Developments in grey preparatory processes of cotton textile materials

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Among all the chemical processes of textile materials, the grey preparatory process has been the most neglected area for research till mid-sixties. The escalating energy and labour costs, stringent pollution control regulations, scarcity of water and greater demand for quality textiles have compelled the textile chemists to consider the preparatory processes more seriously. The R&D work carried out over the last four decades to overcome these problems in desizing, scouring and bleaching of cotton is reported. The developments that have taken place in the designing of preparatory processing machinery, including singeing, are also reported.

Keywords: Bleaching, Cotton, Desizing, Scouring

1 Introduction

Cotton as a natural product is made up of its main constituent, cellulose and up to 10% by weight of natural impurities which can vary greatly depending on variety, territory, growth conditions and ripeness at the time of harvest. Such natural concomitants of cotton are in particular proteins, pectin, waxy esters and waxy alcohols, hemicellulose, lignin substances, resins, coloured pigments, organic acids, mineral salts with cations of Ca, Mg, Na, K, Mn, Cu and Al, and the anions carbonate, phosphate, sulphate, chloride and silicate. These impurities mean that raw cotton is completely water-repellent and has a harsh and unacceptable hand and also has a yellowish/brownish appearance and would lead to serious problems in bleaching, dyeing or printing. Therefore, they must be removed completely as far as possible. In addition to these natural concomitants, there are also substances applied deliberately or inadvertently during the growth and in the various processing stages. Here, a distinction has to be made between the substances applied during growth and harvest such as insecticides and fungicides, and the substances applied during mechanical processing of cotton such as tints and starches. All the above-mentioned natural and processing-based concomitants of very different chemical constituents are present on the cotton fibre. They all have essentially negative effects on the processing stages of bleaching, dyeing and printing. If not properly removed, they can show up, after processing by way of inadequate hydrophilicity, insufficient bleach effects, fabric damage in the course of bleach, precipitation in the treatment liquors, roll deposition, brown specks due to the seed coating, unlevel dyeing/printing and poor colour fastness. The object of grey preparation is to prepare the material so as to remove all the impurities as completely as possible and in particular as uniformly as possible without causing excessive damage to cotton.

Traditionally, it was established that grey preparatory process should produce perfectly pure substrates for further processes. Therefore, elaborate methods were devised which consumed large amounts of chemicals, water, energy and time. These traditional methods, desizing-kier boiling-bleaching, aim to completely remove the impurities, especially the wax present in cotton, so as to have maximum absorption. The realization of the fact that it is not necessary to remove the wax completely for the production of a dyed or finished material has paved the way for many new techniques, which are economical and ecofriendly. Cracking of the wax film on the cotton surface is considered to be sufficient for increasing the wetting power of the cloth. Keeping this fact in mind, continuous processes like J-box bleach and flash scouring (vaporloc) were introduced to the industry in late sixties. Though these continuous processes were found to be cost effective and ecofriendly when compared to the traditional techniques, they were not accepted by the industry after mid-seventies due to changes in the production patterns. With the introduction of blends, the market demand for a variety of fabrics with small batch sizes have made the continuous processes uneconomical.
Yet another reason is the replacement of large composite units by medium and small-scale processing units. A close look at the developments that have taken place between sixties and eighties reveals that researchers have tried in following four directions to overcome the problems associated with the traditional processes:

- Using traditional formulations of chemicals in new machinery, thereby reducing the time and energy consumed to produce acceptable quality (continuous processes),
- Using new formulations of chemicals like solvents in new machinery to produce clinically pure substances (solvent processes),
- Using traditional formulation of chemicals with slight modifications to produce acceptable quality using existing machinery (cold processes), and
- Using a combination of traditional and new formulation of chemicals in existing machinery to carry out simultaneously more than one operation to produce acceptable quality (solvent-assisted aqueous processes and combined processes).

The continuous processes were not accepted by the industry after seventies for the reasons mentioned earlier. Though the solvent processes produce excellent quality they did not see the light of the industry because of the prohibitive capital investments and dangers involved in handling the solvents. Many formulations are reported in the literature to carry out preparatory processes either at a low temperature or at room temperature for fine and medium variety fabrics. Combined desizing-scouring, scouring-bleaching, desizing-bleaching and desizing-scouring-bleaching processes were introduced with an aim to save energy, time and other costs. One can derive the benefits of these combined processes at the expense of some quality and so they are accepted by the industry to a very limited extent. For example, cottonseed coating can not be efficiently removed by either cold processes or combined processes. The only efficient method to remove this impurity is the traditional kier boiling.

All the above developments banked upon the use of mineral acids or enzymes or mild oxidizing agents (sodium bromite, persulphates) for desizing, alkali such as sodium hydroxide or chlorinated hydrocarbons such as perchloroethylene for scouring and hydrogen peroxide for bleaching. Though the use of mild oxidizing agents for desizing helps in partial bleaching of cotton they have not made a significant entry into the industry, probably due to high cost of these chemicals. As of now, mineral acid/enzyme, sodium hydroxide and hydrogen peroxide are the only chemicals which are well accepted and cost effective for desizing, scouring and bleaching respectively.

In late eighties and early nineties, a substantial amount of research work has gone in to enhance the efficient use of hydrogen peroxide in strong alkaline medium without the use of sodium silicate as the stabilizer. The ban on use of hypochlorites also induced the researchers to look for alternative chemicals, such as peracetic acid and ozone for bleaching. During this period, a few novel approaches like electrochemical processes, plasma treatment, advanced oxidation treatments, and use of liquid carbon dioxide were also attempted to make grey preparatory process economical and ecofriendly. However, many of these novel methods are still at the lab stage. It is difficult to forecast their acceptability by the industry. The recent developments in biotechnology and genetic engineering have prompted textile researchers to think of using enzymes for all three preparatory processes. As of now, the researchers are having a strong belief that only enzymatic processes can make the chemical processing of textiles economical and ecofriendly.

With this hope, today, many leading textile research institutes are working on the use of enzymes for various applications such as scouring, bleaching, decolouring of dyed materials and discharge printing. Another kind of research, which is now in progress, is the cultivation of coloured cotton to completely eliminate grey preparation and dyeing.

In addition to the above-mentioned developments in the chemistry of preparatory processes, significant contribution has been made by the machine manufacturers over the last 40 years in designing the machinery to produce high quality material with uniform properties at an economical/competitive cost in ecofriendly manner. All these developments are summarized below.

