Hydrogen peroxide and potassium per-oxo-disulphate combined room temperature bleaching of jute, cotton and jute-cotton union fabrics — An energy-efficient ecofriendly process

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A method for room temperature bleaching of jute, cotton and jute-cotton union fabrics using a combination of H\textsubscript{2}O\textsubscript{2} and K\textsubscript{2}S\textsubscript{2}O\textsubscript{8} has been optimized. The measurement of physical properties, such as breaking tenacity, weight loss and surface appearance, including SEM study indicates that the proposed room temperature bleaching process is less damaging to the three types of fabrics studied as compared to conventional hot (85\degree C) H\textsubscript{2}O\textsubscript{2} bleaching. The whiteness index is within the acceptable range. The suggested reaction mechanism indicates that K\textsubscript{2}S\textsubscript{2}O\textsubscript{8} acts as a peroxide booster showing a synergistic action. This room temperature bleaching process is energy efficient, ecofriendly and economical, which can be easily adopted by both small scale and large scale sectors.

Keywords: Cotton, Jute, Jute-cotton union fabric, Peroxide bleaching, Room temperature bleaching, Peroxide booster, Whiteness index

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1 Introduction

Demand for jute and jute-cotton union fabrics based home textiles including furnishing fabrics is gradually increasing due to consumer’s preference for ecofriendly natural fibres. Such fabrics need to be subjected to various chemical processing operations for value addition. Preparatory processes, which include desizing, scouring and bleaching, are important before dyeing, printing or finishing operations. Unlike cotton, jute is a multi-cellular and multi-constituent fibre composed of cellulose, hemicellulose and lignin. Hence, it is difficult to control the action of any oxidative chemicals to any one constituent of jute. That is why, the chemical composition of the bleach-bath and the process parameters meant for cotton are not exactly applicable to jute.\textsuperscript{1,5} It is a known fact that the conventional hot H\textsubscript{2}O\textsubscript{2} bleaching of cotton and jute causes oxidative degradation of the fibre\textsuperscript{3}. The process is also energy consuming. It is thought to minimize the fibre degradation by H\textsubscript{2}O\textsubscript{2} bleaching at room temperature. A few studies on ambient temperature bleaching of jute at the fibre and yarn stage and low-temperature bleaching of cotton fabric have been reported in literature.\textsuperscript{4-12} However, the same has not been studied on jute-cotton union fabrics.

In the present study, attempts have been made to optimize the bleach-bath composition and the process parameters for room temperature bleaching of jute, cotton and jute-cotton union fabrics using a combination of H\textsubscript{2}O\textsubscript{2} and K\textsubscript{2}S\textsubscript{2}O\textsubscript{8}. A tentative mechanism for the effect of K\textsubscript{2}S\textsubscript{2}O\textsubscript{8} in boosting the action of H\textsubscript{2}O\textsubscript{2} has also been proposed and discussed.

2 Materials and Methods

2.1 Materials

2.1.1 Fabrics

Ex-loom plain weave raw jute, cotton and jute-cotton union fabrics of the specifications (i) jute — 63 ends/dm, 59 picks/dm, 260 g/m\textsuperscript{2} (raw), 240 g/m\textsuperscript{2} (desized and scoured), 195 tex (warp), 214 tex (weft), and 0.90 mm thickness; (ii) jute-cotton (75:25 w/w) — 80 ends/dm, 70 picks/dm, 280 g/m\textsuperscript{2} (raw), 260 g/m\textsuperscript{2} (desized and scoured), 420 tex (warp), 185 tex (weft), and 0.70 mm thickness; and (iii) cotton — 216 ends/dm, 216 picks/dm, 106 g/m\textsuperscript{2} (raw), 102 g/m\textsuperscript{2} (desized and scoured), 35 tex (warp), 17 tex (weft), and 0.16 mm thickness, were used for the study.
2.1.2 Chemicals
Commercial grade hydrochloric acid (1N, 3.6%), sodium carbonate, sodium hydroxide pellets (assay 98%), sodium metasilicate (Na₂SiO₃.5H₂O), potassium per-oxo-disulphate (K₂S₂O₈), hydrogen peroxide (50% strength), ethylenediaminetetraacetic acid (EDTA), non-ionic wetting agent (Lissapol-D) and non-ionic detergent (Nonidet P-40), obtained commercially, were used. Stabilizer-AWNI (diethylene-triamine-pentamethylene phosphate, a non-silicate organo-phosphate based peroxide stabilizer) supplied by M/s Clariant was used.

2.2 Methods

2.2.1 Desizing
Desizing of the jute, cotton and jute-cotton union fabrics was done employing 20-30 mL/L of aqueous solution of 3.6% HCl (0.5% owf) at 60°C for 1 h using a laboratory jigger, keeping the material-to-liquor ratio at 1:5 (w/v). After desizing, the fabrics were thoroughly washed with hot and normal water and finally dried in air.

