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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 breakage 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 (H_2O_2) 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.

$$-OCl + Protein\text{-}NH_2 \longrightarrow NCl + H_2O$$

- 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 (H_2O_2).

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, H_2O_2 (35%), Detergent, Sequestering agent, Anti-creasing agent, peroxide stabilizer, was used. Catalyst was used for low temperature bleaching to activate the H_2O_2 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:

$C_{17}H_{35}OOC\text{-}CH_2$

$C_{17}H_{35}OOC\text{-}CH \quad + 3NaOH$

$C_{17}H_{35}OOC\text{-}CH_2$

$\longrightarrow 3C_{17}H_{35}COONa + CH_2OH$

$CHOH$

CH_2OH

Recipe of high temperature (HTB) bleaching:

NaOH (Flakes) =1.5 g/l

H_2O_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_2O_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:

$$H_2O_2 \longrightarrow HOO^- + H^+$$

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

$$2H_2O_2 \longrightarrow 2\,H_2O+O_2.$$

This results a high degree of degradation of the peroxide. The

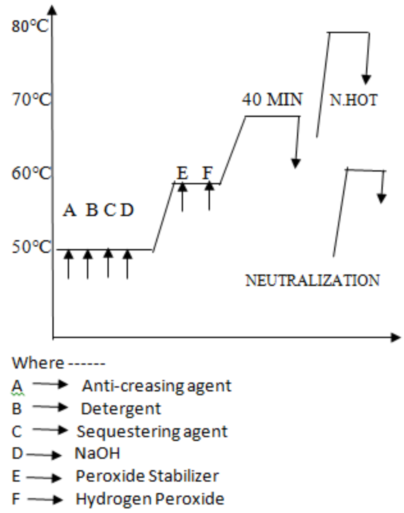

Figure 1: High Temperature (HTB) Bleaching.

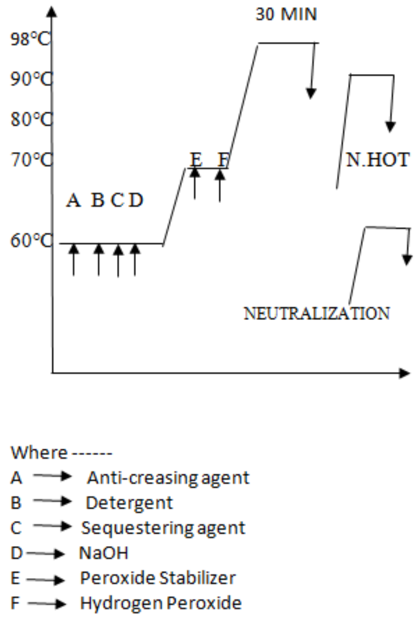

Figure 2: Low Temperature (LTB) Bleaching.

interim reactions result in the production of the free radicals which are not selective and will react and damage the cellulosic 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

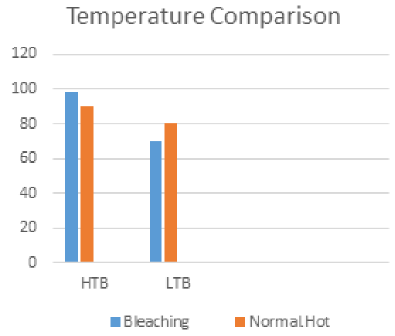

Figure 3: Graphical temperature Comparison.

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

Table 1: Evaluation of bleaching performance.

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 × 60 Min.

All necessary auxiliaries are used for both cases like-levelling agent, sequestering agent, soaping agent. But, in case of low temperature bleached fabric 0.25 g/l anti-creasing used whereas for high temperature bleached fabric 0.5 g/l anti-creasing agent used because of the remaining natural wax. After dyeing, in case of low temperature bleached fabric 1 g/l softener used whereas for high temperature bleached fabric 2 g/l softener used to get required hand feel because of the remaining natural wax works as softener [11-13].

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

Water Cost : 0.05 USD /m³ Effluent treatment Cost (ETP) : 0.225 USD/m³		
Parameter	**98°C × 30 min.**	**70°C × 40 min.**
1st bath	1050 liter	1050 liter
2nd bath	1050 liter	1050 liter
3rd bath	1050 liter	1050 liter
4th bath	1050 liter	-
TOTAL	4200 liter	3150 liter
Total Water cost	0.21 USD	0.157 USD
Total ETP cost	0.945 USD	0.708 USD
Water cost/kg	0.0014 USD	0.0010 USD
ETP cost/kg	0.0063 USD	0.0047 USD

Table 2: Water consumption comparison (Bleaching).

