Evaluation of the antimicrobial effect and strength properties of polyester, polyester/cotton and cotton treated with Anolyte.

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CHAPTER 1

1.1. Introduction

The hygiene barrier provided by sanitation and medical advances can easily be compromised. Exposure to pathogenic bacteria can occur as a result of contact with an infected individual, contaminated object or inadequate care habits (Aiello *et al.,* 2008). Textile fabrics are often the problem when it comes to the control of microorganisms in diverse areas, as microbial protection is not only necessary in health care settings, but also in the food industry like restaurants, hotels, etc. In these settings, textiles are exposed to microorganisms where elements such as moisture and nutrients are readily available and the textiles then act as disease vectors by transmitting infectious diseases (Thiry, 2010a; Lee, Yeo & Jeong, 2003). Textiles are sources of cross-contamination because they have large surface areas, retain moisture, and are difficult to clean or disinfect in place (Thiry, 2010a). During the cleaning procedure, the antimicrobial treatments have to be strong enough to kill the infectious agents and efficacy must be proven to the satisfaction of government regulatory standards and hospital administration personnel (Thiry, 2010b). Neither natural nor synthetic fibres have resistance to microorganisms and therefore various antibacterial finishes and disinfectants have been developed (Lee, Yeo & Jeong, 2003). Unfortunately, these strong antimicrobial agents are detrimental to the properties of the textile fibres and the textile products have to be replaced very often.

Nowadays there is a wide range of disinfectants available; unfortunately, the amount of cultures of pathogens resistant to liquid chemical germicides also increases (Bakhir *et al.,* 2003). There is, therefore, a need and interest in a practical and effective disinfectant and effective antimicrobial treatment for the inactivation of microorganisms (Venkitanarayanan *et al.*, 1999b). Chlorine has been among the most frequently used chemical disinfectants for laundry. Unfortunately, disinfection with high doses of chlorine is undesirable, because it can lead to the formation of mutagenic chlorinated by-products (Lehtola *et al.,* 1999).

Anolyte is one of the potential alternatives for environmentally friendly broad-spectrum microbial decontamination and has been proven to have a strong bactericidal activity for the inactivation of many pathogens like *Escherichia coli* O157:H7, *Listeria monocytogenes* and *Bacillus cereus* (Kim, *et al.,* 2000; Park *et al.,* 2002; Fabrizio &

Cutter, 2005). Anolyte is acidic electrolyzed water and is generated by the electrolysis of a dilute salt solution. Anolyte has a high oxidation potential, pH between 2 and 9 (Marais & Williams, 2001) and contains high concentrations of dissolved chloride and oxygen and functions as a bactericide (Nakae & Inaba, 2000). Anolyte has been successfully used as a disinfectant in different fields such as agriculture, dentistry and medicine (Ayebah, Hung & Frank, 2005), but not yet in textiles.

The advantages of using Anolyte are: (1) it is a non-thermal treatment for microbial inactivation; (2) no chemicals except NaCl are required; (3) it has a strong antimicrobial effect to prevent cross-contamination of processing environments; (4) it can be produced on site and on demand with the concentration for direct usage and no dilution from concentrated chemicals needed; (5) it has less potential as a health hazard to the worker (Park, Hung & Brackett, 2002). Huang *et al.* (2008:331) indicated that to them the most important advantage of the Anolyte is its safety. Although it is a strong acid, it is not corrosive to skin, mucous membranes or organic material.

According to eWater Systems (2009) there are additional benefits as a disinfectant on materials to those already mentioned like, being more effective than other alternatives such as peracetic acid and sodium hypochlorite. It saves water because there is no need to rinse after sanitizing. Time is saved because this one system replaces an array of chemical training and it is easy to use. It is fast acting and, therefore, requires less contact time. There are no residues, so products are not tainted by chemicals and the process is virtually odour free, and as it returns to ordinary water after some time, it is not a threat to the environment. However, the efficacy of Anolyte on textile materials has not yet been established.

Microorganisms are present everywhere around us, even in the air and on humans. In the hospital environment and in the food industry, the two pathogens occurring most frequently are *Staphylococcus aureus* (*Staph. aureus*) and *Escherichia coli* (*E. coli*). Bacteria are classified as Gram-positive or Gram-negative based on the content and structure of their cell wall. *Staphylococcus aureus* is a Gram-positive bacterium and *E. coli* is a Gram-negative bacterium (Garbutt, 1997). Therefore, these two pathogens were chosen for this study.

Cotton is a natural cellulose fibre that comes from a renewable resource – seed of the cotton plant (Cohen & Johnson, 2010) and is biodegradable (Chen & Burns, 2006). Cotton fibres are widely used and represent more than 50% of the world textile production. Therefore, it is an appropriate fibre for evaluating the effects of laundering (Fijan *et al.,* 2007; Hashem, 2007). Polyester, a synthetic fibre, is very commonly used for apparel and many other purposes (Siriviriyanun, O'Rear & Yanumet, 2007). Their production increased most rapidly and they have very practical properties such as strength, resilience and launderabillity (Fryczkowski, Rom & Fryczkowska, 2005). The primary market for polyester fibre is apparel as polyester represents approximately 35% of all fibres used in apparel annually, in comparison, cotton represents 40% (Hatch, 1993). These two fibres are often blended and used to produce a variety of products like curtains, bed linen, overcoats and surgical gowns, with more favourable properties than either cotton or polyester.

1.2. Problem statement

Protective clothing (overcoats) is worn in slaughter houses for protection of meat from contamination and the protection of workers from blood, fluids, and other contaminants on carcasses. These overcoats are sent out to be laundered and people assume that it is clean and sterile afterwards, but this is not necessarily always the case; furthermore, the overcoats are subjected to harsh processes like boiling that cause damage. Hospital laundry has the potential to be a source of infection and have been implicated in several outbreaks (Orr *et al.,* 2002). Despite concerns about antibiotic-resistant bacteria and improved infection control measures, health care workers may unknowingly carry microorganisms on their attire, including nursing uniforms and white coats (Treakle, 2009). It has been proved that hospital dry cleaning cycles are not effective in disinfecting textile material contaminated with microorganisms (Bates *et al.,* 1993). Common touch-areas where transmission occurs include privacy curtains, furniture, bedding material and the garments of the healthcare workers (Thiry, 2010a). It has been reported that 65% of nurses who performed care activities on patients with *Staph. aureus* in a wound or urine, contaminated their nursing uniforms or gowns (Boyce *et al.*, 1997). Harsh chemicals are needed to eliminate the pathogens on the clothing and personnel often take their work uniform home where it is subjected to home laundering, which presents a dangerous situation.

The range of disinfectants is growing, there are hundreds of biocidal agents for pre-sterilizing treatment, sanitation and all-levels of disinfection. However, the amount of cultures of pathogens resistant to liquid chemical germicides is increasing. Recurrent replacement of one biocidal agent to another does not solve the problem. Ideal disinfectants should have a high bactericidal activity, long shelf life, be ready for use and utilized after use without a negative effect on the environment (Bakhir *et al.,* 2003). Therefore, a disinfectant must have a broad spectrum of biocidal activity, which could be used for years with certainty that microorganisms could not adapt to it.

According to Kerwick *et al.* (2005) electrochemical disinfection is one of the feasible alternatives to chlorination. Gao & Cranston (2008) noted that most of the biocides used on textiles induce bacterial resistance, which can lead to increased resistance to that substance, especially in clinical use. Anolyte has a "life time" that is necessary for disinfection. After its use, it degrades without the formation of toxic substances and does not require neutralization before discharging. Anolyte is activated during a period of relaxation, which is the time during which spontaneous change of its chemical characteristics, catalytic and biocatalytic activity takes place. The mixture of metastable active agents eliminates the microbes' ability to adapt to the bactericidal effect of the Anolyte (Bakhir *et al.,* 2003).

As humans we use and pollute more than the ecosystem can bear. Cleaning such as laundering has a significant impact on the environment. Good drinking water is becoming scarce in many countries, while household water consumption is increasing. About 25% of the household water consumption is due to textile cleaning and dishwashing (Terpstra, 1998). Cleaning is also responsible for most of the energy consumption and production of detergents where non-recoverable raw materials are used. The drained wastewater goes to clearing plants or pollutes the surface waters (Terpstra, 1998). Therefore, it is crucial to investigate practices that minimize the burden on the environment.

1.3. Aims

This study will investigate the efficacy of Anolyte as a disinfectant against *E. coli* and *Staph. aureus*. The efficacy of the Anolyte will be compared to that of filtered water, detergent and a combination of detergent and sodium hypochlorite. The antimicrobial action of these agents will be determined at temperatures of 24, 30 and 60°C to determine the effect of temperature on the efficacy of the agents.

A need is recognized for a new disinfectant for textile products, which is effective against pathogenic microorganisms, while it is not harmful to the environment and can be used at a lower temperature in order to conserve energy.

1.4. Hypothesis

To evaluate disinfection properties:

- The Anolyte, filtered water, detergent, and sodium hypochlorite solution will reduce/inhibit the growth of *E. coli* and *Staph. aureus.*
- Different temperatures of 24, 30 and 60°C will influence the efficacy of the Anolyte, filtered water, detergent, and sodium hypochlorite solution.

To evaluate the influence on fabric properties:

- The Anolyte, filtered water, detergent, and sodium hypochlorite solution will have an effect on the tensile strength of the polyester, polyester/cotton and cotton.
- Different temperatures of 24, 30 and 60°C will affect the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tensile strength of the polyester, polyester/cotton and cotton.
- The number of laundering cycles (5, 10, and 20) will affect the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tensile strength of the polyester, polyester/cotton and cotton.
- The Anolyte, filtered water, detergent, and sodium hypochlorite solution will have an effect on the tearing strength of the polyester, polyester/cotton and cotton.
- Different temperatures of 24, 30 and 60°C will affect the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tearing strength of the polyester, polyester/cotton and cotton.
- The number of laundering cycles (5, 10, and 20) will affect the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tearing strength of the polyester, polyester/cotton and cotton.

1.5. Terminology

Detergents: Organic molecules that serve as wetting agents and emulsifiers because they have both polar hydrophilic and nonpolar hydrophobic ends. Due to their amphipatic nature, detergents solubilize otherwise insoluble residues and are very effective cleaning agents (Prescott, Harley & Klein, 2005).

Dimensional stability: A general property of a material, component or structure, which enables it to maintain or retain its shape, size or any dimension (Wolff, 2004).

Disinfection: The killing, inhibition or removal of microorganisms that may cause disease. The primary goal is to destroy potential pathogens, but disinfection also substantially reduces the microbial population (Prescott, Harley & Klein, 2005).

Electrochemical Activation: A technology used to produce meta-stable aqueous media by way of electrochemical exposure (Bakhir *et al.*, 2006).

Elongation: The limiting tensile deformation that corresponds to tensile strength and is expressed in percent of the test length (Švédová, 1990).

Inoculum; Inoculation: Implantation of microorganisms into a culture medium to encourage their growth; a culture medium containing microorganisms (Thiry, 2010b)

Log reduction: A reduction of bacteria on a (base 10) logarithmic scale (Thiry, 2010b).

Sterilization: The process by which all living cells, viable spores, viruses and viriods are either destroyed or removed from an object or habitat (Prescott, Harley & Klein, 2005).

Tearing strength: The force required to propagate an existing tear (Saville, 2004).

Tensile strength: A measure of the ability of a material to resist a force that tends to pull it apart (Houghton, 2005).

Warp: The yarns that are threaded through the loom in a woven fabric, parallel to the selvage (Kadolph, 2010).

Weft: It is the yarns perpendicular to the selvage, which interlace with the warp yarns in a woven fabric (Kadolph, 2010).

CHAPTER 2:

LITERATURE REVIEW

2.1 Introduction

Dirty textiles can contain many types of microorganisms that may be pathogenic, depending on the use of the textiles (Fijan *et al.,* 2008). The clothes of health workers, curtains, furniture covers, bed linen, etc. can easily be contaminated with, and be potential carriers of microorganisms (Fijan & Sostar-Turk, 2010). Textiles used in the meat processing industry are suppose to protect against contamination from microorganisms as well as to protect the workers from microorganisms contained in the carcasses, faeces, bone dust, blood clots, etc. Textiles in the catering industry are used to cover tables in restaurants, as napkins, and mostly for aesthetic purposes (Fijan *et al.,* 2008), and can be easily contaminated.

The textiles are usually laundered in industrial laundries and it is very important that the procedure is efficient enough to destroy microorganisms and at the same time not to cause excessive damage to the textiles due to the use of large amounts of bleaching and disinfecting agents. A disinfection effect is achieved if the number of bacteria is reduced with 5 log steps of 100 cfu. If the wash temperatures and detergents allow residues to build up in the fibres, microbial growth will be exacerbated (Fijan & Sostar-Turk, 2010). Microorganisms can survive and multiply in damp clothes that have been washed with only detergent and stored at room temperature. Clothing and bed linen placed in a wash with contaminated articles can themselves become contaminated by the transfer of the microorganisms in the water and onto the other articles in the load (Aiello *et al.,* 2008).

Textiles can be disinfected by boiling at 100°C for 30 minutes, unfortunately not all textiles can withstand such treatment and heat sensitive textiles has to be disinfected by treatment with chemicals. In some instances, heat-sensitive laundry is immersed in disinfectants for up to 12 hours at room temperature, or treated in laundry machines, which allow the control of the concentration of detergent and disinfectant, proportion of laundry to water, temperature and contact time. For chemo-thermal disinfection, the temperature should reach at least 40°C and the active ingredients of the detergents are aldehydes, quaternary ammonium compounds, phenolics, and chlorine releasing agents (Paulus, 2005).

Chemo-thermal laundering procedures are becoming more common due to (Fijan & Sostar-Turk, 2010):

1. An increasing tendency to use cotton blends that do not withstand high laundering temperatures.
2. Minimizing water consumption by using water-soluble detergents that do not need diluted baths for good performance and by lowering the washing temperature, therefore no need for as many rinsing baths to achieve a cool down effect.
3. At least a 5% minimization of energy consumption due to the decreased temperature.
4. Use of non-toxic, biodegradable washing and disinfecting agents.
5. Decreasing costs in the competitive market of industrial laundries.

Various factors will affect the efficacy of disinfectants, such as the microorganisms, environment of the microorganisms, contaminated object, microbiocidal ingredients, and the mode of application. The main factor is the target microorganisms as microorganisms differ in their sensitivity to disinfectants. The testing of the bactericidal efficacy of a disinfectant should therefore include a Gram-positive bacterial species (e.g. *Staphylococcus aureus*) and a Gram-negative species (e.g. *Escherichia coli*). Temperature, pH, contact time, disinfectant concentration and mechanical action are other factors that will affect the efficacy of a disinfectant (Paulus, 2005).

For medical applications, textiles and clothes can also be disinfected by the use of steam. By adding peracetic acid to the steam, the disinfection effect is increased. High pressure can also be used, with the addition of supercritical carbon dioxide as a solvent in which the textile material is treated at temperatures 32 – 120°C and pressure 74 – 300 bar. Unfortunately under these conditions the fibre damage is severe and the lifetime of the textiles is very short (Schmidt *et al.,* 2005).

2.2 Anolyte

2.2.1 Development of electrochemically activated water

Centuries ago, there was a notion that fresh water cannot be electrolyzed due to its low content of ions. This was proven wrong as fresh, ultra-fresh and even distilled water can be electrolyzed, but it requires a high voltage between the electrodes, while the water electrolytic decomposition goes on at a low current density.

According to Tomilov (2002), V. M. Bakhir stated in 1972 that Anolyte and Catholyte generated from low mineralized water in a diaphragm electrochemical reactor, have physical and chemical parameters and reactivity that differ strongly from those of model Catholyte and Anolyte prepared through dissolution of chemicals in water. He discovered significant differences in reactivity and physical and chemical parameters and therefore named their relaxation period "activated" (Tomilov, 2002).

2.2.2 Production of electrochemically activated water

Electrochemical activation is physical and chemical combining electrochemical and electrophysical actions (Lobyshev, 2007). A process has been developed where electro-chemically activated water (ECA) is produced by an anode-cathode system. The inventor describe the process as a change of the molecular state of the water (Marais, 2000). Water and diluted NaCl are the only raw products used. Fresh or distilled water is also suitable for use, but these require a higher voltage that leads to unnecessary high electricity consumption. Therefore, NaCl is dissolved in the water for higher ion content and a lower voltage is required for the process to commence successfully (Tomilov, 2002). This diluted NaCl solution passes through a unit containing a flow-through electrolytic module (FEM) that comprises of the anode that is a titanium cylinder with special coating, and fits inside the cathode, which is a hollow cylinder also from titanium with a coating. The electrodes are then separated by a ceramic membrane as indicated in Figure 2.1.

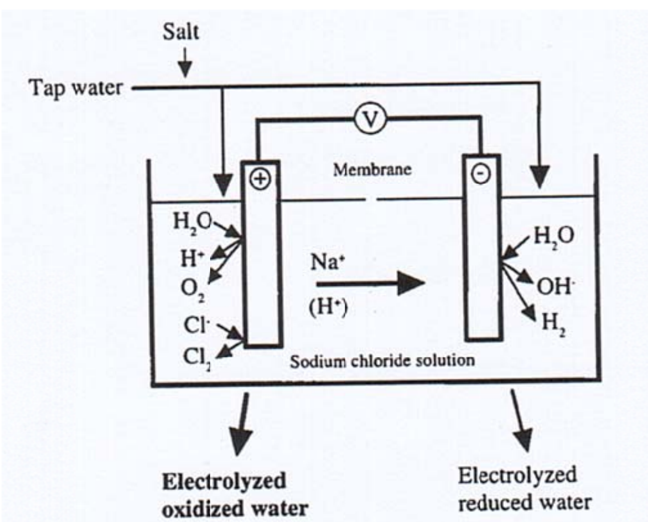


Figure 2.1: Production of electrolyzed water (Nakae & Indaba, 2000).

When a direct electric current is passed through this cell, negatively charged ions such as hydroxide and chloride in the NaCl solution move to the anode, give up electrons, and become oxygen gas, chlorine gas, hypochlorite ions, hypochlorous acid and hydrochloric acid. Positively charged ions such as hydrogen and sodium move to the cathode to take up electrons and become hydrogen gas and sodium hydroxide (Hsu, 2005) according to the following formulas (Nakae & Indaba, 2000):

Positive electrode

H_2O » $\frac{1}{2}O_2 + 2H^+ + 2e^-$

$Cl_2 + H_2O$ » $H^+ + Cl^- + HClO$

Negative electrode

$2H_2O + 2e^-$ » $H_2 + 2OH^-$

The water produced at the positive electrode has a low pH, high oxidation-reduction potential and contains dissolved chloride, oxygen and hydroxy radical, and is known as Anolyte. Water produced at the negative electrode has a high pH, low oxidation-reduction potential, contains alkaline minerals, and is known as Catholyte (Nakae & Indaba, 2000).

Venkitanarayanan *et al*. (1999a) summarised the chemical reactions in the production of Anolyte as “Sodium chloride dissolved in deionised water that dissociates into negatively charged chlorine (Cl^-) and hydroxy (OH^-) ions and positively charged sodium (Na +) and hydrogen ions (H+). The chloride and hydroxy ions are attracted to the anode and each ion releases an electron (e^-) to become a radical. The chloric and hydroxy radicals combine and form hypochlorous acid (HOCl), which separates from the anode. Two chloric radicals can combine to form chlorine gas. At the cathode section, each positively charged sodium ion receives an electron and becomes metallic sodium. The metallic sodium combines with water molecules to form sodium hydroxide and hydrogen gas.” After production the solution exists in a metastable state while containing many free radicals and a variety of molecules for 48 hours. The solution then returns to a stable state and becomes inactive again. These solutions display properties that are dependent upon the strength of the initial saline solution, the applied potential difference and the rate of generation (Gulabivala *et al.*, 2004).

No difficulties have been found in the generation of acidic Anolyte as disinfecting solution; however, it has some negative aspects such as its high corrosiveness level and pungent smell of chlorine (Bakhir *et al.*, 2006).

Acidic Anolyte has a pH value lower than 5 and is known as "A-Anolyte", but a need for a solution with a neutral pH value became evident and "AN-Anolyte" was developed. It is manufactured by means of anodic processing of the parent sodium solution. The pH value correction within the anodic procedure is done by adjusting the current share transferred by hydroxyl ions from the cathodic chamber to the anodic chamber, with sodium hydroxide concentration existing in the cathodic chamber being maintained at an increased level. It was proved a strong antimicrobial solution and possesses detergent properties as well. However, it is characterised by high corrosiveness and a pungent smell of chlorine (Bakhir *et al.*, 2006).

According to Ryoo, Kang & Sumita (2002) the deterioration of Anolyte after electrolysis is due to CO_2 over-saturation. The CO_2 concentrations increased as exposure time to air increased after generation. After 2–3 hours of exposure to air, the CO_2 concentration decreased gradually to the level of normal water. Oxidation-reduction potential (ORP) changes followed the same pattern, while pH did not change significantly.

Storage conditions affect the chemical and physical properties of Anolyte. Len *et al.* (2002) concluded that Anolyte stored under open and agitated conditions had the highest chlorine loss. Under open conditions, the chlorine loss was primarily through the evaporation of dissolved chlorine gas. Agitation enhanced the chlorine loss through evaporation. The chlorine in strongly acidic electrolyzed water had evaporated after 30 hours when agitated and 100 hours when not agitated. According to Guenzel *et al.* (2008), Anolyte returns to its original state, as there seems to be rapid chlorine loss due to the evaporation of dissolved chlorine gas and HOCl decomposition. Under closed conditions the Anolyte is much more stable and chlorine self-decomposition could be the mechanism of chlorine loss. Agitation had no effect on the chlorine loss under closed conditions. It was found that increasing the pH reduces chlorine loss and therefore pH adjustment could be useful in situations where stable bactericidal activity is required.

2.2.3 The antimicrobial mechanisms of Anolyte

Three distinct characteristics have been suggested to be responsible for the antimicrobial effect of Anolyte namely (1) chlorine content and hypochlorous acid, (2) pH, and (3) ORP. According to Park, Hung & Brackett (2002) the mechanism of inactivation by Anolyte is not clear, but it is believed that it involves the presence of hypochlorous acid and the high ORP. The Anolyte and chlorinated water both contain a similar amount of residual chlorine (25 mg/l); the better antimicrobial effect observed in Anolyte could be because of its lower pH and/or high ORP value. Reports by Kim *et al.* (2000) suggest that the ORP of a solution might be the primary factor affecting microbial inactivation. The oxidation-reduction potential is the ability of a substrate to lose or gain electrons. A specific range of ORPs is required for the growth of aerobic (200 to 800 mV) and anaerobic (-200 to -400 mV) bacteria. Positive and negative ORPs are respectively indicative of its oxidizing and reducing ability (Issa-Zacharia *et al.*, 2011). When a solution with such a high oxidizing capability (Anolyte) is applied to bacteria, ions are withdrawn and the cellular membrane becomes unstable, which facilitates the entry of antimicrobial agents. Park, Hung and Chung (2004) found that electrolyzed oxidizing water had a stronger bactericidal activity than diluted electrolyzed oxidizing water with the same pH. This could be due to the reduced ORP values with the same residual chlorine concentrations.

Len *et al.* (2002) made the conclusion that the maximum microbicidal activity of Anolyte occurs at pH 4. This pH has the highest concentration of HOCl and this indicates that HOCl is the primary component for inactivation. High ORP values are related to the concentration of HOCl, but it has been reported that the ORP of a treatment solution may be a greater determinant of microbial inactivation because it is an indication of oxidation capability, regardless of pH and chlorine concentration. An ORP of 650 mV should result in the immediate destruction of *E. coli* irrespective of the pH or chlorine concentration (McPherson, 1993; Jay *et al.*, 2005). Issa-Zacharia *et al.* (2010) concluded that ORP plays an important role, in combination with a high proportion HOCl, in killing *E. coli* and *Staph. aureus*. An explanation for the high ORP of Anolyte could be the oxygen released by the rupture of the weak and unstable bond between hydroxy and chloric radicals (Venkitanarayanan *et al.*, 1999a).

Park, Hung & Chung (2004) observed that at a residual chlorine concentration of 2.0 mg/l or above, there is complete microbial inactivation regardless of the pH. According to Nakagawara *et al*. (1998), the available chlorine concentration represents the sum of the concentrations of Cl_2, HClO and ClO^-. They suggest that the bactericidal activity is not directly related to the hydroxy radicals and concluded that the bactericidal activity is due to the chemical equilibrium of Cl_2, HClO and ClO^-, and the major component being Cl_2. The microbicidal activity is best between pH 4 and 5, where the maximum concentration of hypochlorous acid is reached. Koseki *et al.* (2001) agree that the available chlorine is the main factor of antimicrobial activity. According to them, the available chlorine (HOCl) produces ·OH that acts on microorganisms thus, the more ·OH produced the better the antimicrobial activity. Hypochlorous acid is said to be the most effective form of the chlorine compounds and will kill the microbial cell by inhibiting glucose oxidation by chlorine-oxidizing sulfhydryl groups of certain enzymes important in carbohydrate metabolism (Water Review Technical Briefs, as cited in Kim *et al.*, 2000).

According to Venkitanarayanan *et al*. (1999b) it is possible that the low pH of the Anolyte sensitizes the outer membrane of bacterial cells which gives easier entry for the hypochlorous acid into the bacterial cell. Stan & Daeschel (2003) indicates that the Anolyte is less effective in a system that is richer in organic matter than in an aqueous system, because the free chlorine and radical species are rapidly inactivated by contact with organic material.

The effectiveness of the Anolyte as disinfecting agent will depend on its ability to make contact with the microorganism and its ratio to the organic material. Kim *et al.* (2003) also indicated that the Anolyte was more effective when better access was provided into the material to reach the microorganisms. Oomori *et al.* (2000:368) examined the effects of organic materials on Anolyte. They demonstrated that in the presence of amino acids and proteins, the available chlorine in the Anolyte is quickly transformed into *N*-chloro compounds. They also indicated that when *E. coli* is used, there is a significant difference in bactericidal activity between free and combined available chlorines in the Anolyte. Combined available chlorines have lower bactericidal activity than the free form at the same concentration. They concluded that the presence of organic materials results in the formation of combined chlorine, which have lower bactericidal activity. Cloete *et al.* (2009) reported that the Anolyte killed the *E. coli* immediately upon exposure, by interfering with their protein composition due to oxidative stress. The presence of free radicals with their oxidizing effects is very important. Microorganisms generally do not possess antioxidant defence systems, and certain human defence cells kill microbes by producing some of these same free radicals (Marais & Brözel, 1999).

Zinkevich *et al.* (2000) indicated that electrochemically activated water with a pH of 5.l5 and redox potential of 1100 mV acts upon *E. coli* cells by damaging double stranded DNA, RNA and proteins. It probably destroys the covalent bonds in the nucleic acid chains and protein chains. Their results revealed that after 30 seconds of exposure, the cells considerably increased in size. They proposed that within 30 seconds of exposure the Anolyte was present in the cells, interfering with the metabolic activity, causing damage to the cell membrane and cell wall. The final rupture of the cytoplasm after 5 minutes is a result of the total destruction of proteins, DNA and RNA. The mixture of metastable active agents eliminates the microbes' ability to adapt to the effect of Anolyte. A small concentration of active oxygen and chlorine compounds guarantees absolute safety for humans and the environment after long-term use of Anolyte (Bakhir *et al.,* 2003).

2.2.4 Successful use of Anolyte

According to the available literature, Anolyte has mostly been used in the medical and food industry. It has been shown that Anolyte can be used for various applications in the medical industry and at present, there are no data on the presence of microflora that are resistant to Anolyte. In St Petersburg there are 25 hospitals using Anolyte as a disinfectant (Bakhir *et al.,* 2004). Activated Anolyte kills microorganisms of bacterial, viral and fungal etiology like *Staph. aureus, Pseudomonas (Ps.) aeruginosa, E. coli,* hepatitis B virus, poliomyelitis virus, HIV, adenovirus, pathogens causing tuberculosis, salmonellosis, dermatomycosis, and others. Anolyte is used in various departments of surgery, pathology, diagnostic centres, waiting rooms, rehabilitation centres, physiotherapy, dental, ultrasonic and x-ray (Bakhir *et al.,* 2003). It is also used in military hospitals to clean surgeons and nurses' hands (Mikhailov & Mistryukov, 1999).

It has been reported (Ayebah, Hung & Frank, 2005) that the Anolyte was more effective as a disinfectant when the object has been treated with the Catholyte first and then with the Anolyte. There was a significantly higher inactivation of *L. monocytogenes* when biofilms were first treated with Catholyte and then Anolyte than with the Anolyte alone. The Catholyte is not an effective bactericide, but it conditions the biofilm to facilitate the antibacterial action of the Anolyte by destabilizing or dissolving the extracellular polymeric substances that surround the attached cells, thereby facilitating penetration of the active components found in the Anolyte. The combination will lead to no extra cost as both the Catholyte and Anolyte are produced simultaneously during electrolysis.

It has also been demonstrated by Vorobjeva, Vorobjeva & Khodjaev (2004:592) that Anolyte (pH 2.84, ORP 1125 and available chlorine content of 43 ppm) was effective against various opportunistic pathogens including *E. coli* and *Staph. aureus*. It can therefore be recommended for use as a disinfectant for medical devices and equipment.

A study by Lee & Choi (2006) showed that electrolyzed water significantly reduced the growth of *Actinobacillus actinomycetemcomitans, Fusobacterium nucleatum, Porphyromonas gingivalis, Prevotella intermedia* and *Treponema denticola* in culture and on toothbrushes. They concluded that the electrolyzed water could successfully be used as a mouthwash. Anolyte (pH of 2.4 and ORP 1 100 mV) has also been found to be effective against *Ps. aeruginosa* on the ocular surface (Shimmura *et al.,* 2000).

Anolyte has also been shown to be effective in many areas of the food industry and the efficiency of Anolyte to kill microorganisms was studied on a variety of organisms in different applications. Venkitanarayanan *et al.* (1999a:4278) found that the Anolyte water had great antimicrobial activity at pH 4 and 23 ^{o}C against *E. coli* O157:H7, *Salmonella* (*S.) enteritidis*, and *L. monocytogenes*. However, much higher rates of inactivation were observed at 35 and 45 ^{o}C. The Anolyte water had a pH between 2.3 and 2.7, ORP between 1150 and 1164 mV and a free chlorine content of 76 and 81 ppm. They also indicated that soaking of cutting boards in Anolyte at higher temperatures decreased the exposure time needed to achieve the same reduction in bacterial counts obtained with longer soaking at lower temperatures. Their results revealed that the immersion of smooth plastic cutting boards in Anolyte is an effective method to inactivate food-borne pathogens. Park, Hung & Kim (2002) concluded that the electrolyzed oxidizing water is effective on many diverse surfaces (glass, stainless steel, glazed ceramic tile, unglazed ceramic tile, and vitreous china).

There was also a complete inactivation of *Staph. aureus* and *Enterobacter aerogenes,* which indicated that the Anolyte could prevent cross-contamination from treatment solutions. Nakagawara *et al.* (1998:691) indicated that Anolyte could successfully prevent the infection of methicillin resistant *Staph. aureus*. Park, Hung & Chung (2004:17) demonstrated that Anolyte effectively inhibited *E. coli* O157:H7 and *L. monocytogenes* with a pH between 2.6 and 7, if sufficient residual chlorine of at least 1.0 to 2.0 mg/l was present on surfaces.

Bosilevac *et al.* (2005) found that Anolyte was successful in controlling pathogens (mainly *E. coli*) on carcasses. The Anolyte had a pH of 2.4, 70 ppm chlorine and was at 60 ^{o}C. According to Issa-Zacharia *et al.* (2011) it was the high amount of hypochlorous acid and high ORP of slightly acidic electrolyzed water that made it effective against *E. coli* and *Salmonella.*

The results found by Bari *et al.* (2003:547) revealed that Anolyte effectively reduced *E. coli* O157:H7, *Salmonella* and *L. monocytogenes* on the surfaces of tomatoes, with no significant influence on the appearance, taste or colour. Kim, Hung & Brackett (2000:207) found that higher chlorine concentration and longer treatment were more effective in reducing bacterial populations. *Bacillus (B.) cereus* was more resistant to the Anolyte than the *E. coli* O157:H7 and *L. monocytogenes*. The Anolyte had a pH of about 2.5, ORP of about 1150 mV and residual chlorine between 10 and 56 mg/l. Kim, Hung, Brackett & Frank (2001:98) indicated that Anolyte with a pH of 2.6, ORP of 1160 mV and residual chlorine of 56 mg/l could significantly reduce the number of biofilm forming bacteria after a 30 second treatment and was an effective means to inactivate biofilm forming bacteria on equipment surfaces.

Huang *et al.* (2006) concluded that Anolyte was an effective sanitizer for cleaning surfaces to prevent fish and shellfish from secondary pollution of bacteria. The Anolyte had a pH of 2.47 ± 0.02, ORP of 1159 ± 4 mV and free chlorine concentration of 120 ± 4 ppm. Liu & Su (2006:153) concluded that Anolyte could be successfully used to reduce *L. monocytogenes* contamination on seafood processing gloves. Ordinary tap water and Anolyte were examined, but usually chlorine was used commonly to disinfect these gloves. The tested gloves consisted of a natural rubber latex, natural latex, and nitrile. A significant reduction was observed after treatment with Anolyte compared to that of the tap water and when the gloves were soaked in the Anolyte for 5 minutes, the *L. monocytogenes* cells were eliminated from the inoculated gloves. The Anolyte was prepared with pH 2.6, chlorine content of 40 ppm, and the ORP was 1125 mV and used within 2 hours of production. Liu, Duan & Su (2006:250) used Anolyte to inactivate *L. monocytogenes* on seafood processing surfaces. The Anolyte had a chlorine concentration of 50 ppm, ORP of 1150 mV and pH 2.5.

Park *et al.* (2001:1371) concluded that Anolyte (pH 2.5, ORP 1130 mV and residual chlorine of 45 ppm) is an effective disinfectant for killing *E. coli* O157:H7 and *L. monocytogenes* on lettuce. A study by Park, Hung & Kim (2002:1278) confirmed that the electrolyzed oxidizing water (Anolyte) with 10 mg/l of residual chlorine effectively reduced the populations of *E. coli* O157:H7, *L. monocytogenes,* and *B. cereus* vegetative cells after 60 seconds on different surfaces of glass, stainless steel, ceramic tile and vitreous china. No viable cells of all three bacteria were observed in the Anolyte after treatment. However, it was indicated that the treatment was less effective without agitation that might be due to the limited ability of the chlorine to penetrate the attached microbial cell layers.

A study by Fabrizio & Cutter (2003:1384) demonstrated that Anolyte with a pH of 2.3, ORP of 1155 mV; a free chlorine concentration of 83.4 ppm and total chlorine content of 86.3 ppm was an effective treatment against *Salmonella enterica* subsp. *enterica* serovar Typhimurium (*S.* Typhimurium; Tindall et al., 2005) and *L. monocytogenes* at different temperatures. Russel (2003:160) found that Anolyte with a pH of 2.1, ORP of 1150 mV and free chlorine of 8 mg/L could eliminate *S.* Typhimurium*, Staph. aureus* and *L. monocytogenes* on eggshells.

A study by Park, Hung & Brackett (2002) and another by Kim, Hung & Russel (2005:1783) showed that acidic Anolyte was effective in reducing the population of *Campylobacter (C.) jejuni* on chicken, as well as for the prevention of cross-contamination of processing environments. Fabrizio *et al.* (2002:1598) found that Anolyte with a pH of 2.6, ORP of 1150 mV and chlorine content of 20 to 50 ppm, could reduce *S.* Typhimurium on poultry surfaces following extended refrigerated storage. According to Stan & Daeschel (2003:2022), Anolyte can successfully be used to disinfect alfalfa seeds. The Anolyte had a pH of between 2.5 – 2.58 and an ORP of 1074 – 1079 mV.

Anolyte has been shown to be an effective antimicrobial agent against *Penicillium expansum* in suspension and on wounded apples. Okull & LaBorde (2004:26) concluded that Anolyte was a promising alternative to chlorine sanitizers for minimizing post harvest infection of apples. The Anolyte had a pH of 3.1, ORP of 1133 mV and free chlorine of 59.6 ppm.

The results of Koseki *et al.* (2004:1250) concurred that the Anolyte more effectively removed the microorganisms when the cucumbers were prewashed with Catholyte. The Catholyte would act as a surfactant, the hydrophobicity of the surface would be decreased, and the Anolyte could easily be exposed to the surface microorganisms. They also concluded that it was easier to disinfect smoother surfaces of, for example lettuce and tomatoes, than those of cucumbers and strawberries.

Research with negative results:

Fabrizio & Cutter (2005:333) attempted to use Anolyte water to reduce *L. monocytogenes* on ready-to-eat meats. There were slight reductions but even with prolonged contact time, it was not enough to meet the requirements.

2.3 Disinfectants

The most commonly used chemical agents for high level of disinfection are glutaraldehyde, the association of peracetic acid/hydrogen peroxide (0.5-2%) and sodium hypochlorite (1%). For medium level disinfection the products generally used are sodium hypochlorite (0.3 – 0.5%), iodophors, phenol derivates, 70% ethyl alcohol and 92% isopropyl alcohol. Quaternary ammonium compounds and low concentration sodium hypochlorite (0.2%) are used for low level cleaning and disinfection (Bouzada *et al.,* 2010).

2.3.1 Sodium hypochlorite

Composition

Various antimicrobial active chlorine compounds are commercially available, which include sodium hypochlorite. Hypochlorites are salts of the hypochlorite ion (OCl^-). The sodium salt produces an aqueous solution and the active species is undissociated hypochlorous acid (HOCl) and not chlorine. The dissociation of hypochlorous acid to the less microbicidal form (hypochlorite ion) is dependent on pH.

HOCl and OCl^- in aqueous solutions are referred to as either "free residual chlorine" or as "free available chlorine". Once these compound have reacted with ammonia or *N*-organo compounds to form a series of lower oxidation potential compounds such as monochloramine (NH_2Cl), dichloramine ($NHCl_2$) or a variety of organo-*N*-chloro compounds, it is referred to as either combined chlorine, combined residual chlorine, or combined available chlorine.

The free and available chlorine is collectively described as total residual (available) chlorine (Rutala & Weber, 1997).

Development

The trend toward colder wash temperatures increases the risk of microorganisms surviving the laundering process, unless the detergent possesses antimicrobial activity or another agent such as chlorine bleach is added. Chlorine was first used as textile bleach around 1785 in the United States. According to Belkin (1998:150), during the first half of the 19th century, Kock clinically demonstrated its disinfecting capability. In 1938, commercial laundry practices included a high temperature wash of 73.8°C or higher, and a dosage of 100 ppm chlorine bleach. The polyester/cotton blends required low temperature formulations (48.88 – 60°C) to ensure the "no-iron" attribute. Later on studies were conducted on the survival of bacterial populations with different machines, wash cycles, detergents, temperatures and exposure times (Belkin, 1998:150). These results were published in 1975 and demonstrated a significant reduction in bacterial counts with chlorine bleach and low temperature. Coloured fabrics could unfortunately not be processed without losing colour. It was noted that these two methods of chlorine washing and high temperature washing would reduce the useful life of some fabrics. In 1984, the Centres for Disease Control and Prevention noted that chlorine bleach should be included in all laundering formulations (Belkin, 1998:150). According to Barrie (1994), sodium hypochlorite should be added to the penultimate rinse at temperatures below 60°C, because above 60°C it is highly active and will cause chemical damage to textiles.

The few studies that evaluated the effect of sodium hypochlorite independently from the wash temperature indicated that the effect of bleach depended on the concentration, contact time, water pH (Wilson *et al.,* 2007). According to the South African Bureau of Standards (2010) chemical disinfection of textiles can be done with sodium hypochlorite where the available chlorine is at least 150 mg/L in the first rinse after the main wash, and should remain at this concentration for at least 6 minutes, and not exceed 60 ºC and a pH value of 10.5. According to Gerba & Kennedy (2007), the laundry steps most important in the reduction of viruses are the addition of bleach, but the dilution of pathogens in wash water is also considered a factor of importance. They reported a 99.99% virus reduction after the final rinse, when bleach was included in the laundering process. Van der Poel (2001) also agreed that laundries use hypochlorite at a lower temperature of 60°C for the disinfection of temperature-sensitive fabrics. Sodium hypochlorite has the disadvantage of being slightly unstable as the active chlorine concentration in the solution rapidly decreases during storage (Deza *et al.,* 2005).

Toxicity

Contact with sodium hypochlorite may lead to tissue injury, which may range from mild irritation to frank necrosis depending on the physical form and duration of exposure. It can irritate the conjunctiva, respiratory tract, or gastrointestinal tract (Rutala & Weber, 1997; Patel *et al.,* 2007). Injury can occur through direct contact, ingestion, direct exposure or inhalation. Exposure to liquid household bleach rarely results in caustic injury and injury due to sodium hypochlorite use in healthcare facilities is extremely low. When combined with an acid or ammonia, hypochlorite may produce chlorine or chloramine gas. Exposure may result in irritation of mucous membranes and the respiratory tract, with coughing, choking, and dyspnoea. Chemical pneumonitis or pulminory edema may occur after extreme exposure (Rutala & Weber, 1997).

Environmental impact

Chlorine and chlorine compounds work fast and effective as disinfectants but is unstable in concentrate and should be used in dilution, rapidly loses activity in the presence of organic material and heavy metals, can lead to skin irritation, has high toxicity and is dangerous to the environment (Block, 2001). Unfortunately, disinfection with high doses of chlorine is undesirable, because it can lead to the formation of mutagenic chlorinated by-products (Lehtola *et al.,* 1999).

Impact on textiles

Sodium hypochlorite can cause damage to fabrics (Fijan, Sostar-Turk, Neral & Pusic, 2007), which leads to increased costs for replacements. Damaged bed linen releases higher levels of lint that may act as a vector for spreading bacteria into the environment. It is also not recommended for use on coloured fabrics (Hall *et al.,* 2009). Tarhan & Sariisik (2009) found that the loss in cotton fabric strength increased as the duration of washing with sodium hypochlorite increased. A decrease of approximately 40% was recorded after 60 minutes exposure.

2.3.2 Antimicrobial mechanisms of disinfectants

Different bacteria react differently to bactericides, due to inherent characteristics such as cell envelope composition and non-susceptible proteins, or to the development of resistance either by adaption or by generic exchange (Cloete, 2003). Mechanisms of inactivation can be categorized into two pathways. First is damage to the cell surface components. The cell peripheral structure (cell wall) provides a protective barrier against environmental stress to microorganisms. Physicochemical change in cell surface would therefore precede any further damage in intracellular constituents and their functions. Alternatively, cell death could be induced by direct impairment in intracellular functions (Cho *et al.,* 2010).