2.2.2 Scouring
Raw or desized fabrics were scoured in a lab-jigger using 4 g/L of soda; 1g/L detergent; 1:5 MLR; 8-9 pH; 80°C (jute) and 100°C (cotton and jute-cotton) temp; and 30 min (jute), 60 min (jute-cotton) and 120 min (cotton) treatment time. After scouring, all the fabric samples were washed thoroughly in hot and normal water and finally dried in air.

2.2.3 Conventional Hot Hydrogen Peroxide Bleaching
Raw (control) or suitably desized/scoured fabrics were subjected to conventional hot H₂O₂ bleaching in a lab-jigger using 3% owf (jute), 2% owf (jute-cotton) and 1.5% owf (cotton) H₂O₂; 8% owf (jute), 6% owf (jute-cotton) and 4% owf (cotton) Na₂SiO₃; 0.7% owf (jute and jute-cotton) and 0.3% owf (cotton) NaOH; 10.5 pH; 0.05% owf EDTA; 0.05% owf wetting agent; 1:5 MLR, 2 h treatment time; and 85°C temp.

In each of the above cases, the pH of the bleach bath was maintained by adding small amounts of 1% NaOH drop-wise. After bleaching, each fabric sample was washed thoroughly under running water, followed by neutralization with 1.5% acetic acid solution for 15 min, before further washing with hot and normal water. Finally, the washed fabric samples were dried in air.

2.2.4 H₂O₂ and K₂S₂O₈ Combined Bleaching at Room Temperature
Room temperature bleaching was accomplished under the combined oxidative action of H₂O₂ and K₂S₂O₈ as dual oxidative agents, H₂O₂ being the main bleaching agent and K₂S₂O₈ being a peroxide booster at room temperature (30°C) using higher concentration of alkali (NaOH) in standing exhaust bath system for 2-12 h. To optimize the bleaching recipe and treatment conditions, the experiment was carried out using varying concentrations of H₂O₂, potassium persulphate (K₂S₂O₈), NaOH, wetting agent, sodium metasilicate (stabilizer) and/or Stabilizer-AWNI and different treatment time at room temperature (30°C). Each fabric was also subjected to room temperature bleaching by pad-roll technique for subsequent evaluation of their properties and cost comparison.

2.2.5 Determination of Weight Loss and Moisture Regain
Weight loss of the treated fabrics was determined by the usual oven dry weight method taking bone dry weight of the samples before and after the treatment and expressing the results as a percentage of the initial bone dry weight of the sample without treatment. The moisture regain of a selected oven dry jute fabric sample was determined according to the standard method.

2.2.6 Measurement of Bending Length
The bending length of the selected fabric samples in both warp and weft directions was measured as per the standard test method using Cantilever type Sasmira fabric stiffness tester with a specimen size of 200 mm × 25 mm.

2.2.7 Measurement of Breaking Tenacity and Breaking Extension
Warp-way and weft-way breaking tenacity (cN/tex) and the breaking extension (%) of selected fabric samples were measured by the ravelled strip method as per the standard procedure using an Instron (Model-1445) CRT-Universal tensile tester with a traverse speed of 100 mm/min and a pretension of 0.5 N.

2.2.8 Measurement of Whiteness and Brightness Indices
Whiteness index as per Hunter Lab-Scale formula and CIE (1976) Lab-Scale formula (for cotton fabric only as per convention), and brightness index as per ISO-standard formula of the selected fabric samples were directly evaluated using a computer aided Macbeth 2020 plus reflectance spectrophotometer (with D₆₅ standard illuminant and
10° standard observer setting) and associated colour measurement software.

2.2.9 Determination of Copper Number
Copper number (a measure of aldehyde group content in the cellulose and/or hemicellulose molecular chain) of selective jute and cotton fibre samples taken out from the corresponding untreated and treated fabrics was estimated as per Schwalbe-Braidy method.26,27

2.2.10 Scanning Electron Microscopic Study
The surface morphology of jute and cotton fibre samples taken out from the corresponding untreated and treated fabrics was examined according to the prescribed procedure28 after gold-palladium alloy coating using JEOL scanning electron microscope (Model JSM-5200) at an operating voltage of 20 kV, using a magnification of ×1000.

3 Results and Discussion
Initially a study was carried out to assess the oxidative action of \( \text{H}_2\text{O}_2 \) and \( \text{K}_2\text{S}_2\text{O}_8 \), separately and in combination, on jute fabric under different conditions of treatment and the relevant results are shown in Table 1. It can be observed that 1% \( \text{K}_2\text{S}_2\text{O}_8 \) treatment of jute fabric at room temperature (30°C) and treated fabrics was examined according to the prescribed procedure28 after gold-palladium alloy coating using JEOL scanning electron microscope (Model JSM-5200) at an operating voltage of 20 kV, using a magnification of ×1000.