2 Oxidative Desizing

Oxidative desizing is suitable for the complete range of starches, CMC and PVA. Sodium bromite, a mild oxidizing agent, was thought of as a desizing agent in sixties and seventies but it is no longer popular. Today, oxidative desizing means the use of persulphates and hydrogen peroxide in alkaline pretreatment. Persulphates and perphosphates are recommended for use in caustic scouring processes to increase starch degradation. It offers the possibility of combining desizing and scouring operations.
Adrian and Rosch\(^1\) suggested a novel oxidative desizing agent consisting of potassium persulphate, a surfactant and a solubilizer (isopropanol, glycolic acid butyl ester, cyclohexanol or butyl di-glycol). In this novel method, it is claimed that the concentration of persulphate can be reduced by about 25% without sacrificing the desizing efficiency. The use of such low persulphate concentration helps in minimizing cellulose degradation. To derive these advantages, it is suggested not to add persulphate and surfactant separately to the bath, but first to prepare a mixture of persulphate and surfactant and then to add the liquor. The use of solubilizer is recommended if desizing bath contains high concentration of anionic surfactant. During oxidative desizing process, oxidative degradation of cellulose is unavoidable. To overcome this problem, a novel method has been suggested by Kothe and Angstmann\(^2\). Here, the desizing bath is made of a desizing agent (peroxydisulphate) and an oxidation-resistant, water-soluble dispersing agent (water-soluble maleic acid polymer or acrylic acid polymer or water-soluble salts of these polymers). It is stated that during oxidative desizing process it is not necessary to completely convert the macromolecules of starch into water-soluble compounds. Instead these macromolecules can be converted into water-insoluble fragments by a small quantity of peroxycodisulphate, which can then be dispersed by the dispersing agent. Accordingly, the amount of peroxycodisulphate employed can be so low that the danger of an objectionable degree of damage to cellulose can be avoided with certainty. It is true that under such low concentration the starch is also not degraded so as to make it water soluble, but according to Kothe and Angstmann such solubility is in fact not required. The starch is decomposed into sizeable fragments, which are then dispersed by the dispersing agent.

Streit and Witt\(^3\) suggested suitable formulations to convert the peroxycodisulphate into a storage-stable, extremely fluid and easily meterable form. This is achieved by preparing aqueous solution of peroxycodisulphate, water-soluble polymer or copolymer of acrylic acid or maleic acid and an anionic wetting agent. Adrian and Rosch\(^4\) have also suggested an aqueous liquid oxidative agent made of persulphate, peroxodiphosphate and wetting agent with an aim to use substantially low amount of oxidizing agent and also to make the dosage of the chemical easy.

3 Enzyme Desizing

The enzyme α-amylase has been used in textile industry for the removal of starch for many years. It is one of the earliest known industrial applications of enzymes. The most common sizing ingredient is starch in native or modified form. However, other polymeric substances, for example polyvinyl alcohol (PVA), polyvinylpyrrolidone (PVP), polyacrylic acid (PAA) or derivatives of cellulose, may also be abundant in the size. Small amounts of fats or oils are also added to the size as lubricant. In case the size comprises a starch, the desizing may be carried out using a starch-degrading enzyme (e.g. an amylase). In case where the size comprises fat and/or oil, the treatment may comprise the use of a lipolytic enzyme (a lipase). In case where the size comprises a significant amount of cellulose derivatives, the treatment may be carried out with a cellulolytic enzyme, either alone or in combination with other enzymes such as amylases and/or lipases.

An enzyme hybrid having a catalytically active amino acid sequence of an enzyme, such as lipase or an amylase linked to an amino acid sequence containing a cellulose-bonding domain, is reported in the literature\(^5\). This hybrid enzyme helps in improving enzymatic removal of size present in the fabric due to increased affinity (relative to the unmodified enzyme) for binding to a cellulose material. To desize starch-based sizes at higher temperatures, the enzyme mixtures are recommended by Bayer Aktiengesellschaft\(^6\). These mixtures contain at least one high temperature amylase (HTA) and one low temperature amylase (LTA) in HTA to LTA activity ratio (%) of 10:90 to 90:10. These mixtures develop at least 60% of their maximum activity in the temperature range of 30°-90°C. They can be diluted with water and treated with customary additives.

Fornelli and Souren\(^7\) suggested the use of high frequency fields along with enzymes for desizing of starch, degumming of silk and deweighting of polyamides. High frequency fields are also used for peroxide bleaching of cotton, regenerated cellulose, linen and jute. In all these processes, the material is padded with the appropriate chemicals and passed through a high frequency field (13.56 MHz) for 10 s. The process is repeated twice before washing and drying. It is reported that the quality of the final product is as good as that of the conventional methods.
4 Enzyme Scouring

The use of sodium hydroxide and hydrogen peroxide for scouring and bleaching respectively involve substantial cost by way of the cost of chemicals, energy, water and effluent treatment. Further, the non-selective nature of these processes causes structural damage to the cellulose. It is argued that the impurities in cotton are the naturally occurring compounds and therefore should be able to be hydrolyzed and removed by enzymes. Based on this argument, a few enzymes have been proposed for scouring. In a US patent, a cross reference of Japanese patent (JP 7572747) described a scouring method for ramie by using cellulose decomposing enzyme and pectin decomposing enzyme. In the same US patent, another cross reference of East German patent (DD 264947 A1) described a method to pretreat cotton by using a fungal enzyme complex containing fungal cellulase, hemicellulase, pectinase and protease in addition to amylase derived from fungal, animal, bacterial or vegetable origin. The benefits claimed are elimination of alkali and reduced contamination of waste water. Bach and Schollmeyer described the treatment of grey cotton with pectinase and pectinase/cellulase. These combinations can bleach grey cotton to a greater whiteness with hydrogen peroxide. In contrast, Rossner described that cotton fabric treated with enzymes and subsequently bleached with hydrogen peroxide cannot be bleached to that degree of whiteness as that of alkaline scoured and bleached fabric. A Japanese patent described that an enzyme capable of releasing intact pectin from cotton can have a scouring response; the benefits being a milder treatment with a reduced energy and a lower cost of waste water disposal without environmental pollution. The use of an oil and fat decomposing enzyme either alone or in combination with pectin-liberating enzyme is described in a US patent application. Miller et al. recommended the use of pectinase in alkaline pH at about 50°C in a low-calcium or calcium-free environment for scouring cotton fabrics. They claim that enzyme scoured fabric shows an enhanced response to the subsequent chemical treatments.

In recent times, increasing amounts of high-melting lubricants are employed to facilitate high speed weaving. A major part of the lubricants is found to have melting points above 50°C. In an attempt to remove these hydrophobic esters during desizing, Lund et al. suggested the use of thermostable lipolytic enzyme at an elevated temperature, i.e. a temperature elevated to a point exceeding the melting point of lubricants applied to the fabric.