The initial stage of bactericidal action is binding to the cell surface after which it should pass through the cell wall of Gram-positive bacteria or outer membrane of Gram-negative bacteria, to reach the site of action at the cytoplasm membrane or cytoplasm. In Gram-positive bacteria there are no specific receptor molecules to assist or block bactericide penetration. Therefore the intrinsic resistance of Gram-positive bacteria is low. However, the Gram-negative cell envelope has evolved to regulate the passage of substances in and out of the cell to a remarkable degree. All the components of the cell envelope, except peptidoglycan, play a role in the barrier mechanisms, because it is spongy and permeable (Cloete, 2003).

Microbial growth in textiles can result in a range of unwanted effects in the textile itself as well as on the wearer. These include the generation of unwanted odour, stains and discolouration in the fabric, a reduction of mechanical strength and cross contamination (Gao & Cranston, 2008). Therefore, it is important to treat textile articles with antibacterial agents, which can inhibit growth or kill invading bacteria in several ways. It can cause cell wall damage or inhibition of cell wall synthesis; or by changing the chemical or physical state of proteins and nucleic acid inside the cell; or by inhibiting enzymes in the cell which retard normal biological activities and metabolism; or by inhibiting the synthesis of protein or nucleic acids which will interrupt the growth of the bacteria (Abo-Shosha *et al.*, 2007). When bacteria are exposed to an environmental stress such as temperature, acidity, increased NaCl concentrations or chemical agents, they respond in several ways. Usually they produce shock proteins, which main function is to repair damages caused by the stress factor or eliminate the stress agent (Ohtsuka *et al.,* 2007). Bacteria can also protect themselves by the alternation of the ratio of the fatty acids of the cell membrane. When the concentration of saturated fatty acids in the membrane increases to be higher than that of the membrane, fluidity decreases and the cells become more resistant to stress factors (Brown *et al.*, 1997)

Acid stress is the combined biological effect of low pH and weak acids present in the bacterial cellular environment. At a low pH the acids are mostly uncharged and diffuse via the cellular outer membrane to the inner part of the cell. Here they dissociate which leads to a decrease of the internal pH of the cell. The lower the external pH of the cell, the higher the influx of acids in the cell. Strong acids, like HCl, lead to trafficking of the dissociated hydrogen in the cell via the membrane leading to an increase of the internal pH of the cell. The constant influx of protons in the cell leads to cellular death due to energy depletion (Bearson *et al.,* 1997; Foster, 2004).

2.4 Laundering and temperature

Standard laundering practices have changed over the years and can contribute to the transmission of microorganisms. The common laundering practices can allow bacteria to remain in laundered items after standard washing and rinsing (Aiello *et al.,* 2008). According to Broze (1999) laundering is "a complex process that takes place in a water medium and is influenced by temperature, duration, washing agents (surfactants, builders, bleaching, whitening and auxiliary agents), disinfecting agents and mechanical treatment". The minimum amount of active ingredients and the optimal laundering procedure should be used to maintain hygiene and the quality of the textile material (Fijan, Sostar-Turk, Neral & Pusic, 2007). Standard detergent and rinsing practices do not always deliver large reductions in microbial counts. The microorganisms in the laundry can contaminate other laundry in the machine and the machine itself, which will lead to the contamination of subsequent loads of laundry (Kagan, Aiello & Larson, 2002).

Industrial laundries will process most linen in continuous batch washers. It is treated thermally and chemically to remove soiling and microorganism contamination. This process includes a pre-wash, main wash and rinse, which is usually followed with tumble drying. Soils and stains are removed by a combination of agitation, time, temperature, detergent and bleach agents like sodium hypochlorite (Anandjiwala *et al.*, 2007). The effect of the type of machine, size of load and level of soil can have the same impact on the cleanliness of the item at the end of the process as the combination of detergent, water, dilution and wash temperature (Wilson *et al.,* 2007).

During the main laundering cycle, soil and microorganisms will be suspended in the water and the majority of microorganisms will be drained during the rinse. Microorganisms in the soil aggregates on the surface of the laundry can survive severe wash conditions. Dirt that remains after the wash process will serve as a medium for microorganisms. Microorganisms can also be killed by heat during thermal disinfection. When suspended in the suds the microorganisms become sensitive to heat and chemical disinfectants (Terpstra, 1998; Patel *et al.,* 2006).

Temperature plays a very important part during laundering. Traditionally, heavily soiled laundry was boil-washed at 95°C, lightly soiled and coloured items at 60°C. As a substantial part of energy consumption is due to water heating, wash temperatures has been reduced to 60 and 40°C, respectively (Terpstra, 1998). Due to the saving of costs by reducing time, energy, detergents, disinfecting agents, and even water, microorganisms are surviving the laundry procedure and adapting to another habitat (Fijan, Cencic, & Sostar-Turk, 2006; Hall *et al.,* 2009). Laundry procedures are not economical if the water is heated to 90°C and the optimum temperature is around 60°C (Fijan, Cencic, & Sostar-Turk, 2006). The temperature of the water would not affect bacterial counts in the fabric with the addition of sodium hypochlorite bleach, but in the absence of sodium hypochlorite, high-temperature cycles will be more effective and low-temperature cycles (22 – 48°C) can increase the cross-contamination of articles (Kagan, Aiello & Larson, 2002; Hall *et al.,* 2009). According to Fijan, Sostar-Turk & Pusic (2007) most laundries use a thermal process to disinfect textiles. Currently, cotton/polyester blends are used increasingly and cannot endure high temperatures of thermal disinfection. They found that with ordinary thermal laundering all bacteria, including *Staph. aureus*, survived the 60°C, but no organisms were found at 75°C.

The England Health Service Guidelines for the disinfection measures of hospital laundries state that laundering programs should contain a disinfection stage that lasts 10 minutes at 65°C or 3 minutes at 71°C (Patel *et al.,* 2006). The study by Fijan, Koren, Cencic & Sostar-Turk (2007) indicated that all microorganisms survived the normal laundering procedure at 35°C, but no microorganisms were found after the 75°C wash with detergent and bleaching agent containing hydrogen peroxide. However, it is preferred to employ a higher temperature of 80°C to ensure thorough disinfection. The use of colder washes with the addition of sodium hypochlorite or hydrogen peroxide to the penultimate rinse is recommended for fabrics that are unable to withstand these temperatures (Patel *et al.,* 2006; Wilson *et al.,* 2007).

According to the SABS (2010) for thermal disinfection, wash temperature should be maintained at 80ºC for at least 10 minutes, 65ºC for 15 minutes or 60ºC for 30 minutes after the bulk wash has attained this temperature. Steyn (1994) indicated that a laundering temperature of 54°C was necessary to eliminate *E .coli* during laundering. Munk *et al.* (2001) found that 100% of *E. coli* was killed when washed at 50 or 60°C, whereas *Staph. aureus* survived 50°C, but 100% were killed at 60°C. According to Netcare™ in South Africa, chemical disinfection of hospital linen is unacceptable. A thermal disinfection process must be utilized with a minimum temperature of 75°C and this should be maintained for 4 minutes in the mix cycle and 7 minutes in the wash cycle. Chlorine bleaches and oxylic acid may not be used under any circumstances. Heat liable materials like knitted polyester, should be washed at 40°C to avoid damage, and the temperature in tumble driers should be limited to 60°C, but it has been previously shown that 40°C is not adequate to eliminate microorganisms (Netcare, 2005). Aiello *et al.* (2008) indicated that fewer people use bleach or iron their laundered items, which contribute to the increased amount of bacteria on laundered items.

2.5 Laundry detergents

Cleanliness is essential to our well-being and detergents are essential products to safeguard our health. Laundry detergents are used in millions of households over the world to remove soils from fabrics. In ancient times, soap was used to wash laundry and the first commercial detergent was produced just after World War II. The production of laundry detergents grew rapidly into a worldwide industry. Laundry detergent formulations vary from region to region for several reasons. Manufacturers are sensitive to consumer preferences for example fragrances, mildness, etc., which vary between different cultures. Time and temperature settings of washing machines can differ over countries, requiring specific detergent formulations to achieve proper foaming and cleansing activity. Finally, water supplies vary in their hardness and metallic content that will affect the efficiency of surfactants (Johnson & Marcus, 1996).

The detergent industry is facing dramatic changes and is focused on coping with economics, safety and environment, technology and consumer requirements. The consumption of energy, water, and chemicals need to be considered and therefore new technologies are being developed with the challenge to use the limited resources of the earth carefully, exploit renewable ones and prevent pollution as much as possible (Friedman, 2004).

2.5.1 Composition of Detergents

Consumer laundry detergents perform the same basic function, but formulations are many and varied. Laundry detergents may contain any number of ingredients to enhance the process.

Surfactants

Surfactants are surface active agents that can be described as a heterogeneous, long-chain molecule that contains hydrophobic and hydrophilic parts. Through changing the hydrophilic and hydrophobic parts of the molecule, properties like wetting ability, emulsifying ability, disperse ability, foaming ability and control, can be adjusted (Bajpai & Tyagi, 2007:328).

Surface active agents (surfactant) improve the wetting ability of water, loosen and remove soil, emulsify and suspend soil in the wash. Surfactants are usually made up of a hydrophilic and hydrophobic component (Bajpai & Tyagi, 2007; Cameron, 2007). The hydrophilic component is attracted to the water molecules, which results in the aligning of the molecules at the surface and internally so the hydrophilic molecules are toward the water and the hydrophobic molecules are away from the water. This internal group of molecules is known as a micelle. Because surfactants orient at surfaces and form micelles they have the ability to absorb solids, liquids and gases. The hydrophilic ends are oriented to the water, and the hydrophobic ends toward the soil. Surfactants form a protective coating around the suspended soil allowing the soil to be removed from the textile (Cameron, 2007). The different types are categorized according to the ionic properties they exhibit in water. There are four major categories that are used in laundry detergents today: cationic surfactants, anionic surfactants, non-ionic surfactants and amphoteric surfactants (Bajpai & Tyagi, 2007:329).

Cationic surfactants have a positively charged nitrogen atom and at least one hydrophobic, long chain substituent in the molecule. A widely used cationic surfactant is alkyl dimethyl benzyl ammonium chloride. **Nonionic surfactants** do not ionize in solution and the lack of charge enables them to avoid water hardness deactivation. They are good at removing oily type soils and are frequently used in low sudsing detergent powders. They are mostly based on ethylene oxide, but several classes can be identified: alcohol ethoxylates, alkyl phenol ethoxylates, fatty acid ethoxylates, monoalkanolamide ethoxylates, sorbitan ester ethoxylates, fatty amine ethoxylates and ethylene oxide propylene oxide copolymers (Bajpai & Tyagi, 2007). Nonionic surfactants can also be used to cleanse animal fibres such as wool and silk, to avoid the ionic absorption on the amino groups in the fibres because the electrostatic force does not work for non-ionic surfactants (Yu *et al.,* 2008). **Anionic surfactants** often have sodium, potassium, or ammonium groups, as in sodium stearate. These are the most widely used surfactants. Most common anionic surfactants are based on ethylene oxide, referred to as ethoxylated surfactants. Another important class is the polyhydroxy products such as glycol esters, glycerol esters, glycosides and sucrose esters. Amine oxides and sulfonyl surfactants represent non-ionics with a small head group. There is another group called **amphoteric surfactants**, which contain both cationic and ionic groups. Amphoteric surfactants show excellent compatibility with other surfactants, forming mixed micelles. They are chemically stable in both alkalis and acids. Their surface activity varies widely and depends on the distance between charged groups, showing maximum activity at isoelectric point (Bajpai & Tyagi, 2007). With the introduction of better dissolving detergent powders, linear alcohol sulphate surfactants are used, with longer chain lengths that lead to higher surfactancy and performance (Cameron, 2007).

Builders

The efficiency of the surfactant is affected by the hardness or softness of the water. Large amounts of surfactants in detergents also significantly increase biological demand in water and impose a heavy load on sewage works and the environment due to their eco-toxicity. Therefore, builders are used in conjunction with surfactants to reduce water hardness by combining with divalent calcium and magnesium ions, making them less available and prohibiting their interference with the surfactant action (Yu *et al.,* 2008). Builders are used to enhance the detergent action. Builders provide an acceptable level of alkalinity and help to suspend and disperse soils and prevent their redeposition (Cameron, 2007).

Sequestering Builders are polyphosphates which inactivate the mineral ions which cause the water to be hard, and are able to suspend them in the solution. Citrate is not as strong as the polyphosphates, but it has a desirable effect and also contributes to the detergency performance of the liquid detergents (Bajpai & Tyagi, 2007:330).

Precipitating Builders include sodium carbonate, polyphosphate and sodium silicate (Yu *et al.,* 2008). Silicates soften the water by forming a precipitant with the hardness ions which can be washed away when the fabric is rinsed (Bajpai & Tyagi, 2007:330). This is done by forming insoluble calcium compounds (Yu *et al.,* 2008).

Phosphate builders were commonly used in laundry detergents but they have been blamed for causing eutrophication of lakes and other water sources (Cameron, 2007). Even a minor change in phosphorous concentration can have a major influence on the growth of microbes (Lehtola *et al.,* 1999). The addition of phosphate to water increases the proportion of acids and affects the lipopolysaccharide 3-hydroxy fatty acid, which is indicative of an increase in Gram-negative bacteria and changes in their communities in biofilms grown for 11 weeks (Keinänen *et al.,* 2002).

Anti-redeposition agents

Anti-redeposition agents prevent the loosened dirt and soil from redepositing on the clean garment or fabric. The most popular anti-redeposition agent is carboxymethyl cellulose. It is derived from natural cellulose and is very soluble in water. Sodium polyacrylate and polyethylene glycol polymers are also used (Bajpai & Tyagi, 2007). These agents adsorb to the soil or substrate and convey a negative charge to it. The soil will not redeposit on the fabric surface due to this negative charge (Kadolph, 2010).

Zeolite

Zeolites have been successfully used as alternative builders in detergents to replace sodium tripolyphosphate. Compared to phosphates, zeolites can additionally prevent the formation of poorly soluble (partially soluble) inorganic salts, which is a key factor in the formation of textile incrustations (Hui & Chao, 2006). It sequesters the multivalent ions and the anionic surfactants from precipitating out of the solution (Bajpai & Tyagi, 2007).

Alkaline agents

Sodium carbonate and sodium silicate are useful to give negative charges to soils. Oily soil can be easily removed in alkaline solutions due to the formulation of soap in the dirt (Baipai & Tyagi, 2007).

Corrosion Inhibitors

Sodium silicate is often used as a corrosion inhibitor which protects the washing machine during laundering. It protects the mechanical parts of a washing machine against corrosion (Baipai & Tyagi, 2007).

Enzymes

Enzymes are primarily used as stain removers (Johnson & Marcus, 1996). Less than 15 different enzymes are used presently in detergent worldwide. These enzymes originate from *Bacillus amyloliquefaciens, B. licheniformis, B. clausii, B. lentus, B. alkaloophilus* and *B. halodurans.* Subtilisins from *Bacillus* species are used in all laundry detergents. Their function is to degrade protein stains such as blood, milk, egg, grass and sauces (Maurer, 2004).

Protease is an enzyme used in laundry detergents and it helps to break down complex protein soils like blood, grass and milk (Bajpai & Tyagi, 2007:331). Lipases break down fat-based stains, while amylases attack starch-based stains. Cellulases protect fabrics from fibre damage caused by repeated launderings (Johnson & Marcus, 1996). When enzymes are added to the detergent formulation, it has the benefit that the laundering can be done at lower temperatures with improved cleaning (Schroeder *et al.*, 2006).

Other

Laundry detergents may also contain processing aids, colourants, fragrances, oxygen bleach; suds control agents, opacifiers, bleaching agents and optical brighteners.

2.5.2 Antimicrobial efficacy of detergents

Cationic detergents have the advantages of being stable, nontoxic and bland, but are inactivated by hard water and soap. Cationic detergents are often used as disinfectants for food utensils and small instruments. Several brands are on the market and contain benzalkonium chloride or cetylpyridinium chloride (Prescott, Harley & Klein, 2005). Anionic detergents have some antimicrobial properties, but only cationic detergents are effective disinfectants. The most popular are quaternary ammonium compounds characterized by positively charged quaternary nitrogen and a long hydrophobic aliphatic chain. It disrupts microbial membranes and denaturates proteins (Prescott, Harley & Klein, 2005). Cold water laundering with detergents alone is not effective at removing all bacterial contamination or reducing bacterial viability. In fact, bacteria would be released into the laundering water and contaminate other articles in the machine (Hall *et al.,* 2009). Munk *et al.* (2001) found that *E. coli* is the most resistant strain against the antimicrobial activity of commercial detergents, and no antimicrobial activity was observed when using a non-bleach-containing detergent. All detergents with significant antimicrobial activity contained bleach and are in powder form.

2.6 Environmental impacts of disinfectants and detergents

Laundry wastewater is a significant cause of environmental harm since the sanitizers, disinfectants, antibiotics, wetting agents and other surfactants they contain have poor biodegradability (Kist *et al.,* 2008). The size of commercial laundries varies considerably, but one washing tube will produce 48 m^3 of wastewater per day (Van der Poel, 2001). According to Wang, Chou & Kuo (2009) wastewater from coin-operated laundries is a major source of river pollution. The most commonly used methods are insufficient for laundry wastewater treatment, because of the large variability of the amount and composition of laundry wastewater.

In South Africa the manufacturers opposed the ban for phosphate-based detergents, stating that it was going to be to the detriment of the consumer, and they were not able to produce a phosphate-free product with equal washing efficiency. Replacing the phosphate would have increased the cost to the consumer and decreased soil removal efficacy (Wiechers & Heynike, 1986; Pillay, 1994). Phosphate is still included in some detergent formulations in South Africa, but it is associated with environmental issues, which resulted in non-phosphate detergents. One of the issues is eutrophication, which occurs when the nutrient level in the water increases, causing the formation of large algae blooms. This causes slow moving water and non moving masses of water to turn murky and it may even become toxic (Köhler, 2006:58). Eutrophication causes the water life of our natural water resources to die and this is a serious problem (Hui & Chao, 2006).

Sodium hypochlorite bleach (NaOCl) used for laundering and disinfecting reacts with soils and stains and is degraded primarily to salt. Small amounts of chlorinated organic by-products may also be formed, of which only 24% can be identified (Ong *et al.,* 1996).

2.7 Microorganisms

Bacteria are simple, single-celled organisms that are individually too small to see with the naked eye. Bacteria have cell dimensions between 0.2 – 3µm in diameter and 0.5 – 10 µm in length (Garbutt, 1997).

<u>Factors that influence growth:</u>

pH

Microorganisms grow best at pH values around 7.0, although there are few that grow below 4. Each species has a definite pH growth range and pH optimum growth (Prescott, Harley & Klein, 2005). Bacteria are more fastidious in their relationship to pH than moulds and yeasts, especially pathogenic bacteria. Adverse pH affects two aspects of a respiring microbial cell: the functioning of enzymes and transport of nutrients into the cell. The cytoplasmic membrane is relatively impermeable to H^+ and OH^- ions. Their concentration in the cytoplasm therefore remains constant despite wide variations that may occur in the pH of the surrounding medium. When microorganisms are placed in environments below or above neutrality, their ability to grow depends on their ability to bring the environmental pH to a more optimal range. When placed in acid environments, the cell must keep H^+ from entering or expel H^+ ions as rapidly as they enter. Key cellular compounds such as DNA and ATP require neutrality. When microorganisms grow in acid media, their metabolic activity results in the medium or substrate becoming less acidic, yet those that grow in high pH environments tend to cause a lowering of the pH.

Bacterial cells tend to have a residual negative charge and therefore, non-ionized compounds can enter cells, and ionized compounds cannot. At neutral or alkaline pH organic acids do not enter, where at acid pH values, these compounds are non-ionized and can enter the cell. The ionic character of the side chain ionisable groups is also affected on either side of neutrality, resulting in increasing denaturation of membrane and transport enzymes. Among the other effects that are exerted on microorganisms by adverse pH is that of the interaction between H^+ and the enzymes in the cytoplasmic membrane. The morphology of some microorganisms can be affected by pH. Other environmental factors interact with pH, such as temperature. As the temperature increase, the substrate becomes more acid. Concentration of NaCl also has an effect on pH growth rate curves. It has been found that the addition of NaCl broadens the pH growth rate of *E. coli*. When the NaCl exceeds the optimum level, the pH growth range is narrowed. An adverse pH makes cells more sensitive to toxic agents of a wide variety and young cells are more susceptive to pH changes than older cells (Jay, Loessner & Golden, 2005).

Solutes and water activity

All living organisms, including microorganisms need water in the liquid state to exist and grow (Jay, Loessner & Golden, 2005). The water activity of a solution is 1/100 the relative humidity of the solution, when expressed as percent. Microorganisms differ in their ability to adapt to habitats with low water activity. Extra efforts must be expended by microorganisms to grow in a habitat with low water activity because it must maintain a high internal solute concentration to retain water (Prescott, Harley & Klein, 2005). Bacteria generally require higher values of water activity for growth (Garbutt, 1997) than fungi, with Gram-negative bacteria having higher requirement than Gram-positive bacteria (Jay, Loessner & Golden, 2005).

Temperature

Environmental temperature deeply affects microorganisms as they are usually unicellular and their temperature varies with that of the external environment. The most important factor influencing the effect of temperature on growth is the temperature sensitivity of enzyme-catalysed reactions. At low temperature, the growth rate will increase as the temperature rise because the velocity of an enzyme-catalysed reaction will double for every 10°C increase in temperature. Metabolism is more active at high temperatures and the microorganisms grow faster. High temperatures are lethal and damage microorganisms by denaturating enzymes, transport carriers and other proteins. Membranes are also disrupted; the lipid bilayer melts and disintegrates. However, function enzymes operate more rapidly at higher temperatures, the organisms may be damaged to such an extent that it inhibits growth because damage cannot be repaired. At very low temperatures, membranes solidify and enzymes cannot work rapidly. These temperatures influence results in cardinal growth temperatures – minimum, optimum and maximum. The cardinal temperatures for a particular species often depend on other environmental factors such as pH and available nutrients (Prescott, Harley & Klein, 2005).

Oxidation-Reduction potential

Microorganisms have varying degrees of sensitivity to the oxidation-reduction potential (O/R) of their growth medium. The O/R potential of a medium can be described as "the ease with which the substrate gains or loses electrons" (Jay, Loessner & Golden, 2005). When the compound loses electrons, the substrate is oxidized; when electrons are gained, the substrate becomes reduced. Oxidation may also be achieved by the addition of oxygen. Therefore, a good reducing agent is a substrate that readily gives up electrons and one that readily takes up electrons is a good oxidizing agent. When electrons are transferred between compounds, a potential difference is created between the two compounds. This difference can be measured and expressed as millivolts (mV).The more highly oxidized a substance, the more positive its electrical potential; the more highly reduced the substance the more negative its electrical point. When the concentration of oxidant and reductant is equal, a zero electrical potential exists. Aerobic microorganisms require positive values (oxidized) for growth, from 200 to 800 mV, while anaerobes require negative values (reduced) from -200 to -400 mV (Jay, Loessner & Golden, 2005; Issa-Zacharia, 2011).

Nutrient content

For microorganisms to grow and function normally they require water, a source of energy, a source of nitrogen, vitamins and minerals (Jay, Loessner & Golden, 2005).

2.7.1 *Escherichia coli*

The genus *Escherichia* is a typical member of the Enterobacteriaceae that have their principal habitat in the bowel of humans and animals (Jay, Loessner & Golden, 2005).

2.7.1.1 Characteristics

Escherichia is a short, straight Gram-negative bacillus (Levison, 2008; Sussman, 1997). It is non-sporing and usually motile with peritrichous flagella, often fimbriate and occurs singly or in pairs in rapidly growing liquid cultures. Often a capsule or microcapsule is present and a few strains produce polysaccharide slime (Sussman, 1997).

2.7.1.2 Biochemical and culture characteristics

Escherichia coli are a facultative anaerobe capable of fermentative and respiratory metabolism, which grows readily on a wide range of simple culture media and on simple synthetic media. Under anaerobic growth conditions there is an absolute requirement for fermentable carbohydrate. Glucose is fermented to pyruvate, which is converted into lactic, acetic and formic acids. On solid media colonies are non-pigmented and may be smooth or rough. Colonies are usually circular and smooth (Sussman, 1997).

According to Prescott, Haley & Klein (2005) the cardinal temperatures for *Escherichia coli* are:

Minimum: **10°C**

Optimum: **37°C**

Maximum: **45°C**

In contrast to this Groh, MacPherson & Groves (1996) indicated that *E. coli* is one of the most heat-resistant organisms. Their study shows that water heated to 50°C has no significant effect on survival; however, water heated for 5 minutes at 60°C and for any length of time at 70°C or 100°C kills all *E. coli* bacteria. Ahmed, Conner & Huffman (1995) stated that cooking processes that provide an internal temperature of 60°C for 2 – 3 minutes kills *E. coli* in various meat products. *E. coli* reaches optimum growth at pH 7, but is able to grow from pH 4.5 to 9. It has been reported that it can survive in acidic foods such as apple cider, mustard, sweet pickle, custard and mayonnaise, with a pH ranging from 2.8 to 3.7 (Hsin-Yi & Chou, 2001).

2.7.1.3 Distribution

Escherichia coli is a member of the human gastrointestinal tract (Berg, 2004) and colonisation takes place soon after birth. The source is to be found in the mother and inanimate environment. It appears rapidly in the saliva but does not appear to colonise the normal mouth or pharynx (Sussman, 1997). Some strains can cause infection, most commonly in the urinary tract (Berg, 2004). It can also cause infection of the prostate gland, gallbladder, wound infections, infections in pressure sores, foot infections in people with diabetes, pneumonia, meningitis in newborns and bloodstream infections (Levison, 2008).

The function of *Escherichia coli* in the faecal flora is difficult to assess. It has been suggested that it has a nutritional significance by providing a source of vitamins in some animals. In nature, it is also found in soil, water or at any other site it can reach from its primary habitat, usually by faecal contamination. In healthy adults, over 20% of faecal *E. coli* has virulence-associated determinants and in 7% more than one strain is present (Sussman, 1997).

2.7.1.4 Virulence Characteristics

A number of virulence factors have been identified in *E. coli* (Escobar-Páramo *et al.*, 2004). The pathogenic processes that operate in a given infection always involve more than one virulence factor. (Sussman, 1997).

<u>Colonization factors</u>

Mucous surfaces have efficient clearance mechanisms to remove particles and bacteria, and to overcome these clearance mechanisms specific adhesion mechanisms have been evolved (Sussman, 1997).

2.7.1.5 Capsules of *E. coli*

E. coli is very small. Cells are rod-shaped and are 2.5 μm long and 0.8μm in diameter with hemispherical end caps. The cell has a three-layered wall enclosing the cytoplasm. *E. coli* have external organelles, thin straight filaments, called pili, that enable it to attach to substrata, and thicker longer helical filaments, flagella, that enable it to swim (Berg, 2004). Gram-negative bacteria such as *E. coli* characteristically have an outer membrane external to their murein layer. Ipopolysaccharide, a typical compound of this outer membrane, is the O-antigen of wild-type bacteria. Though antibodies directed against the O-antigen usually agglutinate these bacteria, serological studies of *E. coli* show that agglutination of many strains by homologous O-antisera occurs only after heating. This inhibitory effect is due to the presence of antigens distinct from O-antigens that are present as an extracellular envelope, or capsule that covers the O-antigenic lipopolysaccharide. These are called capsular or K-antigens.

Capsules protect pathogenic bacteria against non-specific host defences, notably the action of complement and phagocytes. Thus, encapsulated bacteria are often virulent, and their capsules are virulence factors (Sussman, 1997).

2.7.1.6 *Escherichia coli* in food chains

Abattoirs

Cattle have been established as a major natural resevoir for *E. coli* and play a significant role in the epidemiology of human infection (Omisakin *et al.,* 2003). Animal carcasses are often contaminated with their own intestinal *E. coli* and between carcasses even under good slaughter conditions. It was noted in an abattoir of high hygienic standard that the rectal *E. coli* of animals tended to be washed away during the heavy hosing down that follows the removal of intestines, but recontamination by environmental *E. coli* occurred, presumably derived from other animals (Sussman, 1997). The health risk from *E. coli* and other pathogens is minimized by abattoir carcass inspection for visible signs of fecal contamination supplemented with appropriate hazard analysis and critical control point systems (Omisakin *et al.,* 2003).

Food

A high correlation was found between the faecal *E. coli* stereotypes of hospital patients and those that contaminated their food. A survey of retail processed foods in the U.K. found a contamination rate of 12% by *E. coli* and over a quarter of the confectionery and cakes were contaminated as compared with only 9% of meat and meat-based products. Meat product isolates were more prone to be antibiotic resistant. Similarly, dairy products yielded both pathogenic and antibiotic-resistant *E. coli* (Sussman, 1997; Berge, Atwill & Sischo, 2005).

According to Graham (1997) the amount of illnesses associated with the microorganism *E. coli* O157:H7 raised concerns about the adequacy of disinfectants. *E. coli* can spread through the handling and eating of raw food (Chen-Yu, Eberhardt & Kincade, 2007). One strain produced a toxin that causes brief diarrhoea (Levison, 2008). The medium in which *E. coli* is contained will influence its ability to survive. Evidence suggests that it survives better in fatty foods as there is less water and hence the heat is not transferred as well as in products containing a lot of water. Cooking processes that produce an internal temperature of 60°C for 2 – 3 minutes provide a reduction of 10^5 of *E. coli* in a variety of meat products (Parry & Palmer, 2002).

More is probably known about *E. coli* than any other organism. Humans have a continuing intimate relationship with *E. coli*. However, in spite of all the research, there continue to be many gaps in our knowledge of this interaction between *E. coli* and humans (Sussman, 1997).

2.7.2 *Staphylococcus aureus*

Staph. aureus is one of the most feared pathogens because of their ability to cause overwhelming sepsis and death. Staphylococci have shown an upsetting ability to develop resistance to antimicrobial agents (Becker *et al.,* 2007).

2.7.2.1 Characteristics

The cocci are roughly spherical cells. They can exist as individual cells but are associated with characteristic arrangements that are frequently used in bacterial identification. Diplococci arise when cocci divide and remain together to form pairs. Long chains result when cells adhere after repeated divisions in one plane. *Staphylococcus* divides in random planes to generate irregular grapelike clumps (Prescott, Harley & Klein, 2005).

2.7.2.2 Biochemical and culture characteristics

There are many strains of *Staph. aureus,* some strains produce toxins that cause food poisoning, toxic shock syndrome and scalded skin syndrome. Many strains have developed resistance to antibiotics (Levison, 2008). According to Bremer *et al.* (2004) and Prescott, Harley & Klein (2005) the cardinal temperatures for *Staph. aureus* are:

Minimum: **6.5°C**

Optimum: **30-37°C**

Maximum: **46°C**

According to Bremer *et al.* (2004) and Valero *et al.* (2009) the minimum pH where *Staph. aureus* can survive is 4.0 and the maximum 10, with the optimum being pH 6 – 7. *Staph. aureus* is also able to grow in sodium chloride with concentrations up to 25% (Valero *et al.,* 2009). The different combinations of temperature, pH and water activity can largely influence the growth of *Staph. aureus* boundaries (Valero *et al.,* 2009).

2.7.2.3 Distribution

These bacteria are spread by having direct contact with an infected person, contaminated object or by inhaling infected droplets dispersed by sneezing or coughing

(Levison, 2008). *Staph. aureus* is very commonly found and is a transient skin microflora. It is also frequently associated with a variety of skin infections and survives on contaminated hands. It can withstand the drying of fabrics and is a prominent nosocomial pathogen (Sattar *et al.,* 2001). People can move the bacteria from their nose to other body parts with their hands (Levison, 2008). *Staph. aureus* can cause boils, skin infections, pneumonia and meningitis. It is also responsible for scaled skin and toxic shock syndromes (Chen-Yu, Eberhardt & Kincade, 2007: 259). Infections can range from mild to life threatening. Bacteria can travel through the bloodstream and infect any site in the body and bones (Levison, 2008).

2.8 Textile materials as a disease vector

Textile materials are in constant contact with microorganisms, not only from the skin but also from the environment (Teufel & Redl, 2006). Textiles have long ago been recognized as media to support the growth of microorganisms. They need an environment that provides nutrients to survive and food can be found in the form of skin cells, humid air or a damp textile product (Chen-Yu, Eberhardt & Kincade, 2007). Some of the substances added to fibres, such as lubricants, antistats, natural-based auxiliaries and dirt, can also provide a food source for microorganisms.

The factors that define the fabric e.g. thread thickness, product thickness, linear density, etc. determine the area that microorganisms would attack (Szostak-Kotowa, 2004). Textile products are sensitive to contamination by, growth of, and are responsible for the transmission of not only natural flora but also pathogenic microorganisms (Sun & Worley, 2005; Üreyen *et al.,* 2010). Bacteria move from person to person or object to object via air and touch transmission. Pathogenic bacteria are carried by 40% of areas that are regularly touched but irregularly cleaned like curtains (Thiry, 2010a). Methicillin resistant *Staph. aureus* was found to survive on the textile materials in the hospital (Neely & Maley, 2000). It has been indicated that 20% of infections occurring after surgery was caused by bacteria coming from surgeons gowns (Pilonetto *et al.*, 2004).

Bacteria are found almost everywhere in the environment and can quickly multiply when basic requirements such as moisture, oxygen, nutrients and appropriate temperature are present (Mao & Murphy, 2001; Gao & Cranston, 2008) and they will thrive even under severe conditions (Zohdy *et al.*, 2003). Textile products provide all such requirements and there is nourishment in natural and synthetic fibres in the form of the polymer or other sources such as sweat, sebum and food stains (Kim *et al.*, 2003). When microorganisms multiply in clothing it can cause degradation like discolouration, strength loss, unpleasant odour and a slick, slimy feel, and in some cases affect human health (Schindler & Hauser, 2004).

Natural fibres are more easily and rapidly affected by microorganisms (Schindler & Hauser, 2004; Szostak-Kotowa, 2004), especially cellulose fibres like cotton are target fibres for microorganisms because they are porous, and their hydrophilic structure retains water, oxygen, and nutrients (Kut *et al.,* 2005). During microbiological attack, enzymes act to release glucose from the cellulose, which can be used as a source of carbon for growth (Szostak-Kotowa, 2004). Most synthetic fibres are more resistant to microbial attack, due to their high hydrophobicity (Gao & Cranston, 2008), but Takashima *et al.* (2004) tested the ability of *Staph. aureus* to bind to textile fibres. They found that it bound to polyester at a very high ratio (96.2%) but to cotton at a very low ratio (2%). They concluded that clothes made of polyester can be recognized as a medium that spread *Staph. aureus* since 100 mg of the polyester fibres bound more than 5 x 10^6 cfu on their surface. The same amount of cotton fibres bound less than 2 x 10^3 cfu. The interactions that determine binding characteristics are not known. Ionic interactions could be involved, because they found that in a 3-M sodium chloride solution and a neutral pH, binding was partially inhibited (Takashima *et al.,* 2004).

Hsieh & Merry (1986:544) found that the *E. coli* did not show any preference to adhere to a specific fibre, and adhered differently from the *Staph. aureus.* The *Staph. aureus* preferred the polyester and their adherence increased with the amount of polyester in the fabrics. However, their results indicated that both *Staph. aureus* and *E. coli* were adhering to polyester. Sattar *et al.* (2001) indicated that *Staph. aureus* transfer on moist or dry fabrics was higher from polyester/cotton than from cotton fabric, and friction had a significant influence on the transfer rate. Pilonetto *et al.* (2004) also indicated that bacteria isolated from hospital gowns were mainly Gram-positive, but when they examined the frequency of types of pathogens, 39% was Gram-negative and 61% was Gram-positive. Bajpai *et al.* (2011) found maximum adherence of *E. coli* cells on cotton and the least on polyester. According to them the adherence to cotton occurred in two phases: an initial rapid phase followed by a stationary phase. In the cases of polyester and polyester/cotton the adherence increased linearly through the exposure time. They also reported that adherent *E. coli* cells did not cover the fabric uniformly and numbers were higher near rough surfaces, therefore surface morphology of the fabric and yarn plays an important role in adherence. Their Fourier transform infrared studies revealed that both cotton and *E. coli* have abundant free hydroxyl groups that may interact strongly with each other and other hydrophilic groups such as carboxyl, phosphate, and amides.

In clinical settings textiles can be an important source of bacteria that may contaminate patients and personnel as well as the direct and indirect environment. Bacteria can normally be found on human skin, nasal cavities and other areas. Approximately 30% of healthy people are carriers of *Staph. aureus*. Shedding from our bodies occur all the time and when a bacterium is shed into a textile fabric between the patient and the bed, either in his pyjamas or directly onto the sheet, the moisture and temperature in the textile micro-environment, promotes its proliferation (Borkow & Gabbay, 2008). A study by Neely & Maley (2000) indicated that *Staph. aureus* survived for days to months after drying on commonly used hospital fabrics. *Staph. aureus* survived up to 21 days on cotton and polyester/cotton blend, while lasting 56 days on polyester.

Leonas (1998) indicated that when liquids carry microorganisms, it will move rapidly through the fabric, but the fabric contains a microporous membrane and only if the pores are larger than the microorganisms can they transmit through the fabric. A smooth fabric surface promotes movement of the liquid along the surface rather than to penetrate the fabric, but the tight packing of the yarns and smooth filament fibres enhance wicking of the liquid. The wicking effect can result in fabric penetration. The irregular surface of the fabric prevents liquid to move off the fabric and promotes penetration.

Therefore, wet fabrics are poorer barriers than dry fabrics, the porosity of fabrics increase after laundering as the fabric has a more open structure, and microorganisms and liquids can pass through the fabrics more easily.

2.9 Textile fibres

According to Mowbray (2011) the fibre production in the world has increased by 30% in the last ten years. Cotton and polyester accounted for an approximate 61 million tonnes of textile fibre production in 2010, which is 83% of the 73 million tonnes of fibres produced.

2.9.1 Cotton

Cotton is widely accepted as a clothing material because it is readily available in most parts of the world and properties like durability, conduction of heat and moisture absorption. Its biodegradability is a great attraction. Unfortunately it has drawbacks like inflammability, poor wrinkle recovery and poor crease retention. It also is prone to bacterial attack (Hipler & Elsner, 2006). Cotton offers comfort during wear and therefore many articles are made from it like leisure clothing, outdoor tents and uniforms, household articles and textiles in medicinal use (Abo-Shosha *et al.,* 2007).

2.9.1.1 Production

Cotton is a seed fibre, which grows on bushes. When die blossom falls off the seed begins to grow. Inside the seedpod or boll, there are usually seven to eight seeds containing hundreds of thousands cotton fibres. When the boll is ripe the white fibres grow and expand until they split the boll open (Kadolph, 2010:61). Cotton is usually picked by machine and therefore, contains many immature fibres. The cotton is pressed into a brick after picking and taken to a gin to separate the fibres from the seeds. In the saw gin, the fibres are picked up by a whirling saw and taken to a knifelike comb, which only permits the fibres through. The fibres are now called lint, and pressed into bales and sold to spinning mills or exported (Kadolph, 2010:61).

After ginning, the seeds are covered with very short fibres known as linters. The linters are removed from the seeds and can be used to a limited extent as raw material for the production of rayon and acetate. Linters can also be used as stuffing in upholstery, mops, blankets, rugs, medical supplies, etc. Linters can also be converted to cellophane, photographic film, fingernail polish, and methylcellulose that are used in make-up and chewing gum (Kadolph, 2010:61).

2.9.1.2 Structure

The fibre is a single cell, which grows from the fibre as a single tube (Kadolph, 2010:61). Cotton staple fibres range between 0.32 – 6.35 cm in length, with a small diameter ranging between 16 – 20 micrometers. Usually as the fibre becomes longer, it also becomes narrower. The ratio of length-to-width ranges from 6000:1 for the longest and smallest diameters of about 350:1 for the shortest and widest types (Hatch, 1993). The longer the length of the fibre, the better the fibre properties and the higher the quality of the fabric (Cohen & Johnson, 2010), therefore longer fibres are used in softer, smoother, stronger, and more lustrous fabrics (Kadolph, 2010:62). Fibre length is determined by taking a sample from a bale of cotton, sorting the fibres according to length and then calculating the average staple length as well as the variation or uniformity ratio (Kadolph, 2010:61).

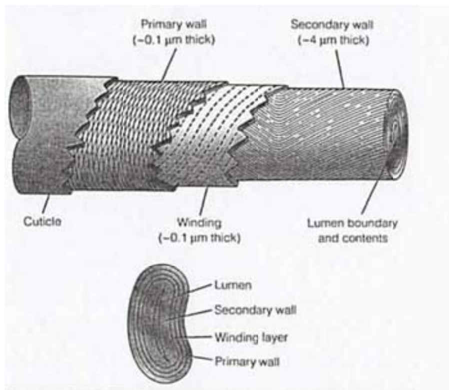


Figure 2.2: The submicroscopic structure of cotton fibre (Hatch, 1993).

Four distinct regions can be identified, but the fibre grows almost to full length before the secondary wall begins to form. The **cuticle** contains pectin, wax and fats and is only a few molecules thick, while covering the primary wall (Kadolph, 2010:62; Hartzell-Lawson & Hsieh, 2000). The wax protects the rest of the fibre against degrading agents during consumer use, but the scouring and bleaching in the fabric manufacturing process, remove much of it, then the rest is removed during laundering (Choudhury, 2006; Hartzell-Lawson & Hsieh, 2000). The **primary cell wall** is composed of fibrils, which is very fine structures. The primary cell wall can be seen as a sheath of spiralling fibrils. Each layer spirals 20-30° to the fibre axis. Mature fibres have thick walls and immature fibres, thin primary walls. When the wall is too thin, the fibre can bend and becomes entangled. During the processing of immature cotton, clumps or neps are formed which lowers the quality of the textile as it will not dye uniformly and the surface is irregular.

Beneath the primary cell wall lays the **secondary cell wall** that consists of concentric layers of cellulose. The layers deposited at night differ from those deposited during the day in density, which leads to the formation of growth rings seen in the cross-section (Kadolph, 2010:62). This forms the bulk of the fibre. The first layer of the secondary wall differs in structure form the remainder of the wall, so it is specifically named the winding layer. The secondary cell wall consists of up to 95% cellulose (Maxwell *et al.,* 2003).

