Dyeing of jute: Effect of progressive removal of hemicellulose and lignin

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Progressive removal of hemicellulose and lignin from jute separately affects the functional group (-CHO and -COOH) pattern and consequently the dyeability of the fibre with respect to an acid and a direct dye. Uptake of direct dye by jute fibre improves on hemicellulose removal while that of acid dye suffers adversely at low levels of hemicellulose removal but improves when about 70% of hemicellulose is removed. Removal of lignin from jute increases its -CHO and -COOH contents and lowers the uptake of both acid and direct dyes by the fibre.

Keywords: Dyeing, Hemicellulose, Jute fibre, Lignin

1 Introduction

Chemical processing of jute has assumed importance in recent years on account of the efforts to diversify the use of jute in newer areas such as decoratives, carpets, soft-luggages and apparels. While considerable literature is available on bleaching of jute, that on jute dyeing is rather scanty. Jute is a multicellular and multiconstituent fibre and apart from α-cellulose (~60%), other two major chemical constituents of jute are hemicellulose (~23%) and lignin (~14%). Besides, a portion of lignin and hemicellulose are reportedly linked chemically through ester linkage formed by the carboxyl groups of hemicellulose and the hydroxyl groups of lignin. During the chemical treatments, such as scouring and bleaching, jute suffers loss of weight mainly due to the losses of hemicellulosic and lignin constituents. The extent and the composition of the material lost depend on the type of chemical treatment to which jute is subjected. It is also known that chemical treatment of jute brings about change in the functional group pattern of the fibre, which, in turn, is likely to affect its dyeability. In the present investigation, an attempt has been made to evaluate the effects of removal of lignin and hemicellulose separately on the dyeability of jute with a direct and an acid dye.

2 Materials and Methods

2.1 Materials

2.1.1 Jute

Lightly combed and dewaxed raw jute fibre (Corchorus olitorius) of TD-2 grade was used.

2.1.2 Chemicals and Dyestuffs

Laboratory reagent grade chemicals and distilled water were used for all chemical treatments. For dyeability studies, Atul direct sky blue FB (C.I. Direct Blue 24410) and Atul acid fast red A (C.I. Acid Red 15620) were used after purification following the method of Robinson and Mills.

2.2 Methods

2.2.1 Dewaxing of Jute

Raw jute fibre was dewaxed with ethyl alcohol-benzene (1:2, v/v) mixture for 6 h in a Soxhlet apparatus, washed successively with ethyl alcohol & distilled water followed by drying in air to obtain dewaxed jute (DJ).

2.2.2 Removal of Lignin and Hemicellulose from Jute

Different degrees of removal of lignin from DJ was effected by treating a part of DJ with 0.7% aqueous NaClO3 solution at 97±2°C for specified durations at pH 4.0 using 1:50 fibre-to-liquor ratio. The treated fibre was antichlored with 2% sodium metabisulphite solution at 50°C for 30 min, washed with water and dried under vacuum at 40°C before weighing.

Jute with progressively lower hemicellulose content was prepared by treating DJ for 1 h at 25°C with 1% and 5% NaOH solutions separately and for 30 min with 7% NaOH under boiling condition (97±2°C) using the fibre-to-liquor ratio of

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1:50 in each case. This was followed by washing with water, neutralization with 1% acetic acid solution, further washing with water till free from acid, and drying under vacuum at 40°C before weighing.

2.2.3 Determination of Major Chemical Constituents and -CHO and -COOH Contents

The major chemical constituents (α-cellulose, hemicellulose and lignin) of the dewaxed and the chemically modified jute fibre samples were determined following the standard procedures and have been expressed on the basis of 100 g of untreated bone-dry jute fibre. The -CHO group content, expressed in terms of copper number, and -COOH group content of the jute fibre samples were determined following the standard methods.

