

Optimised chlorine-free bleaching systems for jute and jute/cotton blend fabrics

Y Cai & S K David

Department of Textile Technology, School of Fibre Science & Technology
University of New South Wales, Sydney 2052, Australia

Received 4 February 1997; accepted 14 October 1997

A sequential two-stage bleaching process using peracetic acid followed by hydrogen peroxide has been developed specifically for jute and jute/cotton blend fabrics. A peracetic acid system is optimised for jute by the selection of suitable buffering and stabilising agents. A superior bleaching effect is obtained by using TSPP as a stabiliser in the presence of a phosphate buffer, under mildly alkaline conditions (pH 8.0-8.5), whereby excellent fibre brightness may be achieved at temperatures as low as 40-60°C. A conventional H₂O₂-Na₂SiO₃ system has also been further optimised for jute by the exclusive use of sodium metasilicate at high concentrations of 3.5-4.0 g/l. Sequential bleaching with these independently optimised system results in an excellent degree of overall fabric brightness, such that the 1st-stage peracetic acid bleach may be carried out at relatively low temperature (30-40°C). This combination process therefore offers an effective, environmentally favourable and energy efficient option to conventional peroxide-utilising and chlorine bleaching processes. A further advantage is that it may also be successfully extended to the bleaching of jute/cotton blends. Furthermore, fabric tensile strength loss is less than that observed with high temperature H₂O₂-Na₂SiO₃ bleaching and the tendency towards photoyellowing of the combination bleached fabrics is not adversely affected, despite the high level of fabric brightness achieved.

Keywords: Bleaching, Hydrogen peroxide, Jute, Jute/cotton blend, Peracetic acid

1 Introduction

In current practice, bleaching processes that are commonly applied to jute involve the use of either sodium chlorite or hypochlorite, followed by an alkaline H₂O₂ treatment^{1,2}. However, due to the environmental problems associated with chlorine bleaching, the processes that exclusively utilise peroxygen compounds are now gaining greater importance for cellulosic fibres³. Recently, a sequential two-stage bleaching process using peracetic acid and H₂O₂ has proved to be a viable and environmentally safe alternative to the sodium hypochlorite/H₂O₂ process^{4,5}. However, almost all investigations have been conducted on cotton and linen, with comparatively little work done on jute. The high degree of lignin and other non-cellulosic matter in jute generally necessitates more rigorous bleaching conditions or a higher consumption of the bleaching agents in comparison to that in case

of cotton¹. Furthermore, a potential disadvantage in adopting the peracetic acid process for jute bleaching relates to its higher chemical cost compared to hypochlorite bleaching^{3,4}.

Hence, the aim of this work has been to develop a jute-specific bleaching process, utilising peracetic acid and H₂O₂-Na₂SiO₃ in a sequential system, that serves to optimise the commercial feasibility of jute bleaching.

Initially, the peracetic acid process has been adapted for jute fibre such that effective bleaching can be achieved at temperatures as low as 40-60°C. Secondly, in the conventional H₂O₂-Na₂SiO₃ bleaching process, sodium carbonate and metasilicate levels have been optimised for maximum jute fibre brightness. Finally, the above two optimised processes have been combined in a sequential bleaching operation, which utilises the low temperature advantage of the peracetic acid

stage such that a more efficient bleaching process with excellent fibre brightness is achieved overall. The peracetic acid/H₂O₂-Na₂SiO₃ combination system has also been extended to the bleaching of a jute/cotton (30/70) blend fabric. The tensile strength loss and tendency towards photoyellowing of the bleached fabrics are further assessed and compared with those resulting from a high temperature H₂O₂-silicate bleaching system.

2 Materials and Methods

2.1 Materials

Plain weave jute fabric (260.8 g/m²) and plain weave jute/cotton (30/70) fabric (405.6 g/m²) were supplied by Ahmedabad Textile Industry's Research Association (ATIRA), Ahmedabad, India. Plain weave cotton fabric (unbleached) (153.4 g/m²) was supplied by Charles Parsons, Sydney, Australia.

