# ANOLYTE AS AN ALTERNATIVE BLEACH FOR COTTON FABRICS

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# DECLARATION

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# CHAPTER 1

## 1.1 INTRODUCTION

The textile industry based on fibre science and technology develops fibres in huge quantities to cater for the demands in the market to provide clothing made from cotton, wool, polyester, nylon and many other fibres and blends. This is done to specifically satisfy the needs of all consumers. Being close to the body, unbreakably linked to our well-being, as a means of expressing our personality and present in a thousand ways in our day to day activities, textiles are inevitable features of the human society (Topalovi 2007:7). The odour and cleanliness of these textile products is often a determinant of their acceptability for consumers. Bleaching is therefore essential to prepare fibres and fabrics for dyeing, and is often required to remove stains in core.

According to Tavčer (2012:20), important factors for improving textile wet processing include a reduction in processing costs, in environmental impact and improvement in quality. The author expounds that these drivers continue to stimulate research into new chemicals and processes, including the development of new bleaching agents and processes because bleaching is a critical part of textile preparation.

Bleaching is defined as a process that fibres go through to remove yellowish natural impurities prior to dyeing and printing (Lim *et al* 2005:121). Bleaching creates a uniform white base of cellulose fibres that enables level dyeing of pale or bright hues especially in the production of household products (Xu *et al* 2011:73). However, this process involves high levels of energy and the use of corrosive chemicals like hypochlorite in order to achieve the desired results.

Though bleaching is necessary Cai & Evans (2007:115) argue that bleaches degrade the quality of fibre and fabrics, by damaging the tensile strength (Maekawa *et al* 2007:222). Bleaches such as hydrogen peroxide have over the years proved not only to cause damage to the fibre but also pose a threat to the environment and the people who are in contact with chemicals. They use high levels of energy and also storage of these chemicals pose a challenge (Maekawa *et al* 2007:222).

Cotton fibre dominates the textile sector as an ecofriendly fibre because it has extremely good comfort and hygiene. Approximately 50% of textiles are made from cotton since these fibres are particularly suitable for the manufacture of sport and leisure textiles, medical non-implantables and healthcare/ hygiene (Lazić *et al* 2012:225). Menachem (2007:642) describes cotton fabrics as cool in hot weather. They also provide warmth for cold weather depending on the pockets of air that are entrapped between fibres in the fabric to the wind. Furthermore, cotton fibres make good insulators when padded or quilted into garments.

They have good absorbency qualities hence they are used in making towels and sheets. Cotton fabrics do not have a static electricity problem. Cotton is a versatile fibre that is widely used for most valuable goods in apparel, home furnishings and industrial. However, cotton fibres may act as a suitable medium for microorganism growth hence processes like bleaching are carried out in cotton products not only for bleaching purposes but to also disinfect. Eren & Ozturk (2010:1) expound that, cotton preparation processes like desizing, scouring and bleaching consume large amounts of energy, water and chemicals; which pollutes the environment and impact on the Ozone layer, hence a need for new technologies which are environmentally friendly as they are capable of reducing pollution.

The current work aims at finding out if using electrochemically activated (ECA) water – Anolyte could be used in the textile industry as an alternative to the hypochlorite bleach and hydrogen peroxide that is mostly used. In the last decade, ECA water has commonly been used in water treatment and recently in sanitization of industrial facilities and as a disinfectant in hospitals and the food production industry (Ghebremichael *et al* 2011:210). The authors explain that, ECA has a high disinfection efficacy (Huang *et al* 2008:329) compared with chlorine because of the presence of oxidants. Anolyte is used as disinfectant as ECA technology has secured FDA and EU approval for use as an advanced disinfectant in the food and beverage processing industries. It does not affect the taste, colour and appearance of the products.

In a study conducted by Natasha van Heerden (2010:5) the author established that electrochemically activated water may be an environmentally friendly media for washing. The author adds that, Catholyte as an environmentally friendly washing agent is an attractive alternative to conventional laundry detergents because it removes soil efficiently from polyamide 6, 6, fabric without causing damage to the fabric thereby minimizing the impact on the environment. The laundering of textile fabrics with electrochemically activated water would contribute to the more green approach of consumers and manufacturers experience across the world. Research done by Van Zyl (2012:130) also indicated that Catholyte is also efficient when laundering cotton.

ECA is produced by passing a dilute salt solution (NaCl) through an electrolytic cell to obtain Anolyte and Catholyte; where Anolyte has a pH ranging from (2.3-2.7) and a high ORP of more than 1,000 mV and Catholyte has pH between 10-11.5 and a low ORP of - 800 to – 900 mV (Ghebremichael *et al* 2011:210). Production of electrolyzed water is cheap (Huang *et al* 2008:329), as only water and salt is needed making it easy to be produced and safe to use. The electrolyzed water returns to normal water after 48 hours if not used. Bechtold, Maier & Schrott (2010:66) in their research discovered that, the use of electrochemical activated water allows improved process control and consistency during bleaching of denim, and this is one of the positive results yielded by the use of Anolyte in textile processes.

Though hydrogen peroxide and hypochlorite bleaches have long been used in the textile industry, they have negative impact on the environment. According to Khan *et al* (2012:30) hypochlorite bleaches produce chlorine gas which is dangerous to human beings; it damages the fibres especially wool and acrylic fibres and turning them yellow. As for hydrogen peroxide bleach, it requires more energy, labour, water and time when bleaching (Hashem *et al* 2010:534) but it is environmentally safer as compared to hypochlorite bleach.

Cotton fibre was used in this research to compare the effectiveness of Anolyte, sodium hypochlorite and distilled water in bleaching unbleached cotton, bleached cotton; cotton soiled with tea, blackcurrant juice, blood (aged) and soot mineral and lastly cotton dyed with reactive red dye and vat dye. The bleaching process varied in bleaches, temperature and length of bleaching and all these factors were compared against one another. Bleached samples were further tested for tenacity, colour change and stiffness.

In a research carried out by Vermaas (2011:158), it was discovered that Anolyte is a viable alternative to chemical disinfectants for the destruction of *E. coli* and *Staph. aureus* on cotton, polyester/cotton and polyester fabrics, at low temperatures of 24-30°C without having a more detrimental effect on the tensile and tearing strength of the fabrics than the currently used chemical disinfectants such as sodium hypochlorite. The findings indicated that Anolyte is a good disinfectant that could be used in hospitals, agricultural sectors and other places where disinfection is needed. This factorial study which is a laboratory experimental research aimed at finding out if Anolyte could be recommended to be used in the textile industry as well as home laundering as alternative bleach to hypochlorite as it is cheap, easy to produce, environmentally friendly and safe to use.

## 1.2 PROBLEM STATEMENT

Bleaching is an important step in textile finishing and new innovations are needed for a new bleaching process or bleach which is environmentally friendly, affordable to produce and use. Bleaching is an important step in textile finishing but it causes damage to fibres and the environment. Hydrogen peroxide bleach decreases the tensile strength of individual fibres due to oxidation of cellulose as it is a byproduct of the bleaching process, which may lead to adverse effects on the fibres mechanical properties (Yilmazer & Kanik 2009:45). Using hydrogen peroxide and hypochlorite bleaches have posed problems of environmental concern, with safety of handling and storing these solutions. Wasif & Indi (2010:353) adds that the rising fuel cost tends to make hydrogen peroxide bleaching uneconomical.

Electrochemically activated water (ECA) is currently used in sanitation and water treatment of industrial production facilities instead of chlorine bleaches as a disinfectant. It is expected that it might have bleaching qualities as well. Solovyov *et al* (1995:298) explains that Anolyte with active chlorine concentration causes irreversible damage to the membrane of most microbes in one minute hence used in sterilization processes.

A more eco-friendly process for bleaching fibres using low temperatures, reduced pH, short treatment period and low chemical concentration is needed, hence the production of Anolyte as an alternative bleach rather than using sodium hypochlorite and hydrogen peroxide bleach. Anolyte is considered a more environmentally friendly disinfectant compared to chlorine and peroxide; Anolyte allows improved process control, consistency and low production costs. Although the ECA solutions have antimicrobial properties, the effect of Anolyte on the whiteness of cotton fibres cotton has not been established. Therefore, the researcher aims at comparing the bleaching effect of Anolyte and sodium hypochlorite and distilled water on cotton; unbleached cotton, bleached cotton, dyed cotton and stained cotton. Bleach temperature and length of exposure was considered to determine their effect on tensile strength, stiffness and whiteness of fibres exposed to these bleaches.

## 1.3 AIM

The aim of the study was to investigate the effectivity of Anolyte as a bleaching agent against the commonly used sodium hypochlorite and distilled water was used as control. The second objective was to determine the efficiency of Anolyte as bleach at temperatures 24°C 30°C, 40°C, 60°C and 80°C. The third objective was to determine the effect Anolyte had on the stiffness, whiteness and tensile strength of cotton after it has been exposed for 9 minutes, 18 minutes, 30 minutes, 45 minutes, 1 hour, 1 hour 30 minutes and 2 hours respectively. The textile materials tested consisted of bleached cotton, unbleached cotton, dyed cotton and stained cotton.

## 1.4 HYPOTHESES

- **Hypothesis 1:** Anolyte, sodium hypochlorite and distilled water will have an effect on the tensile strength of bleached cotton and dyed cotton.
- **Hypothesis 2:** Anolyte, sodium hypochlorite and distilled water will have an effect on the stiffness of bleached cotton, unbleached cotton and dyed cotton.
- **Hypothesis 3:** Anolyte, sodium hypochlorite and distilled water will have an effect on the whiteness of bleached cotton, unbleached cotton, dyed cotton and stained cotton.
- **Hypothesis 4:** Different temperatures 24 °C, 30 °C, 40 °C, 60 °C and 80 °C will affect the influence of Anolyte, sodium hypochlorite and distilled water on the tensile strength, stiffness and whiteness of bleached cotton, unbleached cotton, dyed cotton and stained cotton.
- **Hypothesis 5:** Bleaching times of 9 minutes, 18 minutes, 45 minutes, 1 hour, 1 hour 30 minutes and 2 hours will influence the effect of Anolyte, sodium hypochlorite and distilled water on the stiffness and whiteness of unbleached cotton and stained cotton.
- **Hypothesis 6:** The number of laundering cycles 5, 10 and 20 will influence the effect of Anolyte, sodium hypochlorite and distilled water on the tensile strength, stiffness and whiteness of bleached cotton and dyed cotton.
- **Hypothesis 7:** Anolyte, sodium hypochlorite and distilled water will not yellow bleached cotton.

## 1.5 DEFINITION OF TERMS

- **Anolyte:** Anolyte is an electro-chemically activated water solution and is produced by the electrolysis of regular tap water that contains dissolved sodium chloride. The Anolyte solution produced is a very powerful disinfectant against all bacteria, viruses, algae, molds, spores and other pathogens (Activated Environmental Solutions 2014:1)

- **Bending rigidity:** is a measurement of the couple required to bend the fabric to a certain curvature (Behera & Hari 2010:173).

- **Bleaching**: is the step used to remove unwanted colour from the fibres by using chemicals such as sodium hypochlorite and hydrogen peroxide (Carmen and Daniela 2012:60). This includes removal of among others soils and stains i.e. a type of sanitizing effect.

- **Colour measurement:** is a process of assigning numerical values to a colour (Kadolph 2011:445).

- **Dye:** is a complex organic compound that is used to add colour to materials by binding with them. It is composed of chromophore, the coloured portion of the dye molecule and auxochrome which slightly alters the colour (Kadolph 2011:447).

- **Dyeing**: is the process of adding colour to the fibres, which normally requires large volumes of water not only in the dye bath, but also during the rinsing step. Depending on the dyeing process, many chemicals like metals, salts, surfactants, organic processing aids, sulphide and formaldehyde, may be added to improve dye adsorption onto the fibres (Carmen and Daniela 2012:60).

- **Reactive dyes:** these are dyes that combine chemically with the fibre and are mostly used on cotton, other cellulose fibres, silk and nylon (Kadolph 2011:449).

- **Soils:** is any substance not intended to be on a fibre, yarn or textile e.g. gums, mud and wax (Kadolph 2011:479).

- **Stiffness:** is the resistance to bending or creasing of a fabric (Kadolph 2011:569).

- **Textile:** is a general term used to refer to any flexible material that is composed of thin films of polymers or of fibres, yarns or fabrics (Kadolph 2011:570).

- **Vat blue dyes:** are insoluble in water and used mainly for cotton work clothes, sportswear, prints and drapery fabrics (Kadolph 2011:449).

- **Colourfastness:** Resistance to fading; i.e., the property of a dye to retain its colour when the dyed (or printed) textile material is exposed to conditions or agents such as light, perspiration, atmospheric gases, or washing that can remove or destroy the colour. A dye may be reasonably fast to one agent and only moderately fast to another. Degree of fastness of colour is tested by standard procedures. Textile materials often must meet certain fastness specifications for a particular use (Celanese Acetate LLC 2001).

- **Tensile strength**: Tensile strength of a yarn or fabric is defined as a maximum load that it will endure without breaking when subjected to uniaxial tensile loading (Malik *et al* 2011:46).

# CHAPTER 2

## 2.1 INTRODUCTION

The textile industry is one of the largest and basic industries worldwide which covers the needs of a consumer in sectors such as apparel, household textiles, medical textiles, hotel and hospitality and military. Various fibres are manufactured to suit the specific needs. Cotton fibres are the purest of cellulose and the world's most important textile material, because of its good qualities like good absorbency and good abrasion resistance, to mention a few. Therefore, chemical modification on the cotton fibre has been studied as a means of improving its wettability, dyeability, chemical affinity and to improve competitively of the textile products made of blends of cotton with chemical fibres (Shahidi *et al* 2013:34).

Important factors for improving textile wet processing include a reduction in processing costs, a reduction in environmental impact and improvement in quality (Tavčer 2012:20). The efficiency of bleaching effects by various chemicals and conditions are continuously investigated by researchers in order to improve the quality of the products made from cotton fibre and even make a variety of products. These new technologies do have pros and cons that may affect the environment as well as the quality of the end product itself.

Cotton is a natural fibre that is highly used worldwide as its demands keep rising. The textile industries have a challenge as new technologies arise in order to meet the demands and not compromise the quality of the products during processing. New technologies are developed to speed up production, use less water and electricity and avoid endangering the environment as much as possible. However in some instances the processes used in the textile industry pose a danger to the environment, people working in the factories, quality of the finished products and the economy of many countries.

Therefore, this chapter reviews relevant literature associated with the use of Anolyte in the food industry and textile industry. The literature further discusses bleaches and synthetic dyes and their use in the textile industry. Furthermore, the production and properties of cotton fibre is discussed as well as examples of different kinds of stains found on cotton fabrics summarized.

## 2.1.1 ELECTROCHEMICALLY ACTIVATED WATER

The Anolyte solution and Catholyte solution are the two distinct byproducts of the Electro Chemical Activation (ECA Technology) process, whereby the Anolyte solution is a disinfectant and the Catholyte is a detergent. The ECA process concept involves the passage of high voltage current through a brine solution with a membrane interposed between the Anode and Cathode, which produce a substantial electrical potential difference leading to two types of water namely Anolyte and Catholyte (Idris & Saed 2002: 139). Huang *et al* (2008:330) define electrolyzed oxidizing (EO) water also known as strongly acidic electrolyzed water (SAEW) or electrolyzed strong acid aqueous solution (ESAAS), as a novel antimicrobial agent which has been used in Japan and many other countries worldwide for several years. These two solutions are used extensively in several different applications ranging from disinfection to cleaning both in an economical and an environmentally friendly manner.

## 2.1.1.1 ANOLYTE

Electrochemically activated water (EO) is formed by electrolyzing a dilute salt (NaCl) solution that is further separated into a basic fraction (Catholyte) and an acidic fraction (Anolyte) (Kim, Hung & Russell 2005:1779). Marais & Williams (2001:238) explain that, Catholyte is reputed to having a strong cleaning or detergent effect while Anolyte is antimicrobial.

Steponavičius *et al* (2012:193) explain in their research that studies on electro-chemically activated water (Anolyte) demonstrated its bactericidal, antiviral and partially fungicidal properties. The authors add that, recently extensive studies on the use of electro-chemically treated water for the reduction of mycobiotic contamination during the harvest processing have been widely performed in Japan, the United States, China and Russia. On another note Cloete *et al* (2009:379) add that, Anolyte possesses antimicrobial activity against a variety of micro-organisms as a disinfectant used in agriculture, dentistry, medicine and the food industry (Kim *et al* 2001:92).

It was found that the Anolyte is characterized by mycostatic and, especially, bacteriostatic effect on microorganisms, continuing for a 24-hour period. This water was used in post-harvest mycological safety treatment of fruit and vegetables, replacing chemical fungicides. The solution exists in a metastable state after production and contains many free radicals and a variety of molecules and ions (Marais & Williams 2001:238).

Electrolyzed oxidizing water has been considered an alternative to chlorine for disinfection as a result of the properties it possess (Ghebremichael *et al* 2011:210). Research indicate that an ORP value of + 650 mV to 700mV can kill bacteria within seconds (Cloete *et al* 2009:379). Furthermore, the high oxidation potential of ECA solutions may inhibit microbial growth through oxidation of sulfhydryl compounds on cell surfaces and other key metabolites.

Ghebremichael *et al* (2011:210) states that compared to chlorine bleach; EO is a more environmentally friendly disinfectant that has higher disinfection efficacy because of the presence of a mixture of oxidants. Anolyte is a mixed oxidant solution which includes hypo chloric acid (HOCl) and has a high Oxidation Reduction Potential (ORP) greater than 1 000 mV (Ghebremichael *et al* 2011:210).

## 2.1.1.2  MECHANISMS FOR THE PRODUCTION OF ANOLYTE

EO was initially developed in Japan by passing a diluted salt solution (NaCl) through an electrolytic cell within which the anode (Anolyte) and cathode (Catholyte) are separated by a membrane (Huang *et al* 2008:332). Figure 2.1 depicts a flow chart of the production of Anolyte and Catholyte. To generate EO water Kim *et al* (2001:92) explains that there need to be reactions in a cell containing inert positively charged and negatively charged electrodes separated by a membrane, through which diluted salt water passes. Electrodes are subjected to AC voltage where two types of water possessing different properties are produced, that is Anolyte and Catholyte (Robinson *et al* 2010:289). The authors further expands that, Anolyte (the product of the high anode) has a high oxidation potential of around +1000mV, whereas Catholyte (the product of the cathode chamber) has a high reduction potential of around -800mV. The Anolyte has a low pH (2.3 – 2.7), high dissolved oxygen and contains free chlorine. This is why one expects the bleaching to take place (Huang *et al* 2008:332). Because of the potential EO possesses, it has been described by Ghebemichael *et al* (2011:210) as another form of chlorine solution.

Cloete *et al* (2009:379) explains that Oxidation Reduction Potential (ORP) represents the tendency of a chemical compound to scavenge or acquire electrons, thereby becoming reduced. Each chemical entity has its own intrinsic oxidation-reduction potential (ORP) and the more positive the potential, the greater the compounds affinity for energy (electrons) and hence its tendency to become reduced. Thus the highly oxidized Anolyte solutions will actively scavenge electrons from any viable source and local microbes represent the most readily available source of energy. Upon loss of electrons, the microbes also lose their ability to maintain their structure and function and they rapidly absorb water, swell and burst. Cloete *et al* (2009:379) adds that, Catholyte has a pH 11.6 and oxidation–reduction potential (ORP) of -795 mV that contains dilute sodium hydroxide, while the anode produces an electrolyzed acidic solution composed of dilute hydrochlorous acid and contains dilute sodium hydroxide (Fabrizio & Cutter 2005:328) and has a negative oxidation reduction potential (ORP) whereas Anolyte on the other hand has a positive ORP with a pH 2.4 – 2.7, it is an acidic solution composed of dilute hydrochlorous acid (Fabrizio & Cutter 2005:328). The solution produced at the anode possesses a high level of antimicrobial properties (Robinson *et al* 2010:289), therefore it is used as a bacterial disinfectant and sanitizer in hospitals, dental clinics and various other fields (Cloete *et al* 2009:379).

According to Fabrizio & Cutter (2005:328), the only chemical used in the production of EO is sodium chloride and the solution can only be used within 48hrs after production after which it will return to a stable inactive state. It is environmentally friendly and does not cause water pollution (Robinson *et al* 2010:289).

Flow chart on the production of ECA



Figure 2.1: Production of Anolyte and Catholyte. Idris & Saed, 2002:141
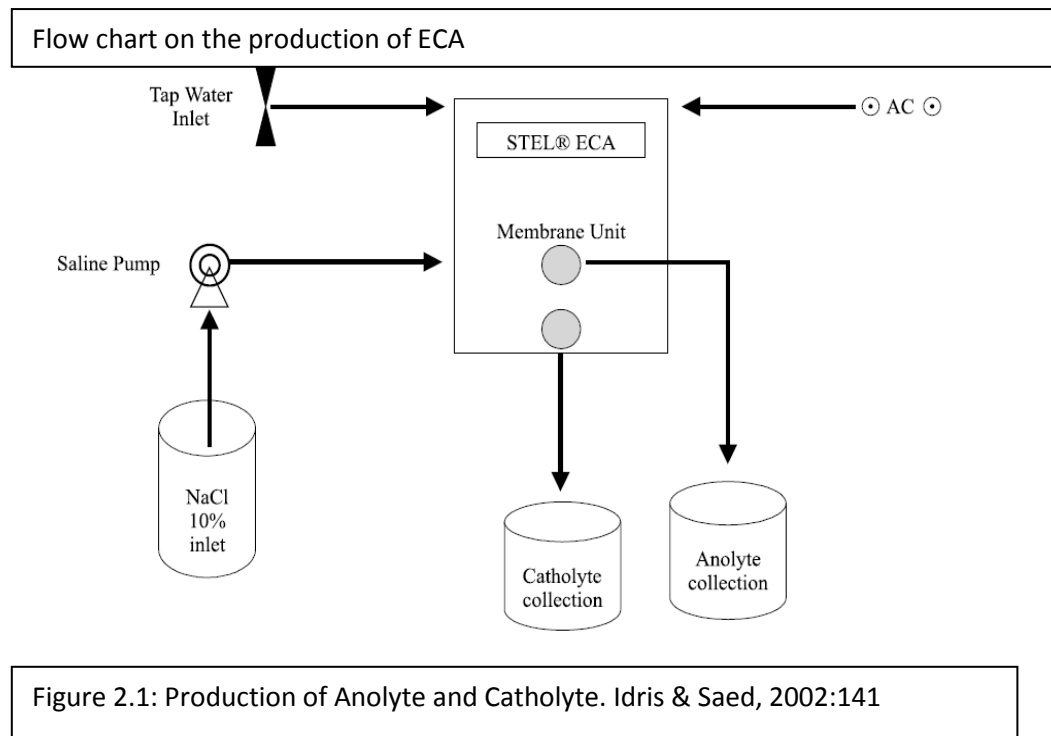
## 2.1.1.3 CHARACTERISTICS OF ELECTROLYZED WATER

Idris & Saed (2002:141) describe Anolyte as a colourless liquid with pH value of 2-3 and contains reactive ions and free radicals which contribute to the powerful oxidising properties. The authors add that despite its powerful properties Anolyte is nontoxic and harmless to humans.

**Environmental effect**

Huang *et al* (2008:331) indicate that EO water has the potential to be more effective and inexpensive as compared to the sodium hypochlorite and acetic acid. It is also said to have less impact on the environment (Huang *et al* 2008:331) as well as user's health because there are no hazardous chemicals added in EO production.

**Bacterial and antimicrobial effect**

Fabrizio & Cutter (2005:328) report that the only chemical used in EO production is sodium chloride. Therefore, Anolyte is acidic and has a high oxidation potential and it is antimicrobial, while Catholyte is an alkaline solution with a high reduction potential making Catholyte to have a strong cleaning or detergent effect (Marais & Williams 2001:238). Nakae & Hideo (2000:511) and Kim *et al* (2001:92) mention that, EO water has strong anti-bacterial effects on most pathogenic bacteria that are most important to food safety. Additionally EO has proved to be effective in cell suspensions attached to poultry surfaces and against spoilage organisms associated with vegetables (Fabrizio & Cutter 2005:328).

## 2. 1.1.4 ADVANTAGES AND DISADVANTAGES OF ANOLYTE

Anolyte is comprehensively used in various fields. Anolyte has antimicrobial effects and cause no harm to human beings as it is used to control microbial growth in various fields like hospitals and agriculture (Cloete *et al* 2009:379). Furthermore, Anolyte was found to be effective in the removal and control of biofilms in a water distribution system and industrial water cooling.

The main advantage of Anolyte as indicated by Huang *et al* (2008:332), is its safety, even though it has a strong acid pH it is not corrosive to skin, mucous membrane or organic material as well as metals like stainless steel. Therefore, it is currently used to sanitize stainless steel in hospitals. This is in comparison to sodium hypochlorite which has proved to be toxic as it irritates the skin and mucous membrane. In their research Steponavičius *et al* (2012:199) expound that, Anolyte is produced by passing a diluted salt solution through an electrolytic cell, therefore the greatest advantage of Anolyte for the inactivation of pathogenic microorganisms relies on its less adverse impact on the environment as well as users' health because of no hazardous chemicals added in its production.

Ghebremichael *et al* (2011:210) adds that, Anolyte is effective for microbial inactivation, making the solution user friendly in various fields. Another advantage of using Anolyte as stated by Huang *et al* (2008:332), is that it is cheap to produce as it is produced from tap water, with naturally organic matter with no added chemicals except NaCl (Kim *et al* 2001:92). The production of Anolyte does not require the use of expensive and toxic chlorine and it is produced at room temperature hence cutting on production costs (Takasu, Masuki & Matsuda 1986:304).

The main disadvantage of Anolyte is that it readily loses its antimicrobial activity if not used within 48 hours (Huang *et al* 2008:332 & Robinson *et al* 2010:284). It cannot be stored for long. The same fact can be considered an advantage as it returns to normal water.

## 2.2  BLEACHES

### 2.2.1 HISTORICAL BACKGROUND OF BLEACHES

According to Carson *et al* (2006:438) chemical bleaching started way back by using soda ash from burnt seaweed, followed by treatment with soured milk to neutralize the fabric and finishing with exposure to sunlight. Bleach has been used by Egyptians, Greeks and Romans as early as 300 B.C. In the middle Ages, the Dutch used crofting as way of bleach. Brennan (2012:1) explains that, in this process fabrics were spread in large fields for sunlight exposure for a long time. The author states that, in 1728, in Scotland fabrics were rather soaked in lye solution for several days then later washed and spread on grass. The author further explains that, this process would be repeated for five or six times until the desired whiteness was achieved. The fabric would later be treated with sour milk and washed again and later crofted to any desirable design. Although this process achieved the desired results, it was time consuming.   Brennan (2012:1) further adds that in the 18th century scientists discovered a chemical that was quicker yet yielding the same results. This was time consuming and chemists discovered chlorine as a quicker way of bleaching fabrics. The whitening of textiles is achieved with different oxidizing or reducing agents that are capable of destroying the natural pigments and matter present in the fibres (Tzanko *et al* 2002:87).

A Swedish chemist Karl Wilhelm Scheele discovered that the chemical element "chlorine" whitened fabrics. The chlorine not only whitened fabrics but also removed stains by chemical reaction that breaks down the undesired colour into smaller particles that can be easily removed by washing. Another author complements what Brennan has claimed that, sodium hypochlorite and water as bleach in the textile industry was discovered in 1787 by the French chemist Berthelot. The author further indicated that Louis Pasteur discovered the disinfectant properties of NaOCl in the late nineteenth century. Lim *et al* (2005:89) correspondingly add that, bleaching is a critical textile process that is commonly required for the preparation of fabrics to remove yellowish natural impurities prior to dyeing and finishing. Bleaches effectively kill

bacteria, fungi and viruses and improve appearance and enhance aesthetic properties of cotton (Khan *et al* 2012:30).

## 2.2.2 ROLE OF BLEACHES IN THE TEXTILE INDUSTRY

It is necessary to improve the textile (fibre, yarn or fabric) by bleaching, as bleaching is a whole sequence of the purification processes for brightening, whitening and cleaning of fibres, yarns or fabrics regardless of whether it is carried out in preparation for dyeing or in the process of undyed goods (Mahmood *et al* 2009:46). The four mainly used bleaching agents are; calcium hypochlorite, sodium hypochlorite, sodium chlorite and hydrogen peroxide (Wasif & Indi 2010:353). According to Wasif and Indi, the bleaching process includes three main steps, namely;

    (i)     Saturating the fabric with the bleaching agent and other necessary chemicals

    (ii)    Raising the temperature to the recommended level for the particular textile and maintaining that temperature for necessary duration

    (iii)   Lastly thoroughly washing and drying the fabric.

Cellulose and most other fibre forming polymers are white in their natural state (Perkins 1995:92), non-cellulosic substances (wax, pectin, proteins, hemicelluloses) on the surface of the fibres may absorb light and thus making the fibre to look yellowish or dull in colour hence a need to bleach to discolour the impurities that cover the whiteness. Perkins (1995:92) further enlightens that even synthetic fibres are often very white but may require bleaching in some cases. These bleaches can either be acidic or alkaline in nature (Kadolph 2011:384). Brennan (2012:1) describes bleach as a chemical compound derived from natural sources used to whiten fabrics through the process of oxidation.

Various oxidizing agents are used to bleach fibres, and during the bleaching process close supervision is needed to ensure that the colour in fibres is destroyed while damage due to oxidation is minimized. The effectiveness of oxidising and reducing agents is pH dependant, as a specific pH permits a reaction mechanism necessary for the purification of fibres, hence a consistency in colour from batch to batch.

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## 2.2.3 BLEACHES AND THE ENVIRONMENT

The two types of bleaches commonly used to date are chlorine (e.g. in the form of hypochlorite, dichlorocyanuric acid) and peroxy compounds (e.g. percarbonate, perborate, hydrogen peroxide) (Carson *et al* 2006:438). However, the two main bleaches used by finishers to bleach textiles are hydrogen peroxide ($H_2O_2$) and sodium hypochlorite (NaOCl) (Moissan 2012:1, Mahmood *et al* 2009:46). Peroxide bleaches are more extensively used than chlorine bleaches in fabric-washing products because of the difficulty of incorporating chlorine bleaches into formulations during processing, and because of their health hazards, ability to cause fibre damage, and odour (Carson *et al* 2006:438). However, sodium chlorite has been used too for many years because its chemical reaction protects 100 % cellulose fibres and their blends and it completely strips colour from textiles before re-dyeing them (Moissan 2012:1). Although chlorine based bleach processes play a significant role, hydrogen peroxide and oxygen are increasingly favored as environmentally acceptable and nontoxic bleaching agents (Wieprecht *et al* 2007:326).

Reinhardt (2006:177) articulates that bleaching systems are essential components of laundry and cleaning products from an economic and ecological point of view. Q-water (2012:1) describes chlorine as highly toxic, corrosive and may be fatal if inhaled. Khan *et al* (2012:30) concurs with Q-water that chlorine is a harsh chemical, harmful to human health and may even destroy the cotton fibre if not monitored as it destroys the cellulose and that affects the quality of the bleached fabric.

Bechtold (2005:121) further warns that though sodium hypochlorite offers a wide range of bleaching effects, easy to use and inexpensive. Reproducibility at the bleaching process may however be affected by lack of stability on storage especially under warm conditions, making the bleach not user friendly hence caution must be taken during use (Bechtold 2005:121).

According to Khan *et al* (2011:1) chlorine causes corrosion to washing machines and is destructive to cotton; it may cause damage to cotton due to the decomposition of cellulose in the aqueous solution of hypochlorite bleach and loses its tensile strength; produces many decomposed product in bleach washing and passes into the effluent where it causes environmental pollution.

Hydrogen peroxide also causes environmental concerns. Tavčer (2012:20) explains that in industrial processes, cotton is mostly bleached with hydrogen peroxide in a highly alkaline medium at high temperatures with the help of chelating agents, stabilizers and other auxiliaries. Agustina & Ang (2012:1) adds that the colour of the effluent released into receiving waters has become a serious environmental problem, as the discharge of pulp, paper, and textile effluents often imparts colour to the receiving waters for miles downstream from the source. The authors further explain that the colour is aesthetically unpleasant and it also reduces light penetration into water decreasing the efficiency of photosynthesis in aquatic plants, thereby, having undesirable impact on their growth. In addition, some of the dyes might be toxic to some organisms.

Hydrogen peroxide due to its biodegradability, almost entirely replaced the chlorine oxidising chemicals (Abdel-Halim & Al-deyab 2011:988). Bleaches are used daily in various industries like textile, hospitals, agriculture and others, hence environmentally safer, more cost effective and energy conserving methods are needed (Hashem *et al* 2010:533).

According to Kumbasar *et al* (2011:50), hydrogen peroxide is the most frequently applied textile bleaching agent because of the environmentally and toxicologically acceptable reaction products of oxygen and water, however  large amounts of water is required after bleaching and before dyeing for washing the residual un-decomposed hydrogen peroxide and the residual alkali (Hashem *et al* 2010:533). Although the bleaching process using hydrogen peroxide in alkaline conditions at high temperature is effective to attain high whiteness for the fabrics (Maekawa *et al* 2007:222), the process is not environmentally friendly as compared to using sodium hypochlorite as the bleaching process which uses a lower temperature to reach the best results.

Rodríguez-Couto (2012:3) claims that sodium hypochlorite is a strong oxidizing agent. It attacks cotton and reduces its strength especially in denim and cannot be used in Lycra containing garments. Additionally, hypochlorite process is environmentally harmful both because chlorite itself is harmful and because the subsequent neutralization step generates high amounts of salts leading to disposal and pollution problems such as increase in biological oxygen demand (BOD) and in chemical oxygen demand (COD) level in effluent with the subsequent increase of effluent processing cost. Anolyte on the other hand is more stable, environmentally friendly and uses less energy and water thus cheap to produce, and could be used as an alternative to sodium hypochlorite and hydrogen peroxide bleaches if it could be effective as a bleach.

## 2.2.4 HYPOCHLORITE BLEACHES

Occidental Chemical Corporation (2000:3) defines hypochlorites as salts of hydrochloric acid (HOCl) where the salts are prepared by reacting chlorine with an alkali or alkaline hydroxide. According to Perkins *et al* (1996:63) hypochlorite ion mainly exists as the hypochlorite ion and little bleaching occurs, Hypochlorite bleaching normally takes place at pH 9.5 -10.0 but bleaching action is greatly accelerated by lowering pH slightly. Reacting chlorine and sodium hydroxide produce sodium hypochlorite:

$Cl_2$ + $2\,NaOH$ = $NaOCl$ + $NaCl$ + $H_2O$
Chlorine + Sodium Hydroxide = Sodium Hypochlorite + Sodium Chloride + Water
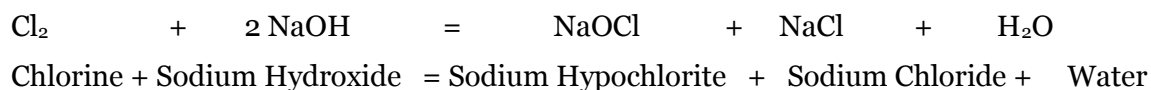
A common method of preparing sodium hypochlorite (NaOCl) is to mix chlorine with a solution of caustic soda. Hypochlorite based bleaches can also be generated by the reaction of water with chlorine gas, with sodium hypochlorite or with organo-chloramines (Vigo 1994:19). The author further explains that, although hypochlorite based bleaches were historically used for bleaching textiles, their commercial use is limited to bleaching cellulosic and cellulosic blends in European countries. Khan *et al* (2012:30) adds that sodium chlorite and hypochlorite have been widely used to bleach cotton in the textile industry, but it has harmful effects on the environment due to chlorine liberation during bleaching and is not accepted for wool and acrylics as they damage the fibre and cause them to be yellow. It is advantageous to use hypochlorite bleach at room temperature but slight heating accelerates the bleaching rate and reduces the amount of hypochlorite required (Perkins 1996:64).

Vigo (1994:20) on the other hand noted that, cellulose fibres are not usually bleached with hypochlorite bleaches with low pH 2.0 – 5.0 because of the dangerous chlorine gas being generated and also cellulose fibres are extensively oxidised at low pH levels by high concentration of HOCl present. It is therefore advantageous to bleach cellulose fibres at pH 5.5 – 7.0 as in this range less oxidation and fibre degradation occurs; excessively high alkalinity on the other hand may damage textiles and retard the bleaching action of the hypochlorite. Sodium hypochlorite releases highly reactive hypochlorite ions under alkaline conditions and the bleach is highly effective at low temperature, excellent at killing germs and cannot be used on coloured clothes (Beach 2011:1).

It must be noted that sodium hypochlorites are not part of detergent formulas but are separate products added during laundering or can be used directly for cleaning surfaces. It is considered advantageous to use sodium hypochlorite bleach as compared to others as it requires less energy, labour, water and time. During manufacturing, temperature and storage affect the stability of hypochlorite solutions as high temperatures will increase the decomposition rate and if kept at low temperatures where it is stable freezing should be avoided. The quality of sodium hypochlorite solutions may be affected by traces of metals such as copper, nickel and cobalt as they cause bleach to catalyse and forms oxygen gas and lowers bleach strength.

Sodium chlorite is a light yellow alkaline liquid that is stable at ambient temperature and when broken down by acids it forms chloride dioxide $ClO_2$, a green gas that is soluble in water (Moissan 2012:1). They must be rinsed out of the textile completely to avoid further chemical reaction as they react with phenolic compounds found in the dye. This means that colour can be removed or altered. Moreover, chlorine in the bleach reacts with protein by breaking protein molecules which results in weakening silk, wool or any hair fibres. The longer the protein fibres are exposed to chlorine the more damage it causes in these fibres. Sodium chlorite is an effective bleach for both natural and synthetic fibres like nylon and polyester which are difficult to bleach with hydrogen peroxide (Perkins 1996:64), to avoid any damages in the fibres cotton can be bleached at pH 4.0 – 5.0 and synthetic fibres at pH 2.0 – 4.0.

## 2.2.5 HYDROGEN PEROXIDE BLEACH

Hydrogen peroxide, a weak acidic colourless liquid, was discovered by Thenard in 1818 and has been used industrially since the mid-19th century (Terry Deed: Anon). The use of hydrogen peroxide grew with the years in the textile industry. Hydrogen peroxide is prepared primarily by anthraquinone autoxidation and it is used widely to prepare other peroxygen compounds and as a nonpolluting oxidizing agent (Ahn *et al* 2001:285). The major use of peroxide is to utilize its strongly oxidizing nature to oxidize various chemical groups. These oxidisable groups primarily include lignins, cyanides, sulphides and phenols (benzyl alcohols).

According to Ahn *et al* (2001:285) hydrogen peroxide produces the perhydroxyl anion (HOO-) through ionization or radical reaction mechanisms which is accepted as the active species for bleaching with hydrogen peroxide in alkaline solution. Furthermore, in the presence of metal ions, the perhydroxyl anion decomposed into oxygen and water by a transition metal catalyzed

process. This decomposition leads to a loss of perhydroxyl ions causing a decrease in the bleaching effect of hydrogen peroxide.

The reaction of hydrogen peroxide is shown below:

$H_2O_2 + HO- \rightarrow HOO- + H_2O$
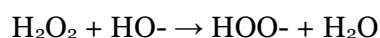
Hydrogen peroxide ($H_2O_2$) is a potent, inexpensive oxidant that chemically degrades chromophoric components in pulps (Poggi & Mancosky 2005:77). Xu, Hinks & Shamey (2011:73) explain that, hydrogen peroxide ($H_2O_2$) is the most widely used bleaching agent in the textile industry, however bleaching is carried out under alkaline conditions which involves high energy consumption and this leads to fibre damage.

According to Hashem *et al* (2010:535) for bleaching to occur, the stability of hydrogen peroxide in textile bleaching is important, as the hydrogen peroxide liberates perhydroxyl anion ($HOO^-$) in aqueous medium which chemically behaves like a weak acid. Sodium hydroxide activates hydrogen peroxide because H+ ion is neutralised by alkali which is favourable for liberation of $HO^-_2$, however at higher pH (above 11) the liberation of $HOO^-$ anion is so rapid that it becomes unstable with the formation of oxygen gas which has no bleaching properties (Hashem 2010:535).

Hydrogen peroxide ($H_2O_2$), peracids and sodium perborate are examples of oxygen bleaches commonly used because they are environmentally friendly, colourless and non-corrosive. Beach (2011:1) says, for hydrogen peroxide to be effective they require an alkaline condition and temperatures of about 50 °C whilst peracids work best at temperatures below 40 °C.

Peroxide bleaching of textiles is effectively achieved under alkaline conditions using sodium hydroxide and sodium carbonate in conjunction with other textile auxiliaries (stabilizers and wetting agents) (Vigo 1994:24). Vigo further explains that the use of stabilizers and wetting agents permits bleaching to be conducted at alkaline pH to be able to slow the rate of peroxide decomposition under alkaline solutions and combine with metal impurities which may catalyse decomposition of peroxide and induce fibre damage. However, peroxides are advantageous to use because of the following; a) their high volatility b) reversion is minimal – meaning they do not bleach beyond the original colour c) they are slow working and easily controllable and d) they are safe to use with an alkaline pH (Bishop Museum 1996:4). Peroxides are explosive therefore care must be taken when handling them.

Industrial bleaching of cotton is mostly done using hydrogen peroxide because it is biodegradable and cheap to use as compared to chlorine (Perkins 1996:62). Hydrogen peroxide

is a well-known environmentally safe bleaching agent for cotton, however bleaching cotton with hydrogen peroxide requires an alkaline medium (normally NaOH), stabilizer and either high temperatures or long dwell times. After bleaching and before dyeing large amounts of water is required for washing out the residual un-decomposed hydrogen peroxide and the residual alkali (Hashem *et al* 2010:534).

Tavčer (2012:20) explains that in industrial processes, cotton is mostly bleached with hydrogen peroxide in a highly alkaline medium at high temperature with the help of stabilizers and other auxiliaries, and the process is energy intensive and can damage the cotton fibres. According to Topalovic *et al* (2007:386), in bleaching of cotton, hydrogen peroxide is commonly applied for 2-5 hours at pH 10.5-12 and temperatures close to boiling point. These conditions pose a problem due to possible radical reactions of bleaching compounds with the fibre and lead to a decrease in the degree of polymerization of cellulose and eventually to a drop in tensile strength.

But as for wool fibre hydrogen peroxide and peroxy compounds damage wool fibres due to progressive oxidation of disulphide bonds ultimately forming cysteic acid which lead to adverse effects on the fibre mechanical properties (Yilmazer & Kanik 2009:45).

According to Tavčer *et al* (2006:85), the decomposition of peroxide bleaching liquor and degradation of cellulose is catalyzed by transition metal ions present in the bleaching solutions or in the fabric. Stabilizers, which act as buffers, sequestrants and dispersants are added in the hydrogen peroxide bleaching baths to prevent fibre degradation. Jeri et al (2013:666) explains that the main pollution in waste water from the textile finishing industry originates from the dyeing and finishing processes, as these processes require the input of a wide-range of chemicals and synthetic dyes, which are generally organic compounds of complex structures. The authors further add that synthetic dyes, present in textile waste water, introduce intensive colour and toxicity to the aquatic system. According to Agustina & Ang (2012:1) the colour is aesthetically unpleasant and it also reduces light penetration into water decreasing the efficiency of photosynthesis in aquatic plants, thereby, having undesirable impact on their growth. Topalovic *et al* (2007:386) state that, the bleaching parameters, e.g. time, temperature, and concentration of chemicals present in the bleaching bath are all interrelated. Thus, hydrogen peroxide can effectively bleach cotton at low temperatures, but long times and higher chemical concentrations are required.

## 2.2.6 STABILIZERS AND WETTING AGENTS

According to Hashem *et al* (2010:535), stabilization is the process of regulation or control of perhydroxyl ion to prevent rapid decomposition of peroxide bleach and to minimise fibre degradation. Both pH and high temperatures lead to decomposition of hydrogen peroxide and degradation of the fibres. However, stabilizers act partly by providing a buffering action which ensures that the pH is not too high. The authors further explain that at higher pH, hydrogen peroxide is not stable hence a stabilizer such as sodium silicate is frequently added in the bleaching bath. These stabilizers control and regulate the bleaching process by multiplicity of functions as they control the formation of free radicals. They also act as buffers, sequestrants and dispersants, whereby the sequestering action inactivates metallic impurities which cause catalytic decomposition of hydrogen peroxide or precipitation of hydroxides or carbonates (Hashem *et al* 2010:535). Sodium silicate is one of the stabilizers used in the bleaching of cellulosic fibres as it is highly effective and cheap. However, sodium silicate is not eco-friendly and also imparts harshness to cotton materials (Wasif & Indi 2010:353).

The functions of stabilizers/activators lie mainly in providing hydroxyl ions (OH−) which displace the dissociation equilibrium of hydrogen peroxide towards the formation of perhydroxyl ions (HO$_2$−), a real bleaching agent (Shao *et al* 2001:272). The authors further explain that the functions of stabilizers depend not only on providing hydroxyl ions but also on stabilizing the activated hydrogen peroxide to limit the formation of molecular oxygen which does not contribute to the bleaching processing.

## 2.2.7 BLEACHES AS STAIN REMOVERS

Wieprecht *et al* (2007:326) in their research explain that in laundry bleach is mainly directed to destroy unwanted stains in order to achieve the intended cleaning effect and also to destroy dyestuff in solution in order to prevent discolouration of acceptor fabrics by migrating dyestuff bleeding from coloured textiles. The authors explain that laundry detergents contain percarbonate salts which release hydrogen peroxide when dissolved in water at temperatures above 60 °C.

## 2.3 DYEING

A dye is used to impart colour to materials of which it becomes a fundamental part (Pollution Prevention and Abatement Handbook 1998:298). The author further explains that dyes are soluble at some stage of the application process, whereas pigments in general retain essentially their particulate or crystalline form during application. Dyes are coloured organic compounds that can selectively bind to tissues. Babu *et al* (2007:145) defines dyeing as treatment of fibre or fabric with chemical pigments to impart colour which arises from chromophore and auxochrome groups in the dyes. The authors expound that in the process of dyeing large amounts of water are used in order for dyes to be transferred into the fibre, yarn or fabric. When the water temperature is raised sufficiently the dyestuff passes from the solution to the fabric uniformly. Additionally, Vassileva *et al* (2008:323) describes dyeing as a heterogeneous process which takes place at the interphase between the dyeing solution and the fibres following the steps below:

(i)     diffusion of the dye in the bulk liquid phase

(ii)    adsorption of the dye on the outer fibres surface

(iii)   diffusion in the bulk of the fibres and

(iv)    adsorption on the inner surface of the fibres.

During the process of dyeing colour is added to the fibres, and this normally requires large volumes of water not only in the dye bath, but also during the rinsing step. Carmen & Daniela (2012:55) state that depending on the dyeing process, many chemicals like metals, salts, surfactants, organic processing aids, sulphide and formaldehyde may be added to improve dye adsorption onto the fibres.

Pollution Prevention and Abatement Handbook (1998:298) explain that dyes are synthesized in a reactor, filtered, dried, and blended with other additives to produce the final product, and the synthesis step involves reactions such as sulfonation, halogenation, amination, diazotization, and coupling, followed by separation processes that may include distillation, precipitation, and crystallization. The author adds that in general, organic compounds such as naphthalene are reacted with an acid or an alkali along with an intermediate (such as a nitrating or a sulfonating compound) and a solvent to form a dye mixture which is later separated from the mixture and purified. Upon completion of the manufacture of actual colour, finishing operations, including drying, grinding, and standardization, are performed; these are important for maintaining consistent product quality.

According to Environmental Health Perspectives (2002:253) the two types of dye commonly used on cotton are direct dye and reactive dye and both are anionic. Cotton develops an anionic charge in water and it needs a special treatment to get the fabric to take up the dye, hence the use of many chemicals which impact negatively on the environment. Dyes used for fabric such as cotton, wool, and silk are complex organic molecules containing chromophore group, whereby they contain some kind of conjugated, alternating double and single bonds in part of the molecule (Katz 2003:1). Katz explains that these molecules can absorb certain wavelengths of visible light and reflect the remaining light and thus give fabric its colour.

