The Effect of Particle Size of Silicone Type Softeners on Color Assessment of Treated Cotton Fabrics

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I declare that the related thesis was written and all the relevant literature was used in accordance with the academic and ethical rules.

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ABSTRACT

THE EFFECT OF PARTICLE SIZE OF SILICONE TYPE SOFTENERS ON COLOR ASSESSMENT OF TREATED COTTON FABRICS

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Finishing processes have an important role in textile manufacturing. Color and handle are important parameters in textile industry. These parameters have the most significant effect for selection of a fabric. Also color and handle are important parameters for customers who educated or non-educated in textile, to evaluating the quality of a fabric. Color assessment is also commercially important and color difference causes several commercially problems in textile manufacturing. Different methods have been tried to solve this problem. One of these is the usage of softeners with different particle sizes. In this study, the effect of the different particle size of the silicone softeners on color difference were investigated for knitted cotton fabrics. Three different particle sized silicone softeners were used. The effect of acidic and alkali pH in softening bath, washing and ironing after softening treatment on color difference were investigated for more detailed results and finding to the best recipe were aimed.

Key words: Silicone softeners, color difference, particle size of softener, soft hand.

ÖZ

SİLİKON YUMUŞATICILARIN PARÇACIK BÜYÜKLÜĞÜNÜN PAMUKLU KUMAŞLARIN TERBİYE İŞLEMİ SONRASI RENK DEĞERLENDİRMESİNE ETKİSİ

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Tekstil üretiminde bitim işlemleri önemli bir yere sahiptir. Renk ve tutum tekstil endüstrisinde önemli parametrelerdir. Bu parametreler kumaş seçiminde en belirleyici etkiye sahiptir. Ayrıca renk ve tutum, tekstil eğitimi almış veya almamış tüm müşteriler için kumaş kalitesinin değerlendirilmesi açısından önemlidir. Renk değerlendirmesi ticari açıdan da önem taşımaktadır ve renk farkı tekstil üretiminde birçok ticari probleme neden olabilmektedir. Bu problemlerin çözümü için farklı yöntemler denenmiştir. Bunlardan bir tanesi de farklı parçacık büyüklüklerinde yumuşatıcılar kullanılması olmuştur. Bu çalışmada farklı parçacık büyüklüklerindeki silikon yumuşatıcıların pamuklu örme kumaşlarda renk değişimine etkisi araştırılmıştır. Üç farklı parçacık büyüklüğünde silikon yumuşatıcılar kullanılmıştır. Daha detaylı sonuçlar elde edebilmek için, yumuşatıcı banyosunda asidik ve alkali pH etkisi ve yumuşatma işleminden sonra yıkama ve ütülemenin renk farkına etkisi araştırılmıştır ve en doğru reçeteyi bulmak amaçlanmıştır.

Anahtar kelimeler: Silikon yumuşatıcılar, renk farkı, yumuşatıcı parçacık büyüklüğü, yumuşak tutum.

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LIST OF ABREVIATIONS

SS	Sum of squares
df	Degree of freedom
ms	Mean of squares
F	F statistic ratio
P	Probability
SNK	Student-Newman-Keuls
ns	Non-significant
*T*g	Glass transition temperature
WI	Whiteness indices
YI	Yellowness indices
Br	Brightness indices
L*	Lightness
a* and b*	Color-opponent dimensions

CHAPTER 1
INTRODUCTION

Finishing of a fabric is important as innovative designs, colors and materials when used for garment manufacture. In textile industry, a soft touch is as important as the visual impact. Handle, one of the most effective ways is used to detect objects. When we go to the market to buy a fabric or garment, firstly we want to touch and we look how it feels. Soft hand is the most important factor affecting the selection of a textile material.

The importance of using fabric softeners has been increasing in textile industry. One of the last stage of the finishing materials used in textile product are softeners. The cause of the use of softeners is to grow up the textile fabric's features. Due to good properties of textile fabrics, customer demand for textile product increases.

The recent years, cationic and silicone softeners are used common in factories of textile industry. After the use of these softeners, fabric color change occurs and in previously studies stated that this issue brings additional costs to firms. Due to discoloration, which occur due to the chemical structure of the softener, commercial problems occur between firms and customers.

1.1 Purpose of the study

The purpose of the study is to investigate the effect of the particle size of silicone softeners on the color difference of fabrics after various applications. Silicone softeners are becoming extremely important because of their very good softness and greater wash permanence compared to other softeners. For this study softeners in three different particle sizes, Silicone 1, Silicone 2 and Silicone 3, were employed and the effect of particle size on color change of fabrics after treatment, laundry, ironing and acidic and alkali treatment conditions with two different colors (red and blue) were investigated.

1.2 Structure of the study

In this study, the effect of different particle sizes of silicone softeners on color difference investigated. The importance of chemical finishing is explained and softening finishing details are given.

Chapter 2 includes literature review which explains chemical finishing, softening effects, softener types and detailed description of silicone softeners.

Materials and methods of this study are given in Chapter 3.

In Chapter 4, the results of color assessments of treated fabrics and statistically evaluations of findings are given and the findings were graphed and sorted in tables. Spectrophotometric measurements and Costat analyses was used as statistical results.

CHAPTER 2
THEORETICAL BASIS OF THE STUDY

Textile wet processing can be thought of having three stages, pretreatment, coloration and finishing. Finishing in the narrow sense is the final step in the fabric manufacturing process, the last chance to provide the properties that customers will value. Finishing completes the fabric's performance and gives it special functional properties including the final 'touch' [1].

2.1. Importance of chemical finishing

Chemical finishing has always been an important component of textile processing, but in recent years the trend to 'high technology' products has increased the interest and use of chemical finishes. As the use of high performance textiles has grown, the need for chemical finishes to provide the fabric properties required in these special applications has grown accordingly.

The amount of textile chemical auxiliaries sold and used globally in one year is estimated to be about one-tenth of the world's fiber production. With fiber production currently at 60 million tons, about 6 million tons of chemical auxiliaries are consumed. The percentage of market share of textile auxiliaries is shown in Fig. 2.1. About 40 % of textile auxiliaries are used in finishing, the largest percentage usage of all textile chemicals, followed by dyeing and printing auxiliaries and pretreatment chemicals. Within the textile finishing group, the product breakdown, is given as a survey in Fig. 2.1 and given in more detail in Table 2.1. Softeners are clearly the most important individual product group. In terms of value, the repellent group is the leader with the highest ratio of cost per amount [1].

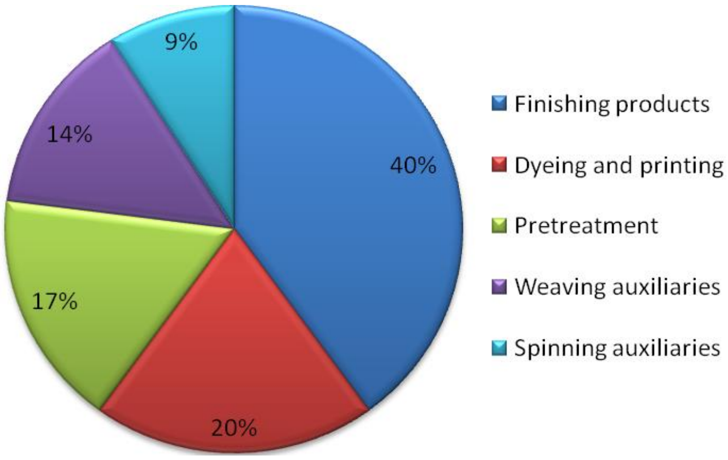

Figure 2.1 Distribution of textile auxiliaries by market share [1]

Table 2.1 Importance of the finishing product groups in order [1]

Value importance	Finishing product group	Value (%)	Amount (%)	Euro/kg
1	Soft handle products based on:	19.9	22.1	2.10
	silicones, including elastomerics	8.9	5.4	3.80
	cationics	5.3	8.0	1.50
	non-ionics, without silicones	5.0	8.1	1.40
	anionics	0.7	0.7	2.10
2	Repellents based on:	15.2	4.1	8.50
	fluorocarbons	13.8	2.4	13.00
	paraffins	1.1	1.6	1.60
	silicones, including elastomerics	0.4	0.1	6.30
3	Flame retardants	13.9	13.9	2.30
4	Products for coating, laminating, fibre and thread bonding	13.8	18.4	1.70
5	Products for easy-care and permanent press finishes	7.9	13.5	1.30
6	Hand builders	7.0	10.0	1.60
7	Antimicrobial products, including protection from insects	1.9	0.3	14.20
8	Antistatic agents, including carpet finishing	1.8	2.3	1.80
9	Non-slip agents	1.2	1.4	2.00
10	Products for soil-release/anti-soiling (without fluorocarbons)	0.04	0.01	6.70
	Remainder, including brighteners, products for sewing thread preparation, anti-felting of wool, carpet back-coating, hydrophilation, delustering and brightening, foaming of finishes	17.4	14.0	

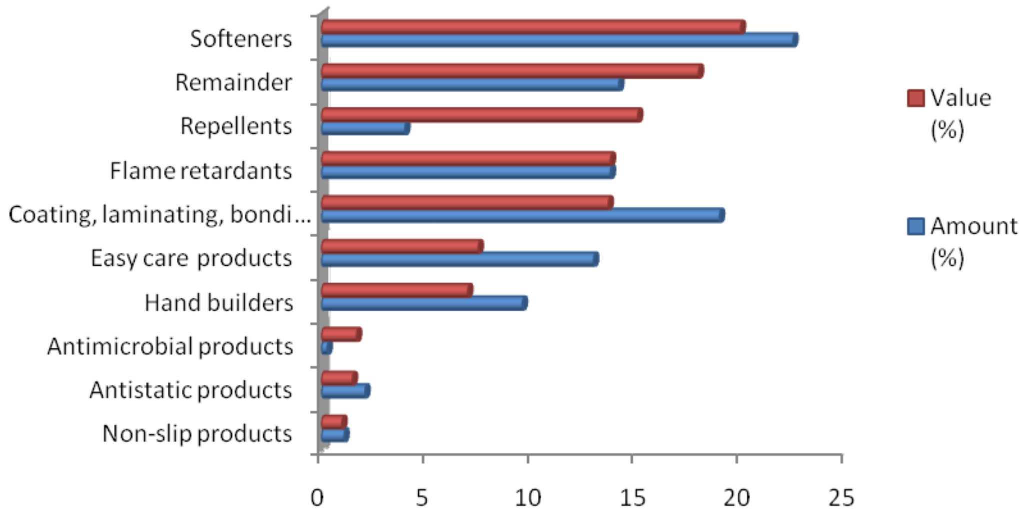

Figure 2.2 Distribution of finishing product groups by amount and value [1]

2.2. Softener

Unfinished textile fibers, in particular natural, have fatty and waxen substances, which cover fibers and protect them from mechanical effects, give water resistance properties. In the manufacturing process of textiles these natural wax substance is removed so woven and knitted fabrics get a good wettability. Dyeing and printing of textiles not very successful without this property. Such textile materials become dry and have unpleasant touch. Fabric softeners are used to provide soft hand for fabrics to make them appealing for consumers. Nowadays softeners have gained great importance in textile finishing; almost no piece of textile leaves the production facilities without being treated with a softener. This softening treatment is applied to give textiles the desired handle, to make further processing easier and to improve the wear properties [2].

2.2.1. General structure of softeners

Softening finishes are the most important of textile chemical after treatments. With chemical softeners, textiles can achieve an agreeable, soft hand, some smoothness, more flexibility and better drape and pliability. The hand of a fabric is a subjective sensation felt by the skin when a textile fabric is touched with the finger tips and gently compressed. The perceived softness of a textile is the combination of several measurable physical phenomena such as elasticity, compressibility and smoothness. During preparation, textiles can become embrittled because natural oils and waxes or fiber preparations are removed. Finishing with softeners can overcome this deficiency and even improve on the original suppleness. Other properties improved by softeners include the feeling of added fullness, antistatic properties and sewability. Disadvantages sometimes seen with chemical softeners include reduced crockfastness, yellowing of white goods, changes in hue of dyed goods and fabric structure slippage [1].

Most softeners consist of molecules with both a (water hating) hydrophobic and a (water-loving) hydrophilic part. Therefore, they can be classified as surfactants (surface active agents) and are to be found concentrated at the fiber surfaces. Most softeners have low water solubility. Therefore softening products are usually sold as oil in water emulsions containing 20–30 % solids. The softener molecules typically contain a long alkyl group, sometimes branched, of more than 16 and up to 22 carbon atoms, but most have 18 corresponding to the stearyl residue. Exceptions to this molecular structure are the special categories of silicones, paraffins and polyethylene softeners. About one-third of the softeners used in the textile industry are silicone based [1, 3].

2.2.1.1. Raw materials

2.2.1.1.1 Conditioning agents

Early fabric softener formulas were relatively simple dispersions of fatty materials that would deposit on the fabric fibers after washing. One of the most common ingredients used was dihydrogenated tallow dimethyl ammonium chloride (DHTDMAC), which belongs to a class of materials known as quaternary ammonium compounds, or quats. This kind of ingredient is useful because part of the molecule has a positive charge that attracts and binds it to negatively charged fabric fibers. This charge interaction also helps disperse the electrical forces that are responsible for static cling. The other part of the molecule is fatty in nature and it provides the slip and lubricity that makes the fabric feel soft.

While these quats do soften fabrics very effectively, they also can make them less absorbent. This is a problem for certain laundry items such as towels and diapers. To overcome this problem, modern formulations use quats in combination with other more effective ingredients. These newer compounds have somewhat lower substantivity to fabric which makes them less likely to interfere with water absorption.

One of the new classes of materials employed in fabric softener formulations today is polydimethylsiloxane (PDMS). Siloxane is a silicone based fluid that has the ability to lubricate fibers to give improved softening and ease of ironing. Other silicones used in softeners include amine-functional silicones, amide-functional silicones and silicone gums. These silicone derivatives are modified to be more substantive to fabric and can dramatically improve its feel [4].

2.2.1.1.2. Emulsifiers

The conditioning ingredients used in fabric softeners are not typically soluble in water because of their oily nature. Therefore, another type of chemical, known as an emulsifier, must be added to the formula to form a stable mixture. Without emulsifiers the softener liquid would separate into two phases, much like an oil and vinegar salad dressing does.

There are three types of emulsifiers used in fabric softener formulations: micro-emulsions, macro-emulsions, and emulsion polymers. Macro-emulsions are creamy dispersions of oil and water similar to hand lotions or hair conditioners. The emulsifier molecules surround the hydrophobic oil or silicone droplets and allow them to be dispersed in water. A micro emulsion is chemically similar, but it creates oil particles that are so small that light will pass around them. Therefore, a micro-emulsion is characterized by its clarity and transparency as opposed to being milky white. Furthermore, one of the advantages of micro-emulsion is that the silicone particles are so tiny that they will actually penetrate into the fibers, while macro-emulsions only deposit on the fiber's surface. The third type, emulsion polymers, creates dispersions that look similar to a macro-emulsion. This system does not use true emulsifiers to suspend and dissolve the oil phase. Instead, emulsion polymers create a stabilized web of molecules that suspend the tiny silicone droplets like fish caught in a net.

The emulsifying system used in softeners must be chosen carefully to ensure the appropriate level of deposition on the fabric. A blend of non-ionic emulsifiers (those that have no charge) and cationic emulsifiers (those that have a positive charge) are typically used. Anionic surfactants (which have a negative charge) are rarely used because the fabric conditioning agents have a positive charge which would tend to destabilize an anionic emulsion [4].

2.2.1.2. Manufacturing process

The preferred method for manufacturing liquid softeners involves heating the ingredients together in one large mixing tank. Mixing tanks should be constructed from high grade stainless steel to prevent attack from the corrosive agents in the formula. The tank is typically equipped with a jacketed shell that allows steam and cold water to be circulated, so the temperature of the batch can be easily controlled. In addition the tank is fitted with a propeller type mixer that is driven by a large electric motor. This kind of mixing blade provides the high shear that is needed to properly disperse the ingredients.

The first step in the manufacturing process is to fill the tank with the specified amount of water. Water is added first because it acts as a carrier for all the other ingredients. Deionized water is used because it is free from metal ions that can affect the performance of the batch. Conventional formulations can contain as much as 80-90% water.

Once the water has been added to the tank, heating and mixing is initiated. When the water has reached the appropriate temperature, the emulsifiers are added. Since these chemicals tend to be waxy solid materials they are added at relatively high temperatures (between 158-176TF [70-80°C]). While the order of addition depends on the specific formula, it usually more effective to disperse the emulsifiers prior to adding the less water-soluble materials, emulsifiers are used between 1- 10 %, depending on the specific chemicals that are selected.

Heating and mixing continues until the batch is homogeneous. At this point cool water is circulated around the tank to lower the temperature. As the batch cools, the remaining ingredients, such as preservatives, dyes, and fragrance, are added. These ingredients are used at much lower concentrations, typically below no more than a few percent for fragrance and less than 1% for preservatives and dyes. When the batch is complete, a sample is sent to the analytical chemistry lab to ensure it meets quality control standards for solids, pH, and viscosity. The completed batch may be pumped to a filling line or stored in tanks until it is ready to be filled [4].

2.2.2. Mechanisms of the softening effect

Softeners provide their main effects on the surface of the fibers. Small softener molecules, in addition, penetrate the fiber and provide an internal plasticization of the fiber forming polymer by reducing of the glass transition temperature Tg. The physical arrangement of the usual softener molecules on the fiber surface is important and shown in Fig. 2.3. It depends on the ionic nature of the softener molecule and the relative hydrophobicity of the fiber surface. Cationic softeners orient themselves with their positively charged ends toward the partially negatively charged fiber (zeta potential), creating a new surface of hydrophobic carbon chains that provide the characteristic excellent softening and lubricity seen with cationic softeners. Anionic softeners, on the other hand, orient themselves with their negatively charged ends repelled away from the negatively charged fibre surface. This leads to higher hydrophilicity, but less softening than with cationic softeners. The orientation of non-ionic softeners depends on the nature of the fibre surface, with the hydrophilic portion of the softener being attracted to hydrophilic surfaces and the hydrophobic portion being attracted to hydrophobic surfaces [1, 5, 6].