Hydrogen peroxide (30% w/v) was supplied by BDH Chemicals Australia Pty. Ltd. Reagent grade chemicals, viz. Acetic anhydride, sodium metasilicate (Na₂SiO₃·5H₂O), sodium carbonate, sodium tetraborate (Na₂B₄O₇·10H₂O), potassium dihydrogen orthophosphate, di-sodium hydrogen orthophosphate and tetrasodium pyrophosphate (Na₄P₂O₇·10H₂O), were obtained from Ajax Chemicals Pty. Ltd, and used without further purification.

2.2 Methods

2.2.1 Scouring

All 100% jute and jute/cotton blend fabrics were initially scoured for 1 h at 85-90°C in a solution containing sodium carbonate (2 g/l) and Lissapol TN 450 (2 g/l). The brightness values (Y) of the scoured jute and jute/cotton blend fabrics were 16.7 and 60.3 respectively. The initial whiteness (WIE) of scoured cotton fabric was 24.4.

2.2.2 Bleaching

2.2.2.1 Peracetic Acid Bleaching

Peracetic acid is formed *in situ* from reaction between hydrogen peroxide and acetic anhydride^{6,7}. Bleaching solutions were prepared by the addition of hydrogen peroxide (37 mmoles/l) and acetic anhydride (34 mmoles/l) to either an unbuffered or buffered medium, which contained a

specified amount of peroxide stabiliser as described in the various bleaching systems below. The solutions were stirred for 5 min to allow complete perhydrolysis of the acetic anhydride, and sodium carbonate was then added in certain cases. All solutions were prepared to give a final liquor ratio of 50:1. The jute or jute/cotton blend samples were then entered into the solution and the temperature rapidly raised to an appropriate level. The final temperature was held for 1-1.5 h.

Bleaching Systems

B Hydrogen peroxide (37 mmol/l)
Acetic anhydride (34 mmol/l)
x g/l sodium tetraborate (borax)
Initial pH set at approx. 7

B_s Hydrogen peroxide (37 mmol/l)
Acetic anhydride (34 mmol/l)
x g/l sodium tetraborate (borax)
Phosphate buffer made up by the addition of 0.0087 m KH₂PO₄ and 0.0304 m Na₂HPO₄
Initial pH set at approx. 7

T Hydrogen peroxide (37 mmol/l)
Acetic anhydride (34 mmol/l)
x g/l tetrasodium pyrophosphate
Na₂CO₃ added after perhydrolysis of peracetic acid for pH adjustment from neutral to mildly alkaline conditions

T_s Hydrogen peroxide (37 mmol/l)
Acetic anhydride (34 mmol/l)
x g/l tetrasodium pyrophosphate
Phosphate buffer made up by the addition of KH₂PO₄ (0.0087 m), Na₂HPO₄ (0.0304m) and Na₂CO₃ for pH adjustment from neutral to alkaline conditions
(Na₂CO₃ was added after perhydrolysis of the peracetic acid solution)

The concentrations of peroxide and acetic anhydride were selected to be the same as those recommended for the low temperature peracetic acid bleaching of cotton⁷ (The H₂O₂ concentration entered into the solution was 0.4 volume).

2.2.2.2 H₂O₂-Na₂SiO₃ Bleaching

Bleaching was carried out using 1 volume hydrogen peroxide with a liquor ratio of 30:1 in all cases. Concentrations of sodium silicate and sodium carbonate were varied as specified. Jute fabric was entered into the bleaching bath and the temperature raised at a heating rate of 3°C/min. The final bleaching temperature of 85°C was held for 2 h.

2.2.2.3 Combination Bleaching

Optimised peracetic acid bleaching was carried out as a 1st-stage process, according to either bleaching systems B_b or T_b, as outlined above. The fabric samples were rinsed, dried (for accurate comparison purposes) and then subjected to a H₂O₂-silicate bleach, system S, at 60°C for 1 h in a 2nd-stage process as described below.

Bleaching System S

Hydrogen peroxide, 0.5 volume
Sodium metasilicate, 4 g/l
Liquor ratio, 25:1
Initial pH, 11.0-11.5

2.2.3 Measurement of H₂O₂ Decomposition

The volume strength of H₂O₂ in solution was measured by titration of the bleaching liquor with 0.1N KMnO₄ in the presence of sulphuric acid. The extent of decomposition was calculated as follows:

$$\text{H}_2\text{O}_2 \text{ Decomposition (\%)} = \frac{V_1 - V_2}{V_1} \times 100$$

where,

V₁ = the volume in ml of KMnO₄ used in titration at the start of bleaching; and

V₂ = the volume in ml of KMnO₄ used in titration at the end of the bleaching.