The hollow canal in the length of the fibre is called the **lumen**. The lumen was full of cell sap, but as it evaporated the fibre collapsed inward, accounting for the twisted-ribbon form and kidney-shaped cross-section. Immature fibres have large lumens, while mature fibres have small lumens, which may not be continuous because the wall closes the lumen in some sections (Hatch, 1993). The lumen is the canal used to transport nourishment during the development of the fibre. In mature fibres, dried nutrients may appear as dark areas under the microscope (Kadolph, 2010:62). The cellulose molecules are organized into parallel arrangements known as crystallites, and into larger aggregates known as fibrils. The simple fibril is made up of 36 cellulose chains and regarded as the basic crystalline unit of cotton cellulose (Maxwell *et al.,* 2003). The fibrils are composed of linear cellulose polymers.

2.9.1.3 Chemical composition and Molecular arrangement

Raw cotton consists of 86-96% cellulose (based on the weight of the fibre), impurities in the fibre range between 4 – 12% and include protein, pectin, fats, waxes, colouring matter and water-soluble substances (Buschle-Diller *et al.*, 1998; Hashem, 2007). After finishing, consists of 99% cellulose (Kadolph, 2010:64). The cellulose polymers have a high degree of polymerization. The most important chemical group on the polymer is the hydroxyl group (-OH) and many of the properties of cotton can be attributed to them. They attract water and dyes, and enable hydrogen bonding between adjacent cellulose chains in the crystalline areas (Hatch, 1993; Collier & Tortora, 2001:75). According to Kadolph (2010:64) longer chain length contributes to fibre strength.

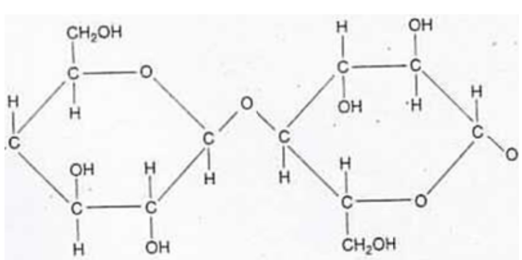


Figure 2.3: Repeating unit of cellulose (Collier & Tortora, 2001).

Cellulose is a polymer of glucose, commonly known as a pyranose structure. This is a ring structure consisting of five carbons and an oxygen atom (Choudhury, 2006). Cotton is

70% crystalline and 30% amorphous. The degree of crystallinity is high but the crystalline portions are often not oriented and at an angle to the axis (Hatch, 1993; Collier & Tortora, 2001; Choudhury, 2006). Hydrogen bonding does not occur between polymers wherever two hydroxyl groups lie opposite each other; these groups are not close enough for hydrogen bonding to occur. Hydrogen bonding rather involves the oxygen atom located between the rings and the hydroxyl group attached to the sixth carbon atom. This bonding gives strength and rigidity to the fibre. Hydroxyl groups react with a variety of chemicals, which allows the modification of cotton with chemical finishing resins. The hydroxyl groups also attract and hold water in the fibre. The backbone of the polymer chain is made up of carbon-oxygen-carbon (-c-o-c-) bonds. They are more subject to breaking by oxygen than carbon to carbon (-c-c-c-) bonds (Hatch, 1993).

Cotton can be altered by chemicals. Mercerization is the treatment of yarns or fabrics with sodium hydroxide, which causes the fibre to swell in order to create a rounder cross-section. It is a permanent physical change that increases absorbency and improves dyebillity. Liquid ammonia can also be used and results in good lustre and dyebillity, also, when these fabrics are treated to be wrinkle-resistant they are not as stiff and harsh as mercerized wrinkle-resistant fabrics (Kadolph, 2010:64).

2.9.1.4. Physical properties

Colour

The colour varies from creamy white to dirty grey. The whiter the fibre, the higher its quality (Hatch, 1993; Collier & Tortora, 2001). However, some naturally coloured cotton can be produced such as brown, rust, red, beige and green. These commercially available naturally coloured cottons are difficult to find and sell for twice the price of white cotton (Kadolph, 2010:61).

Microscopic examination

Mature cotton appears as a flat, twisted ribbon with a tapered tip (Collier & Tortora, 2001). The seed end is irregular, as it has been torn from the cotton seed. No other fibre has a similar structure; therefore, cotton can be positively identified under a microscope. The diameter ranges from 16-20 microns. Mature cotton has a U or a kidney bean cross-sectional shape similar to a collapsed tube (Hatch, 1993; Choudhury, 2006). This shape could be due to the asymmetry of the mechanical strains during drying from a swollen cellular tube to the collapsed fibre form (Choudhury, 2006).

Lustre

Lustre is low, unless the fibre was treated. This is due to the natural twist, which give an uneven surface (Collier & Tortora, 2001). Mercerized and ammonia-treated cotton fabrics have a soft and pleasing lustre (Kadolph, 2010:64).

Specific gravity

Specific gravity of cotton is 1.54, which makes cotton feel heavier in weight than fabrics made from polyester (Collier & Tortora, 2001; Choudhury, 2006).

2.9.1.5 Mechanical properties

Strength

According to Kadolph (2010:63), cotton has medium strength, with a dry breaking tenacity of 3.5 to 4g/d, and according to Krifta (2006); cotton has an average strength of 29.3 g/tex). The lower crystalline orientation decrease strength, while the length of the polymer chains increases strength (Collier & Tortora, 2001; Choudhury, 2006). The end-use of the fibre is largely determined by its length properties (Krifta, 2006). The long-staple fibres produce stronger yarns due to more contact points among the fibres when they are twisted together. Cotton is 30% stronger when it is wet and can therefore be handled roughly during laundering and use (Kadolph, 2010:64). The increased tenacity is brought about by a temporary improvement in polymer alignment in the amorphous regions of the polymer system as a function of swelling. Tenacity is also improved by the uptake of water in the lumen, which untwists the fibre. This means that no special precautions need to be taken when laundering cotton fabric to avoid vigorous agitation, wringing or twisting the fabric to remove water, or hanging it up wet to dry (Collier & Tortora, 2001; Hatch, 1993). According to Gupta (2003) cotton has a breaking strength of 40cN/tex and a 7% strain to fail. When tension is applied to a cotton fibre, the reversal area untwists to elongate the fibre, which generates shear stresses that cause an axial splitting between the fibrils. The split continues around the fibre until it reaches the line of weakness where it then breaks (Harzallah *et al.*, 2010). Cotton also has good abrasion resistance (Kadolph, 2010:64).

Elongation and recovery

Cotton has low elongation of 3% and low elastic recovery (Collier & Tortora, 2001; Kadolph, 2010:64). When a longitudinal force works in on the fibre, it first pulls the polymers that are spiralling around the fibre in the primary and secondary walls more into alignment with the axis. Some elongation of the fibre occurs because the polymers change from spiralling to being more in line with the axis. The force then begins to stress the polymers themselves and strong hydrogen bonds work to prevent polymers from slipping by one another as the force is increased. The fibre elongates very little under increasing force due to the effectiveness of the hydrogen bonded system. In the highly crystalline cotton fibre, the strength of the covalent bonds along the polymer chain is lower than the strength of the hydrogen network, so the fibre breaks instead of elongating very much (Hatch, 1993).

Elastic recovery of cotton is moderate, normally 75% at 2 – 5% extension (Kadolph, 2010:63). Above 5% extension it exhibits less than 50% recovery. Hydrogen bonds are broken when the fibre is elongated, and will reform as the polymers slide by one another. When the stress is removed, polymers stay bonded in their new positions (Hatch, 1993).

Dimensional stability

Cotton fibres are dimensionally stable in water. The fibres swell in the transverse direction when wet, but return to the original diameter when dry. Fabrics may shrink during the first few launderings because it releases tension created during weaving or the finishing process (Hatch, 1993; Collier & Tortora, 2001). According to Kadolph (2010:64) all cotton fabrics will shrink, unless it has received a durable-press or shrinkage-resistant finish. Untreated cotton will shrink less when it is laundered in cold water and drip-dry than those laundered in hot water and tumble dried. When these cotton articles are used again, it might slightly stretch out.

2.9.1.6 Chemical properties

Absorbency and moisture regain

Cotton is a hydrophilic fibre (Cohen & Johnson, 2010). According to Kadolph (2010:64) its moisture regain can be from 7 – 11%. Cohen & Johnston (2010) recorded a regain of 8.5% at 65% humidity and 21°C. The high moisture content is due to the hydroxyl groups that attract water and makes it an absorbent fibre. It is also due to the drawing up of water between the various layers or walls and the absorption of water between the many fibrils on the fibre surface. Water molecules can enter the amorphous regions but not the crystalline regions, because the interpolymer spaces in the crystalline regions are too small (Hatch, 1993). Cotton fabrics will absorb more moisture in cool, clammy conditions and may become uncomfortable as they feel wet and clingy. However, cotton can still be used in hot, humid circumstances, as the fibres absorb moisture and feel good against the skin in high humidity (Kadolph, 2010:64).

Electrical conductivity

Cotton conducts electricity and does not build up static charges (Choudhury, 2006; Kadolph, 2010:64).

Heat conductivity

Cotton has moderately high heat conductivity (Choudhury, 2006) that makes the fabric comfortable in hot weather (Collier & Tortora, 2001).

Effect of heat

Exposure to dry heat cause gradual decomposition and deterioration. When exposed to a flame, it will burn even after the flame is removed. The burning fabric smells like burning paper, with a fluffy grey ash (Collier & Tortora, 2001). Cotton fibres conduct heat energy, which minimize destructive heat accumulation (Choudhury, 2006). Cotton is not thermoplastic, which can be attributed to its long fibre polymers and numerous hydrogen bonds. Polymers are prevented from settling in new positions when heat is applied (Hatch, 1993). It can withstand high ironing temperatures. Physical properties are unchanged by heating at 120°C for a moderate period (Choudhury, 2006).

2.9.1.7 Chemical reactivity

Acids

Mineral acids will degrade and destroy these fibres. Volatile organic acids have no harmful effect, but non-volatile organic acids will degrade the fibre slightly if not removed (Collier & Tortora, 2001). Hot, dilute acids cause the fibre to gradually degrade, although the procedure is slow and may not be immediately evident. Mineral or inorganic acids will degrade the fibre more rapidly. These acidic conditions hydrolyze (break) the cotton polymer at the glycoside oxygen atom, which links the glucose units forming the polymer chain (Hatch, 1993). Fruit and fruit juice stains should be removed quickly with cold water to facilitate easy removal (Kadolph, 2010:64).

Alkalis

Strong alkalis have no harmful effect; therefore, all detergents on the market can be used. High concentrations are used during mercerization that causes the fibre to swell and become stronger (Collier & Tortora, 2001; Choudhury, 2006). Alkaline media can even be used at high temperature without damaging the fibres (Anandjiwala *et al.*, 2007).

Oxidizing agents

Chlorine bleach can be used under controlled conditions, although prolonged or overuse will cause degradation of the fibre (Hatch, 1993; Collier & Tortora, 2001). According to Choudhury (2006) oxidizing agents such as hydrogen peroxide, sodium hypochlorite and sodium chlorite are harmless in dilute concentrations; however, it can cause damage when used in higher concentrations. Damage is restricted to the polymers on the fibre surface and therefore leaves the polymer system largely intact (Hatch, 1993).

Organic solvents

Organic solvents have no harmful effect on cotton and can be used for spot and stain removal (Collier & Tortora, 2001), as well as dry cleaning (Kadolph, 2010:64). Cotton is soluble in cuprammonium hydroxide and cupriethylene diamine; however, these are not used during everyday living and are therefore not in consideration (Choudhury, 2006).

2.9.1.8 Sustainability and environmental concerns

Cotton is the leading fibre crop in the world and of the 85 producing countries, 80 were officially classified as low-income or “developing” countries in 2005. Cotton is, therefore, critical to some of the poorest countries in the world like West and Central Africa (Herring, 2005) where farmers grow cotton to raise an income for their families and therefore when cotton prices are high and their production is good, their income is high. Unfortunately, when cotton prices are low or production is less, their income suffers a decrease. In certain parts of the world, the labour involves harvesting by hand and this is performed by forced child labour. This practice is deplored and many segments of the textile industry refuse to source cotton from segments where there are no minimum age laws. In parts of Central America and Africa, cotton seeds are processed into food to prevent malnutrition (Kadolph, 2010:66).

The environmental impact of cotton production is an increasing concern with the main problems being salination, desertification and poisoning of the environment and human health (Kooistra & Termorshuizen, 2006). Since it is a natural fibre, most consumers believe that it is a good environmentally friendly choice. However, cotton articles cannot be produced without an environmental impact, although cotton is a renewable resource and intrinsically biodegradable (Chen & Burns, 2006).

Fifteen percent of cotton yield loss is due to insect damage (Kooistra & Termorshuizen, 2006). Agricultural chemicals are extensively used to fertilize the soil, fight insects, control disease and plant growth and strip the leaves for harvest. This problem can be made worse by excessive rain that create a runoff contaminated with these chemicals which can be toxic to humans, animals, insects and other plants. Among the wide variety of pesticides used on cotton, some are listed by the World Health Organization as highly hazardous and includes monocrotophis, triazofos, parathion, parathio-methyl, phosphamidon, methamidophos, and demeton-S-methyl. In some countries, these pesticides are no longer permitted but there is not an adequate verification system, therefore they are still in use (Kooistra & Termorshuizen, 2006). In developed countries they use modified practices to reduce the use of chemicals, but unfortunately this is not the case everywhere (Kadolph, 2010:67). In many instances, cotton is harvested by a machine and, therefore, treated with defoliant chemicals to cause the leaves to fall off the plants to prevent staining of the fibres (Chen & Burns, 2006). Impurities such as seeds, dirt and plant residue also result in a more intense cleaning process, but child labour is sometimes the alternative (Kadolph, 2010:67).

Cotton is a water intensive crop that requires large amounts of water for both cultivation and processing. In many areas where the rainfall is low or irregular, irrigation is used. The most commonly used irrigation system is the flood-or-furrow irrigation system. This system is the easiest and cheapest to install, but unfortunately has the lowest water efficiency. Excessive irrigation can upset the water table or the water level of the soil. Cotton grown with no irrigation is marketed as rain-fed cotton (Kooistra & Termorshuizen, 2006; Kadolph, 2010:67).

Genetically modified cotton has been well established because of its resistance to certain insect pests and tolerance to herbicides (Kadolph, 2010:67), and can be referred to as "transgenic cottons" (Chen & Burns, 2006). Other benefits include no loss in fibre quality, less soil erosion and higher incomes for producers. There is, however, some concern about the large-scale production as its long-term environmental and health effects is not known. There is some concern about their impact on other insects as well as the potential of insects developing a resistance to genetically modified crops (Herring, 2005; Kadolph, 2010:67). According to Anon (2011) the largest impacts during agriculture are nitrogen in fertilizer production, ginning energy and irrigation.

Cotton is bleached in a chemical and water solution and rinsed to enable dyeing and printing which add to consumer appeal. These processes use extensive amounts of water (Anon, 2011) and other chemicals, as well as heat (Kadolph, 2010:68). The environmental effect of processing cotton continues to be a concern, although the industry has improved recycling, reduced waste and cleaned up wastewater (Chen & Burns, 2006).

An effort is currently being made to provide consumers with more information at the point of purchase; therefore, several terms are used to describe cotton under more environmentally friendly conditions. **Organic** cotton is produced following standards where organic farming has been used for at least three years. No synthetic commercial pesticides or fertilizers are used and integrated programs help decrease the use of pesticides. According to the European Community Council Regulation the definition of organic farming is: "Production systems designed to produce optimum quantities of product of high quality by using management practices which aim to avoid the use of agro-chemical inputs and minimize damage to wildlife and the environment" (Kooistra & Termorshuizen, 2006). **Transition** cotton is produced by organic farming, but it has not been practiced for the three year minimum. **Green** cotton describes fabric that has been washed with a mild natural-based detergent, but has not been bleached or treated with any other chemicals, except natural dyes. The term **conventional** cotton describes all other cottons. Organic and transition cotton are more expensive as there is a lower fibre yield per acre and the costs of processing free of chemicals (Kadolph, 2010:68). Conventional white cotton still accounts for the majority of cotton products, despite the introduction of environmentally responsible cottons (Chen & Burns, 2006).

Global warming, the rise in the earth's temperature due to human activity, is an important issue of debate and research. Important contributors are believed to be CH_4 and N_2O. Cotton cultivation is believed to contribute to global warming primarily through energy use, burning of organic materials and the CH_4 produced by the use of animal labour (Kooistra & Termorshuizen, 2006).

2.9.2 Polyester

Synthetic polymers such as polyester, have become more widely accepted as the materials of choice in many consumer and industrial applications based on their desirable combination of physical properties, favourable economics and broad versatility (Craver & Carraher, 2000). There are different trade names for polyester; in the UK it is known as Terylene and in the USA as Dacron (Hipler & Elsner, 2006). Although offering many advantages such as durability, crease-resistance and soft hand, polyester has several drawbacks like soil deposition, reduced soil release, and pilling (Sheth & Musale, 2005).

2.9.2.1 Production

Polyester fibres are melt-spun as indicated in Figure 2.2 (Kadolph, 2010:167). The chips are dried and put into hopper reservoirs. The molten polymer is extruded through spinnerets, solidifies and is wound onto cylinders. Further processing depends on the end-use of the fibre. For staple fibres, sets of filaments comprising between 250 – 3000 filaments are brought together and coiled in a large holder. After the extrusion of the fibre, the molecules are disordered and in an amorphous arrangement (Gupta, 2003; Kadolph, 2010:155). Fibres are then heated and drawn to several times their original length to orientate the molecular structure in a more parallel arrangement and bring them closer together to be more oriented and crystalline (Kadolph, 2010:155). The fibres are allowed to relax to release stresses and reduce shrinkage of drawn fibres. The amount of draw depends on the intended use, determines the decrease in fibre size and controls the increase in strength (Kadolph, 2010:155). Drawing is done at a temperature well above glass transition point, which is 80°C. Rate and temperature conditions should be carefully selected to ensure that the amorphous regions are oriented, and crystallization will take place as the temperature drops to room temperature. The amount and conditions of drawing will influence the force-elongation properties of the product. Therefore, industrial fibres like tire cord are more highly drawn than yarns to ensure high strength and less elongation (Gupta, 2003). Heat setting is used to stabilize the shape and dimensions of yarns and fabrics made of heat-sensitive fibres. The yarn or fabric is heated to bring it to the specific temperature where it can be set called the glass transition temperature. At this temperature the molecules can move freely to remove stress within the fibre. When the fibre has cooled, the shape and the molecular structure is locked and the fabric or yarn will be stable at any temperature lower than the set temperature, but higher temperature can cause shrinkage (Kadolph, 2010:156). Heat setting can be applied at any stage of finishing. The tow may be cut into required length, which usually ranges from 38 – 152 mm, and baled to be sold (Collier & Tortora, 2001). For continuous filament yarns, the fibres are either drawn directly and packaged for sale, or wound on bobbins for draw twisting or draw texturing (Collier & Tortora, 2001). Fibre-manufacturers sell four polyester products: filament fibre, staple and tow fibre, fibrefill and non-woven fabric structures.

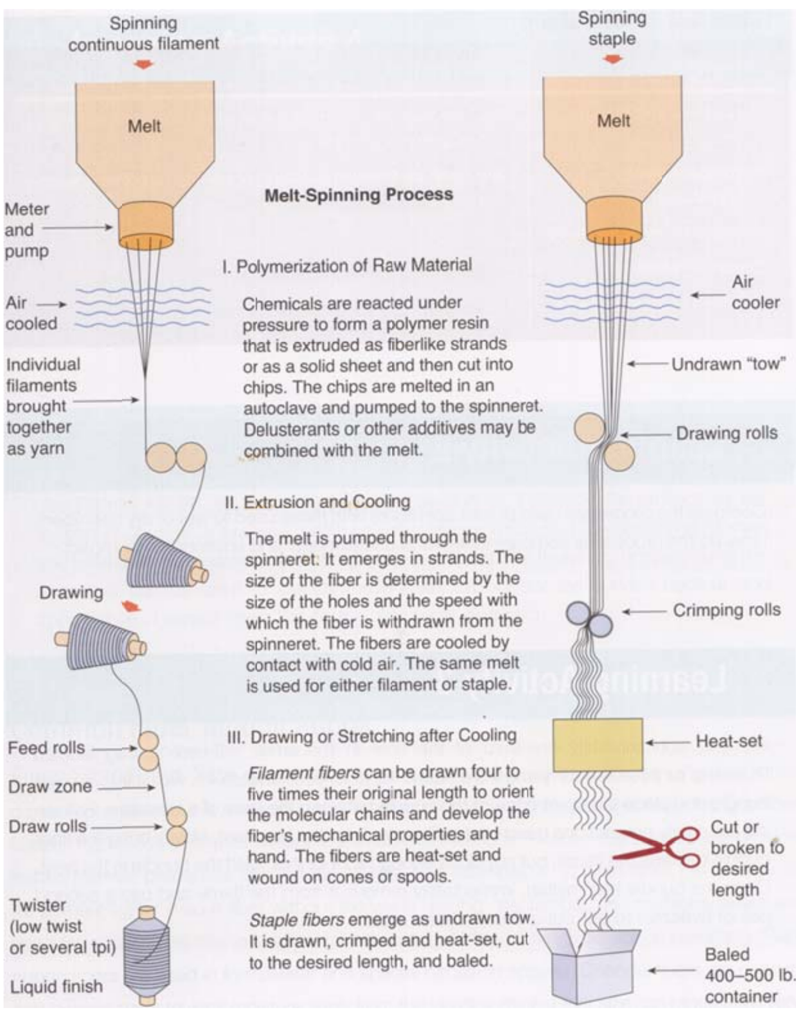
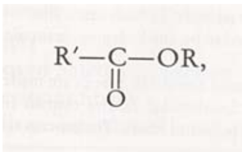


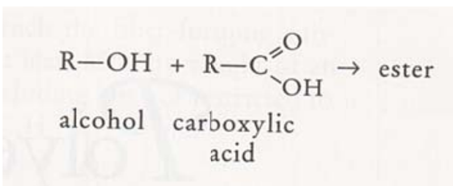
Figure 2.4: The melt spinning processes for filament and staple fibres (Kadolph, 2010:155).

2.9.2.2 Generic groups

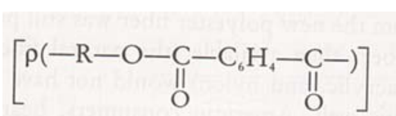
The name "polyester" reflects the chemical linkage of the monomers within the fibre. An ester is a chemical group with the following general structure, where R and R' can be any hydrocarbon chemical group.



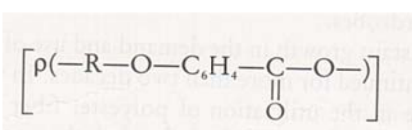
Esters are formed in a reaction between an alcohol and a carboxylic acid:



The alcohol and the acid must have the reactive chemical group –OH and –COOH at each end of the molecule, to synthesize a polymer. In the polyester fibre the carboxylic acid must be an aromatic one, which means a benzene ring is included. As defined by the Federal Trade Commission polyester fibre is "a manufactured fibre in which the fibre-forming substance is any long-chain synthetic polymer composed of at least 85 percent by weight of an ester of a substituted aromatic carboxylic acid, including but not restricted to substituted terephthalate units."



Or parasubstituted hydroxybenzoate units



Various polyester generic groups exist depending on which carboxylic acid or hydroxybenzoate is reacted with a dialcohol (Hatch, 1993).

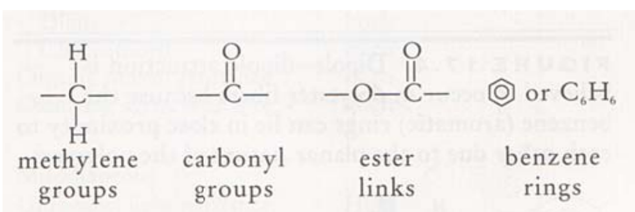
Polyethylene Terephthalate (PET)

PET is the most important member of the polyester generic group of fibres. These are high-molecular-weight compounds with a recurrent ester bond in the main chain. PET is a linear aromatic polyester consisting of terephalic acid and ethylene glycol (Hipler & Elsner,

2006) or ester exchange reaction between dimethyl terephthalate and ethylene glycol at 250 – 300°C in the presence of a catalyst to a DP of 100 – 250. The resultant polymer is isolated by cooling, then solidified and dried. Polyester fibres are melt-spun at 250 – 300°C followed by fibre orientation and stretching (Choudhury, 2006). There are different trade names for polyethylene terephthalate; in the UK it is known as Terylene® and in USA as Dacron® (Hipler & Elsner, 2006). Their production increased the most rapidly of any of the chemical fibres as a result of its very practical properties, polyester is versatile and much more are expected from these fibres (Fryczkowski, Rom & Fryczkowska, 2005). More than 95% of polyester fibre manufactured today is PET (Hatch, 1993).

2.9.2.3 Structure

Polyester fibre is smooth and even in diameter, with no identifiable microscopic features. The cross-section is nearly circular or trilobal depending on the spinneret opening (Choudhury, 2006). Since the fibre is melt-spun, it is easy to change the cross-sectional shape by altering the shape of the spinneret hole: round, trilobal, octolobal, oval, hollow, voided, hexalobal and pentalobal (Kadolph, 2010:167). Fibre diameter ranges between 12 – 25 µm. The fibre could be white or off-white and partially transparent (Hatch, 1993). The important chemical groups are the methylene groups, carbonyl groups, ester links and benzene rings.



The polymer is linear and the degree of polymerization ranges between 115 and 140. The fibres are 35% crystalline and 70% amorphous. However, the polymers in the amorphous area are highly oriented to the fibre axis. The low polarity of the carboxyl oxygen and non-polarity of the methylene hydrogen prevent the formation of hydrogen bonds, but very effective forces of attraction occur as there is a cloud of electrons above and below each benzene ring (Hatch, 1993). According to Hearle (1993) polyester fibres are 50% crystalline, in the sense that the density of packing is halfway between that of perfectly crystal and totally amorphous.

2.9.2.4 Physical properties

Appearance

A variety of cross-sections can be found, including round, trilobal, pentalobal and hollow. The fibres appear as round, long, smooth rods (Cohen & Johnson, 2010) when viewed under a microscope. Spots of pigment will be seen if the fibre has been delustered. Longitudinally, multilobal fibres appear striated (Collier & Tortora, 2001).

Specific gravity

Polyester fibre has a medium specific gravity (Hatch, 1993) and will, therefore, create medium weight fabrics (Collier & Tortora, 2001).

2.9.2.5 Mechanical properties

Strength

Polyester has a high tenacity (Cohen & Johnson, 2010) due to the highly crystalline polymer system, which allows the formation of very effective interpolymer reactions of the electrons of benzene rings. However, the breaking tenacity of polyester can vary with its intended end use. Stronger fibres have been stretched more and therefore their elongation is lower than that of the weaker fibres (Kadolph, 2010:169). Partially oriented filament fibres are stretched more during the production of textured yarns. They have a tenacity of 2-2.5 g/d, which is lower than that of staple fibres, but their elongation exceeds that of other fibres at 120-150%. According to Moody & Needles (2004), polyester is extremely strong with a tenacity of 3-9 g/d (27-81 g/tex). The polyesters are sold in yarn form, called partially oriented yarn. Polyester retains 70-80% of its tenacity following prolonged exposure to temperatures below 150°C (Hatch, 1993). Strength is not affected by moisture (Collier & Tortora, 2001; Kadolph, 2010:169).

Elongation

A moderate amount of stretch can applied before breaking, with elongation primarily dependent on the amount they are drawn during processing. Staple fibres undergo less drawing and therefore have a higher elongation (Collier & Tortora, 2001). According to Needles & Moody (2004) elongation at break is usually between 15-50%, depending on the degree of orientation and nature of the crystalline structure.

Elongation at low stress levels is low. There exists an extensive interpolymer interaction of benzene electrons along the oriented and crystalline polymers, which keep the polymer from slipping. Fibres extend between 2-7% when subjected to forces that would break natural cellulose fibres. The fibres also have a high elastic recovery under low stress. Recovery is 97% at 2% elongation (Hatch, 1993). However, the fibres do not exhibit high elastic recovery after subjected to high levels of stress. The van der Waals forces between polymer chains as well as the benzene electron clouds, allow polymer slippage under high stresses (Moody & Needles, 2004). Polyester fibres perform best when small, repeated stresses are applied, rather than large stresses (Hatch, 1993).

Resilience

Polyester has excellent resilience and can be blended to make easy-care fabrics (Collier & Tortora, 2001; Cohen & Johnson, 2010). Resiliency makes polyester a good fibre-fill in quilted fabrics and furniture padding (Kadolph, 2010:171).

Dimensional stability

The stiffness of the polymer chains resulting from the rigid benzene rings and the strength of the interactions provided by the electron clouds provide dimensional stability (Hatch, 1993).

Abrasion resistance

The abrasion resistance of polyester is good (Collier & Tortora, 2001); however, it is not used successfully in the carpeting market due to its low compression resilience (Hatch, 1993) and static build-up when no additional finishes are applied.

2.9.2.6 Chemical properties

Absorbency and moisture regain

Polyester is hydrophobic (Cohen & Johnson, 2010) with very low moisture absorption (Hatch, 1993; Siriviriyanun, O'Rear & Yanumet, 2007), which according to Kadolph (2010:170) can be set at 0.4 – 0.8%. It is difficult to get water and detergent into the fibre to remove stains, in addition to this, polyester is oleophilic and absorbs oil easily (Cohen &

Johnson, 2010). Moisture does not escape easily between the skin and fabric and the fabric can feel slick and clammy (Kadolph, 2010:170).

Moisture regain is very low, only 0.2 – 0.8% (Collier & Tortora, 2001), even in an environment of 95 – 100% humidity, but according to Siriviriyanun, O'Rear & Yanumet (2007) moisture regain has been set at 0.4%; therefore, polyester fabric can be uncomfortable against the skin. The insignificant amount of moisture in the polyester fabric exists as a molecular film of water on the fibre surfaces (Hatch, 1993). The very low moisture regain of the polyester fibre can be attributed to the lack of polarity to attract water, the presence of benzene rings that are hydrophobic, and the crystalline structure, which resist the entry of water molecules into the polymer system (Hatch, 1993)

Polyester fibres have a low level of wicking due to their round smooth surfaces. Therefore, the transport of vapour and liquid water through polyester fabrics relies on the construction of yarn and fabrics to create porosity. Polyester fabrics do not retain water promptly in the interfibre and yarn voids in the fabric. After a spin cycle, polyester fabric retains only 4% water, which is very low when compared to cotton, which retains 50% and even polyamide at 15%. This is desirable in wet environments because the item will dry quickly, improving the comfort level (Hatch, 1993) and allow the construction of fabrics suitable for sportswear.

Electrical conductivity

Polyester has high electrical resistivity that leads to surface changes and problems associated with electrostatic discharge under conditions of relatively low humidity. This is largely due to the hydrophobicity of the fibre (Hatch, 1993). The static potential of polyester can be lowered by changing the cross-section of the fibre, to incorporate water-absorbing compounds in the melt prior to extrusion. Another option is to add topical finishes such as oil-release and anti-static compounds. When the cross-section is modified, compounds can be incorporated to produce a porous fibre surface, which traps moisture. Other cross-section modifications expand the surface area per unit mass ratio and cause an increase in the absorbency. An antistatic by-component core-sheath fibre combines a polyester core with a softer polyester isophthalate co-polymer sheath that contains carbon-black particles. At only 2% this blend already significantly reduces static build-up (Kadolph, 2010:170).

Effect of heat

Due to its thermoplasticity, pleats and creases can be set permanently into fabrics and it will remain sharp even after repeated launderings. The fibre takes on a "permanent" shape when set at high temperatures. When exposed to temperatures above 195°C, polyester fibres and fabrics will shrink (Hatch, 1993). Polyester fabric will also curl away from an open flame, which makes it a little more difficult to ignite than if the fabric remained over the heat source (Hatch, 1993). Because polyester has very good thermal resistance, products can be sterilized without any problem.

Soiling and staining

Oil is usually not absorbed into the fibre. The benzene rings in the polymer accounts for the adherence of the oil. Polyester resists water-borne staining, but oil-borne staining readily takes place (Hatch, 1993). Soil-release finishes can improve soil removal (Kadolph, 2010:172).

2.9.2.7 Chemical reactivity

Acids

Polyester fibres are resistant to acids (Moody & Needles, 2004) because they cannot break/hydrolyse the polymer chain at the ester linkages or elsewhere. This helps to protect polyester fabrics from the acidic conditions that occur in polluted atmospheres (Hatch, 1993). It can however be attacked by hot, concentrated acids (Moody & Needles, 2004).

Alkalis

Polyester is resistant to degradation by alkaline detergent solutions (Collier & Tortora, 2001), however, the fibre can be degraded partially by concentrated alkalis (Moody & Needles, 2004). This hydrolysis is usually restricted to the polymers near the fabric surface (Hatch, 1993).

Oxidizing agents

Polyester may be bleached with chlorine and oxygen bleaches (Hatch, 1993; Kadolph, 2010:172).

Organic solvents

Polyester will not be harmed by any solvents used in normal dry cleaning (Collier & Tortora, 2001).

2.9.2.8 Biological properties

Polyester fibres are resistant to moulds, fungus, moths and beetles (Hatch, 1993). However, bacteria will grow in soiled items, especially where perspiration have been absorbed (Collier & Tortora, 2001).

2.9.2.9 Sustainability and environmental concerns

Polyester is produced from petrochemicals, which are non-renewable resources (Fletcher, 2008:12). There are concerns about the political, social and pollution impact of the petrochemical industry like drilling in sensitive environments, pipelines and transportation, oil spills, refinement and production of chemicals of which polyester are made, and the use and disposal of hazardous chemicals (Kadolph, 2010:172).

There is relatively large energy consumption during production of polyester, which has far-reaching environmental implications, the most serious of which includes global warming. The production of polyester uses less energy than the production of nylon, but more than cotton (Fletcher, 2008:12). Only a small amount of water is used during production, unfortunately some polyester is made using catalytic agents that contain heavy metals and toxic chemicals, which in turn can contaminate water and soil and have a long-term impact on the environment (Kadolph, 2010:172). However, wet processing uses water. Chemicals are added during processing and produce large volumes of toxic wastewater as a by-product (Moore & Causley, 2004). Emissions to air and water that have a medium to high potential of causing environmental damage if discharged untreated including heavy metal cobalt, manganese salts, sodium bromide and titanium dioxide (Fletcher, 2008:12). Polyester is a melt-spun fibre and therefore no chemicals are used to clean the fibre, as is the case with natural fibres (Kadolph, 2010:172).

Synthetic fabrics like polyester are extremely slow to biodegrade and add to the environmental impact of landfill sites in the very long term. However, these days polyester is extensively recycled. Previously recycled polyester fabric from plastic bottles contained antimony, which is a known carcinogen, unsuitable for prolonged contact with the skin. There are currently many new ways being explored to recycle and reuse polyester. Unwanted garments can be transformed into fibres for new garments and new markets are being established for these garments (Fletcher, 2008: 96). The production of recycled polyester creates less pollution than the fibres made from new raw materials. In the production of recycled polyester appropriate levels of purity of the polymers were achieved and improved spinning methods were used to make good quality fibres with comfortable hand (Kadolph, 2010:172).

2.9.3 Polyester/Cotton

Blending is a combination of components from different fibres that have different characteristics to obtain a product with elements from both fibres. The fibres should be mixed in such a way that the content of each component is the same at every point of the stream to ensure uniform properties (Cyniak, Czekalski & Jackowski, 2006). Blended structures have a number of advantages such as property compensation between constituent fibres, and cost reduction (Pan & Postle, 1995).

When to blend depends on the fibres being combined. Blending may be initiated in the early stages of processing, in a modern bale picker or in opening and cleaning, or in carding. The synthetic component of a blend does not require early cleaning steps as are needed for most natural fibres like cotton, and therefore, can be omitted and blending can take place later (Backer, 1993), but according to Kadolph (2010:229) the earlier in processing the fibres are blended, the better the blend. When two fibre components react differently to carding settings, blending may be postponed until reaching the blending draw frame. In the case of polyester/cotton blends, the sliver input to the draw frames may be in the form of card sliver for the PET and either carded or combed sliver for the cotton component (Backer, 1993).

The following parameters can be changed by blending fibres: tenacity, elongation at break, elasticity, hairiness, abrasion resistance, electric charge, dyeabillity, pilling, friction coefficient and the coefficient of variation of these parameters (Cyniak, Czekalski & Jackowski, 2006). Blended yarns consisting of natural and synthetic fibres have the advantage of successfully combining the best properties of both fibres, such as wear comfort and easy care properties. This can lead to an increased variety of product made, and create a stronger marketing advantage (Baykal, Babaarslan & Erol, 2006).

The blending of polyester and cotton fibres is common practice in the textile industry. When compared with cotton, it has higher breaking and abrasion strength, resilience, is more comfortable and easier to care for. When compared to polyester, it has less pilling, less static charge, easier spinning, and better evenness for sliver, roving and yarn (McCloskey & Jump, 2005; Baykal, Babaarslan & Erol, 2006). According to Collier & Tortora (2001) cotton has been increasingly blended with other fibres to create cotton-like fabrics with better wrinkle resistance and dimensional stability. Polyester/Cotton fabrics will not self-extinguish or draw away from an open flame. In the blend, the molten polyester is retained on a scaffold of unmelted fabric. The combustion of these blends is more rapid than the combustion of a fabric made from either fibre alone (Hatch, 1993).

Polyester/Cotton is commonly used and can be found as gowns and drapes in health care units like hospitals as a tightly woven fabric with added finishes such as reduced flammability, low lint generation and water repellency (Leonas, 1998; Rutala & Weber, 2001).

2.10 Antimicrobial finishes as an alternative to fabric disinfection

Currently there is a lot of research done on the feasibility of antimicrobial finishes on textiles to ensure antimicrobial activity all the time. The antimicrobial can be part of the polymer used for the fibres in synthetic fabrics or part of a coating or finish that binds to the fibres in cellulose fabrics (Thiry, 2010b). According to Simoncic & Tomsic (2010) the most promising antimicrobial agent for textile application include organic compounds like quaternary ammonium compounds, chitosan, polybiguanides, N-halamines and triclosan, as well as inorganic compounds such as nano-sized metals and metal oxides.

One method for producing antibacterial textiles uses conventional finishing processes. Many textiles finished this way are not durable to repeated home launderings. On the majority of textiles, antimicrobials leach or move from the surface they are applied on, like triclosan, quarternary ammonium salts, phenolics, polyamines, and silver ions (Huang & Leonas, 2000). They leach out of the fibre at a variable rate and provide a field of inhibition. The washing durability of these fabrics is limited due to slow release. The antimicrobial that is released can interfere with other desirable microbes such as those in waste treatment facilities.

Other antimicrobial finishes, such as quarternary silanes, are stationary materials chemically bound to the fibre surface. Bacteria encountering the fabric surface are destroyed without migrating. It is a permanent finish that might remain functional throughout the life of the garment or it might be abraded away or become deactivated (Schindler & Hauser, 2004; Kut, Orhan, Günesoglu & Őzakin, 2005).

Several antibacterial finishes are based on metal salt solutions or zinc pyrithione. Nanosized silver colloidal solutions have also been tested (Lee, Yeo & Jeong, 2003). The mechanisms with which antimicrobial finishes control microbial growth are extremely varied, ranging from preventing cell reproduction, blocking of enzymes, reaction with the cell membrane, to damaging the cell wall and poisoning the cell from within (Schindler & Hauser, 2004).

Several mechanisms are proposed for the antimicrobial activity by chitosan: (1) The Polycationic structure of chitosan which can be expected to interact with the predominantly anionic components of the microorganism, resulting in changes in permeability which causes death of the cell by inducing leakage of intracellular components. (2) The chitosan on the surface of the cell can form a polymer membrane that prevents nutrients from entering the cell. (3) Chitosan of lower molecular weight enters the cell, binds to DNA and inhibits RNA and protein synthesis. (4) Chitosan absorbs the electronegative substance in the cell and flocculates them; this disturbs the physiological activities of the microorganism leading to death of the cells (El-tahlawy *et al.,* 2005).

The greatest challenge to antimicrobial finishes is durability and even greater challenge is the wash fastness of the finish to repeated laundering (Sun & Worley, 2005). Teufel & Redl (2006) states that antimicrobial finishes may have harmful effects e.g. they might disturb the normal skin flora and they might cause allergic reactions.

It should also be mentioned that disposables could be used as an alternative to disinfection of reusable textile products, but disposables create waste and leave a negative effect on the environment. Incineration and landfilling used to treat the waste could also create a potential hazard (Lee *et al.,* 2007).

2.11 Conclusion

From this literature review the following could be concluded:

Anolyte has been proven successful in the medical, food and agriculture fields of study and there is no proof that it could not be used successfully in the field of textiles. Currently the world is leaning toward more sustainable processes and is in need of a more environmentally friendly disinfectant. If it could be proved that Anolyte can be used effectively at low temperatures, it will fit perfectly into more sustainable living. The Anolyte will be compared to the disinfecting action of detergent, detergent with added sodium hypochlorite as a disinfecting bleach agent, and filtered water.

Textiles would be disinfected at laundering temperature between 60°C and 100°C (Fijan, Cencic, & Sostar-Turk, 2006), sometimes with added chemicals, but this is not a sustainable process. To be more economical, people are being urged to lower wash temperature to 30°C (Hammer *et al.,* 2011), which alone would not be effective to disinfect textiles. Therefore, laundering temperatures of 24°C (room temperature), 30°C (low-temperature laundering) and 60°C (disinfecting temperature) will be used for this study.

Staph. aureus & *E. coli* is some of the most common bacteria present in the atmosphere, on human skin and on textiles (Borkow & Gabby, 2008; Hsieh & Merry, 1986) and, therefore, chosen for this study.

According to Mowbray (2011), the fibre production in the world has increased by 30% in the last ten years. Cotton and polyester accounted for an approximate 61 million tonnes of textile fibre production in 2010, which is 83% of the 73 million tonnes of fibres produced. It could, therefore, be concluded that cotton, polyester and polyester/cotton would be representative of the main fibres that would be used in textile disinfection.

CHAPTER 3:

MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Preparation of wash liquors

3.1.1.1 Anolyte

During the electrochemical activation of water, a 5% NaCl concentration water solution was "activated" by passing through the water electrolyzer (Hoshizaki Electric Co., ROX-10WB-E unit).