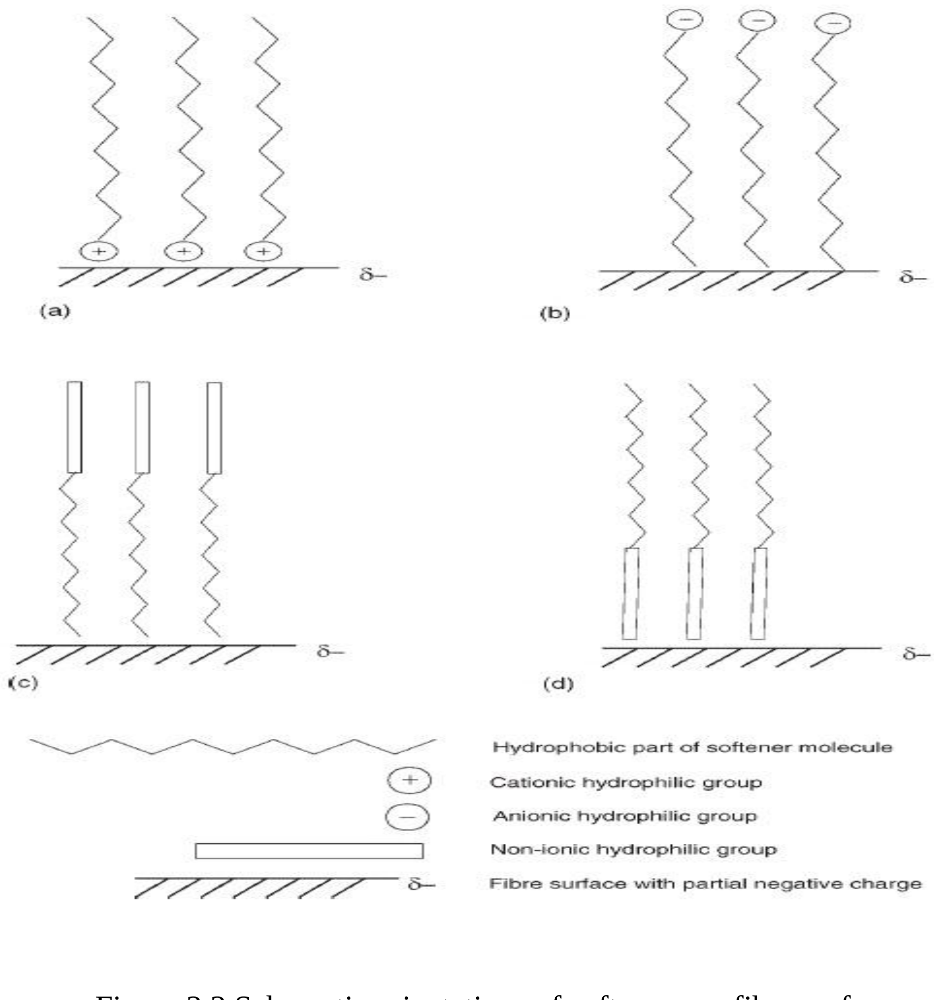

Figure 2.3 Schematic orientations of softeners on fiber surfaces.
(a) Cationic softener and (b) anionic softener at fiber surface. Non-ionic softener at (c) hydro–phobic and (d) hydrophilic fiber surface [3].

2.2.3. Desirable properties of textile softener

- It should be easy to handle.
- It should have good compatibility to other chemicals.
- It should not affect the shade of the material.
- It should not affect the fastness of dyed material.
- It should not cause any yellowing effect on dyed and finished material.
- It should be stable to high temperature.
- It should be non volatile by water vapor.
- It should be non toxic and non caustic.
- It should be easily bio degradable [4].

2.2.4. Schematic comparison of important properties of Softeners

An overview of the generic properties of the different chemical softener types is given in Table 2.2. Naturally, non-ionic softeners have the best compatibility with other finishing compounds [1].

Table 2.2 Important softener characteristics [1].

Chemical Type	Softness	Lubricity	Hydrophilicity	Substantivity	Stability to yellowing	Non-foaming
Anionic	+	++	++	-	++	-
Cationic	+++	-	--	+++	-	+
Amphoteric	++	-	+++	+	-	-
Non-ionic	+	++	++	++	+	-
Polyethylene	+	+++	-	-	+	++
Silicones	+++	+++	- to +	+++	+++ to +	++

2.2.5. Softeners' compatibility and combinability

Softener finishes are often combined with easy care and antistatic treatments. As a rule of thumb, hydrophobic softeners cause an extra soft hand whereas hydrophilic softeners bring about some fullness. In combination with fluorocarbons, most softeners reduce oil repellency. Some ionic, surface active and silicone free softeners are not compatible with water repellents. Since softeners are usually also excellent fibre lubricants, softening finishes often give poor anti-pilling and slippage properties [1].

2.3. Classification of softeners

Based on the ionic natures softener can be classified into six categories:

- Cationic softeners
- Anionic softeners
- Non ionic softeners
- Amphoteric softeners
- Reactive softeners
- Silicone softeners [7].

2.3.1. Cationic softeners

The cationic softeners are very soft, sliding and bulky to the touch and are usually used in colours, since it can modify the white degree applied in almost every fibre. They are little hydrophilic and antistatic [8].

Cationic softeners show the best soft handle and are therefore used for household articles as well as for industrial articles. They have affinity to almost all fibres and are usually applied by the exhaust method. The only problem is the incompatibility with anionic auxiliaries (optical brighteners, dyeing auxiliaries) as well as their tendency to yellow in comparison with non-ionic products. Cationic softeners are mainly used for colored textile substrates [9].

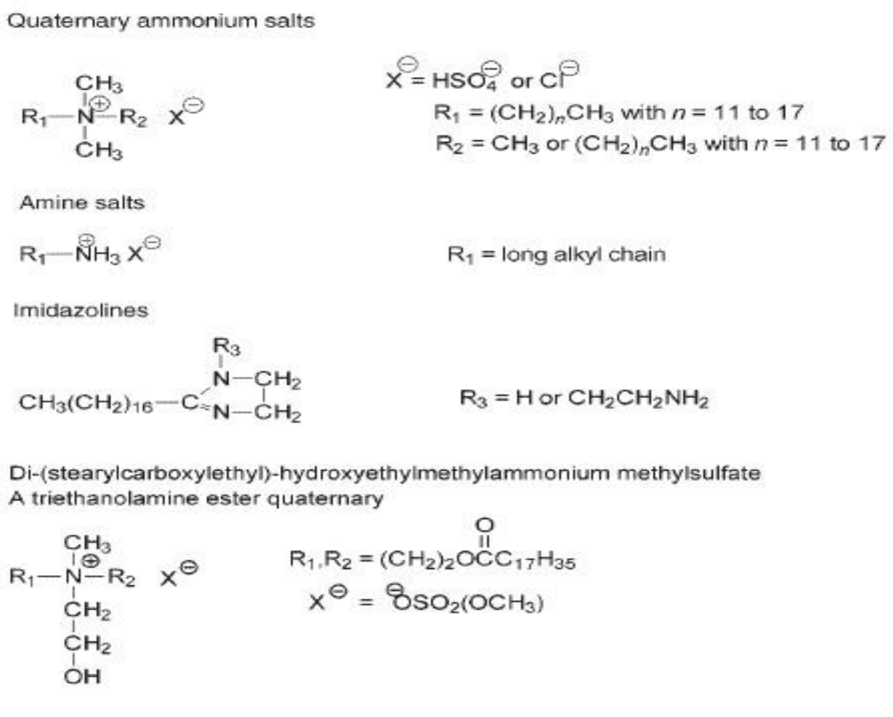

Figure 2.4 Chemical structures of typical cationic softeners [1].

2.3.2. Anionic softeners

The anionic softeners are soft, plain, full and rough to the touch and present an insulating stability. They are stable in alkaline baths and stable to almost every dye, except for cationic softeners with which efficiency is lower than cationic and nonionic softeners [8].

Anionic softeners are heat stable at normal textile processing temperatures and compatible with other components of dye and bleach baths. They can easily be washed off and provide strong antistatic effects and good rewetting properties because their anionic groups are oriented outward and are surrounded by a thick hydration layer. Sulfonates are, in contrast to sulfates, resistant to hydrolysis (Fig. 2.5). They are often used for special applications, such as medical textiles, or in combination with anionic fluorescent brightening agents [1].

Figure 2.5 Chemical structures of typical anionic softeners [1].

2.3.3. Non-ionic softeners

The non-ionic softeners present an independent efficiency from the pH and they are resistant to hard water. Softeners that are part of this group are the amphoterics and softeners based on silicone (with a mediocre hydrophilic effect), and the ethoxylates that have a very good hydrophility, a good insulating stability without causing yellowing, but these ones have an effect less intense than the cationic softeners [8].

Nonionic softeners do not carry any electrical charge and therefore do not possess any distinctive substantivity. Such products are applied by means of forced application i.e. usually in padding mangle procedures. Non-ionic softeners can be combined universally, are stable to temperature and do not yellow. This is the reason why this product class is perfect for finishing optically brightened high-white articles. The soft handle of pure non-ionic products is only average [9].

The example of a non-ionic softener shown in Fig. 2.6,

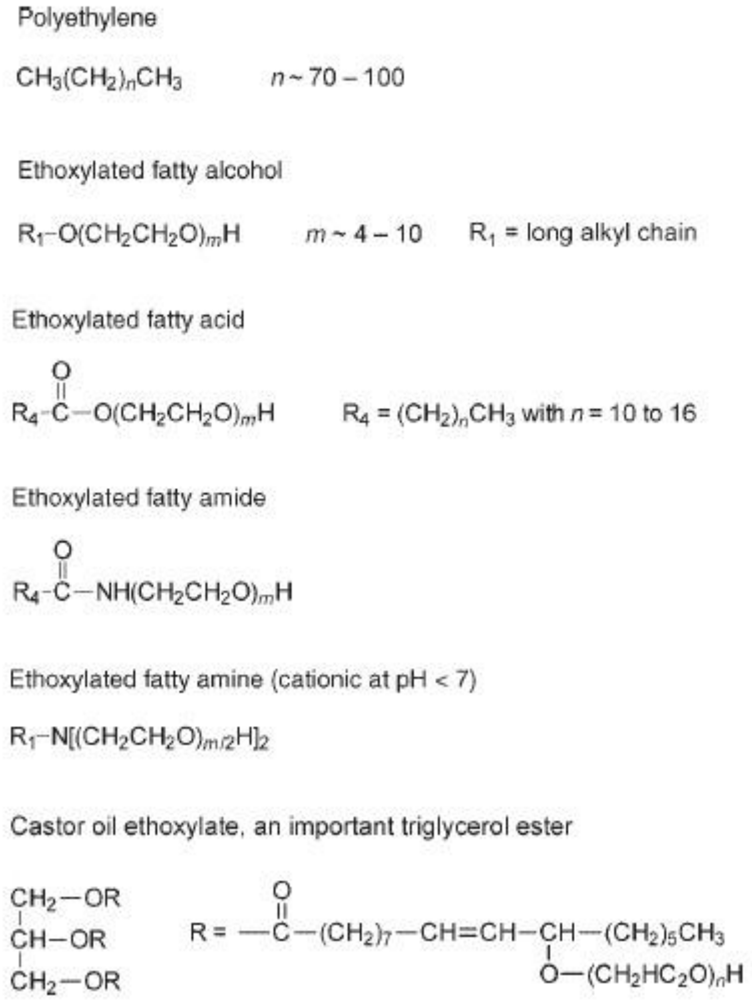

Figure 2.6 Chemical structures of typical non-ionic softeners [1].

2.3.4. Amphoteric softeners

Typical properties are good softening effects, low permanence to washing and high antistatic effects (because of their strong ionic character). They have fewer ecological problems than similar cationic products. Examples of the betaine and the amine oxide type are shown in Fig. 2.7 [10].

Formulations based on amphoteric substances are usually for special products of certain applications. Amphoteric products give an average handle, are normally compatible with white and give the fabric a good hydrophilicity as well as excellent antistatic properties. Furthermore, amphoteric softeners are very sensitive to skin and are often biodegradable. The main application range is hygiene and terry-cloth articles [9].

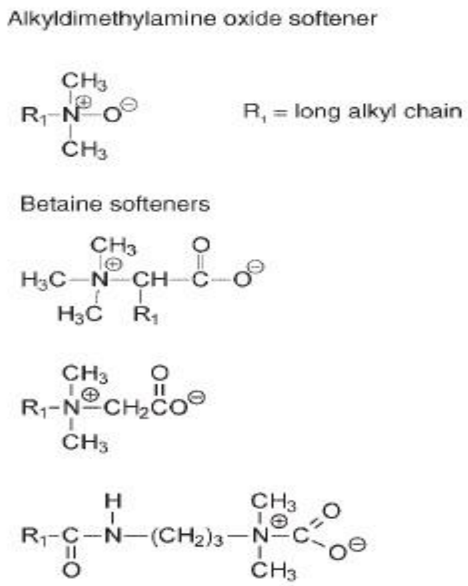

Figure 2.7 Chemical structures of typical amphoteric softeners [10].

2.3.5. Reactive softeners

The reactive softeners are usually applied in permanent finishes they are resistant to washing (on the contrary of others) and react to cellulose fiber. Beyond the soft effect, they have a slight hydrophobic finish [8].

2.4. Basic silicone chemistry

Silicon is the 14th element in the periodic table. Although it does not occur naturally in free form, in its combined form it accounts for about 25% of the earth's crust. Silicone compounds are unique materials both in terms of the chemistry and in their wide range of useful applications. Silicon in combination with organic compounds provides unique properties that function over a wide temperature, making the silicone based products less temperature sensitive than most organic surfactants. These properties can be attributed to the strength and flexibility of the Si-O bond, its partial ionic character and the low interactive forces between the non-polar methyl groups, characteristics that are directly related to the comparatively long Si-O and Si-C bonds. The length of the Si-O and Si-C bonds also allows an unusual freedom of rotation, which enables the molecules to adopt the lowest energy configuration at interfaces, providing a surface tension that is substantially lower than the organic polymers [11].

2.4.1. Silicone softeners

Finishing, the final step of chemical processing, is carried out to improve the properties, attractiveness and serviceability of textile materials. The treatment of textiles with substances that modify their surface properties has been a common practice since most ancient times. Softening of textiles becomes an important finishing process of many after-treatment processes in a textile chemical processing industry. The hand of a fabric is a subjective sensation felt by the skin when a textile fabric is touched with the finger tips and gently compressed. The perceived softness of a textile is the combination of several measurable physical phenomena, such as elasticity, compressibility and smoothness [12].

Silicone softeners have been around for years but were not widely used because of their expense and tendency to come out of solution to form oily spots on the treated fabric. More recently, the chemistry and the stability of baths containing the silicone have improved considerably. At the same time, the finisher has discovered how to blend the various silicones with conventional softeners to make them more efficient. Silicones available today are quite varied in their properties. Some are available in micro-emulsions, which are quite stable in application baths. Various functional chemistries can be chosen from epoxy and non-reactive systems to different amine structures. Most silicones are nonionic; however, some of those with amine functionality may be exhausted because they are cationic. The hand may be varied from dry and slick to soft and buttery. Although silicones have traditionally been hydrophobic, hydrophilic silicones are now available. These newer silicone technologies may incorporate more than one type of chemistry in the same molecule (i.e., amine chemistry for softness along with epoxy chemistry for hydrophilicity). Most of these silicones are quite durable to home laundering. They improve the tear, abrasion resistance, sewing, drape, and durable press properties, but may reduce the tensile strength [13].

Of the silicone softeners available, perhaps the most common in current industrial usage are the amino-functional types (Fig. 2.8). These materials offer a range of handles depending on the relative size of “X” and the ratio of “X:Y”. They may be supplied as surfactant-stabilized emulsions in water, either mechanical or micro emulsions. Mechanical emulsions contain large droplets which tend to coalesce on the fabric, giving surface effects. The micro emulsions, of much smaller droplet size, will tend to migrate into the yarn and give an overall softness to the whole structure [14].

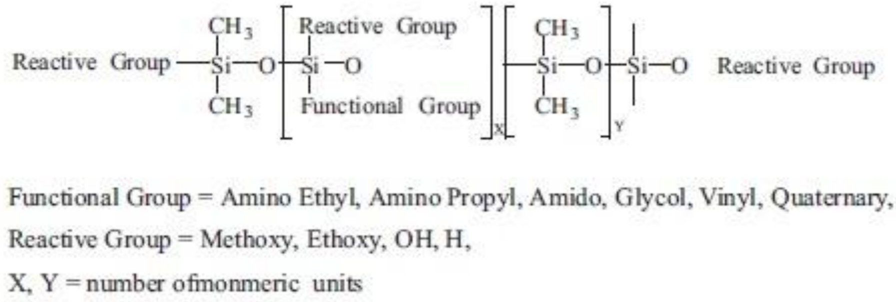

Figure 2.8 General structure of silicone softener [14].

Non-ionic and cationic examples of silicone softeners are shown in Fig. 2.9. They provide very high softness, special unique hand, high lubricity, good sewability, elastic resilience, crease recovery, abrasion resistance and tear strength. They show good temperature stability and durability, with a high degree of permanence for those products that form cross linked films and a range of properties from hydrophobic to hydrophilic [4].

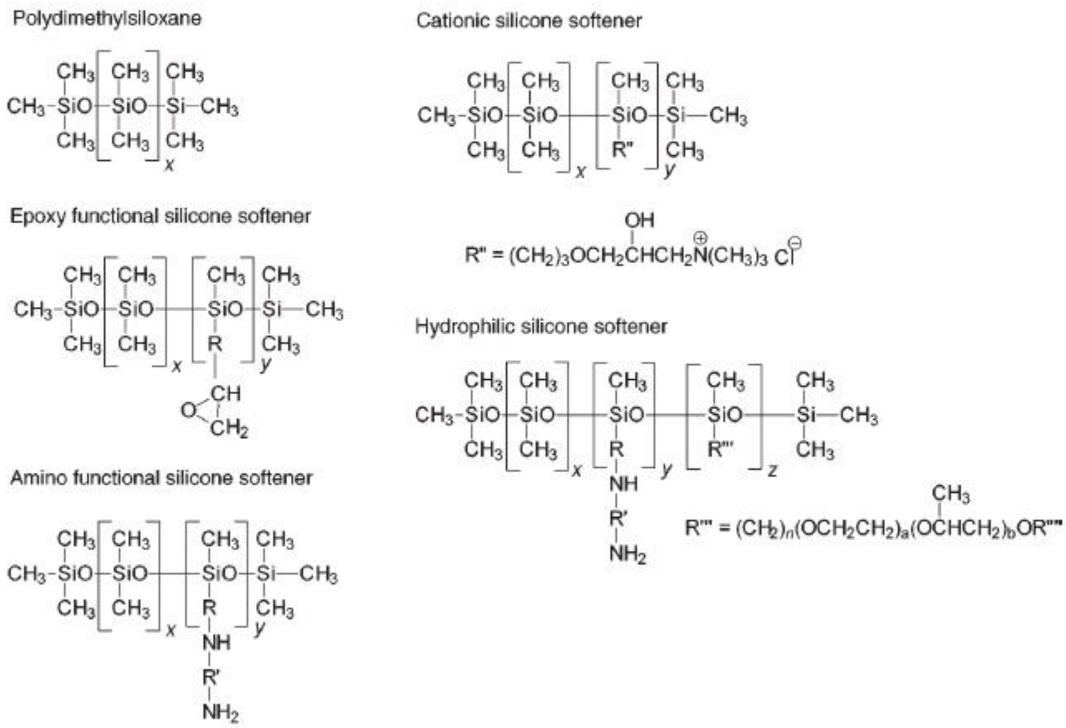

Figure 2.9 Chemical structures of typical silicone softeners [1].