### Table 1— Effect of \( \text{H}_2\text{O}_2 \) and \( \text{K}_2\text{S}_2\text{O}_8 \) treatment separately and in combination under different conditions on properties of jute fabrics

<table>
<thead>
<tr>
<th>Expt. No.</th>
<th>Treatment Description</th>
<th>Breaking Tenacity cN/tex</th>
<th>Breaking Extension %</th>
<th>Bending Length cm</th>
<th>Whiteness Index (Hunter Lab-scale)</th>
<th>Brightness Index (ISO-2470)</th>
<th>Copper Number</th>
<th>Weight Loss %</th>
<th>Moisture Regain %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nil (desized &amp; scoured) (control)</td>
<td>7.04</td>
<td>6.41</td>
<td>5.92</td>
<td>5.75</td>
<td>2.06</td>
<td>3.8</td>
<td>48.50</td>
<td>18.63</td>
</tr>
<tr>
<td>2</td>
<td>3% (owf) ( \text{H}_2\text{O}_2 ) for 2 h at 30°C (pH 10.5)</td>
<td>6.83</td>
<td>6.20</td>
<td>6.04</td>
<td>5.80</td>
<td>3.7</td>
<td>56.60</td>
<td>30.24</td>
<td>3.30</td>
</tr>
<tr>
<td>3</td>
<td>3% (owf) ( \text{H}_2\text{O}_2 ) for 2 h at 85°C (pH 10.5)</td>
<td>6.66</td>
<td>6.06</td>
<td>6.12</td>
<td>5.85</td>
<td>2.72</td>
<td>3.5</td>
<td>70.20</td>
<td>32.65</td>
</tr>
<tr>
<td>4</td>
<td>1% (owf) ( \text{K}_2\text{S}_2\text{O}_8 ) for 1 h at 30°C (pH 5.5)</td>
<td>5.98</td>
<td>5.46</td>
<td>6.30</td>
<td>5.94</td>
<td>4.60</td>
<td>3.5</td>
<td>43.30</td>
<td>14.90</td>
</tr>
<tr>
<td>5</td>
<td>1% (owf) ( \text{K}_2\text{S}_2\text{O}_8 ) for 2 h at 30°C (pH 5.5)</td>
<td>5.66</td>
<td>5.22</td>
<td>6.40</td>
<td>6.02</td>
<td>5.40</td>
<td>3.4</td>
<td>40.20</td>
<td>13.20</td>
</tr>
<tr>
<td>6</td>
<td>Sequential treatment with 1% (owf) ( \text{K}_2\text{S}_2\text{O}_8 ) for 1 h at 30°C (pH 5.5) followed by 3% (owf) ( \text{H}_2\text{O}_2 ) for 2 h at 30°C (pH 10.5)</td>
<td>5.38</td>
<td>5.04</td>
<td>6.62</td>
<td>6.08</td>
<td>5.80</td>
<td>3.2</td>
<td>63.23</td>
<td>34.82</td>
</tr>
<tr>
<td>7</td>
<td>Simultaneous treatment with 1% (owf) ( \text{K}_2\text{S}_2\text{O}_8 ) and 3% (owf) ( \text{H}_2\text{O}_2 ) for 2 h at 30°C (pH 9.8) with 2.5% NaOH</td>
<td>6.20</td>
<td>5.90</td>
<td>6.20</td>
<td>5.40</td>
<td>3.00</td>
<td>3.40</td>
<td>62.20</td>
<td>35.62</td>
</tr>
<tr>
<td>8</td>
<td>Simultaneous treatment with 1% (owf) ( \text{K}_2\text{S}_2\text{O}_8 ) and 3% (owf) ( \text{H}_2\text{O}_2 ) for 2 h at 30°C (pH 8.0) with 0.7% NaOH</td>
<td>6.40</td>
<td>5.83</td>
<td>5.70</td>
<td>5.21</td>
<td>3.20</td>
<td>3.4</td>
<td>60.50</td>
<td>36.51</td>
</tr>
<tr>
<td>9</td>
<td>Simultaneous treatment with 1% (owf) ( \text{K}_2\text{S}_2\text{O}_8 ) and 3% (owf) ( \text{H}_2\text{O}_2 ) for 6 h at 30°C (pH 9.8) with 2.5% NaOH</td>
<td>5.95</td>
<td>5.65</td>
<td>5.01</td>
<td>4.82</td>
<td>3.80</td>
<td>3.4</td>
<td>65.20</td>
<td>38.51</td>
</tr>
<tr>
<td>10</td>
<td>Simultaneous treatment with 1% (owf) ( \text{K}_2\text{S}_2\text{O}_8 ) and 3% (owf) ( \text{H}_2\text{O}_2 ) for 6 h at 30°C (pH 8.0) with 0.7% NaOH</td>
<td>5.40</td>
<td>5.50</td>
<td>5.90</td>
<td>5.41</td>
<td>3.50</td>
<td>3.5</td>
<td>55.64</td>
<td>22.60</td>
</tr>
</tbody>
</table>