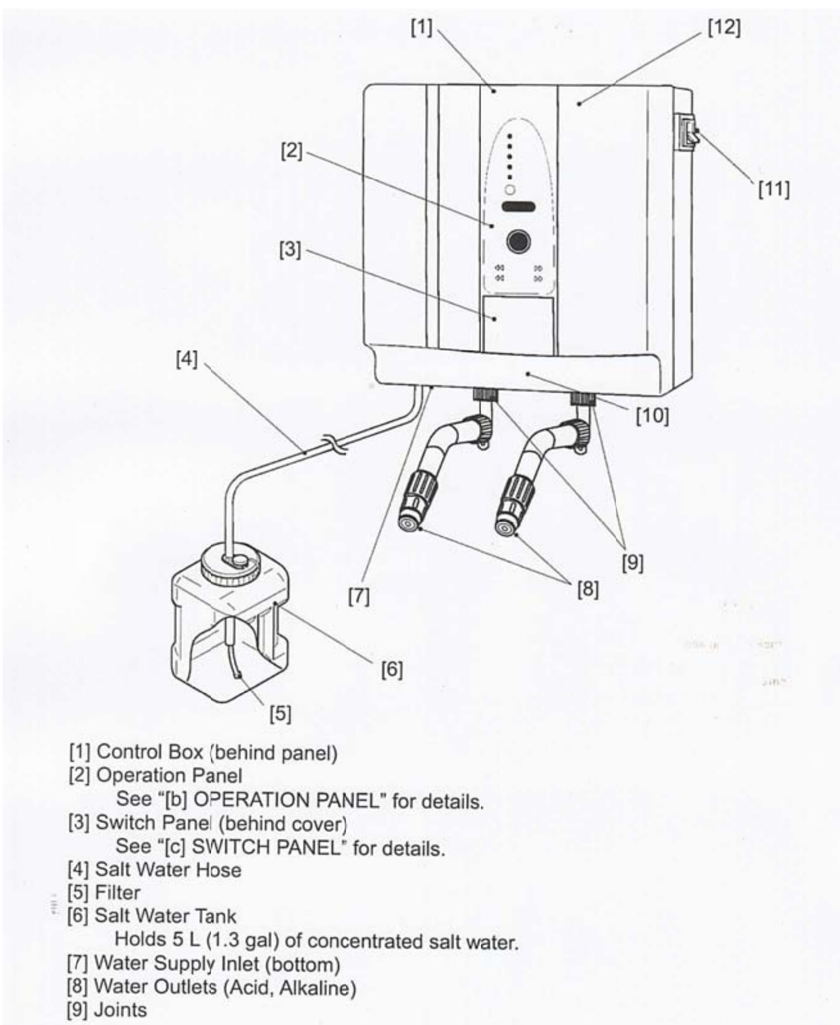


Figure 3.1: An illustration of the water electrolyzer unit (Water Electrolyzer Instruction Manual, Hoshizaki).

Tap water was passed through a filter system to ensure adequate softness before entering the Rox-10WB-E unit. Anolyte and Catholyte were separately produced through pipes at the bottom of the unit at 1-1.5 L/min. The Anolyte had a pH of 2.2-2.4 and an ORP of 1050-1190 mV. The Anolyte was used within 90 minutes of preparation.

The composition of the Anolyte and filtered water are shown in Table 3.1. Eco-Analytica Laboratories, with an Agilent 7500 CE, performed this analysis.

Table 3.1: The composition of the electrochemically activated water and filtered water.

	ANOLYTE	**FILTERED WATER**
	ppm	**ppm**
Na 23	420	22
Mg 24	26	31
Al 27	0.063	0.013
K 39	6.7	7.9
Ca 43	43	49
Mn 55	0.052	0.057
Fe 57	1.7	1.6
Ni 60	0.08	0.015
Cu 63	0.039	0.053
Zn 66	3	3.4
EG	2.78	0.38
Cl	631.68	18.64
PO_4	4.9	0.26
SO_4	33.34	18.71

3.1.1.2 Detergent solution

The ECE Phosphate Reference Detergent Type B without optical brightener was purchased from James H. Heal & Co. Ltd, Halifax, England. The detergent (code 706-736) meets the ISO 105 standard for testing.

Table 3.2: The composition of the ECE Phosphate Detergent as provided by James H. Heal & CO. LTD

Component	Quantity (% mass)
Linear sodium alkyl benzene sulphonate (mean length of alkane chain C11.5)	8
Ethoxylated tallow alcohol (14 EO units)	2.9
Sodium soap, chain length C12-16 13% - 26% : C18-22 74% - 87%	3.5
Sodium tripolyphosphate	43.7
Sodium silicate ($SiO2:Na_2O_2$= 3.3 : 1)	7.5
Magnesium silicate	1.9
Carboxy methyl cellulose (CMC)	1.2
Ethylene diamine tetra acetic acid (EDTA), tetra sodium salt	0.2
Sodium sulphate	21.2
Water	9.9
TOTAL	**100**

Each stainless steel LaunderOmeter canister (Atlas) was filled with 150 ml of filtered water and 0.23 g of Phosphate Reference Detergent B was added. The amount of detergent was calculated as prescribed in the test method to be 0.15% of the total volume. The pH of the detergent solution was 9.35-9.45.

3.1.1.3 Sodium hypochlorite bleach solution

The amount of sodium hypochlorite bleach solution was calculated as follows:

4.54 / % NaOCl = g to add

The correct amount of sodium hypochlorite (Merck, 8.14815.1000) was weighed and added to the filtered water and laundry detergent solution to make a total volume of 150 ml. The solution had a pH of 9.45-9.55.

3.1.1.4 Filtered water

Tap water was passed through a four-phase filtering system, containing 5 micron filters and carbon filters. The filtered water had a pH of 8.3-8.5.

3.2 Textile fabrics

Fabric 1: 100% Cotton

Cotton fabric (Style 400) was purchased from Test fabrics, Inc., West Pittston, Pennsylvania. The weft and warp yarns were machine spun and a plain weave was used to create the fabric, with 36 weft yarns and 30 warp yarns per 10 mm^2. The fabric weighed 0.33 grams per 50 mm^2.

Fabric 2: 100% Dacron (polyester)

Dacron fabric (Style 777) was purchased from Test fabrics, Inc., West Pittston, Pennsylvania. The weft and warp yarns was machine spun and a plain weave was used to create the fabric, with 23 weft yarns and 20 warp yarns per 10 mm^2. The fabric weighed 0.40 grams per 50 mm^2.

Fabric 3: 50/50 Polyester/Cotton blend

Polyester/Cotton fabric (Style 7465) was purchased from Test fabrics, Inc., West Pittston, Pennsylvania. The weft and warp yarns were machine spun from 50% cotton fibres and 50% polyester fibres and a plain weave was used to create the fabric, with 38 weft yarns and 23 warp yarns per 10 mm^2. The fabric weighed 0.30 grams per 50 mm^2.

3.3 METHODS

3.3.1 Antimicrobial effect

3.3.1.1 Bacterial strains and culture media:

For evaluation of the survival of microorganisms in this study, *Staphylococcus aureus* (ATCC 25923) was used to represent the Gram-positive skin microflora and *Escherichia coli* (ATCC 25922) to represent the Gram-negative organisms from faecal contamination. The organisms were grown in 10 ml nutrient broth (Oxoid CM0001) for 24 hours at 37^{o}C and 28^{o}C respectively, streaked out on nutrient agar (Oxoid CM0003) and checked for purity by Gram-staining within 24 hours. Pure cultures were streaked out on nutrient agar slants, incubated at the respective temperatures for 24 hours and stored at 4^{o}C until used.

3.3.1.2 Preparation of inocula:

Test organism growth from a 24 hour nutrient agar slant culture was inoculated loop for loop in 5 ml sterile 1 N phosphate buffer until a density comparable to a McFarland 1 standard (Difco 0691326) and representing 10^6-10^7 organisms/ml. The standardized culture was used to inoculate the various test materials.

3.3.1.3 Inoculation of textiles:

The textile swatches (5 cm x 5 cm) were placed one-by-one in a glass Petri-dish and autoclaved for 60 minutes. Using a microliter pipette, 1 ml of the inoculum was applied carefully onto each swatch, ensuring even distribution. The swatches were left to dry in the opened Petri-dish in the safety cabinet for 45 minutes.

3.3.1.4 Treatment of fabrics

AATCC Test Method 61-2009, procedure 2A and 5A (AATCC Technical Manual, 2009), were followed with the LaunderOmeter (Atlas). The stainless steel canisters were sterilized in the autoclave for 60 minutes. Each of the stainless steel canisters contained a single material swatch aseptically transferred from the Petri-dish, 50 sterilized stainless steel balls and 150ml ***wash liquor***. This solution was preheated to the prescribed temperature (24, 30 or 60°C) and laundered for 45 minutes. Canisters were aseptically opened and each specimen moved, with sterile pliers from the canister to glass beakers containing 150 ml sterile distilled water, where it was rinsed for 1 minute. Each specimen were aseptically moved with sterile pliers from the glass beaker and placed in a sterile WhirlPak™ bag.

3.3.1.5 Determination of effectiveness of wash liquors:

Each of the rinsed swatches was aseptically weighed in a sterile WhirlPak™ bag. The appropriate amount of phosphate buffer was added to ensure a 10^{-1} dilution. Each swatch was homogenized in a stomacher (Lab Blender 400, ART Medical Equipment) for 2 minutes. Further dilutions were prepared in 9 ml phosphate buffers to obtain dilutions to 10^{-4}, which were surface plated on nutrient agar and incubated at 28°C and 37°C for *Escherichia coli* and *Staphylococcus aureus,* respectively. Bacterial counts were reported as number of bacteria or colony forming units (cfu) per ml. For statistical analyses, the bacterial counts were transformed to log cfu/ml. This method was repeated five times with each test fabric, laundering temperature and wash liquor.

3.4.1 Fabric properties

3.4.1.1 Laundering

AATCC Test Method 61-2009, procedure 2A and 5A, were used with the Launder-Ometer (Atlas Electric Devices Co.). The Launder-Ometer provides for an accelerated test procedure because agitation is continuous and requires less water. Samples were taken from each textile material in both warp and weft directions. Each of the stainless steel canisters contained a sample, 50 stainless steel balls and the ***wash liquor***. This solution was preheated to the ***prescribed temperature*** (24, 30 or 60°C) and laundered for 45 minutes, which is equal to five typical machine laundering cycles. Canisters were emptied and each specimen rinsed individually in distilled water at 40°C and allowed to air dry. The samples were laundered for 5, 10 or 20 cycles respectively. Laundering at each temperature and each number of cycles were repeated five times with each test fabric and wash liquor.

3.4.1.2 Dimensional stability

The dimensional stability was evaluated by establishing the amount of threads in both weft and warp directions before and after laundering and calculating the readings in a percentage (%) value. An area of 10 x 10 mm was marked on each sample and the number of threads in the specific area was counted. After the laundering of the samples was complete, the threads in the specific area were counted. The readings were calculated in percentage according to the following formula:

$$\% \text{ Dimensional Change} = \frac{A-R}{A} \times \frac{100}{1}$$

Where A : Thread count before laundering

R : Thread count after laundering

3.4.1.3 Tearing Strength

The tearing strength tests were conducted with the Elmendorf Tearing Strength tester as per ASTM Test Method D 1424 - 63. Tearing strength is expressed as tearing force, which is the average force that is required to continue a tear in the fabric. Samples were taken in both weft and warp directions and conditioned for a minimum of 24 hours at 21 ± 1°C and 65 ± 2% relative humidity before they were tested.

The apparatus was set to be level before tests were conducted. The pendulum was raised to its starting position and the pointer was set against its stop. The conditioned sample was fastened securely in the clamps with its upper edge parallel to the clamps and the yarns to be torn, perpendicular to it. The blade knife was used to cut a slit in the fastened sample. The pendulum was released and the tear continued until the fabric ruptured. The reading was recorded in milli-Newton (mN), which expressed the tearing force. Any readings were disregarded if the sample slipped in the jaw or if puckering occurred.

3.4.1.4 Tensile Strength

The tensile strength tests were conducted with the Instron Tensile Tester and ISO/SANS 13934-1:1999 test method. This test determines the maximum force before the fabric breaks and the elongation at maximum force. The samples were accurately prepared to ensure that all the samples contained the same amount of threads. The samples were conditioned for a minimum of 24 hours at 21 ± 1°C and 65 ± 2% relative humidity before the tests were conducted.

The gauge length of the Instron (testing machine) was set at 100 mm ± 1 mm. The rate of extension was set at 100 mm/min. The ramp rate of the apparatus was 20 kN/min. The samples were placed in the clamps with about zero force (pretension mounting). The sample was clamped with the middle of the sample in line with the centre point of the jaw edges. The test was started and the movable clamp extended until the fabric ruptured. The maximum force in Newton (a) and the extension in millimetres were recorded (b). Any readings were disregarded if the sample slipped during the testing period.

3.4.1.5 Statistical Analysis

Statistical analysis was done to support the interpretation of the results that were obtained. Analysis of variance (ANOVA) was used as it uncovers the main and interaction effects of categorically independent variables (factors) on an interval dependent variable. The ANOVA analysis determined whether the difference in sample means was big enough to conclude that a significant difference exists between the groups. A "sig." or probability value of 0.05 or less leads to the conclusion that the effect is significant and not due to a change in sampling (Viljoen and Van der Merwe, 2000:12-1).

Fisher's exact test was also used to compare the effect of the Anolyte with the other treatments for microbial efficacy as no survival was found in some cases and therefore

ANOVA could not be used. This test is used where the frequency is smaller than five. The total probability of obtaining the observed data or more extreme patterns in the data is the p-value (Glantz, 2005).

CHAPTER 4:
DETERMINATION OF ANTIMICROBIAL EFFICACY

4.1 *Escherichia coli* survival

The statistical analysis of the effects of laundering with water, detergent, Anolyte and sodium hypochlorite solution on the survival of *E. coli* on the cotton, polyester and polyester/cotton fabrics are indicated in Table 4.1. There was a significant difference ($p < 0.05$) between the influence of the Anolyte and all the other treatments. It was the only laundering treatment that had the ability to decrease the *E. coli* counts to 0 cfu/ml on polyester, polyester/cotton and cotton. As already mentioned in the literature review in Chapter 2, three distinct characteristics have been suggested to be responsible for the antimicrobial effect of Anolyte: (1) chlorine content and hypochlorous acid, (2) pH, and (3) oxidation-reduction potential (ORP). Kim *et al.* (2000) suggested that a specific range of ORPs is required for the growth of bacteria. When a solution with such a high oxidizing capability, such as the Anolyte (1050-1190 mV) in this study, is applied to bacteria, ions are withdrawn and the cellular membrane becomes unstable, which facilitates the entry of antimicrobial agents. Jay *et al.* (2005) concluded that an ORP of 650 mV should result in the immediate destruction of *E. coli* irrespective of the pH or chlorine concentration. Issa-Zacharia *et al.* (2010) concluded that ORP plays an important role, in combination with a high proportion of HOCl in killing *E. coli*. An explanation for the high ORP of Anolyte could be the oxygen released by the rupture of the weak and unstable bond between hydroxy and chloric radicals (Venkitanarayanan *et al.*, 1999a).

Nakagawara *et al*. (1998:679) suggested that the bactericidal activity was not directly related to the hydroxy radicals and concluded that the bactericidal activity were due to the chemical equilibrium of Cl_2, HClO and ClO, and the major active component was Cl_2. According to them, the available chlorine (HOCl) produces $\cdot$OH that acts on microorganisms thus, the more $\cdot$OH produced the better the antimicrobial activity. Hypochlorous acid will kill the microbial cell by inhibiting glucose oxidation by chlorine-oxidizing sulfhydryl groups of certain enzymes important in carbohydrate metabolism (Water Review Technical Briefs, as cited in Kim *et al.*, 2000).

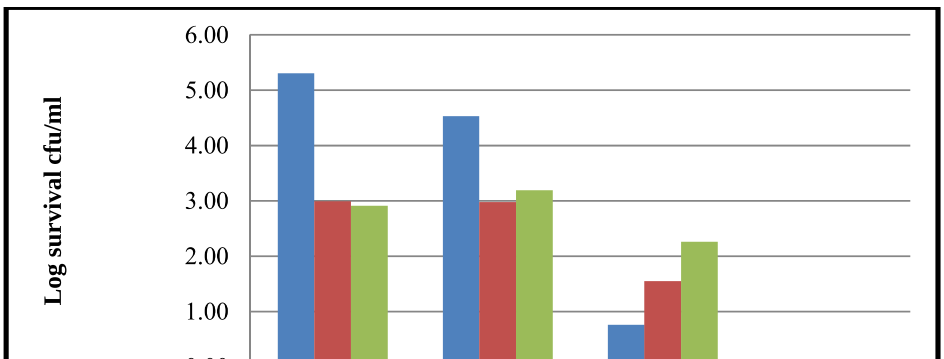
Table 4.1: The effects of the treatments and laundering temperature on the survival of *E. coli* on the cotton, polyester and polyester/cotton fabrics.

			Log survival (cfu/ml)	95% Confidence limits		Significant
COTTON	TREATMENT			(Relative to Anolyte)		
		Anolyte	0.000	0.000000	0.000000	
		Sodium hypochlorite	2.076	1.669835	2.481841	***
		Detergent	3.659	3.253487	4.065494	***
		Water	3.234	2.827559	3.639565	***
				(Relative to 24°C)		
	TEMPERATURE	24°C	2.785	2.453674	3.116675	
		30°C	3.194	2.862586	3.525586	
		60°C	0.000	0.000000	0.000000	***
POLYESTER	TREATMENT			(Relative to Anolyte)		
		Anolyte	0.000	0.000000	0.000000	
		Sodium hypochlorite	0.380	-0.541651	1.301235	***
		Detergent	4.048	3.126944	4.969830	***
		Water	5.379	4.457654	6.300540	***
				(Relative to 24°C)		
	TEMPERATURE	24°C	3.530	2.777740	4.282450	
		30°C	3.008	2.255735	3.760445	
		60°C	0.000	0.000000	0.000000	***
POLYESTER/ COTTON	TREATMENT			(Relative to Anolyte)		
		Anolyte	0.000	0.000000	0.000000	
		Sodium hypochlorite	1.303	0.554864	2.051651	***
		Detergent	2.732	1.983425	3.480212	***
		Water	3.961	3.212254	4.709041	***
				(Relative to 24°C)		
	TEMPERATURE	24°C	2.506	1.894943	3.117065	
		30°C	2.824	2.213417	3.435539	
		60°C	0.000	0.000000	0.000000	***

***, $p < 0.05$

According to Venkitanarayanan *et al.* (1999b:860) it is possible that the low pH of the Anolyte sensitizes the outer membrane of bacterial cells which gives easier entry for the hypochlorous acid into the bacterial cell. White (1999) observed that available chlorine was removed through ORP reactions with a variety of materials such as proteins, vitamins, lipids and minerals. They also indicated that when *E. coli* is used, there is a significant difference in bactericidal activity between free and combined available chlorines in the Anolyte. Combined available chlorines had lower bactericidal activity than the free form at the same concentration. They concluded that the presence of organic materials resulted in the formation of combined chlorine, which had lower bactericidal activity. Cloete *et al.* (2009) reported that the Anolyte killed the *E. coli* immediately upon exposure, by interfering with their protein composition due to oxidative stress. Zinkevich *et al.* (2000:155) indicated that electrochemically activated water with a pH of 5.15 and ORP of 1100 mV acts upon *E. coli* cells by damaging double stranded DNA, RNA and proteins. It probably destroys the covalent bonds in the nucleic acid chains and protein chains.

The results concerning the *Escherichia coli* survival after laundering with water, detergent, Anolyte and sodium hypochlorite solution at 24^{o}C are illustrated in Figure 4.1. After laundering at 24°C with the sodium hypochlorite solution, the *E. coli* survival observed was the least (0.76 log cfu/ml) on the polyester fabric and the most on the cotton fabric (2.26 log cfu/ml). The sodium hypochlorite solution was more effective at eliminating the *E. coli* than the detergent or the water. Munk *et al.* (2001) also found that when the detergent contained a bleach agent such as sodium hypochlorite, it will kill bacteria more effectively than detergent without bleach.



	Water (Control)	Detergent	Sodium hypochlorite	Anolyte
Polyester	5.31	4.53	0.76	0
Polyester/Cotton	2.99	2.98	1.55	0
Cotton	2.91	3.19	2.26	0

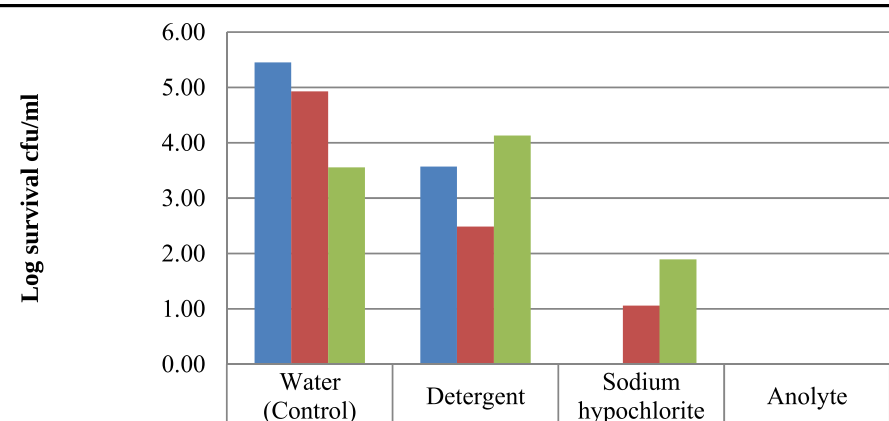
Figure 4.1: The effects of the laundering treatments on the survival of *E. coli* on polyester, polyester/cotton and cotton at 24°C.

According to Cho *et al.* (2010), the mechanism of inactivation during an engineered disinfection process can be categorized into two pathways. First is damage to the cell surface components. The cell peripheral structure (cell wall) provides a protective barrier against environmental stress to microorganisms. Therefore, physicochemical change in the cell surface would precede any further damage in intracellular constituents and their functions. Alternatively, cell death could be induced by direct impairment in intracellular functions. The initial stage of bactericidal action is binding to the cell surface after which it should pass through the outer membrane of Gram-negative bacteria, to reach the site of action at the cytoplasm membrane or cytoplasm. The Gram-negative cell envelope has evolved to regulate the passage of substances in and out of the cell to a remarkable degree. All the components of the cell envelope, except peptidoglycan, play a role in the barrier mechanisms, because it is spongy and permeable (Cloete, 2003).

There was still some *E. coli* survival after laundering at 24°C with the detergent, which was closely related to the survival after laundering with water. After laundering with the detergent and water at 24°C the survival on the cotton and the polyester/cotton fabric were closely related. The survival was the largest on the polyester (4.53 log cfu/ml) and the smallest on the polyester/cotton (2.98 log cfu/ml). Munk *et al.* (2001) also found that detergent without bleach may remove some of the *E. coli* from the contaminated fabric to the wash water and sterile fabric swatches, but there was still survival on the contaminated fabric. Removal of bacteria by the detergent could be due to the surfactant that is present, which helps to reduce the adhesion of the microbe to the fabric by lowering the surface tension (Ainsworth & Fletcher, 1993). According to Hall *et al.* (2009), laundering with detergents alone is not effective at removing all bacterial contamination or reducing bacterial viability. Bacteria would be released into the laundering water and contaminate other articles in the machine.

The water had the largest *E. coli* survival number after laundering. The largest survival was on the polyester fabric (5.31 log cfu/ml) and the smallest on the cotton fabric (2.91 log cfu/ml). According to Gerba & Kennedy (2007), dilution of microorganisms into the water is also an important factor in microorganism reduction. The mechanical action of the laundering process also has an influence on the microorganisms and aids in the disinfection efficacy of the treatments and also the water (Scott, 1999).

The statistical analysis (Table 4.1) indicated that there was a significant difference ($p < 0.05$) between the influence of laundering at 24°C and 60°C. High temperatures damage microorganisms by denaturating enzymes, transport carriers and other proteins. Membranes are also disrupted; the lipid bi-layer melts and disintegrates (Prescott, Harley & Klein, 2005). The temperature of 30°C is used as a colder and more economical laundering temperature (Hammer *et al.,* 2011). As illustrated in Figure 4.2, the Anolyte again eliminated all *E. coli* after laundering. As already mentioned, the efficacy of the Anolyte could be due to the chlorine content and hypochlorous acid, pH, and ORP. There was a significant difference ($p < 0.05$) between the influence of the Anolyte and the influences of the other treatments. After laundering with the sodium hypochlorite solution at 30°C, there was little survival on the polyester/cotton (1.06 log cfu/ml) and cotton (1.89 log cfu/ml), while no organisms was found on the polyester. The action of the sodium hypochlorite has already been mentioned, but is mainly attributed to the damage of the cell surface components and further cell death as induced by direct impairment in intracellular functions (Cho *et al.,* 2010).



	Water (Control)	Detergent	Sodium hypochlorite	Anolyte
Polyester	5.45	3.57	0	0
Polyester/Cotton	4.93	2.49	1.06	0
Cotton	3.56	4.13	1.89	0

Figure 4.2: The effects of the laundering treatments on the survival of *E. coli* on polyester, polyester/cotton and cotton at 30°C.

Laundering with the detergent resulted in the largest *E. coli* survival on the cotton fabric (4.13 log cfu/ml) and the smallest survival on polyester/cotton (2.49 log cfu/ml). After laundering at 24°C, the water and detergent had a closely related influence. However, this is not the case after laundering at 30°C. After laundering with the detergent, smaller survival numbers were found, which could possibly be due to the combination of the detergent, laundering action and temperature. According to Hall *et al.* (2009), laundering with detergents alone is not effective at removing all bacterial contamination or reducing bacterial viability. Bacteria would be released into the laundering water and contaminate other articles in the machine.

After laundering with the detergent and the sodium hypochlorite solution respectively, the largest *E. coli* survival was found on the cotton fabric. Bajpai *et al.* (2011) found maximum adherence of *E. coli* cells on cotton and the least on polyester. According to them the adherence to cotton occurred in two phases: an initial rapid phase followed by a stationary phase. In the cases of polyester and polyester/cotton the adherence increased linearly through the exposure time. They also reported that adherent *E. coli* cells did not cover the fabric uniformly and numbers were higher near rough surfaces, therefore, the surface morphology of the fabric and yarn plays an important role in adherence. Cotton as a staple fibre might have a rougher surface than the smooth polyester filament fibre and as a result the *E. coli* will adhere more to the cotton than the polyester. Their Fourier transform infrared studies revealed that both cotton and *E. coli* have abundant free hydroxyl groups that may interact strongly with each other and other hydrophilic groups such as carboxyl, phosphate, and amides. In contrast to their findings, Hsieh & Merry (1986:544) concluded that *E. coli* did not show any preference to adhere to a specific fibre. Results of the current study (Figures 4.1 and 4.2) are in agreement with those of Hsieh & Merry (1986) i.e. that *E. coli* did not show any preference for a specific fibre.

The largest *E. coli* survival number was obtained after laundering with water alone. The largest survival was on the polyester fabric (5.45 log cfu/ml), while the smallest was on the cotton fabric (3.56 log cfu/ml). As already mentioned, the reduction in organisms after laundering with water could be attributed to the laundering action (Scott, 1999) and the dilution of the organisms into the water (Gerba & Kennedy, 2007).

Data are not shown for *E. coli* survival after laundering at 60°C as there was no survival for any of the treatments and it could be assumed that the high temperature killed all the microorganisms. Prescott, Harley & Klein (2005) indicated that the maximum temperature that E. coli can endure is 45°C. Groh, MacPherson & Groves (1996) indicated that water heated for 5 minutes at 60°C kills all *E. coli* bacteria. Ahmed, Conner & Huffman (1995) stated that a temperature of 60°C for 2 – 3 minutes kills *E. coli.* Munk *et al.* (2001) also found that laundering at 60°C kills all *E. coli.* The statistical analysis (Table 4.1) indicated that there was a significant difference ($p < 0.05$) between the influence of 60°C and the 24°C and 30°C on the survival of the *E. coli*.

Table 4.2: P-values of the combination of treatment and temperature on the survival of *E. coli* on the cotton, polyester and polyester/cotton fabric after laundering.

Fabric	Source	p-value
Cotton	Treatment	0.0002*
	Temperature	0.0817
	Treatment*Temperature	0.0681
Polyester	Treatment	< .0001*
	Temperature	0.3061
	Treatment*Temperature	0.6286
Polyester/cotton	Treatment	0.0005*
	Temperature	0.4376
	Treatment*Temperature	0.0424*

*, significance $p < 0.05$

The analysis (Table 4.2) indicated that treatment had a significant influence ($p < 0.05$) on the survival of *E. coli* on all the fabrics after laundering. The temperature did not have a significant influence on the survival on any of the fabrics, however, the interaction of treatments and temperature had a significant influence ($p < 0.05$) on the survival of *E. coli* on the polyester/cotton fabric after laundering.

4.2 *Staphylococcus aureus* survival

The statistical analysis of the effects of laundering with water detergent, Anolyte and sodium hypochlorite on the survival of *Staph. aureus* on the cotton, polyester and polyester/cotton fabrics are indicated in Table 4.3. There was a significant difference ($p < 0.05$) between the influence of the Anolyte and all the other treatments. It was again the only laundering treatment that had the ability to decrease the *Staph. aureus* counts to 0 cfu/ml on polyester, polyester/cotton and cotton. As already mentioned, three distinct characteristics have been suggested to be responsible for the antimicrobial effect of Anolyte: (1) chlorine content and hypochlorous acid, (2) pH, and (3) ORP. Issa-Zacharia *et al.* (2010) concluded that ORP plays an important role, in combination with a high proportion HOCl, in killing *Staph. aureus*. An explanation for the high ORP of Anolyte could be the oxygen released by the rupture of the weak and unstable bond between hydroxy and chloric radicals (Venkitanarayanan *et al.*, 1999a).

Table 4.3: The effect of treatments and laundering temperature on the survival of *Staph. aureus* on the cotton, polyester and polyester/cotton fabrics.

			Log survival (cfu/ml)	95% Confidence limits		Significant
COTTON	**TREATMENT**			(Relative to Anolyte)		
		Anolyte	0.000	0.000000	0.000000	
		Chlorine	5.808	5.544513	6.072300	***
		Detergent	5.807	5.542917	6.070704	***
		Water	6.010	5.746429	6.274216	***
				(Relative to 24°C)		
	TEMPERATURE	24°C	5.847	5.631902	6.062838	
		30°C	5.903	5.687521	6.118458	
		60°C	0.000	0.000000	0.000000	***
POLYESTER	**TREATMENT**			(Relative to Anolyte)		
		Anolyte	0.000	0.000000	0.000000	
		Chlorine	3.486	3.282075	3.689189	***
		Detergent	4.535	4.331107	4.738221	***
		Water	5.491	5.287675	5.694790	***
				(Relative to 24°C)		
	TEMPERATURE	24°C	4.792	4.625945	4.958353	
		30°C	4.216	4.049333	4.381740	***
		60°C	0.000	0.000000	0.000000	***
POLYESTER/ COTTON	**TREATMENT**			(Relative to Anolyte)		
		Anolyte	0.000	0.000000	0.000000	
		Chlorine	4.800	4.556823	5.042989	***
		Detergent	5.654	5.410565	5.896731	***
		Water	5.664	5.420451	5.906617	***
				(Relative to 24°C)		
	TEMPERATURE	24°C	5.515	5.316692	5.713645	
		30°C	5.230	5.031080	5.428033	***
		60°C	0.000	0.000000	0.000000	***

***, $p < 0.05$

The results concerning the *Staph. aureus* survival after laundering with water, detergent, Anolyte and sodium hypochlorite solution at 24°C are illustrated in Figure 4.3. There was *Staph. aureus* survival found on all the fabrics after laundering at 24°C with the sodium hypochlorite solution. The largest survival found was on the cotton fabric (5.92 log cfu/ml), although the survival on the polyester/cotton fabric (5.25 log cfu/ml) is very close and the smallest survival was on the polyester fabric (3.95 log cfu/ml). These findings are inconsistent with those of Takashima *et al.* (2004) who tested the ability of *Staph. aureus* to bind to textile fibres and found that it bound to polyester at a very high ratio (96.2%) but to cotton at a very low ratio (2%). However, according to Gao & Cranston (2008), most synthetic fibres are more resistant to microbial attack due to their high hydrophobicity. Pilonetto *et al.* (2004) also indicated that *Staph. aureus* attached at high levels to cotton fabric.

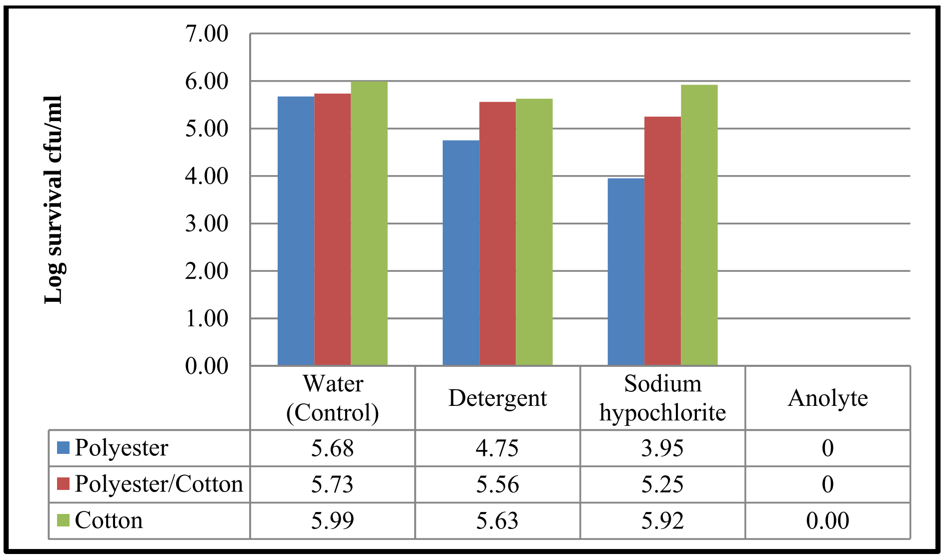
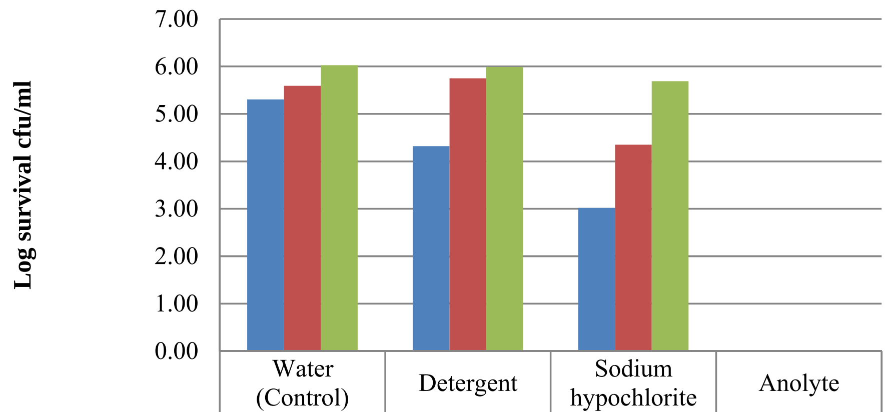


Figure 4.3: The effects of laundering treatments on the survival of *Staph. aureus* on polyester, polyester/cotton and cotton fabrics at 24°C.

The water and the detergent had a very closely related influence. This was also found by Oller & Mitchell (2009) whom indicated that the difference between these treatments was not significant. After laundering at 24°C with the detergent, the smallest *Staph. aureus* survival was found on the polyester fabric (4.75 log cfu/ml) and the largest survival was found on the cotton fabric (5.63 log cfu/ml). Survival after laundering with the water was the largest on the cotton fabric (5.99 log cfu/ml) and the smallest on the polyester fabric (5.68 log cfu/ml). It has been proved that laundering with detergent alone is not effective at removing all bacterial contamination or reducing bacterial viability. In fact, bacteria would be released into the laundering water and contaminate other articles in the machine (Hall *et al.*, 2009). As already mentioned the laundering action should also be kept in mind and could assist water in removing microorganisms from the fabrics (Scott, 1999).

The statistical analysis (Table 4.3) indicated that the temperature of 30°C did not have a significant influence on the survival of *Staph. aureus* on any of the fabrics and it has been indicated that reduced wash temperatures decrease the degree of disinfection (Ainsworth & Fletcher, 1993). There was, however, a significant difference ($p < 0.05$) between the influence of the Anolyte and all the other treatments. It was the only laundering treatment that had the ability to decrease the *Staph. aureus* counts to 0 cfu/ml on polyester, polyester/cotton and cotton. As already mentioned previously, three distinct characteristics have been suggested to be responsible for the antimicrobial effect of Anolyte: (1) chlorine content and hypochlorous acid, (2) pH, and (3) ORP. According to Bremer *et al.* (2004) and Valero *et al.* (2009) the minimum pH where *Staph. aureus* can survive is 4.0, while the pH of the Anolyte used in this study was 2.2-2.4.

The effects of laundering treatments on the survival of *Staph. aureus* on polyester, polyester/cotton and cotton fabrics at 30°C are illustrated in Figure 4.4. There was survival found on all the fabrics after laundering at 30°C with the sodium hypochlorite solution. The largest survival found was on the cotton fabric (5.69 log cfu/ml), while the smallest survival was on the polyester fabric (3.02 log cfu/ml). Rossoni and Gaylarde (2000) also found that after laundering with a low concentration sodium hypochlorite solution (10% active chlorine), *Staph. aureus* was reduced but not eliminated. *Staph. aureus* is also able to grow in sodium chloride with concentrations up to 25% (Valero *et al.,* 2009). It was, however, indicated by Patel *et al.* (2007) that cleaning with detergent and hypochlorite helped to achieve a greater reduction.



	Water (Control)	Detergent	Sodium hypochlorite	Anolyte
Polyester	5.31	4.32	3.02	0
Polyester/Cotton	5.59	5.75	4.35	0
Cotton	6.03	5.99	5.69	0

Figure 4.4: The effects of laundering treatments on the survival of *Staph. aureus* on polyester, polyester/cotton and cotton fabrics at 30°C.

After laundering with the detergent, the smallest survival was found on the polyester fabric (4.32 log cfu/ml) and the largest survival was found on the cotton fabric (5.99 log cfu/ml). It has been proved that laundering with detergent alone is not effective at removing all bacterial contamination or reducing bacterial viability (Patel *et al.*, 2007).

Survival of *Staph. aureus* after laundering with the water was the largest of all the treatments. The largest survival was found on the cotton fabric (6.03 log cfu/ml) and the smallest on the polyester fabric (5.31 log cfu/ml). As already mentioned, the laundering action should also be kept in mind and could assist water in removing microorganisms from the fabrics (Scott, 1999). The temperature of 30°C is used as a colder and more economical laundering temperature and it is not high enough to kill *Staph. aureus* (Hammer *et al.,* 2011). According to Prescott, Harley & Klein (2005), the optimum temperatures for *Staph. aureus* survival are between 30-37°C, while 46°C is the maximum temperature that they can endure.
The same results were obtained after laundering at 30°C as after laundering at 24°C where the highest survival was always found on the cotton fabric and the smallest survival on the polyester fabric. Pilonetto *et al.* (2004) also indicated that *Staph. aureus* attached at high levels to cotton fabric, and Sattar *et al.* (2001) found that *Staph. aureus* transfer was higher from polyester/cotton than from cotton fabric. According to Gao & Cranston (2008), most synthetic fibres are more resistant to microbial attack, due to their high hydrophobicity.

Data are not shown for results of laundering at 60°C, as there was no *Staph. aureus* survival for any of the treatments and it could be assumed that the high temperature killed all the microorganisms. Munk *et al.* (2001) also found that laundering at 60°C kills all *Staph. areus.* Sterilization by heat treatment is based on the inactivation of proteins in the microorganism (Kitajima *et al.,* 2007), and according to Prescott, Harley & Klein (2005) high temperatures damage microorganisms by denaturating enzymes, transport carriers and other proteins. Membranes are also disrupted; the lipid bi-layer melts and disintegrates.

The analysis of the combination of treatment and temperature on the survival of *Staph. aureus* on the cotton, polyester and polyester/cotton fabric after laundering is indicated in Table 4.4. Treatment had a significant influence ($p < 0.05$) on the survival of *Staph. aureus* on the polyester and polyester/cotton fabrics, but not on the cotton fabric. Temperature also had a significant influence ($p < 0.05$) on the survival of *Staph. aureus* on the polyester and polyester/cotton fabrics. However, the interaction of treatments and temperature only had a significant influence ($p < 0.05$) on the survival of *Staph. aureus* on the polyester/cotton fabric.

Table 4.4: P-values of the combination of treatment and temperature on the survival of *Staph. aureus* on the cotton, polyester and polyester/cotton fabric after laundering.

Fabric	Source	p-value
Cotton	Treatment	0.4198
	Temperature	0.6978
	Treatment*Temperature	0.2664
Polyester	Treatment	< .0001*
	Temperature	0.0002*
	Treatment*Temperature	0.1162
Polyester/cotton	Treatment	0.0002*
	Temperature	0.0467*
	Treatment*Temperature	0.0139*

CHAPTER 5:
THE EFFECT OF ANOLYTE, DETERGENT, SODIUMHYPOCHLORITE SOLUTION AND WATER ON THE STRENGTH AND DIMENSIONAL PROPERTIES OF COTTON, POLYESTER AND POLYESTER/COTTON

5.1 Dimensional stability

Dimensional stability is “a general property of a material, component or structure which enables it to maintain or retain its shape, size or any dimension”. In the textile industry, it is related to influences that imply use such as wear, washing and dry cleaning (Wolff, 2004). Fabric shrinkage can cause problems in two main areas, either during garment manufacture or during subsequent laundering. There are a number of causes of dimensional change, most only operate with fibre types that absorb moisture, but relaxation shrinkage can affect any fibre type. Hygral expansion, relaxation shrinkage, swelling shrinkage and felting shrinkage are recognized as general types of dimensional change. According to Cookson *et al.* (1991), relaxation shrinkage occurs in finished fabrics because of the strain imposed during finishing processes, which is then released when the fabric is exposed to conditions of high relative humidity.

No shrinkage was observed for any of the textile fabrics, which were expected as the textile fabrics used for this study was a bleached, desized print cloth. Excellent dimensional stability can be expected from polyester, as long as the heat-setting temperature is not exceeded (Collier & Tortora, 2001). If the fabric has not been heat-set, it may shrink at high temperatures. Its low moisture regain causes it not to shrink when wet and can stabilize fabrics when it is blended with other fibres like cotton. Fabrics made from synthetic fibres like polyester, can be made stable through an operation called thermal stabilization (Rahman & East, 2009). This operation level the supermolecular structure of the fibres, remove internal stresses caused during production and, therefore, give the fibres dimensional stability and decrease consumer shrinkage. This thermal stabilization process consists of treating the textile with hot air at a temperature of 140 - 150°C for 30 - 120 seconds while the fibre is under tension. Devitrication of the fibres and passage into the highly elastic stage takes place at this temperature and the relaxation will result in new intermolecular bonds (Krichevskii, 2001).