With the increase of different fibres that were discovered over the years more synthetic and natural dyes also came into use. Therefore, the increased awareness of environmental issues has been driven by much interest in eco-friendly textile wet processing techniques but the main challenge faced by the textile industry is using safe dyes and chemicals as well as by reducing treatment costs (Ahmed 2005:221). Though dyes play a vital role in the textile industry, Azo dyes if released without proper treatment may be hazardous to the environment due to their toxicity and recalcitrance (Gül *et al* 2012:180). Khatri (2011:84) enlightens that the textile colouration and finishing industry is one of the major contributors to environmental pollution, mainly due to the discharge of non-biodegradable inorganic salts, alkalis, other processing aids and organic matter such as dyes to the effluent. Bleaching with hydrogen peroxide requires a large amount of steam, thereby adding to the fuel cost (Wasif & Indi 2010:353). The authors explain that nowadays fuel is becoming expensive due to fast depletion in fuel reservoir and the rising fuel cost tends to make hydrogen peroxide bleaching uneconomical process. They further add that, conservation of energy is the only step essential to overcome the mounting problems of the worldwide energy crisis and environmental degradation. Dyes also have a negative impact on the fibre itself. Karim *et al* (2007:63) explain that cotton fibres suffer from a rather low decrease in strength after being dyed, especially with reactive and indigo dyes. Dyeing cotton fibres leads to their greater entanglement and cohesion. The authors explain that, this is due to the removal of a large portion of the wax present on the surface of cotton fibres during the scouring and dyeing process. The average length of cotton fibres decreases with a higher rate than that of white cotton fibres after going through the blending, carding and drawing processes. And this fibre damage not only affects the efficiency of the spinning process, but also the mechanical properties of the final yarn and fabric.

## 2.3.1 CLASSIFICATION OF DYES

Dyes are classified as natural and synthetic textile dyes. Dyeing textiles have been practised for thousands of years with the first written record of the use of dyestuff dated as far back as 2600 BC in China (Katz 2003:1). According to Carmen & Daniela (2012:60) Phoenicians used Tyrian purple that was produced from certain species of crushed sea snails in the 15th century BC, and indigo dye produced from the well-known indigo plant since 3000 BC. The dyes from madder plants were used for wrapping and dyeing of Egyptian mummies clothes and also of Incas fine textiles in South America. Natural dyes were mainly extracted from vegetables and animal sources since 1856 (Miller 1992:155). The main sources of natural dyes and pigments were obtained from trunk, bark, roots, leaves, seeds of plants and shells. These dyes were used to dye cotton and wool.

According to Katz (2003:1) in 1856 William Henry Perkin discovered the first synthetic dye, Mauve from coal tar, while searching for a cure for malaria. The author explains that the mauve dye was a brilliant fuchsia colour, but faded easily. Since that time, a great number of synthetic dyes have been manufactured and their resistance to running and fading has been almost eliminated. Azo dyes synthesized by a diazotisation reaction were discovered in 1958 by P. Gries in Germany (Carmen & Daniela 2012:60).

The authors describe these dyes as aromatic compounds produced by chemical synthesis, and having into their structure aromatic rings that contain dislocated electrons and also different functional groups. Furthermore, their colour is due to the chromo gene-chromophore structure (acceptor of electrons), and the dyeing capacity is due to auxochrome groups (donor of electrons). Pollution Prevention and Abatement Handbook (1998:298), describes a chromophore group as a colour giver and is represented by the following radicals, which form a basis for the chemical classification of dyes when coupled with the chromogen: azo ($-N=N-$); carbonyl ($=C=O$); carbon ($=C=C=$); carbon-nitrogen ($>C=NH$ or $-CH=N-$); nitroso ($-NO$ or $N-OH$); nitro ($-NO_2$ or $=NO-OH$); and sulfur ($>C=S$, and other carbon-sulfur groups).

Carmen & Daniela (2012:60) explain that the chromo gene is constituted from an aromatic structure normally based on rings of benzene, naphthaline or antracene. The auxochrome groups are ionizable groups that confer to the dyes the binding capacity onto the textile material. The usual auxochrome groups are: $-NH_2$ (amino), $-COOH$ (carboxyl), $SO_3H$ (sulphonate) and $-OH$ (hydroxyl).

Costa *et al* (2012:483) further adds that dyes can be classified according to their chemical structure in terms of chromophore groups, which are responsible for the different dye colours produced. For example; Azo dyes represent the most important dye class used in the textile industry. They are characterized by the presence of one or more azo chromophores (N=N) and bonds between two or more aromatic rings. Anthraquinone dyes constitute the second most important class of textile dyes, which have the chromophore groups, =C=O and =C=C=, forming an anthraquinone complex 5.6.

Dye characteristics such as resistance to biodegradation, toxicity and resistance to reductive processes, are related to the chemical structure of each dye (Costa *et al* 2012:483). Pollution Prevention and Abatement Handbook (1998:298), adds that the auxochrome or bonding affinity groups are amine, hydroxyl, carboxyl, and sulfonic radicals, or their derivatives, as these auxochromes are important in the use of classification of dyes.

According to Carmen & Daniela (2012:61) the textile dyes are mainly classified in two different ways:

(1) based on its application characteristics (i.e. CI Generic Name such as acid, basic, direct, disperse, mordant, reactive, pigment, vat, azo, insoluble sulphur dye, and

(2) based on its chemical structure respectively (i.e. CI Constitution Number such as nitro, azo, carotenoid, diphenylmethane, xanthene, acridine, quinoline, indamine, sulphur, amino- and hydroxyl ketone, anthraquinone, indigoid, phthalocyanine, inorganic pigment. The textile dyes are also further classified in anionic, nonionic and cationic dyes whereby the major anionic dyes are the direct, acid and reactive dyes and the most problematic ones are the brightly coloured, water soluble reactive and acid dyes (Carmen & Daniela 2012:61). The major nonionic dyes are disperse dyes that do not ionize in the aqueous environment, and the major cationic dyes are the azo basic, anthraquinone disperse and reactive dyes. Dyes are further divided into classes according to the types of fibres they are most compatible with (Goetz 2008: 15). The most notable are; acid dyes, premetalized acid dyes, chrome dyes (mordant dyes), cationic dyes (basic dyes), direct dyes (substantive dyes), direct developed dyes, disperse dyes, naphthol dyes, reactive dyes, sulfur dyes, and vat dyes (Price & Johnson 2005). The authors further explain as follows:

a) **Acid dyes** are used on protein fibres, nylon, spandex, and special type acid dyeable acrylic fibres. Acid dyes produce bright colours that have excellent fastness, or the ability of the dye to stay on the fabric and not rub off or fade, to dry cleaning, but not necessarily to washing or light and perspiration. Pre-metalized acid dyes and chrome

dyes are used for the same types of fibres, but pre-metalized acid dyes are less bright with better fastness to light and sweat. Substances that stain with acid dyes are called acidophilic.

b) **Chrome dyes** result in dull colours and have excellent fastness to light, washing, and perspiration. They are great for wool and carpets.

c) **Cationic dyes** are generally used for acrylic, modacrylic, cationic dyeable polyester, cationic dyeable nylon, cellulosic, and protein fibres. They produce bright colours that have excellent fastness to light, laundering, perspiration, and crocking on synthetics fibres, but poor fastness to washing and light on natural fibres.

d) **Direct dyes** are used on cellulosic fibres and have excellent fastness to perspiration and dry-cleaning, but poor fastness to washing and varied light fastness. Direct developed dyes are used on the same cellulosic fibres, but have good to excellent fastness to laundering.

e) **Disperse dyes** are used for acetate, acrylic, mod acrylic, nylon, polyester, and olefin fibres. The wash fastness with disperse dyes varies with the fibres- poor on acetate, excellent on polyester. Fastness to light is fair to good, but there is some gas fading on acetate. However, fastness to perspiration, crocking, and dry-cleaning is excellent.

f) **Naphthol dyes** are employed for cellulosic fibres. They create bright shades of colour with varying fastness to light. However, they have good fastness to washing and perspiration.

g) **Reactive dyes** are primarily utilized on cellulosic fibres, but occasionally on protein fibres and nylon as well. They generate bright shades with great to excellent fastness in all areas, but are difficult to match shades.

h) **Sulfur dyes** are used on cellulosic fibres to create dull shades such as navy, black, and brown. They have excellent fastness in most areas, but are weak when exposed to chlorine.

i) **Vat dyes** are used on cellulosic fibres. Vat dyes have excellent fastness in all areas as well, especially to chlorine and bleach, however, if not properly applied, they may crock.

j) **Pigments**, which are not a dye, can be used on all fibres. This is because pigments are bound to the fibre by resins and do not need to be absorbed. However, they are susceptible to crocking.

## 2.3.2 STAGES OF DYEING

### a) Dyeing of fibres

Fibres can be dyed while they are in a loose state making the dye solution to have more chance of reaching all the surface areas than when they are twisted into yarns or woven or knitted into fabrics (Miller 1992:157). Fibres can be dyed before any preparation for spinning or during preparation when the fibres have been carded into sliver or after combing processes. Wool and hairs are the natural fibres which can be fibre dyed, while cotton, flax and silk can only be dyed as yarns. Dyeing at this stage has three advantages as outlined by Miller:

i) It gives better penetration of dyestuff into the fibres

ii) It enables mixtures of colours and blending the batches together during spinning process

iii) If large quantity fibres are to be dyed it enables a more even colour to be obtained over the consignment.

However Karim *et al* (2007:63) discovered that, dyeing cotton in the loose state (flock dyeing) leads to an increased amount of fibre damage in comparison to undyed fibres.

### b) Dyeing of yarns

Yarns are dyed into various colours immediately after spinning before they are woven or knitted into fabrics. The dyed yarns are mostly used for fabrics with stripes, checks and other multi coloured patterns. It is a costly method of dyeing and the yarns may be dyed in different forms like skeins, packages or beams.

### c) Dyeing of fabrics

Fabric dyeing is a commonly used method of dyeing which on a piece of woven or knitted fabric, different methods of dyeing can be used which includes: jet dyeing, jig dyeing, pad dyeing and beam dyeing. Though it is a cheap method of dyeing, it can disadvantage heavy or dense woven fabrics as the dye sometimes does not penetrate into the center of the yarns leaving the yarns or fabric lightly coloured or undyed. Another disadvantage of fabric dyeing is that there may be a possibility of a variety of colour variations within one piece of fabric. The dye penetration in this type of dyeing is not as good as in fibre or yarn dyeing.

## 2.3.3 DYE FIXATION

Dye fixation is an important process when dyeing with reactive dyes, the dyeing is completed by a chemical interaction between the dye molecules and active cites of the fibres (Vassileva *et al* 2008:323). The author further enlightens that the degree of dye fixation is mainly affected by the chemical structure of the fibrous polymer which determines the affinity of the dye towards the fibres, the number and the type of the potential active sites where the dye molecules physical and chemical adsorption take place.

Dye stuff can be released into the environment but that is dependent on the degree of fixation on the fibre (Saeed *et al* 2012:191). The authors explain that reactive dye is hydrolyzed to some extent during application processes. Some of the reactive dye stuff is inactivated by a competing hydrolysis reaction. Consequently, the release of the reactive dyes into dye bath effluent is exacerbated by their low fixation to cellulosic fibres as compared with other dye stuff such as acid, basic, disperse and direct dyes (Saeed 2012:191).

Van der Waals forces, hydrogen bonds and hydrophobic interactions (physical adsorption) ensures the dye gets attached in their structure, whereby the uptake of the dye in fibres depends on the dye nature and its chemical constituents (Carmen & Daniela 2012:66). The authors explain that the strongest dye-fibre attachment is due to covalent bonding with an additional electrostatic interaction where the dye ion and fibre have opposite charges.

In alkaline conditions (pH 9-12), at high temperatures (30-70°C), and salt concentration from 40-100 g/L, reactive dyes form a reactive vinyl sulfone ($-SO_3-CH=CH_2$) group, which creates a bond with the fibres (Carmen & Daniela 2012:66). However, the vinyl sulfone group undergoes hydrolysis (i.e. a spontaneous reaction that occurs in the presence of water), and because the products do not have any affinity for the fibres, they do not form a covalent bond. The authors further state that, a high amount of dye constituents are discharged in the wastewater.

## 2.3.4 REACTIVE DYES

In 1956 Imperial Chemical Industries (ICI) introduced the Procion dyes (dichlorotriazine) that gave excellent wash fastness while utilizing a relatively simple dyeing method, which when compared to direct dyes, the reactive dyes had a much simpler chemical structure and gave brighter colours (Gentile 2009:14). Reactive dyes are characterized by nitrogen to nitrogen double bonds, azo bonds (N=N) (see figure 2.2) and used mainly for dyeing cellulosic fibres (Saeed *et al* 2012:191). According to Ahmed (2005:221), a reactive dye require the presence of electrolytes (NaCl or Na2 SO4) which suppress negative charge build-up at the fibre surface and promotes dye up-take. The author further explains that the quantities of the electrolyte present can vary up to 100 g/l depending on the depth of colour required and the structure of the dyes or the dyeing recipe.

Dyeing with reactive dyes is accomplished through the process of fixation of the dye molecules at the active sites of the fibres (Inam Ullah *et al* 2013:132). The authors explain that the reactive dyes employ a chromophore attached to a substituent that is capable of directly reacting with the fibre substrate and the covalent bonds which fasten the reactive dye to cotton making them among the most colourfast of dyes.

Unfortunately, reactive dyeing of cotton fabrics, in addition to its consumption of high concentrations of potentially toxic non-biodegradable salt, relies on an elevated pH (over 10.5) for covalent fixation of the dyes on cotton (Ahmed 2005:221). The author further explains that, under alkaline conditions reactive dyes react with hydroxyl groups of cellulose to form the covalent bonds. These bonds would be expected to lead to excellent wash fastness properties (Ahmed 2005:221). However, the dyes can also react with hydroxyl groups of water present so that they are no longer able to react with cellulose.

Reactive dye is widely used for colouration of cotton due to its ability to give bright shade and good colour fastness properties. Saeed *et al* (2012:191), point out that in recent years reactive dyes have been most commonly used for dyeing cellulose fibres due to their advantages such as better dyeing processing conditions and bright colours especially on cellulosic fibres.

Khatri (2011:84) concurs with others cited above as he observes that reactive dyes have indeed become a default choice for colouration of cotton textiles, because they provide a wide range of inexpensive bright colours with excellent washing fastness which is due to the covalent bonding between the fibre polymers and the dye molecules under alkaline pH conditions. The author further adds that an inorganic salt, such as sodium chloride or sodium sulphate, for dye transfer to and penetration into the fibre, and inorganic alkali, such as sodium bicarbonate, sodium

carbonate or sodium hydroxide, for dye-fibre reaction, are required in substantial quantities to accomplish the dyeing process. Irrespective of the dyeing method using reactive dyes, just about all of the salt and alkali is drained to effluent which are characterized by high levels of dissolved solids which is environmentally undesirable (Khatri 2011:84).

Reactive dyes always have a significant place in textile dyeing because of their high colour fastness and wide colour spectrum (Akcakoca *et al* 2007:23). However, hydrolysis of this dye during dyeing decreases the dyeing efficiency. Additionally the substances of hydrolyzed dyestuff increases the duration of washing processes realized after dyeing. Environmental Health perspectives (2002:253) describes reactive dyes as molecules that combine chromophores (the groups of atoms in a dye molecule that absorb light which leads to colour) with a reactive group that forms strong covalent bonds with fibre via reaction with hydroxyl groups. The author explains that these strong covalent bonds provides good wash fastness for the colour but they require alkaline pH levels of the dye solution and significant amounts of electrolytes up to an amount equal to the weight of the fabric.

According to Yang & Xu (1996:20), reactive dyes are commonly used because of their excellent wash- fastness and convenience in application. However, the affinity of reactive dyes for cellulose is not very high. *Das et al* (2005:221) add that the application process for dyeing cotton is disadvantaged due to poor exhaustion of dye into fibre and use of large amounts of electrolyte. This ultimately leads to generation of effluent containing high concentrations of colour and salt causing environmental pollution (Das et al, Ahmed 2005:221).
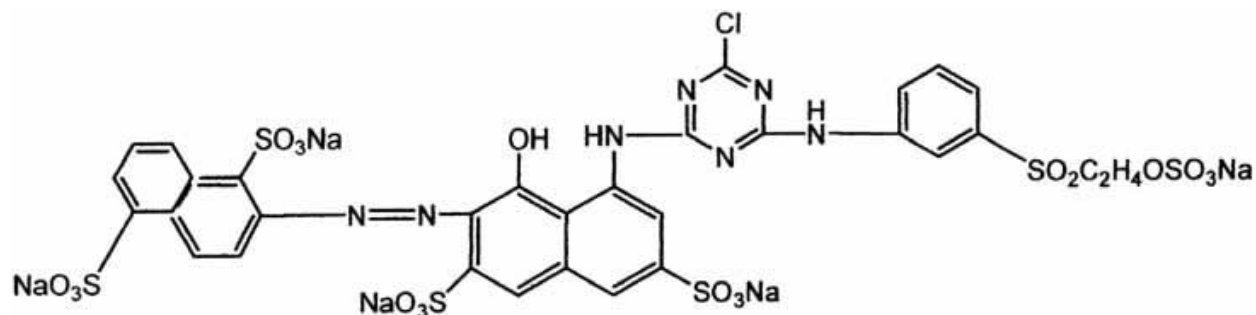


Figure 2.2: Molecular structure of reactive red 195 (Gül, *et al* 2012:180).

## 2.3.4.1 DYEING REACTION AND ROLE OF ALKALI IN REACTIVE DYEING

Eksoy (2012:3) explains that during dyeing of cellulose with reactive dyes, Hydrogen ion of cellulose reacts with Chloro (Cl) or Sulfone ($SO_3$) of the reactive group and forms strong acids like Hydrochloric Acid (HCl) or Sulphuric Acid $H_2SO_4$. Alkali (Soda Ash or Caustic soda) is

important to neutralize this strong acid which will otherwise cease the reaction. Addition of alkali controls rate of reaction of the dyeing mechanism. Therefore it is important to add the alkali slowly. If the pH of dye bath increases at full speed, reaction to the right in the following equation goes very fast and hence patchy dyeing is inevitable.

Soda ash

Cellulose - O H + Cl - R – Dye  $\longrightarrow$  Cellulose - O - R - Dye + HCl
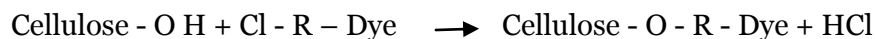
## 2.3.4.2 ROLE OF SALT WITH REACTIVE DYE

According to Eksoy (2012:3) reactive dyes for cotton have negatively charged active groups, they are anionic. Therefore when cotton or viscose fibres are immersed into water, its surface due to hydroxyl ions become also anionic, hence the dye particles and the cellulosic fibre tend to repel each other. The author explains that the addition of salt creates an electrical positive double layer which hides negative electrostatic charge of cotton surface which allows the dye to penetrate the fibre. This negative charge on the cellulose tends to repel anionic reactive dyestuffs from the surface of the cotton, although it is of minimal impact (Farrell 2012:1). The author further explains that more importantly, the solubility of reactive dyes shifts the reactive dye equilibrium towards staying in the aqueous application medium and not towards the surface of the cotton. In order to sufficiently enhance the substantivity of the reactive dye to the surface of the cotton fibre, large amounts of salt are required to force the reactive dye out of the bath onto the surface of the cellulose.

Farrell (2012:1) enlightens that the colouration of cotton with reactive dyes, require vast amounts of salt and water for efficient dye utilization and fastness requirements. The salt is needed to neutralize negative charges produced by cotton in aqueous baths and force the soluble reactive dye out of solution and as a result, large amounts of salt are discharged in the dye bath effluent.

## 2.3.5 VAT DYES

Vat dye is one of the important dyes used on the dyeing of cotton textiles due to its overall good fastness properties suitable for the end use products (Santhi & Moses 2008: 239). Vat dyes account for about 15% of total consumption of textile dyes as they exhibit good fastness to light, acid, alkali, and solvents, and they are mainly used in dyeing cotton fibres (Chaari and Jamoussi

2011:247). The authors indicate that vat dyes cause environmental concerns when released in industrial wastewaters due to their carcinogenic health effects.

Santhi & Moses (2010:349) describe vat dyes as insoluble in water but can be converted into water soluble form (leuco dye) by reduction with a strong reducing agent sodium hydrosulphite (hydros) and solubilizing agent sodium hydroxide. The authors explain that the reduced dye stuff penetrates into the fibre and it is re-oxidized on the fibre back to the insoluble form which remains fixed in the fabric. However, the use of sodium hydrosulphite has been criticized for the formation of non-environmentally friendly decomposition products such as sulphite, sulphate, thiosulphate and toxic sulphur.

Aspland (1992:23) state that in 1901, C.I. Vat Blue 4, indanthrone was synthesized from anthraquinone and spurred the discovery of the whole range of vat dyes, of mostly superior fastness, which are available today. The discovery of hydro (sodium dithionite) in 1904 was equally significant. Vat dyes are in fact pigments as in alkaline reduction they dissolve in water as the leuco-vat dye anions (Aspland 1992:23). The author explains that these anions have substantivity for cellulosic fibres from the reducing baths and their dyeing properties closely resemble those of the simpler direct dye anions.

And once the leuco-vat anions are within the cellulose, the original pigment is regenerated by removing the reducing system and replacing it by an oxidizing system. The author further adds that this procedure gives vat pigment molecules within the fibre and the fastness properties of the dyeing's may be enhanced by soaping, during which individual pigment molecules are rearranged, aggregated and crystallized.

According to Aspland (1992:23), vat dyes are sold as water insoluble pigments, like all other dyes. Under the right circumstances, they can:

(i) be dissolved to give solutions containing individual molecules or molecular ions,

(ii) be transported to the surface of the fibre and

(iii) be sorped on and diffuse into suitable fibre.

Vat dye has the problem of insolubility in water, but when reduced with a strong reducing agent like hydros and solubilizing agent sodium hydroxide, it is solubilized (Santhi & Moses 2008: 239). The authors explain that the reduced dyestuff penetrates into the fibre and it is re-oxidized on the fibre back to the insoluble form, which remains fixed in the fabric. However, the use of sodium hydrosulfite is being criticized for the formation of non-environment friendly decomposition products such as sulphite, sulphate, thiosulphate and toxic sulphur.

Baptista (2009:1) adds that indeed vat dyes, which include indigo and anthraquinone-based dyes, are chemically complex dyes which are insoluble in water. They must first be reduced to

the leuco form in an alkaline solution of sodium hydrosulfite before application to the cotton or rayon fibre. Air oxidation fixes the dye strongly on the fibre, resulting in excellent wash-fastness and light-fastness. Vat dyes, like indanthrene or indigo are practically insoluble in water, but can be reduced in the presence of an alkali and a reducing agent, like sodium dithionite ($Na_2S_2O_4$) through a reduction reaction (Chaari and Jamoussi 2011:247).

These water insoluble vat dyes are converted to soluble anthrahydroquinone compounds (leuco dye), which have a certain affinity to cellulosic fibres. This explains that the reduced dyestuff penetrates into the fibre (decreasing concentration of dyestuff in dye bath) and is reoxidized on the fibre back to the insoluble form which remains fixed in place. The reducing property of sodium dithionite is due to the evolution of hydrogen when dissolved in water or sodium hydroxide (NaOH).

Nonetheless, vat pigments need alkaline reduction to dissolve them, and they are treated to an additional step (oxidation), which causes the original insoluble pigments to be regenerated, once the soluble ions have diffused within the fibre (Aspland 1992:23). The author explains that the third step stated above, the absorption and diffusion of suitable derivatives of vat dyes into cellulosic, parallels that of direct dyes quite closely. One of the keys to successful dyeing with vat dyes is to have control over how and when to convert the pigmentary colours into water soluble colouring chemicals, under conditions in which they will diffuse uniformly into the fibres (Aspland 1992:23).

## 2.4 SOILS AND STAINS ON FABRIC

According to Kissa *et al* (1991:532), a stain is a discolouration caused by intensely coloured substances, which in small amounts can affect the colour and appearance of a textile. On another note, soiling is defined by Islam & Khan (2013:35) as smearing or staining of a large surface area of the fabric with dust or dirt and oil or grease or both. The authors explain that due to absorption and retention of the soil, the whiteness and brightness of a fabric is spoiled and it appears yellowish and dirty.

Kissa *et al* (1991:532) describes a soil on the fabric as constitute of a separate phase - a liquid, a semi liquid or a solid. Whilst a stain is usually caused by molecules of coloured substances deposited on or in fibres or in residual soil. Common stains can be of natural colours, synthetic food colours, substances of biological origin such as blood and proteins; pigments and oxidation products of residual soil or antioxidants.

Islam & Khan (2013:37) explain that a fabric gets soiled by three types of mechanism namely; i) by mechanical adhesion of the soil to the cloth by direct contact with soiled surface or by rubbing of the garments against the skin or picking up dirt from liquors or from air; ii) by adhesion by electrical forces due to attraction of dust particles from air by an electrically charged fibre surface and lastly iii) by re-deposition of soil during washing which occurs particularly with nylon and polyester fabrics. The re-deposition on these fibres takes place because of their oleophilic nature.

Soils can either be water soluble such as soda and coffee, and non- water soluble soils such as fruit and vegetable staining (Price *et al* 2005:206).   For a soil to be released in the fabric the following factors needs to be taken into consideration; nature of the soil, kinds of fibre, nature of the textile fabric, effects of preparation, effects of dyeing and printing, effects of other finishes and washing conditions.

## 2.4.1 TEA STAIN

Satindar *et al* (2012:21) defines tea which is the most popular nonalcoholic beverage in the world as a mixture of variously processed leaves of an evergreen shrub, *Camellia sinensis*. The authors further explain that, flavonoids, flavonols and phenolic acids make up approximately 30% of dried *Camellia Sinensis* by weight. Tang *et al* (2010:8894) adds that, tea polyphenols (TP) is the most important ingredient in tea, and it is mainly composed of catechin, flavones, anthocyan, and phenolic acid. Its main component is catechin with a content of more than 80%. The primary four compounds in catechin are (-)-epicatechin (EC), (-)- epigallocatechin (EGC), (-)-epicatechin gallate (ECG), and (-)-epigallocatechin gallate (EGCG), and the content of (-)-(EGCG) is the highest. TP can be applicable in the fields of foodstuff, clinic, and medication due to its special physiological functions such as anticancer, antibacterial actions, reducing blood fat, and decreasing blood sugar. Deo & Desai (1999:1) states that, there are six types of teas: green, yellow, dark, white, oolong and black. This classification is based on the processing methods employed, the degree of fermentation and the oxidation of the polyphenols present in tea as described by authors above.

Leverette (2014:1) describes tea stain as a tannin stain- a plant component that often shows as a colour in the final product. Fresh tannin stains can be removed by laundering the garment using detergent in the hottest water recommended for the fabric. While older tannin stains may need to be treated with bleach like chlorine bleach which can be used on white garments and linens.

## 2.4.2 BLACKCURRANT JUICE STAIN

Blackcurrants (*Ribes nigrum* L) grow spontaneously throughout the cold and temperate zones and the shrubs are extensively present in Asia, Australia, New Zealand, Russia, Europe and North America (Ohlsson 2006:56). The author adds that blackcurrants are known to have a characteristic strong smell and high contents of anthocyanins and ascorbic acid, as traditionally the berries were used for preparation of juice and jam and as flavours for ice creams, yoghurts and alcoholic beverages. According to Bechtold *et al* (2007:2590) anthocyanins are found in a large number of plant tissues such as berries, blackcurrants and grapes as they represent an important source of red/violet and purple pigments. The authors further explain that, the majority of the coloured compounds are collected in the food, juice and beverage as extracts from these berries can also serve as food colourants and food additives owing to the antioxidants activity of the anthocyanin compounds. Additionally, Advanced applied science (2008:7) explains that, Anthocyanidins and anthocyanins are the most highly coloured of the flavonoids. They are responsible for the scarlets, reds, violets and blues in many flowers, fruits and vegetables. They are found in: pigmented leaves and flowers of many plants, fruit such as blackcurrants, aubergines, oranges, blackberries, raspberries, cherries and redcurrants. Anthocyanins are soluble in water and easily extracted into weakly acidic solution, however, the colour is pH dependent.

## 2.4.3 BLOOD STAIN

PV22.COM Corporation (2014:1) explains that clothes stained with blood should be immediately placed in cold water and use soap washing because the blood is not yet solidified, heme iron exists in the ferrous form, can dissolve in water. The blood stains can be difficult to remove because the hemoglobin in the blood acts a binder when it hits the air and binds with fibres. So items that are just stained with blood, should be washed with cold water immediately (do not use hot water, because the heat cause coagulation of the blood).

### 2.4.4 SOOT AND MINERAL OIL STAIN

Soot is the result of incomplete combustion of carbon- containing fuels, such as petroleum and its by-products (Collier *et al* 2009:489). Paraffin, the waxy residue left behind in the refinement processing of petroleum, not only contains carbon but a host of other chemical compounds, some of which have been found to be toxic, and others labelled as carcinogens. The author explains that soot/mineral oil stain can be laundered using the hottest water safe for fabric. The author adds that in treating fabrics to remove stains, the first consideration must be the composition of the material that has been stained as knowledge of the fibre content may help to determine appropriate solvents.

## 2.5 COTTON FIBRE

Cotton is the most important natural fibre and is used widely to produce apparel, home furnishing and industrial products. It is obtained from the mature capsule of the cotton plant which are carded, combed and graded for manufacturing yarns and fabrics. Gorjanc *et al* (2011:62) describes cotton fibres as the purest form of cellulose and the World's most important textile material accounting for more than half of all fibres used in clothing and household furnishing of which 22.1 million tons were produced in 2009/2010.  According to Meyer *et al* (2013:1) the world's cotton consumption for 2013/2014 was projected at 110.4 million bales and countries which are expected to lead the global cotton mill use are; China, India and Pakistan. The authors further indicate that the world's top producers of cotton forecasted for 2013/2014 were China at 34 million bales, India at 27 million bales, United States at 14 million bales, and lastly Australia and Brazil at 4.5 million and 7 million bales respectively.

Cotton is grown mostly for fibre but it is also a food crop and the major end uses of cottonseeds are vegetable oil for human consumption, whole seed, meal and hulls for animal feed. Cotton is comfortable to wear, its good absorbency, ease to care, moderate cost and durability makes it easy to dye and bleach into different colours hence produces a variety of products needed by the consumer.

## 2.5.1 PRODUCTION OF COTTON

The oldest textiles made from cotton exist from around 5800 BC (Wulfhost *et al* 2006:14). The cotton plant grows in shrub tree or shrub like forms in different heights of 25 cm up to 2 m depending on factors like origin, soil, climate and cultivation conditions. From sowing to harvest cotton takes about 175 – 225 days (Wulfhorst *et al* 2006:14). The authors further express that the classification of cotton is based on degree of contamination, colour, staple length, fineness, strength and maturity. Cotton grows in any place where the growing season is long and the climate is temperate to hot with adequate rainfall or irrigation as when temperatures are below 21°C cellulose will not form (Kadolph 2011:60).

The fineness of cotton varies between 1 and 4dtex, the length varies between 10 and 60 mm; while the fibre lengths are mostly between 25 and 30 mm. The colour depends on the kind, climate and harvesting conditions and lastly the breaking strength is about 25 and 50 cN/tex (Wulfhorst *et al* 2006:14). Cotton fibres are seed hairs from plants of the order Malvales, family Malvaceae, tribe Gossypieae and genus Gossypium (Menachem 2007:524). The cotton plant is described by the author as a tree or a shrub that grows naturally as a perennial but for commercial purposes it is grown as an annual crop. They further add that each cotton fibre is a single, elongated, complete cell that develops in the surface layer of cells of the cottonseed, whereby the mature fibre is a dead, hollow, dried cell wall.

The three principal groups of cotton that are of commercial significance include the following as described by Lawrence (2003:27):

1.  *Gossypium hirsutum*:  it is mostly found in Mexico and Central America and varies in length from about 22 to 24 mm.

2.  *Gossypium barbadense*: it originates from South America and varies in length from 32 to 40 mm.

3.  *Gossypium herbaceum*: it covers cotton of shorter lengths from 13 to 25 mm and are mostly found in India and Asia.

Lawrence (2003:28) explains that during the first ten days of flowering, the fibre grows to its full length as a thin walled tube. And as it matures into 35 days after flowering, the fibre wall is thickened by deposits of cellulose inside the tube leaving a hollow area in the centre.

Cotton is planted in the spring and six months later the cotton boll would be ready to be picked after which it is ginned to remove seeds (Elsasser 2010:45). Cotton can either be harvested by machines or by hand picking. Both ways of harvesting have advantages and disadvantages to the quality of the picked cotton. After harvesting seeded cotton is ginned and goes through a number of cleaning stages depending on the condition of the raw cotton. Cotton will then be classified based on the degree of contamination, colour, staple length, fineness, strength and maturity. The short linters can be used to produce rayon and acetate. The quality of cotton is determined by the ability of cotton fibre to spin, which is dependent on fibre length, diameter and twist.

## 2.5.2 STRUCTURAL PROPERTIES OF COTTON

Cotton fibre is described as a single cell which grows from the seed as a hollow tube over one thousand times as long as it is thick (Kadolph 2011:61). The author further explains that the length of the cotton plays an important role in the quality of the fibre as it affects how the fibre is handled during the spinning process and relates to fibre fineness and fibre tensile strength. The longer the fibre the stronger and finer the yarns hence producing softer and smoother fabrics. On another note Menachem (2007:527) adds that, a mature cotton fibre is dried in a tubular structure, collapsed and twisted giving cotton fibre convolutions which make it different from other fibres.  Under the microscope cotton resembles twisted ribbon with a centred canal known as the "lumen" (Gohl & Vilensky 1983:42 and Elsasser 2010:48). Menachem (2007:542) adds that cotton fibres are composed of 95% of long chain carbohydrate molecules.

According to Gordon & Hsieh (2007:3) cotton fibres are composed of mostly a-cellulose (88.0–96.5%) and the non-cellulosic are located either on the outer layers (cuticle and primary cell wall) or inside the lumens of the fibres whereas the secondary cell wall is purely cellulose. The authors further explain that the specific chemical compositions of cotton fibres vary by their varieties, growing environments (soil, water, temperature, pest, etc.) and maturity. The non-cellulosic include proteins (1.0–1.9%), waxes (0.4–1.2%), pectins (0.4–1.2%), inorganics (0.7–1.6%), and other (0.5–8.0%) substances.

The figure below shows a schematic microscopic view of the cotton fibre.
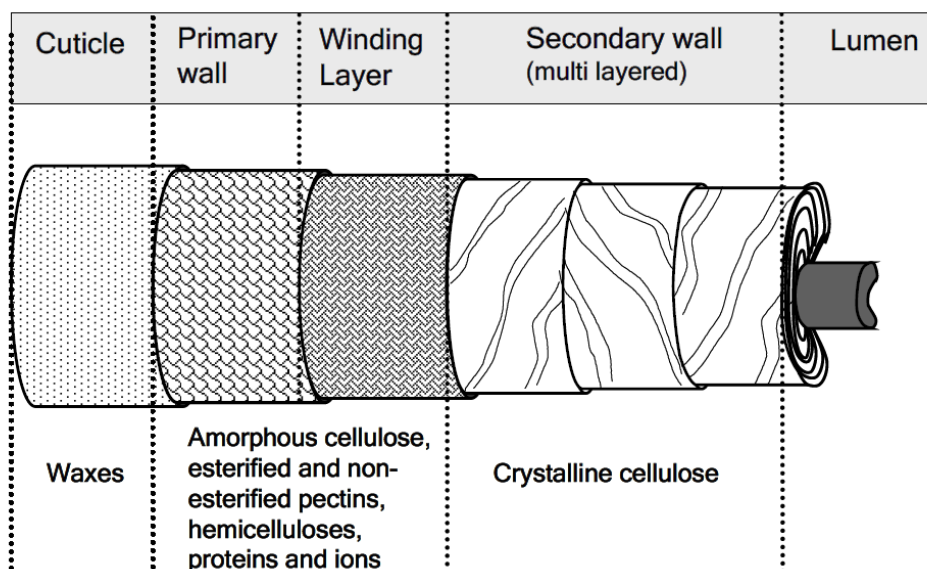


Figure 2.3: Schematic microscopic view of cotton fibre (Agrawal 2005:21)

As indicated by the figure 2.3 above Cotton consists of four parts: Lumen, primary cell wall, secondary cell wall and cuticle. The **secondary cell wall** develops on the interior of the primary cell wall and is built up of cellulose layers which contribute 91% of fibre and a crystallinity of 70%. In the cell wall, cellulose occurs in small crystalline micro fibrils that are arranged in multilayer structure (as shown in the figure above) (Menachem 2007:542, Agrawal 2005:21). The author further alludes that as the secondary cell wall develops on the interior of the primary cell wall, the micro fibrils are thought to be progressively aligned more closely with the fibre axis. The densely packed fibril layers of the secondary wall are considered to be pure cellulose (Menachem, 2007:578). The author adds that the development of the secondary wall provides the fibre with rigidity and body. Furthermore, fibres with thinner secondary wall are termed as immature and those with thicker secondary walls are termed as mature. The characteristics of mature secondary walls closely relate to fibre properties such as good strength, dyeability and reactivity. Kadolph (2011:63) adds that the layers deposited at night differ in density from those deposited during the day. The author adds that cellulose is deposited daily for 20 to 30 days until in the mature fibre, the tube is almost solid.

The **lumen** is the nutrient transportation tube which adds a yellowish shade to the fibre. Menachem, (2007:582) describes the lumen as a central opening in the fibre that spans its length from the base nearly to the tip, and contains the dried residues of cell protoplasm.

The **primary cell wall** of cotton fibres contain less than 30 % cellulose, non cellulose polymers, neutral sugars, uronic acid and various proteins (Gordon & Hsieh 2007:4). The structure of primary cell wall changes as the fibre develops. Menachem (2007:574) describes the primary wall as an inner network of micro-fibrils randomly organized within a mixture of waxes, pectin's, proteins and other non-cellulosic materials. The author further adds that the non-cellulosic components of the cell wall give the fibre surface a non-fibrillar appearance and provide both a hydrophobic protection in the environment and a lubricated surface for processing. The primary cell wall is responsible for maintaining the integrity and strength of the cotton fibre and may account for much of the strength of the cotton fibre (Menachem, 2007:26).

The non-cellulosic covering called the **cuticle** contains waxes, pectin's, mineral matters, fatty acids, high molecular weight alcohols and esters (Hossain & Uddin 2011:16), left over from biosynthesis. The cuticle is intermingled with the primary cell and it is dissolved and removed by industrial scouring of the cotton fibre. Most of the cuticle is dissolved and removed by industrial scouring of fabric, but it has important functions during spinning of the fibres into yarn and during weaving the yarn into fabric (Menachem 2007:545). However, the author explains further that, the reason for scouring is that the waxes block access to the interior of the cotton fibre for molecules such as dyes.
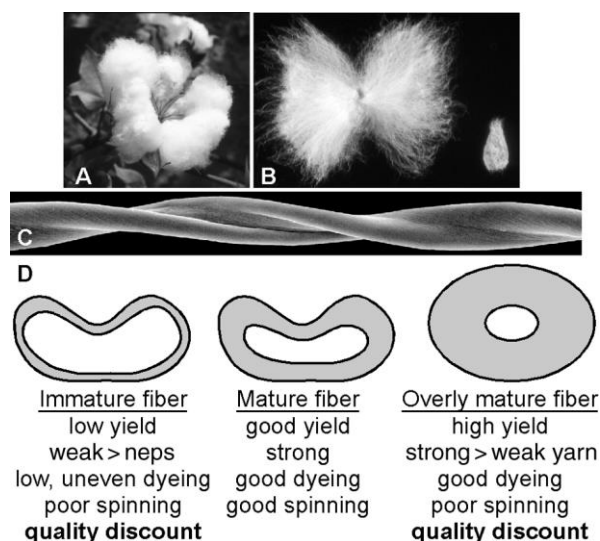


**Figure 2.4: Characteristics of cotton fibre.**

(A) A mature boll ready for harvest contains about 30 cotton seeds with attached fibre (approximately 0.2 · actual size). (B) Left: a single seed with attached lint fibre, which has been combed out to demonstrate its length of about 2.25 cm. Right: a single seed stripped of long lint

fibre retains its coating of short 'fuzz' fibre (approximately 0.5 · actual size). (C) A scanning electron micrograph of a portion of a single fibre showing the characteristic twists that develop upon drying (approximately 300 · actual size). (D) Diagrams and attributes of fibre with varying degrees of maturity Candace *et al* (2005:285).

## 2.5.3 MOLECULAR STRUCTURE OF COTTON

The cellulosic polymers in cotton have a high degree of polymerization. In figure 2.4 the characteristics of a cotton fibre are given. The hydroxyl (--OH) groups on the chains are responsible for many of the properties of cellulosic fibres. Furthermore, these polymers attract water and dyes making cotton absorptive and easy to dye. Tortora *et al* (2009:69) point out that the many hydroxyl groups in cotton make it attract water hence it is highly absorbent and comfortable to wear in hot conditions. Menachem (2007:584) and Collier *et al* (2009:67), explain that the chemical structure shows that the 2-OH, 3-OH and 6-OH sites are potentially available from the same chemical reactions that occur with alcohols. The chains of cellulose molecules associate with each other by forming intermolecular hydrogen bonds and hydrophobic bonds, which form micro fibrils that are later organised to form macro fibrils and subsequently these macro fibrils form fibres (Menachem 2007:584). Due to various chemical reactions that are done on cotton fibre the crystal structure changes with time.

## 2.5.4 PHYSICAL PROPERTIES OF COTTON

### a) Colour

According to Elsasser (2010:23) the colour of cotton varies in shade from white to brown, tan, and black. The yellowish or brown colourization of the cotton fibre is related to the protoplasmic residues of protein and the flavone pigments of the cotton flowers, hence bleaching is required for dyeing (Scout 1970:69, Abdel-Halim & Al-deyab 2011:988). Apart from these, the loom-state fabric is also contaminated with tars, greases from harvesting, ginning, spinning and weaving. Prior to dyeing and bleaching, non-cellulosic substances have to be removed and natural pigments discoloured (Hou *et al* 2010:618).

## b) Lustre

Lustre is defined by Elsasser (2010:26) as the amount of light that is reflected from the fibre. Cotton has a poor lustre as compared to silk and manufactured fibres; however the lustre can be increased through a process called ***mercerization***. Mercerization is the treatment of cotton with a strong sodium hydroxide solution to impart lustre, increase strength and improve dye uptake (Babu *et al* 2007:144). Menachem (2007:546) adds that mercerization can alter the crystal structure but it also reduces the density of the fibre and increases its lustre. Some of the properties of cotton fibres that are improved by the process of mercerization include the following; increase in dye affinity, increase in chemical reactivity, increase in dimensional stability, increase in tensile strength, increase in lustre, increase in fabric smoothness, improvement in the handle and improvement in the appearance  (Shamey & Hussein 2005:22).

Moreover, mercerizing also results in physical changes to the cotton fibre that gives added value to the final product. If the fabric is under tension during the sodium hydroxide treatment the fibre is prevented from shrinking during the swelling process. Surface lustre is developed in part due to the changes that take place in the fibre cross-section. The fibre loses its kidney shape and becomes more circular, thus increasing the surface reflective properties.

The authors further clarify that mercerization of cotton can be done on raw fibre, yarn, knitted or woven fabric and at any stage during preparation. Furthermore, fabrics can be mercerized without tension to mainly increase its strength, and dye affinity or under tension to mainly increase the lustre. Lower concentrations of sodium hydroxide will result in a lower degree of mercerization and less lustre, while the higher concentrations have no beneficial effect.  Shamey & Hussein (2005:23) explain that cotton fibres are swollen by alkali and the fabric shrinks, therefore to obtain the lustre and shrinkage control the fabric must be stretched in a frame to remove the caustic soda used during bleaching as it is very crucial in the development of lustre and shrinkage control. The figures below show the shape of cotton fibres before and after mercerization.
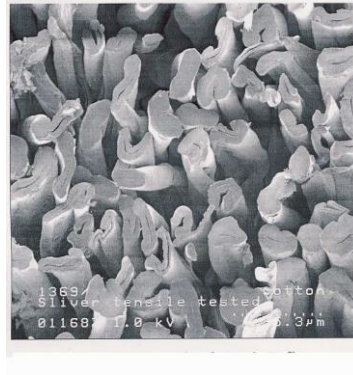
**Figure 2.5:** Electron micrograph of untreated cotton fibres showing the shape of the fibre cross section and the presence of the central canal or lumen in some fibres (Fergusson 2008:13)
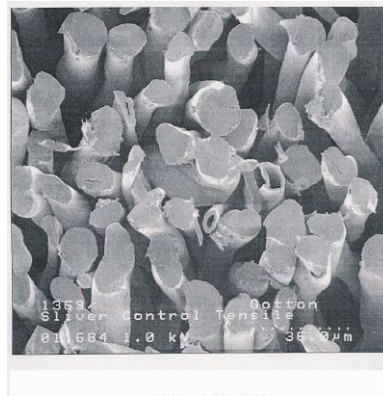


**Figure 2.6:** Electron micrograph showing the effect of treatment with 26% sodium hydroxide (caustic soda) on the fibre cross-section. Note the fibre cross section is more circular (Fergusson 2008:13).

c) **Shape**

Physically all fibres have length, cross section, surface contour and diameter (Elsasser 2010:23). These staple fibres are spun into yarns which are later woven or knitted together to make various items. When viewed under a microscope, cotton not yet mercerized looks twisted and its cross sectional view is a kidney bean shape (Cohen & Johnson 2010:22).

Saville (1999:54) further describes the visual shape of cotton into three groups as follows:

1. *Normal fibres*: are those that after swelling appear as solid rods and show no continuous lumen.

2.  *Dead fibres*: are those that after swelling has a continuous lumen and the wall thickness is a fifth or less than the ribbon width.

3.  *Thin-walled fibres*: are those that are not classified as normal or dead, being or intermediate appearance and thickening.

**d) Length of cotton**

Fibre length is an important property as the length of the fibre makes it easy to process, even yarns can be produced and it determines the strength of the fabric. The length of natural fibres has a range of values even when taken from the same plant or animal (Saville 1999: 58). The author indicates that cotton is a comparatively short fibre with the finest variety namely Sea Island cotton is over 50 mm whilst a variety of Indian cotton may be less than 12 mm. Menachem, (2007:527) adds that the long fibre lengths of cotton is between 12-15 mm and 25.4 mm or longer, and are commonly named lint fibres, which are obtained from the cotton gin. The short cotton fibres are called liners or fuzz fibres and they are normally attached to the seed after ginning.

e)  **Fineness of cotton**

According to Saville (1999:44), fineness is one of the most important properties of the fibres that are made into textile products as the finer the fibre, the finer is the yarn, which enables the garments to be made with a soft and a luxurious handle. The author adds that with natural materials such as cotton, silk, wool and other animal fibres, the finer varieties are reserved for the more expensive apparel and hence command higher prices. Lawrence (2003:31) complements that fibre fineness affects processing performance and the quality of the end product in several ways. Because in the opening, cleaning and carding processes finer fibre cottons require slower processing speeds to prevent damage of the fibres. These undamaged fibres will in turn produce stronger yarns and hence good quality products. According to Menachem (2007:623), some of the most important parameters used to define fineness include: perimeter, diameter, cross-sectional area, mass per unit length and specific fibre length.

## 2.5.5 MECHANICAL PROPERTIES OF COTTON

### a) Tenacity and Abrasion Resistance

Cotton has **good strength** and good **abrasion resistance** though not stronger than flax but its strength increases by 10 to 20% when wet (Elsasser 2010:49). The strength of the cotton fibre increases when wet due to the increased hydrogen bonding. This is because water molecules can easily form hydrogen bonds with the free cellulose hydroxyl groups. It is therefore able to resist wear and tear from rubbing making the fabrics to last long. Most of cotton fabrics are capable of maintaining their strengths for many years indoors in a dry environment, but will deteriorate readily when kept in an outdoor environment (Menachem 2007:615). The author explains that this is due to bacterial attack and sunlight degradation. And due to the poor resistance cotton, is not commonly used for tents awning material in rainy and damp climates.  Collier *et al* (2009:228) adds that abrasion resistance is increased by tighter twist of yarns because in a more tightly twisted yarn many fibres are held in such a way that they appear on the surface  and as a result more fibres are relatively evenly distributed for abrasion. Kadolph (2011:65) states that the abrasion resistance of cotton can be improved by durable press finish or blending cotton with other fibres like polyester.

