Low Temperature Bleaching (LTB): A Sustainable Wet Processing Technique

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Abstract

Bleaching is the first step of textile wet processing. For successful dyeing in the subsequent process; proper bleaching is a must that’s why bleaching is called the heart of textile wet processing like carding is the heart of spinning. commercial bleaching is done all over the world generally in boiling or near boiling temperature that is 98°C to 105°C. But in this case the cellulose loses its strength significantly as the degree of polymerization (DP) decreases due to breaking of cellulose chain. To overcome this problem new technology has developed where bleaching can be done at 70°C. In our study we found that there are several advantages of low temperature bleaching over high temperature bleaching-lower damage of cellulose chain, less processing time, lower energy consumption, lower amount of dyes consumption to produce same depth, lower amount of auxiliaries needed. No negative effect on overall quality test results. So it is observed that low temperature bleaching has outstanding advantages over high temperature.

Keywords: Hydrogen peroxide; Low temperature bleaching; High temperature bleaching; Catalyst; Degree of polymerization; Energy consumption; Dyes consumption; Quality.

Introduction

As the aim of bleaching is the destruction of natural coloring matters to produce pure, permanent and basic white effect. For this purpose two types of bleaching agents are available-oxidizing bleaching agent and reducing bleaching agent. Commercially, normally oxidizing agents are used, among all oxidizing agent hydrogen peroxide (H2O2) is vastly used for its several advantages over hypochlorite.

- In case of vegetable fiber, the coloring matters are nitrogenous substance. In case of reducing bleaching agent the destructed coloring matters come back again by reaction with atmospheric oxygen. So antichlor- treatment is required to overcome this issue.

\[ -\text{OCl} + \text{Protein-NH}_2 \rightarrow \text{NCl} + \text{H}_2\text{O} \]

- In alkaline condition the chlorine of oxidizing agent react with protein fiber causes degradation of protein fiber. To overcome all these difficulties hydrogen peroxide is the solution to the dyeing masters. That's why it is called universal bleaching agent (H2O2).

The general concept about bleaching is that, below 80°C commercial bleaching is not possible as peroxide starts working in higher temperature. To overcome this problem new technology has been developed to activate hydrogen peroxide below 80°C with the help of catalyst. As we know from the definition of catalyst-“A catalyst is a substance that speeds up a chemical reaction, but is not consumed by the reaction; hence a catalyst can be recovered chemically unchanged at the end of the reaction it has been used to speed up, or catalyze” [1-3].

Materials and Methods

Materials

A high temperature-high pressure (HTHP) fabric winch dyeing machine of Fong’s brand from Hong Kong is used to perform the processing in two different temperatures. Commercially available grey colored 100% cotton knit fabric of 160 gsm which is single jersey. The batch weight taken 150 kg as well as commercially available chemicals and auxiliaries along with Reactive dyes were used in this work. For bleaching NaOH, H2O2 (35%), Detergent, Sequestering agent, Anti-creasing agent, peroxide stabilizer, was used. Catalyst was used for low temperature bleaching to activate the H2O2 at 70°C. For neutralising commercial acetic acid is used and after complete dyeing commercial soaping agent is used. Fastness scales were used for test evaluation of fastness to commercial washing to observe any desorption of reactive dye particles from textile materials into the solutions containing soap and sodium carbonate. Crockmeter/Rubbing fastness tester was used for testing of fastness against rubbing on a grey scale rating ranging from 1-5. Spectrophotometer was used for measuring depth of shade. Stenter was used to dry the wet fabrics for quality assessment [4].

Methods

S.M.A.R.T. tactical planning: S.M.A.R.T. tactical plan was developed to conduct this research work, as the work was:

- Specific; because the dye samples were sourced from a specific producer.
- Measurable; because the aspect and outcome of the result was measurable, which were whiteness index, absorbency, color fastness, cost-price, production capacities, production sustainability and processing.
- Achievable; because the production of the catalyst is fully commercial purpose and already using by the factories.
- Realistic; being the production and availability of catalyst are seen all around the world.
- -Time-based; because the whole backward linkage to forward linkage activities such as, production, research, application, results, and evaluation were analyzed within a reasonable time-frame [5].