Although no shrinkage was found for the cotton fabric used in this study as relaxation shrinkage probably already occurred during the bleaching process. Higgins *et al.* (2003) reported shrinkage of cotton fabrics laundered with detergent and suggested that the level of shrinkage increased with successive launderings reaching a maximum after five to ten cycles, where the fabrics will have reached their fully relaxed dimensions. Cotton fibres swell in the transverse directions when wet. Unfinished woven fabrics could shrink with the first few launderings because the laundering will relieve the tension created during weaving and processing. The relaxation of this tension can cause dimensional changes. Cotton fabrics can be given special finishes to prevent relaxation shrinkage (Collier & Tortora, 2001). This, however, indicates that Anolyte will have no influence on the dimensional stability of bleached, desized print cloth of polyester, polyester/cotton or cotton.

5.2 Tensile strength

Consumers expect a textile product to last for a period of time adequate for its end use. Durability can be tested in a laboratory in terms of strength properties that include tensile strength (Kadolph, 2010:42). According to the American Heritage Science Dictionary (2005), tensile strength can be defined as “a measure of the ability of a material to resist a force that tends to pull it apart”. As already mentioned previously in the literature, articles and fabrics used in the medical and food industry are frequently exposed to harsh laundering and disinfecting chemicals and procedures. These procedures and chemicals may cause damage to the fibres and fabrics, which would decrease durability and reduce acceptable time of usage. It is, therefore, important to determine the influence of disinfecting and cleaning agents on durability properties of fabrics such as tensile strength. Therefore, after the laundering of the test fabrics with Anolyte, detergent, sodium hypochlorite solution and filtered water respectively, the tensile strength was determined and expressed in terms of maximum load required to break the fabrics and the percentage displacement at maximum load.

5.2.1 Maximum load required to break the fabrics after laundering with the water, detergent, Anolyte and sodium hypochlorite

5.2.1.1 Cotton

The results concerning the tensile strength of the cotton fabric after laundering with water, detergent, Anolyte and sodium hypochlorite solution are illustrated in Figure 5.1, as well as the statistical analysis of the significance of treatment, temperature and cycles as illustrated in Table 5.1.

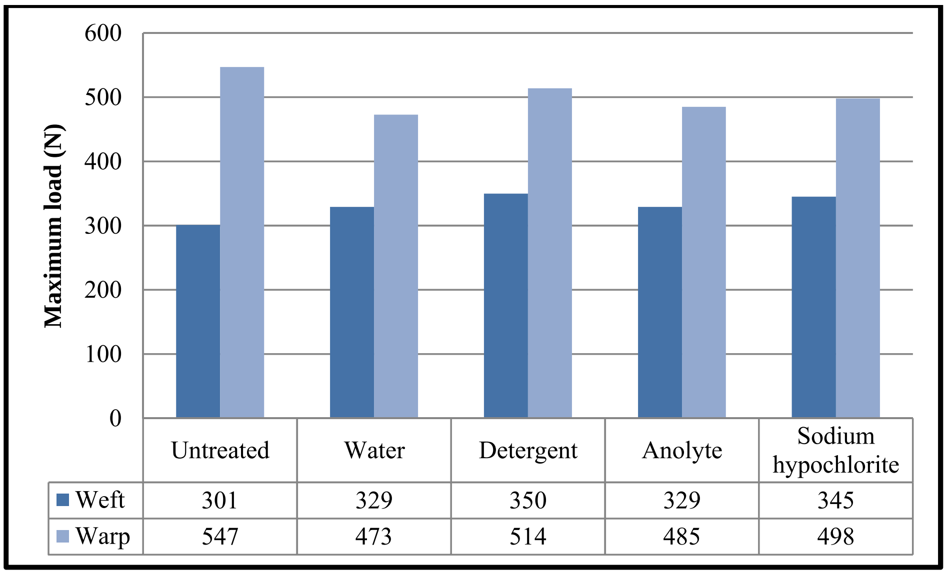


Figure 5.1: The influence of laundering with water, detergent, Anolyte and sodium hypochlorite on the maximum load of the cotton fabric.

The water, detergent, Anolyte and sodium hypochlorite solution caused an increase in maximum load required to break the weft yarns of the cotton fabric. Similar results were obtained by Mukhopadhyay *et al.* (2004) where the maximum load at break increased after laundering of cotton fabric. According to the statistical analysis (Table 5.1) the water, detergent, Anolyte and sodium hypochlorite solution had a significant ($p < 0.05$) influence on the maximum load necessary to break the cotton fabric in both directions. This is illustrated by the data represented in Figure 5.1, which indicates that the detergent had the largest influence on the weft yarns and required the highest maximum load of 350 N to break the weft yarns, while the untreated weft yarns could only carry 301 N.

Table 5.1: Maximum load necessary to break the cotton fabric: Effect of treatment, laundering temperature and number of laundering cycles.

DIRECTION			Mean (N)	Difference	95% limits	Confidence	Significant
WARP	NO TREATMENT		547.330				
WARP	TREATMENT			(Relative to untreated)			
		Anolyte	484.616	62.714	44.641	80.787	***
		Sodium hypochlorite	498.257	49.073	31.000	67.146	***
		Detergent	514.034	33.296	15.223	51.369	***
		Water	472.920	74.410	56.337	92.483	***
				(Relative to untreated)			
	TEMPERATURE	24°C	505.687	41.643	23.798	59.489	***
		30°C	485.950	61.380	43.534	79.226	***
		60°C	485.733	61.597	43.751	79.442	***
				(Relative to untreated)			
	NUMBER OF LAUNDERING CYCLES	5	500.353	46.978	29.132	64.823	***
		10	493.888	53.443	35.597	71.288	***
		20	483.130	64.200	46.354	82.046	***
WEFT	NO TREATMENT		301.290				
WEFT	TREATMENT			(Relative to untreated)			
		Anolyte	329.283	27.993	50.185	5.801	***
		Sodium hypochlorite	345.054	43.764	65.968	21.560	***
		Detergent	349.772	48.482	70.674	26.290	***
		Water	329.409	28.119	50.311	5.927	***
				(Relative to untreated)			
	TEMPERATURE	24°C	339.136	37.846	59.759	15.933	***
		30°C	333.929	32.639	54.559	10.720	***
		60°C	341.981	40.691	62.604	18.778	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	331.148	29.858	51.771	7.946	***
		10	342.855	41.565	63.485	19.646	***
		20	341.117	39.827	61.739	17.914	***

***, $p < 0.05$

The tensile strength of untreated cotton could be classified as medium, which can be attributed to the high degree of crystallinity, but lower orientation (Collier & Tortora, 2001). Lenting & Warmoeskerken (2001) also agree that the crystalline cellulose running along the axis of the fibre is responsible for the tensile strength of the fibre. The increase in maximum load (Figure 5.1) necessary to break the yarns after laundering with detergent could be explained by taking into consideration that detergent is an alkaline solution. The alkali treatment can improve cotton fabric's tensile strength by giving rise to a lattice conversion of the cellulose (Tanczos *et al.,* 2000; Bledzki *et al.,* 2004). It should also be taken into account that detergent can be deposited onto the surface of the fabric and cause an increase in strength (Fijan *et al.,* 2007a). The sodium hypochlorite solution also caused a larger increase in maximum load at 345 N, while the water and Anolyte had a smaller influence on the maximum load that the weft yarns could carry at 329 N. The increase caused by the sodium hypochlorite solution could also be expected as the sodium hypochlorite solution contains the same amount of detergent but the damage could have been caused by the sodium hypochlorite (Sun *et al,* 2001) to lead to the required maximum load just below that of the detergent.

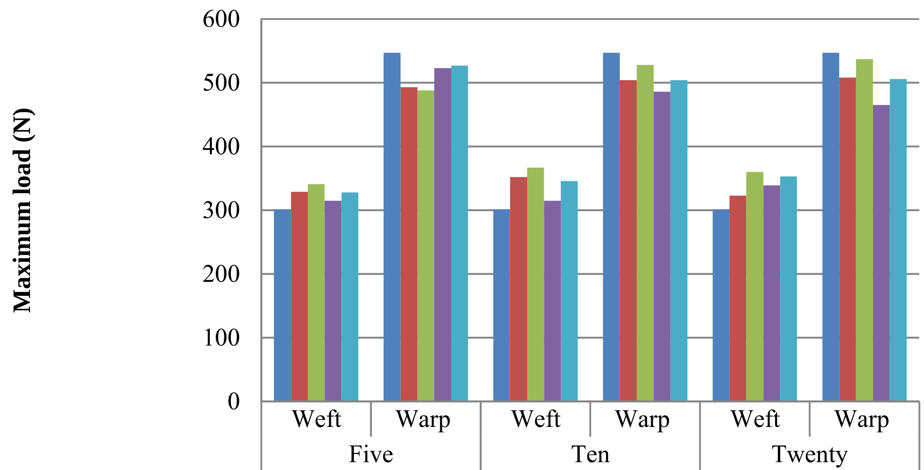
Although all the treatments had a significant ($p < 0.05$) influence when compared to the untreated samples, it was indicated that in the weft direction the Anolyte and the water had such similar influence that the difference was not significant. However, in both directions there were significant ($p < 0.05$) differences in the influences of the detergent as well as the sodium hypochlorite solution, when compared with the Anolyte (Table 5.2). In comparison to the weft yarns it was the untreated warp yarns (Figure 5.1) that could carry the largest maximum load at 547 N, and the water had the largest influence on the warp yarns, as it required 473 N to break. The hydrophilic character of cotton facilitates water absorption, which promotes faster degradation of the matrix interface and in turn, destructively affects the tensile strength (De Carvalho *et al.*, 2009). Warp yarns treated with detergent could carry a load of 514 N, while those treated with the sodium hypochlorite solution broke at 498 N, and those treated with Anolyte could carry only 485 N.

The statistical analysis (Table 5.1) indicated that there was a significant difference ($p < 0.05$) between the load that the untreated fabric could carry and the load after laundering at 24°C. As illustrated in Figure 5.2, the untreated fabric could carry the smallest load in the weft direction, while the water and detergent exhibited the same effect on the cotton fabric laundered at 24°C, where the maximum load increased between five and ten cycles, but then decreased again after 20 cycles. The maximum load after five cycles that the weft yarns treated with water could carry increased with 28 N and those treated with detergent increased with 40 N. The largest increase caused by the detergent could again be due to the deposition of detergent onto the fabric surface, which according to Fijan *et al.* (2007b) could result in an increase in strength.

Table 5.2: Significance of laundering with water, detergent and sodium hypochlorite compared with Anolyte on the maximum load of the cotton fabric.

Direction	Treatment	Mean (N)	Difference	95% Confidence limits		Significant
Weft			(Relative to Anolyte)			
	Anolyte	329.283				
	Sodium hypochlorite	345.054	-15.771	-25.723	-5.818	***
	Detergent	349.772	-20.489	-30.413	-10.564	***
	Water	329.409	-0.126	-10.050	9.799	
Warp			(Relative to Anolyte)			
	Anolyte	484.616				
	Sodium hypochlorite	498.257	-13.641	-21.724	-5.559	***
	Detergent	514.034	-29.419	-37.501	-21.336	***
	Water	472.920	11.696	3.613	19.778	***

***, $p < 0.05$



	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	301	547	301	547	301	547
Water	329	493	352	504	323	508
Detergent	341	488	367	528	360	537
Anolyte	315	523	315	486	339	465
Sodium hypochlorite	328	527	346	504	353	506

Figure 5.2: Maximum load of the cotton fabric after laundering for five, ten and twenty cycles at 24°C.

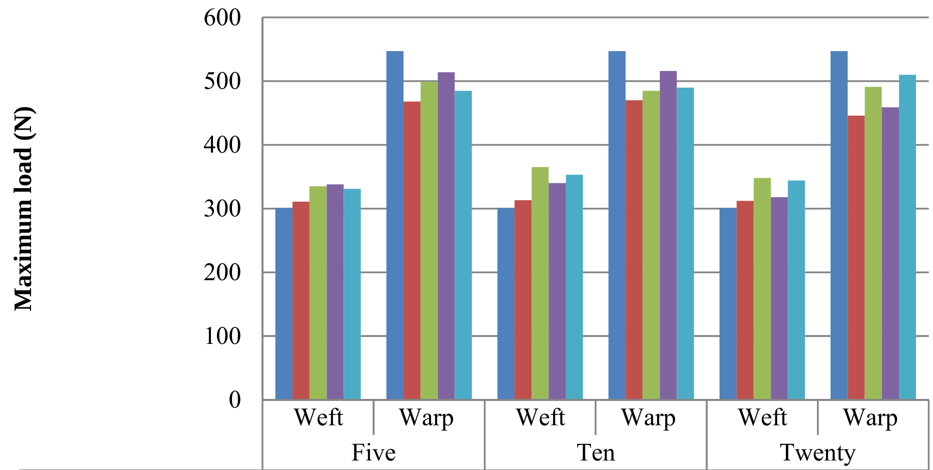
As illustrated in Figure 5.2, laundering with the water, detergent, Anolyte and sodium hypochlorite solution at 24°C caused a general increase in maximum load in the weft direction after twenty cycles, although there were some fluctuations after five and ten cycles. According to the statistical analysis (Table 5.1), the differences between the influences of the water, detergent, Anolyte and sodium hypochlorite solution were significant ($p < 0.05$). In the weft direction the water caused a total increase of 22 N after twenty cycles (323 N). The water had the smallest influence on the maximum load that the weft yarns could carry. The effect of the water could be explained by the changes in the fabric structure as the cotton fabric absorbed water during laundering, especially in the weft direction, as the fabric is more stable in the warp direction (Seyam & El-Shiekh, 1995). The detergent had the largest influence on the maximum load that the weft yarns could carry, when it caused a 59 N increase after twenty cycles (360 N). This could possibly be from the deposition of detergent on the fabric surface (Fijan *et al.*, 2007b). The maximum load that the weft yarns treated with Anolyte could carry increased with 38 N after twenty cycles (339 N). The sodium hypochlorite solution caused an increase of 52 N after twenty cycles (353 N). These increases could be attributed to changes in the fabric structure during laundering (Seyam & El-Shiekh, 1995).

The statistical analysis (Table 5.1) indicated that the number of cycles had a significant ($p < 0.05$) influence on the maximum load that the fabric could carry in both directions. Quaynor *et al.* (1999) also found that the increasing number of laundering cycles had an influence on fabric properties because of fabric construction changes.

The trend observed for the maximum load of the warp yarns was a general decrease in maximum load after twenty laundering cycles with the water, detergent, Anolyte and sodium hypochlorite solution at 24°C, although there were some small increases after five and ten cycles. According to the statistical analysis (Table 5.1), the differences between the influences of the water, detergent, Anolyte and sodium hypochlorite solution were significant ($p < 0.05$). The warp yarns treated with water decreased with 39 N after twenty cycles (508 N). This could be contributed to the hydrophilic character of cotton that facilitates water absorption which promotes faster degradation of the matrix interface and in turn, destructively affects the maximum load (De Carvalho *et al.*, 2009). The detergent caused a 10 N decrease in the maximum load that the warp yarns could carry from untreated to twenty cycles (537 N). According to Sun *et al.* (2001) laundering with detergent can lead to a reduction in cotton fabric strength as a result of damaged cellulose. Laundering with the Anolyte caused the largest decrease of 82 N in maximum load that the warp yarns could carry after twenty cycles (465 N). This could be attributed to the acidity of the Anolyte (pH 2.2 - 2.4) as according to Lam *et al.* (2011) the acidity of an agent can cause a reduction of maximum load of cotton fabrics. The maximum load that the warp yarns treated with the sodium hypochlorite solution could carry decreased with 41 N after twenty cycles (506 N), which is consistent with the findings of Strnad *et al.* (2008) that an oxidizing agent can have a significant influence on the mechanical properties of a fibre, and cause a decrease in breaking force.

The statistical analysis indicated that laundering with the water, detergent, Anolyte and sodium hypochlorite at the temperature of 24°C had a significant influence ($p < 0.05$) on the maximum load that the cotton fabric could carry in both directions.

The statistical analysis (Table 5.1) indicated that laundering with the water, detergent, Anolyte and sodium hypochlorite solution at 30°C as well as the number of cycles had a significant influence ($p < 0.05$) on the maximum load that the weft yarns could carry. It is recommended that cotton could be laundered at temperatures up to 60°C, but as temperature increases, the fibre swelling increase and influence the fabric structure and properties (Carr, 1995).

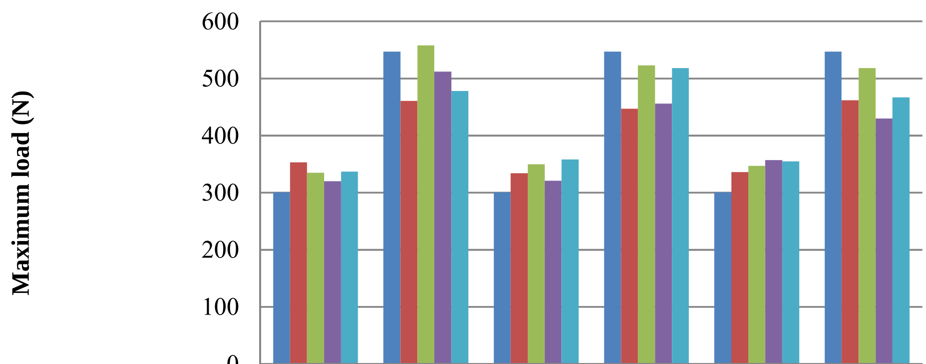


	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	301	547	301	547	301	547
Water	311	468	313	470	312	446
Detergent	335	499	365	485	348	491
Anolyte	338	514	340	516	318	459
Sodium hypochlorite	331	485	353	490	344	510

Figure 5.3: Maximum load of the cotton fabric after laundering for five, ten and twenty cycles at 30°C.

As illustrated in Figure 5.3, laundering with the water, detergent, Anolyte and sodium hypochlorite solution at 30°C caused a general increase in maximum load in the weft direction after twenty cycles, although there were some fluctuations after five and ten cycles. According to the statistical analysis (Table 5.1), the differences between the influences of the water, detergent, Anolyte and sodium hypochlorite solution were significant ($p < 0.05$). The water caused an increase of 11 N in the maximum load that the weft yarns could carry from untreated to twenty cycles (312 N). This could be contributed to the fabric structure and the laundering action as according to Choi *et al.* (2004) the laundering action causes friction between the yarns that decreases fabric properties such as maximum load. The detergent caused the largest increase of 47 N in maximum load that the weft yarns could carry after twenty laundering cycles (348 N). As already previously mentioned, this could be due to changes in the fabric structure as well as depositing of detergent on the fabric (Fijan *et al.*, 2007). The Anolyte caused a 17 N increase in the maximum load that the weft yarns could carry after twenty cycles (318 N), while the sodium hypochlorite solution caused a 43 N increase after twenty cycles (344 N).

As illustrated in Figure 5.3, laundering with the water, detergent, Anolyte and sodium hypochlorite solution at 30°C caused a general decrease in maximum load in the warp direction, although there were some fluctuations after five and ten cycles. In the warp direction after twenty cycles the detergent had caused a 56 N decrease in maximum load that the warp yarns could carry after twenty cycles (491 N). The loss of maximum load in the warp direction could be attributed the mechanical laundering action which causes damage to the fibrillar structure of the cotton fibres which in turn lead to a decrease in fabric strength (Carr, 1995). The Anolyte caused an 88N decrease in maximum load that the warp yarns could carry after twenty cycles (459 N), while the sodium hypochlorite solution caused a 37 N decrease after twenty cycles (510 N). This could again be explained by Strnad *et al.* (2008) who found that oxidizing agents could have a significant influence on the mechanical properties of a fibre, which results in a decrease in the breaking strength and elongation. This is caused by the chemical reactions between the active oxygen and the micromolecular cross-links of the cellulose polymers, which entailed a depolymerisation and weakening of the fibres (Fijan *et al.*, 2007b). Laundering with the water caused the largest decrease of 101 N in maximum load that the warp yarns could carry after twenty cycles (446 N).



	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	301	547	301	547	301	547
Water	353	461	334	447	336	462
Detergent	335	558	350	523	347	518
Anolyte	320	512	321	456	357	430
Sodium hypochlorite	337	478	358	518	355	467

Figure 5.4: Maximum load of the cotton fabric after laundering for five, ten and twenty cycles at 60°C.

Laundering of the cotton fabric with the water, detergent, Anolyte and sodium hypochlorite at 60°C and number of cycles had a significant influence ($p < 0.05$) on the maximum load of the cotton fabric in both directions (Table 5.1). As shown in figure 5.4, the general influence of the water, detergent, Anolyte and sodium hypochlorite solution in the weft direction was an increase in maximum load after twenty laundering cycles, although there were some fluctuations after five and ten cycles. In the weft direction, the Anolyte and the sodium hypochlorite solution had similar influences. The sodium hypochlorite solution caused a 54 N increase in maximum load that the weft yarns could carry after twenty cycles (355 N), while the Anolyte caused a 56 N increase after twenty cycles (357 N). Laundering with the detergent caused a 46 N increase after twenty cycles (347 N) which could again be attributed to the alkaline pH of the detergent as alkali treatment can improve cotton fabric's tensile strength by giving rise to a lattice conversion of the cellulose (Tanczos *et al.,* 2000; Bledzki *et al.,* 2004), especially at high temperatures. The water had the smallest influence and caused a 35 N increase in maximum load that the weft yarns could carry after twenty cycles (336 N) which could again be attributed to the changes in the fabric structure during laundering (Seyam & El-Shiekh, 1995).

As illustrated in Figure 5.4, laundering with the water, detergent, Anolyte and sodium hypochlorite at 60°C caused a general decrease in maximum load after twenty cycles in the warp direction, although there were some fluctuations after five and ten cycles. The maximum load of the warp yarns treated with water decreased with 85 N after twenty cycles (462 N). The detergent caused a decrease of 29 N in the maximum load that the warp yarns could carry after twenty cycles (518 N). The maximum load of the warp yarns treated with the sodium hypochlorite solution decreased with 80 N after twenty cycles (467 N). After laundering with Anolyte the largest decrease of 117 N after twenty cycles (430 N) was recorded. The decrease in maximum load could be due to the changes in the woven structure, which happened during the laundering action at the temperature of 60°C. According to Seyam & El-Shiekh (1995), swelling of the yarns during laundering can lead to a change in the woven construction, which influences the fabric properties.

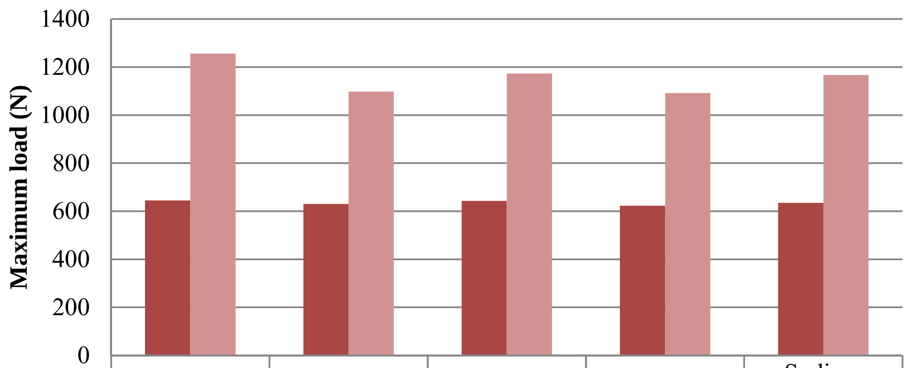
The analysis of the effect of treatment, temperature and cycles on the tensile strength of the cotton fabric is indicated in Table 5.3. The analysis indicates that the laundering with water, Anolyte, detergent and sodium hypochlorite solution had a significant influence ($p < 0.05$) on the maximum load of the cotton fabric in both weft and warp directions. This is supported by the results as indicated in Figure 5.1, where the difference in the effect of the water, detergent, Anolyte and sodium hypochlorite solution can easily be identified. According to the statistical analysis the difference in temperature only had a significant influence ($p < 0.05$) on the warp yarns, where the maximum load of the yarns had a greater difference between the temperatures than those of the weft yarns. As indicated in Table 5.3, the interaction between the treatment and the temperature also had a significant ($p < 0.05$) effect. In the warp direction, the temperature caused a decrease in maximum load as the temperature increased up to 30°C, but there was no difference between the average maximum load at 30°C and 60°C (Table 5.1). The influence of the temperature could be contributed to the fibre content of the fabric. Cotton fibres are hydrophilic (Cohen & Johnson, 2010) and fibre swelling and yarn retractive forces increase with increasing temperatures, which in turn change the fabric structure and influence the fabric properties (Carr, 1995). As the temperature only influenced the warp yarns significantly ($p < 0.05$), the interaction between the cycles and temperature (Table 5.3), as well as the cycles, temperature and treatment was only significant ($p < 0.05$) on the warp yarns, which are once again supported by the results depicted in Figures 5.2 - 5.4. Laitala *et al.* (2011) also found significant changes in maximum load of cotton fabrics between different temperatures and attributed it to the damage caused by the high temperature and laundering action.

Table 5.3: P-values of the effect of treatment, temperature and cycles on the maximum load of the cotton fabric.

Source	Weft p-value	Warp p-value
Treatment*Temperature	0.0389*	< .0001*
Treatment*Cycles	0.1221	< .0001*
Temperature*Cycles	0.3561	0.0182*
Treatment*Temperature*Cycles	0.4267	< .0001*

5.2.1.2 Polyester

The results concerning the tensile strength of the polyester fabric after laundering with water, detergent, Anolyte and sodium hypochlorite solution are illustrated in Figure 5.5, as well as the statistical analysis of the significance of treatment, temperature and cycles as illustrated in Table 5.4. There was a significant ($p < 0.05$) difference between the untreated samples and all the respective treatments.



	Untreated	Water	Detergent	Anolyte	Sodium hypochlorite
Weft	645	630	643	623	635
Warp	1256	1098	1173	1092	1167

Figure 5.5: The influence of laundering with water, detergent, Anolyte and sodium hypochlorite on the maximum load of the polyester fabric.

From Figure 5.5 it is clear to see that in the weft direction the water, detergent, Anolyte and sodium hypochlorite solution had a very closely related influence, however in the warp direction the difference between the water, detergent, Anolyte and sodium hypochlorite are more apparent. In both directions, the untreated yarns could carry the largest load, 645 N in the weft direction and 1256 N in the warp direction, while the Anolyte had the largest influence of the water, detergent, Anolyte and sodium hypochlorite solution at 623 N in the weft direction and 1092 N in the warp direction. It could be possible that the Anolyte and sodium hypochlorite caused hydrolyzation of the ester linkages on the surface of the polyester fibres, which resulted in a loss of tensile strength (Ren *et al.,* 2008).

The statistical analysis of the comparison of the other treatments to Anolyte (Table 5.5) indicated significant differences for the detergent in both directions, and the sodium hypochlorite solution in the warp direction. The fabric treated with the detergent had the closest relationship to the untreated samples, although there was a small decrease in maximum load. Chiweshe & Crews (2000) also found that the treatment of polyester with detergent could increase fibre mobility, which results in slippage and the reduction of fabric strength. Lin *et al.* (2002) also reported that treatment with detergent did not significantly affect the tensile strength of the polyester fabric.

Table 5.4: Maximum load necessary to break the polyester fabric: Effect of treatment, laundering temperature and number of laundering cycles.

DIRECTION			Mean (N)	Difference	95% Confidence limits		Significant
WARP	NO TREATMENT		1255.80				
WARP	TREATMENT			(Relative to untreated)			
		Anolyte	1091.54	164.26	95.84	232.68	***
		Sodium hypochlorite	1167.08	88.72	20.47	156.98	***
		Detergent	1170.46	85.34	16.83	153.84	***
		Water	1096.79	159.01	90.64	227.39	***
				(Relative to untreated)			
	TEMPERATURE	24°C	1140.244	115.56	48.09	183.02	***
		30°C	1126.295	129.51	61.90	197.12	***
		60°C	1127.913	127.89	60.47	195.31	***
	NUMBER OF LAUNDERING CYCLES						
				(Relative to untreated)			
		5	1130.219	125.58	58.14	193.03	***
		10	1134.399	121.40	53.96	188.84	***
		20	1129.945	125.85	58.24	193.46	***
WEFT	NO TREATMENT		644.740				
WEFT	TREATMENT			(Relative to untreated)			
		Anolyte	622.606	22.134	-8.256	52.525	
		Sodium hypochlorite	634.647	10.093	-20.297	40.484	
		Detergent	643.337	1.403	-28.987	31.794	
		Water	629.524	15.216	-15.175	45.606	
				(Relative to untreated)			
	TEMPERATURE	24°C	635.301	9.439	-20.569	39.448	
		30°C	638.694	6.046	-23.963	36.054	
		60°C	623.590	21.150	-8.858	51.158	
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	634.147	10.593	-19.415	40.602	
		10	639.429	5.311	-24.698	35.319	
		20	624.009	20.731	-9.278	50.739	

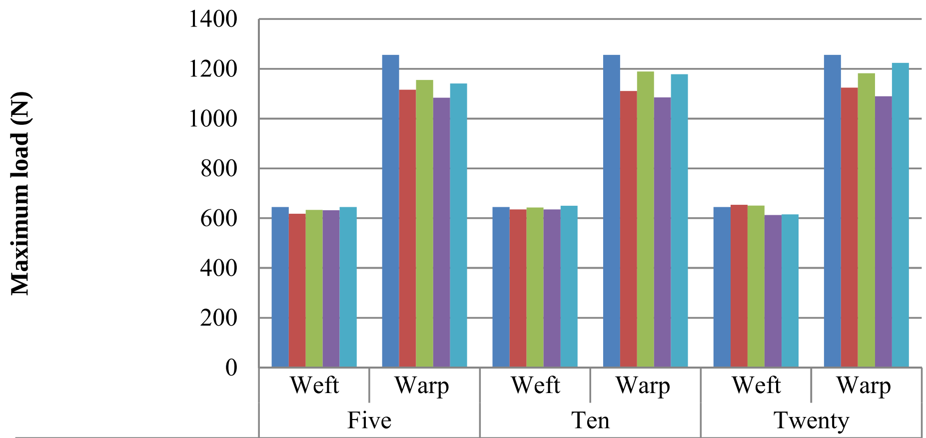
***, $p < 0.05$

The statistical analysis (Table 5.4) indicated that there were no significant differences between the influences of the water, detergent, Anolyte and sodium hypochlorite solution on the maximum load of the polyester fabric in the weft direction. Lin *et al.* (2002) reported that treatment with chlorine did not significantly affect the tensile properties of the polyester fabric. In the warp direction the water, detergent, Anolyte and sodium hypochlorite solution had a ($p < 0.05$) influence compared to the untreated fabric (Table 5.4), while there was a significant difference ($p < 0.05$) between the influences of the Anolyte compared to the sodium hypochlorite solution as well as the Anolyte compared to the detergent (Table 5.5).

Table 5.5: Significance of laundering with water, detergent and sodium hypochlorite compared with Anolyte on the maximum load of the polyester fabric.

Direction	Treatment	Mean (N)	Difference	95% Confidence limits		Significant
Weft			(Relative to Anolyte)			
	Anolyte	622.606				
	Sodium hypochlorite	634.647	-12.041	-25.632	1.550	
	Detergent	643.337	-20.731	-34.322	-7.140	***
	Water	629.524	-6.919	-20.510	6.672	
Warp			(Relative to Anolyte)			
	Anolyte	1091.54				
	Sodium hypochlorite	1167.08	-75.53	-106.41	-44.65	***
	Detergent	1170.46	-78.92	-110.34	-47.51	***
	Water	1096.79	-5.24	-36.38	25.89	

***, $p < 0.05$

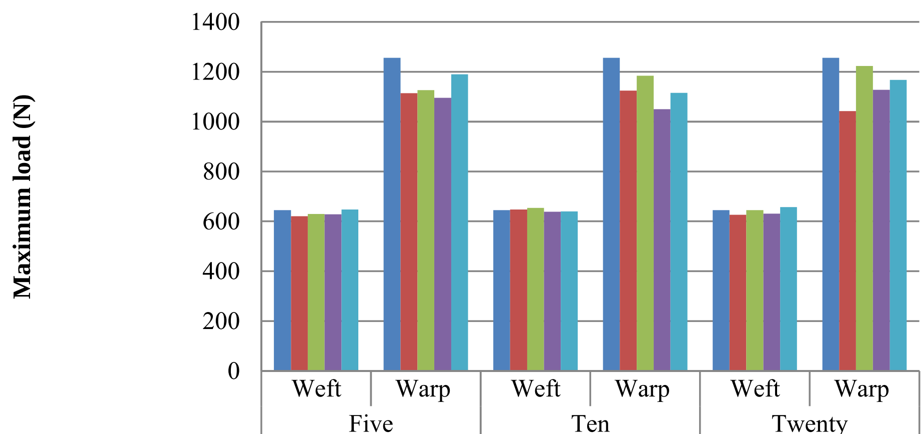


	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	645	1256	645	1256	645	1256
Water	618	1116	635	1111	654	1124
Detergent	633	1155	643	1189	651	1182
Anolyte	632	1084	635	1085	613	1090
Sodium hypochlorite	645	1141	650	1178	615	1224

Figure 5.6: Maximum load of the polyester fabric after laundering for five, ten and twenty cycles at 24°C.

According to the statistical analysis (Table 5.4) laundering of the polyester fabric at 24°C did not have a significant influence on the maximum load in the weft direction. The number of laundering cycles also did not have a significant influence on the maximum load in the weft direction. According to Choi *et al.* (2004) friction of the yarns is caused by the laundering action, which results in a decrease of strength properties. Figure 5.6 illustrated that the Anolyte and the sodium hypochlorite solution caused a decrease in maximum load after twenty laundering cycles. The maximum load of weft yarns treated with Anolyte decreased with 32 N after twenty cycles (613 N). The sodium hypochlorite solution had a similar influence and caused a 30 N decrease in maximum load, which the weft yarns could carry after twenty cycles (615 N). In contrast to the effects of the Anolyte and the sodium hypochlorite solution, laundering with the water and the detergent caused an increase in maximum load in the weft direction after twenty laundering cycles. The water caused an increase of 9 N in the maximum load that the weft yarns could carry after twenty cycles (654 N), while the detergent caused an increase of 6 N after twenty cycles (651 N). Chiweshe & Crews (2000) indicated that the treatment of polyester with detergent could increase fibre mobility, which results in slippage and the reduction of fabric strength.

In contrast to the weft yarns the maximum load of the warp yarns treated with water decreased with 132 N after twenty cycles (1124 N). The detergent caused a decrease of 74 N in the maximum load that the warp yarns could carry after twenty cycles (1182 N). Bendak & El-Marsifi (1991) reported that treatment of polyester fabric with an alkaline solution could have an influence on the weight of the fabric and, therefore, affect breaking strength. The maximum load that the warp yarns treated with Anolyte could carry decreased with 166 N after twenty cycles (1090 N). The sodium hypochlorite solution caused a decrease of 32 N in the maximum load that the warp yarns could carry after twenty cycles (1224 N). Laitala *et al.* (2011) contributed the loss in tensile strength of polyester fabric to the laundering temperature and laundering action that caused damage to the fibres. The statistical analysis (Table 5.4) indicated that laundering of the polyester fabric at 24°C had a significant influence ($p < 0.05$) on the maximum load in the warp direction. The number of laundering cycles also had a significant influence ($p < 0.05$) on the maximum load in the warp direction.

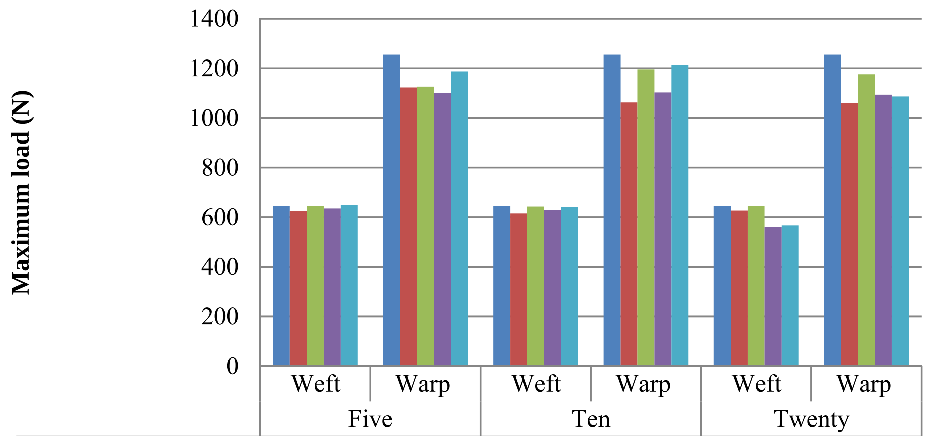


	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	645	1256	645	1256	645	1256
Water	620	1114	647	1124	626	1042
Detergent	630	1126	654	1184	645	1223
Anolyte	629	1095	639	1050	631	1128
Sodium hypochlorite	647	1190	640	1115	657	1167

Figure 5.7: Maximum load of the polyester fabric after laundering for five, ten and twenty cycles at 30°C.

As indicated in figure 5.7, laundering at 30°C with the water and the Anolyte caused a decrease in maximum load in the weft direction after twenty laundering cycles, while an increase was caused by the sodium hypochlorite solution. Although the detergent caused a decrease in maximum load required to break the weft yarns after five cycles and an increase after ten cycles, no influence was recorded after twenty laundering cycles with the detergent. This is in accordance with the findings of Lin *et al.* (2002) who reported that treatment with detergent did not significantly affect the maximum load of the polyester fabric. The water caused the largest 19 N decrease in maximum load that the weft yarns could carry after twenty cycles (626 N). According to Choi *et al.* (2004) friction of the yarns is caused by the laundering action, which results in a decrease of strength properties. The Anolyte caused a decrease in maximum load that the weft yarns could carry of 14N after twenty cycles (631 N). A loss in maximum load could be due to the hydrolyzation of the ester linkages on the surface of the polyester fibres caused by the treatments, which resulted in a loss of tensile strength (Ren *et al.,* 2008). The mechanical action of the laundering process should also be taken into consideration. The sodium hypochlorite solution had an adverse effect in relation to the water and Anolyte as the maximum load increased with 12 N after twenty cycles (657 N).

The water, detergent, Anolyte and sodium hypochlorite solution caused a general decrease in maximum load in the warp direction of the polyester fabric after twenty laundering cycles, although there were some fluctuations after five and ten cycles. Laundering with the water, detergent, Anolyte and sodium hypochlorite solution at 30°C had a significant influence ($p < 0.05$) on the maximum load of the polyester fabric in the warp direction (Table 5.4). The water also had the largest influence in the warp direction as it caused a 214 N decrease in the maximum load that the warp yarns could carry after twenty cycles (1042 N). This could be due to the laundering action, which caused damage to the fibres (Laitala *et al.,* 2011). The detergent had the smallest influence in the warp direction as it caused a 33 N decrease in the maximum load that the warp yarns could carry after twenty cycles. This is in accordance with the findings of Chiweshe & Crews (2000) who found that the treatment of polyester with detergent could increase fibre mobility that results in slippage and the reduction of fabric strength. The Anolyte caused a decrease of 128 N in maximum load that the warp yarns could carry after twenty laundering cycles. Ren *et al.* (2008) indicated that loss in tensile strength could be due to the hydrolyzation of the ester linkages on the surface of the polyester fibres caused by the treatments. The sodium hypochlorite caused an 89 N decrease in maximum load of the warp yarns.



	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	645	1256	645	1256	645	1256
Water	624	1123	616	1063	627	1060
Detergent	646	1126	643	1196	644	1176
Anolyte	636	1102	629	1103	560	1094
Sodium hypochlorite	649	1187	642	1214	567	1087

Figure 5.8: Maximum load of the polyester fabric after laundering for five, ten and twenty cycles at 60°C.

As indicated in Figure 5.8, the Anolyte and sodium hypochlorite solution had the same reaction in both directions where the maximum load of the weft yarns decreased with the number of cycles. After twenty laundering cycles, the water, detergent, Anolyte and sodium hypochlorite solution caused a decrease in maximum load that the weft yarns could carry. According to Siroky *et al.* (2009) polyester fabric strength is influenced by the changes in the fabric structure during laundering. The Anolyte caused the largest decrease of 85 N after twenty laundering cycles, while the sodium hypochlorite solution caused a 78 N decrease in maximum load after twenty cycles. The water caused an 18 N decrease in the maximum load that the weft yarns could carry. According to Choi *et al.* (2004) friction of the yarns is caused by the laundering action, which results in a decrease of strength properties. The detergent had very little influence on the maximum load that the weft yarns could carry and after twenty cycles, it only caused a decrease of 1 N. Lin *et al.* (2002) also reported that treatment with detergent did not significantly affect the maximum load of the polyester fabric support these findings.

According to the statistical analysis (Table 5.4), laundering of the polyester fabric at 60°C had a significant influence ($p < 0.05$) on the maximum load of the polyester fabric in the warp direction. The water, detergent, Anolyte and sodium hypochlorite solution caused a decrease in maximum load in the warp direction of the polyester fabric after twenty laundering cycles. The water had the largest influence on the maximum load, which the polyester fabric could carry in the warp direction, as it caused a 196 N decrease after twenty cycles. According to Gupta (2003), the application of heat in the presence of water can cause a change in the polyester fibre configuration, which in turn would affect fabric properties. The detergent caused the smallest decrease of 80 N in the maximum load that the warp yarns could carry. Chiweshe & Crews (2000) indicated that laundering of polyester with detergent could increase fibre mobility, which results in slippage and the reduction of fabric strength. The Anolyte caused a decrease of 162 N and the sodium hypochlorite solution caused a 169 N decrease in maximum load that the warp yarns could carry. According to Bendak & El-Marsifi (1991) treatment of polyester fabric with acid solutions at 60°C can cause a decrease in tensile strength of the fabric.

Table 5.6: P-values of the effect of treatment, temperature and cycles on the maximum load of the polyester fabric.

Source	p-value weft	p-value warp
Treatment*Temperature	0.5744	0.9191
Treatment*Cycles	0.0184*	0.1863
Temperature*Cycles	0.0141*	0.2324
Treatment*Temperature*Cycles	0.2898	0.2383

Statistical analysis (Table 5.6) indicated that the interaction of treatment and cycles had a significant influence ($p < 0.05$) on the maximum load of the polyester fabric in the weft direction. This is confirmed by the data that showed fluctuations in the maximum loads that the yarns could carry for each of the water, detergent, Anolyte and sodium hypochlorite solution. The temperature and the number of cycles had a significant effect ($p < 0.05$) on the weft yarns and therefore the interaction between treatment and cycles, as well as temperature and cycles was only significant ($p < 0.05$) on the weft yarns. The effect of temperature and cycles was larger and clearly visible on the weft yarns, where the warp yarns were more stable. Van Amber *et al.* (2010) also reported that laundering temperature did not significantly affect fabric properties.

