STUDY THE EFFECT OF DENIER AND FIBER CUT LENGTH ON ZETA POTENTIAL OF NYLON AND POLYESTER FIBERS FOR SUSTAINABLE DYEING PROCESS

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ABSTRACT

This paper reports zeta potential concerning the surface property of the textile fibers that is crucial for dyeing and finishing process. Zeta potential gives a measure of the average charge density at the surface when measured as a function of pH. These interface phenomena influence the adsorption of dyes and finishing agent due to interaction forces between the fiber surface and the solution. A streaming potential method has been used to determine the zeta potential at the surface of the nylon and polyester fibers in supporting electrolyte solution by Electro Kinetic Analyzer. We have investigated the effect of different fibers parameters like denier (fineness) and length on zeta potential. It is found that lower denier (more fineness) and medium length, is the optimum combination for the higher potential of generating surface charge. A comparative study on the Zeta potential of nylon and polyester fibers is also discussed.

Key Words: Textile fiber, Denier, Length, Zeta potential, Isoelectric point

INTRODUCTION

In textile dyeing process, dye uptake by the fiber is, at least in its initial stages, a surface process. The use of colloidal science methods for analysis of the fiber dye solution interface is of importance for understanding the dyeing and finishing of textile materials. When fibers come in contact with water, produce surface charge may be positive or negative due to specific adsorption of ions or dissociation of surface chemical groups. If the fiber surface and dye molecules both have the same charge results in less dye fixation due to repulsion. However, by adding the electrolyte like sodium chloride or sodium sulphate, the charge repulsion factor can be offset and dye fixation is increased. But the use of high salt concentration and low dye fixation lead to environmental problems related to highly coloured effluent with high salt content. Therefore a dyeing procedure leading to high dye fixation could be a great benefit to minimize the environmental problems. Different approaches, such as modification of dye structure to make it more suitable for a given fiber or controlled dosing of dye and salt during the dyeing processor by changing the surface properties of fibers, have been recommended control the effluent problem.

In case of modification of surface properties of fibers, zeta potential plays an important role in the electrical characterization of the textile fibers. A. M. Grancaric et al. have studied zeta potential of different natural and synthetic fibers in different pH at constant ionic strength. They have reported that hydrophobic fibers are showing higher values of zeta potential in compare to hydrophilic fibers. A Haji et al. have studied surface modification by plasma treatment of nylon fiber to improve zeta potential for better dyeing. C. Bellman et al. studied the effect of fiber swelling on zeta potential of natural fibers. They have found that lesser the swelling of the fibers surface
higher will be the potential of generating surface charge. But there is less information available regarding the effect of fibers parameters on zeta potential. The purpose of this paper is to study the zeta potential of Nylon and polyester fiber to investigate the effects of Fiber cut length and denier on zeta potential that could be used for the sustainable dyeing process to control the environmental pollution.

**MATERIAL AND METHODS**

Mainly two types of textile fibers are used for the experimental study, nylon and polyester supplied by vardhman textile limited. Three different denier of nylon fibers are taken and vary the cut length as mention in **Table 1**.

**Table 1 : Single denier polyester of medium length is used for comparison study**

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Parameters</th>
</tr>
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<tbody>
<tr>
<td>Nylon</td>
<td>Denier: 5D, 7D, 15D, Cut Length: 102 mm, 40 mm, 20 mm</td>
</tr>
<tr>
<td>Polyester</td>
<td>Denier: 5D, Cut Length: 40 mm</td>
</tr>
</tbody>
</table>

**Streaming potential method**

In this method, an electrolyte liquid is forced to pass through a cylindrical cell in which solid phase material (textile) fiber is placed. Due to the movement of liquid streaming potential ( ) and streaming current ( ) are generated and the zeta potential can be quantitatively determined according to Helmholtz-smoluchowsky equations (1) and (2).\(^8\)-\(^10\)

\[
U_p = \frac{\varepsilon \varepsilon_0 Q R \Delta p}{n L} \quad \text{(1)}
\]

Or

\[
\varepsilon = \frac{U_p n L}{\varepsilon \varepsilon_0 Q R \Delta p}
\]

\[
I_p = \frac{\varepsilon \varepsilon_0 Q \Delta p}{n L} \quad \text{(2)}
\]

Or

\[
\varepsilon = \frac{I_p n L}{\varepsilon_0 Q \Delta p}
\]

Where \(U_p\) = streaming potential (mv), \(I_p\) = streaming current, (mA), \(\varepsilon\) = Zeta potential (mv), and the dielectric constant and the vacuum permittivity \((8.853\times10^{-12} \text{ Fm}^{-1})\), \(R\) = electrical resistance (ohm), \(\Delta p\) = pressure difference between inlet and outlet in the system, \(Q\) = cross section of capillary (m²), \(n\) = Dynamic viscosity of solution (Pa s) and \(L\) = length of the capillary (m).

The Electro kinetic analyzer (Anton pair) used in this study operates on this principle, and this apparatus is used mainly to determine the zeta potential of fibrous samples. The measuring cell (Fig. 1) consists of a glass cylinder with inlet and outlet tubes for the electrolyte solution. The fiber sample is mounted between a pair of perforated Ag/AgCl disc electrodes. The electrodes are placed onto moveable pistons, which allow a variation of the distance between these electrodes and

![Fig. 1 : Cylindrical cell for measuring the zeta potential of textile fibers](image-url)
therefore an adjustment of packing density of the fiber sample and 0.001M potassium chloride used as an electrolyte solution. The range of pH value of electrolyte solution was investigated up to a maximum pH 9 with 0.1M sodium hydroxide and it was altered by the dosing 0.1 M Hydrochloric acid up to pH 3. Under influence of given pressure, the electrolyte solution flows through the stationary 1 gram of fiber sample. Hydrodynamic flow of the electrolyte solution through stationary fiber samples causes streaming potential. Accordingly, zeta potential is measured by using the Helmholtz smoluchowsky equations number (1) and (2).

