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Feasible Application of Modern Eco-Friendly Treatment of Wool Fabric before Coloration

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Abstract- Preparation is a fundamental factor for any textile material in order to produce the substrate with accurate chemical and physical properties to ensure persuasive colouration and finishing. Pre-treatment plays a significant role for the successful coloration of any kind of natural textile fibre like wool. This paper overview the influence of different types of contemporary preparation techniques applied on wool fibre before coloration such as scouring, carbonising and bleaching. However, traditional wool pre-treatment utilize different chemicals those generate pollution in the effluents; a few of them are erosive which could damage the equipment and the fabric as well. Hence, it also focuses on the recently introduced eco-friendly enzyme based biological application and plasma treatment on wool fibre preparation.

Index Terms- Wool Pre-treatment, Bio-scouring, Plasma, Carbonising, Bleaching, Enzymes.

I. Introduction

Raw wool is a really impure component which generally contaminated with 40% to 70% of superfluous matter[5]. Wool fibre undergoes various types of treatments before dyeing and finishing. The executing of these treatments successfully is crucial, because without appropriate pretreatment it is impossible to produce a quality dyed substrate. Moreover, 60-70% of downstream processing complications are related to poor preparation of the textile material. So, the preparation process requires to "deliver" a fabric where uniform colouration can be attained.

Wool fibre has to undergo different preparation treatments such as scouring, carbonising and bleaching. In order to reduce extensive fibre damage, save energy consumption as well as time and to construct the process more environmentally friendly researchers and industries are now trying to implement enzyme based bio-scouring, bio-bleaching and bio-carbonising. Moreover, application of plasma treatment can perform a pivotal role in scouring process.

II. Wool Scouring

The technique of scouring raw wool fibre is one of the most vital steps in the preparation of wool fibre. Bird (1972)[1] mentioned the following three types of impurities are available in raw wool fibre:

- 40% Wool grease or wax, which generally consists of sterols in alliance with long chain C14-C22 fatty acids, fatty alcohols, cholesterol esters, hydrocarbons and lanolin.
- 5 to 20% is Suint which is extremely complex mixture including potassium salts of fatty acids, proteins, amino acids and mineral sand.
- The remainder is mechanically adhering constituents such as dirt, sand, burrs and vegetable matter.

A. Alkaline Aqueous Scouring Systems

In alkaline aqueous scouring procedure, sodium carbonate is utilised as a builder to improve grease removal and avert redeposition. Sodium carbonate neutralise free fatty acids and aids in emulsifying wool grease therefore promoting grease removal of the wool fibre. Saponification of wool grease proceeds several hours at the boil in caustic alkali[10]. In order to avert degradation of wool, the temperature should not be enabled to rise above 60^0C and the value of pH should not exceed 10[15].

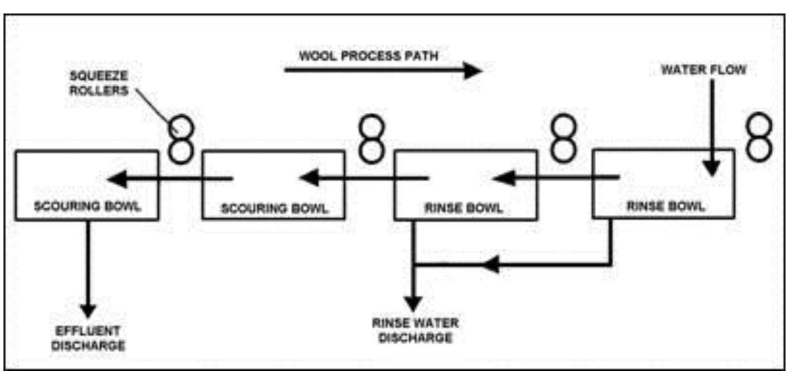


Figure 1: Conventional wool scouring arrangement[18].

Table 1: Initial concentration for wool scouring[15].

Bowl	Synthetic detergent%	Sodium carbonate%	Common Salt %	pH	Temperature °C
First bowl	0.25	0.25	-	9.0	54
Second bowl	0.2	0.2	0.4	10-10.5	52
Third bowl	0.12	0.02	0.5	10	49
Forth bowl	0-0.01	0	0	-	46

B. SOLVENT SCOURING

Preservation of water and abatement of effluent pollutants have encouraged the development of solvent scouring. In continuous solvent scouring system, the preferred solvent is perchloro ethylene. The scouring portion includes a vaned paddle contributing some mechanical action which assists in the removal of particulate dirt[15]. In a contemporary method established by CSIRO, raw wool is conveyed over perforated drums underneath jets ejecting solvents under substantial pressure to abolish extracted grease and dirt[3].