a With additives of 8% sodium metasilicate, 0.7% NaOH, 0.5% wetting agent and 0.05% EDTA.
b After use of \( \text{K}_2\text{S}_2\text{O}_8 \) in the \( \text{H}_2\text{O}_2 \) bleach-bath, a higher amount of alkali (2.5% instead of 0.7%) was used to get the pH nearly 9.8-10.0, other chemical auxiliaries remain same as above.
for 1-2 h at pH 5.5 (Expt. 4 and 5) does not produce any significant bleaching (whitening) action; rather it reduces the whiteness and brightness indices. However, 3% (owf) H₂O₂ treatment of jute fabric at 30°C for 2 h at pH 10.5 with the usual bleach-bath additives (Expt. 2) produces insufficient improvement in whiteness and brightness indices; while the same treatment when carried out by conventional hot (85°C) H₂O₂ bleaching (Expt. 3) produces a whiteness index up to 70.2 (Hunter Lab-scale) along with a consequent higher increase in the brightness index. Moreover, the sequential treatment of the jute fabric with 1% (owf) K₂S₂O₈ for 1 h at 30°C followed by 3% (owf) H₂O₂ treatment for 1 h at 30°C (Expt. 6) shows relatively higher damage of the jute fabric as indicated by much higher copper number, higher loss in fabric tenacity and less improvement in whiteness. On the other hand, when the same treatment is carried out simultaneously in a single bath for 2 h (Expt. 7 and 9) at 30°C with higher amount of alkali (2.5% NaOH), a synergetic effect is obtained, showing higher improvement in whiteness index, less loss in tenacity consequent to less damage of the jute fabric. The same simultaneous treatment with 0.7% NaOH (Expt. 8 and 10) does not produce the accepted level of whiteness.

The above study showed the need to examine the possible mechanism of the observed synergetic action of H₂O₂ and K₂S₂O₈ combined room temperature bleaching of cellulosic / ligno-cellulosic textiles.

3.1 Reaction Mechanism of Combined Oxidative Action of H₂O₂ and K₂S₂O₈

In the presence of an alkali pH (~10.5), H₂O₂ usually produces per hydroxyl (HO₂⁻) ions as bleaching species with the help of thermal energy, which, in turn, produce nascent oxygen for the oxidation of coloured materials, thereby rendering a bleaching effect (Scheme 1a and 1b). At room temperature (30°C), the said decomposition of H₂O₂ is very slow and the bleaching (whitening) effect is not sufficient (Table 1). However, with the use of appropriate dosages of H₂O₂ and K₂S₂O₈ in combination under the presence of sufficient alkali, the bleaching action of H₂O₂ is accelerated due to the peroxide boosting action by persulphate (S₂O₈²⁻) ions (K₂S₂O₈ acts as a peroxide booster) which provides additional nascent oxygen to the aqueous solution and acts as a mild oxidizing agent²⁹ (Scheme 1c) even at 30°C.

At pH 8-8.5, the stability of H₂O₂ is of a higher order and it hardly gets dissociated.³ Again, at a much higher pH (> 10.5), the dissociation of H₂O₂ is increased largely liberating oxygen and consequently the effective concentration of perhydroxyl ion gets decreased, thereby lowering the bleaching efficiency. At a medium alkaline pH (9.0-10.5), the degradation of jute or cellulose fibre is much less, since the liberation of nascent oxygen is controlled in a steady fashion.³ Therefore, the combined oxidative action of H₂O₂ and K₂S₂O₈ is expected to give good results at 9.0-10 pH. Hence, all the combined oxidative bleaching using H₂O₂ and K₂S₂O₈ combination at room temperature was carried out at pH 9.0-10.0.

K₂S₂O₈ also decomposes²⁹ in the presence of heat to produce oxygen molecules (Scheme 2) and hence acts as strong oxidizing agent, which may cause reasonable damage to cellulosic or ligno-cellulosic fibres. Therefore, K₂S₂O₈ treatment in the presence of thermal energy should be avoided.

Besides usual generation of free radical by S₂O₈²⁻ ion on its decomposition to SO₄²⁻ (which is not applicable in this case), an additional reaction of S₂O₈²⁻ ion involving participation of water molecules (in aqueous system) particularly with lowering of pH (below 10.0), due to favorable attraction between the opposite ionic species (Schemes 3b and 3d) becomes increasingly important.³⁰

The OH radical thus formed (Schemes 3c and 3d) in aqueous medium at room temperature may survive by regenerated transfer mechanism and it may suffer limited self anihilation, generating oxygen and water.
via decomposition of $\text{H}_2\text{O}_2$ formed as an intermediate\textsuperscript{30} (Scheme 3e), that is known to have higher stability with lowering of pH. A medium alkaline pH (9-10) favours this reaction, resulting in formation of $\text{H}_2\text{O}_2$ intermediate and an increase in pH favours more generation of oxygen. Above $\text{pH} \geq 10$, the rate of this reaction is much reduced\textsuperscript{30} and it becomes less relevant or practically negligible. Thus, in between $\text{pH} 9$ and $\text{pH} 10$, the $\text{K}_2\text{S}_2\text{O}_8$ is expected to act as a good peroxide booster, accomplishing the above reactions, particularly those as given in Schemes 1c and 3a-e.

