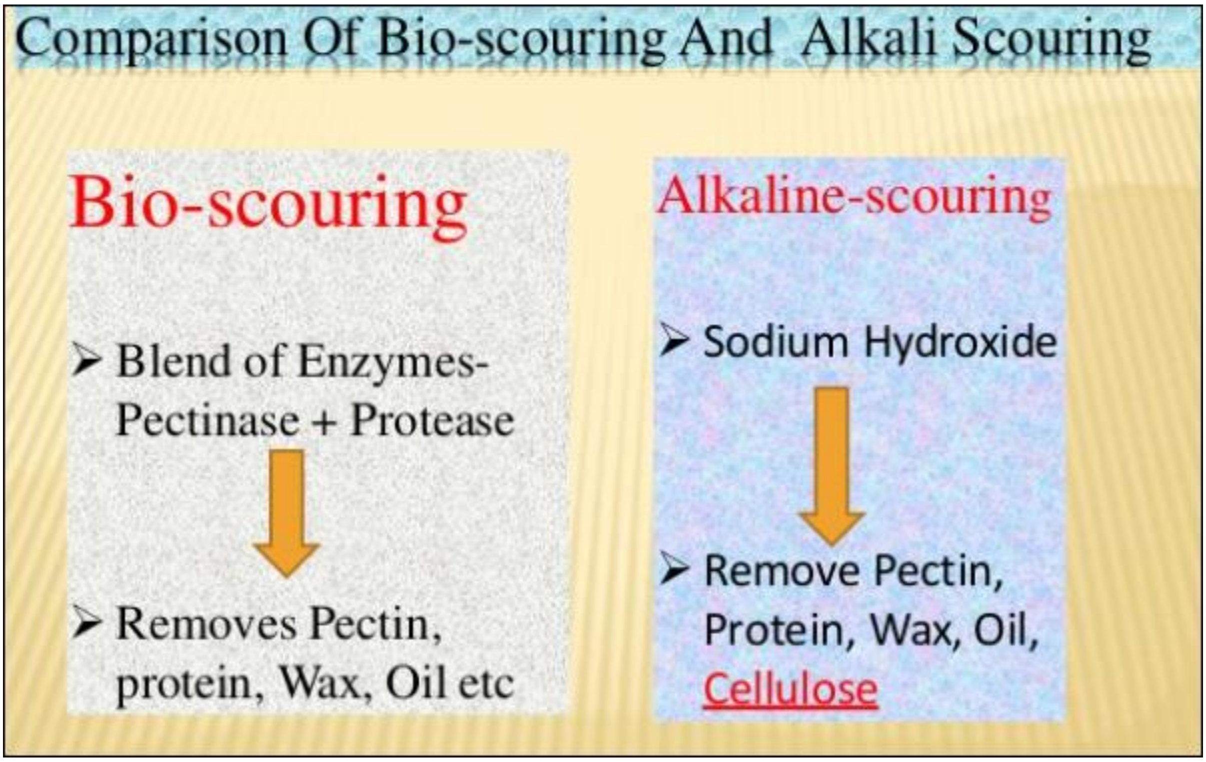
- There is no risk of shrinkage problem, which can be observed in the case of desizing with alkali.
- It is a continuous process, so it is less time-consuming and higher production.
- Fiber damage is significantly less in enzymatic desizing as compared to others.
- Enzymatic desizing is a very economical process.
- Amylase enzyme used in desizing is bio-degradable and environment-friendly. So, the effluent load from this process is much less.

Bio-Scouring (2019,22)

Enzymatic Scouring or Bio-Scouring can be defined as the application of living organisms and their components to remove natural and added impurities. In Textile Processing, the enzymatic removal of impurities also reduces the total chemical consumption and the possibility of an accident.

Enzyme	0.5-1%
Sequestering agent	0.5-1 g/l
Non-ionic detergent	0.5-1 g/l
Temperature	60°C
Time	30 min
M: L	1:10
P^H	6-8