Cotton is the only significant fibre whose strength increases with humidity while most others are weakened by increased moisture (Menachem 2007:623). The author defines tenacity as the power to resist force or the breaking strength or load necessary to break a fibre. According to Collier & Epps (1999:98) strength is one of the tensile properties of textile materials, comprising their resistance to stretching or pulling forces. Cotton has a moderate to low strength (Collier & Epps 1999:106).  Tenacity ranges from 3.0 to 4.9 g/d and its strength is increased by length of the polymer chains (Collier *et al* 2009:68). Behera and Hari (2010:162) add that the tensile properties of woven fabrics depend on the fabric structure, i.e. yarn twist, yarn strength, weave, crimp and cover.

According to Behera and Hari (2010:137), the tensile properties of woven fabrics, together with other mechanical properties such as bending, shear and compression are of considerable importance in determining how the fabric will perform in use. The authors add that the tensile strength of a fabric should be much higher than the maximum stress likely to be encountered in actual use because the fabric is subjected to repeated stresses which degrade the quality of the material in its lifetime.  Behera and Hari (2010:138) explains tensile strength as a measure of

the force required to pull something such as rope, wire or a structural beam to the point where it breaks. The authors define three different versions of tensile strength as follows:

- Yield strength: the stress beyond which the strain in the material changes from elastic deformation to plastic deformation which is a permanent deformation

- Ultimate strength: the maximum stress a material can withstand

Breaking strength: the stress coordinates on the stress-strain curve at the point of rupture is called breaking strength.

## b) Resiliency and elasticity

Cotton is strong but has little elasticity and does not resist deformation so cotton fabrics tend to crease easily. According to Elsasser (2010:49), a resin finish weakens cotton as it affects its softness and draping properties to some extent; however cotton can be blended with resilient fibres like polyester to create fabrics with improved wrinkle resistance. Furthermore, cotton has poor elasticity hence it is sometimes blended with spandex to improve on the poor quality (Kadolph 2011:64). The author explains that the hydrogen bonds holding the molecular chains together are weak when fabrics are bent or crushed together especially when wet. And when the pressure is removed these weak forces cannot pull the chains back to their original position. The author adds that the elastic recovery of cotton is moderate as it recovers 75 % from a 2 to 5 % stretch.

## 2.5.6 CHEMICAL PROPERTIES OF COTTON

### a) Absorbency

Cellulose is hydrophilic and swells in the presence of water and it occurs either in inter-crystalline regions or on the surfaces of the crystallites and gross structures (Menachem 2007:587). Cotton fibre is subject to many treatments that affect its swelling and crystal structure. The chemical reactions involve the water swollen fibre which retains a highly crystalline structure (Menachem 2007:70). The absorbency of the pure fibre and its chemical stability give cotton a good affinity for dyes and its whiteness enables a wide range of colours to be applied. According to Elsasser (2010:49), mercerization and treatment with liquid ammonia improves the absorbency and dyeability of cotton. Hence, cotton is a comfortable fibre to wear in

hot or humid weather conditions because it is absorbent but it dries slowly. Cotton is a very comfortable fibre, durable and can be washed with strong detergents without requiring any special care.

**b) Electrical Conductivity**

According to Tortora *et al* (2009:69) cotton conducts electricity and thus does not build up static electrical charges, that could hinder mechanical processing and has certain discomforts and hazards associated with electrical charges in clothing, carpets, and others (Menachem 2007:627).

**c) Effect of dry heat**

Cottons is flammable when exposed to open flame as it scorches and even burns leaving grey ash and the smell of a burning paper. Tortora *et al* (2009:69) adds that, cotton is not thermoplastic, therefore does not melt when burning; however exposure to dry heat causes decomposition and deterioration of the fibre and high ironing temperatures cause cotton to scorch or turn yellow.

**d) Environmental properties**

Cotton is easily attacked by mildew and silverfish when stored damp in dark and warm places, however moths and carpet beetles will not attack cotton (Elssaser 2010:50). The author further adds that long exposure to sunlight damages cotton as well. Menachem (2007:608) adds that microbial damage can be caused either by bacteria or fungi after boll opening, prior to or after harvest and during storage and to the cotton fabric.

**e) Acids: Oxidising agents**

Cotton suffers severe degradation when treated with very dilute solutions of hydrogen chloride in an aprotic solvent such as benzene, because the small amount of hydrogen chloride in the solvent is redistributed in the water and absorbed on the cotton, forming a very concentrated aqueous solution of hydrochloric acid (Menachem 2007:604)

Cotton can be destroyed by concentrated mineral acids like sulphuric acid and chlorine bleach if not neutralized and washed out as it degrades and destroys the fibre. In contrast strong alkalis like sodium hydroxide do not harm cotton but improve cottons absorbency, lustre and strength as it makes the fibre to swell and become stronger (Tortora *et al* 2009:69). According to Wootton (2001:32) cotton is susceptible to attack by hot dilute or cold concentrated acids, as

well as traces of acid not properly washed out from dyeing and finishing processes, and this can lead to a progressive tenderising of the fibres and loss of fibre strength.

## f) Water

According to Menachem (2007:587) cellulose is hydrophilic and swells in the presence of water as cellulose water interactions are considered to occur either in inter-crystalline regions or on the surfaces of the crystalline and the gross structures. Wootton (2001:30) explains that cotton swells on immersion in water but the wet strength of the yarn is up to 20% higher than in the dry state; on drying the properties revert to the original. Additionally, on exposure to a standard atmosphere (20 °C and 65% relative humidity) cotton will retain approximately 8.5% moisture.

Moisture vapour can pass through openings between fibre, and in the case of cotton which is a hydrophilic fibre, the fibre can serve as a buffer by absorbing moisture vapour and adding to the comfort properties of the fabric (Journal of Textiles, and Apparel Technology and Management 2002:1). When wet cotton becomes too heavy and sags due to the extra weight, hence making it to take a longer time to dry and sticking to the skin restricting movement and the wearer would feel cold.

## g) Alkali: Sodium hydroxide

According to Menachem (2007:587), the swelling of cotton with an aqueous solution of sodium hydroxide is an important commercial treatment, whereby sodium hydroxide is used to mercerize cotton fibre as a way of treating the fibre. Mercerization as explained by Menachem (2007:588) is utilized to improve such properties as dye affinity, chemical reactivity, dimensional stability, tensile strength, lustre and smoothness of the cotton fabrics. The treatment is either applied to the yarn or the fabric. Strong bases have no harmful effect on cotton. Kadolph (2011:62) explain that cotton can be altered by using chemical treatments or finishes e.g. mercerization (treating yarns or fabrics with sodium hydroxide NaOH) which causes a permanent physical change as the fibre swells and creates a rounder cross section. Mercerization yields good results as it improves cottons absorbency and improves dye ability.

## 2.5.7 DYE FOR COTTON

Menachem (2007:620) points out that cotton requires some pre-treatment prior to dyeing and printing and the pre-treatment processes include; singeing, desizing, scouring, bleaching and mercerization. The author explains that the treatments are necessary as they remove natural and human induced impurities so as to increase the affinity with cellulose for dyes and finishes. Furthermore, colour enhancement can be accomplished through the treatment of cotton with cellulase enzymes either before or after dyeing. However, dyeing cotton fibres leads to their greater entanglement and cohesion, due to the removal of a large portion of the wax present on the surface of cotton fibres during the scouring and dyeing process the average length of cotton fibres decreases with a higher rate than that of white cotton fibres after going through the blending, carding and drawing processes (Karim *et al* 2007:63). The composition of the dye molecule, the dyeing conditions, and the nature of the cellulosic substrate influence the kinetics and equilibria in dyeing cellulosic fibres (Menachem 2007:620). The author further states that cotton can be dyed in fibre form, yarn, or fabric with a number of dyes including azoic, direct, indigo, pigment, reactive, sulphur and vat dyes.

Cotton fibres due to hydroxyl groups in their structure, faces the problem of dye attraction and attempts are made to improve dye bonding and dye absorption on materials through chemical modification (Khanjani *et al* 2011:7). Authors explain that when cellulose fibre comes into contact with water it produces a slightly negative charge due to the presence of hydroxyl and carboxyl groups. Whereas common dyes appropriate for cotton dyeing are anionic (reactive and direct) in dye baths, the slightly negative charge on the fibres repels anionic dyestuff and hence the efficiency of dye exhaustion and fixation on cellulosic fibres is generally low (Khanjani *et al* 2011:7).

According to Vassileva (2008:324), cotton fibres have natural porosity - a system of pores and micro-capillaries whose accessibility can increase depending on the dyeing conditions. That is, dyeing with reactive dyes takes place in an alkaline medium which results in a considerable swelling of the cotton fibres and increase of their inner surface. Unless the fabric is uniform in whiteness, absorbency and chemical composition as well as low levels of impurities, it is unlikely that it will take up dye or finish consistently to maximum possible extent (Hashem 2007:85).

# CHAPTER 3

## 3.0 MATERIALS AND METHODS

The focus of this study was to investigate the effectiveness of Anolyte as a bleaching agent against the commonly used sodium hypochlorite and distilled water. The bleaching effect of Anolyte was determined at temperatures 24°C 30°C, 40°C, 60°C and 80°C to determine the effect of temperature on the efficacy of the agent. Woven textile materials consisting of bleached cotton, unbleached cotton, dyed cotton and stained cotton respectively were bleached using Anolyte, distilled water and sodium hypochlorite. The laundered woven fabrics properties after laundering were evaluated in terms of tensile strength, stiffness and whiteness. Further investigations were done on the effect of bleaching temperatures mentioned above and duration of exposure ranged from 9 minutes, 18 minutes, 30 minutes, 45 minutes, 1 hour, 1 hour 30 minutes to 2 hours.

## 3.1 MATERIALS

## 3.1.1 PREPARATION OF BLEACH LIQUORS

### 3.1.1.1 ANOLYTE

The electrochemical activation (ECA) process involves passing of high voltage current through a NaCl water solution. The water electrolyzer unit produces Anolyte and Catholyte (Hoshizaki Electric Co., Rox-10WB-E unit). Anolyte is a colourless liquid with a pH value 2-3 which is harmless to humans.



[1] Control Box (behind panel)
[2] Operation Panel
      See "[b] OPERATION PANEL" for details.
[3] Switch Panel (behind cover)
      See "[c] SWITCH PANEL" for details.
[4] Salt Water Hose
[5] Filter
[6] Salt Water Tank
      Holds 5 L (1.3 gal) of concentrated salt water.
[7] Water Supply Inlet (bottom)
[8] Water Outlets (Acid, Alkaline)
[9] Joints
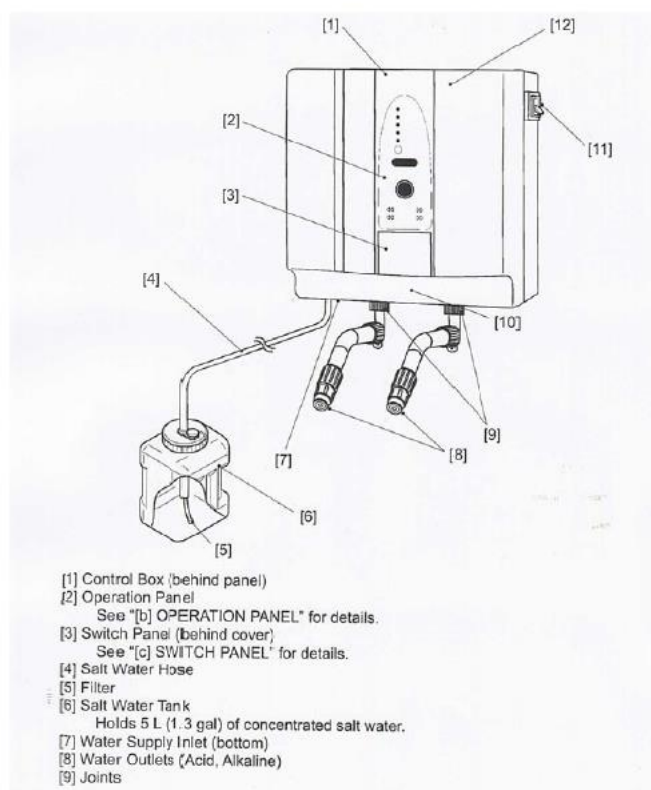
**Figure 3.1: An illustration of the water electrolyzer unit (Water Electrolyzer Instruction Manual, Hoshizaki).**

An ECA machine as shown in figure 3.1 above allows tap water to be passed through a filter system for softness, whereby tap water and salt (NaCl) were supplied and electrochemical activation of the salt solution resulted in the production of Anolyte and Catholyte and they were collected separately through pipes at the bottom unit. The pH of Anolyte ranged from 2.65 -

3.06 whilst the range of ORP was between 986 -1055 mV. The Anolyte solution was used within 1 hour of preparation. The composition of Anolyte is given in table 3.1.

## 3.1.1.2 SODIUM HYPOCHLORITE BLEACH SOLUTION

The amount of sodium hypochlorite solution was calculated as follows:

4.54% NaOCl= g to add

Using the above formula a total amount of 2 ml sodium hypochlorite was measured into each beaker and distilled water added to make a total of 150 ml solution per canister, where 50 balls of stainless steel were added then a test fabric, before placing the canisters into a launder-o-meter.  After bleaching the samples were rinsed in distilled water bath at 40 ± °C for 1 minute before drying.

The sodium hypochlorite solution (5%) used in the experiment was obtained from Associated Chemical Enterprises, from Johannesburg South Africa. Batch No. 7128, control No. 11190 and expiry date 10.11.2013. The tests were conducted from June – August 2013.

Typical Analysis:

Chlorine: 5%

Iron: 0.001%

Sodium hydroxide (NaOH): 1.5%

The pH ranged between 9.65 and 9.70. The composition of sodium hypochlorite is given in table 3.1.

## 3.1.1.3 FILTERED WATER

Using a four phase filtering system with 5 micron filters and carbon filters, tap water would be passed through to obtain the filtered water, in which 150 ml would be measured into each canister with 50 balls of stainless steel and a sample fabric before placing the canister into a Launder-o-meter. The composition of distilled water is given in table 3.1.

**Table 3.1:** Composition of the distilled water, Anolyte and sodium hypochlorite solutions, analyzed at the laboratory of Institute for Groundwater Studies laboratory services, University of the Free State.

|  | UNITS | DISTILLED WATER | ANOLYTE | SODIUM HYPOCHLORITE |
|---|---|---|---|---|
| Free chlorine | mg/L | <0.01 | 1.58 | 0.01 |
| Calcium Ca | mg/L | 30.8 | 32.0 | 32.2 |
| Magnesium | mg/L | 13.2 | 12.6 | 13.5 |
| Sodium Na | mg/L | 32.2 | 245 | 610 |
| Potassium K | mg/L | 3.93 | 2.92 | 4.72 |
| Aluminum Al | mg/L | <0.004 | 0.023 | <0.004 |
| Iron Fe | mg/L | 0.015 | 0.020 | 0.011 |
| Manganese Mn | mg/L | 0.008 | 0.012 | 0.007 |
| Copper Cu | mg/L | 0.010 | 0.051 | 0.015 |
| Nickel Ni | mg/L | <0.010 | <0.010 | <0.010 |
| Zinc Zn | mg/L | 0.325 | 0.619 | 0.118 |
| Sulfate SO4 | mg/L | 26.33 | 34.13 | 26.12 |
| Orthophosphate P | mg/L | <0.05 | <0.05 | <0.05 |
| Barium Ba | mg/L | 0.035 | 0.051 | 0.028 |
| Stronsium Sr | mg/L | 0.92 | 0.147 | 0.074 |
| Silicon Si | mg/L | 0.831 | 0.912 | 0.770 |

## 3.2 TEXTILE FABRICS

The sample size of samples varied as follows: colour change and stiffness samples were cut into 20 cm by 2.5 cm whereas for tenacity the sample size would be 38 cm by 6.5 cm. All fabric test samples were cut and over locked to avoid fraying during bleaching.

### Fabric 1: Unbleached cotton
Unbleached cotton percale sheeting (code T-439 UXW) was purchased from Center for Test materials BV, Netherlands.

### Fabric 2: Dyed cotton

Two different dyed cotton fabrics were purchased from Center for Test materials BV, Netherlands, and these are:

- Cotton dyed with reactive red 195 ( Code E 475)
- Cotton dyed with Vat blue 4 (Code E479)

### Fabric 3: Stained Cotton
Four different stained cotton fabrics from Center for Test materials BV, Netherlands were used. The stained fabrics are described as follows:

- Cotton stained with Tea (code W 10 J)
- Cotton stained with Blackcurrant juice (code W 10 JB)
- Cotton stained with Blood IEC 60456 (code W 10 PBU)
- Cotton stained with Soot /Mineral oil, IEC (code W 10 RM)

### Fabric 4: Bleached cotton
100% cotton test fabric for standard adjacent fabric for colour fastness testing was obtained from Test fabrics style 400, through Dutest agencies in Milnerton, Cape Town.

## 3.3 METHODS

### 3.3.1.1 BLEACHING PROCEDURES

### 3.3.1.2 ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER

The AATCC test method 61-2010, procedure 5A (AATCC technical manual 2009:87) was followed but adjusted to suit the experimental needs. Bleaching procedures was carried out on the following fabrics; unbleached cotton, bleached cotton, stained cotton and dyed cotton using; Anolyte, Sodium Hypochlorite and distilled water solutions. Bleaching took place in the Launder-Ometer (Atlas Electric Devices Co.) machine which was preheated to the correct temperature before any bleaching procedure. Using a Launder-Ometer provides accelerated results in a short time, as 45 minutes of laundering in Launder-Ometer is equal to 5 washes in a home washing machine.

Procedure 7.3.3 in the AATCC test method 61-2010 was followed in the bleaching process. The procedure specifies that, a total of 150 ml bleaching liquor be added into each canister with 50 stainless steel balls and a specimen (test fabric). For sodium hypochlorite, 2 ml was measured and distilled water added into the beaker to make a volume of 150 ml. This solution was in each beaker then filled into each canister with 50 balls of stainless steel.

Anolyte solution and distilled water were prepared an hour before any test was carried out whereby 150 ml bleaching solution was measured into each canister with 50 balls of stainless steel.

After bleaching was carried out, canisters were emptied and each sample was rinsed in distilled water placed in a water bath at 40 °C, removed and allowed to dry at room temperature in a room without any fluorescent lights. The bleaching temperature and cycles varied as follows:

a) ***Unbleached cotton***: bleaching temperatures were 40 °C, 60 °C and 80 °C. Bleaching time varied from 1 hour, 1 hour 30 minutes and 2 hours respectively.

b) ***Stained cotton:*** there were four different stained cotton fabrics from tea, blood, soot/ mineral and blackcurrant juice stains. The bleaching temperatures were 30 °C, 40 °C and 60 °C, whereas bleaching times ranged from 9 minutes, 18 minutes to 45 minutes.

c) ***Dyed cotton:*** cotton dyed with reactive red and vat blue dyes were bleached at 24 °C, 30 °C and 60 °C. The bleaching time was 45 minutes and cycles varied from 5, 10 and 20.

d) ***Bleached cotton:*** the bleached cotton was bleached at 40 °C for 45 minutes and the cycles varied from 5, 10 and 20 cycles. This procedure was followed to determine whether the bleach liquors cause yellowness on bleached cotton.

## 3.4 FABRIC PROPERTIES

### 3.4.1 TENSILE STRENGTH

An Instron Tensile Tester and ISO/SANS 13934-1:1999 test methods were used for the tensile strength measurement as the test determines the maximum force before the fabric breaks. The samples were prepared accurately to ensure the width was 65mm and a length of 380mm for each specimen. The samples were then conditioned for a minimum of 24 hours at 21 ± 1°C and 65 ± 2% relative humidity before tests were conducted. The apparatus was set before tests were conducted. The ramp rate of the apparatus was 20 kN/min, while the gauge length of the testing machine was set at 100 mm ± 1 mm and the rate of extension was set at 100 mm/min. When operating the machine, the highest force registered during the test was recorded and measured to the nearest 1 mm. The breaking strength was calculated in Newton for the mean of breaking strengths of the specimen. A total of 12 readings were taken per set of bleached samples and their totals averaged.

### 3.4.2 STIFFNESS TEST

For stiffness testing ASTM D1388 – 08 Cantilever test was used, which employs the principle of cantilever test bending of the fabric under its own mass. Test samples were preconditioned by bringing them to appropriate moisture equilibrium in the standard atmosphere as directed in Practice D1776, which advises that test samples should be conditioned at 21±1°C and 65 ± 2% relative humidity for 24 hours. After preconditioning, the test specimens were tested in the same conditions.

As the test method specifies, 25mm by 200mm specimen was slid at a specified rate in a direction parallel to its long dimension, until its leading edge projects from the edge of a horizontal surface. A cantilever tester was set on a table with the horizontal platform and inclined reference lines.

The length of the overhang was measured when the tip of the specimen was depressed under its own mass to the point where the line joining the top to the edge of the platform makes a 41.5 °C angle with the horizontal. From this measured length, the bending length and flexural rigidity were calculated. A total of four readings per specimen were recorded from the face and back of each specimen and the readings averaged to the nearest 0.1 cm using the following equation:

*c=O/2*

Where:

*c* = bending length, mm and

*O* = length of overhang, mm.

### 3.4.3 COLOUR MEASUREMENT

AATCC test method 135-1985 for instructional colour measurement of textiles was used in determining the bleaching effect of Anolyte, sodium hypochlorite and distilled water on the specimens. Before any testing the test samples will be preconditioned by bringing them to appropriate moisture equilibrium in the standard atmosphere as directed in Practice D1776, which suggests that test samples should be conditioned at 21±1°C and 65 ± 2% relative humidity for 24 hours.

The spectrophotometer was calibrated before any readings were taken. Five measurements were taken on each specimen before bleaching and after bleaching in order to determine the colour difference. The five measurements were averaged to get the mean and statistically analyzed to determine the extent in colour change.

According to Adeyeni *et al* (2010:19) the CIELAB colour system is a three dimensional uniform colour space with equal distances corresponding to equal perceived colour differences. This system has three axes, *L*, a* and b**. The L* axis represent lightness and extends from 0 (black) to 100 (white). The value a* and - b* represent the redness-greenness and −a* and + b*

yellowness-blueness axis, respectively. When a* and b* coordinates approach zero, the colour becomes neutral. Moreover, a* and b* can be used to derive metric chroma and hue angle. A colour difference (ΔE) between two objects can be calculated within the CIELAB colour system.

To calculate the difference in shade CIE 1975 L*a*b* colour scale formula was used to get an average of ΔE* value, which is the colour difference of the bleached, unbleached, dyed and stained cotton. The colour change was measured according to the following formula:

$$\Delta E* = \sqrt{\Delta a*^2 + \Delta b*^2 + \Delta L*^2}$$

Where ΔE*= colour change, L* ranges from black = zero to white =100, and on the horizontal axis positive a* indicates a hue of red-purple while negative a* ranges from bluish – green. On the vertical axis positive b* indicates yellow and negative b* blue when negative it would be more blue or less yellow.

## 3.4.4 STATISTICAL ANALYSIS

Statistical analysis of the data obtained from the replicate observations per sample of the variable (stained, bleached, unbleached and dyed cotton) were averaged and analysed through an analysis of variance (ANOVA) fitting the three design factors bleach (Anolyte, distilled water and sodium hypochlorite), bleach temperatures, bleach time and bleach cycles. F-tests and P-values for the effects in the model were obtained from the ANOVA. Furthermore, estimates of the differences between least squares means, associated 95% confidence intervals and P- values were also reported. The program used for data analysis was SAS version 9.22, procedure GLM.

# CHAPTER 4

## 4.0 EFFECTS OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON STAIN REMOVAL, STIFFNESS AND TENACITY OF COTTON

The aim of the study was to investigate the effectiveness of Anolyte as a bleaching agent beside the commonly used sodium hypochlorite, and distilled water was used as a control. The bleaching effect of the Anolyte, sodium hypochlorite and the water were determined at different temperatures (24 °C, 30 °C, 40 °C, 60 °C, and 80 °C) and for different duration of exposure to determine the efficacy of the agents. Unbleached cotton was used to determine the bleaching efficiency. Stained cotton was used to determine the stain removal efficiency and bleached cotton was used to determine whether any of the agents cause discolouring. Colour change was used to measure bleaching efficiency and stiffness and tenacity were measured to investigate the possibility of physical damage caused by the agents. The mean differences of the results obtained were statistically analyzed and the results have been presented in graphs and tables to illustrate the effect of all these factors.

Textile products are exposed to soil with staining components in everyday use. There are wide varieties of stains and the stains are normally dispersed rather than being well spread across the fabric and some stains will only be located in one area of the textile. According to Kadolph (2011:251), stain can include particulate matter such as baby oil and fat or grease from food and engines; coloured material such as water-borne stains from beverages and fruit; and environmental soil such as grit and leaf mould. A stain is defined as a local deposit of soil or discolouration on a substrate that exhibits some degree of resistance to removal, as by laundering or dry cleaning (AATCC 2009:207).

AATCC (2009:207) defines soil or dirt as oil or other substances not normally intended to be present on a substrate such as a textile material. These soils come from a number of sources in the environment that textile structures are subjected to during wear and use. These soils could be from solid particulate matter such as clays, minerals, soot; some from oil-borne soils like fats and greases; and lastly from water-borne soils like water-soluble salts.

Textiles are exposed to these stains in industry and in the household. These stains lead to colour change in textiles and thus make the item not to be appealing to the wearer. Detergents and bleaches are used when washing laundry to effectively remove these above described stains. According to Pušić *et al* (2007:407) bleaching agents are important ingredients of a detergent composition as its main purpose is to remove bleachable stains because the surfactants and builders are not efficient enough to remove stains during washing. The authors further add that the most dominant bleaches are sodium hypochlorite as they are able to bleach in a cold bath. Bleaches are often used along with soaps and detergents in laundering. Bleaches are used to whiten fabrics and remove stains. Bleaches oxidize the colouring matter in fabric and some stains are removed by the oxidation of the colouring matter in them. Some dyes are damaged by chlorine bleach; therefore it is rarely recommended that coloured fabrics be bleached with chlorine bleach (Collier *et al* 2009:480). The authors further explain that in treating fabrics to remove stains, the first consideration must be the composition of the material that has been stained as knowledge of fibre content may help to determine appropriate solvents.

The objective of the research was to determine if Anolyte could be used as an alternative stain remover to the commonly used sodium hypochlorite and distilled water was used as a control. The stains that were bleached included blood, tea, blackcurrant juice and soot/mineral oil at temperatures 30 °C, 40 °C and 60 °C and the duration of exposure was 9 minutes, 18 minutes and 45 minutes.

## 4.1 EFFECTS OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON THE REMOVAL OF BLOOD STAIN ON COTTON

According to Collier *et al* (2009:487) if blood stain is fresh, it should be soaked in cold water, while dried stains should be soaked in warm water with a product containing enzymes. However, if the stain remains, it should be re-washed using bleach safe for the fabric. The results regarding the removal of blood stain after bleaching with Anolyte, water and sodium hypochlorite solution at 30 °C for 9, 18 and 45 minutes are illustrated in Figure 4.1 below. All the bleach solutions removed the stain to a certain degree. The results presented show clearly that, sodium hypochlorite and distilled water were more effective in removing the stain than Anolyte at all bleach times. Anolyte best removed blood stain when bleaching for 18 and 45 minutes as the whiteness reached 70.5 ΔE and 70.4 ΔE respectively. It was also noted from Table 4.1 below that, the Lightness (L*) of the bleached blood stain gradually increased with bleach time.

Blood stain was best removed when laundering for 45 minutes with sodium hypochlorite where the whiteness reached 83.2 ΔE. Collier *et al* (2009:487) explain that if the stain is fresh, soak in cold water will give better wash results but these stains were not fresh. Stone (2009:1) concurs with Collier *et al* that, blood stain should be soaked in cold water to dislodge the stain within the fibres. It was noted from the figure that, the whiteness in the removal of blood stain gradually increased as time also increased in both sodium hypochlorite and distilled water.



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 miutes | 69.6 | 72.5 | 80.6 | 48.84 |
| 18 minutes | 70.5 | 74.9 | 81.9 | |
| 45 minutes | 70.4 | 77.4 | 83.2 | |
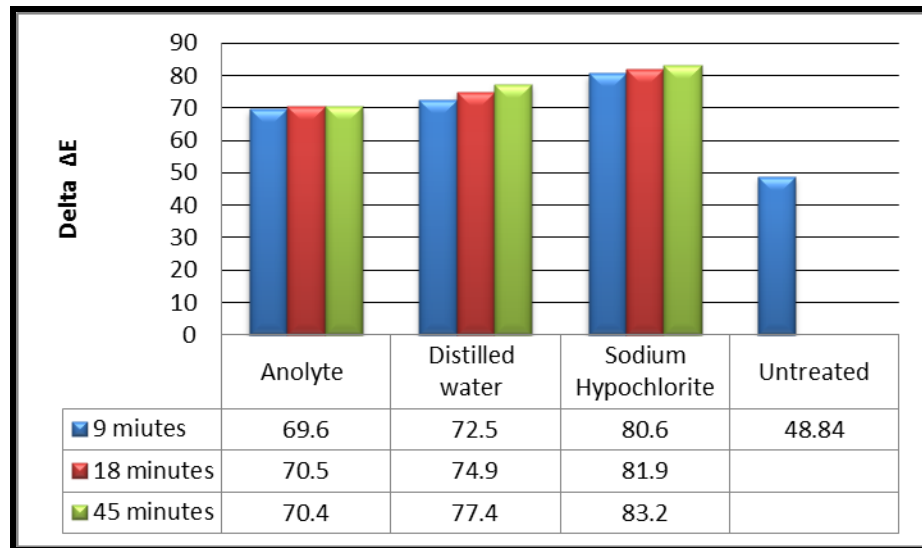
**Figure 4.1: Cotton stained with blood: Effects of Anolyte, sodium hypochlorite and distilled water at 30 °C on colour change (mean values).**

Bleaching with Anolyte, sodium hypochlorite and distilled water at 40 °C on colour change is shown in figure 4.2. As illustrated in figure 4.2 below, blood stain was removed by all bleaches as the whiteness was greater than the untreated after all wash times when bleaching took place at 40 °C. It was noted that the longer the wash time the better the stain removal in all the bleach liquors. Blood was better removed when bleached by sodium hypochlorite for 45 minutes. As illustrated in figure 4.1 the whiteness of the blood stain reached 81.8 ΔE when blood stained cotton was bleached for 18 minutes while it was 81.8 ΔE when bleached for 45 minutes at 40 °C as illustrated in figure 4.2. Figure 4.2 illustrates that Anolyte and distilled water at 40 °C removed the stain better than at 30 °C at all bleach times. But as for sodium hypochlorite the stain brightened gradually as time increased. Sodium hypochlorite removed the blood stain better than Anolyte when bleaching lasted for the shortest time of 9 minutes. Figure 4.2 show that at 9 minutes the whiteness of the bleached stain reached 70.9 ΔE, while the stain bleached with sodium hypochlorite whiteness reached 78.2 ΔE.



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 70.9 | 74.5 | 78.2 | 48.84 |
| 18 minutes | 71.2 | 75.2 | 79.5 | |
| 45 minutes | 71.9 | 77.1 | 81.8 | |
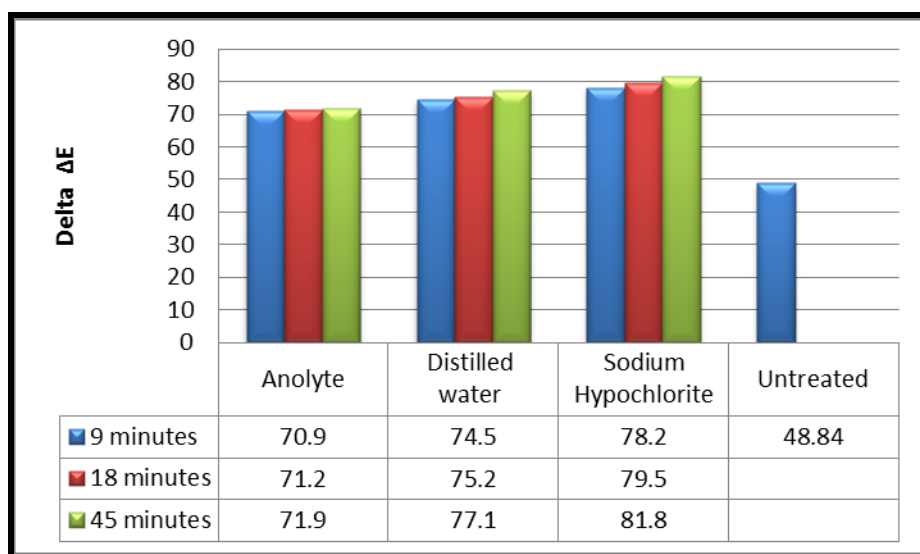
**Figure 4.2: Cotton stained with blood: Effects of Anolyte, sodium hypochlorite and distilled water at 40 °C on colour change (mean values).**

As illustrated in figure 4.3 Anolyte, distilled water and sodium hypochlorite bleaches removed blood stain when the temperature rose to 60 °C but less effective than at lower temperatures. Sodium hypochlorite bleach removed the stain best with whiteness reaching 74.7 ΔE. Distilled water removed the stain better that Anolyte at all bleach times. Anolyte bleach removed blood stain best when bleaching lasted for 18 minutes as the whiteness reached 70.7 ΔE. According to Stone (2009:1) hot water cooks the protein of a blood stain, causing coagulation between the fibres in the yarns of the fabric, making the stains more difficult to remove. Other authors agree (PV22.COM Corporation 2014:1) and advise that clothes stained with blood, should be immediately placed in cold water, use soap washing. Because the blood is not solidified, heme iron exists in the ferrous form, can dissolve in water. When exposed for a long time, heme ferrous in blood is oxidized to ferric iron, and as the protein coagulates in the fabric on the formation of blood spot making it difficult to wash off (PV22.COM Corporation 2014:1). And from the results, it is evident that at low temperature (30°C) blood stain was removed best by sodium hypochlorite. It was noted that, blood stain was less removed when bleach temperatures reached 60 °C.



**Figure 4.3: Cotton stained with blood: Effects of Anolyte, sodium hypochlorite and distilled water at 60 °C on colour change (mean values).**

| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 68.7 | 71.2 | 73.8 | 48.84 |
| 18 minutes | 70.7 | 72.6 | 74.4 | |
| 45 minutes | 68.3 | 71.8 | 74.7 | |

**Table 4.1: Cotton stained with blood: L* a* and b* values of bleach, temperature and time on colour change.**

| Bleach | Temp (°C) | Time (minutes) | Value of L* a* b* values |
|---|---|---|---|
| **Anolyte** | 30 | 9<br>18<br>45 | L*66.2 a*4.6 b*17.5<br>L*68.3 a*3.7 b*17.0<br>L*68.5 a*2.8 b*15.9 |
| | 40 | 9<br>18<br>45 | L*68.7 a*3.9 b*17.2<br>L*69.3 a*2.7 b*16.3<br>L*69.9 a*2.9 b*16.5 |
| | 60 | 9<br>18<br>45 | L*66.7 a*2.9 b*16.0<br>L*68.4 a*4.4 b*17.3<br>L*66.4 a*2.5 b*15.5 |
| **Distilled water** | 30 | 9<br>18<br>45 | L*70.1 a*4.4 b*18.0<br>L*72.9 a*3.2 b*16.8<br>L*75.8 a*2.2 b*15.5 |
| | 40 | 9<br>18<br>45 | L*72.7 a*2.9 b*16.2<br>L*73.3 a*2.6 b*16.5<br>L*75.7 a*1.8 b*14.6 |
| | 60 | 9<br>18<br>45 | L*69.1 a*3.6 b*16.8<br>L*70.8 a*2.9 b*15.7<br>L*69.9 a*3.2 b*15.8 |
| **Sodium Hypochlorite** | 30 | 9<br>18<br>45 | L*79.6 a*0.8 b*12.4<br>L*80.7 a*0.3 b* 13.5<br>L*82.2 a*0.1 b*12.3 |
| | 40 | 9<br>18<br>45 | L*76.9 a*1.4 b* 13.4<br>L*78.4 a* 0.9 b*13.2<br>L*81.1 a*0.8 b*10.1 |
| | 60 | 9<br>18<br>45 | L*72.8 a*2.0 b*11.6<br>L*73.6 a*1.9 b*10.5<br>L*73.9 a*1.8 b*11.0 |

**Table 4.2: Cotton stained with blood: Main effects of bleach, temperature and time on colour change.**

| Cotton stained with blood | | Colour difference mean (ΔE) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| **BLEACHES** | Anolyte | 70.240870 | | | | |
| | Distilled water | 74.127615 | -3.886745 | -4.192253 | -3.581238 | <.0001 |
| | Sodium hypochlorite | | | | | |
| | | 78.642291 | -8.401422 | -8.706929 | -8.095914 | <.0001 |
| | | | (Relative to 30 °C) | | | |
| **TEMPERATURE** | 30 °C | 75.642350 | | | | |
| | 40 °C | 75.588866 | -0.53484 | -0.358992 | 0.252023 | 0.7293 |
| | 60 °C | 71.779561 | -3.862790 | -4.168297 | -3.557282 | <.0001 |
| | | | (Relative to 9 minutes) | | | |
| **TIME** | 9 minutes | 73.327379 | | | | |
| | 18 minutes | 74.535203 | 1.207824 | 0.902316 | 1.513331 | <.0001 |
| | 45 minutes | 75.148195 | 1.820816 | 1.515309 | 2.126324 | <.0001 |

*P value <0.05 statistically significant*

Table 4.1 above indicates that there was a statistically significant difference in colour change between all the bleaches (Anolyte, distilled water and sodium hypochlorite) and bleach times (9, 18 and 45 minutes). However, there was no statistically significant difference in bleach temperatures between 30 °C and 40 °C but there was a significant difference between 30 °C and 60 °C.

According to Ponnusamy *et al* (2008:1124), soil removal from the fabric surface depends on the hydrodynamic conditions, water hardness and temperature of the washing solution, as well as on the nature and concentration of the surfactant system and the nature of the fabric and of the soil themselves. The authors further explain that the removal of the soil from the fabric surface is one of the most critical parameters to optimize. However, the bulk of the soil is readily removed by the mechanical action of the washing machine and the residual 5% or less of the original soil can be very difficult to remove and requires the chemical action of detersive agents. As the laundering temperature increases, the surface activity of the surfactant solution increases, which in turn increases the ease and rate of soil removal. According to literature, higher temperatures markedly improve soil removal; the maximum temperature that can be used may be tempered by a number of factors, including the stability of the textile and its wash fastness. Bleach and temperature as well as bleach and time significantly ($p<0.05$) influenced the colour change in blood stain as indicated by table 4.2 below. However, there was no statistically significant difference bleach, temperature and time as indicated in table 4.2.

According to Pušić *et al* (2007:407) sodium hypochlorite bleaches are dominant bleaches in stain removal especially in a cold bath. And from Figure 4.1, 4.2 and 4.3 blood stains were removed best by sodium hypochlorite at both temperatures 30°C, 40 °C and 60 °C, respectively. The longer the stain was bleached the better the removal of the stain. Distilled water removed the stain even better than Anolyte solutions at 9, 18 and 45 minutes as the ∆E for all the bleach times were higher than that of Anolyte. The pH of Anolyte ranged between 2.06 and 3.05 which were acidic and the pH of distilled water was 8. There is no literature which explained why distilled water removed blood stain better than Anolyte but this could have been due to the acidity of the bleach liquor. Although the bleaches removed the stain at 60 °C it was observed that, blood stain was removed best when bleaching took place at 30 °C for sodium hypochlorite, 40 °C when bleached with Anolyte and distilled water. The best whiteness of blood stain was obtained when bleached with sodium hypochlorite at 30 °C for 45 minutes where it reached whiteness of 83.2 ∆E. The analysis of variance on colour change presented in table 4.3 below

clearly indicates that there was a statistically significant difference in the effects of bleach, time and temperature had on colour change of the bleached blood stained cotton.

**Table 4.3: Analysis of variance colour change of blood stain: P-values of effects of bleach, time and temperature, and of all interaction terms.**

| Source | p-value |
| --- | --- |
| Bleach | <.0001 |
| Temperature | <.0001 |
| Bleach * Temperature | <.0001 |
| Time | <.0001 |
| Bleach * Time | <.0001 |
| Temperature * Time | <.0001 |
| Bleach * Temperature * Time | 0.0022 |

*P value <0.05 statistically significant*

## 4.2 EFFECTS OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON THE REMOVAL OF BLACKCURRANT JUICE STAIN ON COTTON

The results regarding the removal of blackcurrant juice stain on the cotton fabric after laundering with Anolyte, distilled water and sodium hypochlorite at temperature 30 °C are illustrated in Figure 4.4. According to the results, the untreated cotton stained with blackcurrant juice colour was 61.7 ΔE, after bleaching with the three different agents, there was colour change in lightness and the whiteness of the stain varied per bleach. Sodium hypochlorite removed the stain best at bleach times of 9, 18 and 45 minutes with the highest whiteness reaching 90.7 ΔE. The duration of exposure caused only a slight difference for a specific agent. Anolyte removed the juice stain better than distilled water at all bleach times. Distilled water removed the juice stain least with whiteness reaching 73.8 ΔE.

The pH of Anolyte ranged between 2.65 and 3.06 which is acidic; that could be the reason why Anolyte could not remove the stain better than sodium hypochlorite as the blackcurrant juice stain is also acidic. Sodium hypochlorite's pH ranged between 9.65 and 9.70 which are alkaline and it removed the stain best in all the temperature ranges. Bechtold *et al* (2007:2587) explains that blackcurrants are known to have a characteristic strong smell and high contents of anthocyanin and ascorbic acid. The alkalinity of sodium hypochlorite could have had a great influence in removing the stain best. Interestingly, when blackcurrant juice stain was bleached with distilled water, the removal of the stain decreased as time increased while with other bleaches the whiteness increased with time.

| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 81.8 | 74.9 | 89.7 | 61.7 |
| 18 minutes | 81.7 | 75.6 | 90.4 | |
| 45 minutes | 83.1 | 73.8 | 90.7 | |

**Figure 4.4: Cotton stained with blackcurrant juice stain: Effects of Anolyte, sodium hypochlorite and distilled water at 30 °C on colour change (mean values).**

Bleaching temperature had an effect on the colour change of blackcurrant juice as all the bleach liquors removed the stain at all given times at 40 °C. However, figure 4.5 indicates that blackcurrant juice was removed best by sodium hypochlorite bleach at a steadily increasing rate with time. The best results were obtained when bleaching took place for 45 minutes where the whiteness reached 91.3 ΔE. It was observed that when the stain was bleached with Anolyte the stain darkened as time increased as the value of whiteness (ΔE) reduced from 80.4 ΔE to 79.9 ΔE. Table 4.4 clearly shows a steady decline in the values of L* and b* as well. As stated earlier the alkalinity of sodium hypochlorite could have had a great influence in removing the stain best unlike the acidity on the Anolyte bleach.



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 80.4 | 76.7 | 90.1 | 61.7 |
| 18 minutes | 80.3 | 76.3 | 90.5 | |
| 45 minutes | 79.9 | 76.8 | 91.3 | |

**Figure 4.5: Cotton stained with blackcurrant juice stain: Effects of Anolyte, sodium hypochlorite and distilled water at 40 °C on colour change (mean values).**

Figure 4.6 displays the results of bleached blackcurrant juice stain at temperature 60 °C after 9, 18 and 45 minutes of exposure. As discussed above in figure 4.4 and 4.5, Anolyte, distilled water and sodium hypochlorite removed the stain at different rates. It was noted that when temperature rose to 60 °C the stain was removed best with sodium hypochlorite as compared to when bleaching took place at 30 °C and 40 °C respectively. Anolyte continued to remove the blackcurrant stain better than distilled water at all the bleach times. Table 4.4 below shows that, although the lightness (L*) of the blackcurrant stain bleached with sodium hypochlorite increased steadily with bleach time and became whiter, the hue (a*) was on the other hand negative at all wash times making the stain to be bluish.



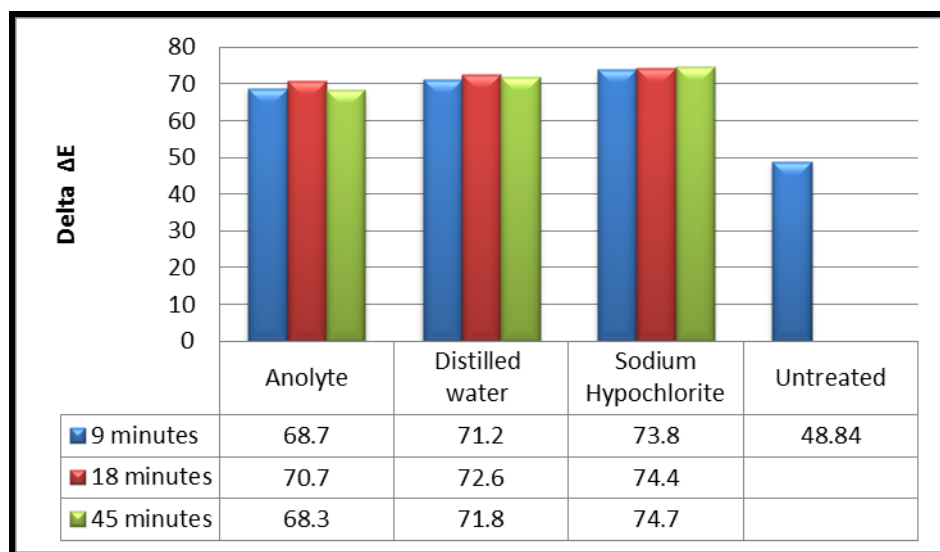| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 80.9 | 78.8 | 91.2 | 61.7 |
| 18 minutes | 80.8 | 79.1 | 91.5 | |
| 45 minutes | 81.9 | 79.2 | 91.4 | |
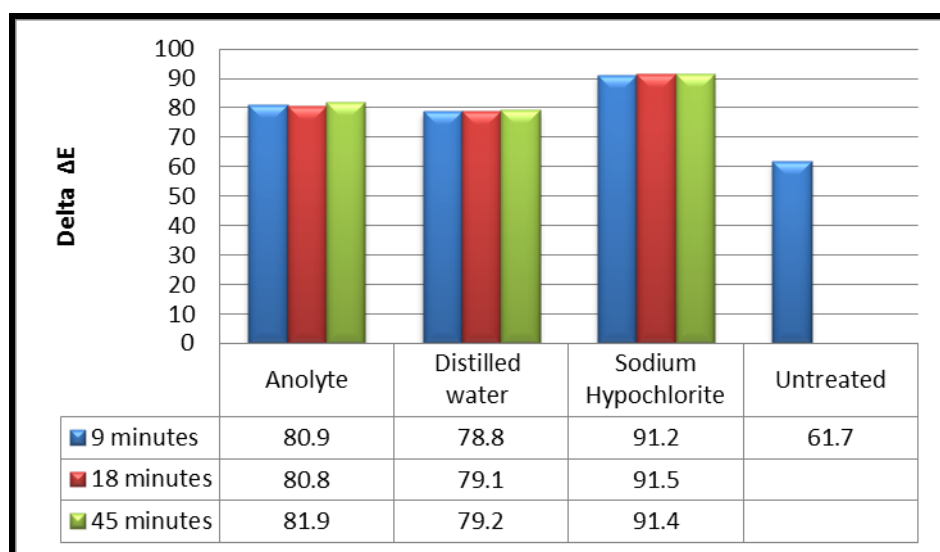
**Figure 4.6: Cotton stained with blackcurrant juice stain: Effects of Anolyte, sodium hypochlorite and distilled water at 60 °C on colour change (mean values).**

**Table 4.4: Cotton stained with blackcurrant juice: L\* a\* and b\* values of bleach, temperature and time on colour change.**

| Bleach | Temp (°C) | Time (minutes) | L\* a\* b\* values |
|---|---|---|---|
| Anolyte | 30 | 9<br>18<br>45 | L\*80.9 a\*2.7 b\*12.1<br>L\*80.8 a\*2.6 b\*12.1<br>L\*82.3 a\*2.4 b\*11.7 |
| | 40 | 9<br>18<br>45 | L\*79.6 a\*2.9 b\*11.3<br>L\*79.4 a\*3.4 b\*11.2<br>L\*79.1 a\*2.9 b\*10.8 |
| | 60 | 9<br>18<br>45 | L\*79.9 a\*3.9 b\*11.8<br>L\*80.1 a\*2.2 b\*10.9<br>L\*81.2 a\*2.3 b\*10.9 |
| Distilled water | 30 | 9<br>18<br>45 | L\*74.3 a\*1.5 b\*9.3<br>L\*74.9 a\*1.2 b\*9.4<br>L\*73.2 a\*0.7 b\*8.8 |
| | 40 | 9<br>18<br>45 | L\*75.9 a\*1.5 b\*10.0<br>L\*75.6 a\*1.4 b\*10.1<br>L\*76.2 a\*1.0 b\*9.1 |
| | 60 | 9<br>18<br>45 | L\*78.2 a\*2.0 b\*9.7<br>L\*78.5 a\*1.3 b\*9.6<br>L\*78.7 a\*1.1 b\*9.1 |
| Sodium Hypochlorite | 30 | 9<br>18<br>45 | L\*89.5 a\*-0.4 b\*6.7<br>L\*90.2 a\*-0.5 b\*5.6<br>L\*90.7 a\*-0.4 b\*3.7 |
| | 40 | 9<br>18<br>45 | L\*89.9 a\*-0.6 b\*6.4<br>L\*90.4 a\*-0.5 b\*4.5<br>L\*91.3 a\*-0.3 b\*1.7 |
| | 60 | 9<br>18<br>45 | L\*91.2 a\*-0.3 b\*1.7<br>L\*91.2 a\*-0.2 b\*0.8<br>L\*91.4 a\*-0.03 b\*-0.04 |

**Table 4.5: Cotton stained with blackcurrant: Main effects of bleach, temperature and time on colour change.**

| Cotton stained with blackcurrant juice stain | | Colour difference mean (ΔE) | Mean difference | 95% confidence interval for mean difference | | P- value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| BLEACHES | Anolyte | 81.224469 | | | | |
| | Distilled water | 76.799570 | 4.424899 | 4.204234 | 4.645564 | <.0001 |
| | Sodium hypochlorite | 90.777529 | -9.553060 | -9.773725 | -9. 332395 | <.0001 |
| | | | (Relative to 30 °C) | | | |
| TEMPERATURE | 30 °C | 82.422853 | | | | |
| | 40 °C | 82.485166 | 0.062313 | -0.158351 | 0.282978 | 0.5768 |
| | 60 °C | 83.893548 | 1.470695 | 1.250030 | 1.691360 | <.0001 |
| | | | (Relative to 9 minutes) | | | |
| TIME | 9 minutes | 82.741116 | | | | |
| | 18 minutes | 82.923011 | 0.181895 | -0.038770 | 0.402559 | 0.1025 |
| | 45 minutes | 83.137440 | 0.396323 | 0.175658 | 0.616988 | 0.0006 |

*P value <0.05 statistically significant*

According to table 4.5 above, there was a statistically significant change in colour difference between the Anolyte and distilled water as well as between Anolyte and sodium hypochlorite. It was also noted that there was a statistically significant difference between bleach temperatures in regard to the removal of blackcurrant juice stain. However, there was no statistical difference between temperatures 30 °C and 40 °C. The table also indicates that there was no statistical difference in bleach times between 9 and 18 minutes.