At a $\text{pH} 9.5-10.0$, the bleaching action is satisfactory, at $\text{pH} < 9$, the bleaching action is not significant and at a $\text{pH} > 10$, the degradation of cellulose/hemicellulose is higher causing more weight loss and drop in tenacity (Table 1). Hence, the use of required amount of alkali along with correct dosages of sodium metasilicate or stabilizer-AWNI (as pH controller cum peroxide stabilizer) and optimization of other process variables have been felt essential.

3.2 Optimization of Process Variables of Low-temperature $\text{H}_2\text{O}_2$-$\text{K}_2\text{S}_2\text{O}_8$ Combination bleaching

3.2.1 Variation in $\text{H}_2\text{O}_2$ Concentration

The effects of $\text{H}_2\text{O}_2$ conc. on fabric properties are shown in Fig. 1A. In general, with an increase in $\text{H}_2\text{O}_2$ conc., there is an increase in the whiteness and brightness indices, weight loss and breaking extension, but a decrease in breaking tenacity and bending length for all the three types of fabrics. However, it shows that the optimum concentrations of

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Scheme 3 — Action of $\text{S}_2\text{O}_8^-$ ions producing \textit{in-situ} $\text{H}_2\text{O}_2$ via generation of $\text{SO}_4^-$ and OH radicals for boosting the $\text{H}_2\text{O}_2$ and $\text{K}_2\text{S}_2\text{O}_8$ combined bleaching action at room temperature

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Fig. 1 — Effects of concentration of hydrogen peroxide (A), potassium per-oxo-di-sulphate (B) and sodium hydroxide (C) used for room temperature bleaching on the properties of jute, cotton and jute-cotton union fabrics [y-axis (left): (–□–) jute, (–△–) cotton and (–o–) jute-cotton; and y-axis (right): (–■–) jute, (–▲–) cotton and (–•–) jute-cotton. Dotted lines indicate corresponding data in weft direction for jute-cotton union fabric]
H$_2$O$_2$ for energy-efficient room temperature bleaching of jute, cotton and jute-cotton union fabrics is respectively found to be 3%, 1.5% and 2.0% for 6 h treatment time at pH 9.8, 9.6 and 9.7; when other variables are prefixed. The use of H$_2$O$_2$ above this optimum concentration and pH results in a higher degradative action on cellulose/hemicellulose present in the constituent fibres, as is indicated by a higher drop in tenacity and shows a marginal or much less improvement in whiteness and brightness indices.

3.2.2 Variation in K$_2$S$_2$O$_8$ Concentration

Studies on effects of K$_2$S$_2$O$_8$ conc. on relevant fabric properties are shown in Fig. 1B. With an increase in K$_2$S$_2$O$_8$ conc., a similar trend as mentioned in the case of H$_2$O$_2$ is observed. However, it shows that the use of 0.75% (owf) K$_2$S$_2$O$_8$ for jute and 0.5% (owf) K$_2$S$_2$O$_8$ for cotton and jute-cotton union fabrics is found to be optimum, when the respective optimum concentration of H$_2$O$_2$ is 3% (owf) for jute, 1.5% for cotton and 2.0% (owf) for jute-cotton union fabrics. However, for all the three types of fabrics, the use of a higher dose of K$_2$S$_2$O$_8$ (> 0.75%) causes an adverse effect on the property parameters of each type of the fabric.

3.2.3 Variation in Sodium Hydroxide Concentration

To study the role of NaOH in the room temperature bleach bath, varying concentration of sodium hydroxide (to maintain the pH between 9.5 and 10) was added in bleach bath, keeping other variables prefixed and the effects of such variations of NaOH on fabric properties are shown in Fig. 1C. The optimum concentration of NaOH is found to be 2.5% (owf) for jute fabric and 2.0% (owf) for both cotton and jute-cotton union fabrics. The use of higher concentrations of NaOH than the optimum level causes surface darkening effect impairing the whiteness and brightness indices particularly for jute fabric due to the known alkaline browning of jute.$^{4,10}$ Also, the excess of NaOH moves the pH of the bleach bath above 10, and the peroxide boosting action of K$_2$S$_2$O$_8$ is reduced as also discussed in section 3.1, thereby reducing the whitening action of jute, cotton and jute-cotton union fabrics.