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**Bleaching:** Our study starts with bleaching—As it is single stage scouring-bleaching the main reaction take place is 1-

### Saponification:

\[
\begin{align*}
&C_{17}H_{35}OOC \cdot CH_2 \\
&C_{17}H_{35}OOC \cdot CH + 3NaOH \\
&C_{17}H_{35}OOC \cdot CH_2
\end{align*}
\]

\[
3C_{17}H_{35}COONa + CH_2OH
\]

\[
CHOH
\]

\[
CH_2OH
\]

**Recipe of high temperature (HTB) bleaching:**

- NaOH (Flakes) = 1.5 g/l
- H\(_2\)O\(_2\) (35%) = 3.0 g/l
- Peroxide Stabilizer = 0.3 g/l
- Detergent = 1.0 g/l
- Sequestering agent = 1.0 g/l
- Anti-creasing agent = 1.0 g/l
- M:L = 1:7
- @98°C × 30 MIN.

**Recipe of low temperature (LTB) bleaching:**

- NaOH (Flakes) = 1.5 g/l
- H\(_2\)O\(_2\) (35%) = 3.5 g/l
- Catalyst = 1.0 g/l
- Detergent = 1.0 g/l
- Sequestering agent = 1.0 g/l
- Anti-creasing agent = 1.0 g/l
- M:L = 1:7
- @70°C × 40 MIN.

**Comparison between two processing condition:** From the two recipes it is seen that the chemical consumption, temperature and time vary in both cases. In second recipe (Figures 1 and 2) temperature for bleaching is 28°C less than first recipe (Figure 1). First recipe occupied with peroxide stabilizer 0.3 g/l (2.2.3) but in second recipe it is totally omitted (2.2.4). In second recipe consumption of hydrogen peroxide (2.2.4) is 0.5 g/l more than first one. Second recipe is arranged with 1 g/l catalyst (2.2.4) whereas no use of catalyst in the first one. First recipe takes 10 min less time (2.2.3) than second one for bleaching completion [6,7]. So, from the two process curves it is clear that in high temperature bleaching, bleaching is carried out at 98°C.

Per hydroxyl ion formation:

\[
H_2O_2 \rightarrow HOO^- + H^+
\]

As alkali favors these reaction, when temperature goes high the rate of reaction also higher, so the reaction turn to free radical route-

\[
2H_2O_2 \rightarrow 2H_2O + O_2
\]

This results a high degree of degradation of the peroxide. The interim reactions result in the production of the free radicals which are not selective and will react and damage the cellulose molecules. This is happening because it is impossible to control the decay of Hydrogen Peroxide and it proceeds by the free radical route. This causes the cellulose molecules to be split into many times. So the cellulose loses its strength significantly which causes lower degree of polymerization (DP) as well as lower bursting strength [8,9].

The normal hot wash after bleaching is carried out at 90°C. Whereas in low temperature bleaching; bleaching is carried out at 70°C with the help of catalyst (Figure 3).

The normal hot wash after bleaching is carried out at 80°C. So in high temperature bleaching the cellulose loses its strength significantly.
in which causes lower degree of polymerization (DP) as well as lower bursting strength (Table 1).

As low temperature bleaching (LTB) happens in lower temperature, so no need of cooling water but in case of high temperature bleaching (HTB) sufficient amount of water need for the machine to cool down, as well as in the ETP the blower takes long time to cool down the water temperature (Table 2) [10].

Dyeing recipe: A typical recipe used to dye both fabrics:

- Reactive Yellow = 0.20%  
- Reactive red = 0.60%  
- Reactive blue = 2.50%  
- Glauber’s salt = 60 g/l  
- Soda ash = 15 g/l  
- @ 60°C x 60 Min.