5.2.1.3 Polyester/Cotton

The results concerning the tensile strength of the polyester/cotton fabric after laundering with water, detergent, Anolyte and sodium hypochlorite solution are illustrated in Figure 5.9, as well as the statistical analysis of the significance of treatment, temperature and cycles as illustrated in Table 5.7.

It is illustrated in Figure 5.9 that the water, detergent, Anolyte and sodium hypochlorite solution had closely related influences on the polyester/cotton fabric, as it all resulted that higher maximum loads could be carried than those of the untreated fabric. Verdu *et al.* (2009) as well as Mukhopadhyay *et al.* (2004) also found that the tensile strength of polyester/cotton fabrics increased after laundering.

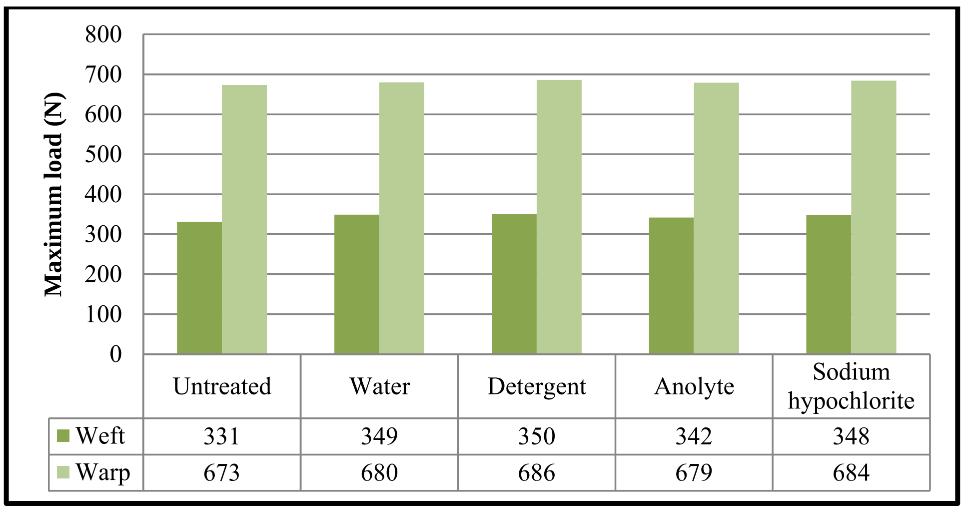


Figure 5.9: The influence of laundering with water, detergent, Anolyte and sodium hypochlorite on the maximum load of the polyester/cotton fabric.

Seyam & El-Shiekh (1995) indicated that changes in the fabric structure during laundering can lead to increased fabric strength. In the weft direction the detergent (350 N) had the largest influence (Figure 5.9) while the Anolyte (342 N) had the smallest influence, and the statistical analysis (Table 5.8) indicated a significant difference ($p < 0.05$) between the Anolyte and the detergent. There was a significant ($p < 0.05$) difference (Table 5.7) in the influence of the detergent (350 N), sodium hypochlorite solution (348 N) and water (349 N) respectively, when compared to the untreated fabric (331 N). In contrast to these findings, Perkins *et al.* (1996) found that laundering with a sodium hypochlorite bleach solution did not have a significant effect on the strength of polyester/cotton fabrics.

Table 5.7: Maximum load necessary to break the polyester/cotton fabric: Effect of treatment, laundering temperature and number of laundering cycles.

DIRECTION			Mean (N)	Difference	95% Confidence limits		Significant
WARP	NO TREATMENT		672.820				
WARP	TREATMENT			(Relative to untreated)			
		Anolyte	678.850	6.030	18.705	6.645	
		Sodium hypochlorite	683.583	10.763	23.438	1.911	
		Detergent	686.300	13.480	26.155	0.805	***
		Water	680.277	7.457	20.131	5.218	
				(Relative to untreated)			
	TEMPERATURE	24°C	684.227	11.407	23.923	1.108	
		30°C	681.589	8.769	21.284	3.746	
		60°C	680.941	8.121	20.636	4.394	
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	683.869	11.049	23.564	1.446	
		10	684.406	11.586	24.101	0.929	
		20	678.483	5.663	18.178	6.853	
WEFT	NO TREATMENT		331.070				
WEFT	TREATMENT			(Relative to untreated)			
		Anolyte	342.097	11.027	23.239	1.186	
		Sodium hypochlorite	347.821	16.751	28.964	4.539	***
		Detergent	350.304	19.234	31.447	7.022	***
		Water	349.111	18.041	30.254	5.829	***
				(Relative to untreated)			
	TEMPERATURE	24°C	345.687	14.617	26.675	2.558	***
		30°C	346.976	15.906	27.965	3.846	***
		60°C	349.337	18.267	30.326	6.209	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	342.152	11.082	23.141	0.976	
		10	348.092	17.022	29.080	4.963	***
		20	351.756	20.686	32.745	8.627	***

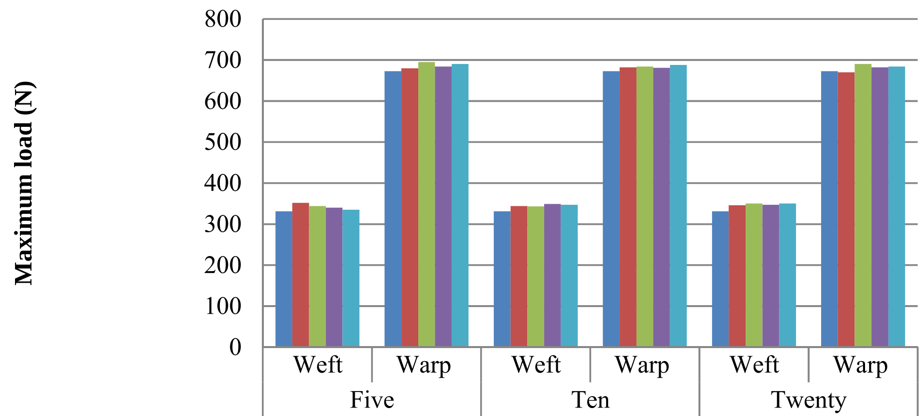
***, $p < 0.05$

In the warp direction it was once again the detergent (686 N) which had the largest influence, while the Anolyte (679 N) had the smallest influence. The statistical analysis (Table 5.8) indicated a significant difference ($p < 0.05$) between the influence of the Anolyte and the detergent in both directions, while there was also a significant difference ($p < 0.05$) between the influence of the Anolyte in comparison to the sodium hypochlorite solution. The only significant difference ($p < 0.05$) found in the warp direction when the treatment was compared to the untreated samples (Table 5.7) was with the detergent.

Table 5.8: Significance of laundering with water, detergent and sodium hypochlorite compared with Anolyte on the maximum load of the polyester/cotton fabric.

Direction	Treatment	Mean (N)	Difference	95% Confidence limits		Significant
Weft			(Relative to Anolyte)			
	Anolyte	342.097				
	Sodium hypochlorite	347.821	-5.724	-11.186	-0.263	***
	Detergent	350.304	-8.208	-13.669	-2.746	***
	Water	349.111	-7.014	-12.476	-1.553	***
Warp						
	Anolyte	678.850				
	Sodium hypochlorite	683.583	-4.733	-10.402	0.935	
	Detergent	686.300	-7.450	-13.118	-1.782	***
	Water	680.277	-1.427	-7.095	4.242	

***, $p < 0.05$

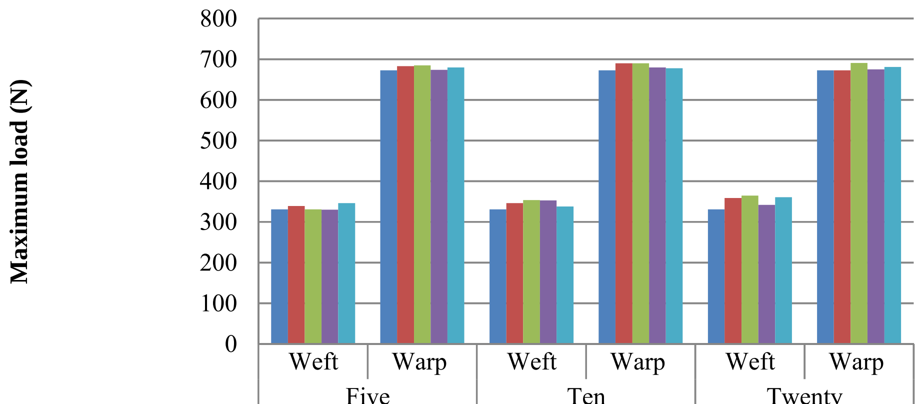


	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	331	673	331	673	331	673
Water	352	680	344	682	346	670
Detergent	344	695	343	684	350	690
Anolyte	340	684	349	681	347	682
Sodium hypochlorite	335	690	347	688	350	684

Figure 5.10: Maximum load of the polyester/cotton fabric after laundering for five, ten and twenty cycles at 24°C.

Although there were small fluctuations after five and ten cycles, the water, detergent, Anolyte and sodium hypochlorite solution generally caused an increase in maximum load in the weft direction of the polyester/cotton fabric after twenty laundering cycles (Figure 5.10). The maximum load of the weft yarns treated with water increased with 15N after twenty cycles (346 N), while those treated with the detergent and sodium hypochlorite solution increased with 19N after twenty cycles (350 N). The largest increase caused by the detergent could again be due to the deposition of detergent onto the fabric surface, which according to Fijan *et al.* (2007) could result in an increase in fabric strength. Anolyte caused the maximum load of the weft yarns to increase with 16 N after twenty cycles (347 N). The effect of the water, detergent, Anolyte and sodium hypochlorite could also be contributed to changes in the fabric structure, which could result in higher strength of the fabric (Seyam & El-Shiekh, 1995). The statistical analysis indicated that laundering at a temperature of 24°C had a significant influence ($p < 0.05$) on the maximum load that the weft yarns could carry. Laitala *et al.* (2011) also found that laundering temperature had an effect on tensile strength of polyester/cotton fabric.

The detergent, Anolyte and sodium hypochlorite caused an increase in maximum load in the warp direction of the polyester/cotton fabric after twenty laundering cycles. The detergent had the largest influence as it caused a 17 N increase in maximum load that the warp yarns could carry. This increase could be due to the deposition of detergent onto the surface of the fabric, which can cause an increase in strength (Fijan *et al.,* 2007). The Anolyte caused a 9 N increase in maximum load of the warp yarns after twenty cycles. The sodium hypochlorite solution caused an increase of 11 N in the maximum load that the warp yarns could carry after twenty cycles. These increases could be attributed to changes in the fabric structure during laundering which could increase the strength of a fabric (Seyam & El-Shiekh, 1995). The water had the opposite effect and caused a small 3 N decrease in maximum load that the warp yarns could carry after twenty laundering cycles. Laundering with the water, detergent, Anolyte and sodium hypochlorite at 24°C did not have a significant influence on the maximum load of the polyester/cotton fabric in the warp direction (Table 5.7).

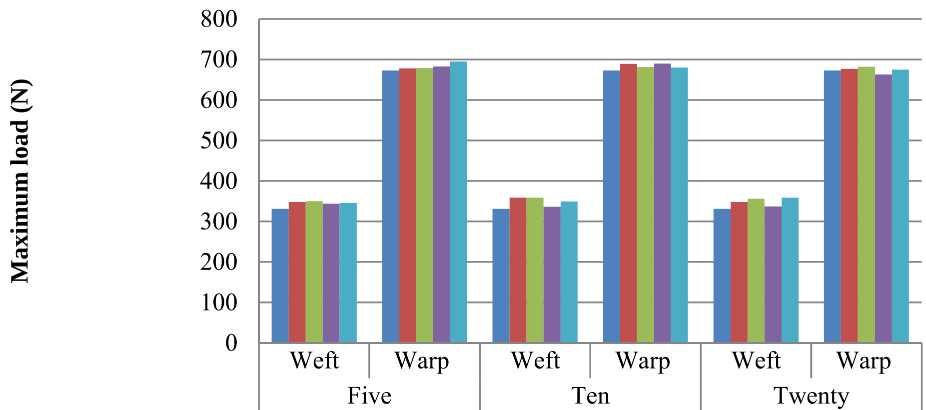


	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	331	673	331	673	331	673
Water	339	683	346	690	359	673
Detergent	331	685	354	690	365	691
Anolyte	330	674	353	680	342	675
Sodium hypochlorite	346	680	338	678	361	681

Figure 5.11: Maximum load of the polyester/cotton fabric after laundering for five, ten and twenty cycles at 30°C.

Laundering of the polyester/cotton fabric with the water, detergent, Anolyte and sodium hypochlorite solution at 30°C had a significant influence ($p < 0.05$) on the maximum load in the weft direction (Table 5.7). Although there were some fluctuations after five and ten cycles, the water, detergent, Anolyte and sodium hypochlorite solution caused an increase in maximum load in the warp direction of the polyester/cotton fabric after twenty laundering cycles (Figure 5.11). The detergent had the largest influence as it caused an increase of 34 N in the maximum load that the weft yarns could carry after twenty cycles (365 N). The largest increase caused by the detergent could again be due to the deposition of detergent onto the fabric surface, which according to Fijan *et al.* (2007) could result in an increase in fabric strength. The sodium hypochlorite solution caused an increase of 30 N in the maximum load that the weft yarns could carry after twenty cycles (361 N). Both of these increased maximum loads could once again be as a result of detergent particles deposited onto the fabric surface resulting in higher fabric strength (Fijan *et al.*, 2007), as the sodium hypochlorite solution also contained detergent. The water caused an increase of 28 N in the maximum load that the weft yarns could carry after twenty cycles. The Anolyte caused an increase of 11 N in the maximum load that the weft yarns could carry after twenty cycles. The increases caused by the Anolyte and the water could be explained by changes in the fabric structure during laundering which contributed to higher strength (Seyam & El-Shiekh, 1995).

In the warp direction the detergent, Anolyte and sodium hypochlorite solution caused an increase in maximum load, while the water had no influence after twenty laundering cycles (673 N). As in the weft direction the detergent had the largest influence and caused an increase of 18 N in the maximum load that the warp yarns could carry after twenty cycles (691 N). The sodium hypochlorite solution caused an increase of 8 N in the maximum load that the warp yarns could carry after twenty cycles (681 N). The Anolyte had almost no influence after twenty cycles as an increase of only 2 N was observed after twenty cycles (675 N). Laundering of the polyester/cotton fabric with the water, detergent, Anolyte and sodium hypochlorite solution at 30°C did not have a significant influence on the maximum load in the warp direction (Table 5.7).



	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	331	673	331	673	331	673
Water	348	678	359	689	348	677
Detergent	350	679	359	681	356	682
Anolyte	344	683	336	690	337	663
Sodium hypochlorite	346	695	349	680	359	675

Figure 5.12: Maximum load of the polyester/cotton fabric after laundering for five, ten and twenty cycles at 60°C.

Figure 5.12. shows that in the weft direction the water, detergent, Anolyte and sodium hypochlorite solution caused an increase in maximum load of the polyester/cotton fabric after laundering at 60°C for twenty cycles. The sodium hypochlorite solution had the largest influence as it caused an increase of 28 N in the maximum load that the weft yarns could carry after twenty cycles (359 N). The detergent caused an increase of 25 N in the maximum load that the weft yarns could carry after twenty cycles (356 N). The increase caused by the detergent could again be due to the deposition of detergent onto the fabric surface, which according to Fijan *et al.* (2007) could result in an increase in fabric strength. The water caused an increase of 17 N in the maximum load that the weft yarns could carry after twenty cycles (348 N), while the Anolyte had the smallest influence as it caused an increase of 6 N in the maximum load that the weft yarns could carry after twenty cycles (337 N). The statistical analysis (Table 5.7) indicated that laundering with the water, detergent, Anolyte and sodium hypochlorite solution at 60°C had a significant influence ($p < 0.05$) on the maximum load in the weft direction.

The water, detergent and sodium hypochlorite caused an increase in maximum load in the warp direction of the polyester/cotton fabric after twenty laundering cycles, while the Anolyte caused a decrease (Figure 5.12). The Anolyte had the largest influence as it caused a 10 N decrease after twenty cycles (663 N). A loss in maximum load could be due to the hydrolyzation of the ester linkages on the surface of the polyester fibres caused by the treatments, which resulted in a loss of tensile strength (Ren *et al.,* 2008). The detergent caused an increase of 9 N in the maximum load that the warp yarns could carry after twenty cycles (682 N). The water caused a small increase of 4 N in the maximum load that the warp yarns could carry after twenty cycles (677 N). The sodium hypochlorite solution caused a small increase of 2 N in the maximum load that the warp yarns could carry after twenty cycles (675 N). Sun *et al.* (2001) also found that after 50 laundering cycles with sodium hypochlorite, polyester/cotton still exhibited excellent breaking strength.

Statistical analysis of the effect of treatment, temperature and cycles on the maximum load of the polyester/cotton fabric are illustrated in Table 5.9.

Table 5.9: P-values of the effect of treatment, temperature and cycles on the maximum load of the polyester/cotton fabric.

Source	p-value weft	p-value warp
Treatment*Temperature	0.3963	0.3290
Treatment*Cycles	0.2421	0.1757
Temperature*Cycles	0.0435*	0.4669
Treatment*Temperature*Cycles	0.1005	0.7129

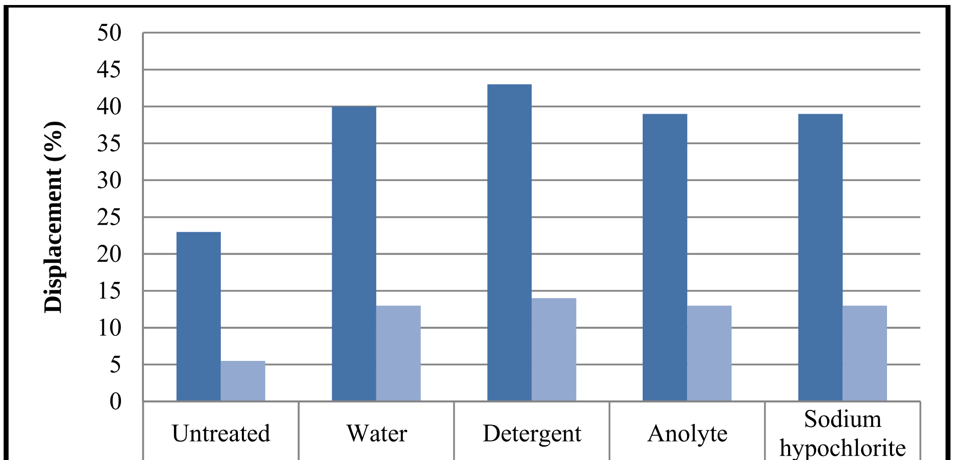
The analysis indicated that only the interaction of the temperature and the cycles had a significant influence ($p < 0.05$) on the maximum load of the weft yarns of the polyester/cotton fabric. This is supported by the results shown in Figures 5.10 to 5.12, where it is indicated that the weft yarns showed a larger variation between the cycles and the maximum load decreased as the temperature increased. As already mentioned, Laitala *et al.* (2011) also found that an increase in temperature could lead to a decrease in tensile strength. In the weft direction, the increase in temperature caused an increase in maximum load. The temperature as indicated in Table 5.7 did not have a significant influence on the maximum load of the polyester/cotton fabric. This is consistent with findings reported by Van Amber *et al.* (2010) that laundering temperature only had a small effect on fabric properties.

5.2.2 Displacement at maximum load

Elongation displacement is the limiting tensile deformation that corresponds to tensile strength and is expressed in percent of the test length (Švédová, 1990).

5.2.2.1 Cotton

The results concerning the displacement at maximum load of the cotton fabric after laundering with water, detergent, Anolyte and sodium hypochlorite solution are illustrated in Figure 5.13, as well as the statistical analysis of the significance of treatment, temperature and cycles as illustrated in Table 5.10.



	Untreated	Water	Detergent	Anolyte	Sodium hypochlorite
Weft	23	40	43	39	39
Warp	6	13	14	13	13

Figure 5.13: The influence of laundering with water, detergent, Anolyte and sodium hypochlorite on the displacement at maximum load of the cotton fabric.

As illustrated in Figure 5.13 the Anolyte and the sodium hypochlorite solution had the same influence on both directions, while the influence of the water on the warp was also coherent with the Anolyte and sodium hypochlorite solution. Raheel & Lien (1982) obtained similar results were cotton increased in displacement at break after laundering. Cotton fibres have an average elongation of 6.7% (Krifta, 2006), but Foulk & McAlister (2002) found it to be 7.42 - 9.51% depending on the micronaire value. In this study, the untreated warp yarns had an average elongation of 5.5% and the weft yarns had an average elongation of 23%. According to Lenting & Warmoeskerken (2001), the amorphous cellulose is responsible for the flexibility of cotton cells. The untreated fabric had the smallest displacement at maximum load in both directions, while the fabric treated with the detergent had the largest.

Table 5.10: Displacement of cotton fabric at maximum load: Effect of treatment, laundering temperature and number of laundering cycles.

DIRECTION			**Mean (%)**	**Difference**	**95% Confidence limits**		**Significant**
WARP	NO TREATMENT		5.48200				
WARP	TREATMENT			(Relative to untreated)			
		Anolyte	8.72637	-3.24437	-3.62618	-2.86257	***
		Sodium hypochlorite	8.76385	-3.28185	-3.66366	-2.90005	***
		Detergent	9.09719	-3.61519	-3.99699	-3.23338	***
		Water	8.37015	-2.88815	-3.26995	-2.50634	***
				(Relative to untreated)			
	TEMPERATURE	24°C	8.77372	-3.29172	-3.66872	-2.91472	***
		30°C	8.56111	-3.07911	-3.45611	-2.70211	***
		60°C	8.88333	-3.40133	-3.77834	-3.02433	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	7.81939	-2.33739	-2.71439	-1.96039	***
		10	8.79389	-3.31189	-3.68889	-2.93489	***
		20	9.60489	-4.12289	-4.49989	-3.74589	***
WEFT	NO TREATMENT		22.6900				
WEFT	TREATMENT			(Relative to untreated)			
		Anolyte	26.1888	-3.4988	-4.4794	-2.5182	***
		Sodium hypochlorite	25.8231	3.1331	-4.1142	-2.1519	***
		Detergent	28.7394	-6.0494	-7.0300	-5.0688	***
		Water	26.7410	-4.0510	-5.0315	-3.0704	***
				(Relative to untreated)			
	TEMPERATURE	24°C	26.9566	-4.2666	-5.2348	-3.2983	***
		30°C	27.6574	-4.9674	-5.9360	-3.9989	***
		60°C	26.0205	-3.3305	-4.2987	-2.3623	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	26.6778	-3.9878	-4.9561	-3.0196	***
		10	28.0990	-5.4090	-6.3776	-4.4405	***
		20	25.8613	-3.1713	-4.1395	-2.2030	***

***, $p < 0.05$

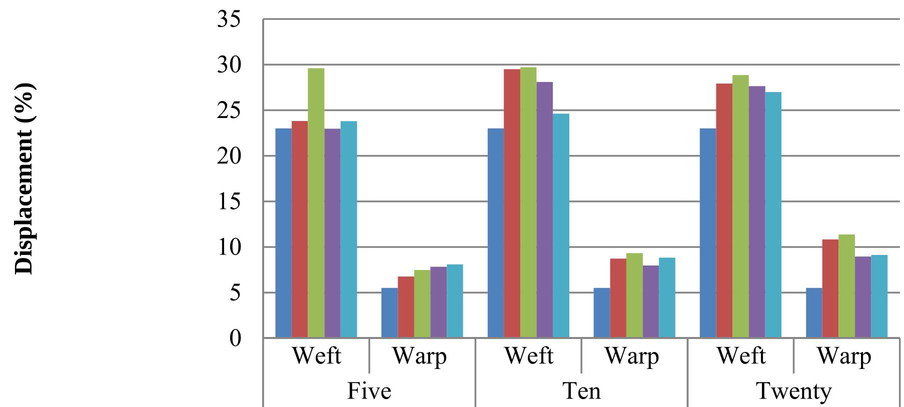
The statistical analysis (Table 5.10) indicated that there were significant differences ($p < 0.05$) between the displacements of all of the water, detergent, Anolyte and sodium hypochlorite in comparison to the untreated fabric. Munshi *et al.* (1993) as well as Leimer *et al.* (1997) indicated that elongation increased after repeated laundering of cotton, which supports the findings illustrated in Figure 5.13.

Table 5.11: Significance of laundering with water, detergent and sodium hypochlorite compared with Anolyte on the displacement at maximum load of the cotton fabric in the weft direction.

Direction	Treatment	Mean (%)	Difference	95% Confidence limits		Significant
Weft			(Relative to Anolyte)			
	Anolyte	26.1888				
	Sodium hypochlorite	25.8231	0.3657	-0.0740	0.8055	
	Detergent	28.7394	-2.5506	-2.9891	-2.1121	***
	Water	26.7410	-0.5521	-0.9907	-0.1136	***
Warp			(Relative to Anolyte)			
	Anolyte	8.72637				
	Sodium hypochlorite	8.76385	-0.03748	-0.20823	0.13327	
	Detergent	9.09719	-0.37081	-0.54156	-0.20007	***
	Water	8.37015	0.35622	0.18547	0.52697	***

***, $p < 0.05$

The statistical analysis (Table 5.11) indicated that there were significant differences ($p < 0.05$) between the influences of the detergent and water, respectively, when compared with the Anolyte. This could be expected as the difference between the displacement at maximum load of the fabrics treated with the Anolyte and Sodium hypochlorite solution respectively, were very closely related. According to Sekiguchi *et al.* (2000) the treatment of cotton with an alkaline agent, such as detergent, can raise the reactivity of hydroxyl groups of cellulose, resulting in improved elongation. The statistical analysis further indicated that the temperatures and the number of cycles had a significant influence ($p < 0.05$) on the displacement at maximum load of the cotton fabric, as illustrated in Figures 5.14 to 5.16.



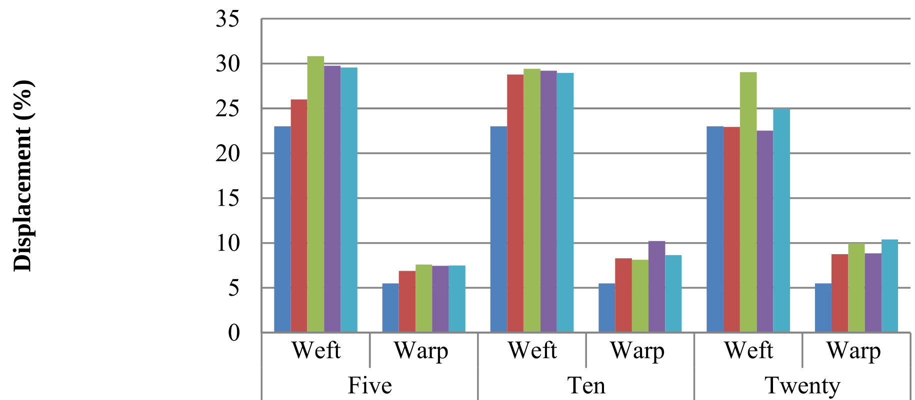
	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	23	6	23	6	23	6
Water	24	7	30	9	28	11
Detergent	30	7	30	9	29	11
Anolyte	23	8	28	8	28	9
Sodium hypochlorite	24	8	25	9	27	9

Figure 5.14: Displacement of the cotton fabric at maximum load after laundering for five, ten and twenty cycles at 24°C.

Figure 5.14 shows that the water, detergent, Anolyte and sodium hypochlorite solution caused an increase in displacement at maximum load after twenty laundering cycles. This is in agreement with the findings of Munshi *et al.* (1993) who found that elongation increased after repeated laundering of cotton fabric. Laundering of the cotton fabric with the water, detergent, Anolyte and sodium hypochlorite solution at 24°C had a significant influence ($p < 0.05$) on the displacement at maximum load in both directions of the fabric. In the weft direction, the detergent caused the largest increase of 6% in displacement at maximum load after twenty cycles (29%). According to Sekiguchi *et al.* (2000) the treatment of cotton with an alkaline agent, such as detergent, can raise the reactivity of hydroxyl groups of cellulose, which results in improved elongation. The Anolyte and the water had the same influence as it caused a 5% increase in displacement at maximum load after twenty cycles (28%). The sodium hypochlorite solution had the smallest influence as it caused a 4% increase in displacement at maximum load after twenty cycles (27%).

In the warp direction, the water and detergent had the same influence as it caused an increase in displacement at maximum load of 5% after twenty cycles (11%). The Anolyte and sodium hypochlorite solution also had the same influence as it caused a 3% increase in displacement at maximum load after twenty laundering cycles (9%).

The increases in displacement at maximum load in both directions of the cotton fabric could be contributed to changes in the fabric structure which became more loosely arranged during laundering (Anandjiwala *et al.*, 2007), which could in turn lead to higher elongation.

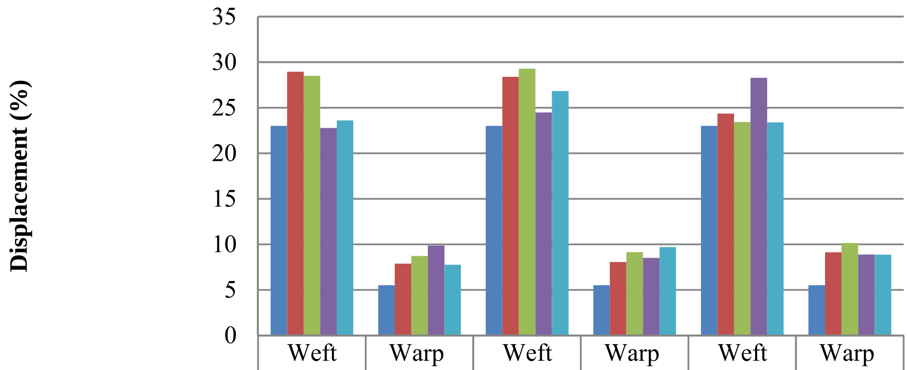


	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	23	6	23	6	23	6
Water	26	7	29	8	23	9
Detergent	31	8	29	8	29	10
Anolyte	30	7	29	10	23	9
Sodium hypochlorite	30	7	29	9	25	10

Figure 5.15: Displacement of the cotton fabric at maximum load after laundering for five, ten and twenty cycles at 30°C.

Figure 5.15 shows that the water, detergent, Anolyte and sodium hypochlorite solution caused an increase in displacement at maximum load after twenty laundering cycles at 30°C. Laundering of the cotton fabric with the water, detergent, Anolyte and sodium hypochlorite solution at 30°C had a significant influence ($p < 0.05$) on the displacement at maximum load in both directions (Table 5.10). After laundering for twenty cycles with the water and the Anolyte, respectively, no influences were found on the displacement at maximum load in the weft direction (23%). The detergent had the largest influence in the weft direction as it caused a 6% increase in displacement at maximum load after twenty cycles (29%). According to Sekiguchi *et al.* (2000) the treatment of cotton with an alkaline agent, such as detergent, can raise the reactivity of hydroxyl groups of cellulose that results in improved elongation. The sodium hypochlorite solution caused a 2% increase in displacement at maximum load after twenty cycles (25%). In the warp direction the Anolyte and the water had the same influence as it caused a 3% increase (9%), while the detergent and the sodium hypochlorite solution had the same influence as it caused a 4% increase in maximum load after twenty cycles (10%).

As all the treatments caused increases in displacement at maximum load in the warp direction of the cotton fabric, it could be contributed to changes in the fabric structure which became more loosely arranged during laundering (Anandjiwala *et al.*, 2007), which could in turn lead to higher elongation.



	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	23	6	23	6	23	6
Water	29	8	28	8	24	9
Detergent	29	9	29	9	23	10
Anolyte	23	10	24	9	28	9
Sodium hypochlorite	24	8	27	10	23	9

Figure 5.16: Displacement of the cotton fabric at maximum load after laundering for five, ten and twenty cycles at 60°C.

Statistical analysis (Table 5.10) indicated that there is a significant difference ($p < 0.05$) between the displacements of the untreated fabric and the fabric laundered at 60°C in both directions. Figure 5.16 indicates that in the weft direction the detergent and the sodium hypochlorite solution had no influence on the displacement at maximum load after twenty laundering cycles (23%), while the water caused a mere 1% increase (24%) and the Anolyte caused a 5% increase (28%). In the warp direction the results were closely related to the results obtained after laundering at 30°C. The water, Anolyte and sodium hypochlorite solution caused an increase of 3% after twenty cycles (23%), while the detergent caused an increase of 4% in displacement at maximum load after twenty laundering cycles. Once again the increases in displacement at maximum load in the warp direction of the cotton fabric, could possibly be explained by changes in the fabric structure which became more loosely arranged during laundering (Anandjiwala *et al.*, 2007), which could in turn lead to higher elongation.

The statistical analysis (Table 5.12) indicated that the interaction of the treatment, temperature and cycles had significant influences ($p < 0.05$) on the displacement at maximum load in both directions of the cotton fabric. Some fluctuations occurred but generally, the water, detergent, Anolyte and sodium hypochlorite caused an increase in displacement at maximum load after twenty laundering cycles. The displacement at maximum load after laundering at 24°C, 30°C and 60°C were very closely related in both directions. However, it seems that there was a decrease in displacement as the temperature increased caused by all the treatments except the Anolyte, which caused the displacement of the cotton fabric to remain stable from 24°C to 60°C after twenty cycles.

Table 5.12: P-values of the effect of treatment, temperature and cycles on the displacement at maximum load of the cotton fabric.

Source	p-value weft	p-value warp
Treatment*Temperature	< .0001*	< .0001*
Treatment*Cycles	< .0001*	< .0001*
Temperature*Cycles	< .0001*	< .0001*
Treatment*Temperature*Cycles	< .0001*	< .0001*

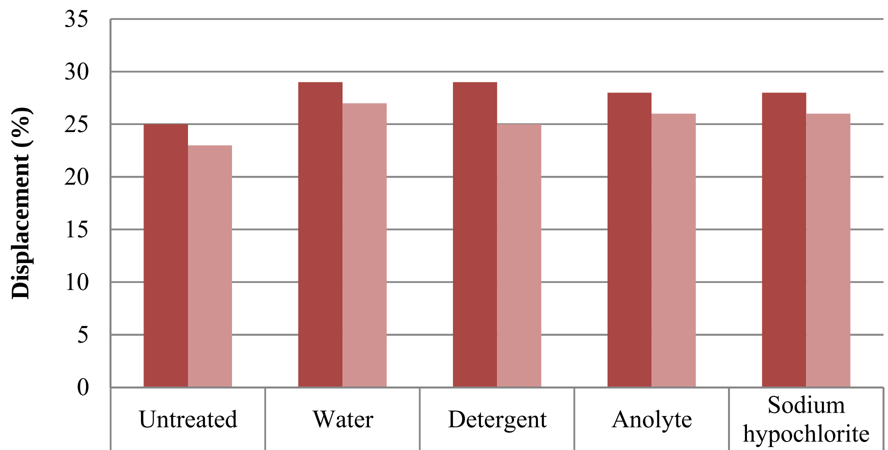
5.2.2.2 Polyester

The results concerning the displacement at maximum load of the polyester fabric after laundering with water, detergent, Anolyte and sodium hypochlorite solution are illustrated in Figure 5.17, as well as the statistical analysis of the significance of treatment, temperature and cycles as illustrated in Table 5.13.

Table 5.13: Displacement of polyester fabric at maximum load: Effect of treatment, laundering temperature and number of laundering cycles.

DIRECTION			Mean (%)	Difference	95% Confidence limits		Significant
WARP	NO TREATMENT		22.9425				
WARP	TREATMENT			(Relative to untreated)			
		Anolyte	21.7598	1.1827	-0.6530	3.0184	
		Sodium hypochlorite	21.7056	1.2369	-0.5946	3.0683	
		Detergent	21.1747	1.7678	-0.0702	3.6058	
		Water	22.5865	0.3560	-1.4786	2.1906	
				(Relative to untreated)			
	TEMPERATURE	24°C	21.9617	0.9808	-0.8293	2.7910	
		30°C	22.5186	0.4239	-1.3901	2.2379	
		60°C	21.0039	1.9386	0.1296	3.7475	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	21.9233	1.0192	-0.7904	2.8288	
		10	22.1492	0.7933	-1.0163	2.6028	
		20	21.3333	1.6092	-0.2048	3.4233	
WEFT	NO TREATMENT		24.7558				
WEFT	TREATMENT			(Relative to untreated)			
		Anolyte	23.6608	1.0950	-0.0438	2.2338	
		Sodium hypochlorite	23.3613	1.3946	0.2558	2.5333	***
		Detergent	23.9217	0.8342	-0.3046	1.9729	
		Water	23.8450	0.9108	-0.2279	2.0496	
				(Relative to untreated)			
	TEMPERATURE	24°C	23.8544	0.9015	-0.2230	2.0259	
		30°C	23.3773	1.0222	-0.1023	2.1466	
		60°C	23.5035	1.2523	0.1278	2.3767	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	23.4960	1.2598	0.1353	2.3842	***
		10	23.8267	0.9292	-0.1953	2.0536	
		20	23.7689	0.9869	-0.1375	2.1114	

***, $p < 0.05$



	Untreated	Water	Detergent	Anolyte	Sodium hypochlorite
Weft	25	29	29	28	28
Warp	23	27	25	26	26

Figure 5.17: The influence of laundering with water, detergent, Anolyte and sodium hypochlorite on the displacement at maximum load of the polyester fabric.

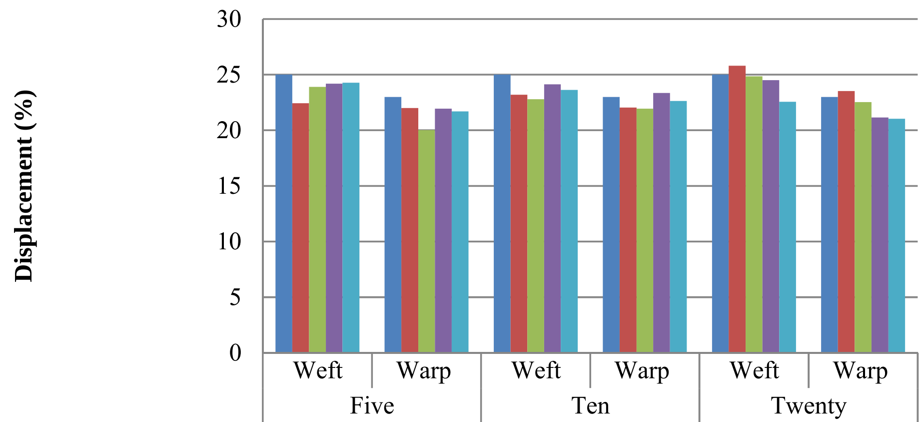
The untreated fabric had the lowest displacement in both directions and according to Collier & Tortora (2001), polyester fibres will stretch a moderate amount before breaking as a result of the amount they are drawn during processing. Gupta (2002) reported the displacement at break of polyester to be 15%, which is lower than what was recorded for this study, but the higher elongation could be contributed to the woven structure of the fabric. All the treatments caused an increase in displacement at maximum load in both directions of the polyester fabric. According to Yoon *et al.* (1984), laundering can influence fabric structure, which would in turn influence elongation of the fabric. In the weft direction the water, detergent, Anolyte and sodium hypochlorite solution had a similar effect, where it caused a 3-5% increase in displacement at maximum load. However, in the warp direction the water had the largest influence, while the detergent had the smallest influence. The Anolyte and the sodium hypochlorite solution had the same effect, which was a smaller influence than that of the detergent and water. The increase in displacement after laundering with the water, detergent, Anolyte and sodium hypochlorite solution could possibly be due to changes in fabric structure. According to Siroky *et al.* (2009) rearrangements in fibre conformations occur while swelling and deswelling during treatments like laundering, will influence the stress distribution within the fabrics. Statistical analysis (Table 5.13) indicated that none of the water, detergent, Anolyte and sodium hypochlorite solution had a significant influence ($p < 0.05$) on the displacement at maximum load in the warp direction of the polyester fabric.

However, in the weft direction the sodium hypochlorite solution had a significant influence ($p < 0.05$) in comparison to the untreated fabric on the displacement at maximum load of the polyester fabric. Munshi *et al.* (1993) indicated that they found no definite trend in the elongation of polyester after repeated laundering, but in this study, it was recorded that five laundering cycles had a significant influence on the displacement at maximum load in the weft direction of the polyester fabric. There was a significant difference between the influence of the water and the Anolyte in the warp direction (Table 5.14).

Table 5.14: Significance of laundering with water, detergent and sodium hypochlorite compared with Anolyte on the displacement at maximum load of the polyester fabric in the weft direction.

Direction	Treatment	Mean (%)	Difference	95% Confidence limits		Significant
Weft			(Relative to Anolyte)			
	Anolyte	23.6608				
	Sodium hypochlorite	23.3613	0.2996	-0.2155	0.8146	
	Detergent	23.9217	-0.2608	-0.7701	0.2484	
	Water	23.8450	-0.1842	-0.6934	0.3251	
Warp			(Relative to Anolyte)			
	Anolyte	21.7598				
	Sodium hypochlorite	21.7056	0.0541	-0.7744	0.8826	
	Detergent	21.1747	0.5851	-0.2578	1.4279	
	Water	22.5865	-0.8267	-1.6622	0.0087	***

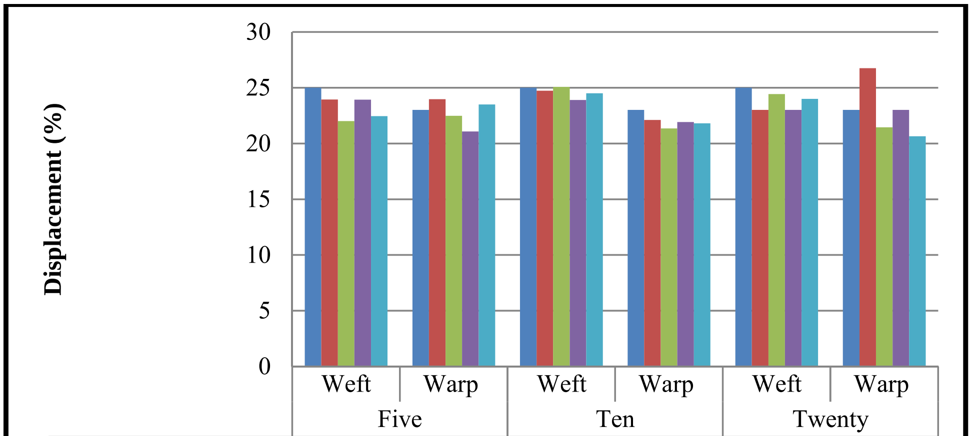
***, $p < 0.05$



	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	25	23	25	23	25	23
Water	22	22	23	22	26	24
Detergent	24	20	23	22	25	23
Anolyte	24	22	24	23	25	21
Sodium hypochlorite	24	22	24	23	23	21

Figure 5.18: Displacement of the polyester fabric at maximum load after laundering for five, ten and twenty cycles at 24°C.