5 Combined Desizing, Scouring and Bleaching

A single-stage desizing, scouring and bleaching of medium and fine varieties of cotton fabrics in a kier was suggested by Parikh. This method involves the use of an organic stabilizer for hydrogen peroxide (diethylenetriamine pentaacetic acid), sodium hydroxide, a non-ionic detergent and anionic wetting agent. The Bombay Textile Research Association (BTRA) also developed a single-stage grey preparation in kier which gives better quality with minimum damage. Sahakari worked out a combined grey preparatory process, which is based on solvent-nonionic emulsion system, known as scourex process. However, in this process, there is a problem of residual starch in the processed fabric. It is reported that a pre-chemicking treatment would reduce the residual starch content. The high chemical cost has acted as deterrent for the wide spread acceptance of this process. Gulrajani and Sukumar worked out a solvent-assisted single-stage grey preparatory process. Here, instead of sodium hydroxide, a scouring agent based on solvent-nonionic surfactant-pine oil combination has been used along with hydrogen peroxide. An optimum recipe for J-box system has been suggested. Other single-stage preparatory processes reported in the literature use tetrapotassium perxydiphosphate (KPP), sodium dipersulphate (SPS) and various combinations of sequestering agents, wetting agents and peroxide stabilizers.

Katz reported that the spent liquor from peroxide bleach bath is highly alkaline and so the liquor has to be subjected to very expensive ion-exchange treatments to reduce the alkalinity to an environmentally acceptable level. To overcome the expensive treatments, they suggested to carry out peroxide bleaching in acid or neutral aqueous solutions so that spent bleach solutions can be discharged in an economic and environmentally acceptable manner. The other advantage of the process is that desizing, scouring and bleaching can be carried out simultaneously in about 15-30 min. Here, the grey cloth is treated in aqueous hydrogen peroxide solution having a pH of 2-7 and temperature of 70°C-100°C. The solution is substantially made free from heavy metal ions and maintained out of contact with all metals while it is in contact with the cloth. To make the process completely free from metal ions, it is recommended that the process be carried out in
glass-lined stainless steel tank. After bleaching, the material is rinsed and dried as in the conventional manner. The results indicated, contrary to general accepted notions, that acid peroxide bleaching can be accomplished in very short periods of time with no damage to the goods. The other advantages of acid peroxide bleaching over the alkaline peroxide bleaching are: stock peroxide solutions can be used directly without further additions, thus eliminating the foaming problems inherent in forming peroxide-alkali admixtures; acid peroxide bleaching is sufficiently exothermic in high peroxide concentrations which reduces the amount of energy that must be furnished to the system; spent acid peroxide bleach solutions can either be dumped directly into waterways or can be made acceptable by simple heating to produce oxygen and water; fumes normally produced during alkaline peroxide bleaching, which are deleterious to health and pollute the air, are avoided.

Sando et al.21 developed a two-bath single-stage desizing, scouring and bleaching of cotton material with neutral peroxide solution. The fabric is padded with neutral peroxide solution and steamed at 140°C for 15 s, followed by hot alkaline pad and again steaming at 140°C for one minute. Baehr et al.22 suggested aerosol/superheated steam application for continuous single-stage desizing, scouring and bleaching of cotton. The fabric is applied under pressure with peroxide, sodium silicate and a special mixture and exposed for 2 min to a saturated steam atmosphere in a steamer.

6 Combined Desizing and Scouring

The first and the foremost combination of grey preparatory processes was effected by incorporating persulphates in the alkaline scouring liquor to achieve desizing and scouring in a single-stage operation. The techno-economic analysis of persulphate and hydrogen peroxide desizing under identical conditions has been carried out by Dickinson23. According to Dickinson et al.23, one-step desizing and scouring, followed by hydrogen peroxide bleaching, has an overall 15% saving in process cost. Optimum conditions for combined desizing and scouring using potassium persulphate along with sodium hydroxide for J-box system has been worked out by Gulrajani25 for cambric and poplin fabrics. Rowe26 has given combined desizing-scouring process based on hydrogen peroxide. It involves the use of a stabilized hydrogen peroxide solution (Albone DS of Dupont) in J-box operation. Albone DS is claimed to be stable at pH 12.

7 Combined Desizing and Bleaching

Complete removal of size coating after weaving is essential to ensure optimum results in the subsequent processes. Enzymatic starch breakdown is preferred because it does not involve any harmful effect on the fibre material. To reduce process cost and increase production, the desizing process is sometimes combined with scouring and bleaching steps. In such cases, non-enzymatic chemicals such as alkali or oxidizing agents are typically used to breakdown the starch, because traditional α-amylases are not very compatible with strong alkaline pH and bleaching agents. Alternatively, unrealistic high amounts of α-amylases, optionally in protected form, have to be used for such combined processes. The non-enzymatic breakdown of size does lead to some fibre damage because of the rather aggressive chemicals used. Accordingly, it would be desirable to use α-amylase enzymes having an improved stability towards, or being compatible with, oxidizing agents at high alkaline pH so as to retain the advantage of enzymatic size breakdown. Cholley27 suggested a single-stage desizing and bleaching using sodium chlorite with a strong alkali, a surface active agent, an activator and an amylolytic enzyme. However, the use of sodium chlorite is undesirable from environmental point of view. Tatín28 reported the use of sodium tetraborate decahydrate as buffer in a bath containing hydrogen peroxide, a sequestering agent, an amylase and a surfactant. In the above two processes, a relatively high amount of α-amylase is used, presumably to compensate for the low oxidation stability of the α-amylase used. Toft et al.29 came out with an oxidation stable α-amylase for combined desizing and bleaching. The process is carried out from a bath containing 1-5 g/l of oxidation stable α-amylase enzyme, 6-25 g/l of hydrogen peroxide (35%), 7-14 g/l of sodium silicate and 0.25-5 g/l of wetting agent. The process is carried out at a pH of 10-11 and a temperature of 90-95°C for 1-2 h. Pad-cold batch and continuous pad-steam methods can also be carried out using the recipe.

Rosch & Sauer30 suggested a simultaneous enzyme desizing and peroxide bleaching. Here, the process is carried out in a mild alkaline (pH 7-8) bath having a surfactant, an enzyme, hydrogen peroxide, urea and peroxide activator. Tetraacetylethylenediamine is recommended as peroxide activator. Sodium bicarbonate or triethanolamine is recommended to maintain alkaline pH. Simultaneous desizing and bleaching with the help of an enzyme and peroxide
respectively encounters certain difficulties. At low alkaline pH, the desizing is good and bleaching is inadequate but at high pH, the bleaching is excellent and the desizing is generally inadequate. Therefore, to overcome this difficulty, a buffer sodium tetraborate decahydrate is suggested by Tatin, which is used along with hydrogen peroxide, a sequestering agent, an amylase and a surfactant.

8 Combined Scouring and Bleaching
Das and Agnihotri suggested a combined scouring and bleaching process in J-box using a small amount of sodium hydroxide along with hydrogen peroxide and sodium silicate. To improve the scouring efficiency, they recommended the use of pine oil along with the above reagents. This process is also known as NPL process. Here, the material is padded with the above chemicals and steamed at 90-95°C in J-box for 90 min. For medium and heavy fabrics, it is recommended that fabric should be desized and given chemicking treatment with 1-3 g/l available chlorine at pH 10 for 30-40 min at room temperature before feeding into J-box.