Blackcurrant juice stain was removed by all bleach liquors at all temperatures. The stain was removed at different levels as indicated by figures, 4.4, 4.5 and 4.6. From the figures, Anolyte removed blackcurrant juice stain best at 30 °C when bleaching took place for 45 minutes, while sodium hypochlorite and distilled removed the stain best at 60 °C when bleaching took place for 45 minutes. From table 4.6, it is noted that, there was a statistically significant difference in colour change between bleach, temperature, bleach and temperature, time, bleach and time and lastly bleach and temperature and time. However, there was no statistically significant difference in colour change between bleach temperature and time.

**Table 4.6: Analysis of variance colour change of blackcurrant juice stain: P-values of effects of bleach, time and temperature, and of all interaction terms.**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Temperature | <.0001 |
| Bleach * Temperature | <.0001 |
| Time | 0.0025 |
| Bleach * Time | <.0001 |
| Temperature * Time | 0.4019 |
| Bleach * Temperature * Time | <.0001 |

*P value <0.05 statistically significant*

## 4.3 EFFECTS OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON THE REMOVAL OF SOOT/MINERAL OIL STAIN ON COTTON

Greases and oils are water insoluble soils which bind to the fabric due to absorption of oil in fabric. Water alone is not enough to remove the insoluble oils, bleaches and detergents can help dislocate it between the woven or knitted fabric much easier (Kadolph 2011:251). According to Collier *et al* (2009:489), soot is the result of incomplete combustion of carbon- containing fuels such as petroleum and its by-products. Paraffin, the waxy residue left behind in the refinement processing of petroleum, not only contains carbon but a host of other chemical compounds, some of which have been found to be toxic, and others labelled as carcinogens. The author explains that soot/mineral oil stain can be laundered using the hottest water safe for the fabric. Figure 4.7 illustrates that soot/mineral oil stain was removed by all the bleaches as the whiteness in all the treated samples was above the whiteness of the untreated which was at 54.4 ∆E. Bleaching with sodium hypochlorite at 30 °C removed the soot/mineral oil stain best when the bleaching time lasted for 45 minutes. The figure also illustrates that the bleaches steadily increased the whiteness of the stained cotton as time increased from 9 minutes, 18 minutes, and 45 minutes. It was also noted that, Anolyte and distilled water bleached the stain at the same rate when bleaching lasted for 45 minutes.



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 57.9 | 58.8 | 63.9 | 54.4 |
| 18 minutes | 58.9 | 60.5 | 65.2 | |
| 45 minutes | 61.8 | 61.7 | 67.9 | |

**Figure 4.7: Cotton stained with soot/mineral oil stain: Effects of Anolyte, sodium hypochlorite and distilled water at 30 °C on colour change (mean values).**

Figure 4.8 presents the results of soot/mineral oil stain bleached at 40 °C with Anolyte, distilled water and sodium hypochlorite. The results are similar to those presented in fig. 4.7 above. Sodium hypochlorite bleach removed the stain best as compared to the other agents as the whiteness of the stain reached whiteness of 68.9 ΔE. There was not much colour difference between the stain bleached with Anolyte and distilled water at all the bleach times. The figure also displays that 9 minutes exposure to sodium hypochlorite bleached the stain better than even 45 minutes with Anolyte or distilled water.

| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 58.8 | 59.3 | 63.4 | 54.4 |
| 18 minutes | 61 | 60.2 | 65.2 | |
| 45 minutes | 62.6 | 63 | 68.9 | |

**Figure 4.8: Cotton stained with soot/mineral oil stain: Effects of Anolyte, sodium hypochlorite and distilled water at 40 °C on colour change (mean values).**

The results concerning the colour change of the soot/mineral oil stain after laundering with Anolyte, distilled water and sodium hypochlorite at 60 °C for 9 minutes, 18 and 45 minutes are illustrated in figure 4.9 below. The figure indicates that all bleach liquors removed the soot/mineral oil as time increased however at different levels of whiteness. As compared to bleach temperatures presented in the figures (fig. 4.7 and 4.8) soot/mineral oil was best removed when the temperature was at 60 °C. Collier *et al* (2009:489) explains that soot/mineral oil stain can be laundered using the hottest water safe for fabric. The best colour difference was obtained when the stain was bleached by sodium hypochlorite for 45 minutes, the whiteness reached 69.5 ΔE. The value of L*(lightness) as indicated in table 4.7 below, shows a steady increase in whiteness in the soot/mineral oil stained cotton bleached with sodium hypochlorite.



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 59.5 | 59.9 | 64.6 | 54.4 |
| 18 minutes | 63.2 | 61.8 | 66.6 | |
| 45 minutes | 65.2 | 65.1 | 69.5 | |

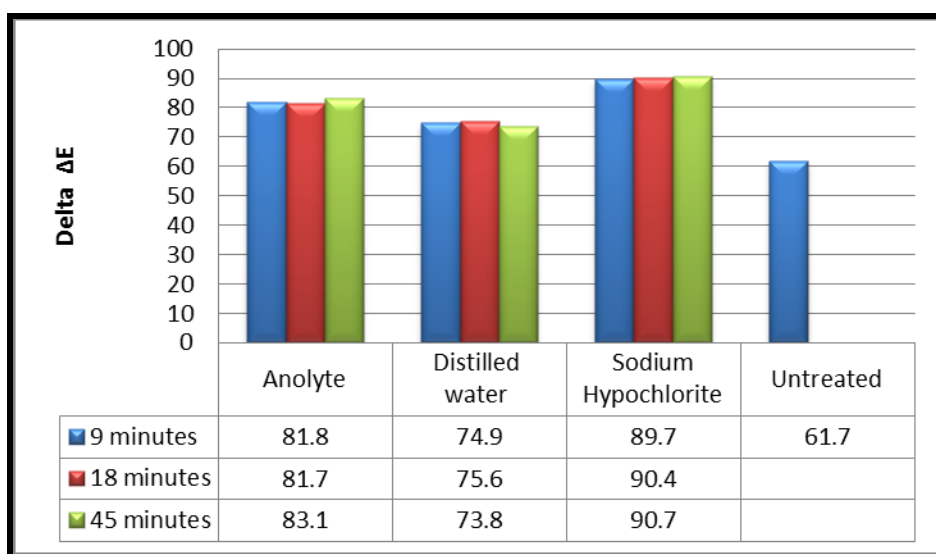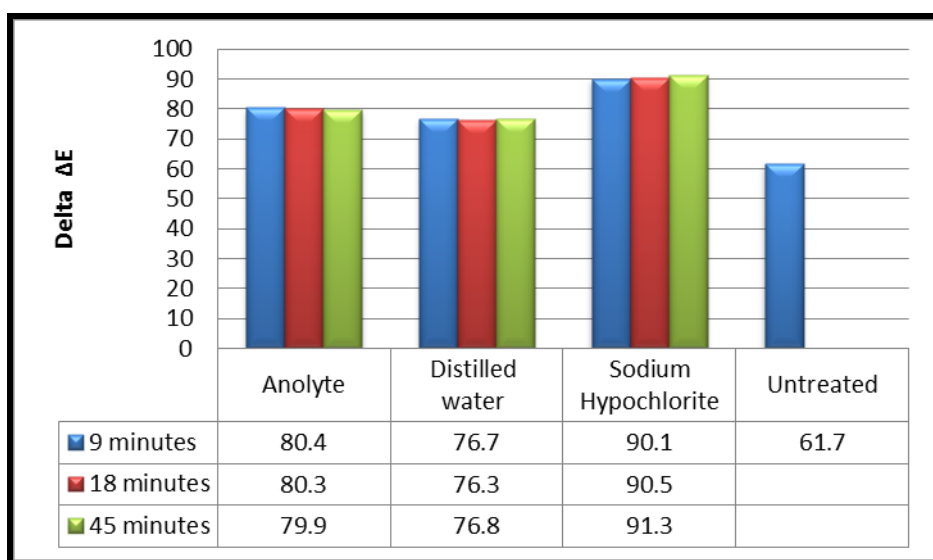**Figure 4.9: Cotton stained with soot/mineral oil stain: Effects of Anolyte, sodium hypochlorite and distilled water at 60 °C on colour change (mean values).**

**Table 4.7: Cotton stained with soot/mineral oil: L\* a\* and b\* values of bleach, temperature and time on colour change.**

| Bleach | Temp (°C) | Time (minutes) | L\* a\* b\* values |
|---|---|---|---|
| Anolyte | 30 | 9<br>18<br>45 | L\*57.8 a\*0.6 b\*2.3<br>L\*58.9 a\*0.6 b\*2.2<br>L\*61.7 a\*0.5 b\*1.9 |
| | 40 | 9<br>18<br>45 | L\*58.7 a\*0.6 b\*2.3<br>L\*60.9 a\*0.6 b\*2.0<br>L\*62.6 a\*0.5 b\*2.1 |
| | 60 | 9<br>18<br>45 | L\*59.5 a\*0.5 b\*2.5<br>L\*63.1 a\*0.5 b\*1.9<br>L\*65.1 a\*0.5 b\*2.1 |
| Distilled water | 30 | 9<br>18<br>45 | L\*58.8 a\*0.6 b\*2.5<br>L\*60.5 a\*0.6 b\*2.3<br>L\*61.6 a\*0.5 b\*2.1 |
| | 40 | 9<br>18<br>45 | L\*59.3 a\*0.6 b\*2.4<br>L\*60.2 a\*0.6 b\*2.1<br>L\*62.9 a\*0.5 b\*2.3 |
| | 60 | 9<br>18<br>45 | L\*59.9 a\*0.6 b\*2.2<br>L\*61.7 a\*0.5 b\*1.9<br>L\*65.1 a\*0.5 b\*1.8 |
| Sodium Hypochlorite | 30 | 9<br>18<br>45 | L\*63.8 a\*0.6 b\*2.1<br>L\*65.1 a\*0.6 b\*2.2<br>L\*67.9 a\*0.5 b\*1.9 |
| | 40 | 9<br>18<br>45 | L\*63.3 a\*0.6 b\*2.3<br>L\*65.2 a\*0.6 b\*2.2<br>L\*68.9 a\* 0.5 b\*1.9 |
| | 60 | 9<br>18<br>45 | L\*64.5 a\*0.6 b\*2.1<br>L\*66.5 a\*0.5 b\*1.9<br>L\*69.5 a\*0.5 b\*1.9 |

**Table 4.8: Cotton stained with soot/mineral oil: Main effects of bleach, temperature and time on colour change.**

| Cotton stained with soot/mineral oil stain | | Colour difference mean (ΔE) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| BLEACHES | Anolyte | 60.986777 | | | | |
| | Distilled water | 61.161808 | -0.175031 | -0.605151 | 0.255089 | 0.4217 |
| | Sodium hypochlorite | 66.124911 | -5.138134 | -5.568254 | -4.708014 | <.0001 |
| | | | (Relative to 30 °C) | | | |
| TEMPERATURE | 30 °C | 61.846269 | | | | |
| | 40 °C | 62.499620 | 0.653351 | 0.223231 | 1.083470 | 0.0032 |
| | 60 °C | 63.927606 | 2.081337 | 1.651217 | 2.511457 | <.0001 |
| | | | (Relative to 9 minutes) | | | |
| TIME | 9 minutes | 60.671050 | | | | |
| | 18 minutes | 62.514811 | 1.843761 | 1.413641 | 2.273881 | <.0001 |
| | 45 minutes | 65.087634 | 4.416584 | 3.986464 | 4.846703 | <.0001 |

*P value <0.05 statistically significant*

The statistical analysis (table 4.8) indicated a statistically significant difference ($p<0.05$) in efficiency between Anolyte and sodium hypochlorite, between temperatures 30 °C, 40 °C and 60 °C and lastly between bleach time of 9 minutes and 18 minutes as well as 9 minutes and 45 minutes. However, there was no statistically significant difference in colour change of soot/mineral oil stain between Anolyte and distilled water as the p-value was 0.42.

An analysis of variance of colour change of soot/mineral oil stain indicated in table 4.9 shows that there were statistically significant differences ($p<0.05$) in colour change between all the bleaches, temperatures, time, bleach and temperature and lastly temperature and time. However, there was no statistically significant difference in colour change between factors bleaches and time as well as between bleach, temperature and time. A closer analysis at figures 4.7, 4.8 and 4.9 clearly displays that soot/mineral oil stain was best removed when bleached by sodium hypochlorite at 60 °C for 45 minutes. In all the figures the stain was best removed in all wash temperatures when bleaching took more time (45minutes) as compared to 9 and 18 minutes. Anolyte removed the soot/mineral oil stain but there was no much difference in the ΔE as observed in the figures mentioned earlier. The results also indicates that there was a steady increase in stain removal as time of exposure increased hence ensuring more whiteness in the bleached fabric.

**Table 4.9: Analysis of variance colour change of soot/mineral oil stain: P-values of effects of bleach, time and temperature, and of all interaction terms.**

| Source | p-value |
| --- | --- |
| Bleach | <.0001 |
| Temperature | <.0001 |
| Bleach * Temperature | 0.0163 |
| Time | <.0001 |
| Bleach * Time | 0.1772 |
| Temperature * Time | 0.0326 |
| Bleach * Temperature * Time | 0.1939 |

*P value <0.05 statistically significant*

## 4.4 EFFECTS OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON THE REMOVAL OF TEA STAIN ON COTTON

Satindar *et al* (2012:21) defines tea as a mixture of variously processed leaves of an evergreen shrub, *Camellia sinensis*, which is the most popular nonalcoholic beverage in the world. The authors further explain that, flavonoids, flavonols and phenolic acids make up approximately 30% of dried *Camellia Sinensis* by weight. According to Johansson & Somasundaran (2007:65), tea causes a tannin stain- a plant component that often shows as a colour on a textile product. The authors explain thus fresh tannin stains can usually be removed by laundering the garment using detergent in the hottest water recommended for the fabric and older tannin stains may need to be treated with bleach like chlorine bleach which can be used on white garments and linens.

The group stains from tea, wine, tomatoes and berries; are very difficult to remove as chromophores are present in the hydrophobic conditions inhibiting the removal of the stain (Johansson & Somasundaran 2007:65). Mere washing with detergent does not remove those kinds of stains, bleaching might be required. The authors state that bleach present in the wash water degrades the chromophores leading to the discolouration of the stain, even when the stain may not be completely removed it is generally no longer visually detectable.

Illustrated in figure 4.10, the tea stain was removed by Anolyte and sodium hypochlorite bleach but darkened more than the untreated at all the bleach times when bleached with distilled water. The best results were obtained when cotton stained with tea stain was bleached at 30 °C by sodium hypochlorite for 45 minutes where by the whiteness of the bleached stain reached 91.6 ΔE. In all the bleach times where sodium hypochlorite bleach was used, there was a steady increase in the whiteness of the bleached stain as time increased.

The best results reached with Anolyte were 83.2 ΔE, where the stain was exposed for 18 minutes to the Anolyte at 30 °C. The distilled water darkened the stain more as the colour difference in ΔE of the bleached tea stain in all the bleach times was less than that of the untreated tea stain which was 81.7 ΔE. The untreated sample was even lighter than the tea stain treated with distilled water and that implied that the water intensified the stain instead. According to Collier *et al* (2009:487) tea stain should be soaked in cold water; pretreat with stain remover, liquid laundry detergent or paste of granular laundry product and water. Further laundering using chlorine bleach or oxygen bleach could be used to improve the whiteness. Figure 4.10 below indicates that the value of b* treated with distilled water at all times ranged from 13.7 − 14.6 which clearly indicates that the stain became more yellowish hence it darkened.



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 83 | 79.5 | 90.7 | 81.7 |
| 18 minutes | 83.2 | 80.1 | 91.1 | |
| 45 minutes | 81.8 | 79.9 | 91.6 | |
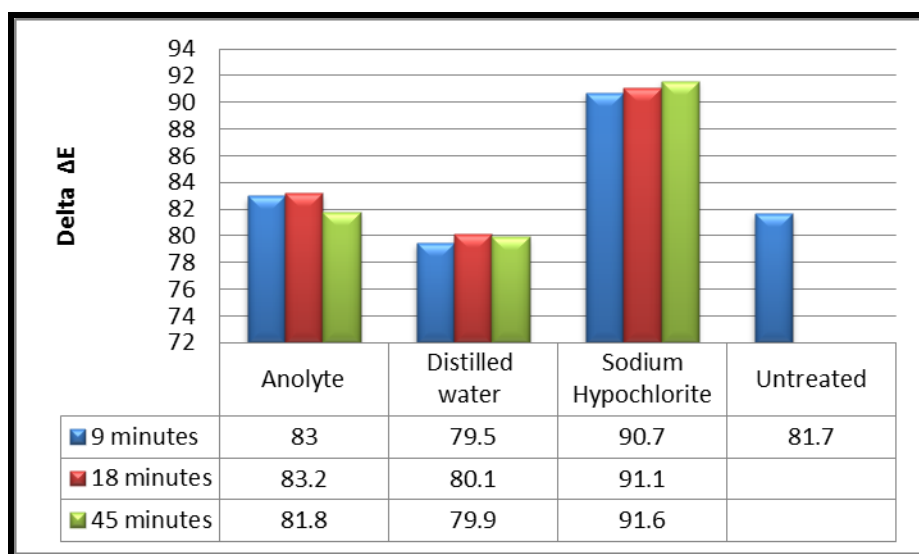
**Figure 4.10: Cotton stained with tea stain: Effects of Anolyte, sodium hypochlorite and distilled water at 30 °C on colour change (mean values).**

Figure 4.11 shows an increase in bleaching temperature to 40 °C for the bleach liquors Anolyte, distilled water and sodium hypochlorite for 9, 18 and 45 minutes respectively. The figure illustrates that Anolyte and sodium hypochlorite removed the stain at different rates. However, when tea stain was exposed to distilled water it darkened at all wash times with ΔE less than that of the untreated which was 81.7 ΔE. The whiteness of the bleached tea stain with Anolyte was best when bleaching time was 18 minutes when the whiteness reached 84.7 ΔE. When bleaching took place for 45 minutes the whiteness was less than that of 18 minutes. Figure 4.11 further shows that the best results were obtained when tea stain was bleached with sodium hypochlorite for 45 minutes with a whiteness of 91.5 ΔE. Bleaching times of 9 and 18 minutes both gave whiteness of 90.9 ΔE.



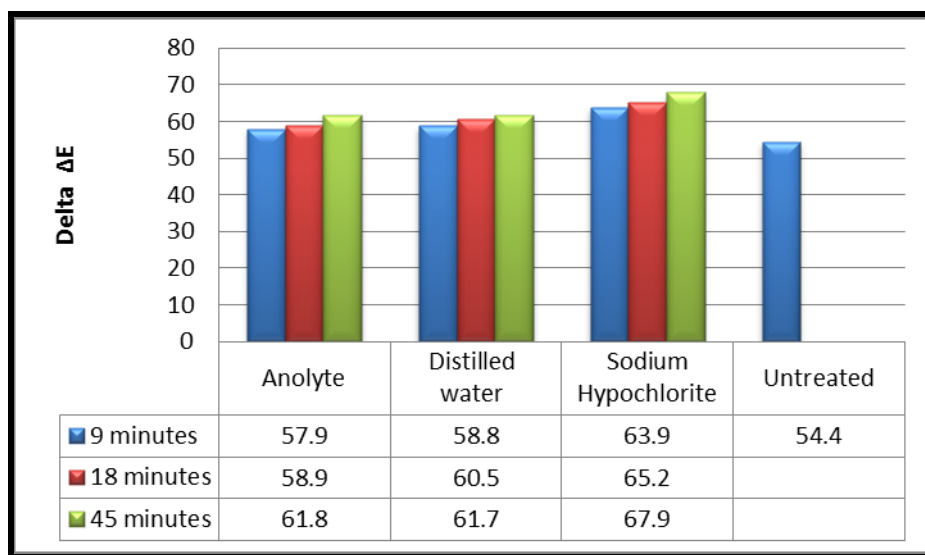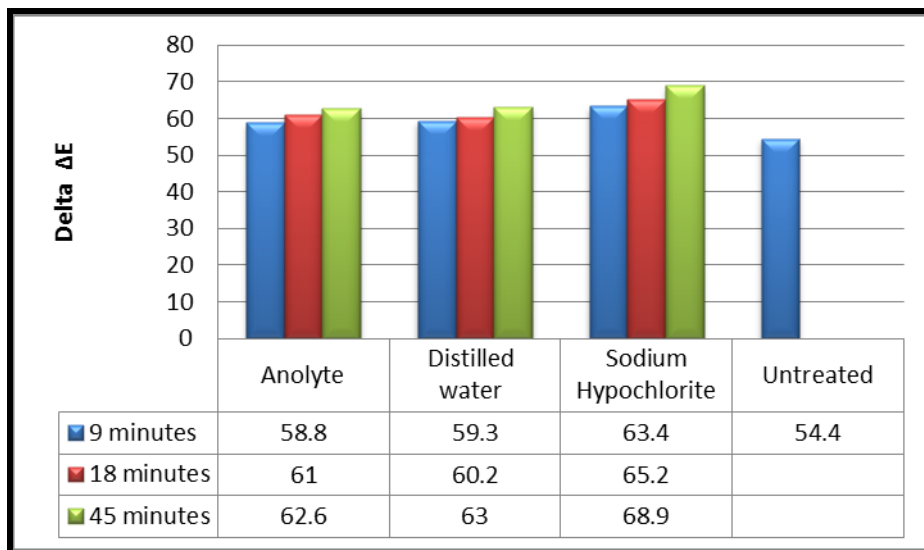|  | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 84.6 | 79.8 | 90.9 | 81.7 |
| 18 minutes | 84.7 | 79.8 | 90.9 | |
| 45 minutes | 83.2 | 80.3 | 91.5 | |
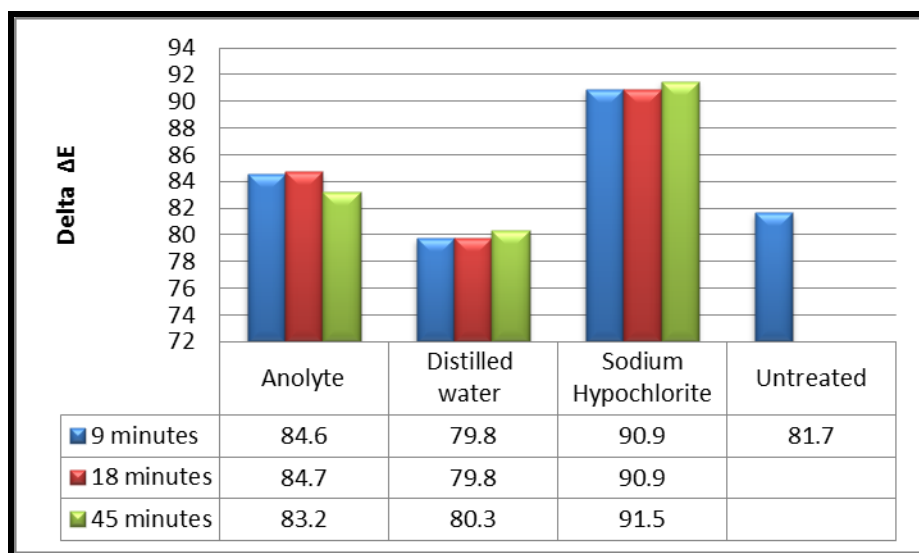
**Figure 4.11: Cotton stained with tea stain: Effects of Anolyte, sodium hypochlorite and distilled water at 40 °C on colour change (mean values).**

Bleaching tea stain with Anolyte, sodium hypochlorite and distilled water at a higher temperature of 60 °C had a great influence on removing the stain and also darkening of the stain. Figure 4.12 shows that sodium hypochlorite gave the best results when bleaching time was 45 minutes as the whiteness reached 91.5 ΔE. According to Stone (2009:1) fresh tannin stains usually can be removed by laundering the fabric using detergent (not soap) in hot water (if safe for the fabric), without any special treatment. Natural soap (bar soap, soap flakes, or detergents containing natural soap) makes tannin stains more difficult to remove and old tannin stains need bleach treatment. Treatment with distilled water made the stain to even darken in all the bleach times as the whiteness was less than the whiteness 81.7 ΔE of the untreated samples. Cotton stained with tea stain bleached with Anolyte was best removed when bleaching took the shortest time of 9 minutes as the whiteness reached a maximum of 86 ΔE. It was observed that, the stain intensified with increase in exposure time when treated with water. And the effectivity of the Anolyte diminishes with increase in exposure time.

| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 9 minutes | 86 | 80.3 | 91.4 | 81.7 |
| 18 minutes | 82.8 | 79.9 | 91.2 | |
| 45 minutes | 81.9 | 80.2 | 91.5 | |

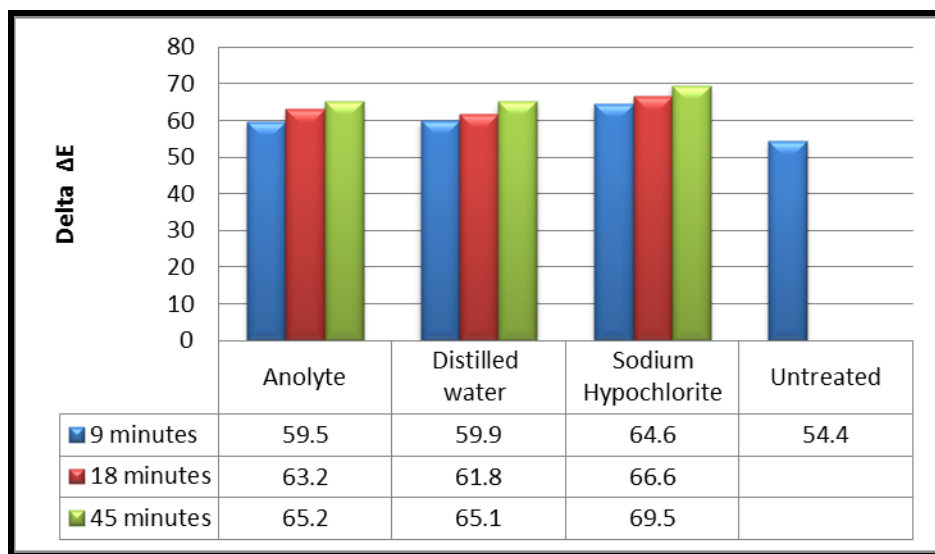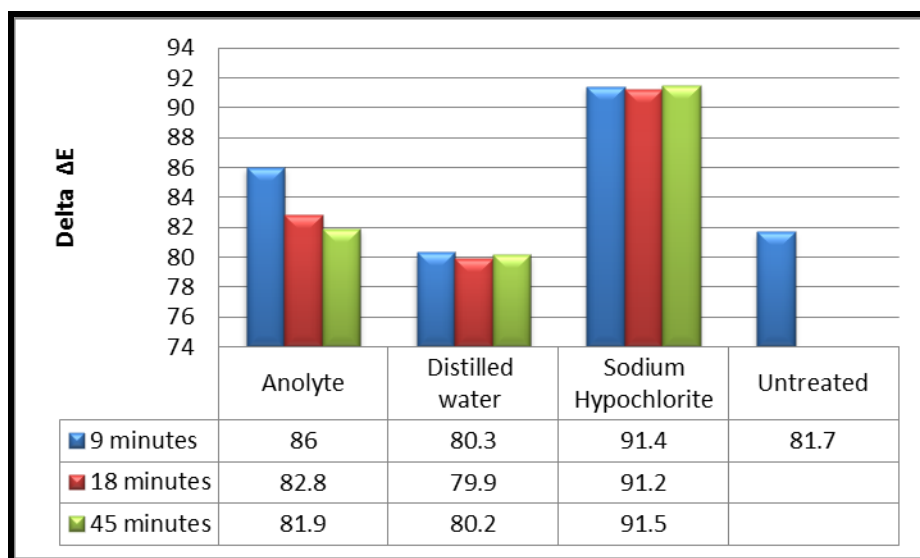**Figure 4.12: Cotton stained with tea stain: Effects of Anolyte, sodium hypochlorite and distilled water at 60 °C on colour change (mean values).**

**Table 4.10: Cotton stained with tea: L\* a\* and b\* values of bleach, temperature and time on colour change.**

| Bleach | Temp (°C) | Time (minutes) | L\* a\* b\* values |
|---|---|---|---|
| Anolyte | 30 | 9<br>18<br>45 | L\*82.3 a\*2.3 b\*10.5<br>L\*82.7 a\*2.3 b\*8.9<br>L\*81.4 a\*1.9 b\*8.6 |
| | 40 | 9<br>18<br>45 | L\*84.1 a\*1.9 b\*9.2<br>L\*84.3 a\*1.4 b\*8.4<br>L\*82.8 a\*1.2 b\*7.5 |
| | 60 | 9<br>18<br>45 | L\*85.6 a\*1.1 b\*8.5<br>L\*82.5 a\*1.8 b\*6.3<br>L\*81.6 a\*1.7 b\*6.7 |
| Distilled water | 30 | 9<br>18<br>45 | L\*78.2 a\*3.9 b\*13.7<br>L\*78.8 a\*3.6 b\*13.7<br>L\*78.4 a\*3.9 b\*14.6 |
| | 40 | 9<br>18<br>45 | L\*78.5 a\*3.7 b\*13.9<br>L\*78.5 a\*3.9 b\*14.2<br>L\*79.0 a\*3.6 b\*13.7 |
| | 60 | 9<br>18<br>45 | L\*79.0 a\*3.8 b\*13.6<br>L\*78.5 a\*4.0 b\*14.1<br>L\*78.9 a\*3.6 b\*13.5 |
| Sodium Hypochlorite | 30 | 9<br>18<br>45 | L\*90.6 a\*-0.25 b\*2.3<br>L\*91.0 a\*-0.22 b\*2.1<br>L\*91.6 a\*-0.11 b\*1.0 |
| | 40 | 9<br>18<br>45 | L\*90.9 a\*-0.22 b\*1.8<br>L\*90.9 a\*-0.16 b\*1.3<br>L\*91.5 a\*0.05 b\*-0.04 |
| | 60 | 9<br>18<br>45 | L\*91.4 a\*-0.06 b\*0.7<br>L\*91.2 a\*-0.01 b\*0.4<br>L\*91.5 a\*0.04 b\*0.2 |

**Table 4.11: Cotton stained with tea: Main effects of bleach, temperature and time on colour change.**

| Cotton stained with tea stain | | Colour difference mean (ΔE) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| BLEACHES | Anolyte | 83.489646 | | | | |
| | Distilled water | 79.967701 | 3.521945 | 3.270465 | 3.773425 | <.0001 |
| | Sodium hypochlorite | 91.186857 | -7.697211 | -7.948691 | -7.445732 | <.0001 |
| | | | (Relative to 30 °C) | | | |
| TEMPERATURE | 30 °C | 84.536055 | | | | |
| | 40 °C | 85.084818 | 0.548763 | 0.297284 | 0.800243 | <.0001 |
| | 60 °C | 85.023330 | 0.487275 | 0.235795 | 0.738755 | 0.0002 |
| | | | (Relative to 9 minutes) | | | |
| TIME | 9 minutes | 85.130148 | | | | |
| | 18 minutes | 84.858425 | -0.271723 | -0.523202 | -0.020243 | 0.0345 |
| | 45 minutes | 84.655630 | -0.474518 | -0.725997 | -0.223038 | 0.0003 |

*P value <0.05 statistically significant*

Table 4.11 displays the results on the main effects of bleach, temperature and time on colour change. From the table it clearly indicates that there was statistically significant ($p < 0.05$) colour change between the bleaches, Anolyte and distilled water as well as Anolyte and sodium hypochlorite. The table clearly shows that there was a statistically significant difference in colour change in all the temperature interactions relative to 30 °C as well time relative to 9 minutes.

In conclusion, tea stain was removed by both Anolyte and sodium hypochlorite. However, sodium hypochlorite's performance was the best as compared to Anolyte at temperatures 30 °C, 40 °C and 60 °C and at all the bleach times of 9, 18 and 45 minutes. It was observed that the stain was removed best on average by both Anolyte and sodium hypochlorite when temperature was at its highest (60 °C). Table 4.12 below which presents the p-values of effects of bleach, time and temperature clearly shows that there was a statistically significant difference in colour change in all the removal of tea stain. Distilled water, however did not remove the stain at any given temperature and time but rather darkened it. As indicated in table 4.11 above, the bleaches made the stain to be more yellow than lighter hence it darkened.

It was observed that cotton stained with tea, blood, blackcurrant juice and soot/mineral oil stains discussed above were best removed by sodium hypochlorite as compared to Anolyte in all the bleach temperatures of 30 °C, 40 °C and 60 °C at various times of 9, 18 and 45 minutes. Bleach temperature and time had an effect on the whiteness of stains as the higher the temperature and longer the bleaching process the better the stain was removed. It was also observed that, in all the stains except for tea stain, distilled water removed the stains as well but less than Anolyte and sodium hypochlorite bleaches. These results are in agreement with literature as, according to Agustina & Ang (2012:141) temperature influences the activity rate of the bleach as this activity rate is the major factor in both stain removal.

**Table 4.12: Analysis of variance colour change of tea stain: P-values of effects of bleach, time and temperature, and of all interaction terms.**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Temperature | <.0001 |
| Bleach * Temperature | <.0001 |
| Time | 0.0013 |
| Bleach * Time | <.0001 |
| Temperature * Time | <.0001 |
| Bleach * Temperature * Time | 0.0011 |

*P value <0.05 statistically significant*

## 4.5 EFFECT OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON BLEACHED COTTON

Hotels, hospitals and many other hospitality industries use white cotton as sheeting. These need to be kept white no matter how often they are laundered and bleached. Zoller (2009:239) explains that hypochlorite bleaches provide both cleaning and sanitation in laundry where it especially require hygienic and sanitized conditions such as hotels, hospitals and food service industries. However, the colour of the bleached cotton textiles may change over time as it is laundered and bleached to sanitize them.

The objective of the study was to find out if Anolyte, sodium hypochlorite and distilled water as control will cause bleached cotton to change colour and be yellowish after numerous treatment cycles when the bleaching temperature is kept at 40 °C. Fijan *et al* (2007:252) state that the whiteness in cotton is important because cotton is naturally yellow and to avoid this, whitening and bleaches play an important role in maintaining the whiteness without causing any damage to the cloth. However, sodium hypochlorite may cause yellowing to repeated bleaching of cotton if all protein impurities are not completely removed before bleaching (Menezes & Choudhari 2011:233). In the current study bleached cotton was bleached for 5, 10 and 20 cycles at 40 °C, Anolyte, distilled water and sodium hypochlorite all had an effect.

The results presented in figure 4.13 indicate that sodium hypochlorite whitened the bleached cotton even more than when it is untreated. The whiteness was better when bleaching took place after 10 and 20 cycles as the whiteness reached 91.3 $\Delta E$, although in table 4.13 the value of b* (-b* means blue while +b* means yellow) was negative hence making the colour of the whiteness to be less yellow. Distilled water whitened the bleached cotton slightly better than Anolyte solution after 5 cycles where the whiteness reached 91.3 $\Delta E$ after bleaching with distilled water and 91.2 $\Delta E$ when bleached by Anolyte.

The results also indicate that when bleaching with Anolyte the whiteness became less after 5 cycles (90.6 $\Delta E$) and the whiteness after 20 cycles was 90.4 $\Delta E$, but the whiteness was less than that of the untreated which was 90.6 $\Delta E$. It might indicate that a slight colour change took place. The change could have taken place during drying, as Zoller (2009:239) explains that, although good bleaching results are obtained when bleaching at low temperature, chlorine bleach made the fabric to yellow during drying. The degrading colour loss shown on bleached cotton by Anolyte is evident in the figure below. It was also noted that, when bleached cotton was treated

with sodium hypochlorite the whiteness increased as the cycles increased but there was no difference in the effect at 10 and 20 cycles.

Karmakar (1999:199) explains that bleaching of cotton with sodium hypochlorite is done in alkaline condition (pH 8.5-10), and the hypochlorous acid and hypochlorite ion are present at approximately the same concentrations and hence the rate of attack on cellulose is greatest in this region. The value of b* was positive when cotton was bleached by Anolyte for 20 cycles became more yellow than any other bleached cotton by Anolyte and other treatments. Reference can be made to figure 4.13. The results indicate that, Anolyte caused cotton to become yellower than other treatments.



| | Anolyte | Distilled Water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 91.2 | 91.3 | 91.2 | 90.6 |
| 10 cycles | 90.6 | 91.1 | 91.3 | |
| 20 cycles | 90.4 | 91.1 | 91.3 | |

**Figure 4.13: Bleached cotton: Effect of Anolyte, sodium hypochlorite and distilled water, at cycles 5, 10 and 20 at 40 °C on colour change (mean values).**

**Table 4.13: Bleached cotton: L\* a\* and b\* values of bleach, temperature and cycles on colour change.**

| Bleach | Temp (°C) | Cycles | L\* a\* b\* values |
|---|---|---|---|
| Anolyte | 40 | 5<br>10<br>20 | L\*91.1 a\*0.3 b\*-1.5<br>L\*90.7 a\*0.3 b\*-1.1<br>L\*90.4 a\*0.2 b\*0.6 |
| Distilled water | 40 | 5<br>10<br>20 | L\*91.3 a\*0.3 b\*-1.9<br>L\*90.1 a\*0.3 b\*-1.6<br>L\*91.0 a\*0.3 b\*-1.4 |
| Sodium Hypochlorite | 40 | 5<br>10<br>20 | L\*91.1 a\*0.4 b\*-2.2<br>L\*91.3 a\*0.4 b\*-2.2<br>L\*91.3 a\*0.4 b\*-1.7 |

**Table 4.14: Bleached cotton: Main effects of bleach and cycles on colour change.**

| Bleached cotton | | Colour difference (ΔE) | Mean difference | 95% confidence interval mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| BLEACHES | Anolyte | 90.744375 | 0.000000 | 0.000000 | 0.000000 | |
| | Distilled water | 91.149800 | -0.405425 | -0.583069 | -0.227781 | <.0001 |
| | Sodium hypochlorite | 91.255392 | -0.511017 | -0.688661 | -0.333373 | 0.2359 |
| | | | (Relative to 5 cycles) | | | |
| CYCLES | 5 cycles | 91.218471 | 0.000000 | 0.000000 | 0.000000 | |
| | 10 cycles | 91.018025 | -0.200446 | -0.378090 | -0.022802 | 0.0281 |
| | 20 cycles | 90.913072 | -0.305399 | -0.483043 | -0.127756 | 0.0013 |

*Note. <0.05 statistically significant*

Table 4.14 results show that there was statistically significant difference in colour change between Anolyte and distilled water as the p-value was <0.001. However, there was no statistically significant difference in colour change between Anolyte and sodium hypochlorite. It was noted from the table that there was a significant difference in colour change between all the bleach cycles. The analysis of variance of colour change of bleached cotton shown in table 4.15 indicates that there was a statistically significant difference in the effects of bleach and cycles and all interaction terms.

In fine, sodium hypochlorite gave the best results at all the cycles in making the bleached cotton even whiter. Anolyte on the other hand did not exhibit the whiteness desired as when bleaching for 20 cycles the whiteness darkened more, as the colour was darker than the untreated. Distilled water at all the bleach cycles whitened cotton even better than Anolyte, hence making it a better option to use. In the case of items to be whitened, the results conclude that Anolyte would not be beneficial as it would not bleach white cotton further but rather cause it to be yellowish.

**Table 4.15: Analysis of variance colour change of bleached cotton: P-values of effects of bleach and cycles, and of all interaction terms.**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Cycles | 0.0046 |
| Bleach * Cycles | 0.0052 |

***P value <0.05 statistically significant***

## 4.6 EFECTS OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON UNBLEACHED COTTON

Begum (2012:5) explains that cotton fibres mainly consists of cellulose, protein, wax, sugar, pigments and traces of other impurities and these are removed by scouring with bleaching agents such as hydrogen peroxide. Cotton as a natural fibre has natural colouring matter which makes it to have a yellowish brown colour and the purpose of bleaching is to remove this brownish colour and have the white appearance. Pušić (2007:407) adds that the most dominant bleaches are sodium hypochlorite, as they are able to bleach in a cold bath and sodium perborate as the mostly encountered source of hydrogen peroxide. Its oxidation is evident at higher temperature, starting at 60 °C and the optimum is reached at 90 °C.

The objective of the research was to determine if bleaching with Anolyte, sodium hypochlorite and distilled water as control could give the whiteness desired by removing the brownish impurities found on cotton fibres when bleaching takes place at temperatures 40 °C, 60 °C and 80 °C, when the duration was 1 hour, 1 hour 30 minutes and 2 hours respectively.

According to Kim *et al* (2007:1788) cotton's natural colour is due to flavonoid compounds, with the types and quantities of these flavonoids depending on the growing environments. The authors further explain that, when cotton is used in textiles the flavonoids are eliminated in the bleaching process, usually with hydrogen peroxide. The results in figure 4.14 indicate that Anolyte and sodium hypochlorite were able to bleach unbleached cotton at various whiteness rates, while distilled water darkened the unbleached cotton. The whiteness of the untreated cotton was 90.6 ΔE and after bleaching at 40 °C with sodium hypochlorite, whiteness reaching 91.8 ΔE was obtained when the duration of bleaching was 1 hour 30 minutes, making the whiteness the best results obtained. Anolyte bleached cotton better than distilled water at all bleach times. It was illustrated in figure 4.14 that, the best bleaching for both Anolyte and sodium hypochlorite were reached after bleaching for 1 hour 30 minutes. Time factor did not influence the colour change on the unbleached cotton bleached with distilled water as it gave the same results through out and the whiteness was darker than the 90.6 ΔE of the untreated.

| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 1 hour | 90.9 | 90.1 | 91.6 | 90.6 |
| 1 hour 30 minutes | 91.2 | 90.1 | 91.8 | |
| 2 hours | 90.6 | 90.1 | 91.5 | |
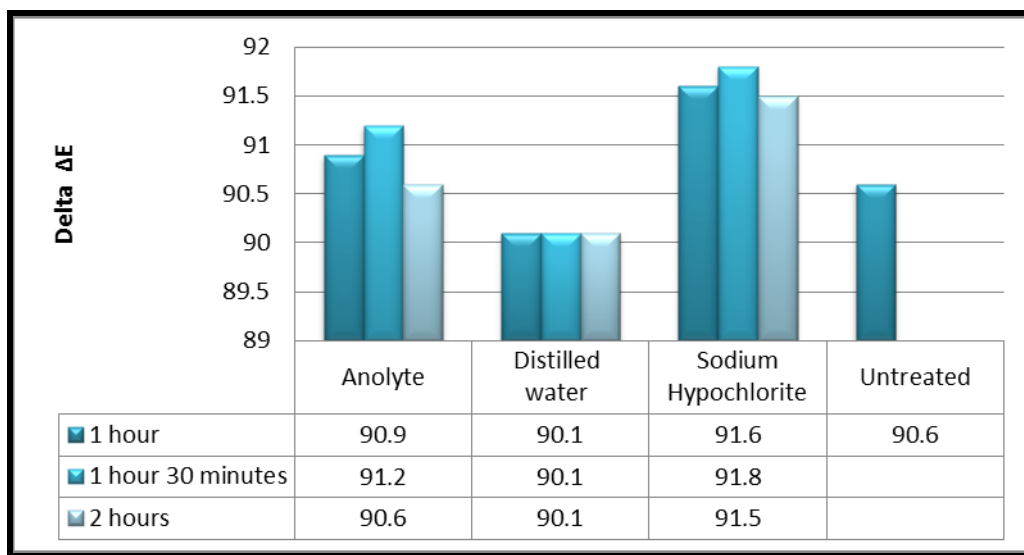
**Figure 4.14: Unbleached Cotton: Effects of Anolyte, sodium hypochlorite and distilled water at 40 °C on colour change (mean values).**

The effects of bleaching treatments at 60 ºC on unbleached cotton by Anolyte, sodium hypochlorite and distilled water for 1 hour, 1 hour 30 minutes and 2 hours are illustrated in Figure 4.15. There was colour difference in whiteness caused by Anolyte and sodium hypochlorite only. Sodium hypochlorite bleached cotton slightly to reach whiteness 91.7 ΔE after bleaching for 2 hours. The whiteness of the unbleached cotton, bleached with sodium hypochlorite increased as time increased. According to Shamey & Hussein (2005:19), if whiteness is of primary importance it requires a high temperature and long bleaching time. It is evident in the figure 4.15 and 4.16 that, the whiteness improved when unbleached cotton was bleached with sodium hypochlorite as time increased. While bleaching unbleached cotton with Anolyte the whiteness decreased slightly as time increased. Anolyte was able to remove the impurities on cotton and reaching the best whiteness of 91.4 ΔE after bleaching for 1 hour. The best results achieved when bleaching cotton with Anolyte was equal to the lowest results obtained when bleaching cotton with sodium hypochlorite. Distilled water did not have a bleaching effect on the unbleached cotton as it darkened the cotton compared to the untreated.

| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 1 hour | 91.4 | 90.4 | 91.4 | 90.6 |
| 1 hour 30 minutes | 91.1 | 90.4 | 91.4 | |
| 2 hours | 90.8 | 89.8 | 91.7 | |
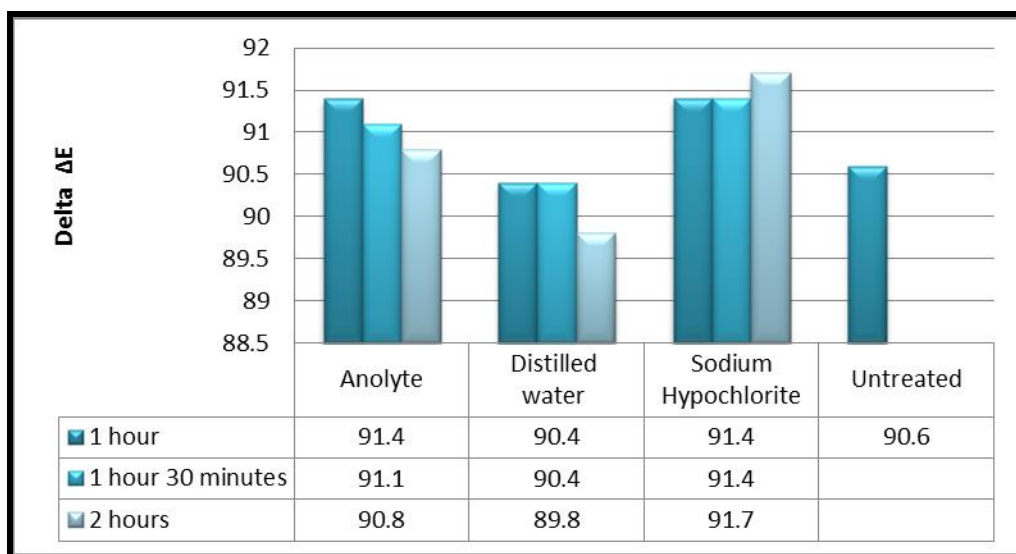
**Figure 4.15: Unbleached Cotton: Effects of Anolyte, sodium hypochlorite and distilled water at 60 ºC on colour change (mean values).**

Figure 4.16 clearly displays that with an increase in temperature to 80 °C sodium hypochlorite bleached the unbleached cotton best as the whiteness reached 92.1 ΔE after 2 hours. However, it was noted that the whiteness of bleached unbleached cotton decreased as bleaching time increased. Anolyte was also able to whiten the cotton to a maximum of 91.6 ΔE after 1 hour and 1 hour 30 minutes which were less than sodium hypochlorite.  In their study, Špička & Tavčer (2013:411) reported that the whiteness of cotton bleached with sodium hydroxide increased as temperature rose. The whiteness of unbleached cotton rose with temperature especially when bleached with sodium hypochlorite. As shown in fig 4.14 and 4.15 earlier distilled water could not remove any impurities in the unbleached cotton but rather even darkened it more. As indicated in table 4.16 below, value b* in all treatments for distilled water was more yellow than any other bleaches. In a study carried out by Huang *et al* (2012:1551), the authors discovered that the whiteness of bleached cotton with hydrogen peroxide also increased when treated at high temperature of 70 °C. Though the authors used different bleach from the current study, it is evident that higher temperature played a great role in brightening the bleached cotton.