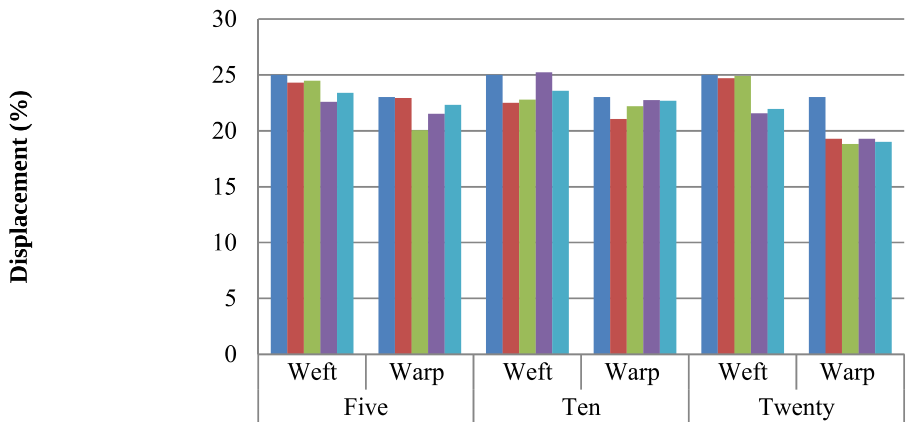
The displacement of the polyester fabric at maximum load after laundering at 24°C for five, ten and twenty cycles is given in Figure 5.18. The effect of the water, detergent, Anolyte and sodium hypochlorite solution on the displacement at maximum load of the polyester fabric in both directions was very small. After five cycles, all the treatments caused a decrease in displacement at maximum load; however after twenty laundering cycles the displacement was almost the same as the untreated fabric, except the fabric treated with the sodium hypochlorite solution, which was 2% lower in both directions than the untreated fabric. Statistical analysis (Table 5.13) indicated that there was not a significant difference between the displacements at maximum load of the untreated fabric and those after laundering at 24°C.



	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	25	23	25	23	25	23
Water	24	24	25	22	23	27
Detergent	22	22	25	21	24	21
Anolyte	24	21	24	22	23	23
Sodium hypochlorite	22	24	25	22	24	21

Figure 5.19: Displacement of the polyester fabric at maximum load after laundering for five, ten and twenty cycles at 30°C.

The effect of laundering at 30°C and 60°C on the displacement at maximum load is depicted in figures 5.19 and 5.20, repectively. Once again, the water, detergent, Anolyte and sodium hypochlorite solution did not have a large influence on the displacement at maximum load. In the weft direction there was a decrease of 1 - 2% after twenty cycles. In the warp direction the water and the sodium hypochlorite solution initially caused a very small increase while the Anolyte and detergent caused a decrease in maximum load. However, after twenty cycles the water still caused an increase, while the other treatments caused a small decrease. The statistical analysis (Table 5.13) indicated that the 30°C did not have a significant influence on the displacement at maximum load.



	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	25	23	25	23	25	23
Water	24	23	23	21	25	19
Detergent	24	20	23	22	25	19
Anolyte	23	22	25	23	22	19
Sodium hypochlorite	23	22	24	23	22	19

Figure 5.20: Displacement of the polyester fabric at maximum load after laundering for five, ten and twenty cycles at 60°C.

According to the statistical analysis (Table 5.13), laundering at 60°C had a significant influence ($p < 0.05$) on the displacement of the polyester fabric. After twenty cycles, the water and detergent caused the displacement to return to the same amount as the untreated fabric in the weft direction, while the Anolyte and sodium hypochlorite solution caused a small decrease of 3%. However, in the warp direction the water, detergent, Anolyte and sodium hypochlorite solution caused a 4% decrease in displacement at maximum load from untreated to after twenty laundering cycles. According to Haji *et al.* (2011), alkaline agents can cause a decrease in fabric elongation, which could explain the decrease caused by the detergent and sodium hypochlorite solution.

Table 5.15: P-values of the effect of treatment, temperature and cycles on the displacement at maximum load of the polyester fabric.

Source	p-value weft	p-value warp
Treatment*Temperature	0.3479	0.2204
Treatment*Cycles	0.0001*	0.0049*
Temperature*Cycles	0.0007*	< .0001*
Treatment*Temperature*Cycles	< .0001*	0.3826

As shown in Table 5.15, the interaction of the treatment and the cycles, as well as the temperature and the cycles had a significant influence ($p < 0.05$) on the displacement at maximum load of the polyester fabric. The interaction of the treatment, temperature and cycles only had a significant influence ($p < 0.05$) on the displacement in the warp direction, while the interaction between treatment and cycles, as well as temperature and cycles were significant in the warp direction. It is also important to consider that the maximum load that the fabric could carry holds a relation to the displacement at maximum load. Therefore, the higher the maximum load the higher the displacement will be (Kadolph, 1998:161).

5.2.2.3 Polyester/Cotton

The results concerning the displacement at maximum load of the polyester/cotton fabric after laundering with water, detergent, Anolyte and sodium hypochlorite solution are illustrated in Figure 5.21, as well as the statistical analysis of the significance of treatment, temperature and cycles as illustrated in Table 5.16.

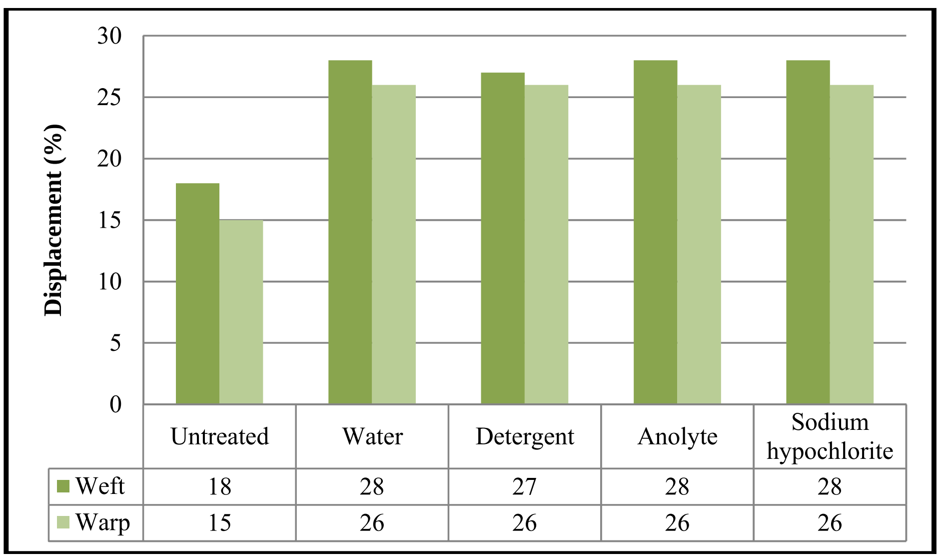


Figure 5.21: The influence of laundering with water, detergent, Anolyte and sodium hypochlorite on the displacement at maximum load of the polyester/cotton fabric.

It is clearly illustrated in Figure 5.21 that the water, detergent, Anolyte and sodium hypochlorite solution had very similar effects in both directions and caused an increase in displacement at maximum load. Verdu *et al.* (2009) as well as Mukhopadhyay *et al.* (2004) also found that the elongation of polyester/cotton fabrics increased after laundering.

Table 5.16: Displacement of polyester/cotton fabric at maximum load: Effect of treatment, laundering temperature and number of laundering cycles.

DIRECTION			Mean (%)	Difference	95% Confidence limits		Significant
WARP	NO TREATMENT		15.09400				
WARP	TREATMENT			(Relative to untreated)			
		Anolyte	17.42519	-2.33119	-2.65684	-2.00553	***
		Sodium hypochlorite	17.25030	-2.15630	-2.48195	-1.83064	***
		Detergent	17.09978	-2.00578	-2.33143	-1.68013	***
		Water	17.28244	-2.18844	-2.51410	-1.86279	***
				(Relative to untreated)			
	TEMPERATURE	24°C	16.94394	-1.84994	-2.17150	-1.52839	***
		30°C	16.90661	-1.81261	-2.13417	-1.49105	***
		60°C	17.94272	-2.84872	-3.17028	-2.52717	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	17.09678	-2.00278	-2.32433	-1.68122	***
		10	17.32911	-2.23511	-2.55667	-1.91355	***
		20	17.36739	-2.27339	-2.59495	-1.95183	***
WEFT	NO TREATMENT		17.54333				
WEFT	TREATMENT			(Relative to untreated)			
		Anolyte	18.46044	-0.9171	-1.3860	-0.4483	***
		Sodium hypochlorite	18.30533	-0.7620	-1.2309	-0.2931	***
		Detergent	18.22541	-0.6821	-1.1509	-0.2132	***
		Water	18.52978	-0.9864	-1.4553	-0.5176	***
				(Relative to untreated)			
	TEMPERATURE	24°C	18.09061	-0.54728	-1.01024	-0.08432	***
		30°C	18.29533	-0.75200	-1.21496	-0.28904	***
		60°C	18.75478	-1.21144	-1.67441	-0.74848	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	18.46522	-0.92189	-1.38485	-0.45893	***
		10	18.27867	-0.73533	-1.19829	-0.27237	***
		20	18.39683	-0.85350	-1.31646	-0.39054	***

***, $p < 0.05$

The statistical analysis (Table 5.16) indicated that all the treatments had a significant influence ($p < 0.05$) on the displacement at maximum load in both directions of the polyester/cotton fabric. In the weft direction, the detergent had the smallest influence and caused a 9% increase in displacement, while the water, sodium hypochlorite solution and Anolyte caused a 10% increase. In the warp direction the water, detergent, Anolyte and sodium hypochlorite had the exact same influence by causing an 11% increase in displacement at maximum load.

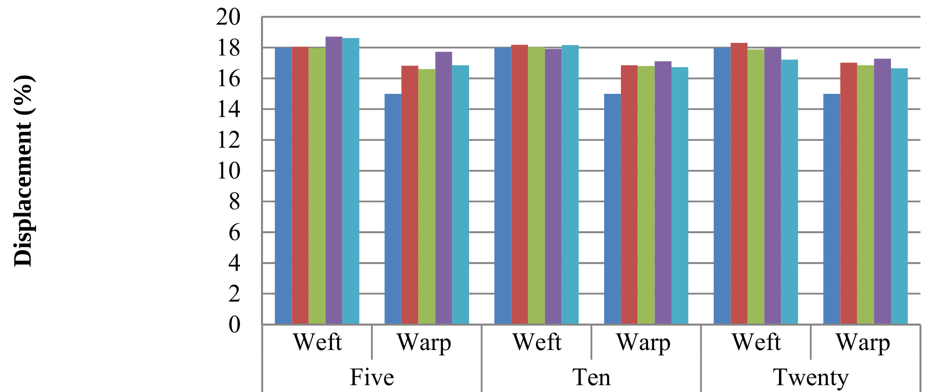
It could also be noticed that the difference in displacement between the warp and the weft directions is not as large as with the 100% cotton fabric, which could be contributed to the polyester content of the fabric. As this is a blend of cotton and polyester the increase in displacement could be due to the reaction of the water, detergent, Anolyte and sodium hypochlorite solution with the cellulose of the cotton (Sekiguchi *et al.,* 2000) as well as the fabric structure (Siroky *et al.,* 2009). Once again, Munshi *et al.* (1993) indicated that they found no definite trend in the elongation of polyester/cotton after repeated laundering.

Table 5.17: Significance of laundering with water, detergent and sodium hypochlorite compared with Anolyte on the displacement at maximum load of the polyester/cotton fabric in the weft direction.

Direction	Treatment	Mean (%)	Difference	95% Confidence limits		Significant
Weft			(Relative to Anolyte)			
	Anolyte	18.46044				
	Sodium hypochlorite	18.30533	0.1551	-0.0546	0.3648	
	Detergent	18.22541	0.2350	0.0254	0.4447	***
	Water	18.52978	-0.0693	-0.2790	0.1403	
Warp			(Relative to Anolyte)			
	Anolyte	17.42519				
	Sodium hypochlorite	17.25030	0.17489	0.02925	0.32053	***
	Detergent	17.09978	0.32541	0.17977	0.47104	***
	Water	17.28244	0.14274	-0.00290	0.28838	

***, $p < 0.05$

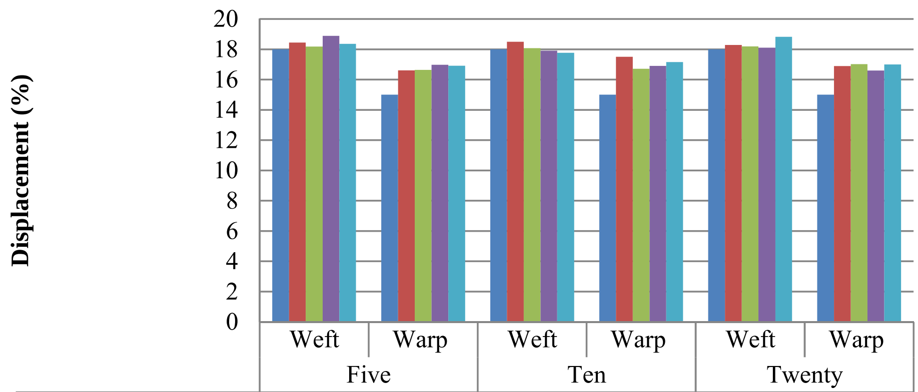
According to the statistical analysis (Table 5.17) there was a significant difference ($p < 0.05$) between the influences of the detergent in comparison to the Anolyte in both directions, while in the warp direction there was also a significant difference ($p < 0.05$) between the sodium hypochlorite solution and the Anolyte.



	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	18	15	18	15	18	15
Water	18	17	18	17	18	17
Detergent	18	17	18	17	18	17
Anolyte	19	18	18	17	18	17
Sodium hypochlorite	19	17	18	17	17	17

Figure 5.22: Displacement of the polyester/cotton fabric at maximum load after laundering for five, ten and twenty cycles at 24°C.

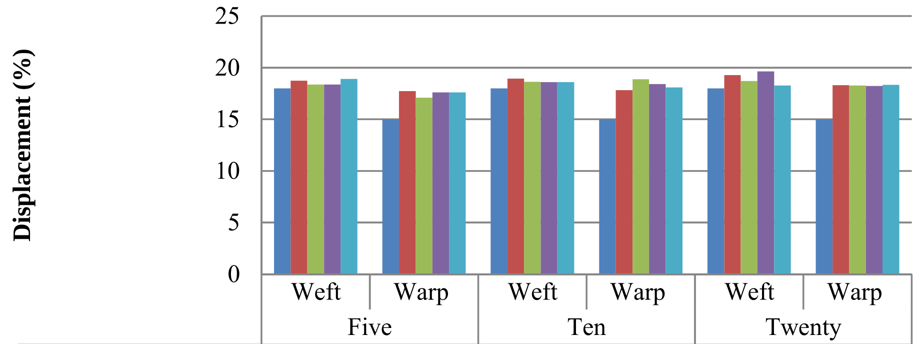
Although the statistical analysis (Table 5.16) indicated that laundering at 24°C and the number of laundering cycles had a significant influence ($p < 0.05$) on the displacement at maximum load, the differences were very small in the warp direction, while there were almost no differences in the weft direction. After twenty cycles the displacements in the weft direction (Figure 5.22) of the fabric laundered with water, detergent and Anolyte were the same (18%) as the untreated fabric, while the sodium hypochlorite solution (17%) caused a 1% decrease in displacement. However, in the warp direction all the treatments (17%) caused a 2% increase in displacement at maximum load. These small influences could be a result of the polyester content of the fabric as the results indicated that laundering did not influence the displacement at maximum load of the polyester after twenty laundering cycles significantly.



	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	18	15	18	15	18	15
Water	18	17	18	18	18	17
Detergent	18	17	18	17	18	17
Anolyte	19	17	18	17	18	17
Sodium hypochlorite	18	17	18	17	19	17

Figure 5.23: Displacement of the polyester/cotton fabric at maximum load after laundering for five, ten and twenty cycles at 30°C.

The results obtained after laundering at 24°C (Figure 5.22) and 30°C (Figure 5.23) did not differ much, where it is again, only the sodium hypochlorite solution, which had a different effect than the other treatments, and only in the weft direction. The displacements did not change much from untreated to twenty cycles. The Anolyte, detergent and water had no influence after twenty cycles (18%), while the sodium hypochlorite solution (19%) caused a 1% increase. In the warp direction, all the treatments (17%) caused a 2% increase in displacement after five cycles. This remained stable up to twenty cycles, except for the fabric treated with water (18%) which showed an increase of 1% after ten cycles, but decreased again with 1% after twenty cycles. According to Yoon *et al.* (1984) laundering can influence the fabric structure, which would in turn influence elongation of the fabric, but in this case not much change occurred. Although there was not much influence by the water, detergent, Anolyte and sodium hypochlorite solution, the statistical analysis (Table 5.16) indicated that laundering at 30°C and the number of laundering cycles had a significant influence ($p < 0.05$) on the displacement at maximum load of the polyester/cotton fabric in both directions.



	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	18	15	18	15	18	15
Water	19	18	19	18	19	18
Detergent	18	17	19	19	19	18
Anolyte	18	18	19	18	20	18
Sodium hypochlorite	19	18	19	18	18	18

Figure 5.24: Displacement of the polyester/cotton fabric at maximum load after laundering for five, ten and twenty cycles at 60°C.

After laundering at 60°C (Figure 5.24) for five cycles the detergent and the Anolyte had no influence on the displacement at maximum load in the weft direction. However, the water and the sodium hypochlorite solution (19%) caused a 1% increase. All the treatments caused a 3% increase in displacement at maximum load in the warp direction of the polyester/cotton fabric after twenty cycles. According to Yoon *et al.* (1984) laundering can influence the fabric structure, which would in turn influence elongation of the fabric. According to the statistical analysis (Table 5.16), laundering at 60°C had a significant influence ($p < 0.05$) on the displacement at maximum load of the polyester/cotton fabrics.

Table 5.18: P-values of the effect of treatment, temperature and cycles on the displacement at maximum load of the polyester/cotton fabric in the warp direction.

Source	p-value weft	p-value warp
Treatment*Temperature	0.8903	0.0006*
Treatment*Cycles	0.0162*	0.0184*
Temperature*Cycles	0.0017*	< .0001*
Treatment*Temperature*Cycles	0.0003*	0.0269*

According to the statistical analysis (Table 5.18), the interaction of the treatment, the temperature and the number of laundering cycles had a significant influence ($p < 0.05$) on the displacement at maximum load in both directions of the polyester/cotton fabric. It was only the interaction of the treatment and temperature, which did not have a significant influence in the weft direction of the polyester/cotton fabric.

5.3 Tearing strength

"Tearing strength is the force required to propagate an existing tear" (Saville, 2004).

5.3.1 Cotton

The results concerning the tearing strength of the cotton fabric after laundering with water, detergent, Anolyte and sodium hypochlorite solution are illustrated in Figure 5.25, as well as the statistical analysis of the significance of treatment, temperature and cycles as illustrated in Table 5.19.

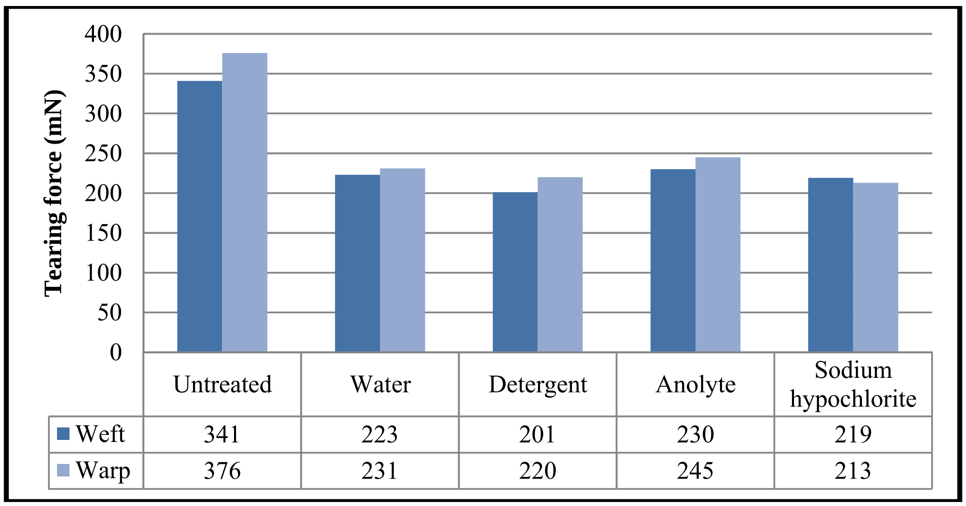


Figure 5.25: The influence of laundering with water, detergent, Anolyte and sodium hypochlorite on the tearing strength of the cotton fabric.

It is clear from Figure 5.25 that the tearing strength decreased after laundering with the water, detergent, Anolyte and sodium hypochlorite solution. In the weft direction it was the detergent that had the largest influence, while the Anolyte had the smallest. The reduction in tearing strength could be attributed to the woven structure. Ozcan & Candan (2005) found that laundering of cotton fabrics can negatively affect physical and mechanical properties, due to the changes in fabric structure. The statistical analysis (Table 5.19) indicated that all the treatments had a significant influence ($p < 0.05$) on the tearing strength in both directions of the cotton fabric. In the warp direction the sodium hypochlorite solution had the largest influence while the Anolyte, again had the smallest influence. According to Lam *et al.* (2011)

treatment with sodium hypochlorite can cause a reduction of tearing force due to the tendering of the fibres.

Table 5.19: Tearing strength of cotton fabric: Effect of treatment, laundering temperature and number of laundering cycles.

DIRECTION			Mean (mN)	Difference	95% Confidence limits		Significant
WARP	NO TREATMENT		375.500				
WARP	TREATMENT			(Relative to untreated)			
		Anolyte	244.667	130.833	101.413	160.254	***
		Sodium hypochlorite	213.167	162.333	132.913	191.754	***
		Detergent	219.778	155.722	126.302	185.143	***
		Water	231.056	144.444	115.024	173.865	***
				(Relative to untreated)			
	TEMPERATURE	24°C	284.542	90.958	61.908	120.009	***
		30°C	223.458	152.042	122.991	181.092	***
		60°C	173.500	202.000	172.950	231.050	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	228.083	147.417	118.366	176.467	***
		10	259.958	115.542	86.491	144.592	***
		20	193.458	182.042	152.991	211.092	***
WEFT	NO TREATMENT		340.500				
WEFT	TREATMENT			(Relative to untreated)			
		Anolyte	229.556	110.944	75.829	146.059	***
		Sodium hypochlorite	218.667	121.833	86.718	156.948	***
		Detergent	201.278	139.222	104.107	174.337	***
		Water	222.833	117.667	82.552	152.782	***
				(Relative to untreated)			
	TEMPERATURE	24°C	217.167	123.333	88.660	158.007	***
		30°C	256.625	83.875	49.202	118.548	***
		60°C	180.458	160.042	125.368	194.715	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	200.167	140.333	105.660	175.007	***
		10	266.417	74.083	39.410	108.757	***
		20	187.667	152.833	118.160	187.507	***

***, $p < 0.05$

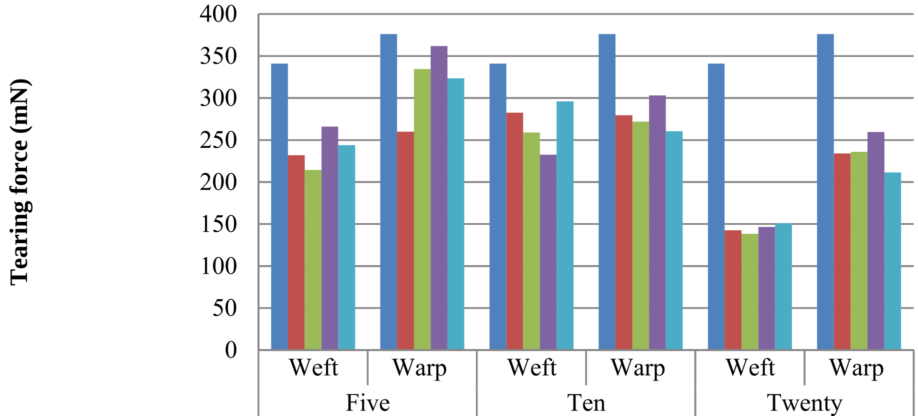
The statistical analysis (Table 5.20) indicated that there was a significant difference ($p < 0.05$) between the effect of the Anolyte and the detergent in the weft direction. In the warp direction however, there was a significant difference ($p < 0.05$) between the influence of the Anolyte and all of the other treatments. The results as depicted in Figure 5.25 indicated that laundering of cotton fabric with detergent caused more damage than laundering with the sodium hypochlorite solution. According to the statistical analysis (Table 5.19) the detergent and sodium hypochlorite had a significant influence on the tearing strength of the cotton fabric in both directions.

Table 5.20: Significance of laundering with water, detergent and sodium hypochlorite compared with Anolyte on the tearing strength of the cotton fabric.

Direction	Treatment	Mean (mN)	Difference	95% Confidence limits		Significant
Weft			(Relative to Anolyte)			
	Anolyte	229.556				
	Sodium hypochlorite	218.667	10.889	-4.815	26.593	
	Detergent	201.278	28.278	12.574	43.982	***
	Water	222.833	6.722	-8.982	22.426	
Warp			(Relative to Anolyte)			
	Anolyte	244.667				
	Sodium hypochlorite	213.167	31.500	18.343	44.657	***
	Detergent	219.778	24.889	11.732	38.046	***
	Water	231.056	13.611	0.454	26.768	***

***, $p < 0.05$

The results after laundering cotton at 24°C are given in Figure 5.26. After laundering for five cycles at 24°C the water, detergent, Anolyte and sodium hypochlorite solution caused a reduction in tearing strength in both directions of the cotton fabric. Ozcan & Candan (2005) found that laundering of cotton fabrics can negatively affect physical and mechanical properties, due to the changes in fabric structure.

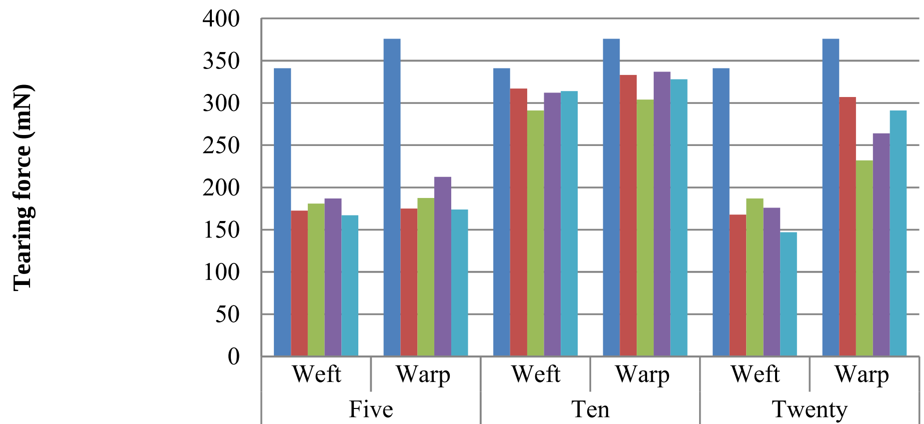


	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	341	376	341	376	341	376
Water	232	260	283	280	143	234
Detergent	215	335	259	272	139	236
Anolyte	266	362	233	303	147	260
Sodium hypochlorite	244	324	296	261	151	212

Figure 5.26: Tearing strength of the cotton fabric after laundering for five, ten and twenty cycles at 24°C.

As shown in figure 5.26, the detergent had the largest influence in the weft direction by causing a 202 mN decrease from untreated to twenty cycles (139 mN), while the Anolyte caused a 193 mN decrease (147 mN). The decrease caused by the Anolyte could possibly be explained by the acidic pH (2.2 - 2.4). According to Kang *et al.* (1998) acids cause degradation of the cellulose in the cotton, which in turn leads to a loss in fabric strength. Khedher *et al.* (2009) explained that the decrease could be due to the "acidic catalysis of the condensation polymerization as well as the degree of reticulation and the immobilization of the amorphous and flexible zones in the fibre, by the transverse links of the cellulose cotton that prevents the alignment of molecular chains and crystallites". The water caused a decrease of 198 mN in tearing strength after twenty cycles (143 mN), while the sodium hypochlorite solution caused a 190 mN decrease (151 mN). Morton & Thomas (1983) and Khedher *et al.* (2009) reported that chlorine bleach causes chemical damage to cotton fibres, which results in strength-loss of fabrics.

In the warp direction, the sodium hypochlorite solution caused the largest decrease of 164 mN in tearing strength from untreated to twenty cycles (212 mN), which is in accordance with the findings of Perkins *et al.* (1996) who reported that cotton fabric decreased significantly in strength after laundering with sodium hypochlorite solution. The water and detergent had closely related influences where the water caused a 142 mN decrease in tearing strength after twenty cycles (234 mN) and the detergent caused a 140 mN decrease (236 mN). The Anolyte had the smallest influence as it caused a 116 mN decrease in tearing strength after twenty cycles (260 mN). The statistical analysis (Table 5.19) indicated that laundering with the water, detergent, Anolyte and sodium hypochlorite solution at 24°C had a significant influence ($p < 0.05$) on the tearing strength of the cotton fabric in both directions.

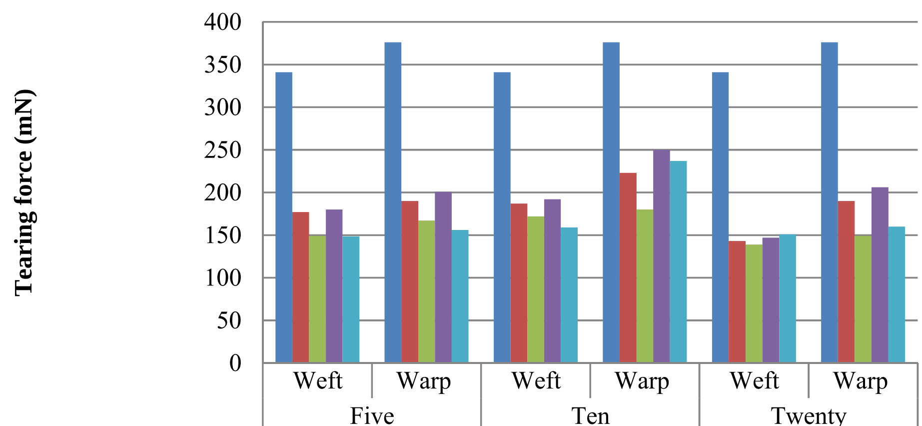


	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	341	376	341	376	341	376
Water	173	175	317	333	168	307
Detergent	181	188	291	304	187	232
Anolyte	187	213	312	337	176	264
Sodium hypochlorite	167	174	314	328	147	291

Figure 5.27: Tearing strength of the cotton fabric after laundering for five, ten and twenty cycles at 30°C.

The laundering of the cotton fabric at 30°C (Figure 5.27) with the water, detergent, Anolyte and sodium hypochlorite solution caused a decrease in tearing strength in both directions. In the weft direction the sodium hypochlorite solution had the largest influence by causing a decrease of 194 mN from untreated to twenty cycles (147 mN) and the detergent had the smallest influence by causing a decrease of 154 mN after twenty cycles (187 mN). According to Morton & Thomas (1983) laundering with detergent can cause higher levels of crosslinking in cotton fabrics that can lead to fabric strength loss as a result of higher fabric rigidity and greater levels of mechanical attrition. Lam *et al.* (2011) found that treatment with an agent such as sodium hypochlorite can cause a reduction of tearing force due to the tendering of the fibres. The water caused a 173 mN decrease after twenty cycles (168 mN). The Anolyte caused a 165 mN decrease after twenty cycles (176 mN). Once again the decrease caused by the Anolyte could possibly be due to the acidic pH (2.2-2.4). According to Kang *et al.* (1998) acids cause degradation of the cellulose in the cotton that in turn leads to a loss in fabric strength. The detergent caused a 160 mN decrease in tearing strength after five cycles (181 mN), a 110 mN increase after ten cycles (291 mN) and another 104 mN decrease after twenty cycles.

In the warp direction, the detergent had the largest influence by causing a 144 mN decrease from untreated to twenty cycles (232 mN), while the water had the smallest influence by causing a 69 mN decrease after twenty cycles (307 mN). The Anolyte caused a 112 mN decrease after twenty cycles (264 mN) and the sodium hypochlorite solution caused an 85 mN decrease after twenty cycles (291 mN). Gouda & Ibrahim (2008) also found that laundering with sodium hypochlorite solution caused a decrease in cotton fabric strength because of damaged cellulose, which lowers fabric strength. The statistical analysis (Table 5.19) indicated that laundering with the water, detergent, Anolyte and sodium hypochlorite solution at 30°C had a significant influence ($p < 0.05$) on the tearing strength of the cotton fabric in both directions.



	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	341	376	341	376	341	376
Water	177	190	187	223	143	190
Detergent	149	167	172	180	139	149
Anolyte	180	201	192	250	147	206
Sodium hypochlorite	149	156	159	237	151	160

Figure 5.28: Tearing strength of the cotton fabric after laundering for five, ten and twenty cycles at 60°C.

Laundering with the water, detergent, Anolyte and sodium hypochlorite solution at 60°C caused a reduction in tearing strength of the cotton fabric in both directions (Figure 5.28). This could be explained by the findings reported by Carr (1995) that when water-swollen cellulose fibres are subjected to repeated mechanical action at high temperatures, it can cause fibre fibrillation damage, which can significantly change the mechanical properties of the fabric. The detergent had the largest effect in both directions, while in the warp direction the Anolyte had the smallest influence and in the weft direction the sodium hypochlorite solution had the smallest influence. In the weft direction, the water caused a 198 mN decrease in tearing strength after twenty cycles (143 mN). The detergent caused a 202 mN decrease after twenty cycles (139 mN). This could be explained by the findings of Morton & Thomas (1983), who claims that laundering with detergent can cause higher levels of crosslinking in cotton fabrics, which creates greater levels of mechanical attrition because of fabric rigidity, which in turn accounts for the strength loss. The Anolyte caused a 194 mN decrease in tearing strength after twenty cycles (147 mN). The sodium hypochlorite solution caused a 190 mN decrease after twenty cycles (151 mN).

In the warp direction the water caused a decrease of 186 mN after twenty cycles (143 mN), while the detergent caused the largest decrease of 227 mN after twenty cycles (149 mN). The Anolyte caused the smallest decrease of 170 mN after twenty cycles (147 mN). Once again the decrease caused by the Anolyte could possibly be due to the acidic pH (2.2 - 2.4). According to Kang *et al.* (1998) acids cause degradation of the cellulose in the cotton, which in turn leads to a loss in fabric strength. The sodium hypochlorite solution caused a 216 mN decrease after twenty cycles (160 mN). Sun *et al.* (2001) found that laundering with detergent and a bleach solution reduced the strength of cotton fabric as a result of damaged cellulose. The statistical analysis (Table 5.19) indicated that laundering with the water, detergent, Anolyte and sodium hypochlorite at 60°C had a significant influence ($p < 0.05$) on the tearing strength of the cotton fabric in both directions. Sun *et al.* (2001) also indicated that higher laundering temperature would contribute to greater damage of cotton fabric and therefore lead to reduced strength.

Table 5.21: P-values of the effect of treatment, temperature and cycles on the tearing strength of the cotton fabric.

Source	p-value weft	p-value warp
Treatment*Temperature	0.9471	0.5675
Treatment*Cycles	0.1225	0.9092
Temperature*Cycles	< .0001*	< .0001*
Treatment*Temperature*Cycles	0.0053*	0.5685

The analysis of the interaction of treatment, temperature and cycles (Table 5.21) indicated that the interaction of temperature and cycles had a significant influence ($p < 0.05$) on the tearing strength of the cotton fabric in both directions. According to Agarwal *et al.* (2011) most of the changes in mechanical properties resulting from laundry are related to physicochemical changes occurring at the fibre level in cotton. The interaction of treatment, temperature and cycles however, only had a significant influence ($p < 0.05$) on the weft direction of the cotton fabric.

5.3.2 Polyester

The results concerning the tearing strength of the polyester fabric after laundering with water, detergent, Anolyte and sodium hypochlorite solution are illustrated in Figure 5.29, and the statistical analysis of the significance of treatment, temperature and cycles as illustrated in Table 5.22.

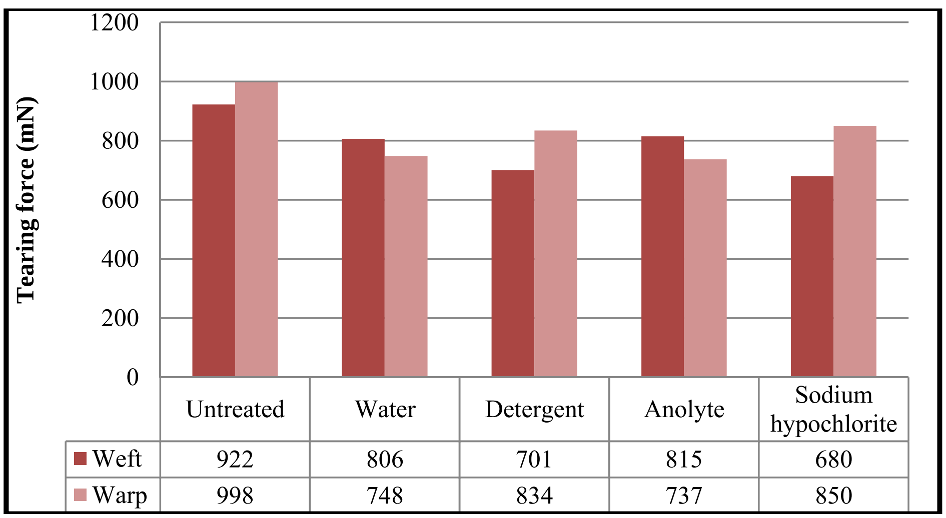


Figure 5.29: The influence of laundering with water, detergent, Anolyte and sodium hypochlorite on the tearing strength of the polyester fabric.

As illustrated in Figure 5.29, all the treatments caused a decrease in tearing strength after laundering; this is in accordance with the findings of Munshi *et al.* (1993) who indicated a decrease in tearing strength of polyester fabrics after laundering. According to the statistical analysis (Table 5.22) all of the treatments had a significant influence ($p < 0.05$) on the tearing strength of the polyester fabric in both directions.

Table 5.22: Tearing strength of polyester fabric: Effect of treatment, laundering temperature and number of laundering cycles.

DIRECTION			Mean (mN)	Difference	95% Confidence limits		Significant
WARP	NO TREATMENT		997.500				
WARP	TREATMENT			(Relative to untreated)			
		Anolyte	737.444	260.056	222.923	297.188	***
		Sodium hypochlorite	850.278	147.222	110.090	184.355	***
		Detergent	834.278	163.222	126.090	200.355	***
		Water	748.333	249.167	212.034	286.299	***
				(Relative to untreated)			
	TEMPERATURE	24°C	799.917	197.583	160.918	234.249	***
		30°C	794.458	203.042	166.376	239.707	***
		60°C	783.375	214.125	177.460	250.790	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	851.125	146.375	109.710	183.040	***
		10	764.958	232.542	195.876	269.207	***
		20	761.667	235.833	199.168	272.499	***
WEFT	NO TREATMENT		922.000				
WEFT	TREATMENT			(Relative to untreated)			
		Anolyte	814.611	107.389	68.048	146.730	***
		Sodium hypochlorite	680.278	241.722	202.381	281.063	***
		Detergent	700.667	221.333	181.992	260.674	***
		Water	806.167	115.833	76.492	155.174	***
				(Relative to untreated)			
	TEMPERATURE	24°C	746.708	175.292	136.446	214.138	***
		30°C	749.083	172.917	134.071	211.763	***
		60°C	755.500	166.500	127.654	205.346	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	739.458	182.542	143.696	221.388	***
		10	756.167	165.833	126.987	204.679	***
		20	755.667	166.333	127.487	205.179	***

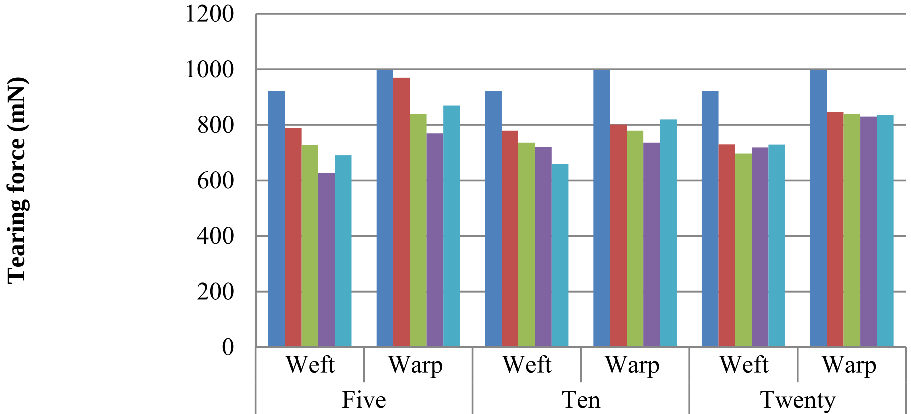
***, $p < 0.05$

In the weft direction (Figure 5.29) the sodium hypochlorite solution had the largest influence, while the Anolyte had the smallest influence. However, in the warp direction the Anolyte had the largest influence and the sodium hypochlorite solution had the smallest. This is very opposing findings. According to Bendak & El-Marsifi (1991) at high temperatures, strong acids and alkalis can degrade polyester fibres, which would result in lower fabric strength. Statistical analysis (Table 5.23) showed that there was a significant difference ($p < 0.05$) between the influence of the Anolyte compared to that of the detergent as well as the sodium hypochlorite solution. The general decrease in tearing strength could also possibly be contributed to the alterations in the structure of the woven polyester fabric during laundering (Chiweshe & Crews, 2000).

Table 5.23: Significance of laundering with water, detergent and sodium hypochlorite compared with Anolyte on the tearing strength of the polyester fabric.