9 Stabilization of Hydrogen Peroxide
It is well known that a simple solution of hydrogen peroxide is ineffective in bleaching without additives. Alkaline solutions of hydrogen peroxide produce too fast a rate of decomposition and thus must have a stabilizer to control the rate of hydrogen peroxide decomposition. Sodium silicate is commonly used as a stabilizer. It has an excellent anti-catalytic effect against heavy metals such as iron, copper, nickel, magnesium and their compounds. Heavy metals and their compounds are able to enter and contaminate the bleaching bath through the water, chemicals, machine or even the fabric to be processed. They cause catalytic decomposition of peroxide, which, in turn, leads to fibre damage. However, a serious disadvantage of this stabilizer is that calcium and/or magnesium silicates are precipitated where hard water is used, resulting in a harsh feel, formation of marks on the material and difficulties during dyeing, finishing and sewing operations. To overcome this problem, α-hydroxyacrylate acid polymer and an oligomer of phosphonic acid ester have been suggested by De ceuster et al. and Schafer and Berendt respectively. A rapid low-temperature peroxide bleaching using magnesium salt (mixture of magnesium oxide and citric acid) as stabilizer and potassium hydroxide as alkali is suggested by Sheppard. Here, the bleach liquor is made from 4.4% hydrogen peroxide (50%), 1.8% potassium hydroxide (45%) and 1.5% magnesium salt stabilizer. The material is treated in a bath ratio of 10:1 at about 90°C for a maximum period of 10 min. The resulting goods are claimed to be soft, absorbent, matte-free with Hunter scale whiteness >110 and extractable solids less than 0.65%. Burlington Chemicals of USA has come out with a silicate-free stabilizer made of magnesium acetate, an aminoalkylphosphonic acid and dipicolinic acid. In the presence of stabilizer, hydrogen peroxide retention is nearly 100% at 49°C for up to 37 days and it imparts good alkaline stability for 30 min at 88°C. The bleached fabrics are found to be soft, silicate-free with Hunter scale whiteness >85. Low levels of extractable solids are reported because of silicate-free stabilizer.

Baehr et al. reported that many silicate-free stabilizers have been developed earlier. However, on comparison with silicate containing stabilizers, it was observed that the desired effects in regard to desizing, whiteness and the final average DP are not obtained with these silicate-free stabilizers. To overcome these disadvantages, Baehr et al. recommended stabilizers based on organic acids and/or salts thereof comprising: (a) polyhydroxy and/or hydroxycarboxylic acids and their alkali metal and/or ammonium salts; (b) polyacrylic acids and their partially neutralized form; and (c) polyamine and/or amine polyphosphonic acids and their alkali metal and/or ammonium salts with the ratio by weight of components a: b: c being 1-6:0.2-1:0.4-4.

Takeuchi suggested peroxide bleaching under low alkaline conditions wherein the liquor contains salts from organic phosphonic acids and water-soluble alkylamides. It is claimed that an unsurpassed bleaching effect can be achieved in the temperature range of 80°-130°C under low alkaline conditions (pH 10-10.7) without the use of silicate. As a replacement to sodium silicate in peroxide bleaching bath, Smolens recommended the use of sodium orthosilicate and magnesium-polyphosphate while Schafer and Berendt recommend oligomers of phosphonic acid esters. Kothe and Grunwald suggested a pre-treatment process by which it is possible to carry out peroxide bleaching without silicate as stabilizer. The pre-treatment process consists of treating the fabric with dithionate (hydrosulphite) which can be carried out along with enzymatic desizing.

In addition to sodium silicate, inorganic phosphates are also employed as stabilizers. Because of the
excessive fertilization of the waste waters, the inorganic phosphates are replaced by (poly)phosphates. However, these phosphates are difficult or even impossible to degrade and thus pollute the waste waters again in a different manner. The non-biodegradable ethylenediamine tetraacetic acid (EDTA), which is not absorbed by sewage sludge, is unacceptable in its use as hydrogen peroxide regulator. Moreover, with EDTA the remobilization of heavy metals is not completely excluded. Bayer Aktiengesellschaft\textsuperscript{58} suggested peroxide bleaching regulator (stabilizer) which is completely free from phosphorus and EDTA. It consists (by weight) of 28\% aqueous sodium gluconate solution (60\%), 5\% nitritotriacetic acid trisodium salt, 8\% citric acid monohydrate, 2\% magnesium oxide and 6\% sodium hydroxide solution. The remainder (51\%) is demineralized water. This regulator is suitable for continuous pad-steam, cold pad-batch and hot batch processes.

10 Pre-cleaning Operations
To reduce the treatment time for desizing and scouring, few pre-cleaning operations prior to bleaching are reported in the literature. Bucheler and Fornelli\textsuperscript{26} suggested a pad-batch method for demineralization of cotton materials from a bath containing a commercial wetting agent, citric acid, sodium gluconate and hydrochloric acid. The process can also be extended for desizing or bleaching by addition of a commercial enzyme or hydrogen peroxide plus a commercially available organic stabilizer and sodium hydroxide respectively. BASF\textsuperscript{57} suggested a two-stage continuous preparatory process for cotton materials consisting of pre-cleaning and hydrogen peroxide bleaching, in which alkaline scouring can be dispensed with. The pre-cleaning bath consists of customary surfactants/auxiliaries and enzymes. In addition, the bath also contains dispersants/complexing agents. These agents are capable of dispersing and preventing the precipitation of insoluble compounds of inorganic and organic kinds, for example the insoluble hydroxides or carbonates of alkaline earth or heavy metals and also the insoluble salts of these cations, for example pectinate, fatty acids or sizes. They also remove alkaline earth and heavy metal ions from cotton by complexing. Thus, the pre-cleaning creates ideal precondition for subsequent problem-free peroxide bleaching and dyeing. The pre-cleaning helps in high bleaching effect, low peroxide consumption, less fabric damage and good hydrophilicity.

Katz\textsuperscript{58} suggested a pre-treatment prior to peroxide bleaching with an aim to enhance the bleaching effect in a short time. The process consists of soaking the fabric in water for a short duration followed by padding with strong alkali (pH 10-14) and heating it to about 100\°C for a maximum period of 210 s. They also suggested that the alkaline pre-treatment can succeed or precede an acid treatment at pH 3 or below for a maximum period of 10 s at low temperature. Sando et al.\textsuperscript{59} suggested continuous desizing and scouring of cotton fabrics which could be completed in a very short time. According to this method, the fabric is passed through hot water (70°-80°C) for about 1 min to remove the soluble impurities and then it is padded with an enzyme at 40°-60°C and steamed at 100°C for 1 min. The desized fabric is then made to come in contact successively with 0.1-0.2\% alkaline sodium chlorite at 80°-90°C for about 20 s, hot sulphuric acid (pH 2-3) solution at 90°C for 20 s and 1-1.5\% sodium hydroxide solution at 50°-60°C for 10 s. The fabric is then steamed for 60 s at 95°C and washed in hot water.