3.2.4 Variation in Concentration of Peroxide Stabilizers

In this case, varying concentration of sodium metasilicate stabilizer (common stabilizer) and organo-phosphate stabilizer (stabilizer-AWNI) as

![Fig. 2 — Effects of concentration of Stabilizer-AWNI (A), sodium metasilicate stabilizer (B), wetting agent (C) and treatment time (D) used for low temperature bleaching on the properties of jute, cotton and jute-cotton union fabrics [y-axis (left): (–□–) jute, (–△–) cotton and (–○–) jute-cotton; and y-axis (right): (–•–) jute, (–▲–) cotton and (–♦–) jute-cotton. Dotted lines indicate corresponding data in weft direction for jute-cotton union fabric]
peroxide decomposition controller and pH controller has been used in the bleach bath, keeping other variables prefixed and the effects of such variation on fabric properties are shown in Figs 2A and 2B.

The efficacy of stabilizer-AWNI (Fig. 2A) has been found to be much higher than sodium metasilicate stabilizer (Fig. 2B), and hence the required optimum concentration of stabilizer-AWNI (2% for jute, 1.5% for cotton and 2% for jute-cotton) is much lower than the dosages required for sodium metasilicate (8% for jute, 4% for cotton and 6% for jute-cotton), to achieve comparable level of whiteness. Use of higher dosages of sodium metasilicate or stabilizer-AWNI than the respective optimum concentration level impairs the whiteness and brightness indices of all the fabrics; the effect is more prominent when higher dosage of sodium metasilicate is used. This is probably due to re-deposition of silica particles from sodium metasilicate on the fabric surface.

3.2.5 Variation in Concentration of Wetting Agent

Under comparable conditions of treatment, a minimum dose level of the wetting agent is found to be beneficial for achieving optimum level of whitening at shorter optimum time period in the room temperature bleaching process. Hence, varying concentration of wetting agent was used in the bleach-bath, keeping other variables prefixed and the effects of such variation on fabric properties are shown in Fig. 2C.

The observed optimum concentration of the wetting agent for room temperature bleaching process is found to be 0.5% (owf) for each of the three types of fabrics.

3.2.6 Variation in Treatment Time

The effect of variation in treatment time on fabric properties for room temperature bleaching keeping other variables prefixed has been studied and the relevant results are shown in Fig. 2D. The higher treatment period though results in a much higher increase in weight loss and consequent higher drop in tenacity and bending length, the improvement in whiteness and brightness indices is not as promising as expected beyond a certain treatment time. The optimum time period for the room temperature bleaching process is found to be 6, 4 and 5 h respectively for jute, cotton and jute-cotton union fabrics.

3.3 Comparison between Conventional Hot H2O2 Bleaching and Room Temperature H2O2-K2S2O8 Combined Bleaching

Changes in important textile-related properties after the room temperature bleaching of jute (Expt. 11), cotton (Expt. 14) and jute-cotton union (Expt. 17) fabrics maintaining their respective optimum conditions of treatment and after the conventional hot (85°C) H2O2 bleaching of jute (Expt. 12), cotton (Expt. 15) and jute-cotton union (Expt. 18) fabrics have been evaluated and compared in Table 2. It is observed that the H2O2 and K2S2O8 combined bleaching offers some net advantages over conventional hot H2O2 bleaching for each type of fabric particularly in terms of lower weight loss and drop in tenacity observed (Table 2). However, the improvement in whiteness index is, to some extent, less in the room temperature bleaching process as compared to that in conventional hot bleaching process for each type of fabrics, more so particularly for jute and jute-cotton union fabrics. Lower weight loss and a marginally higher tenacity retention with a similar level of reduction in bending length are the major property advantages obtained by this room temperature bleaching process for each type of fabrics. Besides these technical advantages, the room temperature bleaching is an energy-efficient and cost saving process. A comparison of process cost for bleaching jute fabric by conventional H2O2 bleaching and room temperature H2O2-K2S2O8 combined bleaching (considering pad-roll technique) is given in Table 3, which shows a net saving of Rs 1.50/kg for bleaching jute fabric by the room temperature bleaching over the process cost of conventional hot bleaching. This room temperature bleaching process may thus prove to be suitable for both the centralized sector as well as the rural based handloom/decentralized sector. Moreover, the action of H2O2-K2S2O8 combination during room temperature bleaching for a longer duration (4-6 h) produces more aldehyde (dialdehyde cellulose) groups as indicated by the higher copper number than in conventional hot H2O2 bleaching for 2 h. The same is further supported by marginally higher moisture regain value obtained in case of room temperature bleaching of all the three types of fabrics. The reason for higher copper number and lower weight loss in
Table 2 — Comparison of important textile-related properties of jute, cotton and jute-cotton union fabric for room temperature \( \text{H}_2\text{O}_2-K_2\text{S}_2\text{O}_3 \) combined bleaching and conventional hot \( \text{H}_2\text{O}_2 \) bleaching