C. BIO-SCOURING Of WOOL

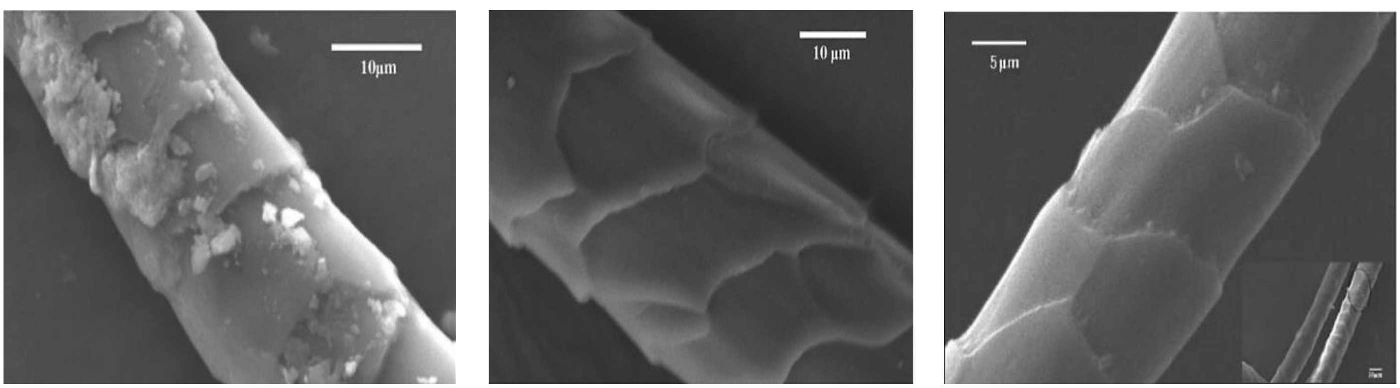
In an aqueous-scouring treatment, the high scouring temperature (60–90°C) wasted excessive heat energy and there was too much organic solvent to demolition in the solvent-scouring waste water[14]. In order to resolve above complications, enzymatic bio-scouring treatment is a recent evaluation in wool pre-treatment process.

The enzyme with acceptable bio-scouring effect was a combination of *Bacillus subtilis* and *Candida lipolytica*, and the ratio these two was 1:4[17].

Table 2 : Process parameters of bio-scouring[17].

Enzyme consumption	pH	Batch Ratio	Temperature(°C)	Time(hrs)
6%	**7.0**	**1:33.28**	**40.44°C**	**18.11**

Under the above mentioned condition, the fat content of bio-scoured wool was only 0.75%, which is reduced to 0.31% compared to that of traditional scouring. Moreover, the lanolin was reclaimed as a valuable material in industry by centrifugation from wastewater. In addition, the residual lanolin, perspiration, chaffy, short wool and silt were utilized to make ecological organic fertilizer by compost treating[17].



(a) Raw Wool (X3000) **(b) Traditional Scouring (X2500)** **(c) Bio-Scouring (X1000)**

Figure 2: SEM Comparison of Wool Fibre[17].

According to scanning electronic microscope (SEM) photographs, it could be observed that the bio-scoured surface with enzyme was very clean and smooth in comparison with that scoured with traditional process[17].

D. LOW TEMPERATURE PLASMA TREATMENT ON WOOL SCOURING

In order to enhance the effectiveness of scouring process, plasma treatment as environmentally friendly technique have employed in wool fabric nowadays. A Europlasma CD600 machine at a radio frequency of 13.56 MHz and O_2 is applied there as plasma gas. The conditions of plasma treatment are represented in the following table[13].

Table 3: Plasma treatment parameters[13].

Gas	Power(Watt)	Gas flow rate (Standard litre per minute)	Treatment time (Minute)
O_2	**300**	**0.3**	**3**

The following figure exhibits outcomes of the scouring of O_2 plasma treated wool fabrics at distinctive time interval. The results in table disclose that 8.86% of the oils, fat, and wax were abolished after O_2 plasma treatment of wool. This is executed as the topmost of the layer of fabric is stripped off by engraving of the O_2 plasma operation[13].