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 1 hour | 91.6 | 90.4 | 91.9 | 90.6 |
| 1 hour 30 minutes | 91.6 | 90.4 | 91.7 | |
| 2 hours | 91.5 | 89.6 | 92.1 | |

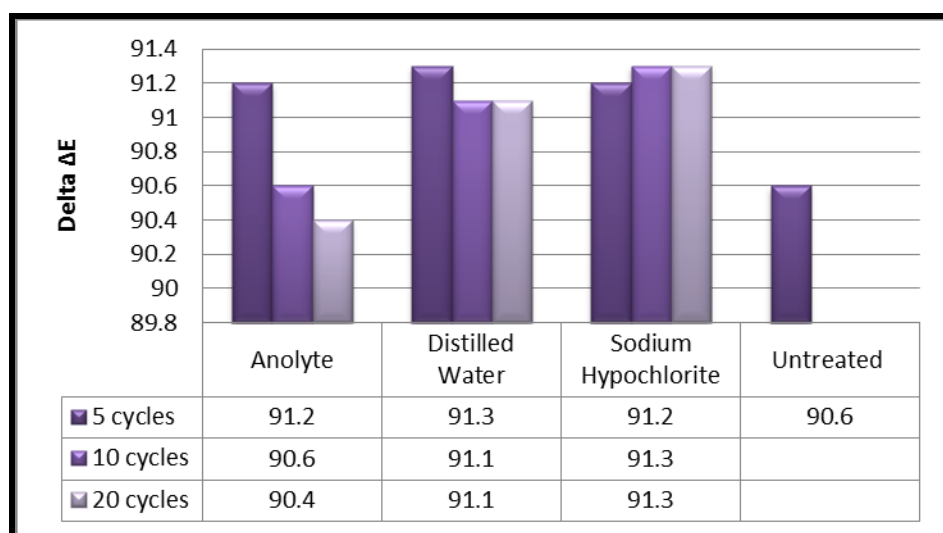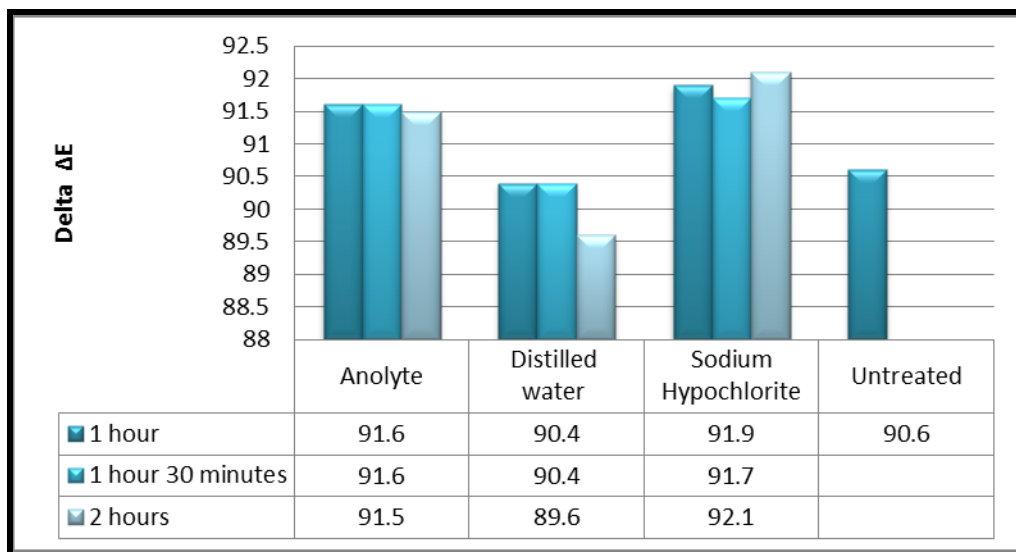**Figure 4.16: Unbleached Cotton: Effects of Anolyte, sodium hypochlorite and distilled water at 80 °C on colour change (mean values).**

**Table 4.16: Unbleached cotton: L* a* and b* values of bleach, temperature and time on colour change.**

| Bleach | Temp (°C) | Time (hour & minutes) | L* a* b* values |
|---|---|---|---|
| Anolyte | 40 | 1 hour<br>1 hr. 30 mins<br>2 hours | L*90.9 a*0.2 b*-0.6<br>L*91.1 a*0.2 b*-0.9<br>L*90.6 a*0.1 b*-0.1 |
|  | 60 | 1 hour<br>1 hr. 30 mins<br>2 hours | L*91.4 a*0.2 b*-0.98<br>L*91.1 a*0.1 b*-0.1<br>L*90.9 a*0.1 b*0.1 |
|  | 80 | 1 hour<br>1 hr. 30 mins<br>2 hours | L*91.6 a*0.2 b*-0.6<br>L*91.6 a*0.2 b*-0.9<br>L*91.5 a*0.2 b*-0.5 |
| Distilled water | 40 | 1 hour<br>1 hr. 30 mins<br>2 hours | L*90.0 a*0.4 b*1.9<br>L*90.0 a*0.3 b*1.6<br>L*90.0 a*0.3 b*1.6 |
|  | 60 | 1 hour<br>1 hr. 30 mins<br>2 hours | L*90.4 a*0.3 b*1.5<br>L*90.4 a*0.3 b*1.6<br>L*89.8 a*0.3 b*1.7 |
|  | 80 | 1 hour<br>1 hr. 30 mins<br>2 hours | L*90.4 a*0.3 b*1.3<br>L*90.4 a*0.3 b*1.4<br>L*89.8 a*0.3 b*1.5 |
| Sodium Hypochlorite | 40 | 1 hour<br>1 hr. 30 mins<br>2 hours | L*91.6 a*0.3 b*-1.8<br>L*91.8 a*0.3 b*-1.8<br>L*91.5 a*0.4 b*-1.8 |
|  | 60 | 1 hour<br>1 hr. 30 mins<br>2 hours | L*91.4 a*0.4 b*-1.96<br>L*91.4 a*0.3 b*-2.1<br>L*91.6 a*0.3 b*-1.8 |
|  | 80 | 1 hour<br>1 hr. 30 mins<br>2 hours | L*91.9 a*0.3 b*-1.98<br>L*91.7 a*0.3 b*-1.6<br>L*92.1 a*0.3 b*-1.8 |

**Table 4.17: Unbleached cotton: Main effects of bleach, temperature and time on colour change.**

| Unbleached cotton | | Colour difference mean (ΔE) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| BLEACHES | Anolyte | 91.204163 | | | | |
| | Distilled water | 90.155226 | 1.048937 | 0.911427 | 1.186448 | <.0001 |
| | Sodium hypochlorite | 91.680740 | -0.476577 | -0.6140088 | -0.339067 | <.0001 |
| | | | (Relative to 40 °C) | | | |
| TEMPERATURE | 40 °C | 90.865234 | | | | |
| | 60 °C | 90.945158 | 0.079923 | -0.057587 | 0.217434 | 0.2518 |
| | 80 °C | 91.229737 | 0.364503 | 0.226992 | 0.502013 | <.0001 |
| | | | (Relative to 1 hour) | | | |
| TIME | 1 hour | 91.090812 | | | | |
| | 1 hour 30 minutes | 91.070297 | -0.020515 | -0.158025 | 0.116996 | 0.7680 |
| | 2 hours | 90.879020 | -0.211792 | -0.349302 | -0.074281 | 0.0029 |

*P value <0.05 statistically significant*

An analysis on the main effects of bleach, temperature and time on colour change caused to the unbleached cotton shown on table 4.17 displays that there was a statistically significant difference in colour change between all the bleaches as the p-value was <0.005. However, it was noted from the table that there was no statistically significant difference between temperatures 40 °C and 60 °C. There was also no statistical difference on times, between 1 hour and 1 hour 30 minutes. Table 4.18 below shows an analysis of variance on colour change and from the table, there was no statistically significant difference between temperature and time as well as between bleach-temperature and time.

Sodium hypochlorite is a commonly used bleach at home and industries and it has proved that it bleached cotton much better than Anolyte at all bleach temperatures and times. The best results on bleaching were obtained when bleaching with sodium hypochlorite took place at 80 °C for 2 hours where it reached whiteness of 92.1 ΔE. Anolyte also bleached the unbleached cotton best when temperature was at its highest (80 °C) as it reached the best whiteness of 91.6 ΔE. At that high temperature, distilled water made unbleached cotton to be even darker. The unbleached cotton treated with distilled water was less dark than the untreated when bleaching was at 40 °C.

**Table 4.18: Analysis of variance colour change of unbleached cotton: P-values of effects of bleach, time and temperature, and of all interaction terms.**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Temperature | <.0001 |
| Bleach * Temperature | 0.0044 |
| Time | 0.0046 |
| Bleach * Time | 0.0142 |
| Temperature * Time | 0.6278 |
| Bleach * Temperature * Time | 0.1278 |

*P value <0.05 statistically significant*

## 4.7 EFFECTS OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON COLOUR OF DYED COTTON

The durability of garments depends on their ability to serve the needs of the consumer without changing in colour or dimension during use or after laundering. Change of colour of textiles after applying different finishing influence the client to choose items when purchasing. Mangut (2008:80) explains that colour fastness tests which simulate the effects of daily usage on properties such as colour, washing and dimension of the garments are very important because of their ability to test the garments according to real consumer needs. Sharma & Grover (2011:165) defines colour fastness of a coloured textile as its resistance to changes subjected to a particular set of conditions. These set of conditions may include either the dye itself getting decomposed inside the fibre there by getting converted into a colourless or differently coloured compound and secondly it can detach from the substrate. Dyed fabrics must show the longest possible wear life without changing their colours and the multiple effects. Coloured textiles are subject to various conditions like washing once or several times and there can be alterations in hue, value or intensity.

Coloured textiles are used at home, in hospitals and the hospitality industry and time and again these fabrics need to be bleached to sanitize the fabrics as they are used on many occasions. According to Perkins *et al* (1996:127) repeated bleach wash cycles may result in colour change at levels unacceptable to the wearer of clothing.

According to Kadolph (2011:252) dyes are large complex organic molecules. One portion of the molecule produces colour (chromophore); another portion may alter the colour within the general hue family (auxochrome); and still another portion tends solubility to the molecule (the solubilizing group). Dyes may differ in their colour fastness by fibre type. The author further explains that, solubility cycle dyes such as sulphur, vat and indigo classes form insoluble pigments close to the fibre surface and exhibit poor fastness to crocking and abrasion.
Reactive dyes form strong bonds within the fibre but require good rinsing after dyeing to avoid bleeding. Bleeding is a characteristic common with dyes that migrate well. Bleeding is loss of colour from textile materials during wet processing. During cleaning the colour migrates into the cleaning solution and may bond with other materials causing irregular stains on them. Another problem in washing is poor colourfastness which appears as colour loss, change or transfer. Colour loss may occur when weakly bonded dye molecules migrate out of the fibre and

cause both colour loss or colour change when dye molecules are degraded. When a dye molecule is degraded or damaged it may lose its ability to produce a colour or remain bonded to the fibre thus a total number of molecules colouring a material decreases hence the product looks faded (Kadolph 2011:253-254).

Various textile items are laundered every day to remove all sorts of stains that hinder the item to be comfortable. Coloured items face a challenge as when bleached they may lose colour and become unattractive to the user. Linen used in hospitals, hotels and hospitality service may need to be bleached once in a while to sterilize them. Some of the linen are coloured and due to the nature of their use sterilization is a need but the bleaches used may fade the colour of the sheeting, reduce their strength and even affect its bending properties making it uncomfortable to the user. Anolyte is commonly used in water treatment and recently in sanitization of industrial facilities and as a disinfectant in hospitals and the food production industry (Ghebremichael *et al* 2011:210). Vermaas (2011:158) in her study concluded that, Anolyte is a viable alternative to chemical disinfectants for the destruction of *E. coli* and *Staph. aureus* on cotton, polyester/cotton and polyester fabrics, at low temperatures of 24-30°C without having a more detrimental effect on the tensile and tearing strength of the fabrics than the currently used chemical disinfectants such as sodium hypochlorite.

Dyed cotton may lose colour especially dark and intense colours due to repeated laundering. According to Kadolph (2011:443) colour loss takes place when dyes and prints do shift hue or fade when exposed to light and other environmental factors. The colour may move on to other fabrics or material during storage, processing or use. On the effect of bleaches on coloured fabrics Miller (1992:175) advices that bleach should be avoided where coloured materials are concerned unless the precise control of strength appropriate to the material can be guaranteed. Apart from colour loss cellulosic fibres can be progressively degraded by bleach treatments becoming a little weaker each time until the tenderness of the fabric easily tears.

The objective of the research was to investigate the effects of Anolyte, sodium hypochlorite and distilled water bleach temperature 24 °C, 30 °C and 60 °C on colour change. Secondly the research aimed at finding the effects of repeated laundering (5, 10 and 20 cycles) on the colour of reactive red dyed cotton and vat blue dyed cotton. The objective of the study is to find out if Anolyte could be used in the textile industry as an alternative to the hypochlorite bleach and hydrogen peroxide that is mostly used and not fade the colour of cotton, affect the tenacity and stiffness of cotton.

## 4.7.1 EFFECTS OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON THE COLOUR OF REACTIVE RED DYED COTTON.

Bleaching reactive red dyed cotton with Anolyte, sodium hypochlorite and distilled water resulted in colour loss. The colour of the untreated cotton was 73.9 ΔE, and as presented in figure 4.17 below, sodium hypochlorite removed colour especially when bleached for 5 cycles. The colour loss was gradually less as bleach cycles increased. There was more colour loss when bleaching at 24 °C for 5 cycles where by the whiteness reached 74.9 ΔE. Broadbent (2001:339) explains that reactive dyes on cellulosic fibres give dyeing with good to very good fastness to washing and other wet processes. Apparent inferior fastness to washing is usually because of incomplete removal of unreacted and hydrolyzed dye from the material by washing after dyeing. Distilled water did not have much of an effect in the removal of colour especially when bleached for 10 and 20 cycles as the whiteness (ΔE) was very close to that of the untreated. Reactive red dyed cotton bleached by Anolyte at 5 and 10 cycles was darker than the untreated. Table 4.19 shows that the value of b* was very low hence making the bleached samples to be less yellow than the untreated. However, the samples bleached for 20 cycles did not change colour as its whiteness remained at 73.8 ΔE, which was very close to the untreated.



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 64.9 | 74.2 | 74.9 | 73.9 |
| 10 cycles | 67 | 73.8 | 74.4 | |
| 20 cycles | 73.8 | 73.8 | 74 | |
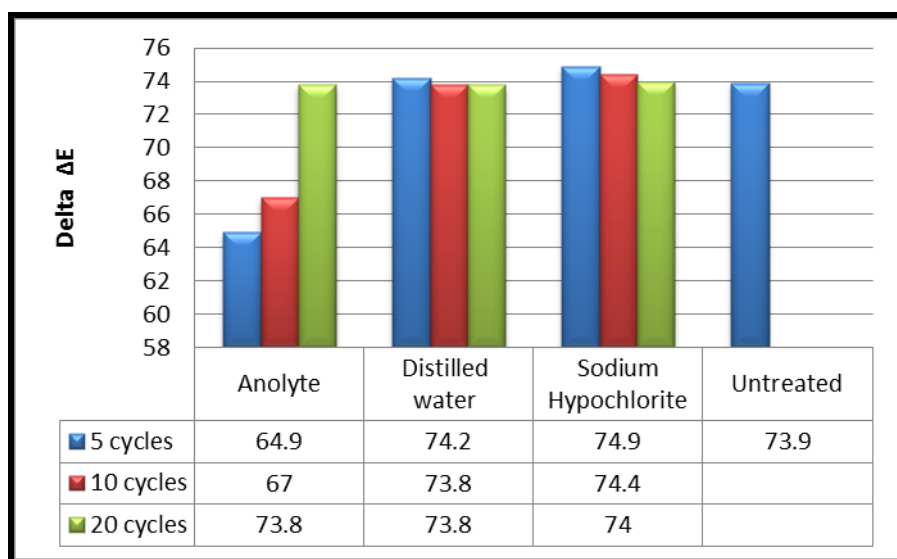
**Figure 4.17: Reactive red dyed cotton: Effects of bleach cycles at 24 °C on colour change (mean values).**

According to Perkins (1996:63) hypochlorite bleaching is most often done at room temperature but slight heating greatly accelerates the bleaching rate and reduces the concentration of hypochlorite bleach required. With an increased temperature of 30 °C, figure 4.18 shows that there was not much difference in the effects of bleaches at 24 °C on colour change as compared to fig. 4.17 above. Agustina & Ang (2012:142) conducted a research on textile effluent de-colourization and they focused on fibre reactive dyes as, reactive dyes represent an integral market share (almost 45% of all textile dyes produced annually belong to the fibre reactive class). Secondly, these dyes have low fixation rates, which results in highly coloured spent dye-baths whose treatment is inadequate in conventional wastewater treatment plants. Sodium hypochlorite did not remove much of the colour of the dye as the whiteness of the bleached reactive red dyed cotton reached only 74.5 ΔE when bleaching for 5 cycles. It was noted that, distilled water did not remove any colour from the reactive red dyed colour as the colour of the bleached fibres remained the same after 5 and 10 cycles where the whiteness remained at 73.9 ΔE. Anolyte removed the dye less than the other in 5 and 10 cycles. More colour was removed when bleaching was done for 20 cycles where the whiteness reached 81.4 ΔE. The whiteness of the bleached reactive red dyed cotton with Anolyte for 5 and 10 cycles, was less (65.1 ΔE) than that of the untreated (73.9 ΔE).



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 65.1 | 73.9 | 74.5 | 73.9 |
| 10 cycles | 65.1 | 73.7 | 74.4 | |
| 20 cycles | 81.4 | 73.9 | 74.1 | |
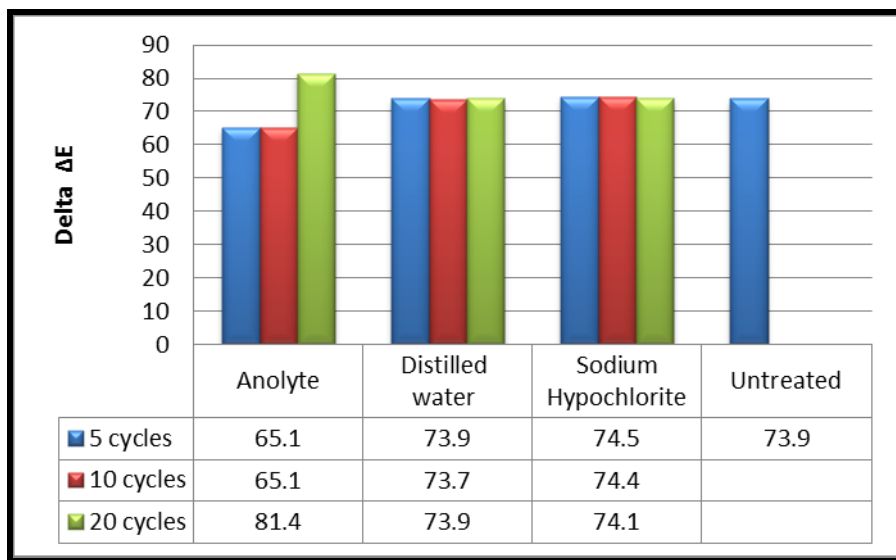
**Figure 4.18: Reactive red dyed cotton: Effects of bleach cycles at 30 °C on colour change (mean values).**

Figure 4.19 below evidently shows that bleaching reactive red dyed cotton with Anolyte at 60 °C for 10 and 20 cycles lead to high colour loss where the whiteness reached 79.9 ΔE and 85.1 ΔE, respectively. The pH for Anolyte was between 2.65 and 3.06 and according to table 3.1 the quality of free chlorine within Anolyte was 1.58 m/L. Anolyte was therefore acidic and Collier *et al* (2009:479) explains that some dyes are damaged by chlorine bleach therefore; it is rarely recommended that coloured fabrics be bleached with chlorine bleach. High temperature too had an effect in more colour being lost.

Agustina & Ang (2012:141) explain that the temperature of the bath during bleaching operation is critical as the higher the temperature, the faster-acting and more efficient the bleach or detergent. The authors further add that high temperatures could cause excess dye bleeding or loss on coloured items. Furthermore, the temperature also influences the activity rate of the bleach as this activity rate is the major factor in both stain removal and possible fabric damage. Sodium hypochlorite removed the reactive red dye from the dyed cotton fabric but it was far less than that of Anolyte.

According to table 3.1, sodium hypochlorite had only 0.01 m/L of free chlorine which was far less as compared to the chlorine in Anolyte hence caused less damage. Distilled water did not remove reactive red dye like the other two bleaches, fig 4.19 shows that the colour of the bleached samples were very close to the unbleached. In a study conducted by Perkins *et al* (1996:127), the authors determined to what extent repeated bleach soak/wash cycles degrade or change the colour of cotton. And it was evident in their findings that repeated bleach cycles results in colour loss that may be unacceptable to the wearer.
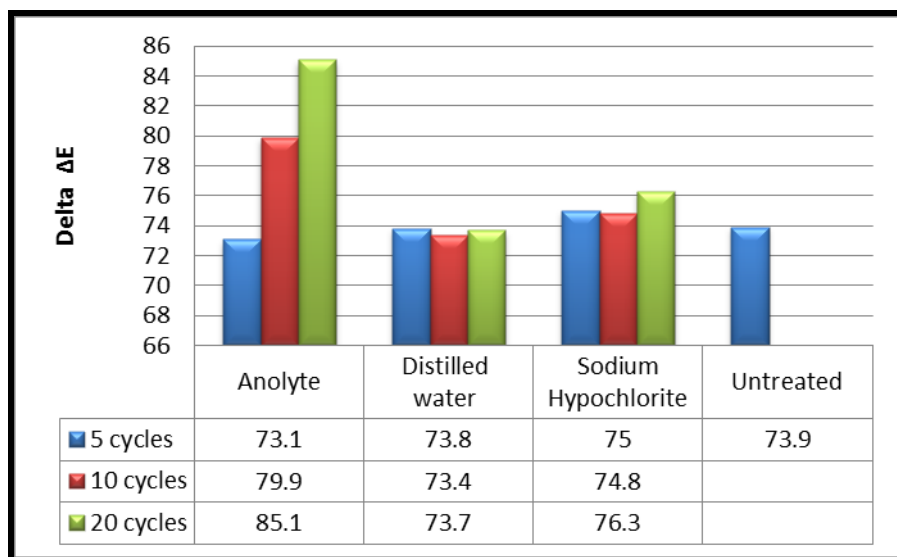
**Figure 4.19: Reactive red dyed cotton: Effects of bleach cycles at 60 °C on colour change (mean values).**

**Table 4.19: Reactive red dyed cotton: L\* a\* and b\* values of bleach, temperature and cycles on colour change**

| Bleach | Temp (°C) | Cycles | L* a* b* values |
|---|---|---|---|
| Anolyte | 24 | 5<br>10<br>20 | L*56.9 a*30.9 b*2.7<br>L*61.9 a*25.6 b*2.4<br>L*71.3 a*18.0 b*5.2 |
| | 30 | 5<br>10<br>20 | L*56.7 a*31.6 b*3.8<br>L*61.2 a*27.3 b*3.6<br>L*80.3 a*10.9 b*7.1 |
| | 60 | 5<br>10<br>20 | L*69.9 a*17.5 b*11.5<br>L*77.9 a*12.2 b*13.0<br>L*84.1 a*5.7  b*11.2 |
| Distilled water | 24 | 5<br>10<br>20 | L*47.8 a*56.7 b*-3.5<br>L*47.3 a*56.4 b*-3.5<br>L*47.3 a*56.5 b*-3.4 |
| | 30 | 5<br>10<br>20 | L*47.6 a*56.5 b*-3.6<br>L*47.4 a*56.3 b*-3.6<br>L*47.5 a*56.5 b*-3.6 |
| | 60 | 5<br>10<br>20 | L*47.5 a*56.4 b*-3.6<br>L*47.1 a*56.2 b*-3.6<br>L*47.3 a*56.4 b*-3.4 |
| Sodium Hypochlorite | 24 | 5<br>10<br>20 | L*49.4 a*55.9 b*-4.2<br>L*50.3 a*54.6 b*-4.9<br>L*53.1 a*51.2 b*-6.1 |
| | 30 | 5<br>10<br>20 | L*49.7 a*55.3 b*-4.6<br>L*50.7 a*54.2 b*-5.1<br>L*53.6 a*50.8 b*-6.2 |

| | 60 | 5 | L*54.3 a*51.4 b*-6.9 |
| | | 10 | L*57.6 a*47.1 b*-7.7 |
| | | 20 | L*66.7 a*36.1 b*-8.1 |

**Table 4.20: Reactive red dyed cotton: Main effects of bleach, temperature and cycles on colour change.**

| Reactive red dyed cotton | | Colour difference mean (ΔE) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| **BLEACHES** | Anolyte | 73.031116 | | | | |
| | Distilled water | 73.798218 | -0.767103 | -0.941740 | -0.592465 | <.0001 |
| | Sodium hypochlorite | 74.711014 | -1.679899 | -1.854536 | -1.505261 | <.0001 |
| | | | (Relative to 24 °C) | | | |
| **TEMPERATURE** | 24 °C | 72.300088 | | | | |
| | 30 °C | 73.118031 | 0.817943 | 0.643306 | 0.992581 | <.0001 |
| | 60 °C | 76.122228 | 3.822140 | 3.647503 | 3.996778 | <.0001 |
| | | | (Relative to 5 cycles) | | | |
| **CYCLES** | 5 cycles | 72.151054 | | | | |
| | 10 cycles | 73.176092 | 1.025038 | 0.580401 | 1.996769 | <.0001 |
| | 20 cycles | 76.213203 | 4.062149 | 3.887512 | 4.236789 | <.0001 |

*P value <0.05 statistically significant*

Table 4.20 clearly shows that there was a statistically significant difference in the interactions between bleaches Anolyte and distilled water as well as between Anolyte and sodium hypochlorite. With regards to temperatures, there was a statistically significant difference in temperatures 30 °C and 60 °C relative to 24 °C. Bleach cycles also had a statistically significant difference in colour change as p value was <0.005 in all the interactions between 5 cycles and 10 cycles as well as 5 cycles and 20 cycles.

Table 4.21 below shows the analysis of variance of colour change of reactive dyed cotton and according to the table, it shows that there was a statistically significant difference in the bleaches, temperature and cycles.

Collier *et al* (2009:418) explain that reactive dyes applied most commonly to the cellulosic fibres cotton, rayon and linen as reactive dyes have a good wash fastness because of the chemical bonds between the dye and fibre are strong. In summary, bleaching reactive red dyed cotton with Anolyte resulted in loss of colour when bleaching temperatures rose to 30 °C and 60 °C, respectively. More colour loss was noted when bleaching was at the highest temperature of 60 °C more than on the other temperature. It was also noted that, more colour loss was experienced when bleach cycles increased from 5 to 10 to 20 cycles. Sodium hypochlorite caused less colour

loss as compared to Anolyte, however, at 60 °C more colour was lost than with the other temperatures. Bleaching with distilled water lead to the least colour loss and results in a colour loss were similar to the untreated. Miller (1992) advice that bleaches should be avoided where coloured materials are concerned unless precise control of strength appropriate to the material can be guaranteed as cellulosic fibres can be progressively degraded by bleach treatments little weaker each time until the tenderness of the fabric becomes obvious by tearing. However, bleaching reactive red dyed cotton with Anolyte did not result in any colour loss when bleaching temperature was at 24 °C after bleaching for 5, 10 and 20 cycles. Anolyte can safely be used to bleach reactive red dyed cotton without causing colour loss. Vermaas (2011:158) adds that, Anolyte is a viable alternative to chemical disinfectants for the destruction of *E. coli* and *Staph.Aureus* on cotton, polyester/cotton and polyester fabrics at low temperatures of 24- 30 °C. Anolyte can be used as a disinfectant on reactive dyed cotton without causing much colourless.

**Table 4.21: The analysis of variance of colour change of reactive red dyed cotton: P-values of effects of bleach, temperature and cycles.**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Temperature | <.0001 |
| Bleach * Temperature | <.0001 |
| Bleach * Cycles | <.0001 |
| Temperature * Cycles | <.0001 |
| Bleach * Temperature * Cycles | <.0001 |

*P value <0.05 statistically significant*

## 4.7.2 EFFECTS OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON THE COLOUR OF VAT BLUE DYED COTTON

Broadbent (2001:379) describes vat dyes as dyes that provide outstanding colour fastness and they are very expensive, like reactive dyes. They usually have excellent fastness to washing, chlorine bleaching, alkali, boiling and light. Vat dyes also have the advantage of being the only dyes for cellulosic materials that do not give shade changes on application of topical reactive finishes for cotton, such as flame resist finishes. On another note, Collier *et al* (2009:418) explain that vat dyes are insoluble in water. In order to apply them to textiles they are chemically reduced to alkaline solution form, after the fibre has been exposed to the vat dye it need to be reoxidised to make it insoluble. This creates a colour that is extremely fast to both light and washing.

The majority of institutional table linens are white, though they can be dyed in a wide range of colours. Santhi & Moses (2008:239) explain that coloured products especially those made of cotton may create a problem due to poor colourfastness. The authors further add that vat dyes are a group of dyes that can be used to produce bright colours in cotton textiles with a high degree of wash-fastness. Vat dye is one of the important dyes used on the dyeing of cotton textiles due to its overall good fastness properties suitable for many end use products.

The objective of the research was to investigate the effects of Anolyte, sodium hypochlorite and distilled water bleach temperature 24 °C, 30 °C and 60 °C on colour change aimed to find the effects of repeated laundering (5, 10 and 20 cycles) on the colour of reactive red dyed cotton and vat blue dyed cotton. This was intended was to find out if Anolyte could be used in the textile industry as an alternative to the hypochlorite bleach and hydrogen peroxide that is mostly used and not fade the colour of cotton, affect the tenacity and stiffness of cotton.

Figure 4.20 illustrates the results of vat blue dyed cotton treated with Anolyte, distilled water and sodium hypochlorite at 24 °C. The colour of the untreated sample was 57.6 ΔE and after bleaching with Anolyte for 20 cycles the whiteness reached 60.4 ΔE thus making the sample to be whiter or slightly faded. Table 4.22 below shows that the value of b* was very low in samples bleached at 5 and 10 cycles hence making the sample to be less yellow. It was also noted that the whiteness in the samples bleached by Anolyte and sodium hypochlorite gradually increases as the number of cycles increased but for distilled water the whiteness declined slightly as cycles

increased. The whiteness of the colour of vat blue dyed cotton bleached with sodium hypochlorite and distilled water was less than that of the untreated after all the bleach cycles. According to table 4.22, the values of b* clearly shows that the bleaches lead to a more bluish or less yellow colour in the samples. The only treatment at 24 °C that caused colour loss was treatment with Anolyte for 20 cycles. This is in agreement with the claims of Broadbent as well as Collier and co-workers that vat dyes are colourfast. According to Satindar *et al* (2012:21) textile materials are coloured for value addition, looks and fulfilling the desires of consumers. These coloured materials under-go vigorous laundering processes which may cause mechanical changes in the appearance of the garments. Hence the bleach used on the textiles should not destroy the colour on the item.



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 55.5 | 56.7 | 50.9 | 57.6 |
| 10 cycles | 57.1 | 55.6 | 51.5 | |
| 20 cycles | 60.4 | 55.5 | 53.1 | |
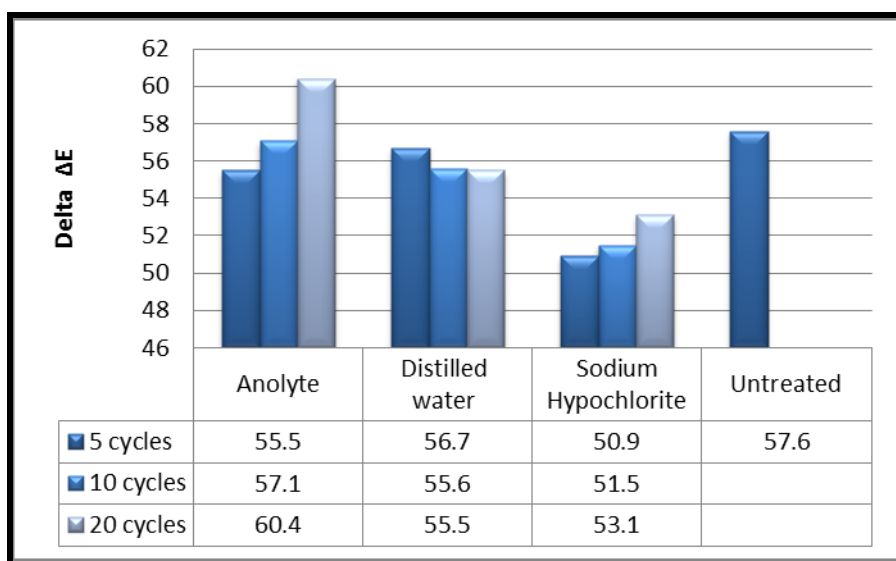
**Figure 4.20: Vat blue dyed cotton: Effects of bleach cycles at 24 °C on colour change (mean values).**

Santhi & Moses (2008:239) explains that vat dye is one of the important dyes used on the dyeing of cotton textiles due to its overall good fastness properties suitable for many end use products. Figure 4.21 shows that elevation of the treatment temperature to 30 °C follow the same tendency. Although there was colour loss it only took place where the vat blue dyed cotton was treated with Anolyte for 20 cycles where by a value of 62.2 ΔE in whiteness was reached. Bleaching with Anolyte at 5 and 10 cycles lead to no colour loss but rather a more bluish to less yellow colour in the bleached vat blue dyed cotton as their colour was less than that of the untreated. No colour was lost when vat blue dyed cotton was bleached with sodium hypochlorite and distilled water. This results thus in agreement with Broadbent (2001:379) who claims that vat dyes as dyes that provide outstanding colour fastness to washing and chlorine bleaching.



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 55.4 | 56.9 | 51.1 | 57.6 |
| 10 cycles | 56.3 | 55.3 | 52.1 | |
| 20 cycles | 62.2 | 55.3 | 53.9 | |
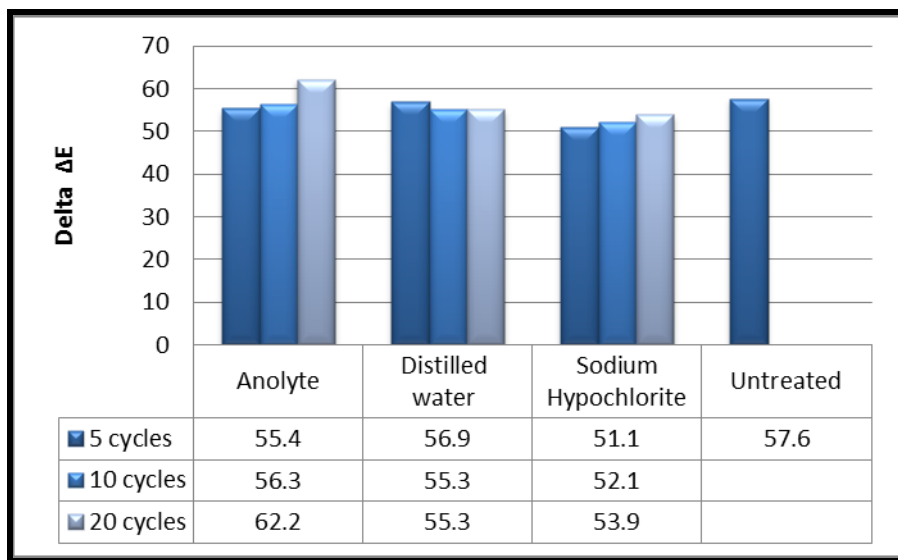
**Figure 4.21: Vat blue dyed cotton: Effects of bleach cycles at 30°C on colour change (mean values).**

As observed in figures 4.20 and 4.21 above, an increase in bleach cycles for Anolyte lead to more colour loss. Figure 4.22 shows that bleaching with Anolyte at 60 °C also caused colour loss on the vat blue dyed cotton, increasing with increase in the number of treatment cycles and the worst loss reached 65.3 ΔE after 20 cycles. The yellowness increased from 8.2 – 13.9 with increase in cycles when Anolyte was used as bleach (table 4.22). From the figure it was noted that, there was colour loss also when vat blue dyed cotton was bleached with sodium hypochlorite after 20 cycles, where the whiteness reached 59.8 ΔE. The yellowness (b*) in bleached vat blue dyed cotton with sodium hypochlorite increased from 8.2 to 13.9 with increase in cycles with the Anolyte. While those treated with sodium hypochlorite the yellowness changed from -13.4 to -13.9. Distilled water did not lead to any colour loss as the colour of the bleached samples intensified compared to the untreated sample whiteness (57.6 ΔE).



| | Anolyte | Distilled water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 60.8 | 57.2 | 52.6 | 57.6 |
| 10 cycles | 62.5 | 56.3 | 54.6 | |
| 20 cycles | 65.3 | 55.1 | 59.8 | |
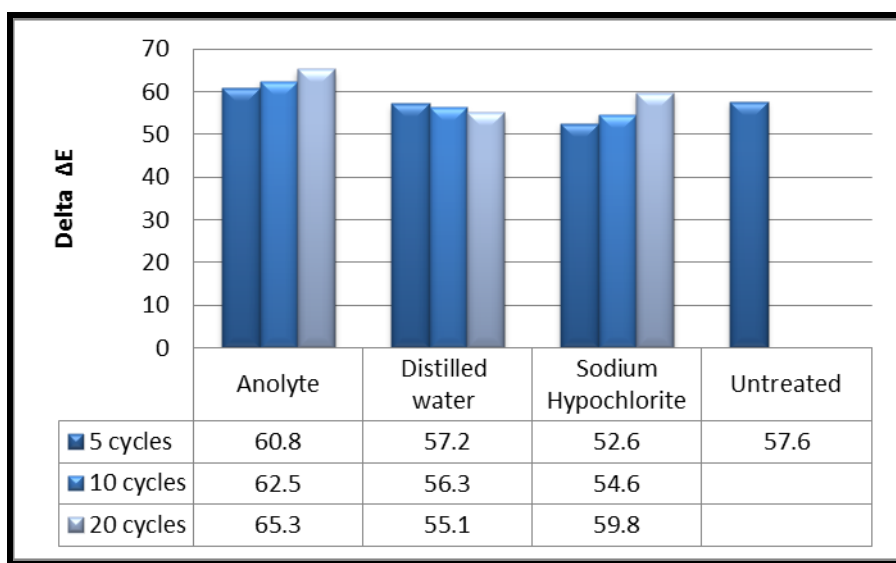
**Figure 4.22: Vat blue dyed cotton: Effects of bleach cycles at 60°C on colour change (mean values).**

**Table 4.22: Vat blue dyed cotton: L* a* and b* values of bleach, temperature and cycles on colour change.**

| Bleach | Temp (°C) | Cycles | L* a* b* values |
|---|---|---|---|
| Anolyte | 24 | 5<br>10<br>20 | L*52.6 a*-17.7 b*-0.1<br>L*54.7 a*-18.1 b*3.0<br>L*57.0 a*-18.1 b*8.0 |
| | 30 | 5<br>10<br>20 | L*52.7 a*-17.6 b*-0.2<br>L*53.5 a*-17.7 b*1.1<br>L*58.6 a*-18.0 b*10.3 |
| | 60 | 5<br>10<br>20 | L*57.5 a*-17.9 b*8.2<br>L*59.1 a*-17.3 b*10.4<br>L*61.8 a* -15.9b*13.9 |
| Distilled water | 24 | 5<br>10<br>20 | L*41.6 a*2.9 b*-38.4<br>L*41.8 a*2.4 b*-38.0<br>L*42.2 a*1.0 b*-36.3 |
| | 30 | 5<br>10<br>20 | L*41.9 a*2.8 b*-38.4<br>L*41.8 a*2.2 b*-37.6<br>L*41.9 a*0.9 b*-36.0 |
| | 60 | 5<br>10<br>20 | L*41.8 a*3.2 b*-38.8<br>L*41.8 a*2.4 b*-37.6<br>L*41.6 a*1.1 b*-36.1 |
| Sodium Hypochlorite | 24 | 5<br>10<br>20 | L*46.3 a*-11.1 b*-18.3<br>L*48.0 a*-13.5 b*-12.8<br>L*50.4 a*-15.1 b*-7.6 |
| | 30 | 5<br>10<br>20 | L*46.8 a*-11.7 b*-16.8<br>L*48.3 a*-13.9 b*-11.4<br>L*51.2 a*-15.2 b*-7.4 |
| | 60 | 5<br>10<br>20 | L*49.1 a*-13.3 b*-13.4<br>L*51.8 a*-14.5 b*-9.2<br>L*57.6 a*-15.6 b*-3.9 |

**Table 4.23: Vat blue dyed cotton: Main effects of bleach, temperature and cycles on colour change.**

| Vat blue dyed cotton | | Colour difference mean (ΔE) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| BLEACHES | Anolyte | 59.508505 | | | | |
| | Distilled water | 56.212783 | 3.295722 | 3.174718 | 3.416727 | <.0001 |
| | Sodium hypochlorite | 53.301679 | 6.206826 | 6.085821 | 6.327830 | <.0001 |
| | | | (Relative to 24 °C) | | | |
| TEMPERATURE | 24 °C | 55.273228 | | | | |
| | 30 °C | 55.520020 | 0.246792 | 0.125787 | 0.367796 | <.0001 |
| | 60 °C | 58.229719 | 2.956491 | 2.835486 | 3.077495 | <.0001 |
| | | | (Relative to 5 cycles) | | | |
| CYCLES | 5 cycles | 55.257384 | | | | |
| | 10 cycles | 55.911670 | 0.654286 | 0.533282 | 0.775291 | <.0001 |
| | 20 cycles | 57.853912 | 2.596528 | 2.475524 | 2.717532 | <.0001 |

*P value <0.05 statistically significant*

Table 4.23 clearly shows that there was a statistically significant difference in the interactions between bleaches Anolyte and distilled water as well as between Anolyte and sodium hypochlorite. With regard to temperatures, there was a statistically significant difference in temperatures 30 ℃ and 60 ℃ relative to 24 ℃. Bleach cycles also had a statistically significant difference in colour change as p value was <0.05 in all the interactions between 5 cycles and 10 cycles as well as 5 cycles and 20 cycles. Table 4.24 below shows the analysis of variance colour change of vat blue dyed cotton. According to the table there was a statistically significant difference in the bleaches, temperature and cycles.

In conclusion, vat blue dyed cotton has shown that indeed it has a good colourfastness as even after being subjected to the bleaching conditions it was able to sustain the colour. Bleaching vat blue dyed cotton with Anolyte at 24 °C and 30 °C for 5 and 10 cycles caused less, if no, colour loss hence making these conditions conducive to bleach the dyed items. Sodium hypochlorite as well proved to be effective in bleaching vat blue dyed cotton without damaging it except when bleach temperature was 60 °C.

**Table 4.24: The analysis of variance colour change of Vat blue dyed cotton: P-values of effects of bleach, temperature and cycles.**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Temperature | <.0001 |
| Bleach * Temperature | <.0001 |
| Bleach * Cycles | <.0001 |
| Temperature * Cycles | <.0001 |
| Bleach * Temperature * Cycles | <.0001 |

*P value <0.05 statistically significant*

## 4.8 EFFECT OF ANOLYTE, SODIUM HYPOCHLORITE AND DISTILLED WATER ON THE STIFFNESS OF DYED, UNBLEACHED AND BLEACHED COTTON

According to Adanur (1995:601) one of the outstanding attributes which a textile fibre must have is flexibility. The author further explains than the rigidity of cotton is influenced by the type of cotton used as finer cotton shows less rigidity than coarser fibre; fine Egyptian cottons are in the range 1.0-3.0 mN/m$^2$; American cottons, 4.0- 6.0 mN/m$^2$; and coarse Indian cottons, 7.0-11.0 mN/m$^2$. Rigidity will vary with growth conditions and fibre maturity and the fibre rigidity increases with temperature and decreases with moisture content (Menachem 2007:627). Fabric stiffness and handling is an important decision factor for the end users. The degree of fabric stiffness is related to its properties such as yarn and fabric structure (Yüksekkaya *et al* 2008:1). The authors add that the flexural rigidity of the fabrics bending stiffness is important for both consumer and industrial applications of fabrics. Moreover, fabric stiffness may not be wanted too high for a good drape in apparel and garment fabrics, it may be an important requirement especially for industrial fabrics to be used widely in heavy duty applications such as geotextiles and forming fabrics. Collier *et al* (2009: 47) adds that flexibility also affects comfort. A fibre that bends easily will deform to the touch of human skin and feel soft.

The objective of the study was to find out the effect of Anolyte, sodium hypochlorite and using distilled water as control on the stiffness of bleached reactive red dyed cotton, vat blue dyed cotton, bleached cotton and unbleached cotton.