2.2.4 Fabric Testing

Colour parameters were measured using a Gardner/Neotec Spectrogard Colour System. Light fastness to yellowing of the bleached samples was determined by exposing fabric samples to a mercury vapour, tungsten filament, internally phosphor-coated lamp (AS2001.4.21) according to the set-up described by Fincher *et al.*⁸ Fabric samples were also exposed behind window glass to natural sunlight. Light fastness ratings are quoted

according to the fading rates of Blue Light Fastness Standards as specified in BS 1006. The tensile strength of the fabrics was determined using an Instron tensile tester (Model 1122).

3 Results and Discussion

3.1 Optimisation of Peracetic Acid Bleaching

3.1.1 Tetrasodium Pyrophosphate (TSPP) Stabilised Systems

Peracetic acid bleaching is generally carried out under mildly acidic to neutral conditions (pH 6-7) in the presence of stabilisers such as polyphosphate (e.g. sodium hexametaphosphate) or sodium tetraborate, the preferable bleaching temperature range being 50-80°C^{4,6}. In this work, TSPP was initially introduced as a stabiliser with peracetic acid under phosphate buffered and unbuffered conditions. The effects of pH, phosphate buffer and temperature dependence in the bleaching of jute are shown in Fig. 1. As expected, an increase in temperature from 40 to 60°C results in higher brightness values for both systems, either in the absence or presence of phosphate buffer. A significant advantage in the presence of phosphate buffer (system T_b), however, is realised at lower temperature (40-50°C) and high pH (8.5) with relatively high brightness values obtained when compared with bleaching in the absence of phosphate buffer (system T). Furthermore, at any

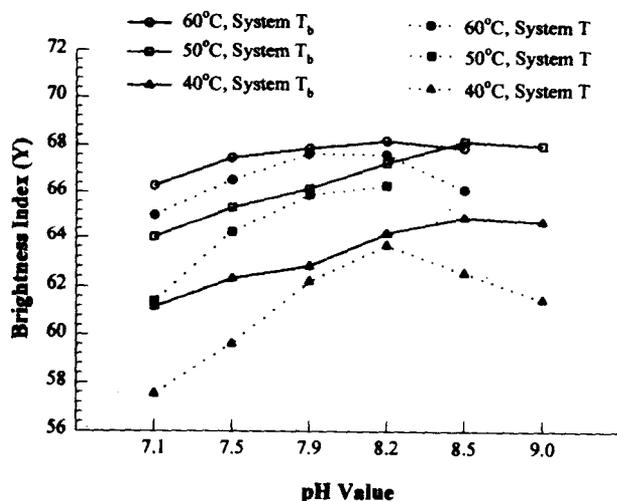


Fig. 1—Effect of pH, temperature and phosphate buffer on the brightness index of bleached jute fabric (All the bleaching solutions contained 5 g/l TSPP. The samples were bleached at indicated temperature for 1.5 h)

given temperature and pH, the bleaching effect in presence of phosphate buffer is superior to that observed in absence of phosphate buffer. An excellent bleaching effect is therefore obtained with peracetic acid at 50°C with TSPP (5 g/l) and phosphate buffer in the pH region of 8.5.

Fig. 2 shows the effect of TSPP concentration on the efficiency of jute bleaching at low temperature (40°C). Under mildly alkaline conditions, increase in the concentration of TSPP produces a marked improvement in brightness, levelling off above 6 g/l. In the presence of a phosphate buffer (bleaching system T_b), however, the same marked improvement in brightness is obtained at much lower concentrations of TSPP (2-3 g/l) and a slightly higher pH of 8.5. Hence, the effect of TSPP as stabiliser is clearly enhanced by the presence of a phosphate buffering system.