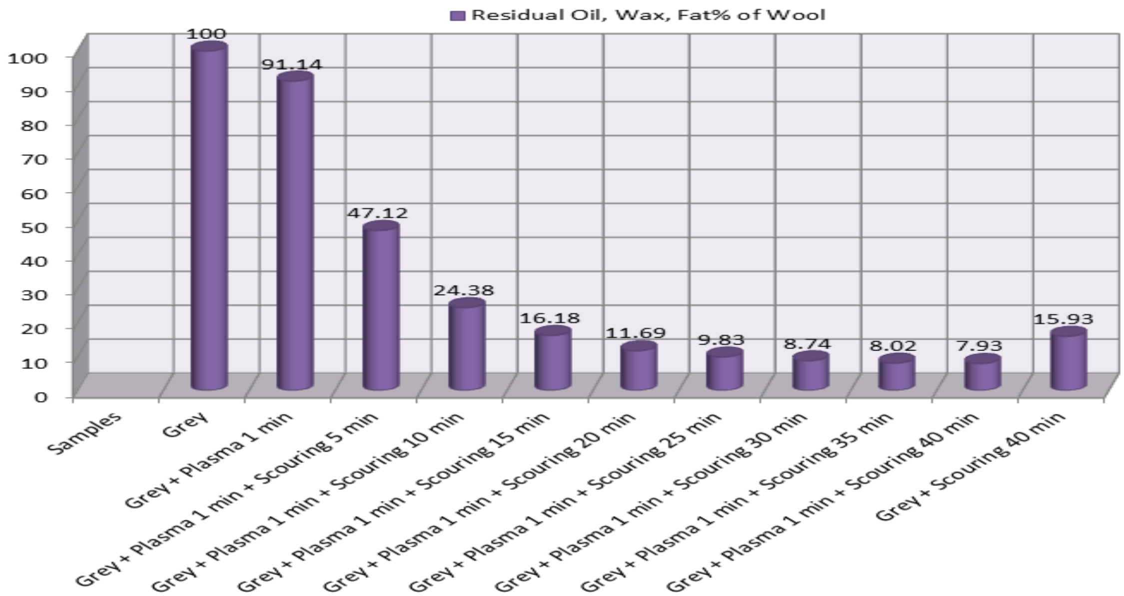
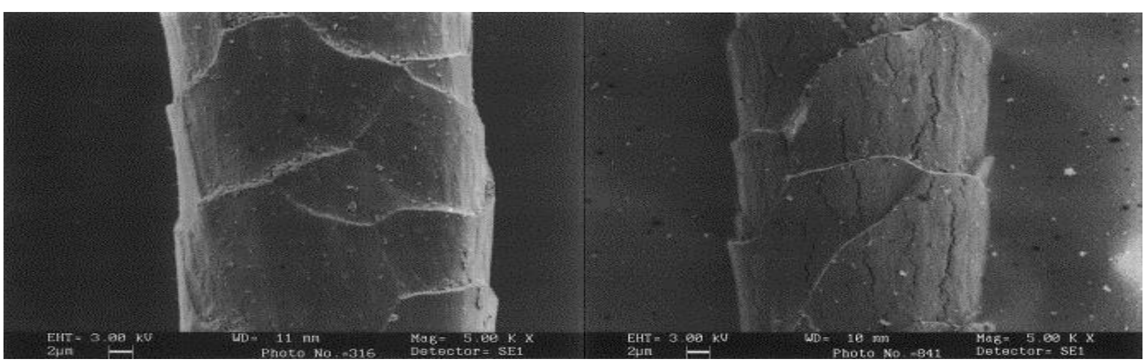


Figure 3: Residual oil, fat, and waxes of plasma treated and untreated wool samples[13].

On the contrary to 40 minutes needed for traditional scouring, 20 minutes and 25 minutes of scouring can be applied for plasma treated wool fabric. This process is environmentally friendly. The most substantial aspect is that surface properties of fabric change significantly after short plasma treatment without altering bulk characteristics and the exploitation of chemical is very less due to physical method[13].



(a) Untreated specimen(mag. 5000X) **(b) Plasma treated specimen(mag. 5000X)**

Figure 4 : SEM photographs of wool fibre[6].

It is observed that holes are evident on the O_2 plasma treated wool fabric surfaces, which results by the ablation effect of nonpolymerizing reactive plasma gas. These holes can contribute dye molecules to penetrate the fibre surface and accelerate rate of dyeing[13].