2.2.4 Dyeing

Jute fibre samples, each weighing about 5 g, were dyed with 1% dye (on weight of fibre) at 85 ± 2°C for 120 min, keeping the fibre-to-liquor ratio at 1:50, without using any dyebath assistant in a stoppered borosilicate conical flask. The dyebath was preheated to the specified temperature before entering the fibre sample into it. To determine the rate of dyebath exhaustion, aliquots were removed from the dyebath at selected intervals followed by addition of equal volumes of hot (85 ± 2°C) water to the bath. The per cent exhaustion of the dyebath was determined spectrophotometrically using a Shimadzu UV 3000 spectrophotometer.

2.2.5 Determination of Fibre Fineness

The fineness (tex) of jute/modified jute fibres was determined gravimetrically following the method of Bandopadhyay et al.

3 Results and Discussion

The effects of progressive removal of hemicellulose and lignin separately from jute on its major chemical constituents, copper number, carboxyl value and fibre fineness are shown in Table 1. Fig. 1 shows the effect of progressive removal of hemicellulose from dewaxed jute on its dyeability with the acid and the direct dyes whereas Fig. 2 shows the effect of progressive removal of lignin from dewaxed jute on its dyeability with respect to the same set of dyes.

3.1 Effect of Progressive Removal of Hemicellulose on Dyeability

From Fig. 1a it is apparent that both the equilibrium dyebath exhaustion and the rate of dyebath exhaustion of the acid dye on jute decrease sharply on treatment of dewaxed jute (DJ) with 1% NaOH when the hemicellulose content of jute is brought down from 23% to about 17%. Equilibrium dyebath exhaustion, which is 46% for DJ, drops to about 30% for the treated fibre. However, the equilibrium dyebath exhaustion as well as the rate of exhaustion tends to improve with further removal of hemicellulose and the former reaches a value of 66% when the hemicellulose content of jute is brought down to 6.02%. The lignin content of jute, however, remains virtually unaffected during the hemicellulose removal. The changes in the dyeing behaviour of jute with the progressive removal of hemicellulose as observed above is apparently caused by the changes in the functional group pattern of jute that accompany the removal of hemicellulose as shown in Table 1. It is observed that the carboxyl group content of jute increases significantly on treatment with 1% NaOH when the degree of hemicellulose removal is lowest. However, with progressive increase in

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Treatment</th>
<th>Weight loss %</th>
<th>Fibre fineness tex</th>
<th>Chemical constituents, %</th>
<th>Copper number</th>
<th>COOH group content milli eq/100 g bone-dry sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Dewaxing (Control)</td>
<td>1.0</td>
<td>2.18</td>
<td>60.80 - Hemicellulose 23.00, Lignin 3.60</td>
<td>3.70</td>
<td>11.52</td>
</tr>
<tr>
<td>B</td>
<td>1% NaOH, 25°C, 1 h</td>
<td>6.65</td>
<td>2.00</td>
<td>60.54 - Hemicellulose 17.01, Lignin 13.06</td>
<td>1.98</td>
<td>21.62</td>
</tr>
<tr>
<td>C</td>
<td>5% NaOH, 25°C, 1 h</td>
<td>10.20</td>
<td>1.93</td>
<td>60.48 - Hemicellulose 13.62, Lignin 12.75</td>
<td>1.80</td>
<td>16.33</td>
</tr>
<tr>
<td>D</td>
<td>7% NaOH, 97 ± 2°C, 30 min</td>
<td>18.55</td>
<td>1.75</td>
<td>60.59 - Hemicellulose 6.02, Lignin 12.15</td>
<td>1.45</td>
<td>6.94</td>
</tr>
<tr>
<td>E</td>
<td>0.7% NaClO₂, 97 ± 2°C, 10 min</td>
<td>3.70</td>
<td>2.12</td>
<td>60.58 - Hemicellulose 22.78, Lignin 10.10</td>
<td>3.62</td>
<td>14.85</td>
</tr>
<tr>
<td>F</td>
<td>0.7% NaClO₂, 97 ± 2°, 40 min</td>
<td>7.85</td>
<td>1.99</td>
<td>60.48 - Hemicellulose 22.46, Lignin 6.30</td>
<td>3.98</td>
<td>20.78</td>
</tr>
<tr>
<td>G</td>
<td>0.7% NaClO₂, 97 ± 2°C, 120 min</td>
<td>13.55</td>
<td>1.88</td>
<td>60.67 - Hemicellulose 22.18, Lignin 0.96</td>
<td>4.86</td>
<td>24.68</td>
</tr>
</tbody>
</table>