<table>
<thead>
<tr>
<th>Expt. No.</th>
<th>Treatment Description</th>
<th>Initial ( \text{pH} )</th>
<th>Breaking tenacity cNtex</th>
<th>Breaking extension %</th>
<th>Berding length cm</th>
<th>Whiteness index (Hunter Lab-scale)</th>
<th>Brightness index (ISO-2470)</th>
<th>Weight loss %</th>
<th>Copper number</th>
<th>Moisture regain %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Warp</td>
<td>Weft</td>
<td>Warp</td>
<td>Weft</td>
<td>Warp</td>
<td>Weft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Nil (desized &amp; scoured) (control)</td>
<td>9.8</td>
<td>6.73</td>
<td>6.05</td>
<td>6.55</td>
<td>5.26</td>
<td>2.8</td>
<td>3.5</td>
<td>67.0</td>
<td>38.94</td>
</tr>
<tr>
<td>11</td>
<td>Room temperature bleaching [3% ( \text{H}_2\text{O}_2 ), 0.75% ( K_2\text{S}_2\text{O}_3 ), 8% sodium metasilicate, 2.5% NaOH, 0.5% wetting agent, 0.05% EDTA, at 30°C for 6 h]</td>
<td>10.8</td>
<td>6.66</td>
<td>6.06</td>
<td>6.12</td>
<td>6.83</td>
<td>2.8</td>
<td>3.4</td>
<td>70.2</td>
<td>44.30</td>
</tr>
<tr>
<td>12</td>
<td>Conventional bleaching [3% ( \text{H}_2\text{O}_2 ), 8% sodium metasilicate, 0.7% NaOH, 0.5% wetting agent, 0.05% EDTA, at 85°C for 2 h]</td>
<td>-</td>
<td>4.88</td>
<td>3.37</td>
<td>6.96</td>
<td>10.10</td>
<td>1.8</td>
<td>1.5</td>
<td>77.3 (27.4)</td>
<td>55.21</td>
</tr>
<tr>
<td>13</td>
<td>Nil (desized &amp; scoured) (control)</td>
<td>9.6</td>
<td>4.62</td>
<td>3.08</td>
<td>7.30</td>
<td>10.57</td>
<td>1.6</td>
<td>1.3</td>
<td>80.8 (36.4)</td>
<td>61.52</td>
</tr>
<tr>
<td>14</td>
<td>Room temperature bleaching [1.5% ( \text{H}_2\text{O}_2 ), 0.5% ( K_2\text{S}_2\text{O}_3 ), 4% sodium metasilicate, 2% NaOH, 0.5% wetting agent, 0.05% EDTA, at 30°C for 4 h]</td>
<td>10.0</td>
<td>4.42</td>
<td>3.09</td>
<td>7.18</td>
<td>10.74</td>
<td>1.6</td>
<td>1.2</td>
<td>86.4 (41.5)</td>
<td>72.23</td>
</tr>
<tr>
<td>15</td>
<td>Conventional bleaching [1.5% ( \text{H}_2\text{O}_2 ), 4% sodium metasilicate, 0.3% NaOH, 0.5% wetting agent, 0.05% EDTA, at 85°C for 2 h]</td>
<td>-</td>
<td>2.41</td>
<td>7.82</td>
<td>10.43</td>
<td>3.26</td>
<td>1.6</td>
<td>1.0</td>
<td>52.0</td>
<td>24.20</td>
</tr>
<tr>
<td>16</td>
<td>Nil (desized &amp; scoured) (control)</td>
<td>9.7</td>
<td>2.21</td>
<td>7.34</td>
<td>10.35</td>
<td>3.49</td>
<td>1.4</td>
<td>1.3</td>
<td>68.5</td>
<td>47.34</td>
</tr>
<tr>
<td>17</td>
<td>Room temperature bleaching [2% ( \text{H}_2\text{O}_2 ), 0.5% ( K_2\text{S}_2\text{O}_3 ), 6% sodium metasilicate, 2% NaOH, 0.5% wetting agent, 0.05% EDTA, at 33°C for 5 h]</td>
<td>10.8</td>
<td>2.18</td>
<td>7.29</td>
<td>13.57</td>
<td>5.80</td>
<td>1.4</td>
<td>1.3</td>
<td>73.1</td>
<td>50.23</td>
</tr>
<tr>
<td>18</td>
<td>Conventional bleaching [2% ( \text{H}_2\text{O}_2 ), 6% sodium metasilicate, 0.7% NaOH, 0.2% wetting agent, 0.05% EDTA, 85°C for 2 h]</td>
<td>-</td>
<td>4.88</td>
<td>3.37</td>
<td>6.96</td>
<td>10.10</td>
<td>1.8</td>
<td>1.5</td>
<td>77.3 (27.4)</td>
<td>55.21</td>
</tr>
</tbody>
</table>