3.1.2 Borax Stabilised Systems

Borax stabilised systems have been reported to be very successful for peracetic acid bleaching of cotton, especially in the presence of 2,2'-bipyridine (bipy), coupled with sodium lauryl sulphate⁷ (SLS). Bipyridine is considered to form a

trischelate with ferrous ions naturally present in cotton fibre, which catalyzes the bleaching process. SLS desorbs the red trischelate from cotton and also functions as a stabiliser for the peracetic acid by preferential association with the trischelate. In this study, the application of borax systems for jute was also investigated and compared to the TSPP stabilised systems. The results (Fig. 3) show that whilst the incorporation of a phosphate buffer in the borax/peracetic acid system enhances the fibre brightness of jute, little effect is observed in the bleaching of cotton (system B compared with system B_b). On the other hand, the addition of bipyridine in bleaching system B markedly improves the fibre whiteness of cotton, whereas when employed in jute bleaching, the jute fibre becomes heavily stained with a low resultant brightness. These sharply contrasting results are presumably attributable to the far greater metal ion content of jute fibre⁹. During jute bleaching, an accelerated decomposition of peracetic acid may occur due to a relatively high content of ferrous ions or the trischelate being released into the bleaching

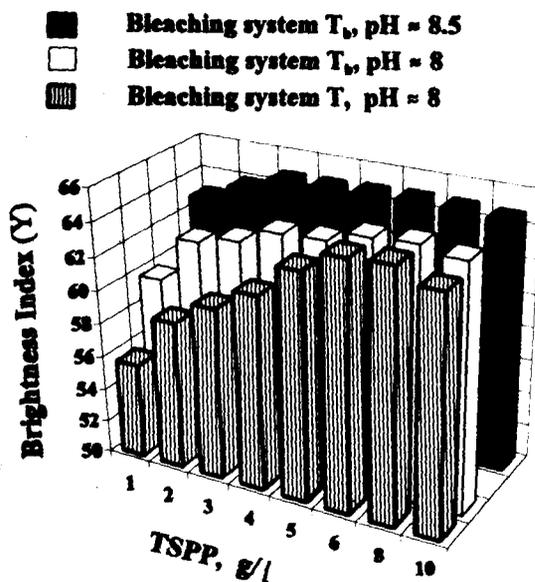


Fig. 2—Combined effect of TSPP concentration and phosphate buffer on the brightness index of peracetic acid bleached jute (In all cases, bleaching was carried out at 40°C for 1.5h)

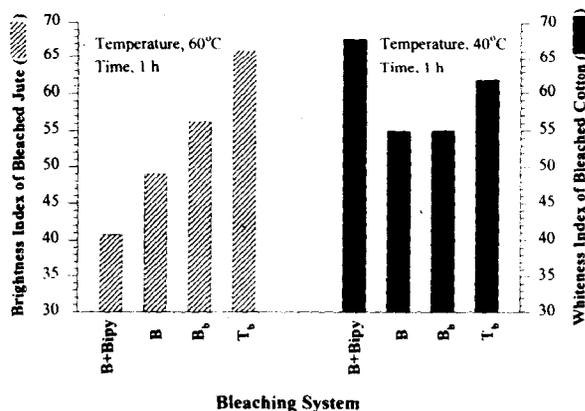


Fig. 3—Effect of different bleaching systems on the brightness and whiteness indices of bleached jute and cotton (T_b : pH=8.2)

solution. In addition, the high content of ferrous ions present within the complex structure of jute may render trischelate desorption by SLS more difficult. An overall comparison, therefore, clearly indicates that the peracetic acid-TSPP system (T_b) results in the best bleaching effect on jute at relatively low temperatures. This system is therefore particularly suited to the bleaching of jute, but also offers an improvement on the conventional peracetic acid bleaching (system B) of cotton.

3.1.3 Temperature Dependence of Different Bleaching Systems

Pronounced differences in temperature dependence are obtained between the peracetic acid systems (stabilised with either borax or TSPP) and a $\text{H}_2\text{O}_2\text{-Na}_2\text{SiO}_3$ bleaching medium as shown in Fig. 4. If $\text{H}_2\text{O}_2\text{-Na}_2\text{SiO}_3$ is utilised, a high temperature is essential for adequate bleaching action, as expected. By comparison, selection of a suitable stabiliser, such as TSPP, in peracetic acid bleaching offers a far superior bleaching system overall, with excellent fibre brightness produced at relatively low temperatures (40-50°C). Hence, the benefit of using TSPP, an excellent metal ion chelator, as a stabiliser is evident in the bleaching of jute fibre, which is characterised by a much higher iron content than other cellulosic fibres such as cotton.