With an aim to provide an improved process for bleaching with hydrogen peroxide and also to reduce the peroxide consumption, Litz et al.\textsuperscript{50} suggested a method wherein the fabric is repeatedly treated with hydrogen peroxide and an oxygen-containing head space. The fabric is padded with hot peroxide and silicate and then exposed to oxygen atmosphere having at least 35\%(by volume) concentration. The addition of sodium sulphite, an oxidation enhancer, to peroxide bath helps in improving the bleaching effect.

11 Cold Processes
Cold grey preparation is an attractive proposition due to ever increasing energy cost. The process is highly suitable to Indian cottage industry as it can be operated with very simple equipment. Further, attractive excise duty advantages are available for completely cold processed materials. The Ahmedabad Textile Industry's Research Association (ATIRA) developed a catalytic process to scour and bleach at room temperature\textsuperscript{51}. In this process, the usual scouring and bleaching recipes are mixed with a catalyst developed by ATIRA and processed for 36 h. Though the process cost is very low, it has not been accepted by the industry due to very long process time. Subsequently, the process has been modified\textsuperscript{16} so that it can be completed in about 22 h at 60°C. The practical experiences in implementing this process were reported by Kothari\textsuperscript{52}. Another cold process
developed by NPL is reported by Das and Mandava Walla. This process uses soda ash, sodium metasilicate, hydrogen peroxide and an emulsifying agent. Though this process has the cost advantage, the quality of the finished material is poor, especially the removal of black seed particles is not effective.

12 Electrochemical Processes

Cooper suggested electrochemical mercerization (scouring) and bleaching of textiles. It is claimed that the process is economical and free from pollution. It does not require conventional caustic soda, acids and bleaching agents. The treatment is carried out in a low voltage electrochemical cell. The cell produces base in the cathodic chamber for mercerization (scouring) and an equivalent amount of acid in the anodic chamber for neutralizing the fabric. Gas diffusion electrodes are used for one or both electrodes and may simultaneously generate hydrogen peroxide for bleaching. The configuration of the cell is a stack of bipolar electrodes, in which one or both of the anode and cathode are gas diffusion electrodes. The process does not produce hydrogen gas bubbles at the cathode, thereby avoiding the need to mitigate hazards associated with the evolution of hydrogen gas. A Soviet technique employs electrochemical treatment of cotton in aqueous solution of sodium sulphate using controlled current density between two electrodes. At cathode, water is reduced to form hydrogen gas and base and at anode, water is oxidized to produce oxygen gas and acid. Favourable results in mercerization (scouring) and electrochemical sanitization of unmercerized (grey) cotton were reported.

13 Liquid Carbon Dioxide in Preparatory Process

A few references have been cited in the literature on the use of supercritical carbon dioxide for fluorescent whitening of polyester, desizing of yarns sized with hot melt sizes such as perfluoralkane and fluoropolymers and suitable devices to carry out the process.

14 Plasma Treatment of Textiles

Three US patents describe an apparatus and the method of treating textile materials with low-temperature plasma for desizing and scouring. It is claimed that water-repellent foreign matter adhering on the surface are converted into hydrophilic products due to the low-temperature plasma treatment, thereby saving considerable amount of thermal energy, chemicals and water. Two patents have been awarded wherein cotton fabric is continuously treated with low-temperature plasma to carry out desizing and scouring and then subjected to bleaching operation by exposing to ozone and UV radiation.

15 Bleaching

Today, the most common bleaching process is oxidation method and the most common oxidizing agents are sodium/calcium hypochlorites, hydrogen peroxide and sodium chlorite. Of these, hydrogen peroxide continues to be popular because it is non-toxic and odourless and the whiteness obtained is relatively permanent and non-yellowing. In addition, hydrogen peroxide does not have the effluent problem that is associated with chlorine bleaching. For example, during chlorine bleaching, chlorinated hydrocarbons are formed which increase the BOD and COD levels. To replace hypochlorites due to environmental problems and to find cheaper chemical to replace hydrogen peroxide, attempts have been made to study the feasibility of using other oxidizing agents like peracetic acid and ozone. The research findings of these attempts are reported here.

15.1 Peracetic Acid

In Europe and US, peracetic acid has been proven to be an effective bleaching agent in household detergents for more than 30 years and has found wide application in the laundry industry also. For the last three decades it is used for bleaching of synthetics, cellulose acetates, wood pulp, jute, flax and cotton. Peracetic acid is environmentally safe since it decomposes into acetic acid and oxygen during the course of bleaching. Acetic acid is completely biodegradable. However, the acetic acid contributes to higher BOD levels of the effluent. A comparison of this value with the base load of BOD typically present in a textile waste water discharge, which is several hundreds of ppm, shows that this is not a major issue. In view of this, bleaching with peracetic acid appears to be more effective in eliminating the most of the drawbacks of conventional bleaching with alkaline hypochlorite or hydrogen peroxide.

Peracetic acid is used for the removal of “heat-setting discoloration” from nylon. Nylon bleaching is carried out at pH 6.0-7.5 for about an hour at 80°C using 0.3% solution. Degradation of nylon due to peracetic acid treatment does not occur to a large extent. The same bleaching recipe is used for viscose
rayon, secondary cellulose acetate and cellulose triacetate. The fact that peracetic acid gives its best results at pH 6-8 makes it particularly useful for bleaching cellulose acetate\(^\text{64}\). In recent years, peracetic acid has been put forward as a suitable bleaching agent for cellulose fibres, and would seem to be a possible substitute for conventional bleaching agents. It is reported in the literature that peracetic acid causes less damage to cellulose while bleaching cotton and it reduces AOX values of bleach plant effluent\(^\text{72}\). In normal practice, peracetic acid bleaching can be carried out in either presence or absence of catalyst. Woods\(^\text{73}\) showed that excellent bleaching of cotton could be obtained in 15 min at temperature as low as 49°C in a peracetic acid solution containing a chelating agent, a transition metal cation of atomic number 24-29 and sodium dodecylbenzene sulphonate. Of the numerous compounds studied, 2,2'-bipyridine was found to be the most effective chelating agent and cobaltous ion, the most effective transition metal cation. Rucker\(^\text{74}\) re-examined this process with a view to further reduce the temperature to 30°C. He conducted experiments on scoured cotton fabric. The bleaching was done on scoured fabric using a solution containing borax (25.5 moles/l), hydrogen peroxide (36.7 moles/l), acetic anhydride (34.4 moles/l), bipyridine (0.64 moles/l) and sodium lauryl sulphate (2.6 moles/l) at 30°C. The effectiveness of bleaching was evaluated by determining the whiteness index of bleached samples. The scoured cloth had a whiteness index of 32.66. The pH of the bleach solution was varied from 4.75 to 10 at 30°C by using suitable buffers. It was found that at pH 6 and below, bleaching was not satisfactory as at these pH values, the concentration of peracetaic ions was very low. The optimum pH and temperature were found to be 7 and 30°C respectively. Rucker and Cates\(^\text{75}\) investigated the mechanism of catalysis in the peracetic acid bleaching. For this purpose, the bleaching experiments were carried out by varying the concentration of one of the additives at a time. It was found that as the pH increased, the whiteness index increased from 62.56 at pH 4.75 to a maximum of 73.08 at pH 7 and then decreased with further increase in pH, reaching a value of 55.3 at pH 10. The whiteness index reached a maximum of 79 at 50°C and then decreased with increase in the temperature. They also investigated the effect of metal ions during bleaching. It is reported that the treatment of fibres with 2M hydrochloric acid reduces the bleaching effectiveness by removing trace metal ions from the fibres. Sorption of individual metal ions (Cr\(^{3+}\), Mn\(^{2+}\), Fe\(^{2+}\), Co\(^{2+}\), Ni\(^{2+}\), Cu\(^{2+}\), Zn\(^{2+}\)) by HCl-treated cotton fibres prior to bleaching indicates that ferrous ion produces the greatest catalytic effect, and it is only effective when the metal ion is in the fibre as opposed to in solution. Ferrous ions in the fibres sorb 2,2'-bipyridine from solution to form the tris-2,2'-bipyridine-ferrous ion complex that is associated with the fibres, and it is the trichelate associated with the fibres that catalyzes the bleaching. Sodium lauryl sulphate reduces the wasteful decomposition of peracetic acid by preferential association with the trichelate. Presence of magnesium ion in fabric and solution produce excellent bleaching but results in severe fibre degradation. Rucker and Satterwhite\(^\text{76}\) showed the effect of alkyl sulphate surfactant chain length on bleaching. It was found that the bleaching effect increases with the increasing alkyl sulphate surfactant chain length. Walter\(^\text{77}\) reported the peracetic acid bleaching process without catalyst for 100% cotton laces and embroideries. To obtain good whiteness index with less fibre damage, it is recommended that bleaching should be carried out with 15g/l peracetic acid (15%) at pH 7 for 60-70 min at 70°C. Here, it is assumed that the formation of perhydroxyl radical could be responsible for the bleaching action.