Depending on their method of synthesis, silicone softeners can contain variable amounts of volatile siloxane oligomers. Together with volatile emulsifiers these oligomers can cause pollution problems in the waste air from tenter frames. In textile finishing, silicones are also used as water repellents, elastomeric finishes, coatings and as defoamers [1].

The high molecular flexibility of the silicone chain is the reason for the very low glass transition temperature (about –100 °C) and for their special softness. They postulate that to a great extent the methyl groups of the OSi (CH3)2-structure shield the oxygen atoms from outside contact. Therefore the surface of fibers finished with polydimethylsiloxane is mostly non-polar and hydrophobic. In the case of cellulose, wool, silk and polyamide fibers, there are strong hydrogen bonds between the hydroxyl or amino groups of the fibers and the amino groups of the modified silicones (Fig. 2.10, a). These bonds act as an anchor for the silicone, which forms an evenly distributed film on the fiber surface. Good water repellency and very soft hand are the result. With an optimal content of amino side groups, the polysiloxane segments between the anchor sites are long enough to maintain their high flexibility. This is the main reason for the softness and the lubricating effect of amino functional silicones on polar fibers.

In the case of relatively non-polar fibers such as polyester, the hydrophobic segments of the silicone chains interact strongly with the hydrophobic fiber surface (Fig. 2.10, b). The positively charged amino side groups of the silicone chains repel each other and give rise to enhanced flexibility of the silicone chain loops [1].

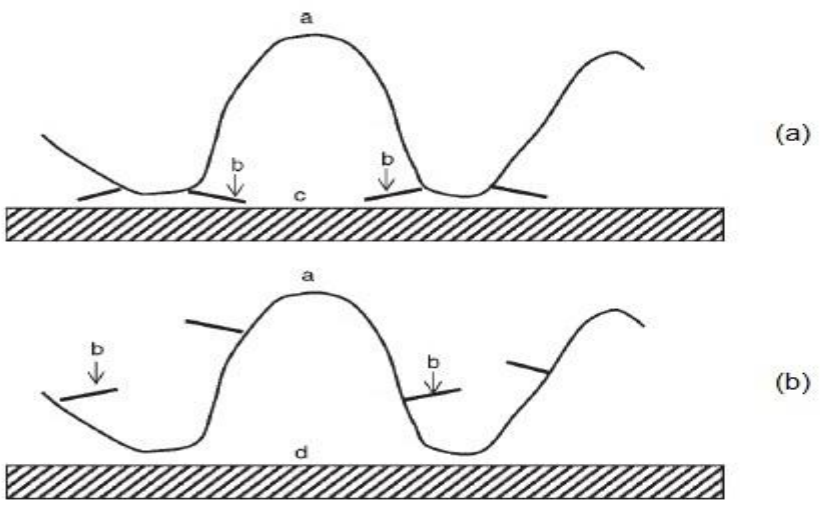

Figure 2.10 Schematic arrangements of amino-modified silicone softeners on the fiber surface [1].

a) loops of the polydimethylsiloxane chain,
b) partially cationic aminoethylaminopropyl side groups (about half of them are positively charged),
c) fiber surface with partially negative charge, for example cotton and wool,
d) Hydrophobic attraction of unmodified silicone chain segments and fiber surface, for example polyester [1].

2.4.1.1. Silicone applications in textile industry

The Application of silicone softeners turns hard and a brittle fabric into a soft pleasant textile with which the buyer can expect a high degree of wearing comfort. Silicone have wide spread applications in the textile industry from fiber, yarn and fabric production to final product finishing. Their distinctive chemistry imparts a range of characteristics. A variety of silicone technologies have application in the textile industry. They include,

- Polydimethylsiloxanes.
- Amido, Amino Functional Silicones.
- Methyl Hydrogen Silicones.
- Epoxy Functional Silicones.
- Hydroxy functional Silicones.
- Silicone Polyethers.
- Epoxy Polyether Silicones [15, 16].

2.4.1.2. Silicone emulsions particle size

Some research papers have been published on different effects of silicones on textile fibers but few of them have been reported on the effects of silicone particle size on different properties of fibers [17]. Silicone softeners are classified into three groups according to particle size; macro, micro and nano-silicones. Nano-silicone softeners penetrate the fabric inner structure more easily than others [18].

- Micro emulsion
- Macro emulsion
- Nano emulsion

Today, macro and micro emulsion silicone softeners based on high moisture absorbency are commercial classes of softeners [17].

Particle size of macro emulsion silicone softeners is 150–250 nm while the particle size of micro emulsion silicone softener is lower than 30 nm. The softener droplets in micro emulsion silicone softeners are smaller and allow them to penetrate the inner structure of the yarn or the fabric while macro emulsion silicone softeners can only load on the yarn or fabric surfaces [19].

This effect is shown in Figure 2.11,

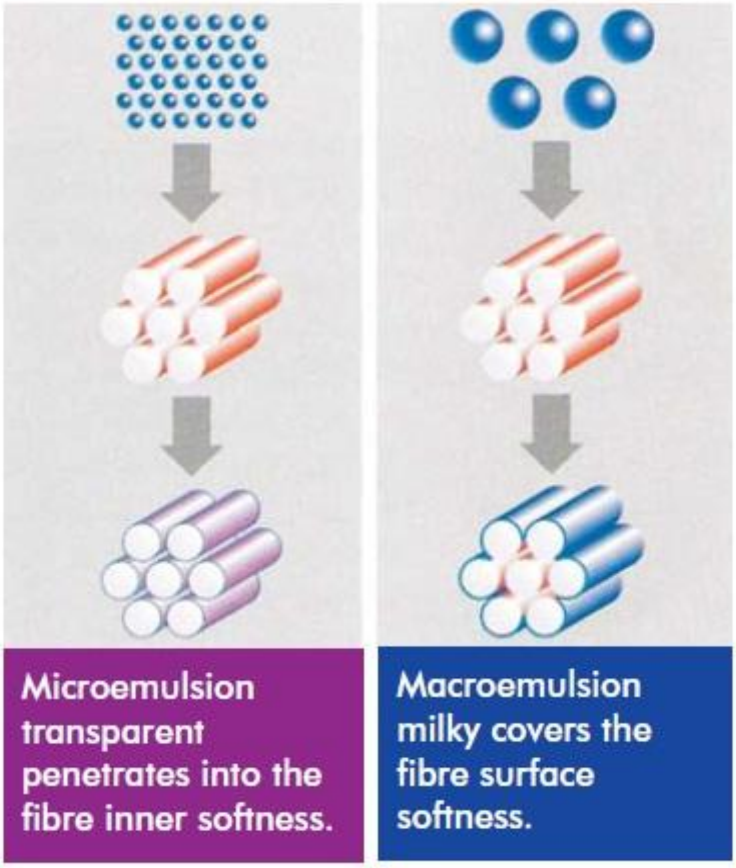

Figure 2.11 Micro & Macro emulsions [20]

Due to the fact that particle size of the micro emulsion silicone softeners are smaller, they penetrate the inner structure of the yarn or the fabric while macro emulsion silicone softeners settle on the surface of the yarn or the fabric. Similarly, the penetration effect of nano emulsion silicone softeners is higher than the micro emulsion silicone softeners. Furthermore, owing to multiplicity of bonds and ability of the molecule to easily diffuse into the fiber because of its nano molecular size, the durability of the nano finish is much better than the conventional polymer based finish. In the last decade the use of nano-silicone softeners has grown rapidly in textile wet processing [18].

2.4.1.3. Advantages of silicones

Silicones are water clear oils that are stable to heat and light and do not discolor fabric. They produce a slick silky hand and are preferred for white goods. They improve tear and abrasion resistance and are excellent for improving sewing properties of fabrics. Amino functional silicones improve durable press performance of cotton goods. Epoxy functional is more durable [21].

2.4.1.4. Disadvantages of silicones

The silicones are water repellent which make them unsuitable as towel softeners. Silicones are expensive compared with fatty softeners. Amino functional silicones discolor with heat and aging. They may interfere with redying when salvaging off quality goods [21].

2.4.1.5. Environmental effects of silicones

Non Volatile PDMS (Polydimethylsiloxane) fluid is essentially insoluble in water. These materials become a minor component of the sludge in the treatment plant. If the sludge is incinerated, the silicone content converts to amorphous silica, water and carbon dioxide. Silicone materials are highly resistant to bio degradation by micro organisms, but they undergo very effective degradation via natural chemical process such as catalyzed hydrolysis and oxidation. PDMS breaks down into siloxanols and silanols. PDMS is ecologically inert and has been found to have no effect on aerobic or anaerobic bacteria. It does not inhibit the biological process by which waste water is treated. In the world of eco friendly chemicals in the processing, silicones can offer the best solution to cater the multi dimension demands of the customers [15].

2.4.1.6. The future of silicone softeners

Due to their outstanding performance, the ‘tailorability’ of their properties and their low environmental impact, silicones can anticipate a bright future. They can be regarded as one of the most innovative classes of textile finishing auxiliaries [22].

2.5 Color difference

The primary objective of colorimetry is the numerical description of colors by means of physical measurements. Any two samples with the same numerical specification, for a given set of viewing conditions, will always have identical perceived colors under those conditions. The difference in the numerical descriptions of two colors should also correlate with the actual degree of color difference seen by an observer. Such a system of color specification is extremely valuable. It allows rapid and objective communication of color information, the specification of acceptable color differences and resolution of color matching disagreements between observers. Many industries producing colored materials now use colorimetry. It is a key technique in textile dyeing.

Visual evaluation of color differences involves both the description of the color difference and consideration of the viewing conditions. Even when two observers examine a pair of samples under identical conditions, they may not agree on whether the sample matches, or on the color difference between them. Instrumental color difference measurements eliminate color assessment disagreements arising from variations in the color vision of the observers and in the viewing conditions. In commercial color matching, a product's color may not be identical with that of the target but it may still be acceptable. Color matchers therefore distinguish between color difference perceptibility and acceptability. A color difference evaluation system should ideally allow the specification of the maximum permissible color difference for acceptability as well as the much more stringent tolerance for perceptibility [23].

The most widely used color difference equations in the last decades are CIELAB and CIELUV color difference equations recommended in 1976 by the CIE. In both CIELAB and CIELUV color spaces, the color difference ΔE* between two arbitrary colors is defined as an Euclidian distance in a uniform space comprising a lightness L* axis and red-green, yellow-blue opponent color axes using rectangular coordinates. The color differences in CIELAB color space are given by equation 1:

$$\Delta E^* = (\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \tag{1}$$

Where a* and b* are the redness-greenness and yellowness-blueness scales in CIELAB color space. The color difference formula CIE 76 is in many cases not adapted to human perception. The work in the area of color differences has concentrated on collecting reliable data and developing equations that describe the perceived color-difference results.

CHAPTER 3
MATERIALS AND METHODS

3.1. Materials

The details of knitted cotton fabrics supplied by Fıstık Tekstil / Gaziantep are given in Table 3.1.

Table 3.1 Details of cotton fabric

Wale/cm	Course/cm	Weight (g/cm²)	Knit type
15	20	110	RL Supreme

Then the fabrics were pre-treated and dyed in an uncontrolled industrial environment at Fıstık Tekstil / Gaziantep. The fabrics were dyed with reactive dyes to have primary colours (blue and red) which correspond to two different gamut of the CIELAB color space. The color coordinates of dyed samples are given in Table 3.2.

Table 3.2 Color coordinates of fabric samples

Fabric code	L*	a*	b*	Brightness indices (457)	Whiteness indices (WI CIE)	Yellowness indices (YI E313)	Hue angle (^{0})
Blue	56.11	-3.19	-34.05	49.99	249.17	-120.89	94.05
Red	35.92	53.29	28.25	2.80	-176.15	70.29	31.03

The samples of fabric were prepared in 20 cm X 20 cm dimensions for softening treatment pad application. The details of softeners applied are given in Table 3.3.

Table 3.3 Details of softeners

Chemical used	Type	Commercial name	Density (g/cm3)	≈ pH
Silicone 1	Nonionic	Tubingal RBC	1.01	4.2
Silicone 2	Nonionic	Arristan 65	1.00	4.5
Silicone 3	Nonionic	Arristan 444	1.00	4.5

The application was done by a laboratory type padding machine manufactured by Prowhite Testing Equipments with a model no: PDF01-A/0601001 with 220 VAc 50/60 Hz. (Fig. 3.1) [www.prowhite.eu]. The application recipe was 30 g /l softener.

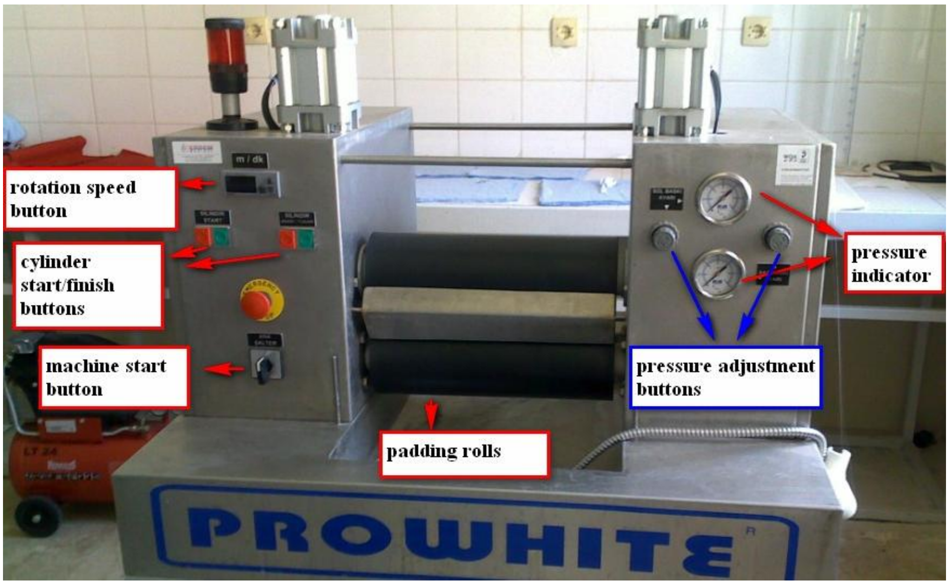

Figure 3.1 Prowhite padding machine

After padding application, the fabric samples were dried with a laboratory type drying machine manufactured by Prowhite Testing Equipments. This is used for drying and fixation after finishing and dyeing (Figure 3.2 and Figure 3.3).

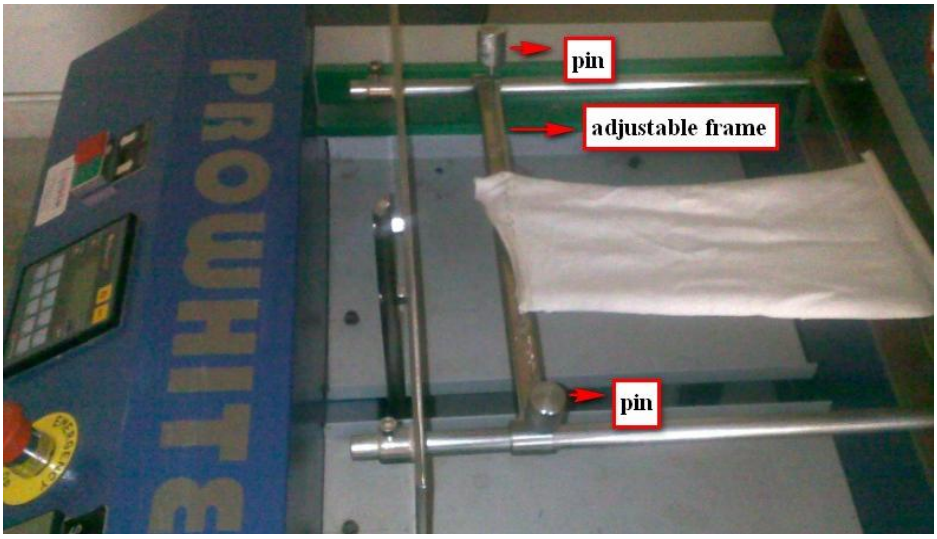

Figure 3.2 Prowhite drying machine

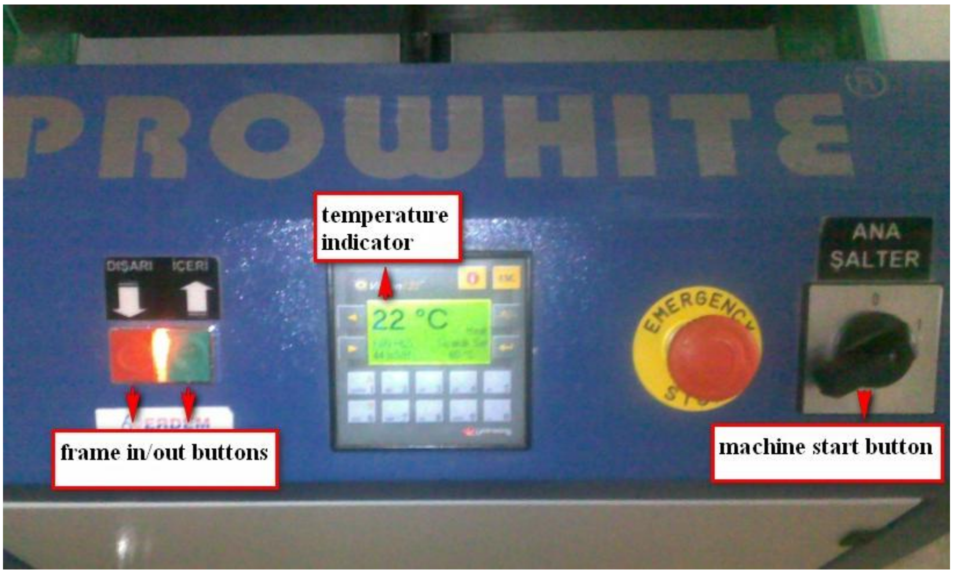

Figure 3.3 Prowhite drying machine

The padding machine was adjusted for required wet pick up ratio about 85%. The 85% wet pick up was acquired with the pressure of cylinders 3 bar and time of passing fabric about 2 m/min and the drying machine was adjusted for required drying temperature 120 °C and 5 min.