An identical trend is observed in the bleaching of jute/cotton blend fabric (Fig. 4). A high degree of brightness may be attained within the entire temperature range of 30-60°C when utilising a peracetic acid-TSPP system. Despite the low jute content (30%) of the fabric blend, a significant advantage is evident in utilising a jute-optimised bleaching system for a pronounced improvement in overall fabric brightness.

3.2 Optimisation of $\text{H}_2\text{O}_2\text{-Na}_2\text{SiO}_3$ Bleaching

Typically, in the bleaching of cotton with hydrogen peroxide and sodium silicate, the addition of alkali (NaOH or Na_2CO_3) is recommended as it improves bleaching efficiency and retards the deposition of insoluble substances onto the fibre^{6,10}. In adopting an analogous system to jute bleaching, however, the influence of these additives on bleaching efficiency has, to date, not been systematically examined. Hence, in attempting to optimise the system for jute, the concentrations of silicate and carbonate were independently varied while maintaining the strength of H_2O_2 at 1 volume and the bleaching temperature at 85°C (Fig. 5). A clearly evident trend is that in the absence of any added carbonate, increasing the concentration of metasilicate from 1 to 4 g/l produces a pronounced increase in jute fabric brightness. At low silicate concentrations (1-1.5 g/l, $\text{pH} \leq 10$) the bleaching action is insufficient, and hence small additions of sodium carbonate (1-1.5 g/l) tend to assist the bleaching process by

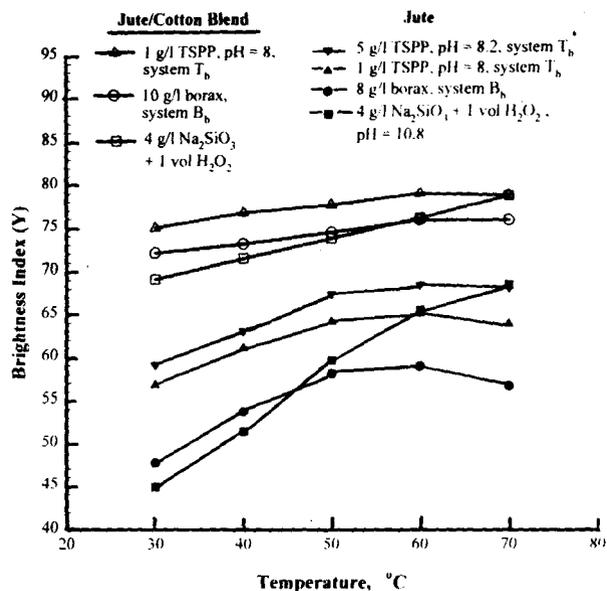


Fig. 4—Effect of temperature and different bleaching systems on the brightness index of bleached jute and jute/cotton (30/70) blend (Jute/cotton blend and jute samples were bleached at indicated temperature for 1 and 1.5 h respectively)

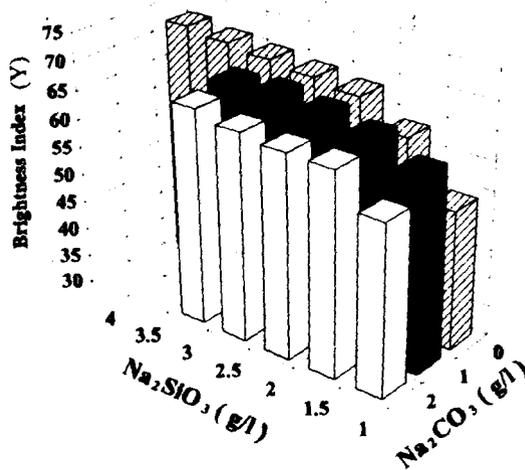


Fig. 5—Effect of Na_2CO_3 and Na_2SiO_3 concentrations on brightness index of H_2O_2 bleached jute at 85°C

increasing the pH . In the presence of high silicate concentrations (>2.5 g/l), on the other hand, the high pH (10.5-11.0) and level of stabilisation achieved result in an excellent bleaching effect on jute, without the necessity for added carbonate.