III. CARBONISING

The object of carbonizing is the removal of cellulosic impurities such as burrs and vegetable fibres from wool. Carbonizing means treating cellulose with strong acid at a high temperature in order to obtain degradation products (including hydrocellulose), which are brittle and can be removed conveniently from the fabric by virtue of an appropriate mechanical treatment[2].

A. TRADITIONAL CARBONISING

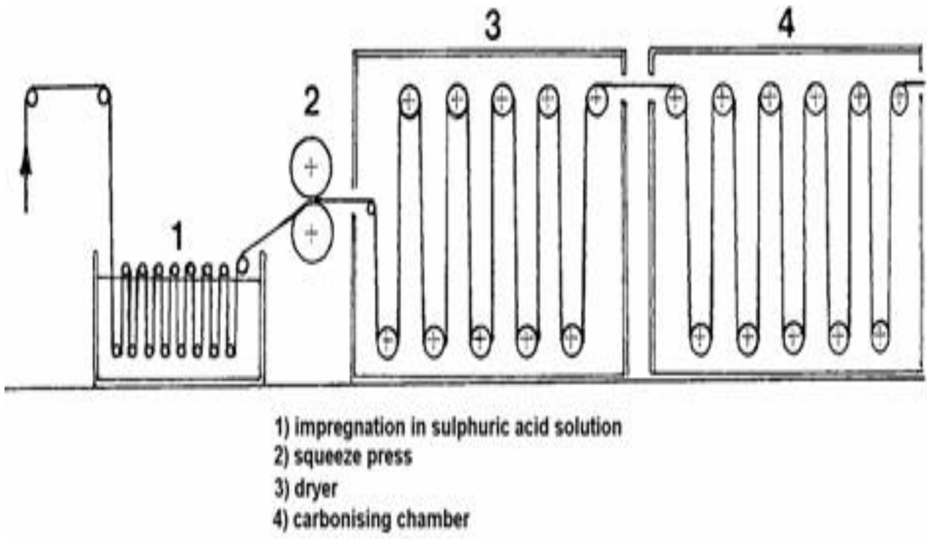


Figure 5: Representation of a conventional carbonising installation plant[18].

The scoured wool fabric is padded, immersed in 5 %(wt. vol.) H_2SO_4 until thoroughly saturated, squeezed, dried slowly and uniformly in open width at 60°-70°C and then backed at 110°C for about 5 min. The charred vegetable material is brittle and is removed in a crushing machine processing iron rollers[1]. Carbonized wool is then rinsed and neutralised with sodium carbonate or ammonia at pH of about 6[2].

A. ENZYMATIC BIO-CARBONIZING

The tensile strength of carbonized fibre decreased by about 25.7% relative to raw wool; due to partial peptide bond hydrolysis during treatment with sulphuric acid[11]. This also results in extensive fibre damage in the subsequent process. For this reason, replacement of chemical carbonisation by enzymes, such as, cellulase and xylanase, has been practiced nowadays in order to reduce wool fibre damage, effluent load and energy consumption[4].

B. METHODS OF BIO-CARBONIZING

Removal of vegetable impurities (i.e. Cellulose, Pectin or Lignin) is carried out using cellulose, pectin and lignin digesting enzymes[4]. Scoured wool fibre is treated separately with the acid cellulase, acid pectinase and xylanase enzymes and then in combination of them (1:1:1) utilizing the process condition represented in the following tables.

Table 4: Process parameters of single enzyme bio-carbonising[4].

Enzyme Concentration	pH	Material : Liquor	Temperature(°C)	Time(mins)
1-20ml/L	**5.0**	**1:25**	**50°C**	**60-210**

Table 5: Process parameters of mixed enzyme bio-carbonising[4].

Enzyme Concentration	**Enzyme ratio**	**pH**	Material : Liquor	**Temperature(°C)**	**Time(mins)**
20ml/L	1:1:1	5.0	1:30	50°C	120

C. EFFECT OF SINGLE ENZYME TREATMENT

Treatment of raw scoured wool fabric with acid cellulase, acid pectinase or Xylanase enzyme removes the vegetable content of wool fibre to various extents. The amount of remaining vegetable matter(1.05%) is about 25% of the total impurity content of raw wool in case of using commercial acid cellulase[4].

Table 6: Effect of treatment of raw wool with single enzymes on its properties[4].