To investigate the effect of acidity, softening recipe was advanced with excessive NaOH (pH: alkali) and HCl (pH: acidic) and applied to fabric samples. pH values of acidic and alkali silicone softener recipes are given in Table 3.4.

Table 3.4 pH values of acidic and alkali silicone softener recipes

Particle sizes / pH values	Acidic pH	Alkali pH	Standard recipe pH
Silicone 1	2.52	12.31	4.5-5
Silicone 2	2.50	12.41	5-5.5
Silicone 3	2.45	12.18	4-4.5

3.2. Methods

After finishing application color assessment and measurements were done to the fabric samples which were treated with softening finish. Test methods and measurement methods used in this experimental study are given in following section.

3.2.1. Color assessment

For color assessments, the color coordinates of samples were measured on a Hunterlab reflectance spectrophotometer (Colorquest II) coupled to a PC under D65/10^0 illuminant with D/0 instrument geometry (Figure 3.4). Four reflectance measurements were made on each sample, rotating the samples 90° before each measurement and the averages of the % reflectance values at the wavelengths between 400-700 nm were recorded. Color coordinates and differences according to the CIELAB (1976) equation were then obtained according to the method and terminology defined in CIE 15.2 as mentioned in AATCC 173 and reported as DE, DWI, DBR and DYI.

The assessments were conducted after softener treatment, after 10 laundries (AATCC 8-2001) and after ironing. The ironing was done at 200 °C and 2 minutes.

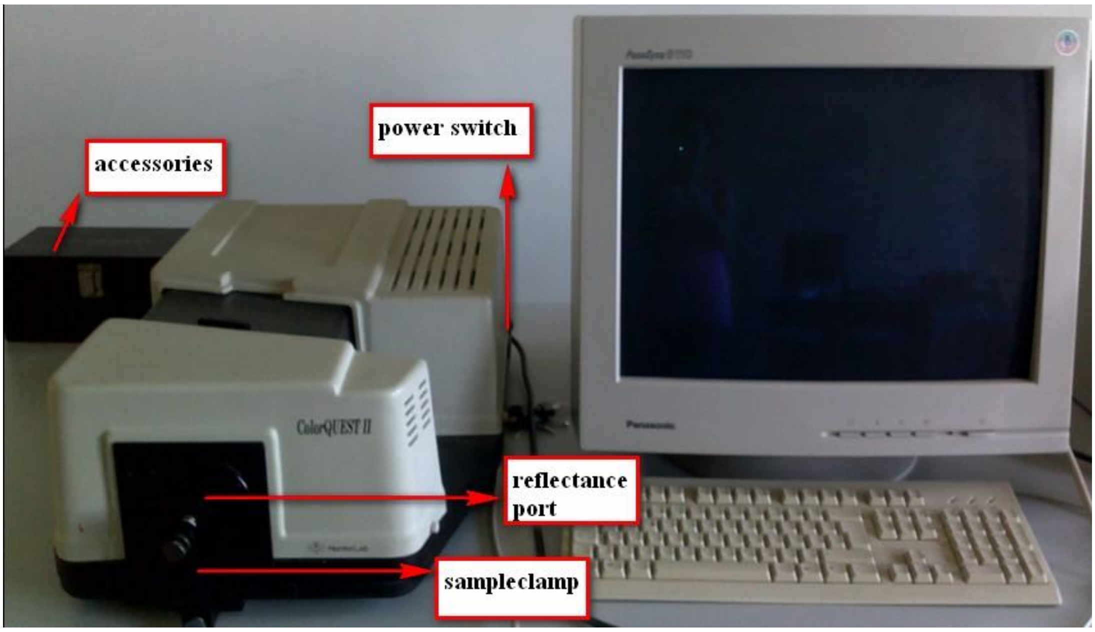

Figure 3.4 Hunterlab reflectance spectrophotometer

3.2.2. Particle Size Analyze of the Silicone Softeners

The particle size measurements of the softeners were performed with a Brookhaven Instruments 90 Plus (Holtsville, NY / USA) using dynamic light scattering technique which is based on simply to pass a beam of light through a colloidal dispersion. When this happens, the particles or droplets scatter some of the light in all directions. When the particles are very small compared with the wavelength of the light, the intensity of the scattered light is uniform in all directions (Rayleigh scattering); for larger particles (above approximately 250nm diameter), the intensity is angle dependent (Mie scattering). If the light is coherent and monochromatic, as from a laser for example, it is possible to observe time-dependent fluctuations in the scattered intensity using a suitable detector such as a photomultiplier capable of operating in photon counting mode. These fluctuations arise from the fact that the particles are small enough to undergo random thermal (Brownian) motion and the distance between them is therefore constantly varying. Constructive and destructive interference of light scattered by neighboring particles within the illuminated zone gives rise to the intensity fluctuation at the detector plane which, as it arises from particle motion, contains information about this motion. Analysis of the time dependence of the intensity fluctuation can therefore yield the diffusion coefficient of the particles from which, via the Stokes Einstein equation, knowing the viscosity of the medium, the hydrodynamic radius or diameter of the particles can be calculated [24].

To determine the particle size of silicone softeners, an emulsion was prepared by diluting the softener in distilled water in a ratio of 1:10; then, polyacrylic measuring cell of Brookhaven 90Plus was filled with approximately 4 mL of the emulsion and it was located in the measuring cuvette of the instrument without shaking or mixing to get laser beam pass through. The instrument applies dynamic light scattering technique. Dynamic light scattering is applied for almost three decades for studying dispersed systems. The software applied in the apparatus of Brookhaven Instr., gives multimodal size distribution basing on the autocorrelation functions for the dispersed light of the laser beam (670 nm) along with polydispersity and effective diameter. Polydispersity is a measure of nonuniformity in the particle size distribution in the studied system. It results from the method of cumulant analysis. In this method no assumption is needed about distribution functions [25]. The basic equation is:

$$g(t) = \int G(\Gamma) e^{-\Gamma t} \partial\Gamma \qquad (2)$$

Where g(t) is measured data, t is the delay time [25], G(Γ) is dependent upon distribution of the particles, and Γ is defined as:

$$\Gamma = Dq^2 \qquad (3)$$

Here D is the translational diffusion coefficient, which is determined from the scattered light and Eq. (4) describes the quantity q:

$$q = \frac{4\pi n}{\lambda}\sin(\frac{\theta}{2}) \quad (4)$$

In which n is the refraction index of the suspending liquid, θ is the scattering angle, and l is the wavelength of the laser light. Finally, the diffusion coefficient is related to the particle diameter d.

$$D = \frac{kT}{3\pi\eta d} \quad (5)$$

Where k is Boltzmann constant, T is absolute temperature, and η is the suspending liquid viscosity. The exponential in Eq. (2) is expanded in a Taylor's series about mean value and then integrated giving a general result. Then the logarithm of the autocorrelation function can expressed as a polynomial in the delay time t. The t powers in Taylor's series are called 'cumulants' of the distribution and they are identical to the 'moments of distributions'. It appeared that practically only first two of them are of reliable meaning. Eq. (3) expresses the first cumulant and the second is given by:

$$\mu_2 = (D^2 - D^{*2})q^2 \quad (6)$$

Here D* is the average diffusion coefficient. Thus, the effective diameter is calculated from Eq. (5) and μ2 moments allows calculation of the variance of the 'intensity' weighed distribution of diffusion coefficient. It gives information about width of the size distribution; more practical is use relative width, i.e. reduced second moment, which is called 'Polydispersity' [25].

$$\text{Poly.} = \mu 2 / \Gamma^2 \quad (7)$$

This is dimensionless magnitude and is close to zero for almost monodisperse sample. For narrow distributed sample it is ca. 0.02–0.08, and becomes higher for broader distributed samples.

As was said above the analysis is based on the intensity of scattered light that is proportional to number of particles N present in the suspension, and having diameter d and mass M. Moreover, the particle shape (if not spherical) factor P(q, d) has to be taken into account (for q see Eq. (4)). The factor is equal to 1 for particles much smaller than the wavelength (<60 nm) as well if the measurements are extrapolated to 0° angle. The diffusion coefficient distribution can be expressed following:

$$D = \Sigma N M^2 P(q, d) D / \Sigma N M^2 P(q, d) \quad (8)$$

The sums deal with all particles in the sample. Because mass M (or volume) is related to the diameter d in third power, the average, called ‘effective diameter’ results as [25]:

$$D_{eff} = \Sigma N d^6 / \Sigma N d^5 \quad (9)$$

if P(q, d)=1 has been assumed. Similarly, it can be defined number average diameter:

$$d_n = \Sigma N d / \Sigma N \quad (10)$$

area average diameter:

$$d_a = \Sigma N d^3 / \Sigma N d^2 \quad (11)$$

and weight average diameter:

$$d_w = \Sigma N d^4 / \Sigma N d^3 \quad (12)$$

From Eqs. (9), (10), (11) and (12) it results that $d_n \leq d_a \leq d_w \leq D_{eff}$, and equality occurs only for monodisperse sample. The bigger differences between the calculated diameters are the broader distribution of the particles in the sample exists. However, although the values are relative, for the same sample all the diameters can be used to characterize the sample. Moreover, the software has option for multimodal size distribution, which applies Non-Negatively constrained Least Squares (NNLS) algorithm with which the solution of Eq. (2) is a more general. It applies the approach of Grabowski and Morrison [26]. With this algorithm the weight (or volume), surface and number fractions from the intensity fractions, first scattering factors have to be calculated. They are obtained by Mie method, but here additionally to the suspending liquid refractive index, the complex refractive index of the particles has to be taken into account.

The duration of the measurement was around 5 minutes. The wavelength of the laser light was 670 nm. The size distributions were determined at 90^0 of the scattering angle of the laser beam and the measurements were carried out at 25^0C room temperature.

Figure 3.5 Brookhaven 90 Plus Particle Size Analyzer [27].

3.2.3. Statistically Evaluation

The contribution of softener type, having factors of three treatment levels, on color assessments were assessed for each fabrics with two different colors using a complete the randomized two way analyze of variance (ANOVA). The results were evaluated at 5% significance level.

We were evaluated the results based on the F-ratio and probability of the F- ratio the lower the probability of the F-ratio, the stronger the contribution of the variation and the more significant the variable. The treatment levels were marked in accordance with mean values, and any levels marked by same letter showed that they were not significantly different.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Spectrophotometric measurements

Color differences are very important for fabric production quality. The color differences in samples cause customer dissatisfaction. The finish applications should not result with color difference. The spectrophotometers can be operated to measure the whiteness and yellowness indices, brightness and besides color difference between standard and sample fabric and etc.

The color values for each blue and red fabric samples which treated with softeners in different particle sizes (Silicone 1, Silicone 2 and Silicone 3) are recorded between 400-700 nm wavelengths. These values are shown in tables and figures for each treatment.

Table 4.1 and Figure 4.1 show reflection values (%) in 400-700 nm wavelength for blue fabric samples which treated with softeners in different particle sizes. The color coordinates of blue fabric are shown in Table 4.2 and Figure 4.2 and the differences of color coordinates of blue fabric are shown in Table 4.3 and Figure 4.3 and values for red fabric samples are shown in Table 4.4, Table 4.5, Table 4.6 and Figure 4.4, Figure 4.5, Figure 4.6.

Table 4.1 % Reflection values of the blue samples within visible region (std. recipe)

λ (nm)	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated	Untreated
400	38.42	35.30	36.35	37.23
420	44.79	40.61	41.67	44.43
440	53.34	48.55	49.44	53.74
460	52.34	47.73	48.47	52.76
480	44.60	40.78	41.44	44.56
500	36.14	33.04	33.57	36.19
520	28.89	26.49	26.96	29.08
540	23.25	21.42	21.85	23.46
560	18.88	17.41	17.80	19.25
580	15.76	14.61	14.99	16.17
600	14.32	13.33	13.72	14.62
620	13.69	12.81	13.16	13.96
640	13.40	12.59	13.03	13.55
660	16.66	15.69	16.41	16.45
680	26.31	24.97	25.94	25.63
700	43.10	41.13	42.22	42.29

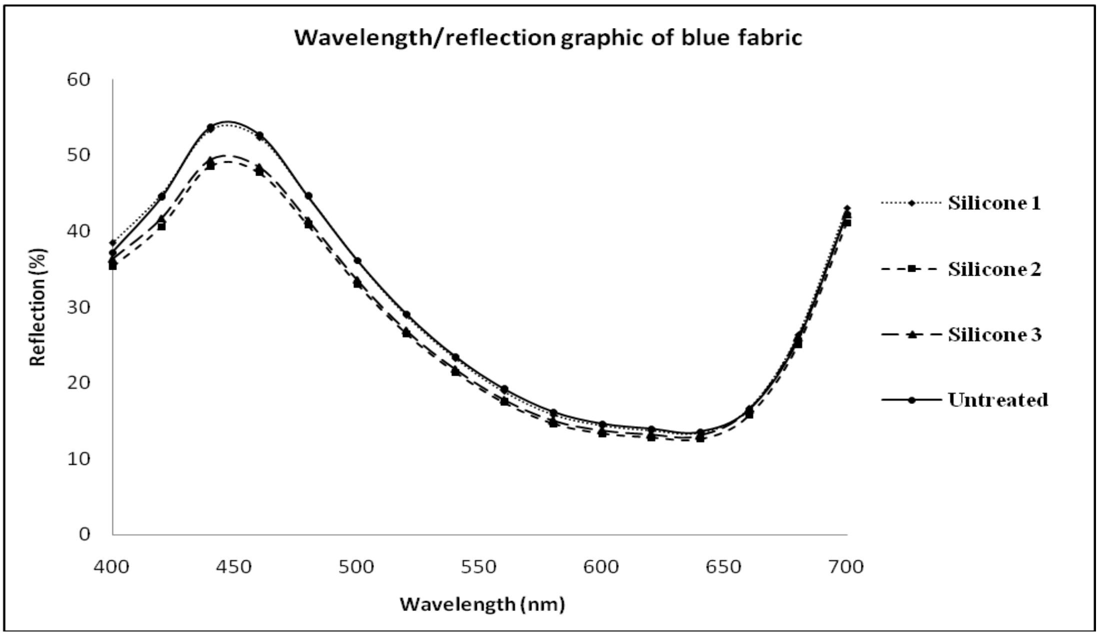

Figure 4.1 Wavelength/reflection graphic of blue fabric (std. recipe)

Table 4.2 Color coordinates of blue fabric (standard recipe)

	L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Untreated	56.11	-3.19	-34.05	--	49.99	249.17	-120.89
Silicone 1 treated	55.86	-3.30	-34.26	0.58	49.76	250.91	-122.41
Silicone 2 treated	53.89	-3.13	-32.81	2.91	45.34	245.85	-119.94
Silicone 3 treated	54.36	-2.92	-32.90	2.47	46.12	245.36	-119.16

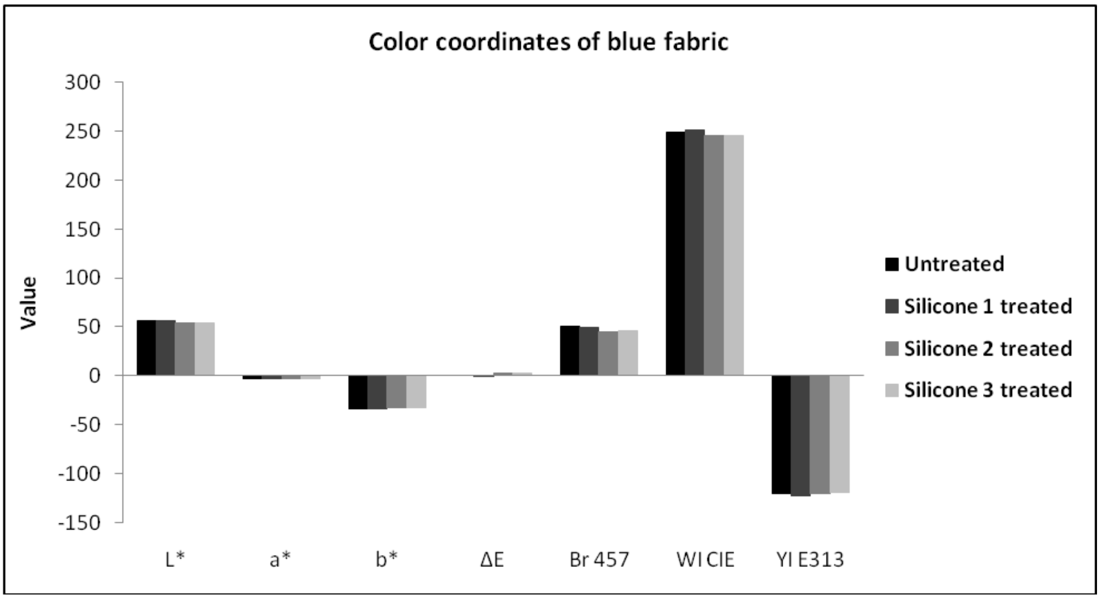

Figure 4.2 Color coordinates graphic of blue fabric (std. recipe)

Table 4.3 Differences of color coordinates of blue fabric (std. recipe)

	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated
ΔL*	-0.25	-2.22	-1.75
Δa*	-0.12	0.06	0.27
Δb*	-0.21	1.24	1.16
ΔWI CIE	1.75	-3.32	-3.81
ΔBr 457	-0.23	-4.65	-3.88
ΔYI E313	-1.52	0.95	1.73
ΔE	0.51	2.55	2.13

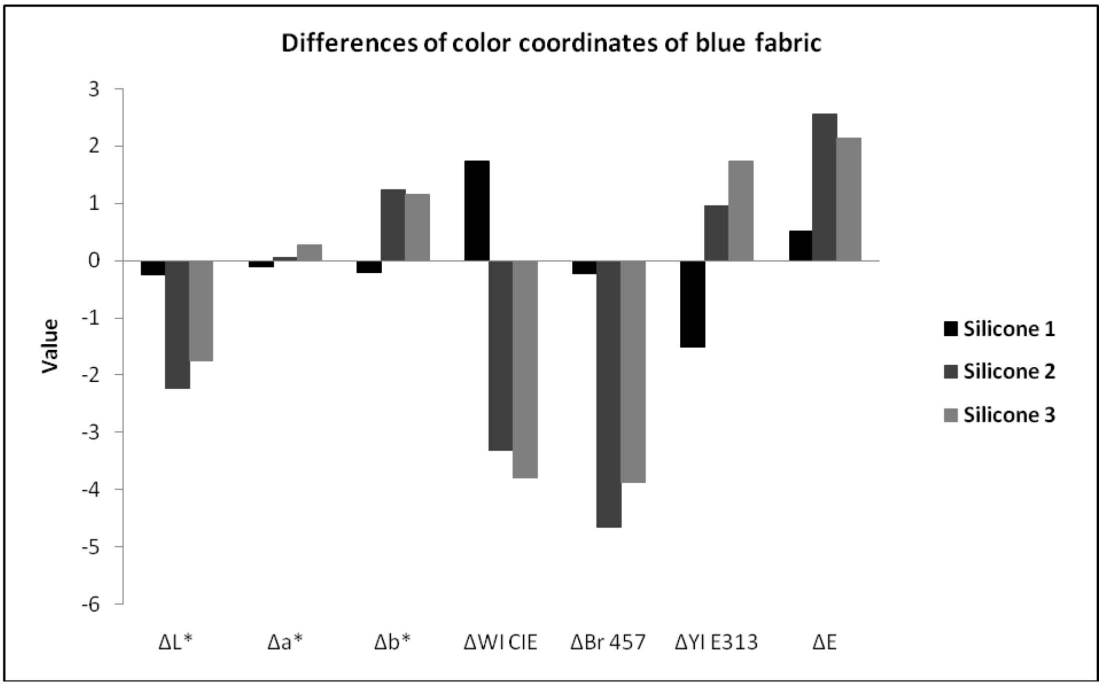

Figure 4.3 Differences of color coordinates graphic of blue fabric (std. recipe)

Table 4.1 and Fig. 4.1 show (%) reflection values between 400-700 nm. In Fig 4.1 reflection values of Silicone 2 and Silicone 3 treated samples were lower than Silicone 1 treated fabric. This difference can be seen more clearly between 400-550 wavelength and it showed that light absorbance of Silicone 2 and Silicone 3 treated fabrics are more than Silicone 1 treated fabric samples. Silicone 1 treated sample reflection value was similar to untreated fabric sample comparing to Silicone 2 and Silicone 3 treated fabric samples.