## 4.8.1 STIFFNESS OF REACTIVE RED DYED COTTON

Figure 4.23 illustrates the influence of Anolyte, sodium hypochlorite and distilled water treatment of reactive red dyed cotton at 24 °C for 5, 10 and 20 cycles on the bending length of reactive red dyed cotton. The bending length of the untreated reactive red dyed cotton was 2.4 cm. Bleaching reactive red dyed cotton with Anolyte for 10 and 20 cycles resulted in a bending length of 2.3 cm, making cotton to be less rigid. While on the other hand bleaching for the shortest period (5 cycles) resulted on the cotton been stiffer (2.6 cm) indicating that Anolyte made the cotton fabric softer. The results were different when bleach treatment was sodium hypochlorite as reactive red dyed cotton became more rigid than the untreated after 5 and 10 cycles of bleaching. It is evident that distilled water had a significant influence on the bending length of reactive red dyed cotton causing the fabric to be more rigid, and their rigidity decreased with an increase in bleach cycles. Adanur (1995:645) explains that a stiffer fibre will remain straight and produce a prickly sensation, as fabric stiffness is a function of both the intrinsic stiffness of the fibres and the geometry of the yarn and fabric structure. The figure suggests that bleached reactive red dyed cotton by sodium hypochlorite and distilled water might be less comfortable to wear than the one bleached by Anolyte.

| bending length (cm) | Anolyte | Distilled Water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 2.6 | 2.7 | 2.5 | 2.4 |
| 10 cycles | 2.3 | 2.7 | 2.6 | |
| 20 cycles | 2.3 | 2.6 | 2.4 | |
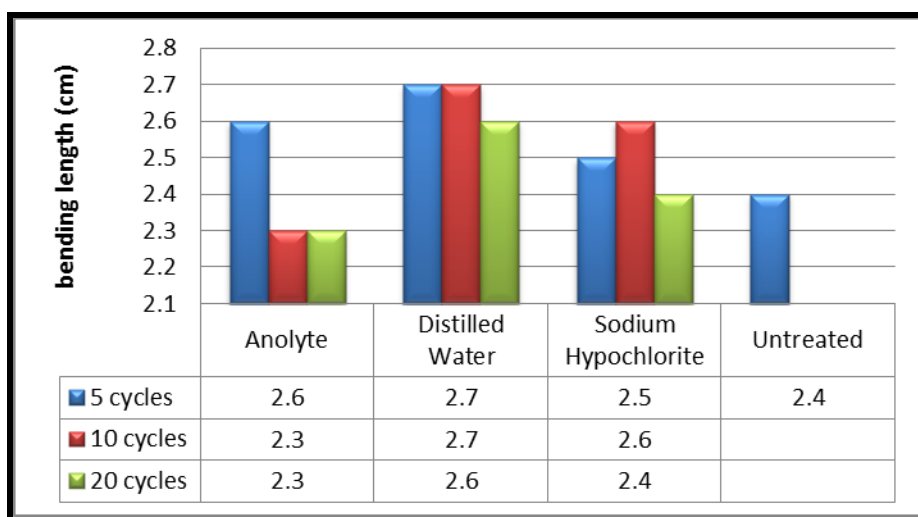
**Figure 4.23: Effect of Anolyte, sodium hypochlorite and distilled water at 24 °C on reactive red dyed cotton stiffness (mean values).**

An increase in bleach temperature to 30 °C had an influence in the rigidity of reactive red dyed cotton as figure 4.24 illustrates. Bleaching reactive red dyed cotton with Anolyte for 10 cycles made the fabric to be least rigid (2.2 cm bending length) as compared to when bleached after 5 and 20 cycles. Menachem (2007:627) explains that rigidity of the fibre is another elastic parameter that is of great significance in describing a fibre resistance to twisting. The figure below indicates that, the bending length of cotton bleached with sodium hypochlorite was greater than the untreated and stiffer reaching a bending length of 2.6 cm. It was observed that the rigidity decreased as bleach cycles increased. Distilled water made the cotton to be more rigid, however the rigidity decreased as bleach cycles increased and after 20 cycles the rigidity is the same as the untreated sample.



| | Anolyte | Distilled Water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 2.5 | 2.7 | 2.6 | 2.4 |
| 10 cycles | 2.2 | 2.5 | 2.5 | |
| 20 cycles | 2.5 | 2.4 | 2.5 | |
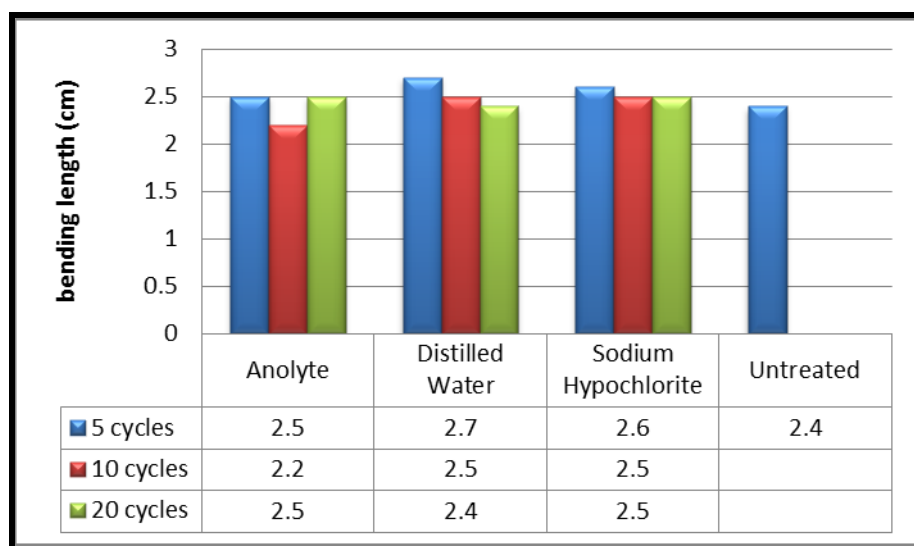
**Figure 4.24: Effect of Anolyte, sodium hypochlorite and distilled water at 30 °C on reactive red dyed cotton stiffness (mean values).**

An increase in temperature to 60 °C as shown by figure 4.25 below show slightly different results as presented by figures 4.23 and 4.24 above. In the figure 4.25, Anolyte did not influence the rigidity of the red dyed cotton bleached for 5 and 10 cycles, as the rigidity of 2.4 cm was the same as the untreated. An increase in the number of bleach cycles to 20 lead to the cotton becoming stiffer and reaching a bending length of 2.5 cm. Sodium hypochlorite bleach, did not change the bending length of reactive red dyed cotton after bleaching for 5 and 20 cycles as it was the bending length was the same as that of the untreated. However, when bleaching with the same bleach for 10 cycle's cotton became less stiff reaching a bending length of 2.3 cm. As seen from the figure that, bleaching cotton with distilled water may lead to stiffer cotton. Behera & Hari (2010:174) explain that bending is a very common phenomenon during the use of fabrics

in garments as it is associated with the selection of fabrics to determine handle. Creasing and wrinkling of fabrics and garments are deformation affecting functional and aesthetic aspects. Several studies of warp and weft bending of woven fabrics have shown that the bending resistance is made up of bending resistance of thread lying in the direction of bending, friction resistant and some unspecified interaction between the threads. And it is clearly indicated in the figure that bleaching with Anolyte and distilled water lead to the cotton becoming slightly stiffer especially after for 20 cycles.



| | Anolyte | Distilled Water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 2.4 | 2.5 | 2.4 | 2.4 |
| 10 cycles | 2.4 | 2.4 | 2.3 | |
| 20 cycles | 2.5 | 2.5 | 2.4 | |

**Figure 4.25: Effect of Anolyte, sodium hypochlorite and distilled water at 60 °C on reactive red dyed cotton stiffness (mean values).**

**Table 4.25: Reactive red dyed cotton: Main effects of bleach, temperature and cycles on stiffness.**

| Reactive red dyed cotton | | Stiffness(cm) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| **BLEACHES** | Anolyte | 2.423944 | | | | |
| | Distilled water | 2.576667 | -0.152722 | -0.215197 | -0.090247 | <.0001 |
| | Sodium hypochlorite | 2.456667 | -0.0327222 | -0.095197 | 0.029753 | 0.3015 |
| | | | (Relative to 24 °C) | | | |
| **TEMPERATURE** | 24 °C | 2.520556 | 0.000000 | 0.000000 | 0.000000 | |
| | 30 °C | 2.500833 | -0.019722 | -0.082297 | 0.042753 | 0.5328 |
| | 60 °C | 2.435889 | -0.084667 | -0.147142 | -0.022191 | 0.0084 |
| | | | (Relative to 5 cycles) | | | |
| **CYCLES** | 5 cycles | 2.556167 | 0.000000 | 0.000000 | 0.000000 | |
| | 10 cycles | 2.434722 | -0.121444 | -0.183920 | -0.058969 | 0.0002 |
| | 20 cycles | 2.466389 | -0.089778 | -0.152253 | -0.027303 | 0.0053 |

*P value <0.05 statistically significant*

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Table 4.25 shows the effects of bleach, temperature and cycles on stiffness. There was a statistically significant difference in stiffness between Anolyte and distilled water as the p-value was <0.001. However, there was no statistically significant difference in stiffness between Anolyte and sodium hypochlorite. There was no statistically significant difference in temperatures between 24 °C and 30 °C but there was a statistically significant difference in stiffness when bleaching was between 24 °C and 60 °C. With regard to bleach cycles, it is evident the interaction between number of bleach cycles were statistically significant.

An analysis of variance of stiffness of reactive red dyed cotton shown in table 4.26 indicated that there was no statistically significant difference in stiffness between bleach and cycles as well as between bleach, temperature and cycles. Whilst other interactions shown in the table show that there was a statistically significant difference in stiffness.

Rigidity is the ability of the fibre to resist bending or creasing which could be caused by the use of chemicals or the molecular structure (Kadolph 2011:41). However, the rigidity of the bleached reactive red dyed cotton was more negatively affected by bleaching with distilled water and sodium hypochlorite than Anolyte.

**Table 4.26: The analysis of variance of stiffness of reactive red dyed cotton: P-values of effects of bleach, temperature and cycles.**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Temperature | 0.0221 |
| Bleach * Temperature | 0.0010 |
| Cycles | 0.0006 |
| Bleach * Cycles | 0.1051 |
| Temperature * Cycles | 0.0482 |
| Bleach * Temperature * Cycles | 0.1536 |

*P value <0.05 statistically significant*

## 4.8.2: STIFFNESS OF VAT BLUE DYED COTTON

Figure 4.26 illustrates the influence of Anolyte, sodium hypochlorite and distilled water bleach cycles at temperature 24 °C on the stiffness of vat blue dyed cotton. Bending length of the untreated vat blue dyed cotton was 2.7 cm. After bleaching with Anolyte the cotton became softer as the bending length reduced to 2.3 cm after bleaching for 5 cycles. According to Sarkar & Khalil (2014:48) the softness could be caused by the fact that the cotton fibres are loosened by bleaching treatment as the fibrils are degraded and partly detached from the main fibre chain,

and softness increased. However, as the bleach cycles increased cotton became stiffer though the stiffness was less than that of the untreated. It was noted that, vat blue dyed cotton increased in stiffness as the bleach cycles increased.

Bleaching vat blue dyed cotton with sodium hypochlorite resulted with cotton becoming stiffer as the number of cycles increased. As shown in figure 4.26, cotton was least rigid after bleaching for 5 cycles and was more rigid after bleaching for 20 cycles reaching a rigidity of 2.8 cm. Sodium hypochlorite caused the cotton to be more rigid than Anolyte. However, the difference in the bleach cycles did not have much influence in the rigidity of bleached vat blue cotton as it was small and did not have any significant difference and this is displayed in table 4.27 and 4.28. Bleaching with distilled water softened the cotton making the bleached cotton to be softer reaching rigidity less (2.6 cm) than that of the untreated (2.7 cm). It is patent that, in all the bleach liquors where bleaching was repeated for 10 cycles, the rigidity of vat blue dyed cotton was 2.6 cm. Bleaching with sodium hypochlorite for 20 cycles caused the fabric to be slightly more rigid than the untreated vat blue dyed cotton.

| | Anolyte | Distilled Water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 2.3 | 2.7 | 2.5 | 2.7 |
| 10 cycles | 2.6 | 2.6 | 2.6 | |
| 20 cycles | 2.6 | 2.6 | 2.8 | |

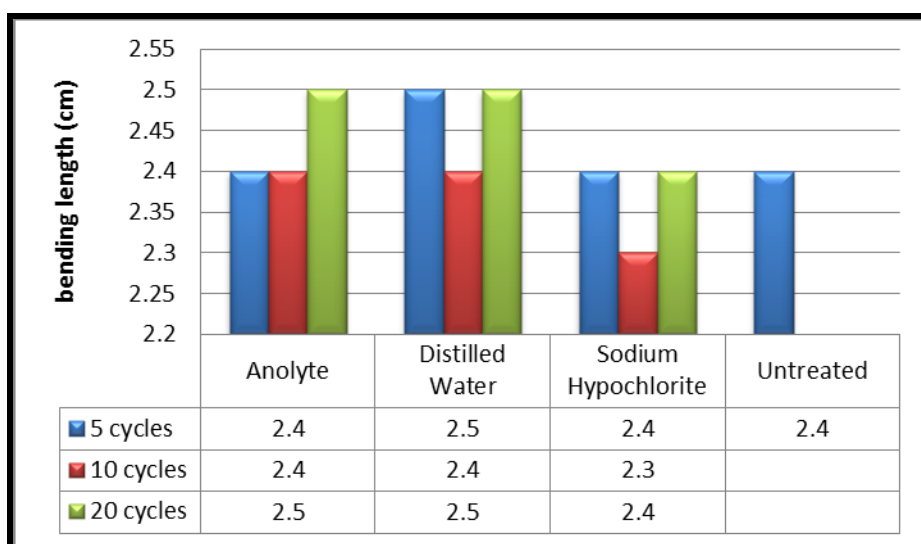**Figure 4.26: Effect of Anolyte, sodium hypochlorite and distilled water at 24 °C on vat blue dyed cotton stiffness (mean values).**

Figure 4.27 illustrates the influences of Anolyte, sodium hypochlorite and distilled water when temperature has increased to 30 °C for 5, 10 and 20 cycles on the stiffness of vat blue dyed cotton. Bleaching with Anolyte for 10 cycles made the vat blue dyed cotton to be softer than after bleaching for 5 and 20 cycles as cotton became stiffer, but not exceeding the bending length of the untreated fabric which was 2.7 cm. Distilled water softened vat blue dyed cotton as the number of cycles increased. At 20 cycles the rigidity was soft reaching a bending length of 2.4 cm. According to Behera (2007:38) the bending behaviour has a very good correlation with fabric handle, and as such low bending rigidity is one of the most desirable properties to achieve better handle. Therefore, bleaching with Anolyte resulted in softer cotton than those bleached with sodium hypochlorite. Bleaching with sodium hypochlorite did not have any influence in the bending length of vat blue dyed cotton, as the bending length of the bleached cotton after 5 and 20 cycles was the same as that of the untreated. The bending length of 2.5 cm was reached by all the bleaches after bleaching for 10 cycles.



| | Anolyte | Distilled Water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 2.6 | 2.7 | 2.7 | 2.7 |
| 10 cycles | 2.5 | 2.5 | 2.5 | |
| 20 cycles | 2.7 | 2.4 | 2.7 | |
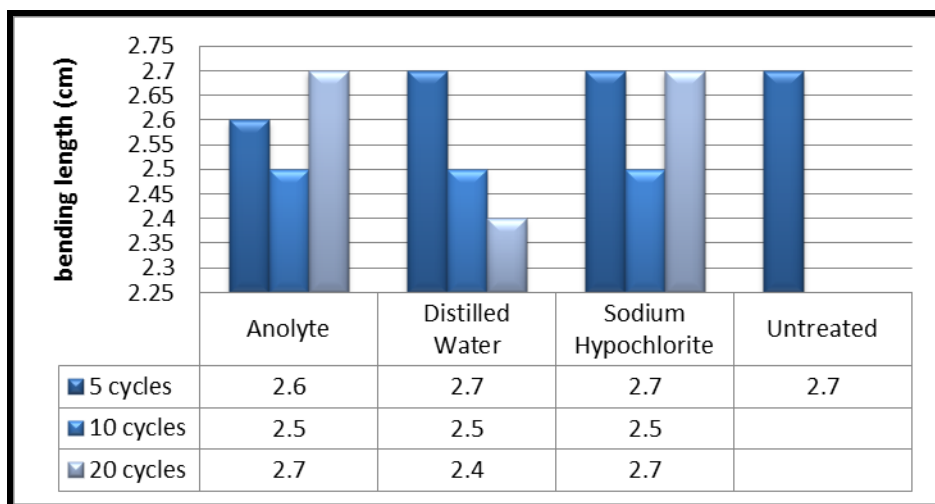
**Figure 4.27: Effect of Anolyte, sodium hypochlorite and distilled water at 30 °C on vat blue dyed cotton stiffness (mean values).**

Figure 4.28 illustrates the effect of treatment with Anolyte, sodium hypochlorite and distilled water at 60 °C on the stiffness of the vat blue dyed cotton. The bending length of the untreated vat blue dyed cotton was 2.7 cm. And it is evident that, bleaching cotton with Anolyte for 10 cycles resulted in the fabric being less rigid/stiff. Though bleached with the same treatment the bending length of vat blue dyed cotton increased after 5 and 20 cycles reaching 2.5 cm but still lower than the untreated (2.7 cm). The bending length of vat blue dyed cotton bleached with sodium hypochlorite increased with the number of cycles. However, the same bending length was obtained when bleaching was done for 10 and 20 cycles. It is obvious that the same bending length of 2.6 cm was obtained after bleaching for 10 and 20 cycles with distilled water and sodium hypochlorite. An increase in temperature did not have an adverse effect on the rigidity of the bleached vat blue dyed cotton. The findings are contrary to what Khan *et al* (2012:33) discovered in their study that, bleaching treatment of denim from 40 to 60 °C had an adverse effect on stiffness. As figure 4.26 indicates, the vat blue dyed cotton was even stiffer when bleach temperature was 24 °C degrees than when at 60 °C.



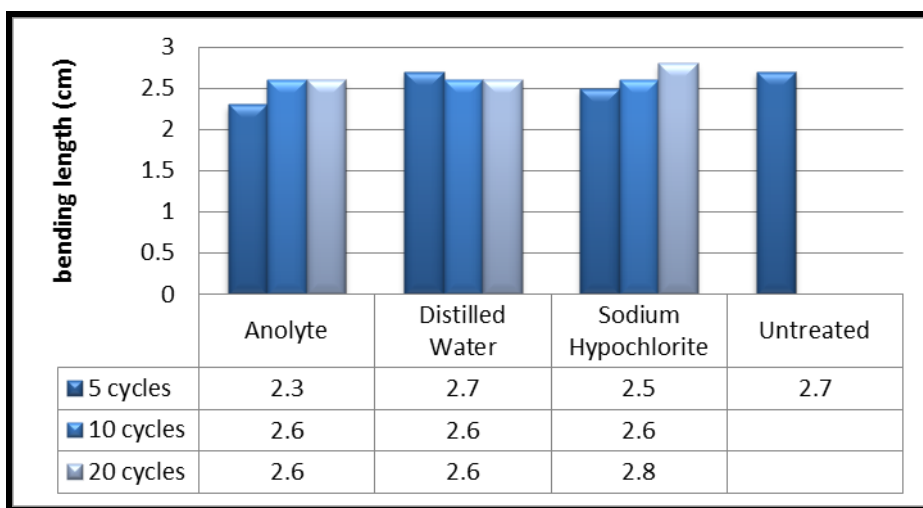|  | Anolyte | Distilled Water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 5 cycles | 2.5 | 2.4 | 2.5 | 2.7 |
| 10 cycles | 2.4 | 2.6 | 2.6 | |
| 20 cycles | 2.5 | 2.6 | 2.6 | |
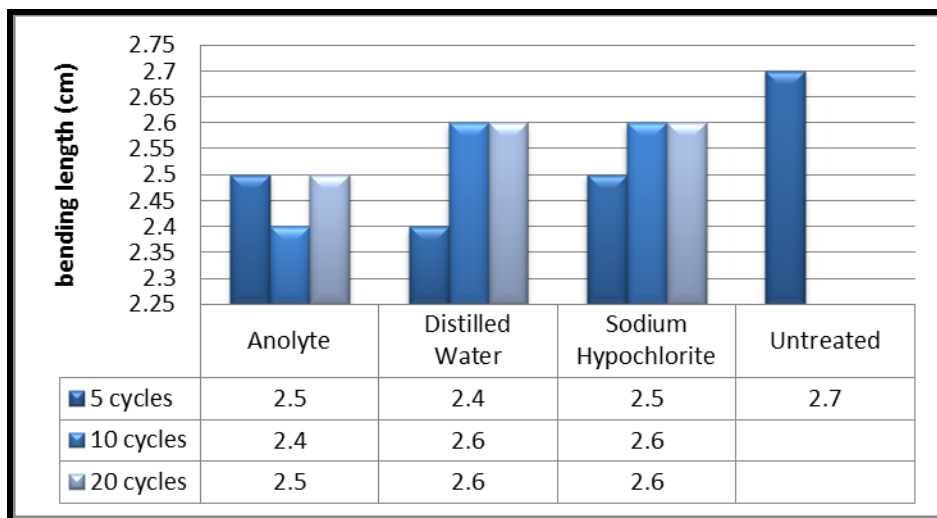
**Figure 4.28: Effect of Anolyte, sodium hypochlorite and distilled water at 60 °C on vat blue dyed cotton stiffness (mean values).**

**Table 4.27: Vat blue dyed cotton: Main effects of bleach, temperature and cycles on stiffness.**

| Vat blue dyed cotton | | Stiffness(cm) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| **BLEACHES** | Anolyte | 2.518889 | | | | |
| | Distilled water | 2.561944 | -0.043056 | -0.102033 | 0.015922 | 0.1508 |
| | Sodium hypochlorite | 2.605278 | -0.086389 | -0.145366 | -0.027412 | 0.0045 |
| | | | (Relative to 24 °C) | | | |
| **TEMPERATURE** | 24 °C | 2.586111 | | | | |
| | 30 °C | 2.584167 | -0.001944 | -0.060922 | 0.057033 | 0.9480 |
| | 60 °C | 2.515833 | -0.070278 | -0.129255 | -0.011301 | 0.0200 |
| | | | (Relative to 5 cycles) | | | |
| **CYCLES** | 5 cycles | 2.551111 | | | | |
| | 10 cycles | 2.535833 | -0.015278 | -0.074255 | 0.043699 | 0.6087 |
| | 20 cycles | 2.599167 | 0.048056 | -0.010922 | 0.107033 | 0.1092 |

*P value <0.05 statistically significant*

Table 4.27 illustrates the effects of Anolyte, sodium hypochlorite and distilled water, temperature and cycles on stiffness. There was no statistically significant difference in stiffness between Anolyte and distilled water. However, there was a statistically significant difference in stiffness between Anolyte and sodium hypochlorite as p-value was <0.05. Interaction between temperatures clearly shows that, there was no statistically significant difference between 24 °C and 30 °C but there was a statistically significant difference in stiffness when bleaching was between 24 °C and 60 °C. With regards to number of bleach cycles, it is evident the interaction between bleach cycles were not statistically significant.

An analysis of variance of stiffness of reactive red dyed cotton shown in table 4.28 indicated that there was no statistically significant difference in stiffness between bleach and temperature and between cycles. Whilst other interactions shown in the table shows that there was a statistically significant difference in stiffness.

In conclusion, the results indicates that bleaching vat blue dyed cotton at 24 °C resulted in an increase in rigidity of bleached cotton by Anolyte and sodium hypochlorite. However, there was no difference in the bending length of cotton bleach with Anolyte after 10 and 20 cycles. But a steady increase in rigidity was observed when the treatment was sodium hypochlorite. The bleach temperature of 30 °C affected the bending length at the same rate. It was observed that after 10 and 20 cycles of bleaching with Anolyte and sodium hypochlorite the same bending lengths were obtained. It can therefore, be concluded that these two treatments had the same effect on the bending properties of vat blue dyed cotton. High temperature of 60 °C resulted in a stiffer vat blue dyed cotton especially after bleaching with sodium hypochlorite and water.

Cotton bleached with Anolyte was less stiff by 0.1 cm when compared to those bleached with sodium hypochlorite, thus making a slight difference in bending length. From the results presented, it was observed that sodium hypochlorite bleach caused vat blue dyed cotton to be stiffer as compared to Anolyte bleached cotton.

**Table 4.28: The analysis of variance stiffness of Vat dyed cotton: P-values of effects of bleach, temperature and cycles.**

| Source | p-value |
|---|---|
| Bleach | 0.0173 |
| Temperature | 0.0301 |
| Bleach * Temperature | 0.2030 |
| Cycles | 0.0895 |
| Bleach * Cycles | 0.0577 |
| Temperature * Cycles | 0.0021 |
| Bleach * Temperature * Cycles | 0.0501 |

*P value <0.05 statistically significant*

## 4.8.3: STIFFNESS OF UNBLEACHED COTTON

Figure 4.29 illustrates the effect of treatment with Anolyte, sodium hypochlorite and distilled water at 40 °C on the stiffness of the unbleached cotton. From the figure, the bending length of the treated unbleached cotton was less than the untreated cotton after bleaching with Anolyte or sodium hypochlorite at all bleaching times of 1 hour, 1 hour 30 minutes and 2 hours respectively. Unbleached cotton bleached with sodium hypochlorite for 1 hour and 1 hour 30 minutes had the least bending length of 1.5 cm thus making the cotton less stiff. After bleaching with Anolyte for 1 hour and 2 hours the bending length reached 1.7 cm, less stiff than the untreated fabric. It is evident that, the bending length increased as time increased in the bleach liquors Anolyte and sodium hypochlorite.

| | Anolyte | Distilled Water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| ■ 1 hour | 1.6 | 2 | 1.5 | 2.4 |
| ■ 1 hour 30 mins | 1.7 | 2.2 | 1.5 | |
| ■ 2 hours | 1.7 | 2 | 1.8 | |
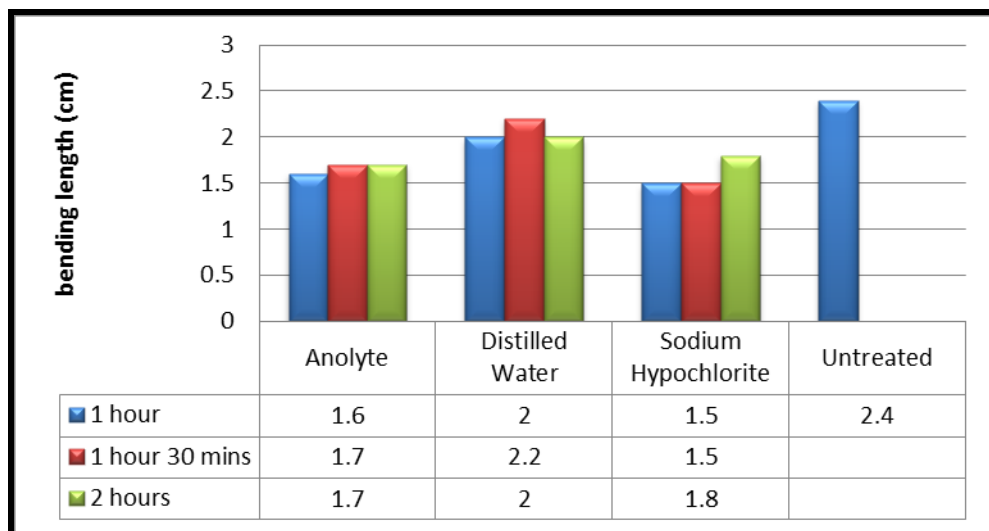
**Figure 4.29: Effect of treatment duration on unbleached cotton stiffness at 40 °C (mean values).**

Figure 4.30 illustrates the effects of an increased bleach temperature of 60 °C on stiffness of unbleached cotton treated with Anolyte, sodium hypochlorite and distilled water. The rigidity of the untreated unbleached cotton was 2.4 cm and from the figure below, after bleaching the unbleached cotton with the bleach liquors, they did not get stiffer than the untreated fabric. Bleaching unbleached cotton with Anolyte had the same bending length of 1.7 cm at all bleach times of 1 hour, 1 hour 30 minutes and 2 hours. It was noted from the figure that, the bending length of unbleached cotton bleached with sodium hypochlorite became less rigid as time increased. Unbleached cotton bleached by Anolyte at all bleach times and sodium hypochlorite for 2 hours was the least rigid or the softest.

| | Anolyte | Distilled Water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| 1 hour | 1.7 | 1.9 | 2.2 | 2.4 |
| 1 hour 30 mins | 1.7 | 1.7 | 2.1 | |
| 2 hours | 1.7 | 2.1 | 1.7 | |
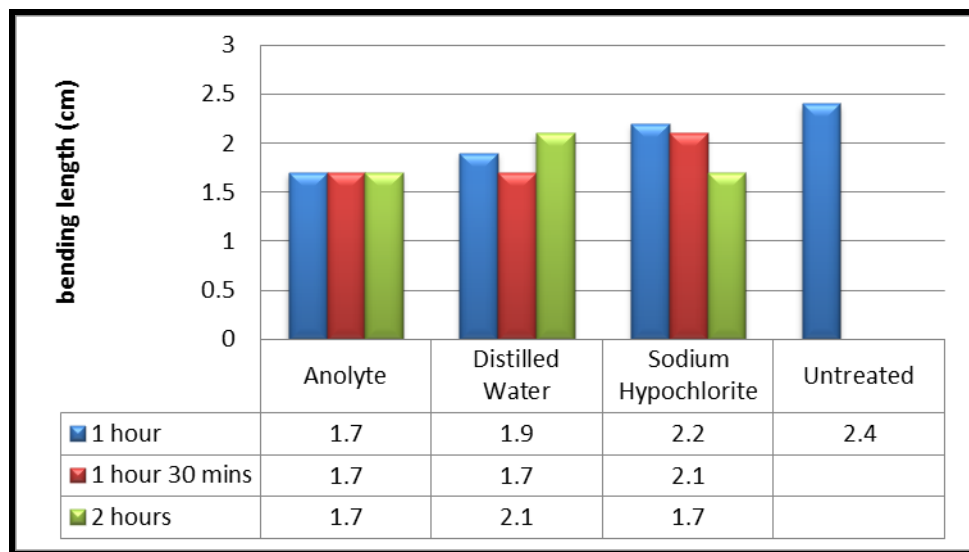
**Figure 4.30: Effect of treatment duration on unbleached cotton stiffness at 60 °C (mean values).**

Figure 4.31 demonstrates the rigidity of unbleached cotton when bleach temperature of Anolyte, sodium hypochlorite and distilled water was 80 °C. Although the bending length of untreated cotton was 2.4 cm, the bending length of all the treated samples did not exceed that of the untreated. The bending length of the unbleached cotton bleached with Anolyte did not show any difference in bending length after various bleaching times of 1 hour, 1 hour 30 minutes and 2 hours. The rigidity of the bleached fabric was 1.5 cm which was the least rigid of all the treated samples. It is evident from the figure that, the bending length of the unbleached cotton bleached with sodium hypochlorite increased as time increase hence making the fabric even stiffer than when treated with Anolyte but still less stiff than the original fabric. The bending length of samples bleached with distilled water was more rigid than those treated with Anolyte or sodium hypochlorite.
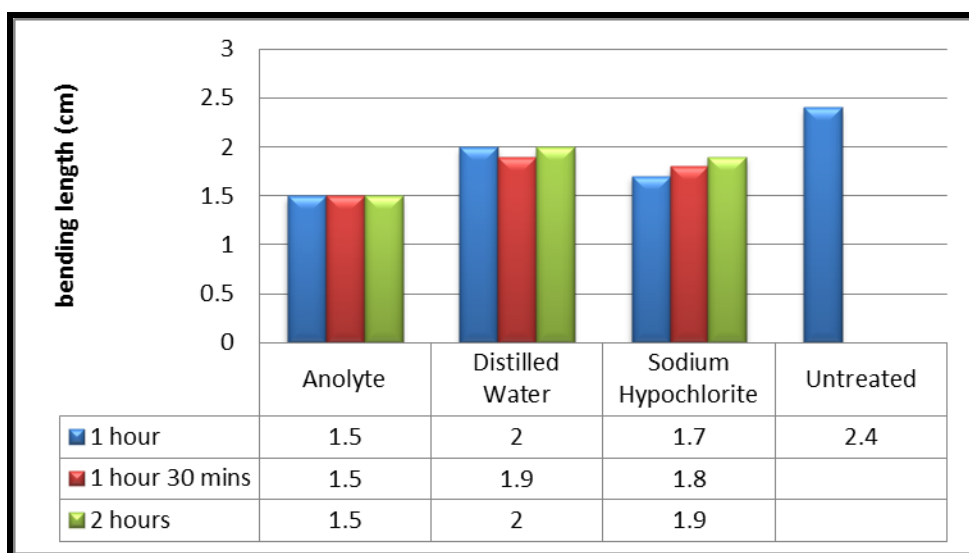


**Figure 4.31: Effect of treatment duration on unbleached cotton stiffness at 80 °C (mean values).**

**Table 4.29: Unbleached cotton: Main effects of bleach, temperature and time on stiffness.**

| Unbleached cotton | | Stiffness(cm) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| **BLEACHES** | Anolyte | 1.629722 | | | | |
| | Distilled water | 1.990000 | -0.360278 | -0.455498 | -0.265057 | <.0001 |
| | Sodium hypochlorite | 1.807667 | -0.177944 | -0.273165 | -0.082724 | 0.0003 |
| | | | (Relative to 40 °C) | | | |
| **TEMPERATURE** | 40 °C | 1.788889 | | | | |
| | 60 °C | 1.867667 | 0.078778 | -0.016443 | 0.173998 | 0.1039 |
| | 80 °C | 1.770833 | -0.018056 | -0.113276 | 0.077165 | 0.7078 |
| | | | (Relative to 1 hour) | | | |
| **TIME** | 1 hour | 1.800444 | | | | |
| | 1 hour 30 minutes | 1.782222 | -0.018222 | -0.113443 | 0.076998 | 0.7052 |
| | 2 hours | 1.844722 | 0.044278 | -0.050943 | 0.139498 | 0.3587 |

*P value <0.05 statistically significant*

Table 4.29 illustrates the main effects of Anolyte, sodium hypochlorite and distilled water, temperature and time on the stiffness of unbleached cotton. It is apparent that, there was a statistically significant difference in bending length between bleach interactions (Anolyte, distilled water and sodium hypochlorite). However, it was noted that there was no statistical difference between the temperature and time interactions. Table 4.30 below shows the analysis of variance of stiffness of unbleached cotton. There were no statistically significant difference on temperatures, time, interaction between bleach and time as well as between temperature and time.

In summary, samples treated with Anolyte were less rigid as compared to those treated with either distilled water or sodium hypochlorite particularly when the bleaching temperature was 60 °C and 80 °C. The rigidity of unbleached cotton treated with Anolyte and sodium hypochlorite for 2 hours gave the same bending length of 1.7 cm. It was also evident from figures 4.29, 4.30 and 4.31 that, samples treated with distilled water and sodium hypochlorite were stiffer than those bleached with Anolyte. The Anolyte had a softening effect on the unbleached cotton.

**Table 4.30: The analysis of variance stiffness of Unbleached cotton: P-values of effects of bleach, temperature and time.**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Temperature | 0.1054 |
| Bleach * Temperature | 0.0003 |
| Time | 0.4115 |
| Bleach * Time | 0.8791 |
| Temperature * Time | 0.2468 |
| Bleach * Temperature * Time | 0.0043 |

*P value <0.05 statistically significant*

## 4.8.4: STIFFNESS OF BLEACHED COTTON

The objective of the study was to find out if bleaching with Anolyte, sodium hypochlorite and distilled water at various temperatures and bleach cycles have an effect on the stiffness of the reactive red dyed cotton, vat blue dyed cotton, bleached cotton and unbleached cotton. The results of the effects of the bleach treatments on the rigidity of bleached cotton follow here. Hospitals and the hospitality industry mostly use bleached cotton; therefore it would be of great benefit to find out if these treatments would make the cotton fabric to be uncomfortable to the consumer.

Figure below (fig 4.32) indicates the effects of Anolyte, sodium hypochlorite and distilled water on the bending length of bleached cotton after 5, 10 and 20 cycles at a bleaching temperature of 40 °C. The bending length of the untreated cotton was 1.6 cm. All the three bleach liquors negatively affected the rigidity of bleached cotton as after bleaching, bleached cotton was more rigid. According to Jucienė *et al* (2006:358) the bending rigidity is important upon selecting the construction of a garment as increase in fabric rigidity lead to worse drape of a garment. After bleaching the bleached cotton with Anolyte for 5 cycles the bending length of cotton was 2.2 cm, and after bleaching for 10 cycles the bending length dropped to 1.9 cm and it rose again to 2.1 cm when the bleach cycles reached 20 cycles. The bending length of cotton bleached with sodium hypochlorite varied with the cycles as when bleached for 5 cycles the bending length was 1.9, then it went to 1.7 when the cycles increased to 10 and lastly reached a bending length of 2.1 cm when the cycles increased to 20 cycles. Bleached cotton treated with distilled water was more rigid than the cotton treated with Anolyte and sodium hypochlorite, as after 5 and 10 cycles the bending length was 2.2 cm and it dropped to 2 cm when bleaching was done for 20 cycles.



| | Anolyte | Distilled Water | Sodium Hypochlorite | Untreated |
|---|---|---|---|---|
| ■ 5 cycles | 2.2 | 2.2 | 1.9 | 1.6 |
| ■ 10 cycles | 1.9 | 2.2 | 1.7 | |
| ■ 20 cycles | 2.1 | 2 | 2.1 | |
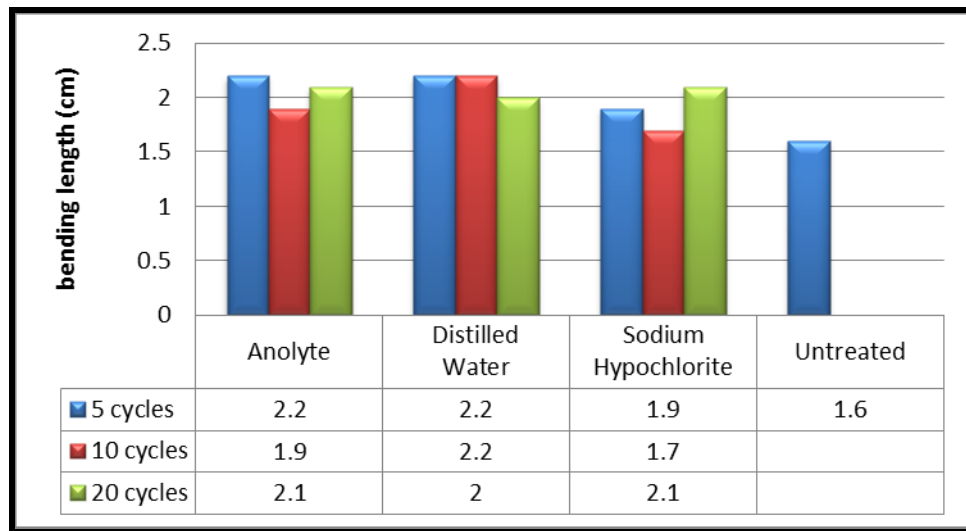
**Figure 4.32: Bleached Cotton: Effect of Anolyte, sodium hypochlorite and distilled water after 5, 10 and 20 cycles on stiffness at 40 °C (mean values).**

**Table 4.31: Bleached cotton: Main effects of bleach, temperature and cycles on stiffness at 40 °C.**

| Bleached cotton | | Stiffness(cm) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | | (Relative to Anolyte) | | |
| **BLEACHES** | Anolyte | 2.070000 | | | | |
| | Distilled water | 2.150833 | -0.080833 | -0.270479 | 0.108812 | 0.3931 |
| | Sodium hypochlorite | 1.918333 | 0.151667 | -0.037979 | 0.341312 | 0.1135 |
| | | | | (Relative to 5 cycles) | | |
| **CYCLES** | 5 cycles | 2.106667 | | | | |
| | 10 cycles | 1.951667 | -0.155000 | -0.344646 | 0.034646 | 0.1061 |
| | 20 cycles | 2.080833 | -0.025833 | -0.215479 | 0.163812 | 0.7839 |

*P value <0.05 statistically significant*

Table 4.31 above clearly shows that, although it made the fabric more rigid the interaction between bleaches and cycles was not statistically significant different in the bending length of bleached cotton. However, the analysis of variance of stiffness of bleached cotton shown in table 4.32 clearly indicates that there was a statistically significant difference in bleach, cycles and between bleach and cycles.

In fine, after bleaching bleached cotton with Anolyte, sodium hypochlorite and distilled for 5, 10 and 20 cycles, the samples became more rigid than the untreated. However, samples treated with sodium hypochlorite were less rigid when bleached for 5 and 10 cycles and Anolyte for 10 cycles more than samples bleached with distilled water and Anolyte. The samples were dried flat at room temperature without any source of light, as that may have an influence on the rigidity of the bleached samples.

**Table 4.32: The analysis of variance stiffness of bleached cotton: P-values of effects of bleach and cycles at 40 °C**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Cycles | 0.0046 |
| Bleach * Cycles | 0.0052 |

*P value <0.05 statistically significant*

## 4.9 THE EFFECT OF ANOLYTE, DISTILLED WATER AND SODIUM HYPOCHLORITE ON THE TENSILE STRENGTH OF VAT BLUE DYED COTTON, REACTIVE RED DYED COTTON AND BLEACHED COTTON

Menachem (2007:623) defines tenacity as the power to resist force or the breaking strength or load necessary to break a fibre under certain strain. Malik *et al* (2011:46) also defines tensile strength of a yarn or fabric as a maximum load that it will endure without breaking when subjected to uniaxial tensile loading. The authors further explain that, tensile strength of a woven fabric is one of the most important properties which make it superior in many applications as compared to non-woven and knitted fabrics. Behera and Hari (2010:162) explain that the tensile properties of woven fabrics depend on the fabric structure, i.e. yarn twist, yarn strength, weave, crimp and cover. The authors further express that, the tensile properties of woven fabrics, together with other mechanical properties such as bending, tear strength and firmness are of considerable importance in determining how the fabric will perform in use, because the fabric is subjected to repeated stresses which degrades the quality of the material in its lifetime. Literature review reveals that the tensile strength of a woven fabric not only depends on the strength of the constituent yarns, but also on many other factors including yarn linear density, yarn twist per unit length, twist direction, yarn structure as influenced by the spinning system, yarn bending behavior, coefficient of friction and initial modulus of the yarn, fabric geometry, warp and weft density, weave design or yarn interlacement pattern, weaving conditions (such as temperature, humidity and yarn tensions during weaving) as well as fabric finishing treatments (Malik *et al* 2011:46).

According to Saravanan *et al* (2009:1) changes in the degree of polymerization, degree of crystallinity and weight loss of fabrics significantly influence tensile properties in terms of tensile elongation, tensile and compressive resilience, shear rigidity, hysteresis and surface friction. Some fabric breaking strength might change upon the processing conditions and affect the performance of the finished product. The ability of the fabric to withstand any pressure during use is most crucial for consumer use and is an important aspect of a finished fabric. Hussain *et al* (2010:243) explain that finished fabrics must conform to certain specifications which include type of fibre, blend used, yarn linear density, fabric count, weave density, fabric strength, colour and finish.

The last objective of the research was to determine if Anolyte and sodium hypochlorite had an adverse influence of the tensile strength of dyed cotton and bleached cotton at temperatures 24 °C, 30 °C, 40 °C and 60 °C when bleached for 5, 10 and 20 cycles.

## 4.9.1 TENACITY OF VAT BLUE DYED COTTON

The results concerning the tensile strength of the vat blue dyed cotton bleached with Anolyte, sodium hypochlorite and distilled water for 5, 10 and 20 cycles at 24 °C, 30 °C and 60 °C as well as the statistical analysis of the significance of the treatment are illustrated in the figures and tables below. Treating vat blue dyed cotton with distilled water for 5 and 10 cycles required the highest maximum load of 758 N and 732 N, while the treated vat blue dyed cotton with sodium hypochlorite needed 745 N after 20 cycles to break the treated cotton. Of all the three bleaches the least maximum load needed to break the bleached vat blue dyed cotton was when the cotton was bleached with Anolyte for 20 cycles.

The cotton fabric that was bleached with distilled water for 20 cycles required 732 N maximum load to reach the breaking limit. These results indicate that Anolyte and sodium hypochlorite did damage to the fabric. This is not surprising seeing that cotton is sensitive and get damaged by an acidic low pH environment. Fijan *et al* (2007:247) reported that there was a decrease in breaking strength and the chemical wear of the laundered cotton cloths as it was obvious that the decrease in breaking strength and chemical wear of the cotton cloth was greatest in the laundering procedures of hospital bed wear and hospital pyjamas.

| | Anolyte | Distilled water | Sodium Hypochlorite |
|---|---|---|---|
| ▪ 5 cycles | 738 | 758 | 737 |
| ▪ 10 cycles | 743 | 732 | 734 |
| ▪ 20 cycles | 731 | 775 | 745 |

**Figure 4.33: Maximum load to break Vat blue dyed cotton after laundering for 5, 10 and 20 cycles at 24°C in Anolyte, distilled water and sodium hypochlorite.**

In a study carried out by Santhi & Moses (2008:241), the authors discovered that there is a substantial reduction in the tensile strength of cotton fabric both in warp direction and weft direction after bleaching, due to vat dyeing as the tensile strength of cotton fabric in warp direction is reduced while in weft direction it is increased. Figure 4.34 below clearly indicates that, the tenacity of bleached vat blue dyed cotton treated with Anolyte and sodium hypochlorite reduced as the number of cycles increased. When the treatment solution was Anolyte the tensile strength was 750 N after bleaching for 5 cycles but it reduced to 753 N after 10 cycles and lastly 732 N after 20 cycles. The same was noted when treatment was sodium hypochlorite as after bleaching for 5 cycles the tensile strength was 745 N but it reduced to 724 N after bleaching for 10 cycles and subsequently to 720 N after 20 cycles.

The vat blue dyed cotton reached breaking point at lower level when treated with sodium hypochlorite (720 N) than when bleached with Anolyte (732 N). Khan *et al* (2012:30) explain that chlorine is a harsh chemical, harmful to human health and destructive to cotton; it also may cause damage to cotton due to the decomposition of cellulose in the aqueous solution of hypochlorite bleach (calcium hypochlorite). The loss in fabric strength increased more as duration of washing, temperature and concentration of bleach increased. The tenacity of vat blue dyed cotton bleached with distilled water was high when bleaching took place for 5 and 20 cycles, with a maximum load of 766 N and 768 N respectively. Khedher *et al* (2009:100) in their study discovered that the washing process, the special treatments and their succession on the

apparel reduce the mechanical properties; this reduction can be seen in warp yarns more than weft yarns. The results in the figure clearly display that both Anolyte and sodium hypochlorite affected the tensile strength of the vat blue dyed cotton. The results are also in agreement with Perkins *et al* (1996:127) who indicate that repeated bleach cycles may result in a loss of strength as there is a progressive change in the morphology of cotton fibres.