RESULTS AND DISCUSSION

Effect of fiber denier on zeta potential

Change in Zeta potential with pH for three denier of nylon fibers viz. 5D, 7D and 15D with 40 mm cut length is shown in the Fig. 2. It is observed that at higher alkaline pH, 5 denier nylon fiber is showing higher value of negative zeta potential (-48 mV) as compare to 7 and 15 denier nylon fibers (-42 mV, -36 mV).

It is also observed that changing the pH value from the alkaline to acidic, negative zeta potential value is approaching to zero. From Fig. 2 it is seen that different denier of nylon fibers are having different isoelectric point, 5 denier nylon fibers is showing higher isoelectric point (IEP) at pH value 4.6 whereas, in case of 7 and 15 denier of nylon fibers, isoelectric points (IEP) are 3.8 and 3.2 respectively. Nylon fiber is showing positive zeta potential in acidic medium due to the nature of disassociation of surface chemical groups.

At high acidic pH, ionization of -COOH groups are suppressed and -NH₂ groups are protonated.

\[
\begin{align*}
\text{H}_3\text{N}^+ - \text{Nylon} - \text{COOH} & \quad \text{pH} < \text{IEP} \\
\leftrightarrow \text{H}_2\text{N}^+ - \text{Nylon} - \text{COO}^- & \quad \text{pH} = \text{IEP} \\
\text{H}_2\text{N} - \text{Nylon} - \text{COO}^- & \quad \text{pH} > \text{IEP}
\end{align*}
\]

In stronger acidic condition in between polymer chain amide groups are also capable of being protonated that is why nylon fiber showing higher positive surface charge in strong acidic condition and in case of high alkali condition –COOH group is easily ionized to generate negative zeta potential. This indicates that there is a marked effect of denier on the measured zeta potential value of the nylon fiber. It is found that lower the denier higher potential of generation surface charge. Finer fiber is having high specific surface area.
which leads to increase the density of chemical groups at the fiber surface. These surface chemical groups tend to get easily ionized. The effect of fiber cut length on zeta potential

The zeta potential for 5 denier nylon fibers of three cut lengths viz. 120mm, 40mm and 20mm is measured. It can be seen from the Fig. 3 that at alkaline pH all the nylon fibers are showing negative zeta potential of different value. As the pH varies from alkaline to acidic, it shows their zeta potential values are approaching to be positive, as the pH moves to words acidic the zeta potential moves to zero. The pH, at which zeta potential value became zero, is called isoelectric point (IEP). Isoelectric point (IEP) of 5 and 15 denier fibers are almost same that is pH 4.6 and for the 20mm cut length, isoelectric point is pH 4.2. This indicates that the isoelectric point (IEP) of a given fiber is dependent on the cut length of the fiber. Further shifting the pH from 4.6 to acidic, zeta potential value became positive and the rate of increasing of zeta potential value for 40mm cut length is higher compare to 120mm and 20mm cut length. Effect of length on measured zeta potential is significant at high pH, due to lower ionic strength of solution which increases the magnitude of the measured zeta potential. Whereas in case of high acidic pH, the ionic strength varies significantly as the pH varies. This increased ionic strength at lower pH will act to reduce the magnitude of the measured zeta potential.12-14

Fig. 3 : Zeta potential of 5 denier nylon fiber of different length at various pH

Fig. 4 : Zeta potential of nylon and polyester fiber at various pH
Comparative study on zeta potential of nylon and polyester fiber

A comparative study has been done on zeta potential of nylon and polyester fiber of 5 denier at 40mm cut length by varying pH value. In the Fig. 4, it is observed that the nylon fiber is having the potential of generating positive zeta potential in acidic medium higher as compare to polyester. Isoelectric point (IEP) of the nylon fiber is 4.6 and whereas polyester is 3.8. This is because of the differences in chemical groups present on the surface of these two fibers. Polyester is containing -OH functional group and –COOH functional group. At pH 7.8, nylon fiber is showing higher negative zeta potential (-48mV) compare to polyester (-42mV) due to higher hydrophobicity nature. Nylon fiber is made of -CONH₂ group which is more hydrophobic than the –COOH end functional group. Higher the hydrophobicity lesser will be swelling of inner fiber surface, causes the less adsorption of water molecules compare to ions in the aqueous phase.¹⁵⁻¹⁹

CONCLUSION

Electrokinetic properties of textile fibers can be characterized in terms of zeta potential, this measured values are depends upon the fiber cut length and denier of the fiber i.e. surface area of the fiber. From the results it can be concluded that cut length and denier of the fibers have significant effect on the measured zeta potential. Nylon fiber is generating the higher positive charge in acidic pH as compare to polyester due to their surface chemical groups and finer the fiber, higher will be potential of generating surface charge. The lower denier (5D) and medium fiber length (40mm) could be the best combination for a dyeing procedure leading to high dye fixation could be a great benefit to minimize the environmental problems.

REFERENCES