Color coordinates and its differences are given in Table 4.2, Table 4.3 and Fig. 4.2, Fig. 4.3. In Table 4.2 and Figure 4.2, color coordinates of Silicone 3 treated and Silicone 2 treated fabric samples are found more different than Silicone 1 treated fabric sample. For differences of color coordinates we can say that Silicone 1 softener effect is lower than Silicone 2 and Silicone 3 in color values. Silicone 1 treated fabric sample brightness value difference and ΔE value is lower than other samples. Yellowness indices of Silicone 2 and Silicone 3 treated fabric samples increase, on the other hand Silicone 1 treated fabric sample decreases and for whiteness indices of samples, Silicone 2 and Silicone 3 treated fabric samples point decrease but Silicone 1 treated fabric sample shows increase. According to CIELAB standards, whiteness value differences are related to L* value differences and yellowness value differences are related to b* value differences.

Table 4.4 % Reflection values of the red samples within visible region (std. recipe)

λ (nm)	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated	Untreated
400	5.57	5.25	5.17	5.35
420	3.39	3.15	3.08	3.28
440	3.06	2.84	2.79	2.99
460	2.82	2.63	2.59	2.78
480	2.48	2.31	2.27	2.47
500	2.20	2.06	2.04	2.22
520	2.02	1.90	1.89	2.06
540	2.14	2.02	2.00	2.19
560	2.32	2.20	2.21	2.41
580	5.25	5.00	5.01	5.41
600	18.86	18.22	17.92	18.96
620	41.70	40.66	39.69	41.13
640	61.25	60.08	58.60	59.71
660	71.21	70.00	68.37	68.62
680	75.14	7387	72.33	71.93
700	80.76	79.59	78.13	77.66

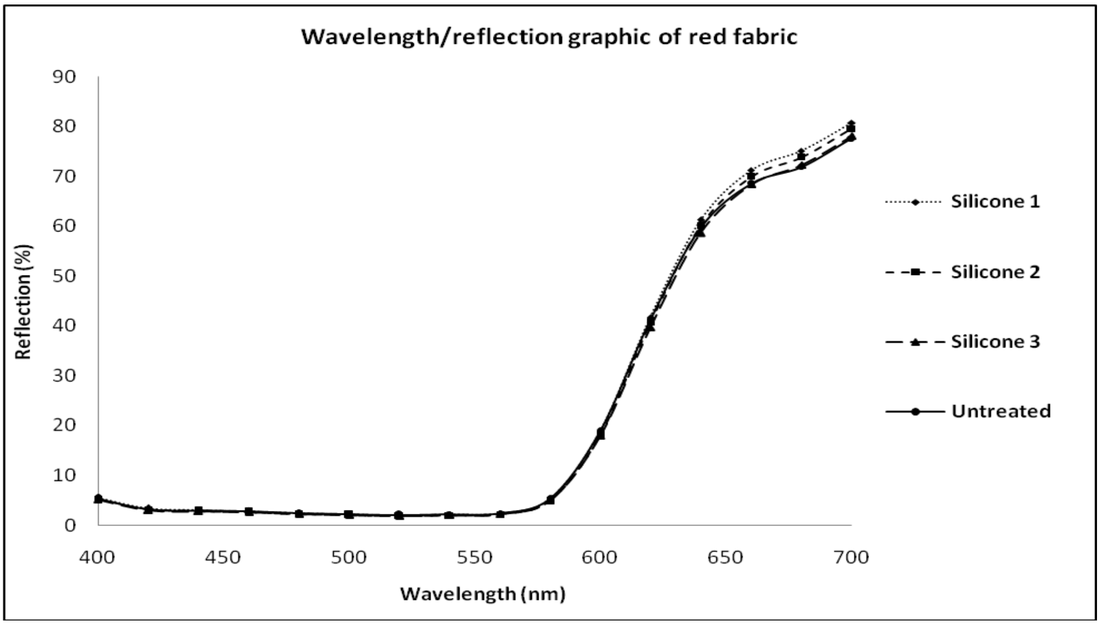

Figure 4.4 Wavelength/reflection graphic of red fabric (std. recipe)

Table 4.5 Color coordinates of red fabric (std. recipe)

	L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Untreated	35.92	53.29	28.25	--	2.80	-176.15	70.29
Silicone 1 treated	36.00	54.07	27.98	0.93	2.85	-173.59	69.90
Silicone 2 treated	35.43	53.91	28.27	0.69	2.66	-177.44	71.03
Silicone 3 treated	35.14	53.33	28.32	0.72	2.61	-178.15	71.09

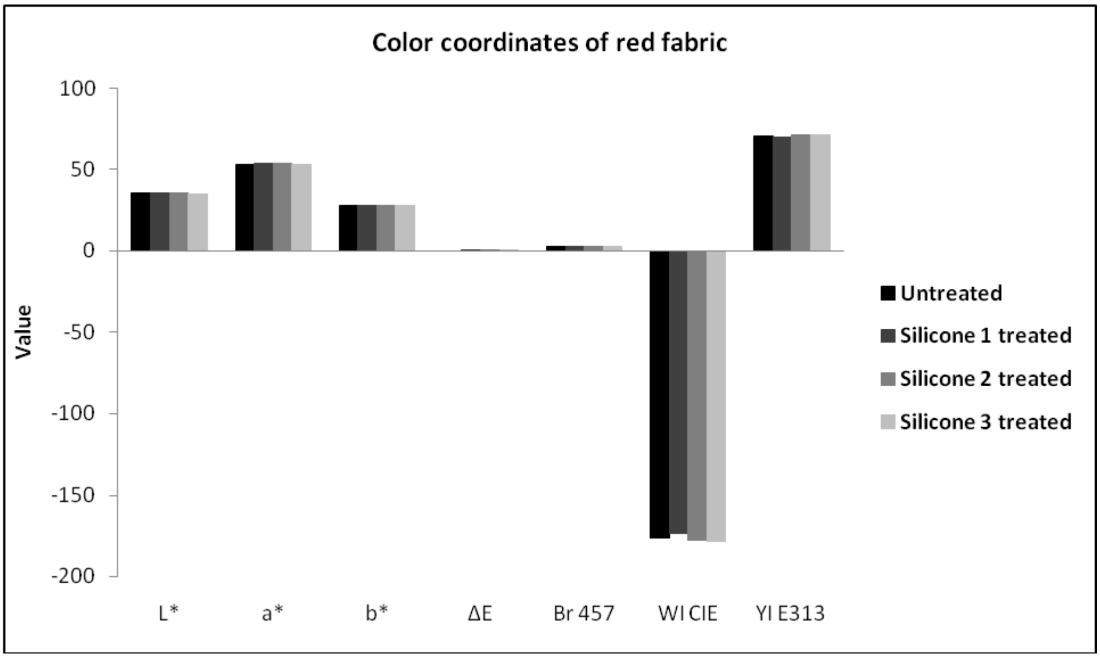

Figure 4.5 Color coordinates graphic of red fabric (std. recipe)

Table 4.6 Differences of color coordinates of red fabric (std. recipe)

	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated
ΔL*	0.07	-0.49	-0.79
Δa*	0.78	0.62	0.04
Δb*	-0.27	0.19	0.07
ΔWI CIE	2.56	-1.29	-2.00
ΔBr 457	0.05	-0.15	-0.20
ΔYI E313	-0.39	0.75	0.80
ΔE	0.95	0.84	0.80

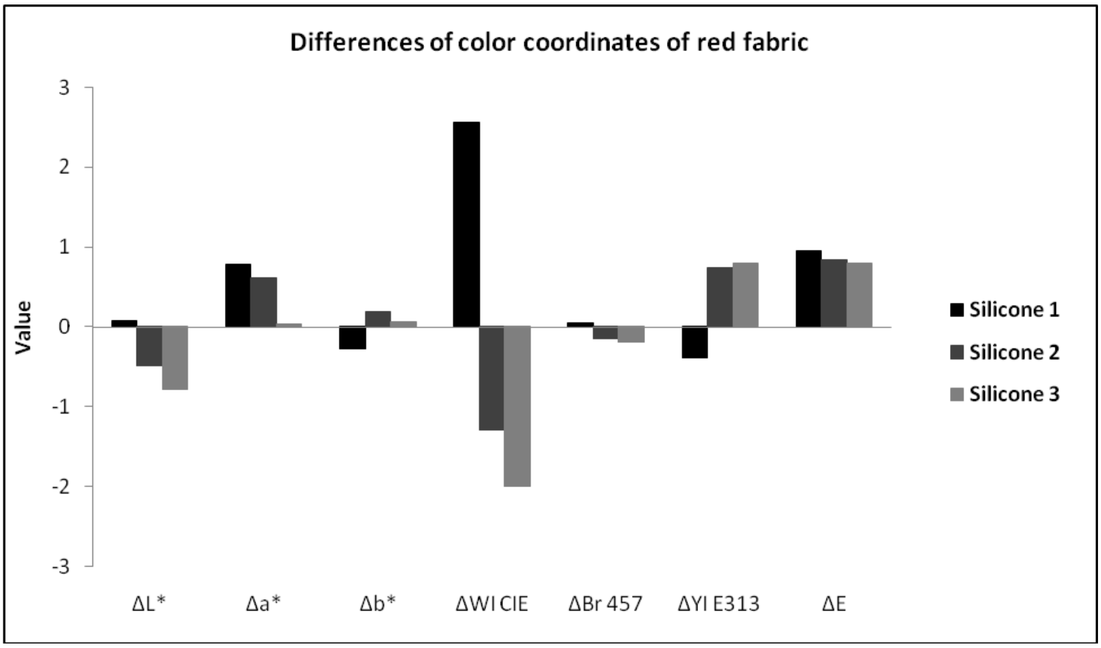

Figure 4.6 Differences of color coordinates graphic of red fabric (std. recipe)

Fig 4.4 shows Silicone 1 treated sample reflection value similar to untreated fabric sample comparing to Silicone 2 and Silicone 3 treated fabric samples. Reflection values of Silicone 1 and Silicone 2 treated samples are noticed higher than Silicone 3 treated fabric and this difference can be seen more clearly at high wavelength and it shows that light absorbance of Silicone 1 and Silicone 2 treated fabrics are less than Silicone 3 treated fabric samples.

Table 4.5, Table 4.6 and Fig. 4.5, Fig. 4.6 shows color coordinates and its differences for red fabric samples. In Table 4.5 and Figure 4.5, color coordinates of Silicone 3 and Silicone 2 treated fabric samples were more different than Silicone 1 treated fabric sample. Whiteness indices value of Silicone 1 treated fabric samples shows a sensible increase and Silicone 2 and Silicone 3 treated fabric samples whiteness value shows decrease. That causes increase L**** value in Silicone 1 treated samples. Decrease in yellowness indices caused by decrease in b* value for Silicone 1 treated fabric samples and increase in yellowness indices caused by increase in b* value for Silicone 2 and Silicone 3 treated samples.

Results for blue fabric samples which treated softener recipe in acidic pH shown in Table 4.7, Table 4.8, Table 4.9 and Figure 4.7, Figure 4.8, Figure 4.9.

Table 4.7 % Reflection values of the blue samples within visible region (acidic pH)

λ (nm)	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated	Untreated
400	46.85	46.68	46.77	37.23
420	53.70	53.58	53.71	44.43
440	62.10	62.03	62.21	53.74
460	59.94	59.79	59.92	52.76
480	51.06	50.81	50.86	44.56
500	41.41	41.13	41.15	36.19
520	33.32	33.04	33.07	29.08
540	27.07	26.82	26.86	23.46
560	22.18	21.96	22.02	19.25
580	18.91	18.73	18.81	16.17
600	17.48	17.34	17.44	14.62
620	16.85	16.70	16.81	13.96
640	16.72	16.62	16.74	13.55
660	21.02	21.03	21.19	16.45
680	31.98	32.09	32.18	25.63
700	46.25	46.02	45.54	42.29

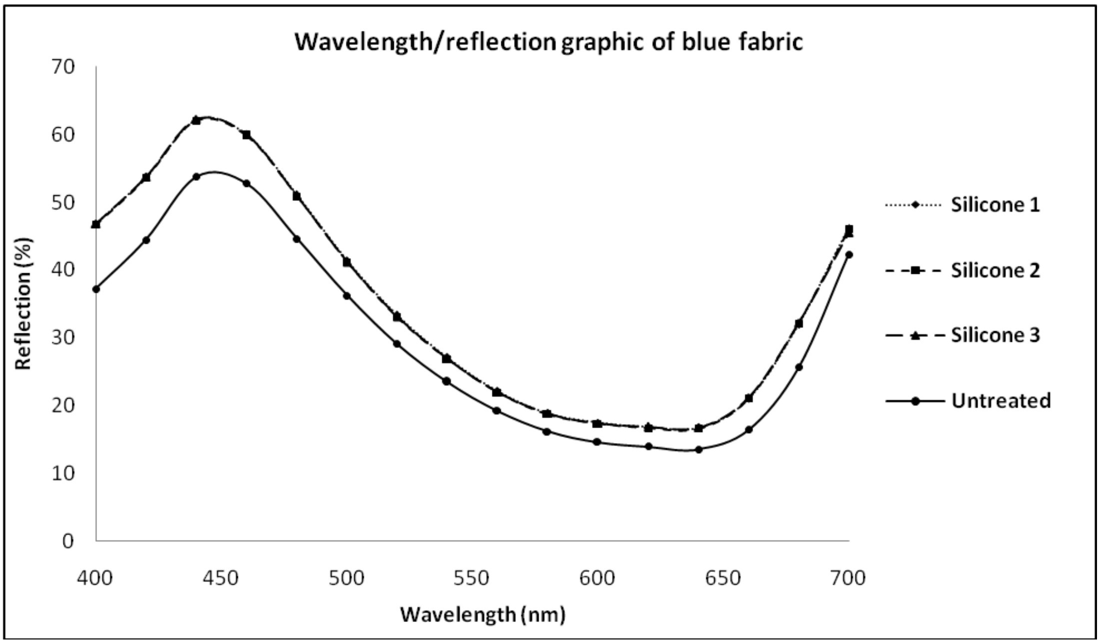

Figure 4.7 Wavelength/reflection graphic of blue fabric (acidic pH)

Table 4.8 Color coordinates of blue fabric (acidic pH)

	L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Untreated	56.11	-3.19	-34.05		49.99	249.17	-120.89
Silicone 1 treated	59.70	-2.10	-35.60	4.52	57.40	251.54	-119.52
Silicone 2 treated	59.51	-1.90	-35.80	4.53	57.25	252.90	-120.76
Silicone 3 treated	59.57	-1.77	-35.82	4.64	57.37	252.91	-120.73

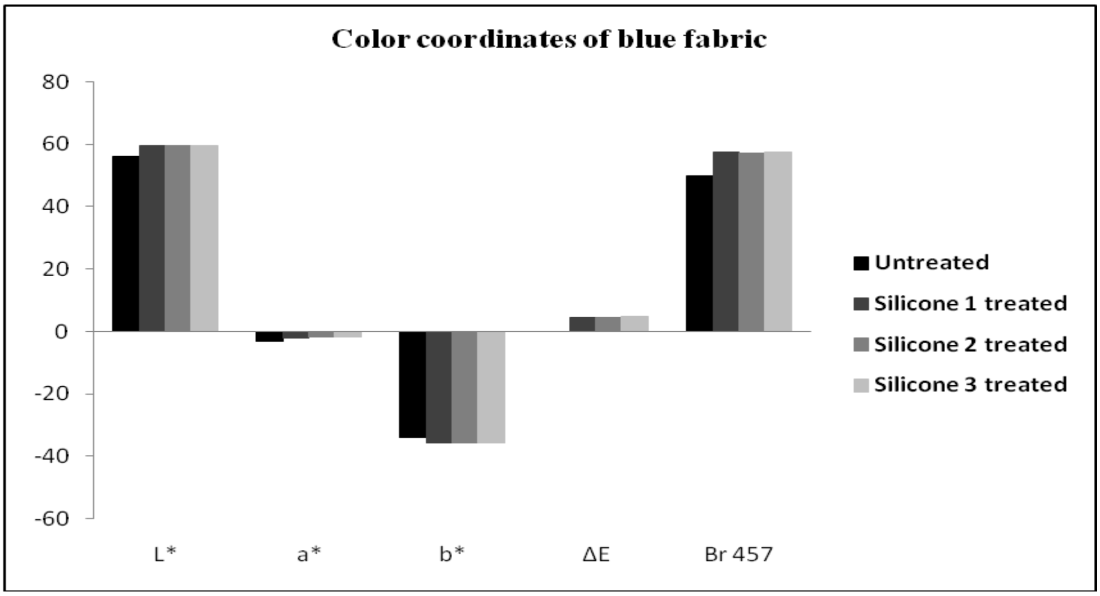

Figure 4.8 Color coordinates graphic of blue fabric (acidic pH)