*Data in the parentheses are the corresponding whiteness indices in CIE 1976.*

*(J) stands for the jute part only in jute-cotton union fabric.*

*(C) stands for the cotton part in jute-cotton union fabric.*
Table 3 — Comparative cost structure for conventional hot (85°C) H₂O₂ bleaching and room temperature H₂O₂-K₂S₂O₈ combined bleaching of jute fabric

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional H₂O₂ bleaching</th>
<th>Room temperature bleaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical cost, Rs/kg of fabric</td>
<td>4.50</td>
<td>5.50</td>
</tr>
<tr>
<td>Water requirement, L/kg of fabric</td>
<td>75-80</td>
<td>75-80</td>
</tr>
<tr>
<td>Associated cost (@ Rs 10/L)</td>
<td>0.75-1.00</td>
<td>0.75-1.00</td>
</tr>
<tr>
<td>Steam requirement, kg/kg of fabric</td>
<td>2.5-3.0</td>
<td>Nil</td>
</tr>
<tr>
<td>Associated cost (@ Rs 0.90/kg of steam)</td>
<td>2.25-2.70</td>
<td>Nil</td>
</tr>
<tr>
<td>Power cost for running jigger or padding mangle, Rs/kg of fabric</td>
<td>0.90-1.10</td>
<td>0.45-0.50</td>
</tr>
<tr>
<td>Power cost for slow running of rolling machine for 4-6 h, Rs/kg of fabric</td>
<td>Nil</td>
<td>0.50</td>
</tr>
<tr>
<td>Manpower cost, Rs/kg of fabric</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Associated cost (@ Rs 150/day)</td>
<td>9.90-10.80</td>
<td>8.70-9.00</td>
</tr>
<tr>
<td>Total cost/kg of fabric</td>
<td>(Average: 10.35)</td>
<td>(Average: 8.85)</td>
</tr>
</tbody>
</table>

A saving of Rs 1.50

Fig. 3 — SEM photographs showing surface morphology of (a) untreated (control) jute, (b) room temperature H₂O₂ (3%) – K₂S₂O₈ (0.75%) combined bleached jute, (c) conventional hot H₂O₂ (3%) bleached jute, (d) untreated (control) cotton, (e) room-temperature H₂O₂ (2%) – K₂S₂O₈ (0.5%) combined bleached cotton, and (f) conventional hot H₂O₂ (2%) bleached cotton.
temperature bleaching at pH 9.5-10.0 under dual oxidizers. Both these oxidizers in combination for a longer period of treatment cause mild oxidation of the cellulosic hydroxyl group to aldehyde, but the action is so slow and mild that it causes very less and limited oxidation of glycosidic linkage causing chain scission, breaking the cellulose chains to smaller fragments to convert them into solubilized form which is much more rapid at 80-85°C even by H₂O₂ alone and this is the major reason for higher weight loss in hot H₂O₂ bleaching at pH 10.5.

3.4 Study of Surface Morphology
The scanning electron micrographs of raw untreated (control) and differently bleached (room temperature H₂O₂-K₂S₂O₈ combined bleaching and conventional H₂O₂ hot bleaching) jute and cotton fibres taken out from the corresponding untreated and treated jute, cotton and jute-cotton union fabrics are shown in Fig. 3. It can be observed that the low-temperature H₂O₂-K₂S₂O₈ combined bleaching of both jute and cotton fibres under specified conditions causes much less oxidative damage to the fibre surface showing almost no cracks/crevices and potholes and thus produces almost no surface scratch on the corresponding fibre surface. Thus, room temperature bleaching process imparts a much cleaner and smoother surface appearance to both jute and cotton (Fig. 3b and 3e) than that obtained by the corresponding conventional hot H₂O₂ bleaching (Fig. 3c and 3f). The observed effect on surface morphology of treated fibres/fabrics may be viewed as a result of controlled, much slower and milder oxidative action by combination of H₂O₂ and K₂S₂O₈ at room temperature (30°C) even after a longer treatment duration (~ 4-6 h) as compared to the observed severe surface scratching for conventional hot H₂O₂ bleaching, though the latter is accomplished within a shorter duration (2 h).

4 Conclusions
4.1 H₂O₂-K₂S₂O₈ combined room temperature bleaching at the optimized conditions of treatment gives marginally lower but acceptable whiteness indices for all the three types of fabrics as compared to conventional hot H₂O₂ bleaching process for corresponding fabrics.

4.2 The net advantages in case of room temperature H₂O₂-K₂S₂O₈ combined bleaching process include lower weight loss, lower drop in tenacity, similar level or marginally higher level of reduction in bending length coupled with reasonable cost saving and energy efficiency, which make this process much suited even for the decentralized/rural handloom sector, besides the large scale sector as well.

4.3 There is a much lower surface damage in each case by the room temperature H₂O₂-K₂S₂O₈ combined bleaching process despite marginally higher increase in copper number (more so in cotton than jute) coupled with marginally higher gain in moisture regain than that obtained by the conventional hot H₂O₂ bleaching.

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References