While a high pH is expected to increase bleaching efficiency with hydrogen peroxide^{2,6,10}, the observed facilitating effect of silicate in jute bleaching is considered to be primarily associated

with its stabilising role. This is indicated by the trend in Fig. 6, where despite maintaining a constant pH of 10.8-11.0 by appropriate addition of carbonate, incremental increases in silicate concentration directly contribute to significantly higher brightness values. The H_2O_2 decomposition profiles in Fig. 7 further illustrate this stabilising effect, where at higher silicate concentrations (>2 g/l) a lower % decomposition of H_2O_2 is measured during the bleaching process. The addition of Na_2CO_3 in fact destabilises the system, increasing the extent of H_2O_2 decomposition for any given concentration of silicate. Hence, in jute bleaching, the addition of Na_2CO_3 assists H_2O_2 - Na_2SiO_3 bleaching only to a limited extent. An improvement in resultant fabric brightness may be obtained with small additions of Na_2CO_3 in the presence of low silicate concentrations. However, this bleaching effect is in fact inferior to that

observed when high concentrations of silicate alone are used. Furthermore, this facilitating effect of silicate in jute bleaching applies over the entire temperature range examined (60-85°C). However, the superiority of the optimised system over the conventional method diminishes at lower temperature bleaching.

Due to the relatively high metal ion content⁹ (e.g. Fe) present in jute that can potentially destabilise peroxide bleaching solutions, a relatively high silicate concentration is recommended compared to that used in the bleaching of cotton. In the latter case, high metasilicate concentrations (2-4 g/l) do not significantly increase whiteness values under similar conditions of bleaching. Although the deposition of precipitates during silicate bleaching poses a potential problem, this may be effectively remedied by the addition of carbonate at the end of bleaching.

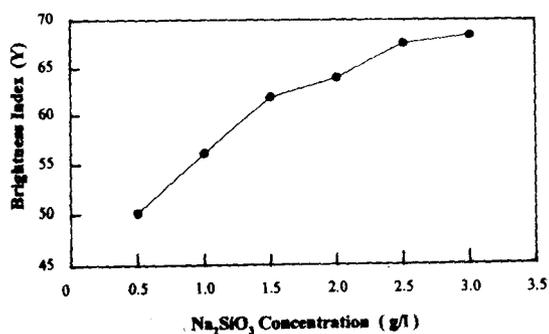


Fig. 6—Effect of Na_2SiO_3 concentration on the brightness of bleached jute at 85°C (pH in all the bleaching solutions was adjusted to 11 with Na_2CO_3)

3.3 Combination Bleaching

Jute fabric is first subjected to each of the optimised peracetic acid systems, as a 1st-stage bleach, and then to the optimised H_2O_2 - Na_2SiO_3 system described above. The temperature of the 1st-stage bleach is varied between 30°C and 60°C and in all cases, the 2nd-stage H_2O_2 - Na_2SiO_3 bleach is carried out using 0.5 vol H_2O_2 at 60°C for 1 h. The overall brightness values obtained from the combination systems are compared against a double H_2O_2 - Na_2SiO_3 system performed at identical 1st- and 2nd-stage bleaching temperatures and times.

Fig. 8 shows that a marked increase in brightness is obtained when a H_2O_2 - Na_2SiO_3 system is used after peracetic acid bleaching for all 1st-stage bleaching temperatures. The relative improvement is especially pronounced for those systems with low brightness after the 1st-stage of bleaching, as might be expected. Importantly, however, even for the peracetic acid-TSPP system at 50-60°C, where high brightness values are obtained at the 1st-stage bleach, significantly greater improvement in brightness is observed after a 2nd-stage H_2O_2 - Na_2SiO_3 bleach (T_b+S) compared to that obtained with a double H_2O_2 - Na_2SiO_3 bleach at 60°C (S^*+S). Hence, a significantly enhanced degree of bleaching results from this combination bleaching process with two