All necessary auxiliaries are used for both cases like-levelling agent, @ 60°C × 60 Min.

Soda ash = 15 g/l  
Glauber’s salt = 60 g/l  
Hand feel  
CIE whiteness index

Table 1: Evaluation of bleaching performance.

| Test Parameter       | High Temperature Bleaching (HTB) | Low Temperature Bleaching (LTB) |
|----------------------|----------------------------------|----------------------------------|
| Absorbency           | Good                             | Moderate                         |
| CIE whiteness index  | 60.44                            | 53.55                            |
| Bursting strength    | 370 Kpa                          | 394 Kpa                          |
| Hand feel            | Harsh                            | Comparatively Soft               |
| Process loss %       | 7.5                              | 6                                |

As low temperature bleaching (LTB) happens in lower temperature, so no need of cooling water but in case of high temperature bleaching (HTB) sufficient amount of water need for the machine to cool down, as well as in the ETP the blower takes long time to cool down the water temperature (Table 2) [10].

Results and Discussion

Results

Low Temperature Bleaching (LTB) has more benefits and some limitations than that of high temperature bleaching (HTB) they are:

Less power consumption: As the process takes place in lower temperature than regular high temperature process so it takes less energy because the catalyst makes peroxide active at lower temperature for bleaching to take place (Table 3).

Less steam consumption: From the process named low temperature (70°C) bleaching it is easily guessed that it will consume less steam than that of high temperature (98°C) bleaching to take place. It takes 28°C less temperature in low temperature bleaching than that of high temperature bleaching. Also the normal hot wash done in 90°C for high temperature process but for low temperature it is done in 80°C which need less steam (Table 4).

Less time consumption: As the process takes place in lower temperature (70°C) than regular high temperature (98°C) process so it takes less time to reach the desired temperature. It takes 120 min for lower temperature bleaching but 100 min for high temperature bleaching presented in Table 3.

Lower water consumption: Due to low temperature process so no need of additional water to cool down the machine temperature to open the lid of the machine. High temperature process takes additional 1050 liter water for the cooling purpose because the machine lid cannot open below 80°C presented in Table 2.

Less amount of anti-creasing agent and softener use: As the process temperature is lower so the bleaching reaction is milder than...
high temperature process one, so less amount of natural wax extraction from fabric happens these remaining natural waxes acts as natural softener. So the amount of softener and anti-creasing agent in the finishing stage reduce by 50% (Table 5).

**Lower amount of dyes required to produce same depth:** As the bleaching reaction is milder so not all of the natural coloring matters are extracted, this remaining natural color makes it possible to achieve same color depth with less amount of dyes use. From the Table 6 it is seen that 12.8% more depth is found with the use of same amount of dyes in case of low temperature bleaching (Figure 4) (Table 6).

**Higher fabric strength and less process lose:** For knit fabric strength means bursting strength as the bleaching reaction is milder so the possibility of cellulose chain degradation as well as the process loss is low.

**No detrimental effect on overall quality parameter:** As this process is new one and have lots of points to differentiate from traditional high temperature process somebody may think it may effect on the final fabric quality. But from the study, it is seen that overall quality like wash fastness, rubbing fastness, perspiration fastness, water fastness, hand feel, mater to meter shade variation, unevenness are same in both process (Table 7).

**Overall lower processing cost:** Low temperature bleaching has overall lower cost than that of high temperature bleaching. Though it has some higher chemical cost in bleaching but other cost like steam, labor, electricity, finishing chemical are less than that of high temperature bleaching (Tables 8 and 9).

**Limitations of low temperature bleaching (LTB) over high temperature bleaching (HTB):** Though Low Temperature Bleaching has lots of advantages over High Temperature Bleaching it has some limitations also. It is a great challenge to produce light & bright shades by using LTB because of the moderate absorbency & lower CIE whiteness index. It has some more chemical cost in LTB than that of HTB (Figure 5).