Treatment	Enzyme conc (mL/L)	Impurities Content (%)
Untreated	-	4.00
Carbonised	-	0.10
Acid Cellulase	1 2.5 5 10 20	2.02 1.82 1.44 1.09 1.05
Acid Pectinase	1 2.5 5 10 20	2.48 2.32 2.05 1.77 1.20
Xylanase	1 2.5 5 10 20	2.61 2.46 2.31 2.12 1.73

Acid cellulase degrades cellulose and hemicelluose, acid pectinase hydrolyses pectin and xylanase remove lignin. However, limited increase of tensile strength is monitored when wool fibre treated with high concentrated (5-20mL/L) cellulase or pectinase enzyme[4].

D. EFFECT OF MIX ENZYME TREATMENT

The synergetic action of three enzymes in one bath is found to be much more effective in removing the vegetable matters from raw wool rather than using individual enzyme[4].

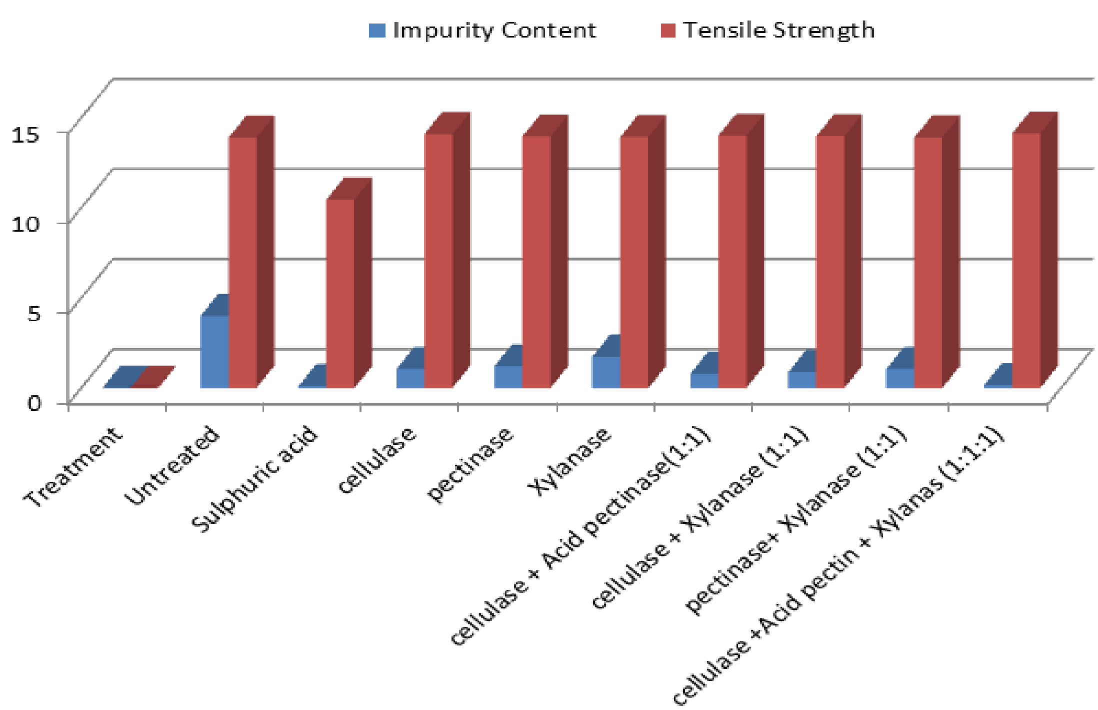


Figure 6: Residual oil, fat, and waxes of plasma treated and untreated wool samples[4].

The percent of vegetable matter in raw wool is reduced from 4 in case of raw wool to 0.16 when wool fibres treated with the mixture of these three enzymes.

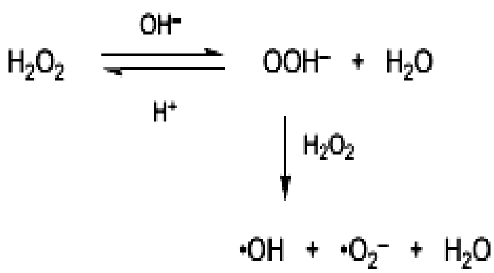
This may be attributed to the ability of each enzyme to remove a definite part of the vegetable matter that contaminates raw wool fabric[4].

IV. WOOL BLEACHING

The purpose of bleaching is to remove as far as possible the natural cream colour of wool, either for the production of white goods or when it is desired to produce bright pale colours[1]. Approximately 10% of the entire world production of wool is bleached[10].