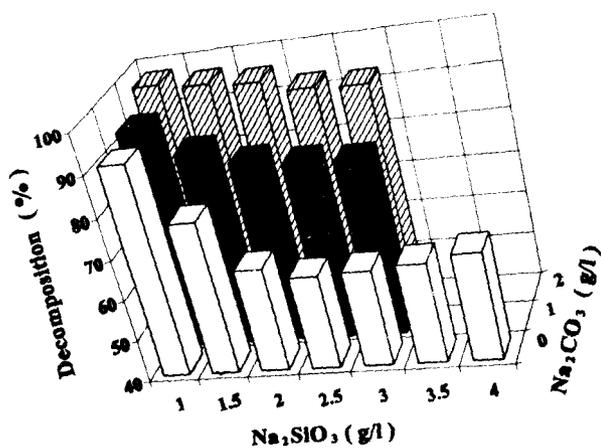


Fig. 7—Effect of Na_2CO_3 and Na_2SiO_3 concentrations on the H_2O_2 decomposition at 85°C after 2 h bleaching

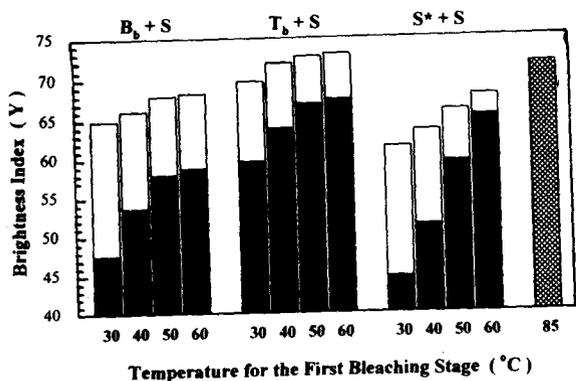


Fig. 8—Brightness index of combination bleached jute [(■) Y after the first bleaching stage, (□) ΔY contributed by the second bleaching stage, and (▨) Single stage H₂O₂-silicate bleach was carried out at 85°C for 2 h with 1 vol. H₂O₂ and LR=30:1. S*: The first stage bleach was carried out for 1.5 h with 1 vol. H₂O₂ and LR=50:1]

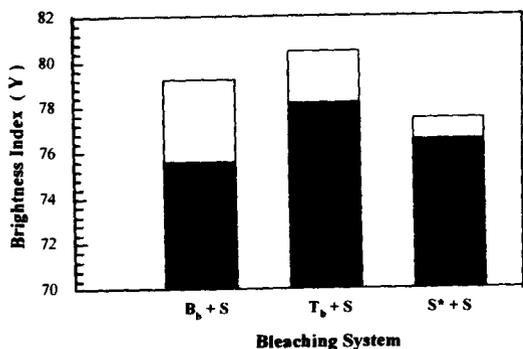


Fig. 9—Brightness index of combination bleached jute/cotton blend [(■) Y after the first bleaching stage, and (□) ΔY contributed by the second bleaching stage. Each bleaching stage was carried out at 60°C for 1 h. In system T_b, 1 g/l TSPP was used. S*: The first stage bleach was carried out with 1 vol. H₂O₂ and LR=50:1]

different bleaching mediums, such that the overall level of fabric brightness is superior to that obtained with either a double H₂O₂-Na₂SiO₃ bleach at 60°C or a high temperature H₂O₂-Na₂SiO₃ bleach (85°C) for 2 h.

A further important benefit in using a combination system is associated with the improved degree of bleaching efficiency obtainable at low bleaching temperatures. For instance, a comparison of the 1st-stage bleaches for systems T_b (peracetic acid-TSPP) and S* (H₂O₂-Na₂SiO₃) shows that in the former case, bleaching at 30°C results in a lower brightness value than bleaching with system S* at 60°C; however, the overall fabric brightness after the 2nd-stage of H₂O₂-

Na₂SiO₃ bleaching at 60°C is significantly superior with the combination system (T_b+S) than with a double H₂O₂-Na₂SiO₃ bleach (S*+S). A similar comparison exists between the peracetic acid-borax and H₂O₂-Na₂SiO₃ 1st-stage systems (B_b+S and S*+S respectively) (Fig. 8). The overall brightness observed after 2nd-stage bleaching in the former case is again superior to that obtained for the double H₂O₂-Na₂SiO₃ bleach. Hence, in utilising a combination system, the 1st-stage peracetic acid bleach may be carried out at a very low temperature (30-40°C), with an excellent brightness level attained overall, followed by a H₂O₂-Na₂SiO₃ bleach at 60°C for 1 h. In particular, bleaching with peracetic acid-TSPP at 40°C, followed by H₂O₂-Na₂SiO₃ at 60°C, results in a fabric brightness level comparable to that obtained with a single (or double) H₂O₂-Na₂SiO₃ bleach at high temperature (85°C, Fig. 8). Thus, this combination bleach avoids the necessity for bleaching at higher temperatures (80-85°C), thereby offering a more energy efficient bleaching option.