**Discussion**

(a) The degree of polymerisation can be derived by the following equation from which one can easily understand the degradation of cellulose chain.

\[
DP = \frac{2032 \log_{10} (74.35 + F) - 573}{F}
\]

(b) The color difference measured by spectrophotometer through CIE L’ a’ b’ color space theory. The theory defined by the Commission Internationale de l’Eclairage (CIE), the L’a’ b’ color space was modeled after a color-opponent theory stating that two colors cannot be red and green at the same time or yellow and blue at the same time. As shown below, L’indicates lightness, a’ is the red/green coordinate, and b’ is the yellow/blue coordinate. Delta s for L’ (\(\Delta L’\)), a’ (\(\Delta a’\)) and b’ (\(\Delta b’\)) may be positive (+) or negative (-). The total difference, Delta E (\(\Delta E’\)), however, is always positive.
ΔL* (L* sample minus L* standard)=difference in lightness and darkness (+=lighter, -=darker)
Δa* (a* sample minus a* standard)=difference in red and green (+=redder, -=greener)
Δb* (b* sample minus b* standard)=difference in yellow and blue (+=yellower, -=bluer)
ΔE*=total color difference

To determine the total color difference between all three coordinates, the following formula is used:
ΔE*=[ΔL*2 + Δa*2 + Δb*2]1/2
(c) The steam calculation is done with the law of thermodynamics-
Q=mCp ΔT

Table 8: Overall Cost Summary: (USD/Kg).

| Parameter | 98°C*30ʹ | 70°C*40ʹ |
|-----------|----------|----------|
| Steam     | 0.198    | 0.145    |
| Water     | 0.0014   | 0.001    |
| ETP       | 0.0063   | 0.0047   |
| power     | 0.00348  | 0.0028   |
| Labour    | 0.008    | 0.006    |
| Chemical  | 0.09     | 0.099    |
| Total     | 0.307    | 0.258    |

Table 9: Chemical consumption comparison (Bleaching & Finishing).

| Chemicals | Dosage | $/kg | Cost | Dosage | Cost |
|-----------|--------|------|------|--------|------|
| NaOH      | 1.5 g/l | 0.43 | 0.68 | 1.5 g/l | 0.68 |
| H2O2 35%  | 3.0 g/l | 0.22 | 0.69 | 3.5 g/l | 0.81 |
| Stabilizer| 0.3 g/l | 1.1  | 0.35 | -      | -    |
| Detergent | 1.0 g/l | 2.8  | 2.94 | 1.0 g/l | 2.94 |
| Sequestering | 1.0 g/l | 1.3  | 1.36 | 1.0 g/l | 1.36 |
| Anticeasing | 1.0 g/l | 0.8  | 0.84 | 1.0 g/l | 0.84 |
| Catalyst | -       | 4    | -    | 1.0 g/l | 4.2  |
| Acetic Acid | 1.0 g/l | 0.64 | 0.67 | 1.0 g/l | 0.67 |
| Peroxide Killer | 0.3 g/l | 1.5  | 0.47 | 0.3 g/l | 0.47 |
| Anticeasing | 0.5 g/l | 1    | 0.52 | 0.25  | 0.26 |
| Softener | 2.0 g/l | 2.5  | 5.25 | 1.0 g/l | 2.63 |

Note: It should be noted that all the unit price is taken from Rupashi Knitex limited.

Conclusion

So from the above study results it is very much clear that low temperature bleaching (LTB) has lots of advantages over high temperature bleaching (HTB). This process is not only cost saving but also eco- friendly due to the used catalyst is a biodegradable chemical. It has some more chemicals cost than the regular process but other side has much more advantages in terms of money as well as quality. More research works are highly required to produce light & bright shades by using low temperature bleaching method. It’s a sustainable technology in terms of energy, water, time.

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