Power Cost: 0.0475 USD/kWh. Machine Main Motor Capacity=5.5 kW		
Parameter	98°C × 30 min.	70°C × 40 min.
Time (min.)	120	100
Total Power Cost	0.522 USD	0.433 USD
Power Cost/kg	0.00348 USD	0.0028 USD

Table 3: Power consumption comparison (Bleaching).

Steam Cost : 0.0078 USD/ kg						
Parameter	**98°C x 30 min.**			**70°C x 40 min.**		
Steps	**Temp (°C)**	**Vol.**	**Steam (kg)**	**Temp (°C)**	**Vol.**	**Steam (kg)**
1st bath	30 to 98°C	1050 liter	1935	30 to 70°C	1050 liter	1170
2nd bath	98 to 80°C	-	-	30 to 80°C	1050 liter	1347
3rd bath	30 to 90°C	1050 liter	1615	30 to 40°C	1050 liter	272
4th bath	30 to 40°C	1050 liter	272		-	-
TOTAL			3822			2789
Total Cost (USD)			29.81			21.75
Steam Cost/kg			0.198			0.145

Table 4: Steam consumption comparison (Bleaching)

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. Deltas for L^* (ΔL^*), a^* (Δa^*) and b^* (Δb^*) may be positive (+) or negative (-). The total difference, Delta E (ΔE^*), however, is always positive.

Labour Cost : 0.60 USD /hour		
Parameter	**98°C x 30 min.**	**70°C x 40 min.**
Time (min.)	120	100
Total Labour Cost	1.2	0.996
Labour Cost/kg	**0.008 USD**	**0.006 USD**

Table 5: Steam consumption comparison (Bleaching).

CMC parameters	High Temperature Bleaching (HTB)	Low Temperature Bleaching (LTB)
CMC DE	Standard	1.1
DL	Standard	-1.28
Da	Standard	0.04
Db	Standard	0.53
DC	Standard	-0.53
DH	Standard	0.08

Table 6: Dyeing shade comparison: Quality Test Parameters comparison: By using spectrophotometer (Data color 650).

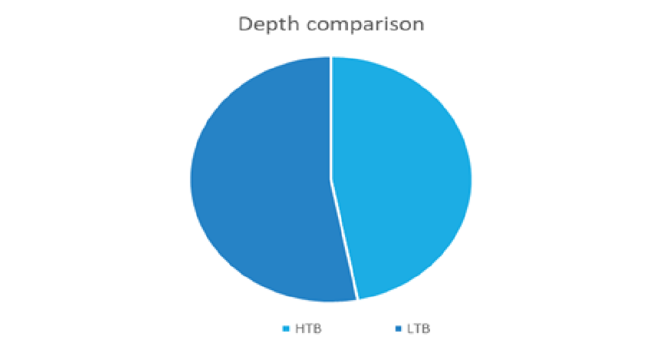

Figure 4: Depth Comparison by Pie chart.

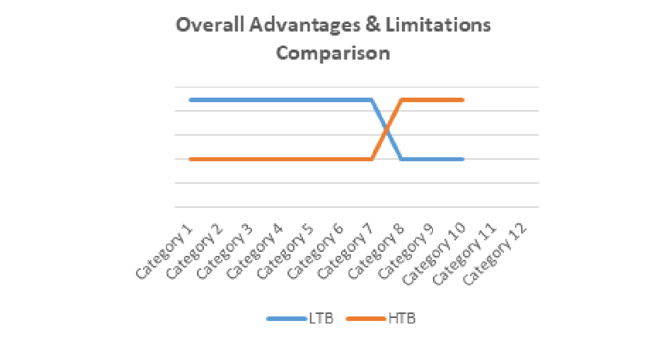

Figure 5: Diagrammatic presentation of overall Advantages & Limitations.

Parameters	High Temperature (HTB) Bleaching	Low Temperature (LTB) Bleaching
Color fastness to wash (ISO 105 -C03)	4	4
Color fastness to rubbing (ISO 105- X12)	3	3
Color fastness to perspiration (ISO 105- E04)	3-4	3-4
Color fastness to water (ISO 105- E01)	4-5	4-5
Hand feel	Desired Softness	Desired Softness
Meter to meter shade variation	ok	ok
Unevenness	No spots	No spots

Table 7: Quality Test Parameters comparison.

Chemical Cost with bath volume 1050 liter					
	98°C x 30 min.			70°C x 40 min.	
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
Anticreasing	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
Anticreasing	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
Total Chem. Cost = 13.77				14.86	
Chem./kg 0.090 USD				**0.099 USD**	

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

Parameter	98°C*30´	70°C*40´
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).

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:

$$\Delta E^*=[\Delta L^*2 + \Delta a^*2 + \Delta b^*2]1/2$$

(c) The steam calculation is done with the law of thermodynamics-

$$Q=mCp\ \Delta T$$

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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