*All figures are expressed on 100 g of untreated bone-dry jute
the extent of hemicellulose removal, the carboxyl group content shows a decreasing trend. Similar observations have been reported by earlier investigators while studying the effect of alkali treatment on jute. Increase in carboxyl group content of jute on treatment with dilute alkali (~1%) has been attributed to the rupture of lignin-hemicellulose ester linkages, while the lowering of the carboxyl content of jute on higher degree of hemicellulose removal is reportedly caused by the loss of polyuronide component of the hemicellulosic constituent of jute. Lowering in the copper number (−CHO group content) of jute with removal of hemicellulose is a consequence of the loss of low molecular weight components. Thus, apparently the initial sharp fall followed by an increasing trend in the acid dye uptake by jute with the progressive removal of hemicellulose is caused by the change in the −COOH group content of the jute fibre as its lignin content, which is reportedly responsible for its affinity for acid dyes, remains practically unaltered. Exhaustion of the direct dye (Fig. 1b), however, follows an increasing trend with the progressive removal of hemicellulose, apparently as a consequence of a combination of factors such as (i) increase in the concentration of α-cellulose and consequently of primary −OH groups in the fibre which are mainly responsible for the affinity of direct dyes for cellulose fibres, as a result of the removal of hemicelluloses which are branched as well and do not contain any primary −OH group, (ii) lowering of copper number, i.e., aldehydic functionality, and (iii) improvement in fibre fineness. Apparently, these factors more than compensate the effect of increase in −COOH content of the fibre at the initial level of hemicellulose removal and unlike in the case of acid dyeing, no lowering in dyebath exhaustion is observed.

3.2 Effect of Progressive Removal of Lignin on Dyeability

From Fig. 2 it is apparent that equilibrium dyebath exhaustion and rate of dyeing with respect to both acid and direct dyes follow decreasing trends with the progressive removal of lignin from dewaxed jute (DJ). Progressive removal of lignin
from DJ, as observed from Table 1, is also associated with a steady and significant increase in its carboxyl content—a phenomenon also reported earlier\(^2,11\), an increase in its copper number at higher stages of lignin removal and improvement in fibre fineness. Decreasing uptake of acid dye by jute on lignin removal may be attributed to the increase in carboxyl content and decrease in lignin content which is reportedly\(^3\) responsible for the affinity of this class of dye for the fibre. Decreasing uptake of direct dye on lignin removal may similarly be attributed to a combined effect of increase in copper number and carboxyl content of the fibre. It is interesting to note that the uptake of direct dye by the fibres having almost identical carboxyl contents is higher for the fibres with lower hemicellulose content (Table 1, Sample C > E, B > F) implying that the presence of hemicellulose has an adverse effect on the uptake of direct dye by jute.

4 Conclusions
4.1 Removal of either hemicellulose or lignin from jute changes the functional group pattern and consequently the dyeability of the fibre with C.I. Acid Red 15620 and C.I. Direct Blue 24410 in the absence of any dyebath assistant.

4.2 Removal of hemicellulose from jute results in increased uptake of direct dye by the fibre. The uptake of acid dye, though suffers adversely at lower levels of hemicellulose removal (up to 40%), improves substantially when about 70% of hemicellulose is removed.

4.3 Removal of lignin from jute lowers uptake of both direct and acid dyes by the fibres.

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