The dyeing properties of cotton fabrics bleached with different concentrations of peracetic acid, namely 1, 2 and 3% (own), for different time periods (20, 40 and 60 min) were studied by Moses\(^\text{77}\). He found that the dye uptake of peracetic acid-treated fabric dyed with both cold and hot brand reactive dyes was substantial. The light and wash fastness were also good. Prabaharan et al.\(^\text{78}\) optimized the concentration of peracetic acid, pH and treatment to obtain acceptable degree of whiteness to dye light and medium reactive shades. The quality of the bleached material was assessed in terms of whiteness index, percent strength loss, cellulose degradation (copper number, carboxyl group content and fluidity) and dye take up. The study revealed that pH plays a major role in peracetic acid bleaching as in the case of hypochlorites and hydrogen peroxide. Two types of mechanisms have been proposed for the bleaching action, which involve the liberation of either nascent oxygen along with acetic acid or perhydroxyl radical along with carbonyl radical. The former reaction occurs in acidic medium and the latter in neutral and alkaline media. For the experimental conditions studied, it was reported that high degree of whiteness
index can be achieved above pH 7. As expected, the degree of whiteness index increased with the increase in time for the whole range of pH studied. However, for a given time, the whiteness index decreased in alkaline medium with the increase in pH. This behaviour of peracetic acid in strong alkaline pH is similar to the effect of pH on hydrogen peroxide bleaching. It is stated that if pH is beyond 10.9, the hydrogen peroxide decomposes very rapidly and hence the liberated perhydroxyl ions escape into atmosphere before they could bleach cotton. The stability of peracetic acid also depends on the temperature; at room temperature, it is relatively stable and starts to decompose with the increase in temperature. Therefore, one would expect an increase in whiteness index with increase in temperature provided the rate of decomposition is such that all the perhydroxyl ions are available for bleaching. If the decomposition rate is very rapid, the ions would escape into atmosphere before they could bleach as it happens with strong alkaline pH. Prabaharan et al. reported that the whiteness index is very poor if bleaching is carried out either below 50°C or above 90°C. The whiteness index considerably increases when the temperature is increased from 50°C to 70°C; however, when the temperature is further increased to 90°C the whiteness index either remains constant or decreases marginally.

A major disadvantage of bleaching cellulose fibres with oxidizing agents is the loss in tensile strength, which is due to the loss in chain length and conversion of hydroxyl groups into carboxyl and aldehyde groups. It is always expected that high degree of whiteness would be accompanied by high loss in strength. Among the conventional bleaching agents, the loss in strength in hypochlorite bleaching is more than that in hydrogen peroxide bleaching for a given degree of whiteness. This is the reason why the latter is more preferred than the former. Therefore, to establish the commercial acceptability of peracetic bleaching process it is necessary to study the tensile properties of these fabrics. Prabaharan et al. reported that the various combinations of process parameters could achieve a particular degree of whiteness index. For example, a particular whiteness could be achieved at a particular pH and concentration with either a low temperature and high time or a high temperature with a low time. In such a situation, will the two samples have same % strength loss? It is reported that % strength loss is most markedly influenced by changes in treatment time, temperature and concentration of peracetic acid in that order. Therefore, minimum % strength loss can be achieved by keeping time and temperature low and increasing the peracetic acid concentration. Prabaharan also compared the mechanical, chemical and reactive dyeing properties of fabrics bleached with peracetic acid, hydrogen peroxide and calcium hypochlorite. This work revealed that for a given degree of whiteness, the % strength loss and the extent of chemical damage (measured in terms of carboxyl and aldehyde groups and DP) are least for peracetic acid followed by hydrogen peroxide and calcium hypochlorite. However, there is no significant difference in reactive dye take up of fabrics bleached with peracetic acid and hydrogen peroxide.