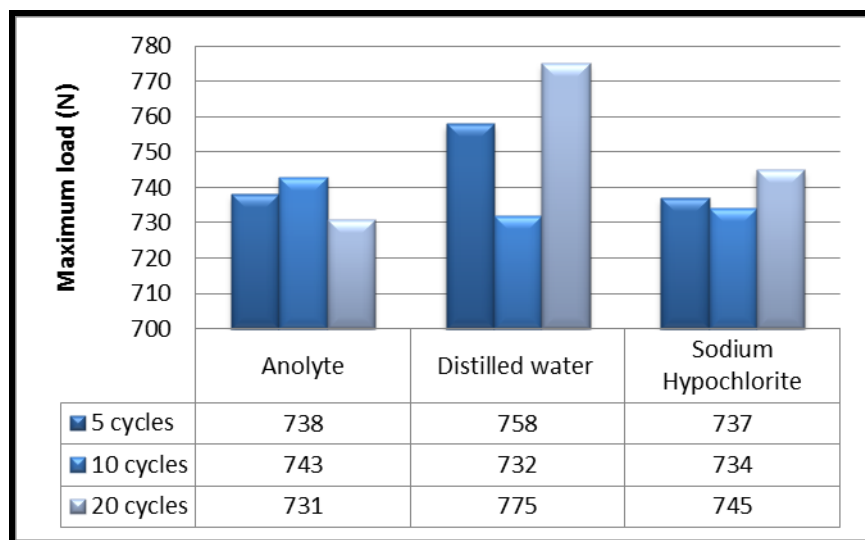| Maximum load (N) | Anolyte | Distilled water | Sodium Hypochlorite |
|---|---|---|---|
| ■ 5 cycles | 753 | 766 | 745 |
| ■ 10 cycles | 750 | 741 | 724 |
| ■ 20 cycles | 732 | 768 | 720 |
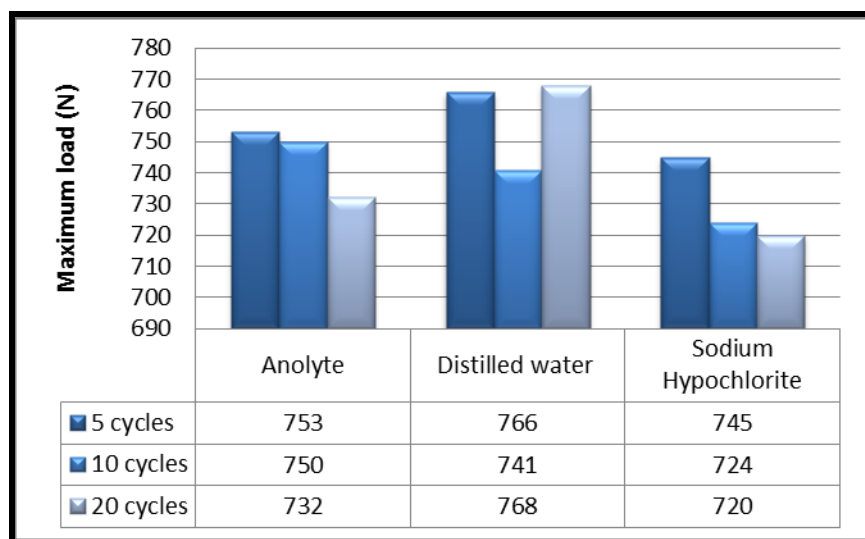
**Figure 4.34: Maximum load to break Vat blue dyed cotton after laundering for 5, 10 and 20 cycles at 30°C in Anolyte, distilled water and sodium hypochlorite.**

Figure 4.35 illustrates that with an increase in bleach temperature to 60 °C the tenacity of cotton reduced further. The tensile strength of cotton was reduced to 674 N and 615 N, respectively when vat blue dyed cotton was bleached with sodium hypochlorite for 10 and 20 cycles at 60 °C, thus a lower maximum load than any reached after treatment at 24 °C and 30 °C. Khan *et al* (2011:18) explains that, among the washing methods, bleach is a widely used method in industry especially for denim washing to achieve required colour shade by hypochlorite bleaching. Chlorine is a harsh chemical, harmful to human health, causes corrosion to washing machines and destructive to cotton; it may cause damage to cotton due to the decomposition of cellulose in the aqueous solution of hypochlorite bleach and loss in tensile strength.

An increase in temperature adversely degraded the quality of vat blue dyed cotton making the fibres so weak that it required less maximum load to break the cotton. Adanur (1995:601) explains that, cotton and rayon have fairly good resistance to weak acids but are severely damaged by even dilute solutions of strong acids such as sulfuric acid and hydrochloric acid; however these fibres have good resistance to strong alkalis. The pH of Anolyte was between 2.65 and 3.06 which was acidic, and according to literature cotton is easily damaged by acidic hence its tensile strength was weakened.

The pH for sodium hypochlorite ranged between 9.65 – 9.78 and in all the figures; 4.33, 4.34 and 4.35, the vat blue dyed cotton treated with sodium hypochlorite reached a lower tenacity than cotton treated with Anolyte. Adanur (1995:601) explains that the breaking strength of a fabric is popularly used both for quality control and as a performance standard. For industrial or other purposes where the fabric is in fact subjected to tension it is proper that breaking strength be measured. Moreover, it gives a quick reliable indication that the fibre, yarn or fabric is up to standard, and the raveled or cut strip tensile test is an excellent method for studying the effects of chemical finishes, heat aging, weathering and microbial deterioration on tensile properties. Khan *et al* (2012:30) enlighten that the loss in fabric strength increased more as duration of washing and temperature of bleach increased.

It was also noted from figure 4.34 (30 °C) and 4.35 (60 °C) that, the tensile strength of vat blue dyed cotton bleached with Anolyte and sodium hypochlorite decreased as the number of bleached cycles and temperature increased. From the results it is clear that the more the bleach cycles, the more the vat blue dyed cotton lost strength. The results are in agreement with a study conducted by Perkins *et al* (1996:129), in their study they discovered that the strength of dyed cotton bleached with chlorine, significantly decreased in strength over 25 cycles. Santhi & Moses (2008:241) agree with the other authors, as in their study carried out to see the effect of ferrous sulphate as reducing agent on textile materials, the authors discovered that, there was a substantial reduction in the tensile strength of cotton fabric both in warp direction and weft direction after bleaching. Tarhan & Sariisik (2009:302) add that they found in their study that fabric strength decreased approximately 40%, especially after hypochlorite (calcium hypochlorite) bleaching for 60 minutes. The loss in strength in this study was not that high as it is the region of 7%.

According to Sarkar & Khalil (2014:48) sodium hypochlorite bleach attacks the outer layer of the fabric surface and decomposes the dye and then slowly penetrates inside the fabric structure. The authors further explain that the protruding fibres are decomposed and then the consistent of yarns of the fabrics are attacked. By the decomposition of the aqueous solution of sodium hypochlorite bleach, the chemical bonds of the primary wall (outer layer) are broken, after that the secondary wall is attacked hence the tensile strength is low. The results shown on the figure below show that, the tensile strength of vat blue dyed cotton bleached with sodium hypochlorite decreased as bleach cycles increased when bleached at 60 °C. Anolyte on the other hand has less effect on the tensile strength as compared to sodium hypochlorite. Distilled water as well has less negative effect as compared to sodium hypochlorite on the tensile strength of vat blue dyed cotton.



| | Anolyte | Distilled water | Sodium Hypochlorite |
|---|---|---|---|
| 5 cycles | 750 | 742 | 707 |
| 10 cycles | 746 | 740 | 674 |
| 20 cycles | 693 | 741 | 615 |

**Figure 4.35: Maximum load to break Vat blue dyed cotton after laundering for 5, 10 and 20 cycles at 60°C in Anolyte, distilled water and sodium hypochlorite.**

**Table 4.33: Vat blue dyed cotton: Main effects of bleach, temperature and cycles on maximum load.**

| Vat blue dyed cotton | | Maximum load (N) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| **BLEACHES** | Anolyte | 737.443 | | | | |
| | Distilled water | 751.497 | -14.054 | -24.003 | -4.105 | 0.0058 |
| | Sodium hypochlorite | 711.446 | 25.997 | 16.379 | 35.615 | <.0001 |
| | | | (Relative to 24 °C) | | | |
| **TEMPERATURE** | 24 °C | 743.778 | | | | |
| | 30 °C | 744.539 | 0.761 | -9.176 | 10.699 | 0.8801 |
| | 60 °C | 712.068 | -31.709 | -41.395 | -22.025 | <.0001 |
| | | | (Relative to 5 cycles) | | | |
| **CYCLES** | 5 cycles | 744.086 | | | | |
| | 10 cycles | 731.703 | -12.384 | -21.922 | -2.845 | 0.0112 |
| | 20 cycles | 724.596 | -19.489 | -29.351 | -9.629 | 0.0001 |

*P value <0.05 statistically significant*

Table 4.33 above indicates the main effects of bleach, temperature and cycles on the maximum load vat blue dyed cotton. From the table, there was a statistically significant difference between Anolyte and sodium hypochlorite as the p-value was <0.0001. There was also a statistically significant difference between Anolyte and distilled water. The table also indicates that, there was a statistically significant difference in temperature interactions between 24 °C and 60 °C. However, there was no statistically significant difference between temperatures 24 °C and 30 °C. It is clear from the table above that, the interactions between bleach cycles were statistically significant.

It was noted in this study that, as temperature increased, the tensile strength of vat blue dyed cotton bleached with sodium hypochlorite at 30 °C and 60 °C decreased more as compared to the tensile strength of cotton bleached with Anolyte and distilled water. Anolyte bleach did not have an adverse effect on the tenacity of vat blue dyed cotton as compared to sodium hypochlorite. In a study conducted by Khan *et al* (2011:20) where the authors studied the effects of bleach in denim garment washing under the influence of 40, 45, 50, 55 and 60°C for 20 minutes were investigated, were the effect of temperature on loss in tensile strength, stiffness, colour fading, fabric weight, elongation at break, water absorption, moisture regain, moisture content and shrinkage. Table 4.34 below gives a summary on the analysis of variance maximum load and it clearly indicates that there was a statistically significant difference in all the interactions except between bleach, temperature and cycles.

**Table 4.34: The analysis of variance maximum load of vat blue dyed cotton: P-values of effects on bleach, time and cycles.**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Temperature | <.0001 |
| Bleach * Temperature | 0.0005 |
| Cycles | 0.0002 |
| Bleach * Cycles | <.0001 |
| Temperature * Cycles | <.0001 |
| Bleach * Temperature * Cycles | 0.3251 |

***P value <0.05 statistically significant***

## 4.9.2 TENACITY OF REACTIVE RED DYED COTTON

Figure 4.36 below displays the results of the maximum load needed to break the reactive red dyed cotton bleached by Anolyte, sodium hypochlorite and distilled water at 24 °C. The tensile strength of reactive red dyed cotton bleached with Anolyte for 5 and 10 cycles was low as the maximum load needed to break the cotton fibres was 605 N and 672 N respectively as compared to the cotton bleached with sodium hypochlorite which required 738 and 693 N. The tensile strength of reactive red dyed cotton bleached with distilled water was the strongest. Reactive red dyed cotton bleached by Anolyte was damaged by the bleach; hence it could carry a lower maximum load before it break the cotton. The lower breaking load could be expected as cotton is sensitive to a low pH environment.



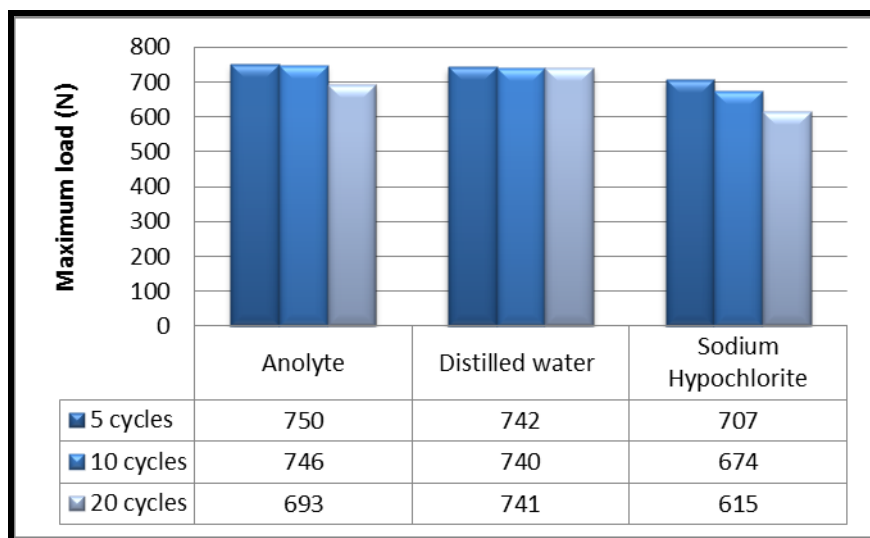| | Anolyte | Distilled water | Sodium Hypochlorite |
|---|---|---|---|
| 5 cycles | 605 | 729 | 738 |
| 10 cycles | 672 | 742 | 693 |
| 20 cycles | 625 | 734 | 709 |

**Figure 4.36: Maximum load to break Reactive red dyed cotton after laundering for 5, 10 and 20 cycles at 24°C in Anolyte, distilled water and sodium hypochlorite.**

An increase in temperature to 30 °C (figure 4.37) indicates that when bleaching reactive red dyed cotton with Anolyte adversely affected the tensile strength of cotton as compared to when bleached with sodium hypochlorite and distilled water. A maximum load of 706 N was needed to break cotton treated with Anolyte after bleaching for 5 cycles and sodium hypochlorite after 20 cycles.

Although in their study, Mahmood *et al* (2009:47) observed that sodium hypochlorite (NaOCl) bleach causes a loss of tensile strength due to the decrease in the molecular chain length. In this research, it was observed that, sodium hypochlorite caused more damage when bleaching temperature was at 60 °C, than at 24 °C and 30 °C. It was noted that, the tensile strength of cotton treated with distilled water and sodium hypochlorite declined as the number of cycles increased. There was a decrease in maximum load needed to break the bleached cotton as the number of bleach cycles increased.



| | Anolyte | Distilled water | Sodium Hypochlorite |
|---|---|---|---|
| 5 cycles | 706 | 726 | 711 |
| 10 cycles | 593 | 726 | 701 |
| 20 cycles | 647 | 695 | 706 |

**Figure 4.37: Maximum load to break Reactive red dyed cotton after laundering for 5, 10 and 20 cycles at 30°C in Anolyte, distilled water and sodium hypochlorite.**

Tensile strength is often the determining factor in choosing a fibre for a specific need. This degradation has the effect of reducing the tensile properties of the fibre and ultimately destroying its integrity. Figure 4.38 indicates the results concerning the tensile strength of reactive red dyed cotton after bleaching with Anolyte, distilled water and sodium hypochlorite at 60 °C for 5, 10 and 20 cycles. It is evident from the figure that, bleaching reactive red dyed cotton at 60 °C with sodium hypochlorite lead to a decrease in tensile strength of the cotton with a maximum of 626 N after bleaching for 20 cycles. The tenacity of cotton was better when reactive red dyed cotton was bleached with sodium hypochlorite at temperatures 24 °C and 30 °C. The figure indicates that, there was a decline in tenacity as bleach cycles increased. In a study conducted by Khan *et al* (2011:4), on the effects of bleach in denim garment washing under the influence of 40, 45, 50, 55 and 60 °C for 20 minutes, their results disclosed that, raising the bleach washing treatment had an adverse effect on tensile strength. It was also noted that Anolyte caused less damage than sodium hypochlorite in the tensile strength of cotton at this temperature. Broadbent (2001:78) explains that, cellulose is susceptible to hydrolysis by hot dilute solutions of mineral acids as this breaks the polymer chain at the oxygen atoms between C-1 and C-4 of adjacent glucose units, causing a dramatic drop in loss of fibre strength called tendering. The author further explains that, because of this sensitivity towards acids, cellulose fibres are never dyed at a pH below 3–4. This would explain the lower values for Anolyte treated cotton. Huang *et al* (2012:1551) concurs with the above mentioned author as they also have noted that the tensile strength of bleached cotton reduce as temperature increase. The tensile strength of cotton treated by Anolyte and sodium hypochlorite was low. Tarhan & Sariisik (2009:302) explain fabric strength decrease approximately by 40%, especially after bleaching with hypochlorite bleaching for 60 minutes. The decrease experienced in this study was not so pronounced. A decrease in tensile strength after bleaching at 60 °C was also noted when vat blue dyed cotton was bleached under the same conditions.

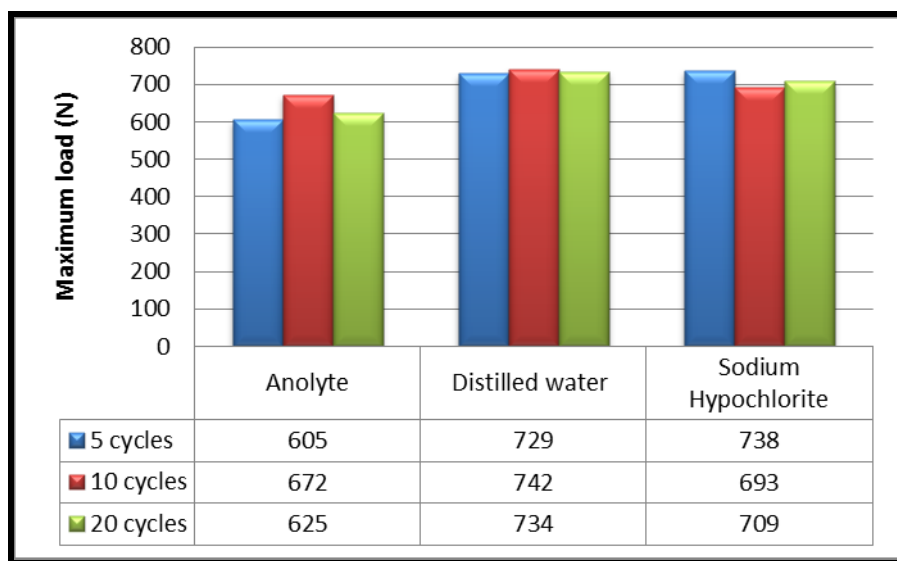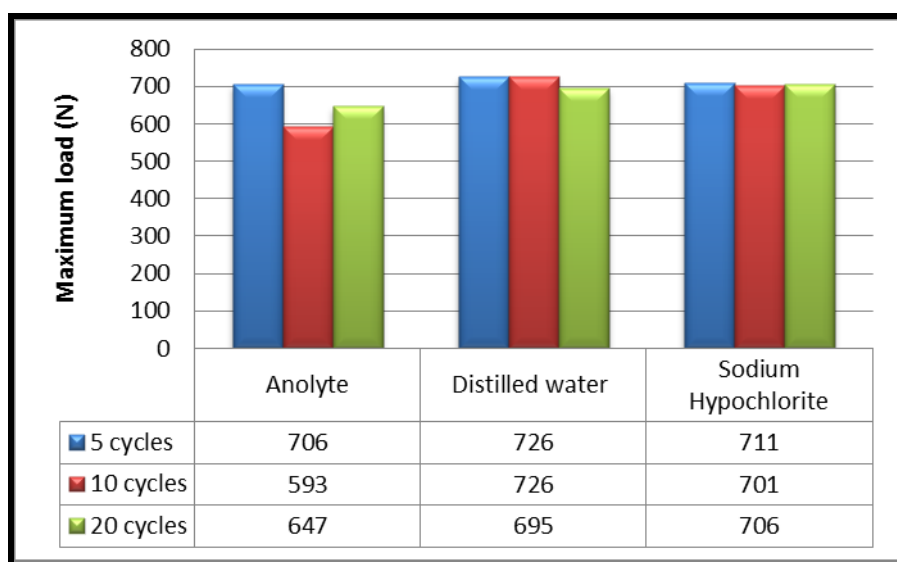| | Anolyte | Distilled water | Sodium Hypochlorite |
|---|---|---|---|
| 5 cycles | 712 | 695 | 692 |
| 10 cycles | 682 | 738 | 667 |
| 20 cycles | 637 | 727 | 626 |
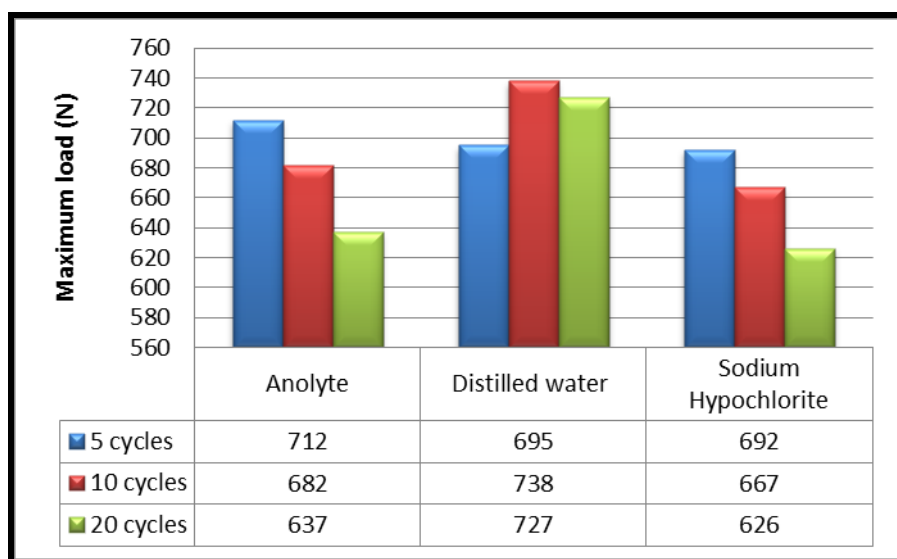
**Figure 4.38: Maximum load to break Reactive red dyed cotton after laundering for 5, 10 and 20 cycles at 60°C in Anolyte, distilled water and sodium hypochlorite.**

**Table 4.35: Reactive red dyed cotton: Main effects of bleach, temperature and cycles on maximum load.**

| Reactive red dyed cotton | | Maximum load (N) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| BLEACHES | Anolyte | 653.211 | | | | |
| | Distilled water | 723.484 | -70.273 | -82.087 | -58.458 | <.0001 |
| | Sodium hypochlorite | 693.635 | -40.424 | -51.728 | -29.119 | <.0001 |
| | | | (Relative to 24 °C) | | | |
| TEMPERATURE | 24 °C | 693.986 | | | | |
| | 30 °C | 690.126 | -3.860 | -15.481 | 7.762 | 0.5137 |
| | 60 °C | 686.218 | -7.769 | -19.162 | 3.625 | 0.1806 |
| | | | (Relative to 5 cycles) | | | |
| CYCLES | 5 cycles | 701.285 | | | | |
| | 10 cycles | 690.514 | -10.772 | -22.204 | 0.661 | 0.0647 |
| | 20 cycles | 678.532 | -22.753 | -34.387 | -11.119 | 0.0001 |

*P value <0.05 statistically significant*

Table 4.35 above clearly indicates that, there was a statistically significant difference between the bleaches Anolyte, distilled water and sodium hypochlorite as the p-values of all interactions were <0.01. However, it was noted from the table that, there was not statistically significant difference between bleach temperatures. Table 4.36 clearly shows that bleach temperatures had no statistically significant influence in tensile strength of reactive red dyed cotton. The interactions between cycles 5 and 10 were not statistically significant, while the interaction between cycles 5 and 20 were statistically significant.

In conclusion, Anolyte bleach did affect the tenacity of reactive red dyed cotton negatively when bleach temperatures were 24 °C and 30 °C, respectively as the maximum loaded needed to break cotton was low. Sodium hypochlorite bleach damaged the cotton fibre more than the other bleaches when the bleach temperature reached 60 °C. It is evident from figure 4.38 that, the tensile strength of cotton decreased as the number of cycles increased from 5 to 20. This was observed in cotton bleached by Anolyte and sodium hypochlorite.

**Table 4.36: The analysis of variance maximum load of reactive red dyed cotton: P-values of effects on bleach, time and cycles.**

| Source | p-value |
|---|---|
| Bleach | <.0001 |
| Temperature | 0.4074 |
| Bleach * Temperature | <.0001 |
| Cycles | 0.0007 |
| Bleach * Cycles | 0.0057 |
| Temperature * Cycles | 0.0005 |
| Bleach * Temperature * Cycles | <.0001 |

*P value <0.05 statistically significant*

### 4.9.3 TENACITY OF BLEACHED COTTON

According to Khan *et al* (2012:30) bleaching treatment improves the appearance and enhancing aesthetic properties of cotton garments. Figure 4.39 below displays the results on the effects of Anolyte, sodium hypochlorite and distilled water on the tenacity of bleached cotton after 5, 10 and 20 cycles at temperature 40 °C. It is evident that the maximum load needed to break cotton was highest and lowest when sodium hypochlorite bleach was used. When bleaching cotton with sodium hypochlorite for 5 cycles, it required 379 N to break the fibres. However, as the number of bleach cycles increased to 20, cotton fibres weakened as the maximum load needed to break cotton reduced to 324 N.

According to Perkins (1996:127) bleach wash cycles may result in a loss of strength at levels unacceptable to the wearers of clothing; as there has been observed progressive changes in morphology of cotton fibres exposed to detergent and chlorine bleach during multiple launderings and as such changes may contribute to reduction in tensile strength. Bleaching cotton weakened the cotton fibres, although the maximum load needed to break cotton bleached with Anolyte was 365 N after 5 cycles and 366 N after 20 cycles, the tenacity of the bleached cotton in all the bleach cycles was higher than 324 N. Cotton was weakened even more when bleached with sodium hypochlorite for 20 cycles as it needed 324 N to break.

It is evident from the figure that, the tenacity of cotton bleached with distilled water gradually increased as bleach cycles increased but the maximum load needed to break the cotton. A decrease in tensile strength was evident when bleached cotton was treated with sodium hypochlorite. Similar results were observed by Špička & Tavčer (2013:411) who discovered in their study that after the bleaching of cotton with chloride the tenacity at maximum load decreased significantly. Tarhan & Sariisik (2009:302) add that fabric strength decrease approximately by 40%, especially after bleaching with hypochlorite bleaching for 60 minutes. It was also noted that cotton bleached with Anolyte for 10 and 20 cycles was stronger than the one bleached with sodium hypochlorite, as it needed a higher maximum load to break the cotton.



| | Anolyte | Distilled water | Sodium Hypochlorite |
|---|---|---|---|
| 5 cycles | 365 | 345 | 379 |
| 10 cycles | 359 | 362 | 346 |
| 20 cycles | 366 | 365 | 324 |
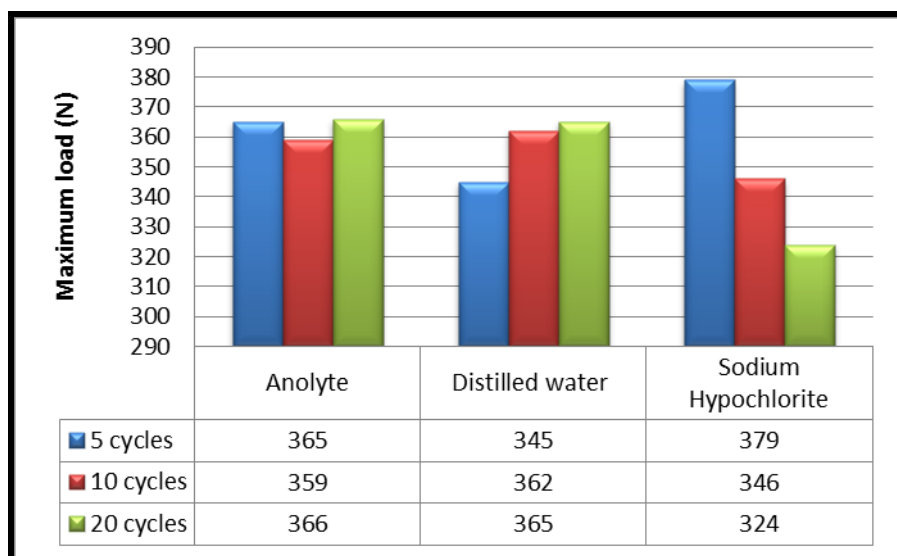
**Figure 4.39: Maximum load to break bleached cotton after laundering for five, ten and twenty cycles at 40°C in Anolyte, distilled water and sodium hypochlorite.**

**Table 4.37: Bleached cotton: Main effects of bleach, 40 °C temperature and cycles on maximum load.**

| Bleached cotton | | Maximum load (N) | Mean difference | 95% confidence interval for mean difference | | P-value |
|---|---|---|---|---|---|---|
| | | | (Relative to Anolyte) | | | |
| **BLEACHES** | Anolyte | 363.248 | | | | |
| | Distilled water | 356.913 | 6.334 | -6.7819 | 19.450 | 0.3398 |
| | Sodium hypochlorite | 349.371 | 13.877 | 0.6538 | 27.101 | 0.2562 |
| | | | (Relative to 5 cycles) | | | |
| **CYCLES** | 5 cycles | 362.783 | | | | |
| | 10 cycles | 355.325 | -7.458 | -20.467 | 5.550 | 0.2576 |
| | 20 cycles | 351.425 | -11.358 | -24.582 | 1.865 | 0.0913 |

*P value <0.05 statistically significant*

According to table 4.37 above there was no statistically significant difference between bleaches as well as between cycles. However in table 4.38 there was a significant difference in maximum load between bleach and cycles.

**Table 4.38: The analysis of variance maximum load of reactive bleached cotton: P-values of effects on bleach and cycles.**

| Source | p-value |
|---|---|
| Bleach | 0.1191 |
| Cycles | 0.2252 |
| Bleach * cycles | 0.0003 |

*P value <0.05 statistically significant*

# CHAPTER 5

## 5.0 CONCLUSIONS & RECOMMENDATIONS

### 5.1 CONCLUSIONS

The efficiency of Anolyte as an alternative bleach to stained cotton, dyed cotton, bleached and unbleached cotton was compared to sodium hypochlorite and distilled water was used as control. Cotton test materials were stained with blood, tea, blackcurrant juice and soot/mineral oil stains, while dyed cotton included reactive red dyed and vat blue dyed, and lastly bleached and unbleached cotton. Bleaching ranged between temperatures 24, 30, 40, 60 and 80 °C to determine the effect of temperature on stain removal and bleaching. The influence of the bleaches, temperature, cycles and time on the textile fabrics were evaluated in terms of stiffness, tensile strength and colour change.

The following conclusions were made based on the hypotheses set for this study and the results obtained:

**HYPOTHESIS 1**

**Anolyte, sodium hypochlorite and distilled water will have an effect on the tensile strength of bleached cotton and dyed cotton.**

The bleach liquors Anolyte, distilled water and sodium hypochlorite had an effect on the tensile strength of reactive red dyed cotton, vat blue dyed cotton and bleached cotton each at a different degree.

It was found that as temperature increased the tensile strength of vat blue dyed cotton bleached with sodium hypochlorite at 30 °C and 60 °C decreased as compared to the tensile strength of cotton bleached with Anolyte and distilled water. It was also noted that Anolyte bleach did affect the tenacity of reactive red dyed cotton when bleach temperatures were 24 °C and 30 °C as the maximum loaded needed to break cotton was low but sodium hypochlorite bleach damaged the cotton fibre more when the bleach temperature reached 60 °C. The results indicate that the tensile strength of cotton decreased as the number of cycles increased from 5 to 20. This was

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observed in cotton bleached with Anolyte and sodium hypochlorite. It was also noted that, sodium hypochlorite affected the tenacity of bleached cotton negatively as the bleach cycles increased, as the maximum load needed to break the cotton was less than that of cotton bleached with Anolyte except after bleaching for only 5 cycles.

From the results it could be concluded that sodium hypochlorite reduced the tensile strength of vat blue dyed cotton more than Anolyte hence weakening the bleached cotton. It was also noted that, Anolyte affected negatively the tensile strength of reactive dyed cotton when bleached at temperatures 24 °C and 30 °C, while sodium hypochlorite negatively affected the tensile strength of the cotton when bleached at 60 °C. It was also concluded that, sodium hypochlorite reduced the tensile strength of bleached cotton more than Anolyte. Distilled water increased the tenacity of both vat blue and reactive red dyed cotton more than Anolyte and sodium hypochlorite.

## HYPOTHESIS 2

**Anolyte, sodium hypochlorite and distilled water will have an effect on the stiffness of bleached cotton, unbleached cotton and dyed cotton.**

Bleach liquors, Anolyte, sodium hypochlorite and distilled water had different effects on the stiffness of bleached, unbleached and dyed cotton. It was discovered that reactive red dyed cotton became stiffer when bleached with sodium hypochlorite than when bleached with Anolyte. The results indicate that, cotton treated with distilled water was more rigid than the cotton bleached by either Anolyte or sodium hypochlorite. From the results, there was a significant difference ($p < 0.05$) between Anolyte and distilled water, while there was no significant difference between Anolyte and sodium hypochlorite.

The rigidity of vat blue dyed cotton was also affected differently by bleaches Anolyte, sodium hypochlorite and distilled water. Anolyte resulted in vat blue dyed cotton being less rigid than when treated with sodium hypochlorite at all temperatures and cycles. While distilled water on the other hand made vat blue dyed cotton to be stiffer than when treated with Anolyte and sodium hypochlorite. There was a statistically significant difference between the influence of the Anolyte and sodium hypochlorite bleach while there was no significant difference in stiffness between Anolyte and distilled water.

The Anolyte bleach reduced the stiffness of unbleached cotton more than sodium hypochlorite especially at temperatures 60 °C and 80 °C. Distilled water caused the unbleached cotton to be

stiffer than the other bleaches. There was a significant difference ($p < 0.005$) between the influence of the Anolyte and the other bleaches.

The stiffness of the bleached cotton at 40 °C was affected by Anolyte, sodium hypochlorite and distilled water differently. It was discovered that, bleached cotton bleached with sodium hypochlorite became less rigid as compared to cotton bleached by Anolyte and distilled water. However, there was no significant difference between the influence of Anolyte and the other bleach liquors on stiffness.

**HYPOTHESIS 3**

**Anolyte, sodium hypochlorite and distilled water will have an effect on the whiteness of bleached cotton, unbleached cotton, dyed cotton and stained cotton.**

The Anolyte, distilled water and sodium hypochlorite had different effects on the whiteness of the stained, bleached, unbleached and dyed cotton.

Blood stain was removed better by sodium hypochlorite than with Anolyte and distilled water. Distilled water even cleaned the stain better than Anolyte. There was a significant difference ($p < 0.05$) between the influence of the Anolyte and sodium hypochlorite and water. Other stains that were best removed by sodium hypochlorite include blackcurrant juice and tea stains. However, in this case Anolyte cleaned the stain better than distilled water, and there was a significant difference between the influence of the Anolyte and other bleaches on colour change. Soot/mineral oil stain was best cleaned by sodium hypochlorite as compared to Anolyte and distilled water. But Anolyte was on the other hand able to clean the stain better than distilled water. Although there was a significant difference between Anolyte and sodium hypochlorite, there was no significant difference in colour difference between Anolyte and distilled water.

Anolyte, distilled water and sodium hypochlorite affected the whiteness of bleached cotton differently. But it was noted that, the whiteness of the bleached cotton was more prominent when cotton was bleached with sodium hypochlorite than with Anolyte and distilled water. Anolyte seemed to darken the bleached cotton as when the bleaching was carried out for 20 cycles the whiteness was even less than that of the untreated. There was a significant difference between the influence of Anolyte and distilled water, while on the other hand there was no difference between Anolyte and sodium hypochlorite.

The results clearly indicate that unbleached cotton was successfully bleached by sodium hypochlorite way better than Anolyte and distilled water in the whole temperature range.

However, Anolyte was able to whiten the unbleached cotton better than distilled water. The best results were obtained when bleaching temperature was at its highest (80 °C) and as the length of bleaching was longest (2 hours). From the results, distilled water darkened the unbleached cotton as the value of the bleached was less than that of the untreated. There was a significant difference ($p < 0.05$) between the influence of the Anolyte and the other bleaches.

It could therefore be concluded that, Anolyte, sodium hypochlorite and distilled water had a positive effect on the whiteness of bleached cotton, unbleached cotton and stained cotton. The Anolyte treatment however, did not provide the desired whiteness when compared to sodium hypochlorite as its performance was undisputable.

### **HYPOTHESIS 4**

**Different temperatures 24 °C, 30 °C, 40 °C, 60 °C and 80 °C will affect the influence of Anolyte, sodium hypochlorite and distilled water on the tensile strength, stiffness and whiteness of bleached cotton, unbleached cotton, dyed cotton and stained cotton.**

The samples were dried flat at room temperature without any source of light even from the fluorescent lights, to prevent any such influence on the rigidity of the bleached samples as discussed below:

a) **Tensile strength of dyed cotton and bleached cotton at temperatures 24 °C, 30 °C, 40 °C and 60 °C.**
   With regard to tensile strength, bleach temperature of the bleach liquors was influential in the results obtained. The tensile strength of vat blue dyed cotton reduced as the bleach temperature increased when sodium hypochlorite was used. However, when vat blue dyed cotton was bleached with Anolyte, the tensile strength increased as temperature rose from 24 °C to 30 °C and lastly 60 °C. There was a significant difference between the influence of temperature at 24 °C and 60 °C, while there was no difference between the influence of temperature at 24 °C and 30 °C. The tensile strength of reactive dyed cotton also decreased as temperature rose when sodium hypochlorite was used as bleach. Anolyte bleach caused the tensile strength of reactive red to steadily decrease as bleach cycles increased but the effects of the bleach were less than that of sodium hypochlorite at all bleach temperatures. The results clearly indicate that, the tensile strength of bleached cotton was greatly affected negatively by temperature. The bleaching

temperature of sodium hypochlorite at 40 °C caused the bleached cotton to be less strong than when bleached with Anolyte.

b) **The whiteness of unbleached, stained and dyed cotton at temperatures 24 °C, 30 °C, 40 °C and 60 °C.**

The whiteness of dyed cotton (vat blue and reactive red) was affected by Anolyte, sodium hypochlorite and distilled water differently as temperature rose. Anolyte bleach removed fewer colours from the reactive red dyed cotton when bleaching was at temperatures 24 °C and 30 °C, as when temperature rose to 60 °C. However, sodium hypochlorite bleach whitened the reactive red dyed cotton more than Anolyte at temperatures 24 °C and 30 °C. There was a significant difference ($p < 0.05$) between the influence of 24 °C temperature and the other temperatures.

Temperature of the bleach liquors had an influence on the whiteness of the different stains examined in the research. As temperature rose from 30 °C to 40 °C and lastly 60 °C the whiteness of the stains (blood, tea, blackcurrant and soot/mineral oil) improved differently when bleached by Anolyte and sodium hypochlorite. It was noted there was no statistical difference between temperatures 30 °C and 40 °C when bleaching blood and blackcurrant stain, but there was a statistical difference between 30 °C and other temperatures for other stains.

c) **Stiffness of unbleached and dyed cotton at temperatures 24 °C, 30 °C, 40 °C, 60 °C and 80 °C.**

Temperature of the bleach liquors had an influence on the stiffness of reactive red dyed, vat blue dyed, bleached and unbleached cotton at different levels as examined in the research. Bleach temperatures had a great influence on the stiffness of the bleached cotton. Anolyte did not cause cotton to be more rigid/stiff after bleaching for 24 °C and 30 °C, as compared to sodium hypochlorite which caused the dyed cotton being stiffer. When vat blue dyed cotton was bleached for 24 °C and 30 °C with Anolyte and sodium hypochlorite the stiffness of the vat blue dyed cotton increased slightly in each treatment. But as temperature rose to 60 °C the rigidity of the dyed cotton reduced making cotton softer in all the bleach treatments, as the value of stiffness was less than the untreated. There was no statistically significant difference in temperatures between 24 °C and 30 °C but there was a statistically significant difference in stiffness when bleaching was between 24 °C and 60 °C when bleaching reactive red dyed cotton.

The results on the stiffness of unbleached cotton bleached at temperatures 40 °C, 60 °C and 80 °C, by Anolyte, sodium hypochlorite and distilled water indicates that, temperature did affect stiffness as the bleached cotton became less stiff with all bleach liquors. Bleaching with Anolyte for 40 °C and 60 °C resulted in similar results, but the stiffness of the cotton bleached with sodium hypochlorite was less as compared to Anolyte. The stiffness of the cotton bleached with sodium hypochlorite rose when bleaching temperature was raised to 60 °C. An increase of temperature to 80 °C resulted in bleached cotton becoming even less stiff than at the other temperatures. Although there were differences in stiffness as temperature rose, the statistical analysis indicate that, there was no statistical significance in the effect of temperature on stiffness between 40 °C and other temperatures.

The study indicates that treating bleached cotton with Anolyte, sodium hypochlorite and distilled water for 5, 10 and 20 cycles, resulted in cotton becoming more rigid than the untreated fabric when bleach temperature was 40 °C. However, samples treated with sodium hypochlorite were less rigid when bleached for 5 and 10 cycles and Anolyte for 10 cycles more than samples bleached with distilled water and Anolyte.

These results lead to a conclusion that different temperatures 24 °C, 30 °C, 40 °C, 60 °C and 80 °C affected the influence of Anolyte, sodium hypochlorite and distilled water on the tensile strength, stiffness and whiteness of bleached cotton, unbleached cotton, dyed cotton and stained cotton at various levels. It was concluded that, the higher the temperature the better the removal of stains and unbleached cotton became whiter. However, an increase in temperature resulted in dyed cotton losing more colour.

**HYPOTHESIS 5**

**Bleaching times of 9 minutes, 18 minutes, 45 minutes, 1 hour, 1 hour 30 minutes and 2 hours will influence the effect of Anolyte, sodium hypochlorite and distilled water on the stiffness and whiteness of unbleached cotton and stained cotton.**

**a) Whiteness**

The whiteness of the bleached stained cotton was greatly influenced by the length of exposure to the bleach to a different extend. Blood, blackcurrant juice, soot/mineral oil and tea stain were best removed as time increased especially when bleached by sodium hypochlorite. However, the whiteness of tea stain decreased as time increased when the stain was bleached with Anolyte. There was a statistical significant difference ($p < 0.05$) between

the influence of bleach times 9 minutes, 18 minutes and 45 minutes. However, there was no statistical difference between bleach times 9 minutes and 18 minutes when bleaching blackcurrant juice stain.

The whiteness of unbleached cotton bleached with Anolyte, sodium hypochlorite and distilled water was influenced by bleach times of 1 hour, 1 hour 30 minutes and 2 hours differently. The results indicate that bleaching unbleached cotton with distilled water resulted in the cotton being darker in colour than the untreated. The whiteness of the unbleached cotton treated by Anolyte also reduced as time increased. When bleaching the unbleached cotton with sodium hypochlorite the whiteness increased when bleaching time lasted for 2 hours. There was a statistically significant difference in whiteness between bleach time 1 hour and 2 hours, while there was no statistical significant difference in whiteness between bleach time 1 hour and 1 hour 30 minutes.

**b) Stiffness**

Bleaching time had an effect on the stiffness of unbleached cotton bleached at different times 1 hour, 1 hour 30 minutes and 2 hours to different extend by bleach treatments Anolyte, sodium hypochlorite and distilled water. Anolyte had little if no effect on the stiffness of unbleached cotton as the rigidity of the bleached cotton remained the same after treatment at 40 °C, 60 °C and 80 °C. The rigidity of unbleached cotton bleached with sodium hypochlorite increased as time increased when bleaching was done at temperatures 40 °C and 80 °C, while the rigidity of the unbleached cotton bleached at 60 °C decreased as time increased. There was no statistically significant difference between the influence of bleach time of 1 hour and other bleaching times.

From the results it could be concluded that as bleaching times increased it influenced the effects of Anolyte, sodium hypochlorite and distilled water on the stiffness and whiteness of unbleached cotton and stained cotton. It was established that, the whiteness of stains increased with time when bleached by the different bleaches. It was concluded also that bleaching time for unbleached cotton by Anolyte did not have any influence in the stiffness of cotton. This was compared to when the cotton was bleached with sodium hypochlorite as the stiffness increased with time when bleached at 40 °C and 80 °C and stiffness decreased with time when bleached at 60 °C. Distilled water caused the unbleached cotton to be stiffer than the other bleaches.

**HYPOTHESIS 6**

**The number of laundering cycles 5, 10 and 20 will influence the effect of Anolyte, sodium hypochlorite and distilled water on the tensile strength, stiffness and whiteness of bleached cotton and dyed cotton.**

### a) Whiteness

The number of treatment cycles of Anolyte, sodium hypochlorite and distilled water had different effects on the whiteness of bleached cotton. It was discovered from the research that the whiteness of bleached cotton treated with Anolyte and distilled water decreased as bleach cycles increased from 5 to 20 cycles. Whereas when bleached cotton was bleached with sodium hypochlorite, the whiteness increased as bleach cycles increased. However, bleach cycles 10 and 20 gave the same effect in whiteness. There was a statistically significant difference ($p < 0.05$) between the influence of bleach cycles 5 and other cycles (10 and 20).

The whiteness of bleached reactive red dyed cotton varied with bleach treatments and cycles. The results indicate that when bleaching reactive red dyed cotton with Anolyte colour was lost more as bleach cycles increased. Bleaching for 20 cycles resulted in more colour being lost hence the dyed cotton becoming whiter. The whiteness of reactive red dyed cotton bleached with sodium hypochlorite was prominent when bleached for 5 cycles especially at 24 and 30 °C. However as bleach cycles increased at these temperatures less colour was lost from the reactive red dyed cotton.  As temperature rose to 60 °C, Anolyte bleach removed more colour in the dyed cotton at 10 and 20 cycles more than sodium hypochlorite. There was a statistically significant difference between the influence of bleach cycles 5 and other bleach cycles 10 and 20.

The whiteness of vat blue dyed cotton bleached with Anolyte, distilled water and sodium hypochlorite varied with the number of bleach cycles. From the results, it was discovered that vat blue dyed cotton bleached with Anolyte lost more dye as bleach cycles increased from 5, 10 to 20 cycles. And this was observed at all the temperatures 24 °C, 30 °C and 60 °C. While when bleaching vat blue dyed cotton with sodium hypochlorite, the whiteness was more prominent as bleach cycles and temperature increased. However, Anolyte removed more colour on the vat blue dyed cotton than sodium hypochlorite. There was a statistically significant difference between the influence of bleach cycles 5 and other bleach cycles 10 and 20.

## b) Stiffness

With regard to stiffness of bleached reactive red dyed cotton, bleach treatments Anolyte, sodium hypochlorite and distilled water had different effects. The results show that, the stiffness of reactive red dyed cotton bleached with Anolyte reduced as cycles increased when bleaching temperature was 24 °C. When bleaching with Anolyte at 30 °C and 60 °C for 5 and 20 cycles there was no change in stiffness. The results indicate further that, the rigidity of reactive red dyed cotton bleached with distilled water decreased as bleach cycles increased at temperatures 24 and 30 °C. Sodium hypochlorite affected the rigidity differently as temperature rose as follows; when bleaching was at temperature 24 °C reactive red dyed cotton was more rigid than at cycle 5 and 20; at 30 °C the rigidity decreased as bleach cycles increased, however the bleach cycles 10 and 20 resulted in the same effect on rigidity; and lastly when temperature increased to 60 °C the rigidity for bleached reactive red dyed cotton was the same after 5 and 20 cycles. There was a statistically significant difference between the influence of bleach 5 cycles and other bleach 10 and 20 cycles.

The stiffness of vat blue dyed cotton bleached at 5, 10 and 20 cycles with Anolyte, distilled water and sodium hypochlorite change differently as temperature rose. The study discovered that, the stiffness of vat blue dyed cotton bleach with Anolyte and sodium hypochlorite increased becoming stiffer as cycles increased at bleaching temperature 24 °C. However, sodium hypochlorite resulted in cotton being more rigid than Anolyte treated cotton. Bleaching by both Anolyte and sodium hypochlorite resulted in the same stiffness with bending length of 2.7 cm after 5 and 20 cycles, whereby the rigidity was the same as that of the untreated. Therefore, the bleaches and bleach cycles had no effect on the stiffness. It was also noted that as temperature rose to 60 °C, the stiffness of vat blue dyed cotton bleached with sodium hypochlorite increased as bleach cycles increased. Bleached for 10 and 20 cycles resulted in the same bending length. The bending length of cotton bleached by Anolyte was less than cotton bleached with sodium hypochlorite. However, it was observed that, bleach 5 and 20 cycles resulted in the same bending length. There was no statistically significant difference between the influence of bleaching for cycles 5 and other bleach cycles 10 and 20.

The stiffness of bleached cotton at 5, 10 and 20 cycles with Anolyte, sodium hypochlorite and distilled water resulted in different bending lengths. Anolyte increased the bending length of bleached cotton more than sodium hypochlorite. The least bending lengths were observed when bleaching was 10 cycles for both Anolyte and sodium hypochlorite bleached cotton. However,

there was no statistically significant difference between the influence of bleach 5 cycles and other bleach 10 and 20 cycles.

### c) Tensile strength

The tensile strength needed to break bleached vat blue dyed cotton fabric treated with Anolyte, sodium hypochlorite and distilled water differ as bleach cycles increased at various temperatures. The maximum load needed to break vat blue dyed cotton treated with Anolyte was less than that bleached with sodium hypochlorite when bleaching temperature was 24 °C. The results from the study indicate that the maximum load needed to break cotton bleached by both Anolyte and sodium hypochlorite decreased as bleach cycles increased. However, cotton bleached with Anolyte at 30 °C and 60 °C required more load to break cotton as compared to those treated with sodium hypochlorite. There was a statistically significant difference between the influence of bleach 5 cycles and other bleach 10 and 20 cycles.

It was discovered that, the maximum load needed to break reactive red dyed cotton bleached with Anolyte, sodium hypochlorite and distilled water at 24 °C was lower when cotton was bleached with Anolyte and higher when bleached with sodium hypochlorite was used. As temperature rose to 30 °C, the maximum load need to break reactive red dyed cotton was more when the cotton was bleached with sodium hypochlorite than Anolyte. In both bleaches more maximum load was needed to break bleached cotton when the cotton was bleached for 5 cycles. An increased temperature to 60 °C resulted in a decrease in maximum load as bleach cycles increased from 5 to 20 cycles for both Anolyte and sodium hypochlorite bleached cotton. However, reactive red dyed cotton bleached with Anolyte required more maximum load at all cycles while cotton bleached with sodium hypochlorite required less tensile strength. There was a statistically significant difference between the influence of bleach 5 and 20 cycles, and there was no statistically significant difference between the influence of bleach 5 and 10 cycles.