Table 4.9 Differences of color coordinates of blue fabric (acidic pH)

	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated
ΔL*	3.59	3.40	3.46
Δa*	1.09	1.29	1.42
Δb*	-1.55	-1.75	-1.77
ΔWI CIE	2.37	3.73	3.74
ΔBr 457	7.41	7.26	7.38
ΔYI E313	1.37	0.13	0.17
ΔE	4.07	4.03	4.15

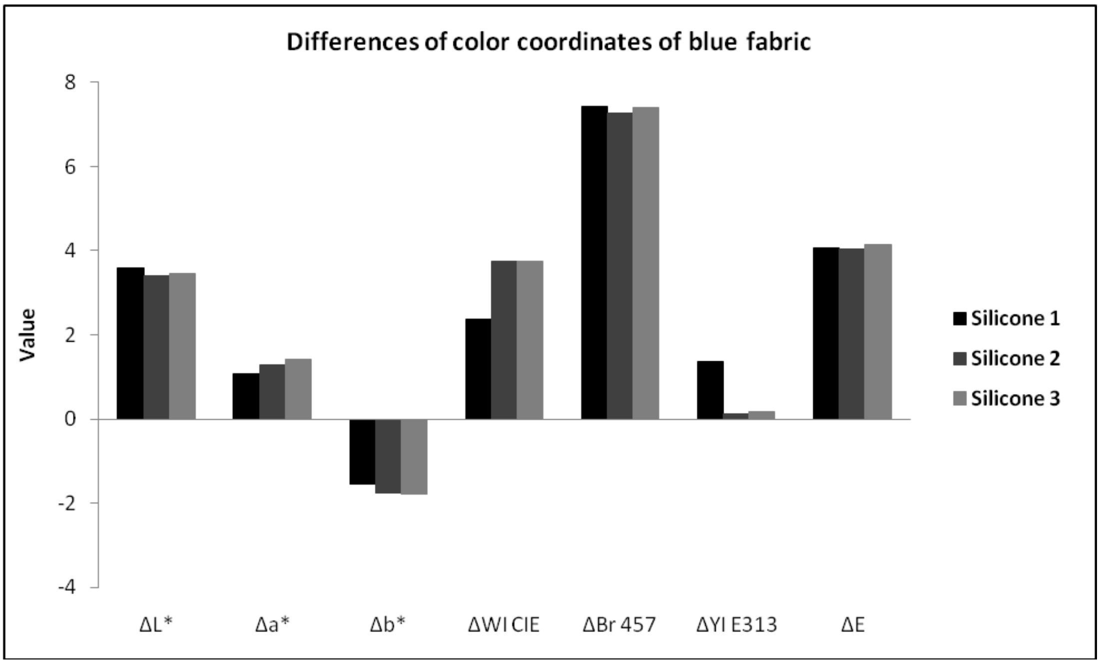

Figure 4.9 Differences of color coordinates graphic of blue fabric (acidic pH)

Fig 4.7 shows Silicone 1, Silicone 2 and Silicone 3 treated fabric samples reflection values are almost equally higher than untreated fabric sample. Light absorption of all samples which treated softener decreases after softening treatment.

Table 4.8, Table 4.9 and Fig. 4.8, Fig. 4.9 shows color coordinates and its differences for blue fabric samples. In Table 4.8 and Figure 4.8, color coordinates of Silicone 1, Silicone 2 and Silicone 3 treated fabric samples are found similar untreated fabric sample. Whiteness indices value of Silicone 1 treated fabric samples shows increase but Silicone 2 and Silicone 3 treated fabric samples whiteness value shows more increase. That causes increase L***** value in Silicone 1 treated samples. Increase in yellowness indices for Silicone 1 treated fabric samples more than increase in yellowness indices for Silicone 2 and Silicone 3 treated samples.

The result values of red fabric samples which were treated in alkali pH with softeners given in Table 4.10, Table 4.11, Table 4.12 and Figure 4.10, Figure 4.11, Figure 4.12.

Table 4.10 % Reflection values of the red samples within visible region (acidic pH)

λ (nm)	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated	Untreated
400	7.01	6.92	7.00	5.35
420	4.40	4.35	4.35	3.28
440	3.80	3.70	3.70	2.99
460	3.33	3.18	3.18	2.78
480	2.86	2.72	2.71	2.47
500	2.58	2.47	2.47	2.22
520	2.38	2.30	2.30	2.06
540	2.53	2.46	2.46	2.19
560	2.71	2.64	2.64	2.41
580	6.01	5.85	5.84	5.41
600	20.23	19.68	19.63	18.96
620	41.88	40.83	40.78	41.13
640	59.55	58.29	58.29	59.71
660	70.54	69.61	69.58	68.62
680	76.59	76.07	75.96	71.93
700	81.30	80.64	80.60	77.66

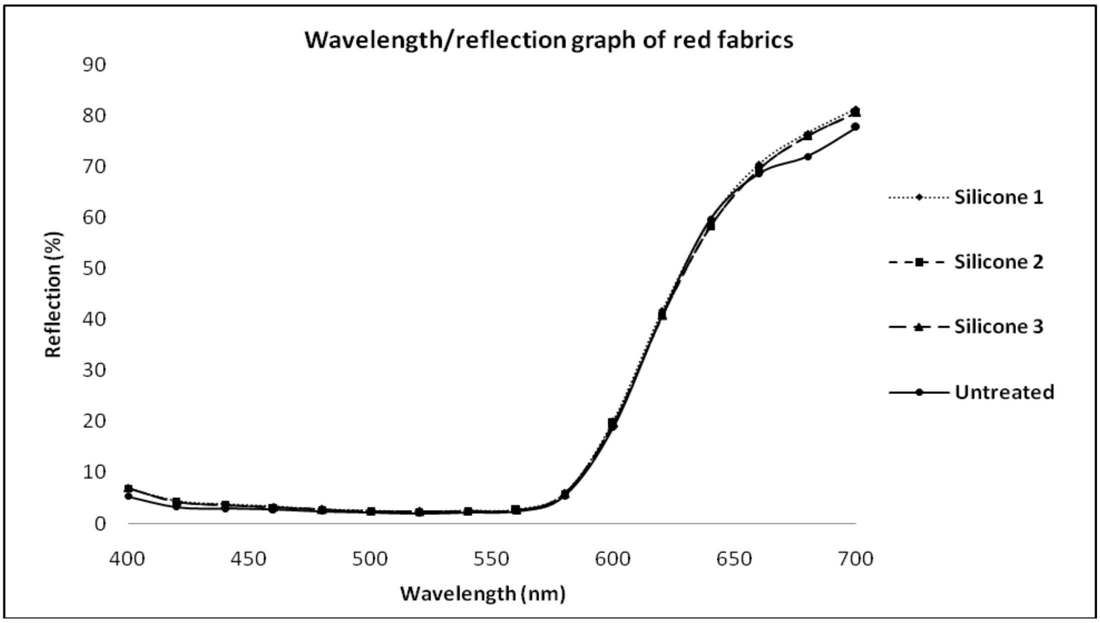

Figure 4.10 Wavelength/reflection graphic of red fabric (acidic pH)

Table 4.11 Color coordinates of red fabric (acidic pH)

	L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Untreated	35.92	53.29	28.25	--	2.80	-176.15	70.29
Silicone 1 treated	36.89	52.90	25.27	1.35	3.44	-157.95	65.08
Silicone 2 treated	36.45	52.63	25.21	1.19	3.32	-158.91	65.39
Silicone 3 treated	36.42	52.63	25.16	1.20	3.32	-158.70	65.35

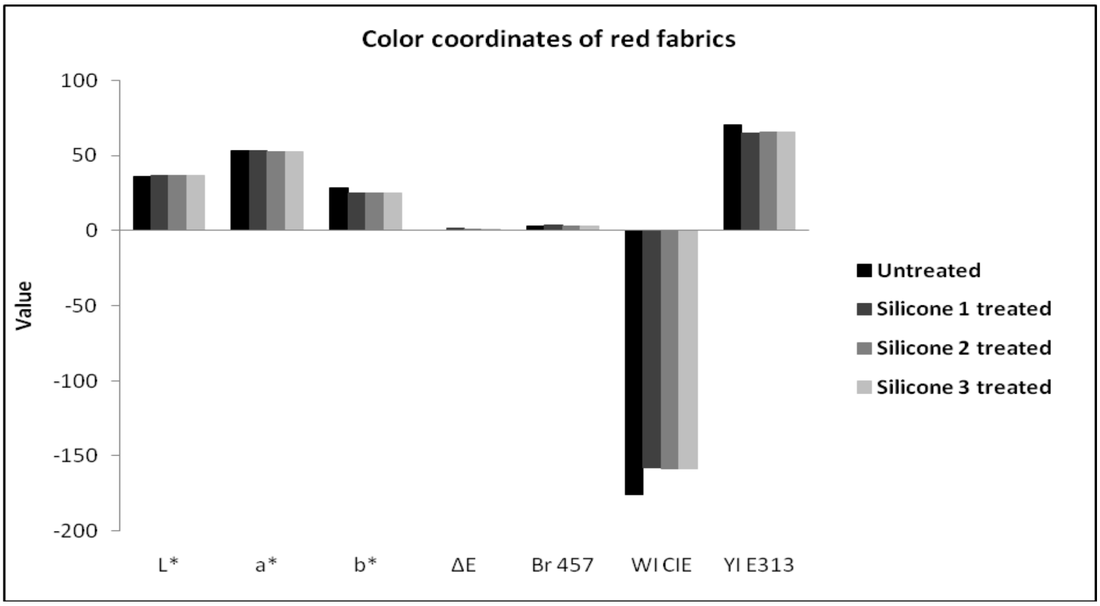

Figure 4.11 Color coordinates graphic of red fabric (acidic pH)

Table 4.12 Differences of color coordinates of red fabric (acidic pH)

	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated
ΔL*	0.97	0.52	0.50
Δa*	-0.39	-0.66	-0.66
Δb*	-2.99	-3.04	-3.09
ΔWI CIE	18.20	17.25	17.45
ΔBr 457	0.64	0.52	0.51
ΔYI E313	-5.21	-4.90	-4.94
ΔE	3.23	3.17	3.21

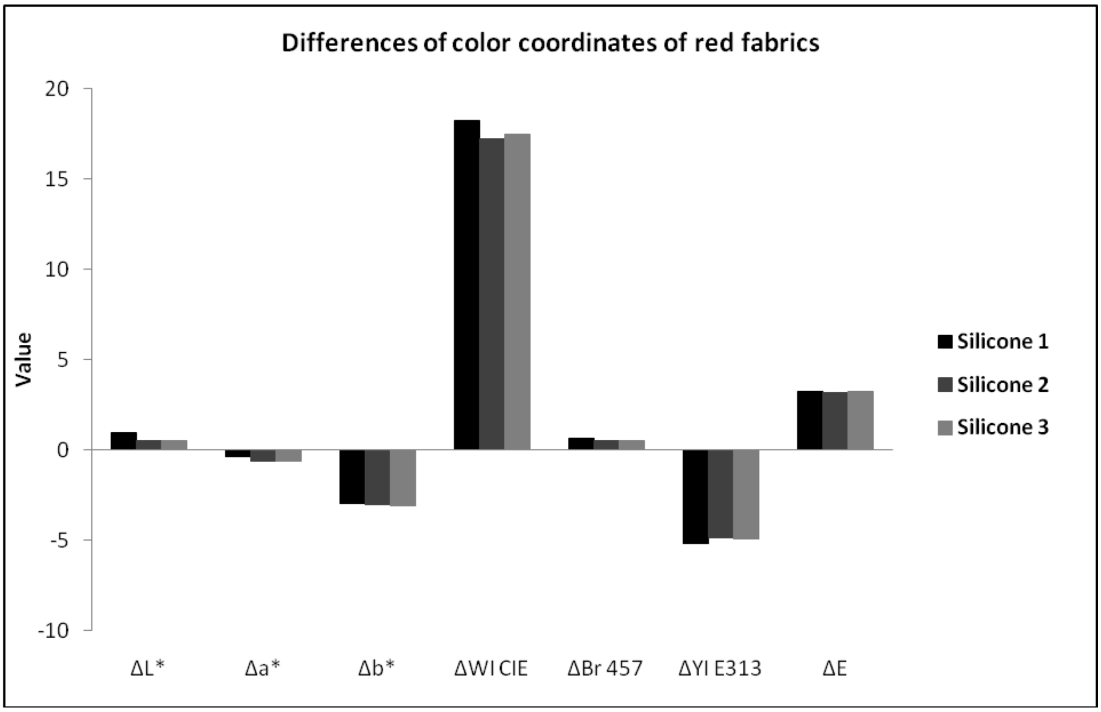

Figure 4.12 Differences of color coordinates graphic of red fabric (acidic pH)

Fig 4.10 shows Silicone 1, Silicone 2 and Silicone 3 treated fabric samples reflection values are almost equally higher than untreated fabric sample in high wavelengths. Light absorption of all samples which treated softener decreases after softening treatment.

Table 4.11, Table 4.12 and Fig. 4.11, Fig. 4.12 shows color coordinates and its differences for red fabric samples. In Table 4.11 and Figure 4.11, color coordinates of Silicone 3 and Silicone 2 treated fabric samples decreases according to untreated fabric sample. Whiteness indices value of Silicone 1 treated fabric samples shows increase but Silicone 2 and Silicone 3 treated fabric samples whiteness value shows less increase. That causes variation of L***** value in Silicone 1 treated samples. Increase in yellowness indices for Silicone 1 treated fabric samples more than increase in yellowness indices for Silicone 2 and Silicone 3 treated samples.

Results of blue fabric samples which treated with softener recipe in alkali pH given in Table 4.13, Table 4.14, Table 4.15 and Figure 4.13, Figure 4.14, Figure 4.15.

Table 4.13 % Reflection values of the blue samples within visible region (alkali pH)

λ (nm)	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated	Untreated
400	47.25	46.88	47.30	37.23
420	54.42	54.11	54.55	44.43
440	63.56	63.39	63.74	53.74
460	61.28	61.12	61.40	52.76
480	51.58	51.36	51.68	44.56
500	41.32	41.05	41.36	36.19
520	32.86	33.82	32.85	29.08
540	26.38	26.08	26.30	23.46
560	21.36	21.07	21.27	19.25
580	17.95	17.67	17.85	16.17
600	16.40	16.14	16.30	14.62
620	15.69	15.45	15.60	13.96
640	15.39	15.16	15.31	13.55
660	19.12	18.91	19.07	16.45
680	29.75	29.60	29.78	25.63
700	47.40	47.46	47.49	42.29

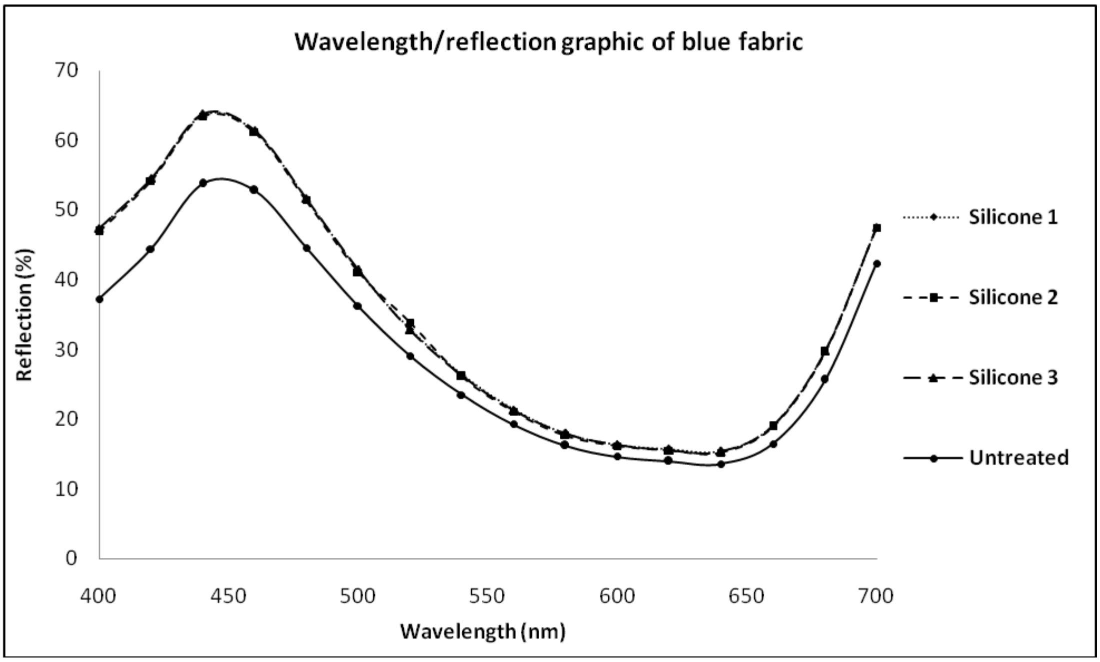

Figure 4.13 Wavelength/reflection graphic of blue fabric (alkali pH)

Table 4.14 Color coordinates of blue fabric (alkali pH)

	L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Untreated	56.11	-3.19	-34.05		49.99	249.17	-120.89
Silicone 1 treated	59.14	-2.05	-37.62	6.00	58.49	263.90	-129.92
Silicone 2 treated	58.88	-1.98	-37.86	6.13	58.30	265.69	-131.65
Silicone 3 treated	59.09	-2.03	-37.83	6.21	58.64	265.15	-130.99