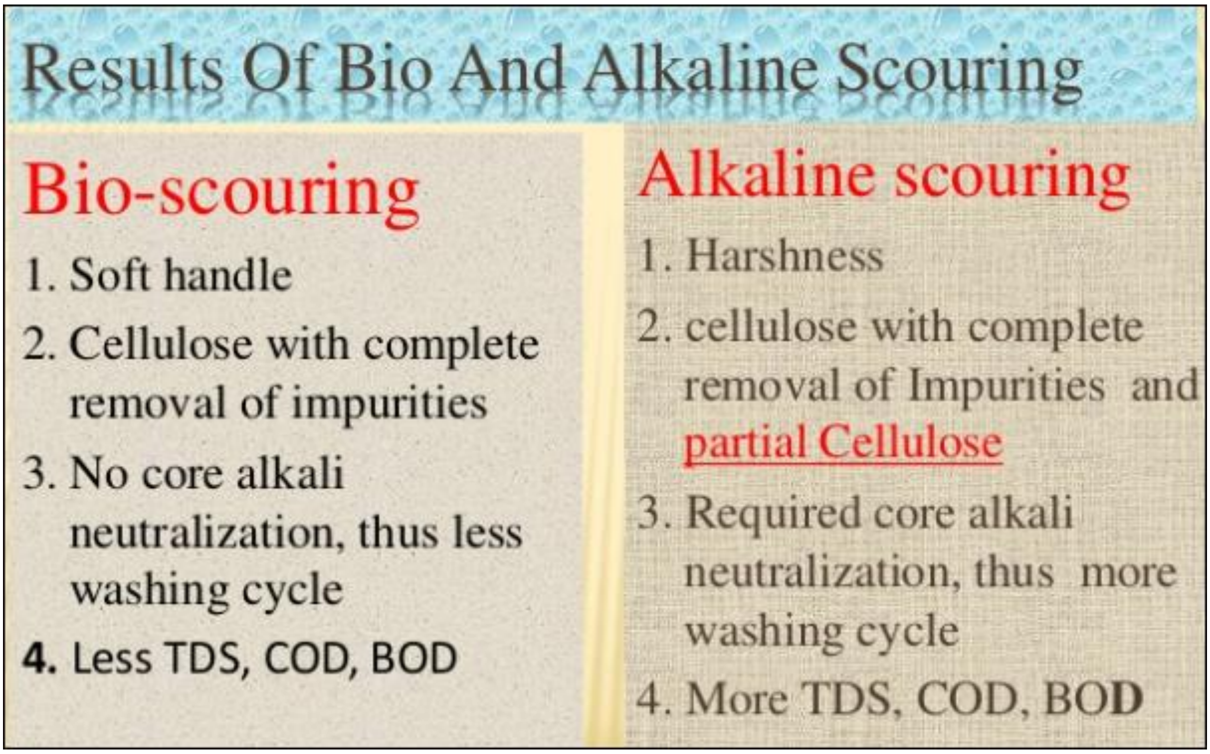
(Process Diagram Important)



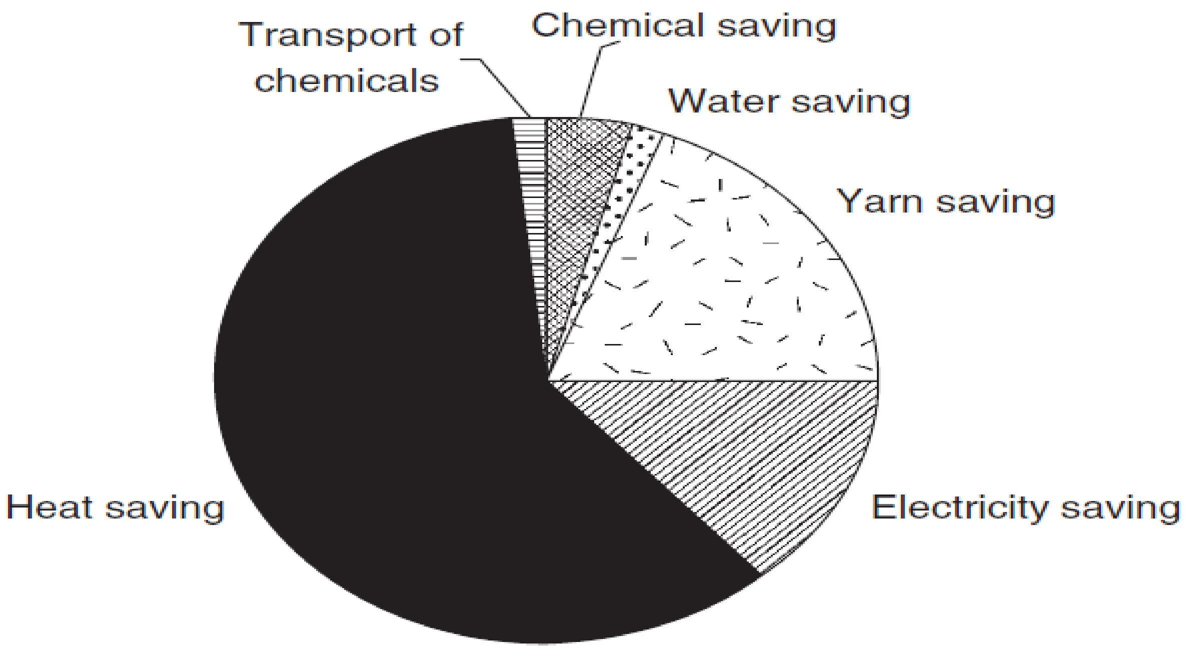
Pectinase: Remove pectin substances

Protease: Catalyse the hydrolysis of protein

Lipase: remove natural fatty substances



Savings through Bio-processing



Bio Bleaching

Bio polishing