Direction	Treatment	Mean (mN)	Difference	95% Confidence limits		Significant
Weft			(Relative to Anolyte)			
	Anolyte	814.611				
	Sodium hypochlorite	680.278	134.333	116.740	151.927	***
	Detergent	700.667	113.944	96.351	131.538	***
	Water	806.167	8.444	-9.149	26.038	
Warp			(Relative to Anolyte)			
	Anolyte	737.444				
	Sodium hypochlorite	850.278	-112.833	-129.439	-96.227	***
	Detergent	834.278	-96.833	-113.439	-80.227	***
	Water	748.333	-10.889	-27.495	5.717	

***, $p < 0.05$



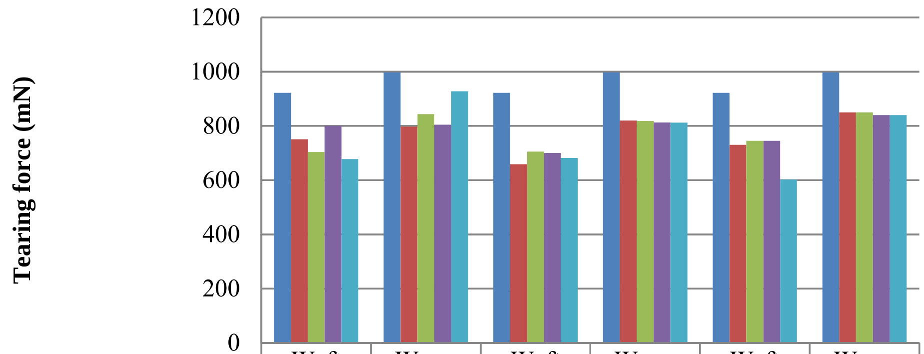
	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	922	998	922	998	922	998
Water	789	970	779	802	730	846
Detergent	727	839	736	779	697	840
Anolyte	627	770	720	736	719	830
Sodium hypochlorite	691	870	659	820	730	835

Figure 5.30: Tearing strength of the polyester fabric after laundering for five, ten and twenty cycles at 24°C.

Figure 5.30 shows that all the treatments caused a decrease in tearing strength in both directions of the polyester fabric after laundering for twenty cycles. As shown in Table 5.22, laundering at 24°C had a significant influence ($p < 0.05$) on the tearing strength of the polyester fabric in both directions.

In the weft direction the water and the sodium hypochlorite solution had the same influence, which also was the smallest decrease in tearing strength, while the detergent had the largest influence. The water and sodium hypochlorite solution caused a 192 mN decrease from untreated to twenty cycles (730 mN). The Anolyte caused a decrease of 203 mN after twenty cycles (719 mN), while the detergent caused the largest decrease of 225 mN after twenty cycles (697 mN). The decrease caused by the sodium hypochlorite solution and the detergent could be explained by the findings of Bendak & El-Marsifi (1991); treatment of polyester with an alkaline agent can lead to weight loss and a decrease in tearing strength.

In the warp direction it was the Anolyte that had the largest influence and caused a 168 mN decrease after twenty cycles (830 mN), while the water had the smallest influence by causing a 152 mN decrease after twenty laundering cycles (846 mN). The detergent (840 mN) caused a 158 mN decrease, while the sodium hypochlorite solution caused a decrease of 163 mN after twenty cycles (835 mN). The loss of tearing strength could also be attributed to the fabric structure. According to Choi *et al.* (2004) the laundering action causes friction between the yarns, which decreases fabric properties such as tearing strength.

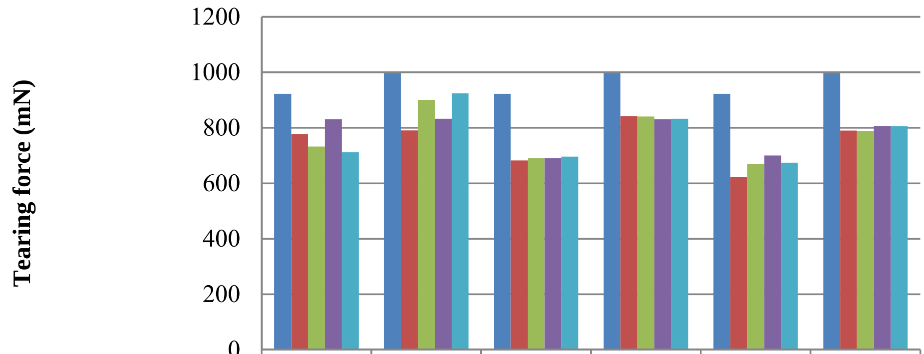


	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	922	998	922	998	922	998
Water	751	797	659	820	730	850
Detergent	704	844	705	818	745	850
Anolyte	801	805	700	813	745	840
Sodium hypochlorite	678	928	682	812	602	840

Figure 5.31: Tearing strength of the polyester fabric after laundering for five, ten and twenty cycles at 30°C.

The water, detergent, Anolyte and sodium hypochlorite solution caused a decrease in tearing strength of the polyester fabric in both directions after laundering at 30°C (Figure 5.31). In the weft direction the detergent and the Anolyte had the same and smallest influence after twenty cycles, while the sodium hypochlorite solution clearly had the largest influence. The detergent and the Anolyte caused a decrease of 177 mN after twenty cycles (745 mN). The water caused a decrease of 192 mN after twenty cycles (730 mN). The sodium hypochlorite solution caused a large decrease of 320 mN after twenty cycles (602 mN). Haji *et al.* (2011) also found that laundering of polyester fabrics with alkaline agents can cause a decrease in fabric strength.

In the warp direction the Anolyte and the sodium hypochlorite solution had the same and the largest influence, while the detergent and the water had the same and smallest influence. The sodium hypochlorite solution as well as the Anolyte caused a decrease of 158 mN after twenty cycles (840 mN), while the detergent and the water caused a decrease of 148 mN after twenty cycles (850 mN). The loss of tearing strength found with the water, detergent, Anolyte and sodium hypochlorite solution could be due to changes in the fabric structure during laundering which could lead to a decrease in fabric strength (Siroky *et al.,* 2009). The statistical analysis (Table 5.22) indicated that laundering of the polyester fabrics at a temperature of 30°C had a significant influence ($p < 0.05$) on the tearing strength in both directions.



	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	922	998	922	998	922	998
Water	778	791	682	843	622	790
Detergent	733	901	691	841	670	789
Anolyte	831	833	691	831	700	807
Sodium hypochlorite	712	925	696	833	674	806

Figure 5.32: Tearing strength of the polyester fabric after laundering for five, ten and twenty cycles at 60°C.

Figure 5.32 shows that all the treatments caused a decrease in tearing strength of the polyester fabric in both directions after laundering at 60°C. In the weft direction the water had the largest influence by causing a 300 mN decrease (622 mN), while the Anolyte had the smallest influence by causing a 222 mN decrease in tearing strength from untreated to twenty cycles (700 mN). The largest decrease in tearing strength could be explained by Gupta (2003) who found that the application of heat in the presence of water can cause a change in the polyester fibre configuration, which in turn would affect fabric properties. The detergent caused a decrease of 252 mN in tearing strength after twenty cycles (670 mN) and the sodium hypochlorite solution caused a decrease of 248 mN after twenty cycles (674 mN).

In the warp direction the detergent had the largest influence, while the Anolyte had the smallest influence, however it should be noted that the water and detergent had very close influences and the Anolyte and sodium hypochlorite solution had very close influences, with only a 1 mN difference. The detergent (789 mN) caused a decrease of 209 mN, while the water caused a 208 mN decrease after twenty laundering cycles (790 mN). The sodium hypochlorite solution (806 mN) caused a decrease of 192 mN, while the Anolyte caused a 191 mN decrease after twenty cycles (807 mN). The statistical analysis (Table 5.22) indicated that laundering with the water, detergent, Anolyte and sodium hypochlorite solution at 60°C had a significant influence ($p < 0.05$) on the tearing strength of the polyester fabric in both directions. This could be attributed to the temperature, as Carr (1995) explained that fibre swelling and yarn retraction forces will increase with increasing temperature, which changes the fabric structure and in turn influence fabric properties.

Table 5.24: P-values of the effect of treatment, temperature and cycles on the tearing strength of the polyester fabric.

Source	p-value weft	p-value warp
Treatment*Temperature	0.0405*	< .0001*
Treatment*Cycles	0.0425*	< .0001*
Temperature*Cycles	0.0003*	< .0001*
Treatment*Temperature*Cycles	0.0001*	< .0001*

The analysis (Table 5.24) indicated that all possible interactions of the treatment, temperature and cycles had a significant influence ($p < 0.05$) on the tearing strength of the polyester fabric in both directions.

5.3.3 Polyester/Cotton

The results concerning the tearing strength of the polyester/cotton fabric after laundering with water, detergent, Anolyte and sodium hypochlorite solution are illustrated in Figure 5.33, as well as the statistical analysis of the significance of treatment, temperature and cycles as illustrated in Table 5.25.

Table 5.25: Tearing strength of polyester/cotton fabric: Effect of treatment, laundering temperature and number of laundering cycles.

DIRECTION			Mean (mN)	Difference	95% Confidence limits		Significant
WARP	NO TREATMENT		319.000				
WARP	TREATMENT			(Relative to untreated)			
		Anolyte	329.667	-10.667	-47.635	26.302	
		Sodium hypochlorite	261.944	57.056	20.087	94.024	***
		Detergent	292.278	26.722	-10.247	63.691	
		Water	308.667	10.333	-26.635	47.302	
				(Relative to untreated)			
	TEMPERATURE	24°C	284.750	34.250	-2.254	70.754	
		30°C	308.542	10.458	-26.045	46.962	
		60°C	301.125	17.875	-18.629	54.379	
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	326.750	-7.750	-44.254	28.754	
		10	305.292	13.708	-22.795	50.212	
		20	262.375	56.625	20.121	93.129	***
WEFT	NO TREATMENT		633.500				
WEFT	TREATMENT			(Relative to untreated)			
		Anolyte	393.278	240.22	195.15	285.30	***
		Sodium hypochlorite	327.556	305.94	260.87	351.02	***
		Detergent	354.544	278.96	233.88	324.03	***
		Water	401.389	232.11	187.03	277.19	***
				(Relative to untreated)			
	TEMPERATURE	24°C	342.033	291.467	246.957	335.976	***
		30°C	417.458	216.042	171.532	260.551	***
		60°C	348.083	285.417	240.907	329.926	***
	NUMBER OF LAUNDERING CYCLES			(Relative to untreated)			
		5	429.833	203.667	159.157	548.176	***
		10	370.242	263.258	218.749	307.768	***
		20	307.500	326.000	281.490	370.510	***

***, $p < 0.05$

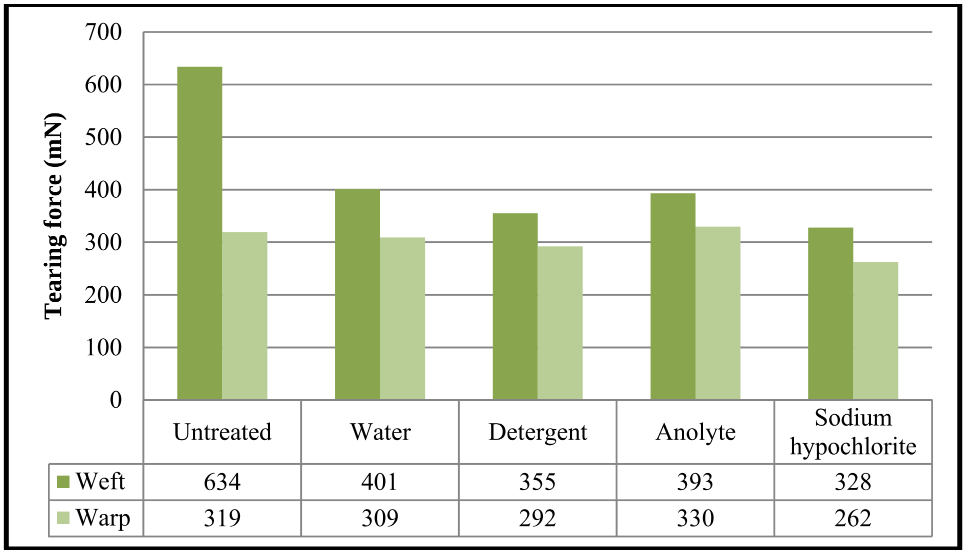


Figure 5.33: The influence of laundering with water, detergent, Anolyte and sodium hypochlorite on the tearing strength of the polyester/cotton fabric.

The water, detergent, Anolyte and sodium hypochlorite solution caused a dramatic decrease in tearing strength in the weft direction, while there is only a small decrease in the warp direction. According to Seyam & El-Shiekh (1995) the warp yarns in a woven fabric is more stable and, therefore, less influenced by laundering. The decrease in tearing strength could be contributed to the laundering action as the abrasion and mechanical action degrades the fibres, which in turn lead to a decrease in fabric strength (Khedher *et al.,* 2009).

The Anolyte caused a small increase in the warp direction. According to the statistical analysis, only the sodium hypochlorite solution had a significant influence ($p < 0.05$) on the tearing strength of the polyester/cotton fabric in the warp direction in comparison to the untreated fabric. According to Herbots *et al.* (2008) the treatment of polyester/cotton fabric with sodium hypochlorite can cause a loss of tearing strength as a result of fibre damage.

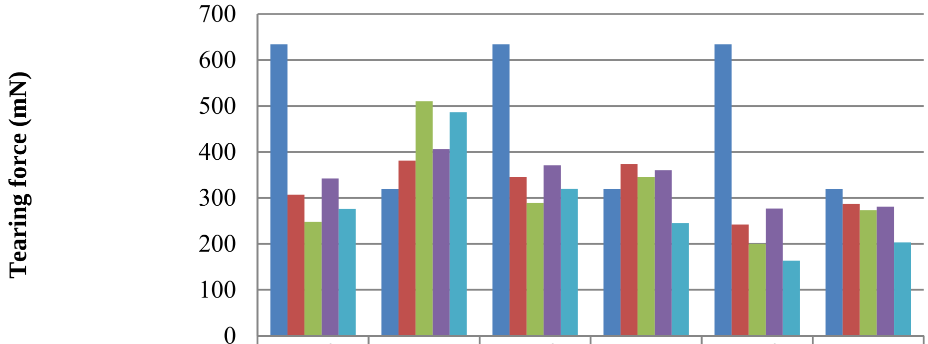
The analysis (Table 5.25) also indicated that only twenty laundering cycles had a significant influence ($p < 0.05$) on the tearing strength of the polyester/cotton fabric in the warp direction. While all the cycles (five, ten and twenty) had a significant influence ($p < 0.05$) on the tearing strength of the polyester/cotton fabric in the weft direction in comparison to the untreated fabric. According to Wilcock & Van Delden (1985), an increased number of launderings will cause a decrease in the properties of polyester/cotton fabrics. There was a significant difference ($p < 0.05$) between the influence of the Anolyte and that of all the other treatments on the tearing strength of the polyester/cotton fabric in the warp direction (Table 5.26). As indicated in Figure 5.33, the water had the smallest influence on the weft direction, while the Anolyte had the smallest influence in the warp direction. The sodium hypochlorite solution had the largest influence in both directions. Herbots *et al.* (2008) reported that the treatment of polyester/cotton fabric with sodium hypochlorite could cause a loss of tearing strength because of fibre damage.

According to the statistical analysis (Table 5.25) the water, detergent, Anolyte and sodium hypochlorite had a significant influence ($p < 0.05$) on the tearing strength of the polyester/cotton fabric in the weft direction in comparison to the untreated fabric. There was a significant difference ($p < 0.05$) indicated (Table 5.26) between the influence of the Anolyte and that of the detergent and the sodium hypochlorite solution.

Table 5.26: Significance of laundering with water, detergent and sodium hypochlorite compared with Anolyte on the tearing strength of the polyester/cotton fabric.

Direction	Treatment	Mean (mN)	Difference	95% Confidence limits		Significant
Weft			(Relative to Anolyte)			
	Anolyte	393.278				
	Sodium hypochlorite	327.556	65.72	45.56	85.88	***
	Detergent	354.544	38.73	18.57	58.89	***
	Water	401.389	-8.11	-28.27	12.05	
Warp			(Relative to Anolyte)			
	Anolyte	329.667				
	Sodium hypochlorite	261.944	67.722	51.189	84.255	***
	Detergent	292.278	37.389	20.856	53.922	***
	Water	308.667	21.000	4.467	37.533	***

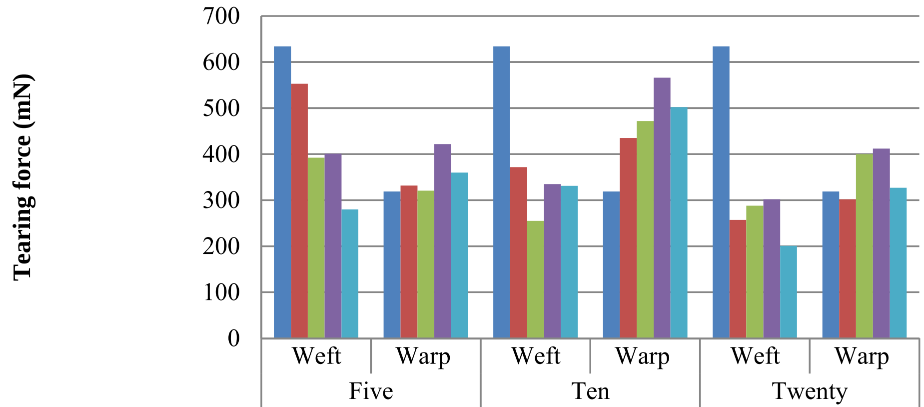
***, $p < 0.05$



	Five		Ten		Twenty	
	Weft	Warp	Weft	Warp	Weft	Warp
Untreated	634	319	634	319	634	319
Water	307	381	345	373	242	287
Detergent	248	510	289	345	200	273
Anolyte	342	406	371	360	277	281
Sodium hypochlorite	276	486	320	245	164	203

Figure 5.34: Tearing strength of the polyester/cotton fabric after laundering for five, ten and twenty cycles at 24°C.

After laundering at 24ºC (Figure 5.34), all the treatments caused a decrease in tearing strength of the polyester/cotton fabric in both directions. In the weft direction the decrease in tearing strength was much larger in the weft direction after twenty cycles, than in the warp direction. The sodium hypochlorite solution had the largest influence in the weft direction by causing a 470 mN decrease in tearing strength from untreated to twenty cycles (164 mN). On the other hand, the Anolyte had the smallest influence by causing a 357 mN decrease after twenty cycles (277 mN). The detergent caused a 434 mN decrease after twenty cycles (200 mN), while the water caused a 392 mN decrease in tearing strength after twenty laundering cycles (242 mN). In the warp direction the water had the smallest influence by causing a 32 mN decrease (287 mN), while the sodium hypochlorite solution had the largest influence in tearing strength after twenty cycles by causing a decrease of 116 mN in tearing strength (203 mN). The Anolyte caused a decrease of 38 mN after twenty cycles (281 mN). The detergent caused a 46 mN decrease after twenty cycles (273 mN). As all the treatments caused a decrease in tearing strength in both directions of the fabric it could be contributed to the laundering action and changes in the structure during laundering which lead to a decrease in fabric strength (Siroky *et al.,* 2009).



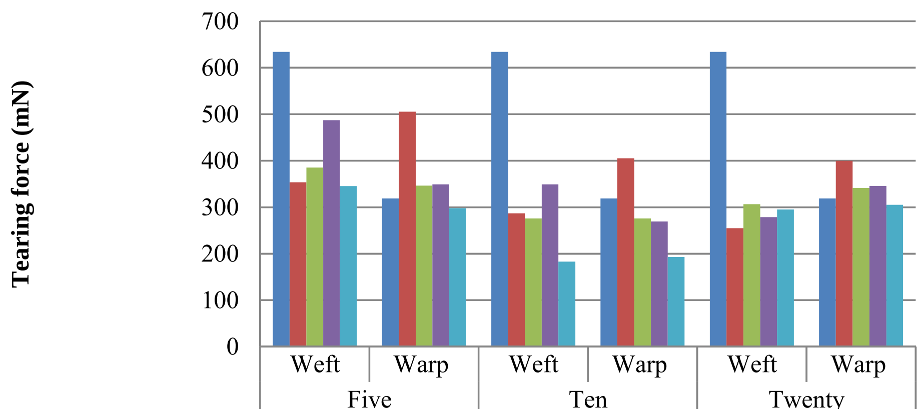
	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	634	319	634	319	634	319
Water	553	332	372	435	257	302
Detergent	392	321	255	472	288	400
Anolyte	401	422	335	566	302	412
Sodium hypochlorite	280	360	331	502	201	327

Figure 5.35: Tearing strength of the polyester/cotton fabric after laundering for five, ten and twenty cycles at 30°C.

The statistical analysis (Table 5.25) indicated that laundering of the polyester/cotton fabric at 30°C had a significant influence ($p < 0.05$) on the tearing strength in the weft direction. According to Ibrahim *et al.* (2002), a rise in temperature can cause a reduction in tearing strength of polyester/cotton fabric. As illustrated in Figure 5.35, the Anolyte had the largest influence in the warp direction, while it had the smallest influence in the weft direction. The sodium hypochlorite solution had the smallest influence in the warp direction and the largest influence in the weft direction. The water, detergent, Anolyte and sodium hypochlorite solution had a similar influence throughout the number of cycles, where in the weft direction the tearing strength decreased as the number of cycles increased. However, in the warp direction the tearing strength increased up to ten cycles, but a decrease was indicated after twenty cycles.

In the weft direction, the Anolyte caused a 332 mN decrease from untreated to twenty cycles (302 mN). The detergent caused a decrease of 346 mN after twenty cycles (288 mN). Water caused a decrease of 377 mN after twenty cycles (257 mN). The sodium hypochlorite solution caused the largest decrease of 433 mN after twenty cycles (201 mN). Wilcock & Van Delden (1985) reported that laundering can lead to the deterioration of fabrics as a result of chemical and mechanical action.

In the warp direction, all the treatments except the water caused an increase in tearing strength, while the water caused a decrease. The Anolyte caused an increase of 93 mN after twenty cycles (412 mN). The detergent caused an increase of 81 mN after twenty cycles (400 mN). The sodium hypochlorite solution caused an 8 mN increase after twenty cycles (327 mN). These increases could possibly be due to the interaction of treatment, temperature and the laundering action. The water caused a decrease of 17 mN after twenty cycles (302 mN). Laitala *et al.* (2011) also found that a higher laundering temperature could decrease the strength of polyester/cotton fabric.



	Five Weft	Five Warp	Ten Weft	Ten Warp	Twenty Weft	Twenty Warp
Untreated	634	319	634	319	634	319
Water	354	506	287	405	255	400
Detergent	386	347	276	276	307	342
Anolyte	488	349	349	270	279	346
Sodium hypochlorite	346	298	183	193	295	305

Figure 5.36: Tearing strength of the polyester/cotton fabric after laundering for five, ten and twenty cycles at 60°C.

According to the statistical analysis (Table 5.25) laundering of the polyester/cotton fabric at 60°C had a significant influence ($p < 0.05$) on the tearing strength of the fabric in the weft direction. According to Figure 5.36, the water had the largest influence in both directions, while the detergent had the smallest influence in the weft direction and the sodium hypochlorite solution in the warp direction after twenty cycles. In the weft direction, the water caused a large decrease of 379 mN after twenty cycles (255 mN). The detergent caused a large decrease of 327 mN after twenty cycles (307 mN). The Anolyte caused a decrease of 355 mN twenty cycles (279 mN). The sodium hypochlorite solution caused a large decrease of 339 mN after twenty cycles (295 mN). Ibrahim *et al.* (2002) reported that higher temperatures could cause a reduction in tearing strength of polyester/cotton fabric. Once again, some increases were found in the warp direction. This time it was the detergent, Anolyte and the water, while the sodium hypochlorite solution caused a decrease in tearing strength after twenty laundering cycles.

In the warp direction the water (400 mN) caused an 81 mN increase, the detergent caused a 23 mN increase and the Anolyte caused an increase of 27 mN after twenty cycles (346 mN). The sodium hypochlorite solution caused a decrease of 14 mN after twenty cycles (305 mN). Gouda & Ibrahim (2008) also found that sodium hypochlorite caused damage to the cellulose structure of cotton, and could therefore lead to lower fabric strength.

Table 5.27: P-values of the effect of treatment, temperature and cycles on the tearing strength of the polyester/cotton fabric in the warp direction.

Source	p-value weft	p-value warp
Treatment*Temperature	< .0001*	0.0020*
Treatment*Cycles	0.0877	0.0003*
Temperature*Cycles	< .0001*	< .0001*
Treatment*Temperature*Cycles	< .0001*	<. 0001*

The interaction of treatment, cycles and temperature had a significant influence ($p < 0.05$) on the tearing strength of the polyester/cotton fabric in both directions. However, the interaction of treatment and cycles only had a significant influence ($p < 0.05$) on the warp direction of the fabric. The temperature did not have a significant effect on the tearing strength in the warp direction (Table 5.25). This is in accordance with the findings of Van Amber *et al.* (2010), whom indicated that laundering temperature did not have a significant effect on polyester/cotton fabric properties.

CHAPTER 6:
CONCLUSION & RECOMMENDATION

6.1 Conclusion

The efficacy of Anolyte as a disinfectant against *Escherichia coli* and *Staphylococcus aureus* was compared against filtered water, detergent and a combination of detergent and sodium hypochlorite. Cotton, polyester and polyester/cotton fabrics were contaminated with *E. coli* and *Staph. aureus* respectively and then laundered at temperatures of 24, 30 and 60°C to determine the effect of temperature on the efficacy of the agents. The influence of the treatments, laundering temperatures and number of cycles on the textile fabrics were evaluated in terms of dimensional stability, tensile strength and tearing strength.

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

Hypothesis 1: The Anolyte, distilled water, detergent, and detergent with sodium hypochlorite will reduce the growth of *Escherichia coli* and *Staphylococcus aureus* during laundering.

The treatments reduced the growth of *Escherichia coli* and *Staphylococcus aureus*, each to a different degree. The Anolyte was found to be the most effective of the treatments in reducing the numbers of the organisms. No *E. coli* was found on any of the fabrics after the contaminated fabrics were laundered with the Anolyte. The sodium hypochlorite solution also reduced the *E. coli* to a small number of organisms, while the detergent and the filtered water were not as successful, but still reduced the numbers of the microorganisms. There was a significant difference ($p < 0.05$) between the influence of the Anolyte and the other treatments. The Anolyte destroyed all *E. coli* and *Staph. aureus,* while the other treatments only reduced the number of organisms.

The Anolyte was shown to be just as successful against the *Staph. aureus* and no survival were found on any of the fabrics after laundering with the Anolyte. The sodium hypochlorite solution, detergent and filtered water were not as successful, but still reduced the number of microorganisms. There was a significant difference ($p < 0.05$) between the influence of the Anolyte and the other treatments.

Hypothesis 2: Different temperatures of 24, 30 and 60°C will influence the efficacy of the Anolyte, distilled water, detergent, and sodium hypochlorite solution.

Temperature had a significant influence ($p < 0.05$) on the survival of *Staph. aureus* on the polyester and polyester/cotton fabrics. Temperature aided in the destruction, especially at 60°C where the temperature was responsible for the destruction of *E. coli* and *Staph. aureus*. There was not a significant difference between 24°C and 30°C, but there was, however, a significant difference between 24°C and 60°C, as well as between 30°C and 60°C. The number of organisms was only reduced after laundering at temperatures of 24°C and 30°C, while all microorganisms were destroyed at 60°C. It was also indicated that the interaction of temperature and treatment had a significant influence on the survival of *E. coli* and *Staph. aureus* on polyester/cotton. The higher the temperature, the lower the *E. coli* and *Staph. aureus* survival after laundering with the treatments.

From the results obtained, it could be concluded for Hypotheses 1 and 2 that the Anolyte will destroy *E. coli* and *Staph. aureus* on cotton, polyester and polyester/cotton when it is laundered at 24°C or 30°C, while the temperature is responsible for the destruction at 60°C.

Hypothesis 3: The Anolyte, filtered water, detergent, and sodium hypochlorite solution will have an effect on the tensile strength of the polyester, polyester/cotton and cotton fabrics.

The tensile strength was measured in terms of the maximum load that the fabric could carry in the warp and weft directions, as well as the displacement at maximum load.

The treatments caused a general increase in the maximum load that the cotton fabric could carry in the weft direction, while it caused a decrease in the warp direction. All the treatments had a significant influence ($p < 0.05$) on the maximum load that the cotton fabric could carry in both directions. The treatments caused a decrease in maximum load that the polyester fabric could carry in both directions. All the treatments had a significant influence on the maximum load that the polyester fabric could carry in the warp direction. The treatments caused an increase in maximum load that the polyester/cotton fabric could carry in the warp and weft direction. From these results it could be concluded that the Anolyte did not influence the maximum load of the cotton, polyester and polyester/cotton fabrics more than the other treatments, although the Anolyte sometimes had the largest influence, it was not significantly different from the other treatments.

The treatments caused an increase in displacement at maximum load in both directions of the cotton, polyester and polyester/cotton fabrics. The detergent and the water had a significantly ($p < 0.05$) larger influence than the Anolyte on the displacement at maximum load of the cotton fabric, while no significant difference was found between the treatments on the polyester fabric. However, on the polyester/cotton fabric, there was a significant difference ($p < 0.05$) between the influence of the Anolyte and that of the detergent and sodium hypochlorite solution, as the other treatments caused a larger increase in maximum load than the Anolyte.

From these results the conclusion could be made that the Anolyte caused an increase in displacement, which was not always significantly different from the influence of the other treatments.

Hypothesis 4: Different temperatures of 24, 30 and 60°C will affect the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tensile strength of the polyester, polyester/cotton and cotton fabrics.

The tensile strength was measured in terms of the maximum load that the fabric could carry in the warp and weft directions, as well as the displacement at maximum load.

All the temperatures had a significant influence ($p < 0.05$) on the maximum load that the cotton fabric could carry in both directions, while it only had a significant influence in the warp direction of the polyester fabric and the weft direction of the polyester/cotton fabric. The interaction of treatment and temperature had a significant influence ($p < 0.05$) on the maximum load that the cotton fabric could carry in both directions. The maximum load that the cotton, polyester and polyester/cotton fabrics could carry decreased as the laundering temperature increased.

There was no definite relationship between the temperature and the displacement at maximum load of the cotton and polyester fabrics, while the polyester/cotton fabric showed an increase in displacement at maximum load as the temperature increased. The temperatures had a significant influence ($p < 0.05$) on the displacement at maximum load of the cotton fabric, as well as the polyester/cotton fabric in both directions, while only 60°C had a significant influence on the polyester fabric. The interaction of treatment and temperature had a significant influence ($p < 0.05$) on the displacement at maximum load of the cotton fabric in both directions and the polyester/cotton fabric in the warp direction. Laundering at 24°C caused an increase in displacement in cotton and polyester/cotton fabrics, while an increase was caused at 30°C in the weft direction of the cotton fabric and a decrease was caused in the warp direction. Laundering at 60°C caused an increase in the warp direction of the cotton and polyester/cotton fabrics, while a decrease was found in the weft direction of the cotton fabric.

It could, therefore, be concluded that the different temperatures of 24, 30 and 60°C affected the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tensile strength of the cotton fabric.

Hypothesis 5: The number of laundering cycles (5, 10, and 20) will affect the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tensile strength of the polyester, polyester/cotton and cotton fabrics.

The tensile strength was measured in terms of the maximum load that the fabric could carry in the warp and weft directions, as well as the displacement at maximum load. No pattern could be established between the number of laundering cycles and the maximum load that the fabrics could carry. It was, however, found that the number of laundering cycles had a significant influence ($p < 0.05$) on the maximum load that the cotton fabric could carry in both directions, while it only had a significant influence on the maximum load that the

polyester fabric could carry in the warp direction and the polyester/cotton fabric in the weft direction. The interaction of the treatment and number of cycles had a significant influence ($p < 0.05$) on the maximum load that the cotton fabric could carry in the warp direction and the polyester fabric could carry in the weft direction.
The number of cycles had a significant influence ($p < 0.05$) on the displacement at maximum load of the cotton fabric and polyester/cotton fabric in both directions, while five laundering cycles had a significant influence ($p < 0.05$) on the displacement at maximum load of the polyester fabric in the weft direction. The interaction of cycles and treatment had a significant influence ($p < 0.05$) on the displacement at maximum load of all the fabrics in both directions. The displacement at maximum load of the cotton and polyester/cotton fabrics increased as the number of cycles increased.

These findings lead to the conclusion that the number of laundering cycles (5, 10, and 20) affected the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tensile strength of the polyester, polyester/cotton and cotton fabrics.

Hypothesis 6: The Anolyte, filtered water, detergent, and sodium hypochlorite solution will have an effect on the tearing strength of the polyester, polyester/cotton and cotton fabrics.

The treatments caused a decrease in tearing strength of all the fabrics in both directions. There was a significant difference ($p < 0.05$) between the influence of the Anolyte and the other treatments on the tearing strength of the cotton fabric in the warp direction, as well as the polyester/cotton fabric in the warp direction. There was also a significant difference ($p < 0.05$) between the influence of the Anolyte and the sodium hypochlorite solution and detergent on the tearing strength of the polyester/cotton and polyester fabrics. Laundering with the detergent and sodium hypochlorite solution led to a larger decrease in tearing strength than that of the Anolyte in both directions of the polyester/cotton fabric and the weft direction of the polyester fabric. However, in the warp direction of the polyester fabric, laundering with the Anolyte caused a larger decrease in tearing strength than the other treatments.

It could, therefore, be concluded that the Anolyte, filtered water, detergent, and sodium hypochlorite solution had a detrimental effect on the tearing strength of the polyester,

polyester/cotton and cotton fabrics. The Anolyte, however, did not have the most detrimental influence on the tearing strength of the fabrics.

Hypothesis 7: Different temperatures of 24, 30 and 60°C will affect the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tearing strength of the polyester, polyester/cotton and cotton fabrics.

The temperatures had a significant influence ($p < 0.05$) on the tearing strength of the cotton and polyester fabrics in both directions, while it only had a significant influence on the tearing strength of the polyester/cotton fabric in the weft direction. The interaction of treatment and temperature had a significant influence ($p < 0.05$) on the tearing strength of the polyester and polyester/cotton fabrics in both directions. The tearing strength of the fabrics decreased as the laundering temperature increased.

These results lead to the conclusion that temperatures of 24, 30 and 60°C affected the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution by causing a decrease in tearing strength of the polyester, polyester/cotton and cotton fabrics as the temperature increased.

Hypothesis 8: The number of laundering cycles (5, 10, and 20) will affect the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tearing strength of the polyester, polyester/cotton and cotton fabrics.

No definite relationship could be established between the number of laundering cycles and the tearing strength. The cycles had a significant influence ($p < 0.05$) on the tearing strength of the cotton and polyester fabric in both directions, while it only had a significant influence on the tearing strength of the polyester/cotton fabric in the weft direction. Twenty laundering cycles also had a significant influence ($p < 0.05$) on the tearing strength of the polyester/cotton fabric in the warp direction. The interaction of treatment and cycles had a significant influence ($p < 0.05$) on the tearing strength of the polyester fabric in both directions and the polyester/cotton fabric in the warp direction.

It could be concluded from these results that the number of laundering cycles affected the influence of Anolyte, filtered water, detergent, and sodium hypochlorite solution on the tearing strength of the polyester, polyester/cotton and cotton fabrics.

The final conclusion that could be derived is 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.

6.2 Recommendation

As no literature could be found on the application of Anolyte on textile fabrics, a wide range of research opportunities exists. Further research could be conducted on the influence of Anolyte on other microorganisms found on textile materials. The Anolyte could also be applied at lower temperatures to establish if it would still eliminate all *E. coli* and *Staph. aureus.* The effect of Anolyte on the properties of fabrics consisting of other fibres than cotton and polyester should be evaluated. It is also believed that Anolyte could have an influence on the colour or whiteness of a fabric, which has not yet been proven.

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ABSTRACT

Textile materials are usually treated with chemicals like sodium hypochlorite and high temperatures to ensure sterility. This poses two potential problems: (1) it has a negative effect on strength properties of the textile fabric; (2) the harmful chemicals are discarded into the environment. Therefore, better and safer methods need to be investigated.

A process has been developed where electro-chemically activated water (Anolyte) is produced by an anode-cathode system and the process is described as a change of the molecular state of the water. After production, the Anolyte exists in a metastable state while containing many free radicals and a variety of molecules and a very high oxidation-reduction potential. It returns to a stable state after 48 hours and become inactive again and, therefore, it is not a threat to the environment when discarded after use. Anolyte has been shown to be an effective disinfection agent in other areas such as the food industry.

The aim of this study was to determine if Anolyte could reduce *E. coli* and *Staph. aureus* on textiles to the same extent as sodium hypochlorite and be effective without implementing such high temperatures. The influence of the Anolyte on textile material should also be evaluated to ensure that it could be used without damaging textile materials more than the currently used disinfection agents.

The antimicrobial effect of the Anolyte was determined by contaminating cotton, polyester and polyester/cotton fabric swatches with *E. coli* and *Staph. aureus*, respectively. Survival was determined after laundering with the respective wash liquors. AATCC Test Method 61-2009 was used with the LaunderOmeter. Wash liquors included filtered water, phosphate reference detergent B, sodium hypochlorite and Anolyte. Temperatures were maintained at 24, 30 or 60°C. The cotton, polyester/cotton and polyester were laundered for 5, 10 or 20 cycles respectively for the evaluation of the influence on tensile strength and tearing strength.

The tensile strength tests were conducted with the Instron Tensile Tester and ISO/SANS 13934-1:1999 test method. The tearing strength tests were conducted with the Elmendorf Tearing Strength tester as per ASTM Test Method D 1424 - 63.

The results indicated that Anolyte destroyed all *E. coli* and *Staph. aureus* on all the fabrics regardless of the temperature. The effect of the other agents were enhanced by the increasing temperature, but after laundering at 60°C no survival was found as a result of the high temperature. The Anolyte did not influence the strength properties of the cotton, polyester and polyester/cotton fabrics to a larger extent than the detergent or sodium hypochlorite solution.

An increase in maximum load required to break the fabric and displacement at maximum load was found for the cotton and polyester/cotton fabrics after laundering treatments, while a decrease was caused after laundering of the polyester fabric. A decrease in tearing strength of all the fabrics was found after laundering with the treatments. The Anolyte also did not affect the dimensional stability of the fabrics.

It could be concluded that the Anolyte is a viable alternative to currently used sodium hypochlorite, while it is effective at low temperatures. The Anolyte do not affect the textile fabrics more negatively than the detergent and sodium hypochlorite combination, and could, therefore, be a successful alternative.

Key words: Anolyte, tearing strength, tensile strength, cotton, polyester, disinfect, *Escherichia coli*, *Staphylococcus aureus*

OPSOMMING

Tekstielstowwe word met chemikalieë soos natriumhipochloriet en hoë temperature behandel om dit te steriliseer. Dit hou twee potensiële probleme in: (1) dit het ‘n negatiewe effek op die sterkte eienskappe van die tekstielstof; en (2) die skadelike chemikalieë word in die natuur vrygestel. Dit lei tot die noodsaaklikheid om beter, veiliger onsmettingsmiddels te ondersoek.

‘n Proses is ontwikkel waar elektro-chemies geaktiveerde water (Anolyte) geproduseer word deur ‘n anode-katode sisteem en die proses word beskryf as die verandering van die molekulêre toestand van die water. Die “Anolyte” bestaan na produksie voort in ‘n metastabiele toestand en bevat baie vrye radikale en ‘n verskeidenheid molekules, asook ‘n baie hoë oksidasie-reduksie potensiaal. Dit keer terug na ‘n stabiele toestand na 48 uur en word dan weer onaktief, daarom is dit nie ‘n bedreiging vir die natuur nadat dit vrygestel is nie.

Die doel van hierdie studie was om te bepaal of “Anolyte” die *E. coli* en *Staph. aureus* op tekstielstowwe tot dieselfde mate sal verminder as chemikalieë soos natriumhipochloriet, asook of dit effektief by lae temperature sal wees. Die invloed wat die “Anolyte” op tekstielstowwe het, moet ook ondersoek word om te verseker dat dit gebruik kan word sonder om meer skade aan te rig as die huidige ontsmettingsmiddels.

Die antimikrobiese effek van die “Anolyte” is ondersoek deur katoen, poliëster en poliëster/katoen monsters onderskeidelik met *E. coli* en *Staph. aureus* te besmet. Oorlewing is bepaal nadat die tekstielmonsters gewas is met die onderskeie wasmiddels. AATCC Toetsmetode 61-2009 was gebruik met die “LaunderOmeter”. Die wasmiddels sluit in: gefiltreerde water, detergent, natriumhipochloriet en “Anolyte”. Temperature van 24, 30 of 60°C is gebruik. Die katoen, poliëster en poliëster/katoen tekstielstowwe is onderskeidelik vir 5, 10 of 20 siklusse gewas vir die evaluering van die invloed op treksterkte en skeursterkte.
Die standaardmetodes is gebruik vir die bepaling van treksterkte (ISO/SANS 139341:1999) en skeursterkte (ASTM D 1424-63).

Die resultate het aangedui dat “Anolyte” al die *E. coli* en *Staph. aureus* op al die tekstielstowwe vernietig het, ongeag die temperatuur. Die invloed van die ander wasmiddels is deur verhoogde temperatuur verbeter, maar nadat daar teen 60°C gewas is, was daar geen oorlewing nie as gevolg van die temperatuur en nie as gevolg van die wasmiddels nie. Die “Anolyte” het nie die sterkte-eienskappe van die katoen, poliëster en poliëster/katoen tot ‘n groter mate beïnvloed as die detergent of natriumhipochloriet nie. ‘n Toename in maksimum krag om breekpunt te bereik en verplasing by maksimum krag is gevind vir die katoen en poliëster/katoen tekstielstowwe, maar ‘n afname is waargeneem vir die poliëster tekstielstof na die wassiklusse met al die wasmiddels. Die “Anolyte het ook nie die dimensionele stabiliteit van die tekstielstowwe beïnvloed nie.

Daar kan afgelei word dat die “Anolyte” ‘n lewensvatbare alternatief is vir natriumhipochloriet as ontsmettingsmiddel wat huidiglik gebruik word en dit is ook effektief teen lae temperature. Die “Anolyte” het nie die tekstielstowwe meer negatief beïnvloed as die detergent en natriumhipochloriet kombinasie nie en daarom kan dit as ‘n suksesvolle alternatief aangewend word.

Sleutelterme: Anolyte, treksterkte, skeursterkte, katoen, poliëster, ontsmet, *Escherichia coli, Staphylococcus aureus*