15.2 Ozone

The powerful oxidizing and bleaching action of ozone is due to the fact that its molecular unit contains three atoms of oxygen and that it is relatively unstable and easily decomposes liberating atom of oxygen in a highly active condition. J.T. Marsh in his text book “An Introduction to Textile Bleaching”, published in 1946, has made a mention on bleaching of cotton with ozone and stated that this process is not economical due to the high cost involved in the production of ozone. Today, the technology is available to produce high volumes of ozone at an economical cost. Therefore, a considerable research work is going on in several research centers to replace chlorine with ozone for bleaching purposes. The paper manufacturing industry in Europe and US had installed pilot plants in early nineties to replace chlorine with ozone to bleach wood pulp. The findings have shown that ozone bleaching produces better quality of paper (whiteness and strength) than chlorine bleaching. A few references are also available where ozone is used for bleaching of cotton fabrics. Sando et al. suggested continuous singeing, desizing, scouring and bleaching of cotton. According to this method, the grey fabric is passed through a singeing machine to remove the fluffs on the surface of the cloth and then passed through a dust collector and subjected to air and corona discharge to remove the burnt dust adhering to the fabric. The fabric is then passed into the drier to remove the moisture completely from the fabric and the completely dried fabric is passed into a low-temperature plasma treating apparatus. Here, sizing and other impurities adhering to the fabric are decomposed due to the low-temperature plasma and
hence the desizing and scouring of the fabric is complete. Finally, this treated fabric is sent to the bleaching apparatus. The interior of this bleaching apparatus is made up of a group of guide rollers in which the fabric is passed and exposed to both sides by UV rays with wavelengths of 160-380 nm and ozone. Ozone concentration of more than 500 ppm is maintained uniformly inside the bleaching apparatus. The bleaching process is completed in gaseous atmosphere by the action of ozone in the presence of UV rays (advanced oxidation). Takahashi and Kaiga\textsuperscript{81} reported the effect of ozone concentration, treatment time, pH, water quality and amount of moisture present during bleaching on the quality of the finished fabric. Prabaharan et al.\textsuperscript{82} attempted to simplify cotton grey preparation using ozone. This investigation has revealed that there is a scope to desize, scour and bleach cotton simultaneously using ozone. It is suggested that the process can be carried out at room temperature in the presence of 24% moisture at pH 5 using high concentration of ozone in oxygen-ozone gas mixture for a very short time, say, of the order of a minute or two. The quality of the bleached material is found to depend on ozone concentration, treatment time, amount of moisture present in the fabric, wetting time, pH, presence of sizing ingredients and natural impurities, fabric construction parameters and design features of ozone application chamber. Among all these process parameters, the treatment time seems to have a high detrimental effect on the quality of bleached material. The results have indicated that the quality of grey ozone bleached material can be brought inline with that of conventional desize-scour-peroxide bleaching process, provided ozone bleaching is carried out in a very short time with high ozone concentration. It is reported that the presence of moisture during bleaching has a very significant effect on the degree of whiteness obtained and the rate of bleaching. 8% moisture content (standard moisture regain) has very little bleaching effect, but the effect increases very rapidly as the % moisture content increases, reaching a maximum at 24%. A further increase in moisture content up to 80% retards the bleaching action and thereafter the amount of moisture present seems to have no effect on the time taken for bleaching. The role played by moisture during bleaching has been explained with the help of a model. The rate and degree of whiteness obtained also depend upon pH. With the increase in pH from 2 to 9, there is a marginal decrease in whiteness and a further increase in pH up to 12 results in very rapid decrease in whiteness. The reason for this effect of pH is explained with the help of ozone decomposition at different pH levels. The design features of ozone application chamber are found to influence the rate of bleaching. Rapid bleaching is found to occur when the fabric is exposed in such a way that ozone passes through the fabric in a direction perpendicular to the plane of the fabric. Prior to bleaching, complete wetting of grey fabric followed by allowing sufficient time for the fibre to swell is found to be necessary for efficient bleaching. The use of non-ionic wetting agent for the purpose of wetting the grey cloth does not seem to have any effect on bleaching. As in the case of conventional bleaching, coarse fabrics are found to take more time to bleach than fine fabrics. The presence of sizing ingredients and natural impurities seems to protect the cellulose from chemical degradation. The removal of vegetable impurities such as black seed coating does not seem to be satisfactory. To achieve a high degree of whiteness, say for OBA treatment, a two-stage bleaching process comprising grey-ozone bleaching followed by hydrogen peroxide/peracetic acid bleaching is suggested.

The literature available on ozone bleaching of cellulose materials clearly shows that this process is not only ecofriendly but also has several advantages over hydrogen peroxide. Therefore, it is likely that the day is not far off for ozone to replace hydrogen peroxide as it is now happening in wood pulp bleaching.

16 Developments in Preparatory Processing Machinery

To achieve the best results at a competitive cost, apart from the use of the best chemicals and proper sequence of operations, the design features of the machines also play a major role. Therefore, the developments that have taken place over the last four decades in grey preparatory machinery (including singeing) for woven and knit fabrics are summarized below. The main features of these developments are automation, on-line measurement and control of the process parameters. They have helped in bringing out consistent quality with substantial savings in time, water, energy and chemicals.

16.1 Fabric Singeing

Though singeing is a dry process, it is always considered as a part of the wet processing. Unlike other wet processing operations, it does not call for
large quantity of water, except for quenching the material after singeing. Therefore, this process is environment friendly. The most significant development that has taken place in direct flame singeing of woven fabrics is the design of burners to produce high intensity flame with uniform temperature using natural gas, butane, propane or LPG. This direct flame singeing has the problems such as uneven flame heights and clogged flame jets. To avoid or eliminate these problems, indirect singeing system has been developed.

In this system, the heat generated is transferred to specially designed heat retention zones, which are made of ceramic stones and form diffused infra-red radiations. These intense diffused rays are directed to the fabric surface. The heat of the rays is able to create the ignition temperature and thus cause burning of the protruding fibres. This indirect system of singeing is considered to be relatively safe even if the fabric has slack and wavy selvages, creases and surface flaws. Another plus point of indirect system is that it does not offer any pointed heat effect as in the case of direct burner-flame system. High production speeds with automated process control and safety gadgets are the other significant features.

The demand for circular singeing machine for the production of high quality circular knits has paved the way for tubular/circular singeing machines in mid eighties. If tubular knits are singed on a flat singeing machine, which is meant for woven fabrics, then there will be problem of edge-centre-edge irregularities. In circular singeing machines, the flat tube is first opened up in the form of a balloon with the help of a circular/ycylindrical expander\textsuperscript{63, 84} or circular basket\textsuperscript{85} or "former"\textsuperscript{86}. It is then subjected to flame so that burning of the fibres takes place not only from the surface of the cloth but also from the shanks of the loop. The shape of the burners is straight or circular or a combination of straight and circular. A brief description of the three different types of singeing machines that are available in the market is given below.

Dornier\textsuperscript{84} developed a singeing machine in which the tubular fabric is opened up with the help of a circular expander wherein the optimum singeing diameter can be automatically adjusted. Eight swiveling burners located on around a ring expander singe the opened fabric balloon. The principle of opening up of the flat tube and the burner design of ring-jet singeing machine of Osthoff-Senge\textsuperscript{85} are different from that of singeing machine manufactured by Dornier. Here, the fabric is opened and guided by a circular basket. At the fabric entry point, the basket is of a conical shape so as to ensure faultless guiding even when the fabric is not properly presented. The central part of the basket is cylindrical in shape and consists of four pairs of guiding rollers distributed over the circumference. These rollers help in smooth and stretch-free transportation of the fabric tube to the upper section, which is again in conical shape. The ring burner is located outside the basket so that the fabric tube runs between the circular basket and ring burner. The burner is adjustable in height so that the distance between burner and fabric can be varied. In Parex-Mather\textsuperscript{36} singeing machine, the flat tube is opened up with the help of a "former". The machine is designed to accommodate different former sizes so that fabric tube widths of 650-1200 mm can be processed. At the singeing position, straight and semi-circular ribbon burners are positioned so that uniform singeing is performed around the full circumference of the fabric tube. All these machines are capable of running at 70-120 m/min. These machines are so designed that the fabric does not get unduly stretched during singeing, thereby retaining its high degree of elasticity.