An analogous trend in brightness is also observed for a jute/cotton (30/70) blend fabric (Fig. 9). Hence, this type of jute-specific bleaching system is ideally suited for bleaching jute/cotton blend fabrics even with a low jute component in the blend.

3.4 Tensile Strength Loss and Light Fastness to Yellowing

The tensile strength loss of the fabrics bleached with the combination system T_b+S (at 60°C/60°C) and the H₂O₂-Na₂SiO₃ system (at 85°C) were found to be 10% and 14% respectively. Hence, for a similar level of fabric brightness, the combination process results in relatively less fabric strength loss compared with H₂O₂-Na₂SiO₃ bleaching at high temperature.

Generally, with jute fibre, the tendency to photoyellowing is associated with the degree of fabric brightness, where the higher the brightness index the greater the degree of yellowing during light exposure¹. The relative propensity of the bleached fabrics towards photoyellowing was observed by artificial (AS 2001.4.21) and sunlight exposure tests. Fastness ratings were found to be 2 in all cases for the combination bleaches and the double H₂O₂-Na₂SiO₃ system. Therefore, a

significantly higher brightness index obtained with the peracetic acid-TSPP/H₂O₂-Na₂SiO₃ combination bleach does not adversely affect the light fastness to yellowing of this bleached sample.

4 Conclusions

4.1 Jute and jute/cotton blend fabrics can be more effectively bleached with the optimised systems described in this work, which provide good suitability for the bleaching of both jute and cotton fibres.

4.2 More efficient bleaching action with peracetic acid is realised in the presence of selected buffering and stabilising agents. TSPP is observed to provide a far superior stabilising effect in jute bleaching than borax. In the presence of a phosphate buffer, the stabilising influence of the TSPP system for jute is further enhanced, resulting in excellent bleaching action at temperatures as low as 40-50°C and mildly alkaline pH (8.0-8.5).

4.3 The addition of bipyridine to the peracetic acid-borax system, which has been reported to effectively bleach cotton at low temperature, is proved to be unsuitable for bleaching jute.

4.4 The bleaching of jute with the H₂O₂-Na₂SiO₃ system can be further optimised for fabric brightness by the exclusive use of sodium metasilicate at high concentrations of 3.5-4.0 g/l. Incorporation of sodium carbonate into the bleaching solution at temperatures of 80-85°C generally results in diminished fabric brightness and it is, therefore, suggested that carbonate may be added to the bleach liquor at the end of bleaching, if necessary, in order to avoid deposition of insoluble precipitates onto the fabric surface.

4.5 An enhanced bleaching effect is obtained on using peracetic acid-TSPP and H₂O₂-Na₂SiO₃ combined system, such that the 1st-stage peracetic

acid bleach may be carried out at relatively low temperatures (30-40°C). Following the 2nd-stage H₂O₂-Na₂SiO₃ bleach at 60°C, the resultant overall brightness is comparable to that observed with a single or double stage H₂O₂-Na₂SiO₃ bleach at high temperature (85°C).

4.6 An added advantage of the combination process is that fabric rinsing between the 1st and 2nd stages of bleaching is not necessary unlike in the chlorine-utilising sequential bleaches frequently used in commercial practice. The overall fabric tensile strength loss is less than that observed with high temperature H₂O₂-Na₂SiO₃ bleaching and the tendency of the bleached fabric towards photo-yellowing is not adversely altered despite the high level of brightness. This peracetic acid/H₂O₂-Na₂SiO₃ combination process, therefore, offers an effective, environmentally favourable and energy efficient alternative to other peroxide-utilising and chlorine bleaching processes currently in practice.

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