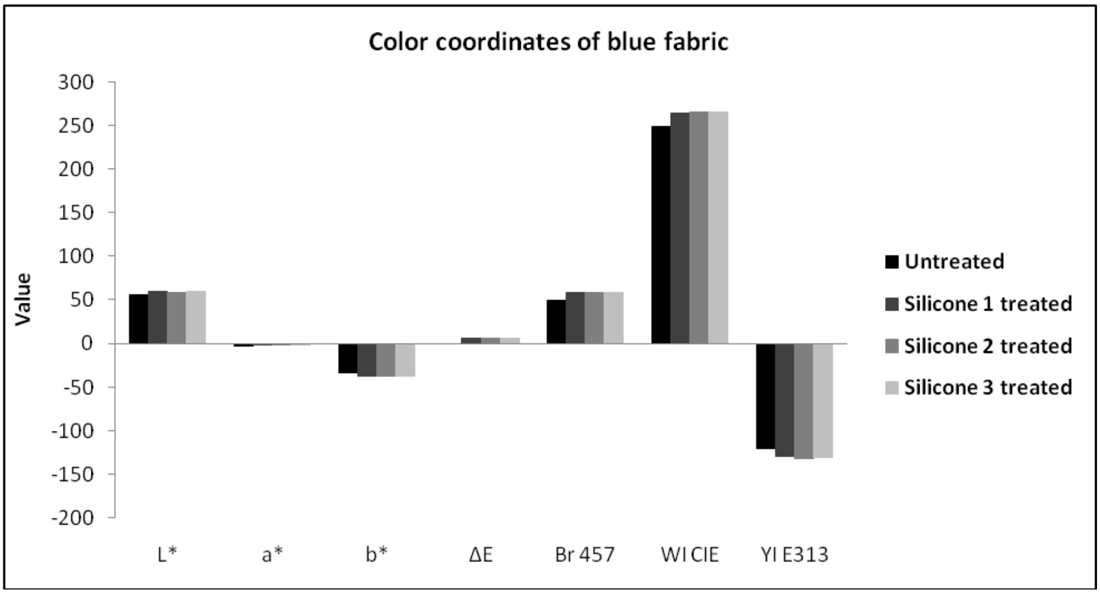

Figure 4.14 Color coordinates graphic of blue fabric (alkali pH)

Table 4.15 Differences of color coordinates of blue fabric (alkali pH)

	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated
ΔL*	3.03	2.77	2.98
Δa*	1.14	1.21	1.16
Δb*	-3.57	-3.81	-3.78
ΔWI CIE	14.74	16.52	15.93
ΔBr 457	8.50	8.31	8.65
ΔYI E313	-9.03	-10.77	-10.10
ΔE	4.82	4.86	4.93

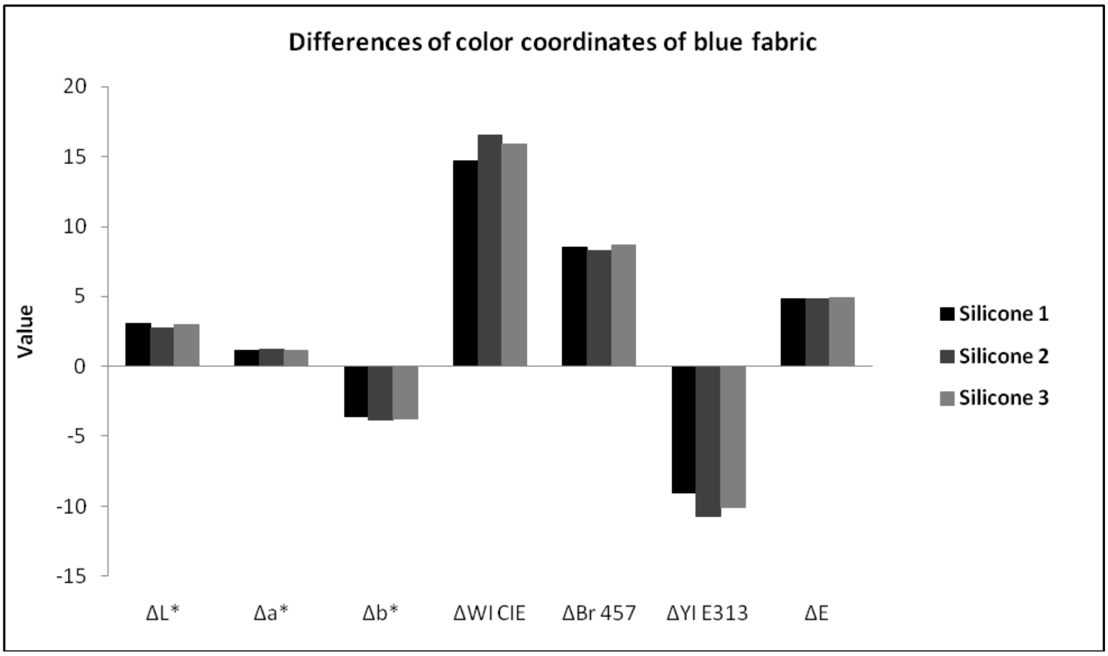

Figure 4.15 Differences of color coordinates graphic of blue fabric (alkali pH)

Fig 4.13 shows light absorption of all samples which treated softener decreases after softening treatment so Silicone 1, Silicone 2 and Silicone 3 treated fabric samples reflection values are almost equally higher than untreated fabric sample.

Table 4.14, Table 4.15 and Fig. 4.14, Fig. 4.15 shows color coordinates and its differences for blue fabric samples. Color coordinates of Silicone 1, Silicone 3 and Silicone 2 treated fabric samples increases according to untreated fabric samples and that values are shown in Table 4.14 and Fig 4.14. For differences whiteness indices value of Silicone 1 treated fabric samples shows increase but Silicone 2 and Silicone 3 treated fabric samples whiteness value shows more increase. That causes increase L***** value in Silicone 1 treated samples. Decrease in yellowness indices for Silicone 1 treated fabric samples less than decrease in yellowness indices for Silicone 2 and Silicone 3 treated samples.

Results of red fabric samples which treated with softener recipe in alkali pH given in Table 4.16, Table 4.17, Table 4.18 and Figure 4.16, Figure 4.17, Figure 4.18.

Table 4.16 % Reflection values of the red samples within visible region (alkali pH)

λ (nm)	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated	Untreated
400	6.81	6.58	6.58	5.35
420	4.16	3.99	4.00	3.28
440	3.66	3.49	3.51	2.99
460	3.31	3.16	3.18	2.78
480	2.88	2.75	2.76	2.47
500	2.55	2.44	2.45	2.22
520	2.31	2.21	2.22	2.06
540	2.43	2.33	2.34	2.19
560	2.58	2.48	2.49	2.41
580	5.66	5.48	5.53	5.41
600	19.88	19.58	19.74	18.96
620	43.64	43.37	43.56	41.13
640	64.14	63.94	64.02	59.71
660	75.02	74.81	74.77	68.62
680	79.47	79.26	79.15	71.93
700	85.29	85.15	84.99	77.66

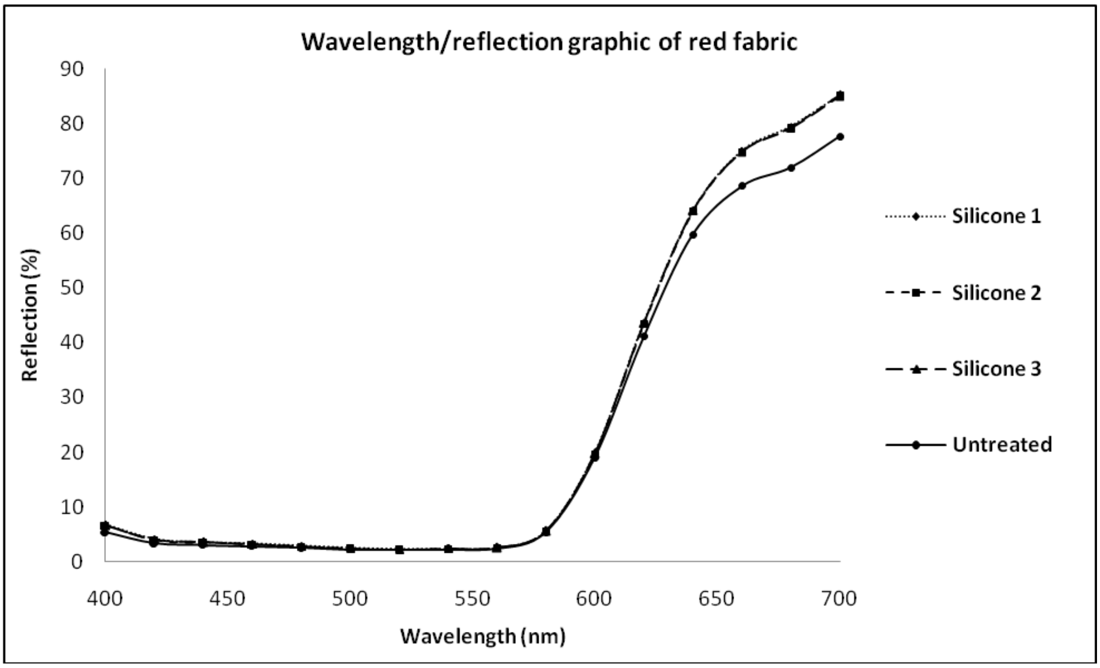

Figure 4.16 Wavelength/reflection graphic of red fabric (alkali pH)

Table 4.17 Color coordinates of red fabric (alkali pH)

	L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Untreated	35.92	53.29	28.25		2.80	-176.15	70.29
Silicone 1 treated	37.14	54.44	26.22	1.90	3.38	-161.12	66.38
Silicone 2 treated	36.86	54.62	26.73	1.87	3.23	-164.32	67.41
Silicone 3 treated	36.94	54.66	26.76	1.95	3.24	-164.29	67.39

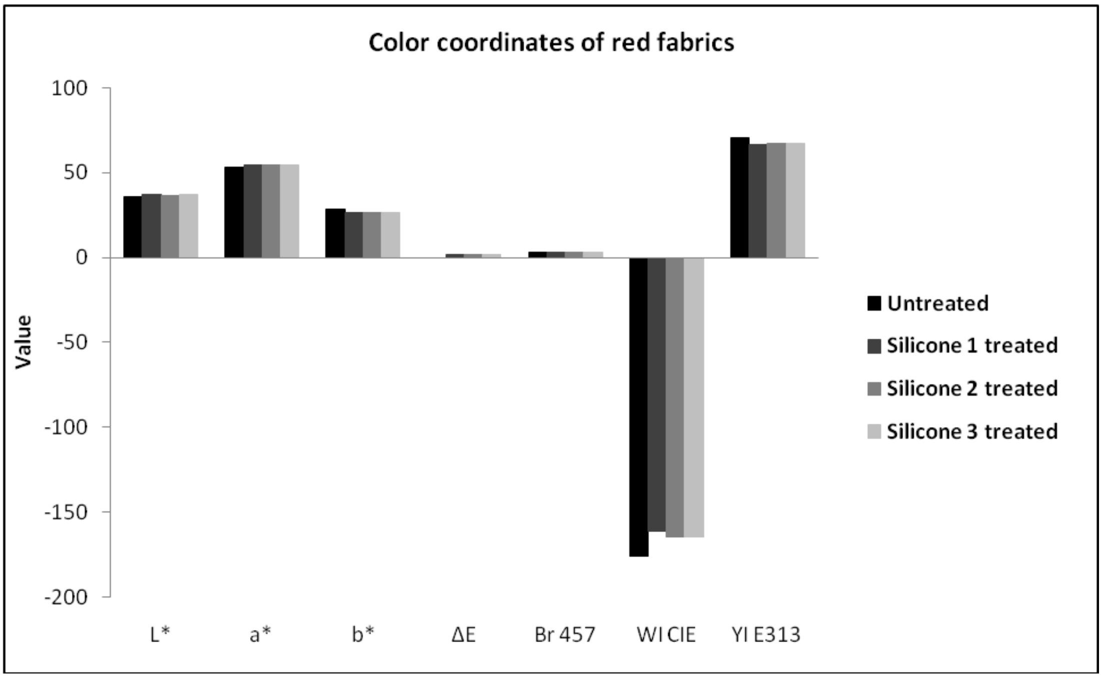

Figure 4.17 Color coordinates graphic of red fabric (alkali pH)

Table 4.18 Differences of color coordinates of red fabric (alkali pH)

	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated
ΔL*	1.21	0.94	1.02
Δa*	1.15	1.34	1.37
Δb*	-2.03	-1.52	-1.49
ΔWI CIE	15.03	11.83	11.86
ΔBr 457	0.58	0.43	0.44
ΔYI E313	-3.91	-2.88	-2.90
ΔE	2.64	2.24	2.27

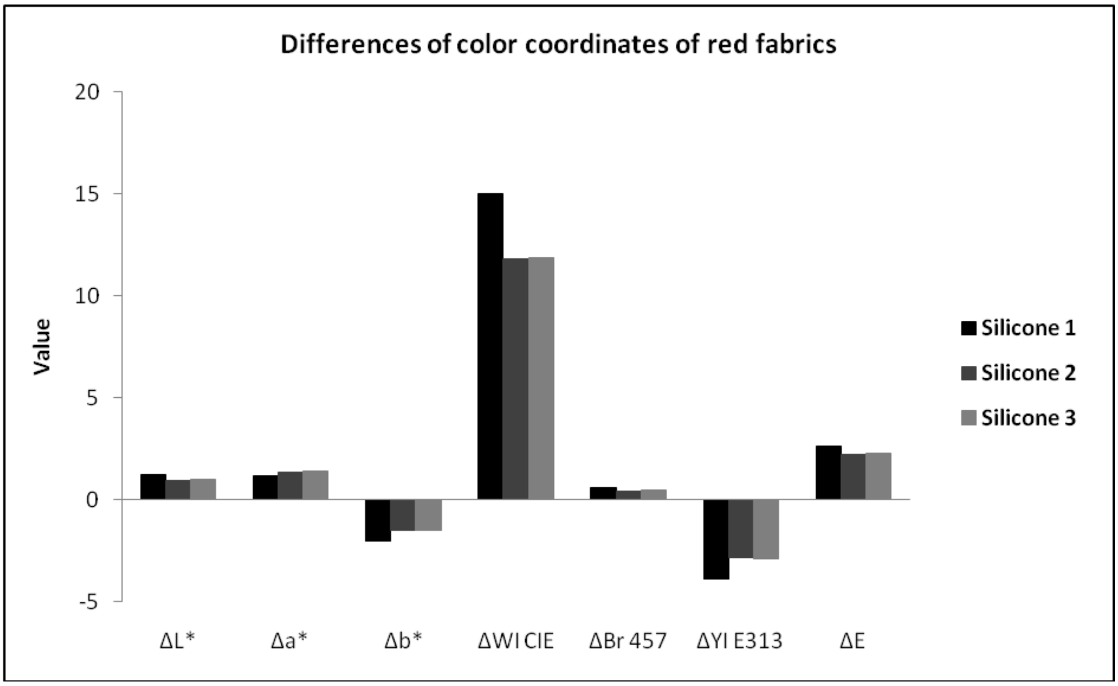

Figure 4.18 Differences of color coordinates graphic of red fabric (alkali pH)

Fig 4.16 shows light absorption of all samples which treated softener decreases after softening treatment so Silicone 1, Silicone 2 and Silicone 3 treated fabric samples reflection values are higher than untreated fabric sample in high wavelengths.

Table 4.17, Table 4.18 and Fig. 4.17, Fig. 4.18 shows color coordinates and its differences for red fabric samples. Color coordinates of Silicone 1, Silicone 3 and Silicone 2 treated fabric samples decreases according to untreated fabric samples and that values are shown in Table 4.17 and Fig 4.17. For differences whiteness indices value of Silicone 1 treated fabric samples shows increase but Silicone 2 and Silicone 3 treated fabric samples whiteness value shows less increase. That causes increase L***** value in Silicone 1 treated samples. Decrease in yellowness indices for Silicone 1 treated fabric samples more than decrease in yellowness indices for Silicone 2 and Silicone 3 treated samples.

The result values of washed blue fabric samples which were treated with softeners given in Table 4.19, Table 4.20, Table 4.21 and Figure 4.19, Figure 4.20, Figure 4.21.