A. PEROXIDE BLEACHING IN ALKALINE CONDITION

Hydrogen peroxide gives a permanent bleaching effect on wool. The active bleaching agent is the perhydroxy anion, –OOH, despite current work has strongly implicated the superoxide radical anion, $.O_2$–[10].



For wool bleaching, the stabiliser is generally tetra sodium pyrophosphate or sodium tri-polyphosphate. Wool is generally oxidatively bleached at pH 8.5–9 for one hour at 50–60 °C in presence of these phosphates. Furthermore, silicate based stabilizers over phosphates in effluents from textile treatment using efficiently these days[10].

B. PEROXIDE BLEACHING IN ACIDIC CONDITION

Wool is processed with a solution of hydrogen peroxide containing formic acid (2.5g/L) at pH 4-4.5 in room temperature. The processed wool is then squeezed to eliminate excess water and passed into a dryer. The chemical degeneration of wool fabric is less and rinsing after washing is not mandatory in this process[7].

C. BLEACHING WITH SODIUM BOROHYDRIDE

This is comparatively recent reductive bleaching technology for wool. It applies the reaction between Sodium borohydride and Sodium bisulphite to produce the active bleaching agent Sodium dithionite.

$$NaBH_4 + 8NaHSO_3 \longrightarrow NaBO_2 + 6H_2O + 4Na_2S_2O_4$$

Damage of wool fibre is significantly less in Sodium Borohydride bleaching compare to peroxide. However, whiteness degree is quite similar to peroxide[16].

D. ENZYME EMBELLISHED BLEACHING OF WOOL

The improvement of whiteness caused by protease in wool bleaching is effected by a number of enzymes applied under both oxidising and reducing conditions. It is generally a two-step process, where an initial etching effect makes the wool more susceptible to subsequent bleaching. The addition of the protease enzyme to a peroxide bath shortens the bleaching time by half for the same whiteness[9].

Table 7: Bleaching of woven cloth with and without protease[9].

Fabric	Enzyme[b] % o.w.f.	Peroxide Bleaching Whiteness, W	Combination bleaching[a] Whiteness, W
1	0.5	27.8	43.1
	0	21.0	32.5
	0.5	33.3	51.0
	0	21.2	33.0
2	0.5	31.8	45.0
	0	26.1	33.0
	0.5	36.2	47.9
	0	26.2	33.5
3	0.5	33.4	46.5
	0	27.2	36.0
	0.5	43.2	58.1
	0	28.	36.6
4	0.5	37.3	49.0
	0	29.4	41 0
	0.5	40.4	58.5
	0	30.7	

*a After peroxide bleaching, cloth was further bleached with Arostit BLN
*b Esperase 8.OL

Table 8: Reductive bleaching together with protease[9].

Enzyme % o.w.f.	Reducing agent%(o.w.f.)	pH	W[a]
Papain			
0	Bisulphite(20)[b]	6.7	11
0.2		6.7	22
0.5		6.7	29
0.5		6.7	20
0.5		6.7	14
0	Dithionite(1 5)	6.7	13
0.1		6.7	16
0.2		6.7	21
0.5		6.7	29
2.0		6.7	44
Esperase8.OL			
0.2	Dithionite(1 5)	7.0	17
0.5	Dithionite(15)	7.0	24
0.2	Sulphite(20)	8.3	16
0.5	Sulphite(20)	8.3	18
0	Sulphite(20)	8.3	1

*a Initial wool whiteness -10
*b Bisulphite is sodium meta bisulphite together with sulphite so as to provide pH 6.7

Reductive bleaching with bisulphite at pH 6.5-6.9 in the existence of papain is probably a fairly cheap and expeditious technique compared with peroxide bleaching, but necessitates modification. In both oxidative and reductive method the minimum weight loss is 3% which is exorbitant for wool because of its higher expanse [9].

V. CONCLUSION

It is obvious that preparation performs a significant role for the successful completion of dyeing and finishing of wool fabric. Without proper pre-treatment it is impossible to accomplish a high quality wool fabric coloration operation. However, due to some drawbacks such as excessive fibre damage, loss of tensile strength, higher amount of effluents in the wastewater and to reduce energy consumption and time, industries are now trying to upgrade the methods of eco-friendly enzyme based biological scouring, bleaching and carbonizing as well as implementation of plasma treatment in wool scouring. This definitely has creating a momentous influence for the textile industry.

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