16.2 Fabric Preparatory Processing Machines

The first modification that has been introduced to the grey preparatory machinery is the introduction of continuous J-box in sixties. It is not ideally suited for heavier fabrics, requires large floor space for a full bleach plant and produces crease marks, especially in heavier fabrics. In addition to these limitations, as mentioned earlier, this method of processing is not accepted by the industry due to change in the production patterns. This gave rise to semi-continuous open width bleach plants. The advantages of these bleach plants are savings in labour, chemicals, water and energy; less floor space; flexibility in batch size; easy handling of fabrics of varying widths; less elongation; and free from rope marks. An excellent report has been published by Bhagwat\textsuperscript{87}, which deals with the evaluation of semi-continuous open width bleach plants manufactured by different machine manufacturers.

Jigger is considered to be the best to process relatively small batches of woven fabrics. Every jigger manufacturer has been trying to make improvements in the machine design so as to minimize batch variations and reduce fabric handling. The noteworthy developments are: automatic stopping
of the machine when the pre-determined number of passages are completed; jerkless, noiseless and gradual reversal of cloth passage; arrangement of monorail and batch lifting and doffing over a battery of jiggers; uniform indirect steam heating for wider width jumbo jiggers to avoid center-selvedge variation; enclosed jiggers for avoiding heat loss through radiation; minimization of water consumption during washing by sucking contaminated water from the fabric.

Another machine, which is commonly used for woven fabrics, is padding mangle. In the case of conventional padding mangle, the pressure is applied to the roller ends only. This naturally results in the deflection of the rollers and also the exertion of higher pressures at the roller ends, leading to non-uniform application of pad liquor across the width of the fabric. The deflection in a bowl centre is directly proportional to the product of linear pressure and support distance raised to the power of four \((d')^4\) and inversely proportional to the product of the modulus of elasticity, moment of inertia and a constant \(k\) for a typical load. Therefore, to reduce the deflection the supporting distance can be reduced. The Kuster swimming roll system is designed based on this principle. In this, an infinite number of supporting points are introduced, thus reducing the deflection of the bowl to almost zero. This padder guarantees uniform pressure across the whole width of the machine and hence uniform application of the pad liquor from selvedge to selvedge.

The other significant innovation is Roberto roll padder introduced by Modern Rollers Ltd, UK. These rolls are designed to extract the utmost amount of water and other liquid contents from the fabrics. On comparing the squeezing performance of different kinds of squeezing bowls, it has been found that the Roberto rolls can offer better squeezing results. Hence, if used prior to drying, they help in substantial saving of energy. These rolls are composed of a minute selection of fibres. Each fibre is microscopically coated with rubber. The entire covering of the rollers consists of these fibres, correctly vulcanized and pressed together. The porosity achieved during the formation process removes an exceptionally large amount of liquid from the fabric. Owing to the special composition, a certain amount of suction effect also takes place, which is responsible for the better squeezing results (very low pick up).

It is needless to say the importance of washing. In today's context, the efficient washing does not mean only the removal of impurities/chemicals that are present on the material but also it means the minimum usage of water. Among the various factors which influence the washing efficiency, the principle of washing plays a major role. It is known for a long time that the extent of agitation of the liquor in the wash tank is a measure of the washing efficiency. Various devices are being introduced by machine manufacturers to agitate the liquor i.e. to create necessary turbulence. Fluted bottom rollers, planetary rollers, corrugated agitators, vibrating drums, suction devices and spray drums are some of the more successful examples.

Hydroextraction and drying are two the operations, which consume a large amount of energy and hence they have a direct say on cost of production. Therefore, to reduce the cost of production, the conventional steam drying systems are now getting replaced by dielectric heating/removal of water by high frequency radiation. These systems, which generally use radio-frequency radiation or microwave radiation, are now used not only as a replacement to the conventional steam drying but also as an addition to the existing drying equipment to achieve a greater throughput, save energy and to control the quality of the dried material. These radiation dryers are also used as pre-dryers (clads, lamps) to achieve low, pre-determined moisture on the material prior to drying/curing/fixing in continuous processes. The purpose of reducing the moisture content is to avoid migration of chemicals during drying.

The technology of knit processing has undergone a radical change over the last ten years, especially in Indian textile industry. The traditional winch is no longer used because it needs very high liquor ratios. Further, it produces very poor quality material. The outstanding quality of knitted structure is its elasticity. Fabrics processed on a winch lose this elasticity and exhibit very high residual shrinkage. The reason for such a poor quality is the high degree of stretch imparted to the material during processing in a winch. Today, the soft-flow machines have completely replaced winches. These machines are designed to handle the knits in a tension-less manner. The liquor ratios that are required for these machines are as low as 1:3 or 1:4. The other noticeable developments are continuous mercerizing-scouring-bleaching ranges, continuous washing ranges, relax drier and compactors. These machines are capable of producing finished goods with very low residual shrinkage, smooth feel with bulky appearance. The induction of
ancillary equipment such as tube-reversing, detwisters and continuous tube-slitting have greatly reduced material handling, resulting in high quality material. The only problem with the above-mentioned new generation of processing machinery is that they are highly capital intensive.

17 Concluding Remarks

The immediate problem the textile industry facing is the absence of an economical solution to the problem of effluents and waste disposal. The other major problems are scarcity of water, increasing energy costs, rapidly changing fashion/consumer demands, resulting in lower lead times for execution of orders and production of finished goods to meet the standards specified by eco-labeling. In addition to these problems, which are common to all textile-producing countries, in India, there are other problems like competition between organized and unorganized sectors, and lack of modernization in weaving and processing sectors. The future performance of the industry solely depends on how these problems will be addressed. The developments in cotton grey preparatory listed in this paper attempt to address these problems, either directly or indirectly. However, there is still a lot to be done to make the cotton grey preparation more economical and eco-friendly. New technologies like enzymatic grey preparation and advanced oxidation seem to provide solutions to the problem of environmental protection. It is worthwhile to mention here that European Union started in early 2000 a revolutionary project, "Bio-pretreatment"—a full pre-treatment process based on enzymes. The project has been funded by EEC and will be completed in 2003. The overall objective of the project is the development of a new enzyme-based continuous process for scouring and bleaching of textiles. It is expected that this innovative and environment-friendly technology using new enzymes will lead to substantial savings in chemicals, energy and water. The specified objectives of the project are development/identification of new (proto) pectinase and bleach enzymes systems suitable for this application; and development of continuous bio-pretreatment process using an optimized enzyme cocktail. At present, no continuous bio-process or enzyme cocktail is available. The main challenge is to find a technological solution for the removal of enzyme-weakened non-cellulose substances from cotton fibres in a continuous way. This will lead to the development of new machinery. It is expected that the bio-pretreatment process will lead to considerable savings in energy (60-80%) and water and will avoid the usage of hazardous chemicals.

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