From the study, it was discovered that the maximum load needed to break bleached cotton after laundering for 5, 10 and 20 cycles was greatly influenced by bleaches (Anolyte, distilled water, sodium hypochlorite) at different levels when bleached at 40 °C. Treating bleached cotton with sodium hypochlorite for 10 and 20 cycles resulted in using the least load to break the treated fabric, as compared to treating bleached cotton fabric with Anolyte bleach. The maximum load needed to break bleached cotton decreased as treatment cycles increased when sodium hypochlorite was used for bleaching. It was however noted that an increase in number of cycles

resulted in the bleached cotton fabric becoming more rigid when treated with distilled water. There was statistically insignificant difference between the influence after 5, 10 and 20 cycles.

From the results obtained it could be concluded that, laundering for 5, 10 and 20 cycles influenced the effect of Anolyte, sodium hypochlorite and distilled water on the tensile strength, stiffness and whiteness of bleached cotton and dyed cotton. It could be concluded that, when bleaching reactive red dyed cotton, as the number of bleach cycles increased Anolyte lost more colour as opposed to treating with distilled water and sodium hypochlorite. The increase in cycles also led to loss of colour when bleaching vat blue dyed cotton. The stiffness of reactive red and vat blue dyed cotton was also affected by number of bleach cycles, as for reactive red dyed cotton stiffness reduced as cycles increased while on vat blue dyed cotton stiffness increased with the number of cycles. It could also be concluded that, as bleach cycles increased the maximum load needed to break the dyed and bleached cotton decreased.

## **HYPOTHESIS 7**

**Anolyte, sodium hypochlorite and distilled water will not yellow bleached cotton.**

The treatments affected the whiteness of the bleached cotton to different extend. It was discovered that sodium hypochlorite was able to whiten the bleached cotton even further after 5, 10 and 20 cycles. Whilst Anolyte on the other hand whitened bleached cotton only after 5 cycles and caused it to be more yellow when bleach cycles increased to 10 and 20. In the case of items to be whitened, the results conclude that Anolyte would not be beneficial as it would not bleach white cotton further.

The ending conclusion gathered from the study is that Anolyte is not effective as a stain remover for blood, tea, soot/mineral soot and blackcurrant juice. Anolyte should not be used to bleach, bleached cotton as it caused yellowing in the bleached cotton. Anolyte cannot be used on coloured materials especially bleaching at high temperature and for many cycles as it causes loss of colour. Anolyte could not bleach unbleached cotton to the highest whiteness but could be used to bleach unbleached cotton to a certain degree of whiteness that could be desired by the consumer. Although Anolyte caused dyed cotton to lose colour, the stiffness of the dyed cotton was less than that bleached with sodium hypochlorite, making the fabric to be much softer and desirable. Anolyte do less damage to the tensile strength of vat blue dyed cotton and bleached cotton as compared to sodium hypochlorite especially when the bleaching temperature is at 24

°C. Therefore, Anolyte could still be used on bleached cotton and vat blue dyed cotton without affecting the tensile properties of the cotton fabrics. If Anolyte would be used as an environment friendly disinfectant for cotton fabrics it will be detrimental to the colour of dyed cotton and bleached cotton but it will be suitable to use on unbleached cotton. The damage done to colour could be weighed against the benefits to man and environment.

## 5.2 RECOMMENDATIONS

As no literature could be found on the use of Anolyte in the textile industry, a number of opportunities exist for further research. It could be recommended that research be done with the actual laundering processes used for hospital textiles and the results of that could be compared in terms of colour, tensile properties as well as the level of disinfection, as the actual laundering processes used for contaminated hospital linen is much more harsh than the laboratory laundering processes that we implemented. Such "real life" research is essential before we can actually recommend that this method be implemented on large scale.

# REFERENCES

- **AATCC Technical Manual. 2009.** American association of textile chemists and colourists. *Volume 86. Research Triangle Park, North Carolina*.

- **ABDEL-HALIM E.S & AL-DEYAB S.S**. **2011.** Low temperature bleaching of cotton cellulose using peracetic acid. *Journal of Carbohydrate Polymers*. Volume 86: 988-994.

- **ACTIVATED ENVIRONMENTAL SOLUTIONS**. **2014:** Retrieved date 05/05/2014 from http://www.activatedenvironmentalsolutions.com/what-is-anolyte.

- **ADANUR SABIT**. **1995.** Wellington sears handbook of industrial textiles. *Techonomic Publishing company, Inc. U. S. A.*

- **ADEYENI, A. A., JARAD, F. D., DE JONG DE JOSSELIN., PENDER, N., & HIGHAM, S.M. 2010.** The evaluation of a novel method comparing quantitative light-induced fluorescence (QLF) with spectrophotometry to assess staining and bleaching of teeth. *Clinic Oral Invest Journal*. Volume 1: 19-25.

- **ADVANCED APPLIED SCIENCE. 2008.** Extracting and testing a natural Plant. *The Nuffield Foundation GCE A2 UNITS*.

- **AGRAWAL PRAMODKUMAR BHAGWANDAS. 2005.** The performance of cutinase and pectinase in cotton scouring. *Thesis, University of Twente, the Netherlands*.

- **AGUSTINA, T. E.A & ANG, H. M.B. 2012.** De-colourization and mineralization of C.I. reactive blue 4 and C.I. reactive red 2 by fenton oxidation process. International *Journal of Chemical and Environmental Engineering*. Volume 3 (3): 141-148.

- **AHMED NAHED S.E. 2005**. The use of sodium edate in the dyeing of cotton with reactive dyes. *Dyes and pigments journal*. Volume 65: 221-225.

- **AHN, B. J., KONDO R., SAKAI K. & PAIK K. 2001**. Effect of activator on hydrogen peroxide bleaching of white ledger. *Journal. Industrial Engineering and Chemistry*. Volume 7 (5): pages 285-291.

- **AKCAKOCA E.P., OZGUNEY A.T. & ATAV R. 2007.** The efficiency of washing agents in the post dyeing removal of hydrolysed reactive dye. *Dyes and pigments journal*. Volume 72: 23-27.

- **ASPLAND J. R**. **1992.** Vat dyes and their Application. *School of Textiles, Clemson University, Clemson, S. C*. Volume 24 (1): 22-24.

- **BABU, B. R., PARANDE, A. K., RAGHU, S., & KUMAR T. P. 2007**. Textile technology: cotton textile processing: Waste generation and effluent treatment. *The Journal of cotton science*. Volume 11:141 – 153.

- **BAPTISTA ROBERT J. 2009.** The chemistry and manufacture of vat dyes. Unpublished paper. Retrieved 20 September 2013.

- **BEACH EMILY. 2011.** The effects of chlorine bleach on the environment. *Retrieved 30/03/2012 from www.livestrong.com/article/217675-the-effects-of-chlorine-bleach-on-the-environment.*

- **BECHTOLD THOMAS, MAHMAD – ALI AMALID & MUSSUK RITA. 2007.** Anthocyanin dyes extracted from grape pomace for the purpose of textile dyeing. *Journal of the Science of Food and Agriculture*. Volume 87 (14): 2589- 2595.

- **BECHTOLD THOMAS, PETER MAIER & WOLFGANG SCHROTT**. **2010.** Bleaching of indigo-dyed denim fabric by electrochemical formation of hypohalogenites *in situ. Journal of colour technology*. Volume 121: 65-68.

- **BEGUM ASMA. 2012.** Advantages of prewashed 100 % cotton knit fabric over scoured – bleached fabric in deep colour reactive dyeing process. Bleached fabric in deep colour reactive dyeing process. *International Journal of Engineering & Technology IJET-IJENS*. Volume 12 (1): 5-15.

- **BEHERA B.K. & HARI P.K. 2010**. Woven textile structure: theory and applications. *Wood head Publishing Limited. UK.*

- **BEHERA B.K. 2007.** Comfort and handle behaviour of linen-blended Fabrics. *AUTEX Research Journal*. Volume 7 (1):33-47.

- **BERECK ATTILA, SILKE DILLBOHNER, BURKHARD WEBER, DIETER RIEGEL, JORG MOSEL, JOHANNES MICHAEL PIEPER AND AXEL BRAKELMANN. 1997**. A simple method for the objective characterisation of - fabric softness. Part 1: Influence of bleaching, dyeing and crosslinking of wool. *JSDC Volume 113, pages 322 to 326.*

- **BISHOP MUSEUM. 1996**. To bleach or not to bleach. The State Museum of Natural and Cultural History. *Conservation handout*. Bernice Street Honolulu Hawai'i 96817-0916 USA.

- **BRENNAN CAROL. SAS-Soap Machines.** Retrieved on the 30/03/2012 from *www.madehow.com*

- **BROADBENT ARTHUR D. 2001.** Basic principles of textile colouration. *Published by the Society of Dyers and Colourists. Company Publications Trust. England.*

- **CAI JACKIE. Y. & EVANS DAVID J. 2007**. Guanidine derivatives used as peroxide activators for bleaching cellulosic textiles. *Commonwealth Scientific & Industrial Research Organization (CSIRO), Colouration Technology*. Volume 123: 115- 118.

- **CANDACE H. HAIGLER, DESHUI ZHANG & CURTIS G. WILKERSON**. **2005.** Biotechnological improvement of cotton fibre maturity. *Physiologia Plantarum*. Volume 124: 285–294.

- **CARMEN ZAHARIA & DANIELA SUTEU. 2012**. Textile organic dyes – characteristics, polluting effects and separation/elimination procedures from industrial effluents – A critical overview, organic pollutants ten years after the Stockholm convention - environmental and analytical update, *Dr. Tomasz Puzyn (Ed.), ISBN:978-953-307-917-2, Intec, Available from:* [http://www.intechopen.com/books/organic-pollutants-ten-yearsafter](http://www.intechopen.com/books/organic-pollutants-ten-yearsafter)

- **CARSON P.A., C.S. FAIRCLOUGH, C. MAUDUIT & M. COLSELL**. **2006.** Peroxy bleaches: Part 1. Background and techniques for hazard evaluation. *Journal of Hazardous Materials A136*. Pages 438–445.

- **CELANESE ACETATE LLC. 2001.** Complete textile glossary. Three Park Avenue. New York.

- **CHAARI ISLEM and JAMOUSSI FAKHER. 2011.** Application of activated carbon for vat dye removal from aqueous solution. *Journal of Applied Sciences in Environmental Sanitation*. Volume 6 (3): 247-256.

- **CLOETE T. E., THANTSHA M. R., MALULEKE M. R. & KIRKPATRICK R. 2009.** The antimicrobial mechanism of electrochemically activated water against *Pseudomonas aeruginosa and Escherichia coli* as determined by SDS-PAGE analysis. *Journal of Applied Microbiology*. Volume 107:379 -384.

- **COHEN A.C. & JOHNSON I. 2010.** Fabric science. 9th Edition. Fairchild books. New York.

- **COLLIER B.J, BIDE M. & TORTORA**. **2009.** Understanding textiles. 7th Ed. Pearson Prentice Hall. New Jersey.

- **COLLIER BILLIE J. & EPPS HELLEN H. 1999.** Textile testing and analysis. Prentice Hall Inc. United Kingdom.

- **COSTA MAYARA CARANTINO, FRANCISCO SUETÔNIO B. & MOTA E ANDRÉ BEZERRA DOS SANTOS. 2012.** Effect of dye structure and redox mediators on anaerobic azo and anthraquinone dye Reduction. *Quim. Nova Journal*. Volume 35 (3): 482-486.

- **DAS D., S. BAKSHI AND D. B.DATTA. 2005.** Dyeing of Sericin-modified Cotton with reactive dye in absence of salt national institute of fashion technology, (Ministry of Textiles, and Govt of India). The fibre society spring international conference 2010-May12-14 held at UIB – Uludağ Exporters Union and BUTEKOM–Bursa Textile & Confection Research Center.

- **DEO H T & B K DESAI. 1999.** Dyeing of cotton and jute with tea as a natural dye. *226 JSDC.* Volume 115 (7-8):224-227.

- **EKSOY. 2012.** Cotton: Spirit of textiles. Retrieved on the 26/11/2013 from *www.eksoy.com*.

- **ELSASSER VIRGINIA HENCKEN. 2010.** Textiles: concepts and principles. 3rdedition. Fairchild Publications, Inc. U.S.A.

- **ENVIRONMENTAL HEALTH PERSPECTIVES. 2002.** Innovations: a cleaner way to colour cotton. Volume 110 (5): 252 – 254.

- **EREN HUSEYIN AKSEL & OZTURK DILEK. 2010**. The evaluation of ozonation as an environmentally friendly alternative for cotton preparation. *Textile research Journal.* Volume 0(0): pages 1-8.

- **EVANS BRUCE A. ANON**. Potential water and energy savings in textile bleaching. Chemicals and Pigments Department, Chestnut Run, Wilmington, DL 79898.

- **FABRIZIO K.A. & CUTTER C.N. 2005.** Application of electrolyzed oxidizing water to reduce *Listeria monocytogenes* on ready to eat meat. *Journal of Meat Science.* Volume 71: 327 – 333.

- **FARRELL MATTHEW JULIAN. 2012**. Sustainable cotton dyeing. Thesis. North Carolina State University.

- **FERGUSSON STANLEY MACARTHUR. 2008.** The effect of laundry detergents and residual alkali on the light fastness of reactive dyes on 100% cotton. Thesis. School of Fashion & Textiles Design & Social Context Portfolio RMIT University.

- **FIJAN SABINA, SONJA ŠOSTAR TURK & BRANKO NERAL. 2007.** The influence of industrial laundering of hospital textiles on the properties of cotton fabrics. *Textile Research Journal.* Volume 77 (4): 247–255.

- **GENTILE DANIELA BERNADETTE. 2009**. Reduced Salt Usage in Dyeing of 100% Cotton Fabric. Dissertation. RMIT University.

- **GHEBREMICHAEL K., MUCHELEMBA E., PETRUSEVSKI B. & AMY G. 2011**. Electrochemically activated water as an alternative to chlorine for decentralized

disinfection. *Journal of water supply; research and technology*. Volume 60 (4): 210-218.

- **GOETZ CHARITY. 2008.** Textile dyes: techniques and their effects on the environment with a recommendation for dyers concerning the green effect. Thesis. Liberty University.

- **GOHL E. P. G. & VILENSKY L. D. 1983.** Textile science. Longman Cheshire Pty Ltd. Australia.

- **GORDON S & HSIEH Y-L. 2007.** Cotton: Science and technology. Woodhead Publishing Limited. Cambridge, England.

- **GORJANC M., KOVAČ F., & GORENŠEK M. 2011.** The influence of vat dyeing on the adsorption of synthesized colloidal silver onto cotton fabrics. *Textile research journal*. Volume 82 (1): 62-69.

- **GÜL .S,, O. EREN, S, KIR AND Y. ÖNAL. 2012.** A comparison of different activated carbon performances on catalytic ozonation of a model azo reactive dye. *Water science technology Journal*. Volume 66 (1): 179-184.

- **HASHEM MOHAMED M. 2007.** An approach towards a single pre-treatment recipe for different types of cotton. *Fibres and textiles Journal in Eastern Europe*. Volume 15 (2) 61: 85-92.

- **HASHEM MOHAMED, MANAL EL-BISI, SAMER SHARAF & RAKIA REFAIE. 2010.** Pre-cationization of cotton fabrics: An effective alternative tool for activation of hydrogen peroxide bleaching process. *Journal of Carbohydrate Polymers*. Volume 79: 533–540.

- **HOSSAIN SONIA & UDDIN KOUSHIC. 2011.** Comparative analysis between conventional pre-treatment and bio-preparation. *International Journal of Engineering & Technology. IJET-IJENS*. Volume 11 (3): 14-19.

- **HOU A., ZHANG X. & ZHOU Y. 2010.** Low temperature bleaching of cellulose fabric with (N-[4-triethylammoniomethyl]-benzoyl) caprolactam chloride as novel cationic activator for $H_2O_2$ bleaching. *Journal of Carbohydrates Polymers*. Volume 82: 618-622.

- **HOUCK MAX M. Editor. 2009.** Identification of textile fibres. Wood Head publishing in textiles. Cambridge. New Delhi, Number 84.

- **HUANG GANG, WANG JUNHUA, DONG FENGCHUN & JIA YONGTANG. 2012.** Application of activators for hydrogen peroxide bleaching at low temperature. *2nd International Conference on Electronic & Engineering and Information Technology. Published by Atlantis Press, Paris, France*. Pages 1550- 1553.

- **HUANG YU-RU, HUNG YEN-CON, HSU SHUN-YAO, HUANG YAO-WEN & HWANG DENG-FWU. 2008.** Application of electrolyzed water in the food industry. *Journal of Food control.* Volume 19: 329 – 345.

- **HUSSAIN TAVEER, MALIK ALI ZULFIQAR & TANWARI ANWARUDDIN.** **2010.** Prediction of tensile strength of polyester/cotton blended woven fabrics. *Indian Journal of fibre and fabrics & textile research.* Volume 35: 243- 249.

- **IDRIS AZNI & SAED KATAYON. 2002.** Degradation of phenol in wastewater using Anolyte produced from electrochemical generation of brine solution. *Global nest: the international Journal.* Volume 4 (2-3): 139-144.

- **INAM ULLAH, SHAUKAT ALI, MUHAMMAD ASIF HANIF, SHAUKAT ALI SHAHID ISLAM MD. MAZEDUL & KHAN ADNAN MAROOF. 2013.** Functional properties improvement and value addition to apparel by soil release finishes - a general overview. *Research Journal of Engineering Sciences.* Volume 2 (6): 35-39.

- **ISLAM MD. MAZEDUL & ADNAN MAROOF KHAN. 2013.** Functional properties improvement and value addition to apparel by soil release finishes - a general overview. *Research Journal of Engineering Sciences.* Volume. **2(6):** 35-39.

- **ISO/SANS. 1999.** 13934-1 Textiles tensile properties of fabrics- Part 1: Determination of maximum force and elongation at maximum force using the Strip Method.

- **IZHEVSK STATE MEDICAL ACADEMY, IZHEVSK. ANON 2.** Investigation of Human Cells to assess the toxicity of Disinfectants used for destroying microbes and viruses at the work place. (Anolyte Vs Sodium Hypochlorite).

- **JERI TINA, ROEL J. M. BISSELINK, WILLY VAN TONGEREN & ALENKA M. LE MARECHAL. 2013.** De-colourization and mineralization of reactive dyes, by the H2O2/UV process with Electrochemically Produced H2O2. *Acta Chim. Slov. Volume 60, pages 666–672.*

- **JOHANSSON, I. & SOMASUNDARAN, P. 2007.** Handbook of cleaning/decontamination of sources (Volume 2). Amsterdam: Elsevier.

- **JOURNAL OF TEXTILES, AND APPAREL TECHNOLOGY AND MANAGEMENT. 2002.** 100% Cotton Moisture Management. *North Carolina University. Volume 2, Issue 3.*

- **JUCIENĖ MILDA, DOBILAITĖ VAIDA AND KAZLAUSKAITĖ GUIEDRĖ. 2006.** Influence of Industrial Washing on Denim Properties. *Materials Science (Medziagotyra)* Volume 2 (4): 355-359.

- **KADOLPH SARAH J. 2011.** Textiles. 11th Edition. Prentice Hall. U.S.A.

- **KAJIWARA K. 2009.** Synthetic textile fibres: Structure characteristics and identification. *Otsuma women's University of Japan.* Pages 68 -87.

- **KARIM S. KARBALAIE, GHAREHAGHAJI A.A. & TAVANAIE H. 2007.** A study of the damage caused to dyed cotton fibres and its effects on the properties of rotor- and ring-spun mélange yarns. *FIBRES & TEXTILES in Eastern Europe July / September.* Volume 15 (3) (62): 63-67.

- **KARMAKAR S.R. 1999.** Chemical technology in the pre-treatment processes of textiles. Elsevier Science, B.V. Netherlands.

- **KATZ DAVID. 2003.** Dyes and dyeing. Retrieved on the 03/10/2013 from http://www.chymist.com/Dyes.pdf.

- **KHAN MD. MASHIUR RAHMAN, MD. IBRAHIM H. MONDAL & MD. ZULHASH UDDIN. 2011.** Effect of Bleach Wash on the Physical and Mechanical Properties of Denim Garments. *International Conference on Mechanical Engineering 2011 (Icme2011) 18-20 December 2011, Dhaka, Bangladesh. Pages 1-6.*

- **KHAN MD. MASHIUR RAHMAN, MD. IBRAHIM H. MONDAL, A.B.M. FAKRUL ALAM & MD. MOHSIN HOSSAIN. 2012.** Modification of Denim Garment with the Treatment of Bleaching Powder. *Canadian Journal on Chemical Engineering & Technology.* Volume 3 (2): 30-36.

- **KHANJANI, Y., FARIZADEH, K., & AHMADI, S. 2011.** Improve of direct dye (Direct Orange 46) sorption on pre-treated cotton fabric by cationic agent. *Journal of Applied Chemical Research.* Volume 18: 7 – 14.

- **KHATRI AWAIS. 2011.** Use of Biodegradable Organic Salts for Pad-Steam Dyeing of Cotton Textiles with Reactive Dyes to Improve Process Sustainability. *2011 International Conference on Education, Research and Innovation (IPEDR).* Volume 18: 83-89.

- **KHEDHER FAOUZI., SOUFIEN DHOUIB, SLAH MSAHLI & FAOUZI SAKLI. 2009.** The influence of industrial finishing treatments and their succession on the mechanical properties of denim garment. *Autex research journal.* Volume 9 (3): 93-100.

- **KIM C., Y.-C. HUNG & S. M. RUSSELL. 2005.** Efficacy of electrolyzed water in the prevention and removal of fecal material attachment and its microbicidal effectiveness during simulated industrial poultry processing. *Poultry Science.* Volume 84: 1778- 1784.

- **KIM CHYER, YEN-CON HUNG', ROBERT E. BRACKETT and JOSEPH F. FRANK. 2001.** Inactivation of lzsteria monocytogenes biofilms by electrolyzed oxidizing water. *Journal of Food Processing Preservation.* Volume 25: 91-100.

- **KIM SUYEON, DIEGO MOLDES, ARTUR CAVACO-PAULO. 2007.** Laccases for enzymatic colouration of unbleached cotton. *Enzyme and Microbial Technology.* Volume 40: 1788–1793.

- **KISSA E., DOHNER J. M., GIBSON W. R. & STRICKMAN. 1991**. Kinetics of staining and bleaching. *JAOCS.* Volume 68 (7): 532- 538.

- **KUMBASAR E. PERRIN AKÇAKOCA, AYŞEGÜL E. KÖRLÜ & CANDAN CAN. 2011** The effects of activator on whiteness and hydrohility during the hydrogen peroxide Bleaching. *Tekstil Ve Konfeksiyon 1/.* Pages 50-57.

- **LAWRENCE CARL A. 2003.** Fundamental of spun yarn technology. CRC Press. USA.

- **LAZIĆ V., ŠAPONJIĆ Z., VODNIK V, DIMITRIJECVIĆ S, JOVANČIC J., & RADETIĆ M. 2012.** A study of the antibacterial activity and stability of dyed cotton fabrics with different forms of silver. *Journal of the Serbian Chemical Society.* Volume 77 (2): 225-234.

- **LEVERETTE MARLOWE MARY. 2014.** How do I remove Tea stains from clothes? About.com Laundry. Retrieved from http://laundry.about.com/od/stainremoval/f/removeteastain.htm 20/02/2014.

- **LIM SANG-HOON, JUNG JIN LEE, DAVID HINKS AND PETER HAUSER. 2005.** Bleaching of cotton with activated peroxide Systems. *Colour Technology.* Volume. 121: 90-95.

- **MAEKAWA MASAKO, AKIKO HASHIMOTO & MITSURU TAHARA. 2007.** Effects of pH in Hydrogen Peroxide Bleaching of Cotton Fabrics Pretreated with Ferrous Sulfate. *Textile Research Journal.* Volume 77 (4): 222–226.

- **MAHMOOD NASIR, N. A. JAMIL, M. ARSHAD, M.Q. TUSIEF & M. IFTIKHAR. 2009.** Interaction study of polyester and multi bleached cotton blends for the tensile properties of rotor spun mélange yarn. *Pak. Journal of Agricultural Science.* Volume 46 (1): 46-50.

- **MALIK ZULFIQAR ALI, MUMTAZ HASAN MALIK, TANVEER HUSSAIN & FAROOQ AHMED ARAIN. 2011.** Development of models to predict tensile strength of cotton woven fabrics. *Journal of Engineered Fibres and Fabrics.* Volume 6 (4): 46-52.

- **MANGUT MURUVVET. 2008**. Effects of repeated home laundering and non-durable press on the colour properties of plain woven polyester fabric. *Indian Journal of Fibre and Textile research.* Volume 33: 80-87.

- **MARAIS J. T, WILLIAMS W. P. 2001**. Antimicrobial effectiveness of electro-chemically activated water as an endodontic irrigation solution. *International Endodontic Journal.* Volume 34: 237–243.

- **MATE MADHURI SAHASRABUDHE & GIRISH PATHADE. 2012.** Biodegradation of C.I. Reactive Red 195 by Enterococcus faecalis strain YZ66. *Journal of World J Microbial Biotechnology.* Volume 28: 815–826.

- **McINTYRE J.E. Editor. 2005.** Synthetic Fibres: Nylon, Polyester, Acrylic, Polyolefin. Woodhead Publishing Limited. England.

- **MENACHEM LEWIN. 2007.** Cotton fibre chemistry and technology. CRC press, Taylor & Francis group. USA.

- **MENEZES EDWARD & CHOUDHARI MRINAL. 2011.** Pre-treatment of textiles prior to dyeing. *ISBN: 978-953-307-565-5, In Tech.*

- **MEYER LESLIE, MACDONALD STEPHEN & KIAWU JAMES**. **2013.** Cotton and wool outlook: global cotton production to decline in 2013/2014 but still exceed consumption. United States Department of Agriculture. *World Agricultural Supply and Demand Estimates, Economic Research Services USDA.*

- **MILLER EDWARD. 1992.** Textiles: properties and behavior in clothing use. BT Bats ford Ltd London.

- **MISTIK S. ILKER, S. MÜGE & YÜKSELOĞLU. 2005.** Hydrogen peroxide bleaching of cotton in ultrasonic energy. *Journal of Ultrasonics.* Volume 43: 811–814.

- **MOISSAN HENRI RUE. 2012.** Bleaching textile using Sodium chlorite. CRRA. France.

- **MORTON W.E. & HEARLE J. W. S. 1997.** Physical properties of textile fibres. Bookcraft, Midsomer Norton, Bath, UK.

- **MUHAMMAD MUSHTAQ & AMIR SHAFEEQ. 2013.** Performance of pretreated antimicrobial agent (AEM-5707) on cotton fabric dyed with reactive dye. *International Journal of Chemical and Biochemical Sciences.* Volume 3: 132-135.

- **NAKAE HAJIME & HIDEO INABA. 2000**. Effectiveness of electrolyzed oxidized water irrigation in burn-wound infection model. *The Journal of* TRAUMA *Injury, Infection, and Critical Care.* Volume 49 (2) no.3: 511-514.

- **NATASHA VAN HEERDEN. 2010.** The Evaluation of Electro-Chemically Activated Water as an Alternative Detergent for Polyamide and Machine Washable Wool. Masters Dissertation. University of the Free State, South Africa.

- **NEEDLES HOWARD L. 1986.** Textile Fibres, Dyes, Finishes, And Processes: A Concise Guide Noyes Publications Mill Road, Park Ridge, New Jersey. USA.

- **OCCIDENTAL CHEMICAL CORPORATION. 2000.** Oxy-Chem Sodium Hypochlorite Handbook. Basic chemicals group. Dallas.

- **OHLSSON ANNA. 2006.** Comparison of flavour compounds in juices from different blackcurrant varieties chemistry. University of Kalmar, School of Pure and Applied Natural Sciences examination Project Work.

- **PERKINS H.M., RIGAKIS K. B. & CROWN E. M. 1996.** The acceptability of chlorine bleach pretreatment for removal of chloropyrifos residues from cotton and polyester/cotton fabrics. *Archives, of environmental contamination and toxicology.* Volume 30: 127-131.

- **PERKINS WARREN S. 1996.** Advances made in bleaching practice. 1995 AATCC international conference. ATI January 1996.

- **PERKINS WARREN S. 1996.** Textile Colouration & Finishing. Carolina Academic Press. North Carolina.

- **POGGI M. A. & D. G. MANCOSKY. 2005.** Atomic force microscopic analysis of hydrogen peroxide bleached kraft northern black spruce fibres. *Journal of Microscopy.* Volume 220: 77–83.

- **POLLUTION PREVENTION AND ABATEMENT HANDBOOK. 1998.** Dye Manufacturing. The World Bank Group in collaboration with the United Nations environment programme and United Nations Industrial Development Organizations. The World Bank Group. Washington DC.

- **PONNUSAMY THIRUSELVAM, SUSHILKUMAR A. DUBAL & SHAMIN A. MOMIN. 2008.** Studies in detergency: influence of different factors for removing motor oil stain from the cotton fabric. *Journal of Dispersion Science and Technology.* Volume 29: 1123–1128.

- **PRICE, A., COHEN, A., & JOHNSON, I. 2005**. Pizzuto's fabric science. New York: Fairchild Publications.

- **PUŠIĆ T, JELĬČIĆ JASEKA & MILA NUBER. 2007.** Investigation of bleach active compounds of washing. *Tekstil.* Volume 56 (7): 407-411.

- **PV22.COM CORPORATION. 2014.** How to wash the blood stains on the clothes. Retrieved on the 02/07/2014 from http://pv22.com/archives/7f41ececc70c72593d095c14/.

- **Q-WATER. 2012.** Comparison of Eco-Q Anolyte to Chlorine. Oklahoma Baptist University.

- **REINHARDT G. 2006.** Fingerprints of bleach systems. *Journal of Molecular Catalysis A: Chemical.* Volume 251:177–184.

- **RIZA ATAV & OSMAN NAMIRTI. 2001**. Dyeing of polyamide fabrics with a natural dye: recommendation for dyers concerning the green effect. Thesis. Liberty University.

- **ROBINSON G.M., S.W.-H. LEE, J. GREENMAN, V.C. SALISBURY & D.M. REYNOLDS. 2010**. Evaluation of the efficacy of electrochemically activated solutions against nosocomial pathogens and bacterial endospores. *The Society for Applied Microbiology, Letters in Applied Microbiology.* Volume 50: 289–294.

- **RODRÍGUEZ-COUTO S. 2012.** Laccases for denim bleaching: An eco-friendly alternative. *The Open Textile Journal.* Volume 5: 1-7.

- **SAEED Q, BHATTI, I. A., ZUBER, M., NOSHEEN S., ZIA, M. A., & ABBAS, M. 2012.** Study of application of Mono azo reactive dyes on Cotton by exhaust method and printing properties. International Journal of Basic & Applied Sciences. Volume 12 (6): 191- 197.

- **SALAM, M. A., SHEIK, R. K., & FAROUIQUE, F. I. 2006.** Improvement of the colour fastness properties onto bleached sulfonated Jute with Direct Dyes. *Journal of textile and apparel, technology and management.* Volume 5 (3):1-4.

- **SANTHI P. & MOSES J. JEYAKODI. 2008.** The study on the reduction process of Vat dye on cotton fabric using ferrous sulphate and its effect on effluent load. *Current World Environment.* Volume 3(2):239-244.

- **SANTHI P. & MOSES J.J. 2010.** Study on different reducing agents for effective vat dyeing on cotton fabric. *Indian Journal of Fibre & Textile Research.* Volume 35: 349-352.

- **SARAVANAN D., VASANTHI N.S. & RAMACHANDRAN T. 2009.** A review on influential behaviour of bio polishing on dyeability and certain physic-mechanical properties of cotton fabrics. *Carbohydrate Polymers.* Volume 76: 1–7.

- **SARKAR JOY & KHALIL ELIAS. 2014.** Effect of industrial bleach wash and softening on the physical, mechanical and colour properties of denim garments. *Journal of polymer and textile engineering.* Volume 1 (3): 46-49.

- **SARKAR MD. SOLAIMAN JOY & KHALIL ELIAS. 2014.** Effect of enzyme washing combined with pumice stone on the physical, mechanical and colour properties

of denim garments. *International journal of research in advent technology*. Volume 2(9): 65-69.

- **SATINDAR KAUR, CHATTOPADHYAY D.P. & VARINDER KAUR. 2012.** Dyeing of Bamboo with Tea as a Natural dye. *Research Journal of Engineering Sciences*. Volume 1 (4): 21-26.

- **SAVILLE B. P. 1999.** Physical testing of textile. The Textile Institute. Wood head Publishing Limited. Cambridge England.

- **SCOUT EVELYN E. 1970.** Introduction to textiles. 3rdedition. John Wiley & Sons, co. U.S.A.

- **SHAHIDI SHEILA, JAKUB WIENER & MAHMOOD GHORANNEVISS. 2013.** Surface modification methods for improving the dyeability of textile fabrics. Intec open Science. *http://dx.doi.org/10.5772/53911*

- **SHAMEY R. & HUSSEIN T. 2005**. Critical solutions in the dyeing of cotton Textile Materials. *The Textile Institute. doi:10.1533/tepr.2005.0001.*

- **SHAO JIANZHONG, LIU JINQIANG & CARR C M. 2001.** Investigation into the synergistic effect between UV/ozone exposure and peroxide pad–batch bleaching on the printability of wool. *Colour and technology Journal*. Volume 117: 270-275.

- **SHARMA ANSHU & GROVER EKTA. 2011.** Colourfastness of walnut dye on cotton. *Indian journal of natural products and resources*. Volume 2 (2): 164-169.

- **SOLOVYOV A.A., A.N. GOLENDUKHIN, T.G. GLUSHKOVA, G.G. LYUDKOV & STEINER NORBET. 1995.** Evaluation of peracetic acid as an environmentally safe alternative for hypochlorite. *World Bank Group*. Pages 298-300.

- **ŠPIČKA NINA & TAVČER PETRA FORTE. 2013**. New combined bio-scouring and bio-bleaching process of cotton fabrics. *Materials and technology*. Volume 47 (4): 409-412.

- **STEPONAVIČIUS DAINIUS, ALGIRDAS RAILA, AUŠRA STEPONAVIČIENĖ, ALBINAS LUGAUSKAS & AURELIJA KEMZŪRAITĖ. 2012.** Preventive measures reducing superficial mycobiotic contamination of grain. *Annals of agricultural and environmental Medicine*. Volume 19 (2):193-201.

- **STONE JANIS**. **2009.** Quick 'n Easy Stain Removal. IOWA State University. University Extension.

- **TAKASU Y., MASUKI Y. & MATSUDA. 1986.** Electrochemical chlorination of butadiene using $CeCl_3$-MeCN Anolyte. *Journal of applied electrochemistry. Volume 16*:304-306.

- **TANG R-C., TANG HUI & YANG CHENG. 2010**. Adsorption Isotherms and mordant dyeing properties of tea polyphenols on wool, silk and nylon. *American Chemical Society*. Volume 49: 8894-8901.

- **TARHAN, M. & SARIISIK, M. 2009.** A Comparison among performance characteristics of various denim fading processes. *Textile research Journal*. Volume 79 (4): 301-309.

- **TAVČER FORTE PETRA. 2012.** Low temperature bleaching of cotton induced by glucose oxidase enzymes and hydrogen peroxide activators. *Journal of Bio-catalysis and Biotransformation*. Volume 30 (1): 20-26.

- **TAVČER PETRA FORTE, PAVLA KRIŽMAN & POLONCA PREŠA. 2006.** Combined bio-scouring and bleaching of cotton fibres. J*ournal of Natural Fibres*. Volume 3, No. 2/3, pages 83-97.

- **TERRY DEED (ANON 1) (**Du Pont Peroxide Ltd.) with editing by Heather Wansbrough. I-Chemicals-E-Hydrogen Peroxide-6.

- **TOPALOVI. T. 2007.** Catalytic bleaching of cotton: molecular and macroscopic aspects .Thesis. University of Twente, the Netherlands.

- **TOPALOVIC TATJANA , VINCENT A. NIERSTRASZ , LORENZO BAUTISTA , DRAGAN JOCIC, ANTONIO NAVARRO & MARIJN M.C.G. WARMOESKERKEN. 2007.** XPS and contact angle study of cotton surface oxidation by catalytic bleaching. *Journal of colloids and surfaces and physicochemical engineering Aspects*. Volume 296: 76–85.

- **TOPALOVIC TATJANA, VINCENT A. NIERSTRASZ, LORENZO BAUTISTA, DRAGAN JOCIC, ANTONIO NAVARRO MARIJN & M. C. G. WARMOESKERKEN. 2007**. Analysis of the effects of catalytic bleaching on cotton. *Cellulose*. Volume. 14: 385–400.

- **TORTORA P.G., BIDE M J., COLLIER B. J. 2009. 7th** Ed. Understanding textiles. Pearson Prentice Hall. U.S.A.

- **TORTORA PHYLLIS G. & COLLIER BILLIE J. 2001. 6th** Ed Understanding textiles. Prentice hall. Upper saddle river, New Jersey.

- **TZANKO T., COSTA A. S., GÙBITZ M. & CAVACO-PAULO. 2002.** Hydrogen peroxide generation with immobilized glucose oxidase for textile bleaching. *Journal of Biotechnology*. Volume 93:87 – 94.

- **VAN ZYL J.S. 2012.** Katoliet as detergent vir katoen-, poliëster-en poliësterkatoenmengelstot. Master's Thesis. University of the Free State, Bloemfontein South Africa.

- **VASSILEVA, V., VALCHEVA, E., & ZHELEVA, Z. 2008.** The kinetic model of reactive dye fixation on cotton fibres. *Journal of the University of Chemical Technology and Metallurgy.* Volume 43 (3): 323 - 326.

- **VERMAAS JANA F. 2011**. Evaluation of the antimicrobial effect and strength properties of polyester, polyester/cotton and cotton treated with Anolyte. Ph.D. Thesis University of the Free State, South Africa.

- **VIGO TYRONE L. 1994.** Textile Processing and Properties and Properties: Preparation, Dyeing, Finishing and Performance. Elsevier Science B. V. Netherlands.

- **VISSER D.J. 1985**. Biological influences on the quality properties of wool. *South African Journal of Animal Science.* Volume 15 (3): 123-127.

- **WALLACE MICHELLE. 2002.** 100% Cotton Moisture Management. *Journal of textiles and apparel technology and management. North Carolina University.* Volume 2 (3): 1-10.

- **WANG XIN, SHEN XIAOLIN & XU WEILIN. 2012.** Effect of hydrogen peroxide treatment on the properties of wool fabric. *Journal of Applied Surface Science.* Volume 258:10012-10016.

- **WASIF A.S & INDI Y.M. 2010.** Combined scouring-bleaching of cotton using potassium persulphate. *Indian journal of fibre & textile research.* Volume 35: 353-357.

- **WIEPRECHT T, HAZENKAMP M., ROHWER H., SCHLINGLOFF G & XIA J. 2007.** Design and application of transition metal catalysts for laundry bleach. *C.R. Chimie journal.* Volume 10:326-340.

- **WOOTTON DAVID B. 2001.** The application of textiles in rubber. Polestar Scientifica, Exeter, United Kingdom.

- **WULFHORST BURKHARD, GRIES THOMAS & VEIT DIETER. 2006.** Textile Technology. Hanser Publishers, Munich. Germany.

- **XU CHANGHAI, HINKS DAVID & SHAMEY RENZO. 2011**. Development of a novel bleaching process for cotton. *AATCC review.* November/December 2011, U.S.A:73 - 77.

- **XU KAN, SHAO JIANG LAOA, HAI YING QINA, BIN HONG LIUB, & ZHOU PENG LI. 2010.** A study of the direct dimethyl ether fuel cell using alkaline Anolyte. *Journal of Power Sources.* Volume. 195: 5606–5609.

- **YANG YIGI AND XU LAN. 1996.** Reusing hydrolysed reactive dye bath for nylon and wool dyeing. *American dyestuff reporter*. Pages 27-34.
- **YILMAZER DUYGU & KANIK MEHMET. 2009.** Bleaching of wool with sodium borohydride. *Journal of Engineered Fibres and Fabrics*. Volume (4)3:45 – 50.
- **YÜKSEKKAYA MEHMET EMIN, THOMAS HOWARD, & SABIT ADANUR. 2008.** Influence of the fabric properties on fabric stiffness for the industrial fabrics. *TEKSTİL ve KONFEKSİYON*. Pages 263-267.
- **ZHANG FEI, JACOBSON KYLE S., TORRES PAOLO & HE ZHEN. 2010.** Effects of Anolyte recirculation rates and Catholytes of electricity generation in a litre scale up flow microbial fuel cell. *Journal Energy and Environment Science*. Volume 3: 1347 – 1352.
- **ZOLLER URI. 2009**. Handbook of detergents. Taylor and Francis group. LLC, USA.

# ABSTRACT

Bleaches are used in the textile industry for brightening, whitening and cleaning fabrics. The two commonly used bleaches are hypochlorite and peroxide bleaches. Peroxide bleaches are used more often than chlorine bleaches in fabric finishing. Chlorine is a harsh chemical harmful to human health and may even destroy the cotton fibre if not monitored. It destroys the cellulose and that affects the quality of the bleached fabric. Large amounts of these bleaches are released into the environment through washing and they harm the environment and ozone layer. Hence, new and better ways of bleaching needs to be investigated.

Electrochemically activated water (Anolyte) has been recently introduced to the food industries as a disinfecting agent. Disinfection with Anolyte has been successful and convenient because Anolyte is generated onsite by simple electrolysis of a dilute salt solution. The production of Anolyte requires lower production cost and hazards associated with handling, transportation and storage. Anolyte is stable and after 48 hours the solution become inactive water and can be discarded without causing harm to the environment. Although Anolyte has been successful in the food industry, extensive research has not been done to determine whether it can be used in the textile industry.

The aim of this study was to investigate the effectiveness of Anolyte as a bleaching agent compared to the commonly used sodium hypochlorite. Distilled water was used as control. The efficacy of Anolyte was determined at 24°C 30°C, 40°C, 60°C and 80°C. The effect of Anolyte and sodium hypochlorite on bleached cotton, unbleached cotton, dyed cotton and stained cotton respectively were evaluated in terms of tensile strength, stiffness and whiteness. Further investigations were done on the effect of bleaching temperatures mentioned above and duration of exposure ranged from 9 minutes, 18 minutes, 30 minutes, 45 minutes, 60 minutes, 90 minutes and 120 minutes. The study was an experimental research where bleaching of samples was done according to AATCC Test Method 61- 2009 carried out in the Launder-Ometer.

Reactive red dyed cotton, vat blue dyed cotton, bleached cotton and unbleached cotton were laundered for 5, 10 or 20 cycles respectively for the evaluation of the influence on tensile strength, stiffness and colour change. The tensile strength tests were conducted with the Instron Tensile Tester and ISO/SANS 13934-1:1999 test method. The stiffness test ASTM D1388 – 08 the Cantilever principle was used. While AATCC test method 135-1985 for instructional colour measurement of textiles was used in determining colour change.

The results gathered from the study indicated that Anolyte was less effective than sodium hypochlorite as a stain remover for blood, tea, soot/mineral oil and blackcurrant juice. Anolyte caused more colour loss on coloured materials than sodium hypochlorite especially at high temperatures. Anolyte was less effective in bleaching unbleached cotton than sodium hypochlorite but without harming the tensile strength of the cotton. Although Anolyte caused dyed cotton to lose colour, the stiffness of the dyed cotton was less than that bleached with sodium hypochlorite, making the cotton fabric to be much softer and desirable. It was also gathered that sodium hypochlorite reduced the tensile strength of vat blue dyed cotton and bleached cotton more than Anolyte. However, Anolyte on the other hand reduced the tensile strength of reactive red dyed cotton more than sodium hypochlorite.

**Key words: Anolyte, tensile strength, rigidity, stiffness, pH, colour change, sodium hypochlorite, bleach, cotton.**

# OPSOMMING

Bleikmiddels word in die industrie vir die verheldering, witmaking en die skoonmaking van tekstielstowwe gebruik.  Die twee bleikmiddels wat mees algemeen gebruik word, is hipocloriet- en peroksiedbleikmiddels.  Peroksiedbleikmiddels word meer dikwels as chloorbleikmiddels in tekstielafwerking gebruik.  Chloor is 'n skerp chemikalie wat skadelik is vir menslike gesondheid en kan selfs katoenvesels vernietig as dit nie goed gemonitor word nie.  Dit vernietig die sellulose wat 'n effek op die kwaliteit van die gebleikte stof het.  Groot hoeveelhede van hierdie bleikmiddels word in die omgewing deur middel van waswater vrygelaat en dit besoedel die omgewing en die osoonlaag.  Dus behoort nuwe en beter maniere van bleiking ondersoek te word.

Elektrochemies geaktiveerde water (Anolyte) is onlangs aan die voedselindustrie as 'n ontsmettingsmiddel bekendgestel.  Ontsmetting met Anolyte is suksesvol en gerieflik omdat Anolyte in die werksplek geproduseer kan word deur 'n eenvoudige elektroliese van 'n verdunde soutoplossing.  Die vervaardiging van Anolyte verg laer produksiekoste en die risiko's wat met die hantering, vervoer en berging gepaard gaan.  Anolyte is stabiel en na 48 uur raak dit weer onaktief en verander in normale water en word dit weggevoer sonder om die omgewing te beskadig.  Alhoewel Anolyte suksesvol in die voedselindustrie gebruik word, is daar nog nie uitgebreide navorsing gedoen oor hoe dit in die tekstielindustrie gebruik kan word nie. Hierdie navorsing poog om die leemte te help vul.

 Die doel van hierdie studie was om die effektiwiteit van Anolyte as 'n bleikingsmiddel te vergelyk met die algemeen gebruikte natriumhipochloriet.  Gedistilleerde water is as kontrole gebruik.  Anolyte se doeltreffendheid is getoets by 24°C, 30°C, 40°C, 60°C en 80°C. Die effek wat Anolyte en natriumhipochloriet op gebleikte -, ongebleikte -, gekleurde en aangevuilde katoen het, is geëvalueer in terme van treksterkte, styfheid en witheid.  Verdere navorsing is gedoen om die effek van bleikingstemperatuur (soos bo genoem) en die duur van blootstelling wat gewissel het van 9, 18, 30, 45, 60, 90 en 120 minute te bepaal.  Die studie was 'n eksperimentele navorsingsondersoek waar monsters gebleik is volgens die AATCC 61-2009 toetsmetode en is in 'n Launder-Ometer gedoen.

Reaktiewe rooi gekleurde -, blou kuip gekleurde -, gebleikte – en ongebleikte katoen is vir 5, 10 of 20 siklusse respektiewelik gewas om die invloed op die treksterkte, styfheid en kleurverandering te evalueer.  Die treksterkte toets is op 'n Instron-toetser en ISO/SANS 13934-1:1999 uitgevoer.  Die styfheidstoets ASTM D 1388-08, die vrybalkbeginsel is gebruik.  Terwyl

die AATCC 135-1985 toetsmetode vir die instrumentele tekstielkleurmeting gebruik is om die kleurverandering te bepaal.

Die resultate wat verkry is van hierdie studie dui aan dat Anolyte minder doeltreffend is as natriumhipochloriet om bloed, tee, roet/minerale olie en bloubessiesap vlekke te verwyder. Anolyte veroorsaak ook meer kleurverlies as natriumhipocloriet veral by hoër temperature. Dit laat ook gekleurde katoen, veral by hoë temperature en vele siklusse, kleur verloor. Anolyte was ook minder doeltreffend in bleiking van ongebleikte katoen, maar dit kan gebruik word op ongebleikte katoen sonder om die taaiheid van die stof te benadeel. Alhoewel Anolyte gekleurde katoen kleur laat verloor het, was die styfheid van gekleurde katoen minder as dié wat met natriumhipochloriet gebleik was. Dit maak die katoen veel sagter en meer aanvaarbaarder. Natriumhipochloriet het die treksterkte van die blou kuip gekleurde katoen en gebleikte katoen meer verminder as die Anolyte. Die Anolyte het egter die treksterkte van die rooi reaktiewe kleurstof gekleurde katoen meer verminder.


**Sleutelwoorde:** **Anolyte, treksterkte, styfheid, kleurverandering, natriumhipochloriet, bleik, katoen.**