Table 4.19 % Reflection values of the blue samples within visible region (washed)

λ (nm)	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated	Untreated
400	36.88	38.45	39.36	37.23
420	44.07	45.58	46.25	44.43
440	53.01	54.46	54.95	53.74
460	52.26	53.55	53.81	52.76
480	44.52	45.64	45.92	44.56
500	36.36	37.24	37.39	36.19
520	29.23	29.93	30.08	29.08
540	23.56	24.14	24.30	23.46
560	19.27	19.72	19.81	19.25
580	16.17	16.58	16.66	16.17
600	14.61	15.00	15.10	14.62
620	14.03	14.42	14.50	13.96
640	13.76	14.16	14.26	13.55
660	16.73	17.19	17.41	16.45
680	25.91	26.53	26.90	25.63
700	42.25	43.04	43.57	42.29

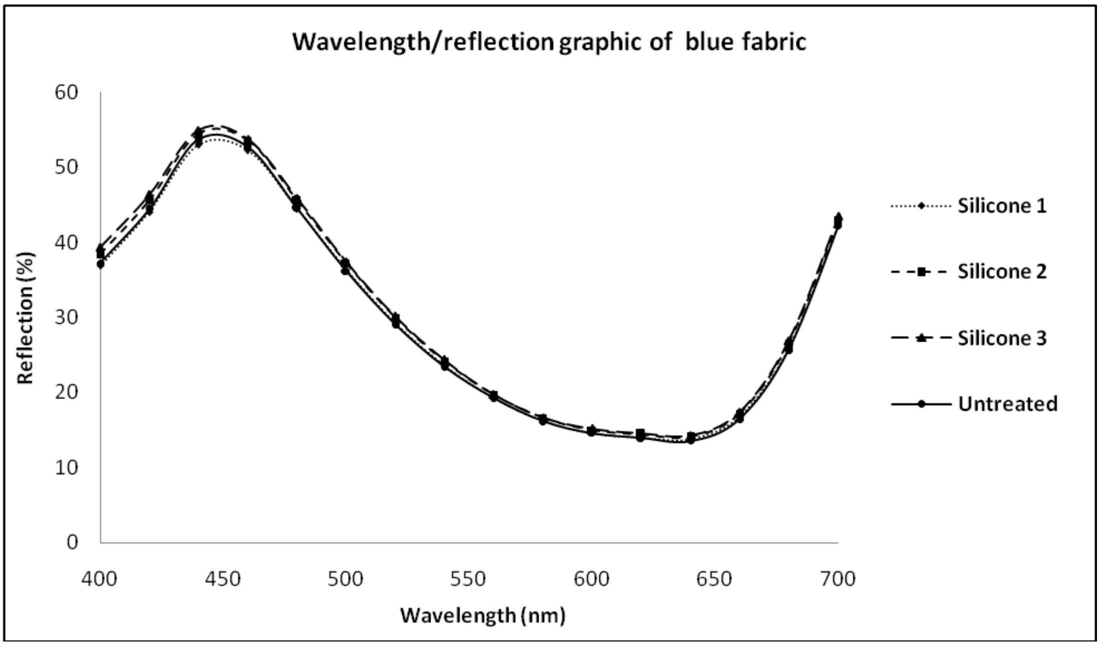

Figure 4.19 Wavelength/reflection graphic of blue fabric (washed)

Table 4.20 Color coordinates of blue fabric (washed)

	L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Untreated	56.11	-3.19	-34.05		49.99	249.17	-120.89
Silicone 1 treated	56.15	-3.62	-33.50	0.83	49.57	246.00	-118.45
Silicone 2 treated	56.74	-3.49	-33.88	0.99	50.87	247.16	-118.84
Silicone 3 treated	56.87	-3.35	-34.06	0.86	51.21	247.97	-119.28

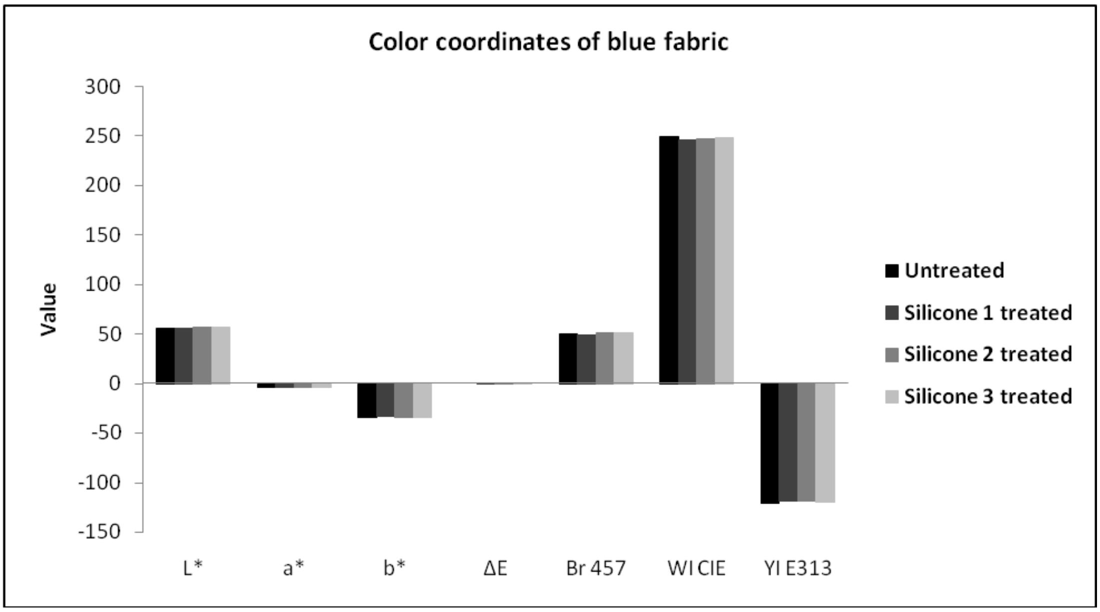

Figure 4.20 Color coordinates graphic of blue fabric (washed)

Table 4.21 Differences of color coordinates of blue fabric (washed)

	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated
ΔL*	0.04	0.63	0.76
Δa*	-0.43	-0.30	-0.16
Δb*	0.55	0.17	-0.01
ΔWI CIE	-3.18	-2.01	-1.21
ΔBr 457	-0.42	0.88	1.21
ΔYI E313	2.44	2.06	1.61
ΔE	0.75	0.91	0.82

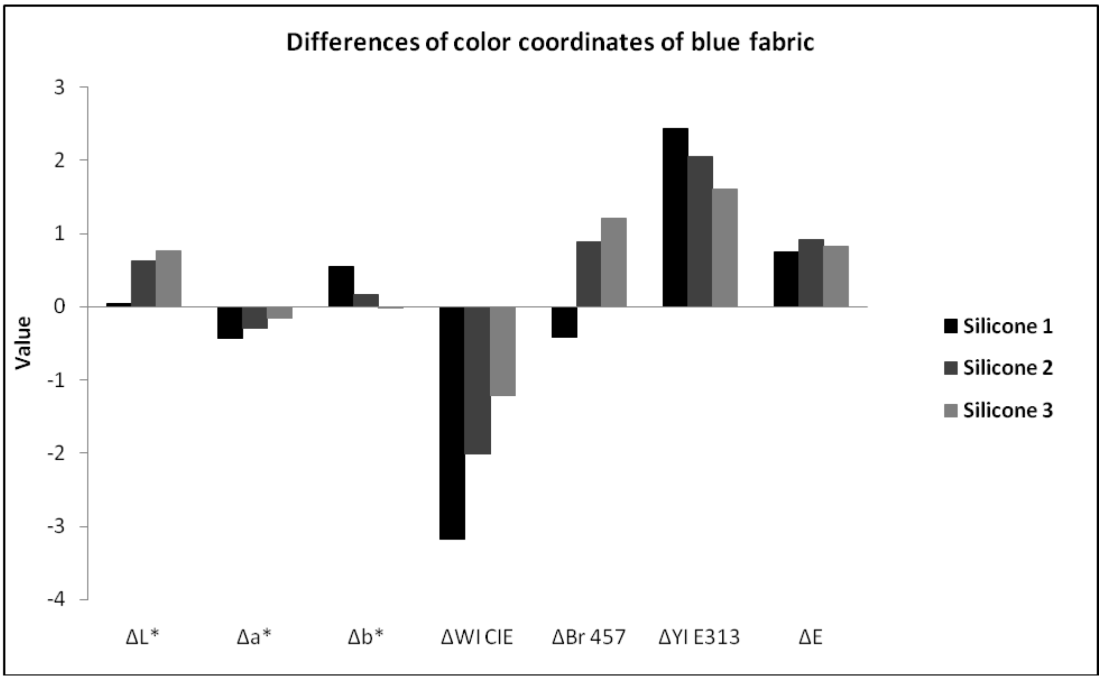

Figure 4.21 Differences of color coordinates graphic of blue fabric (washed)

Fig 4.19 shows light absorption of all samples which treated softener decreases after softening treatment so Silicone 1, Silicone 2 and Silicone 3 treated fabric samples reflection values are higher than untreated fabric sample but difference of reflection values are not very noticeable in high wavelengths.

Table 4.20, Table 4.21 and Fig. 4.20, Fig. 4.21 shows color coordinates and its differences for blue fabric samples. Color coordinates of Silicone 1, Silicone 2 and Silicone 3 treated fabric samples almost equally according to untreated fabric samples and values are shown in Table 4.20 and Fig 4.20. For color difference values, whiteness indices value of respectively Silicone 1, Silicone 2 and Silicone 3 treated fabric samples decreases because of difference in L* values. Yellowness indices of respectively Silicone 1, Silicone 2 and Silicone 3 treated fabric samples increases because of difference in b* values.

The result values of washed red fabric samples which were treated with softeners given in Table 4.22, Table 4.23, Table 4.24 and Figure 4.22, Figure 4.23, Figure 4.24.

Table 4.22 % Reflection values of the red samples within visible region (washed)

λ (nm)	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated	Untreated
400	6.80	6.85	6.81	5.35
420	4.12	4.15	4.14	3.28
440	3.62	3.65	3.64	2.99
460	3.29	3.31	3.31	2.78
480	2.87	2.89	2.90	2.47
500	2.57	2.60	2.61	2.22
520	2.35	2.38	2.39	2.06
540	2.48	2.51	2.52	2.19
560	2.65	2.68	2.69	2.41
580	5.68	5.75	5.70	5.41
600	19.69	19.86	19.62	18.96
620	43.49	43.69	43.32	41.13
640	64.17	64.38	63.95	59.71
660	75.52	75.77	75.35	68.62
680	80.50	80.78	80.35	71.93
700	85.56	85.79	85.38	77.66

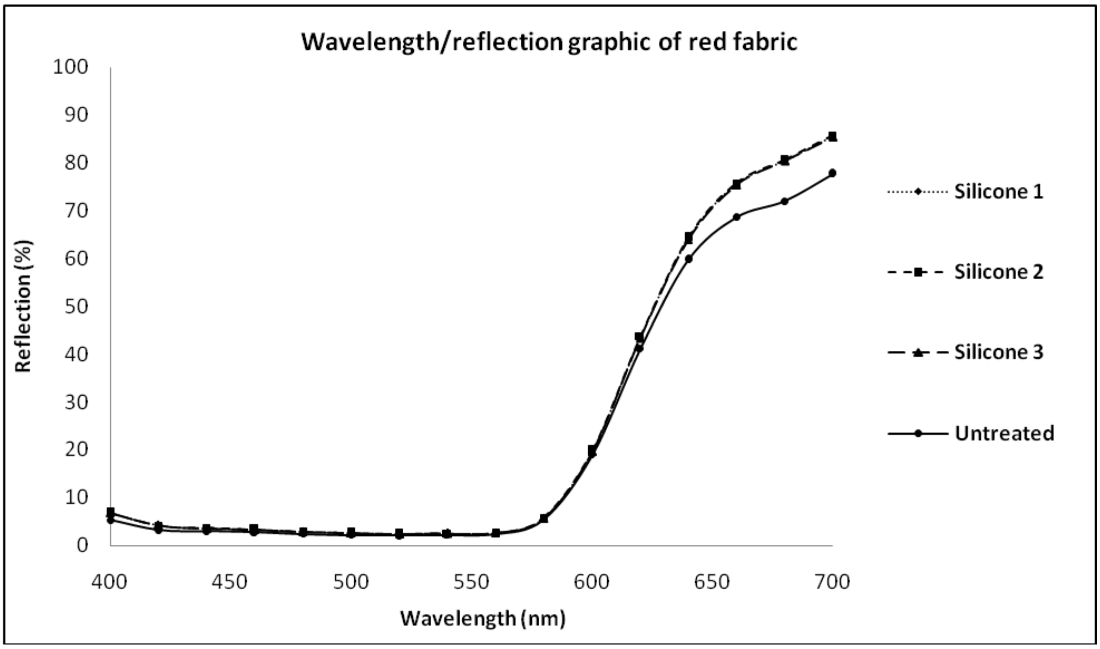

Figure 4.22 Wavelength/reflection graphic of red fabric (washed)

Table 4.23 Color coordinates of red fabric (washed)

	L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Untreated	35.92	53.29	28.25		2.80	-176.15	70.29
Silicone 1 treated	37.15	54.25	26.43	1.75	3.36	-162.43	66.68
Silicone 2 treated	37.27	54.26	26.47	1.84	3.38	-162.41	66.65
Silicone 3 treated	37.16	54.02	26.28	1.59	3.38	-161.85	66.43

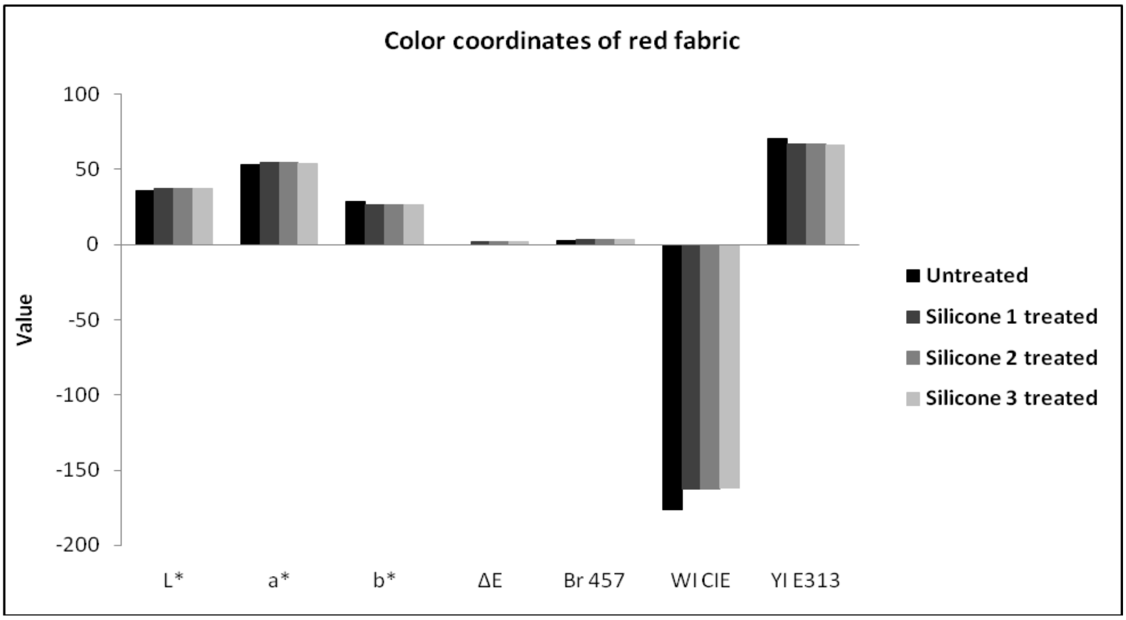

Figure 4.23 Color coordinates graphic of red fabric (washed)

Table 4.24 Differences of color coordinates of red fabric (washed)

	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated
ΔL*	1.23	1.35	1.24
Δa*	0.97	0.98	0.74
Δb*	-1.83	-1.78	-1.97
ΔWI CIE	13.72	13.74	14.30
ΔBr 457	0.55	0.58	0.58
ΔYI E313	-3.61	-3.64	-3.86
ΔE	2.41	2.44	2.45

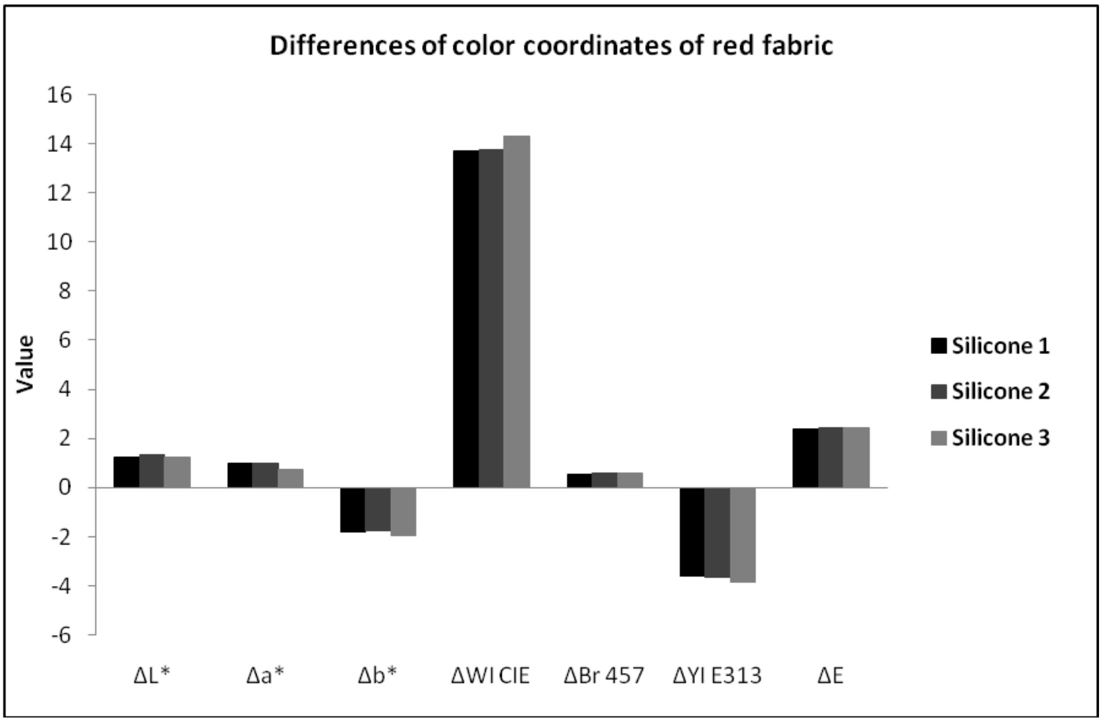

Figure 4.24 Differences of color coordinates graphic of red fabric (washed)

Fig 4.22 shows light absorption of all samples which treated softener decreases after softening treatment so Silicone 1, Silicone 2 and Silicone 3 treated fabric samples reflection values are higher than untreated fabric sample. Difference values for reflection, seen more clearly in high wavelengths.

Table 4.23, Table 4.24 and Fig. 4.23, Fig. 4.24 shows color coordinates and its differences for red fabric samples. In Table 4.23 and Figure 4.23, color coordinates of Silicone 3 and Silicone 2 treated fabric samples decreases according to untreated fabric sample. Whiteness indices value of Silicone 3 treated fabric samples shows increase more than Silicone 2 and Silicone 3 treated fabric samples whiteness value. Decrease in yellowness indices for Silicone 3 treated fabric samples more than decrease in yellowness indices for Silicone 2 and Silicone 1 treated samples. That causes variation of b***** value in Silicone 3 treated samples.

The result values of ironed blue fabric samples which were treated with softeners given in Table 4.25, Table 4.26, Table 4.27 and Figure 4.25, Figure 4.26, Figure 4.27.

Table 4.25 % Reflection values of the blue samples within visible region (ironed)

λ (nm)	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated	Untreated
400	36.99	36.84	38.86	37.23
420	44.04	43.48	45.35	44.43
440	53.03	52.31	54.20	53.74
460	52.27	51.63	53.40	52.76
480	44.53	43.97	45.57	44.56
500	36.37	35.91	37.27	36.19
520	29.25	28.87	30.05	29.08
540	23.56	23.30	24.35	23.46
560	19.35	19.11	20.02	19.25
580	16.25	16.08	16.89	16.17
600	14.76	14.57	15.37	14.62
620	14.11	13.96	14.72	13.96
640	13.87	13.70	14.43	13.55
660	17.24	16.86	17.77	16.45
680	26.98	26.31	27.56	25.63
700	43.69	42.78	44.41	42.29

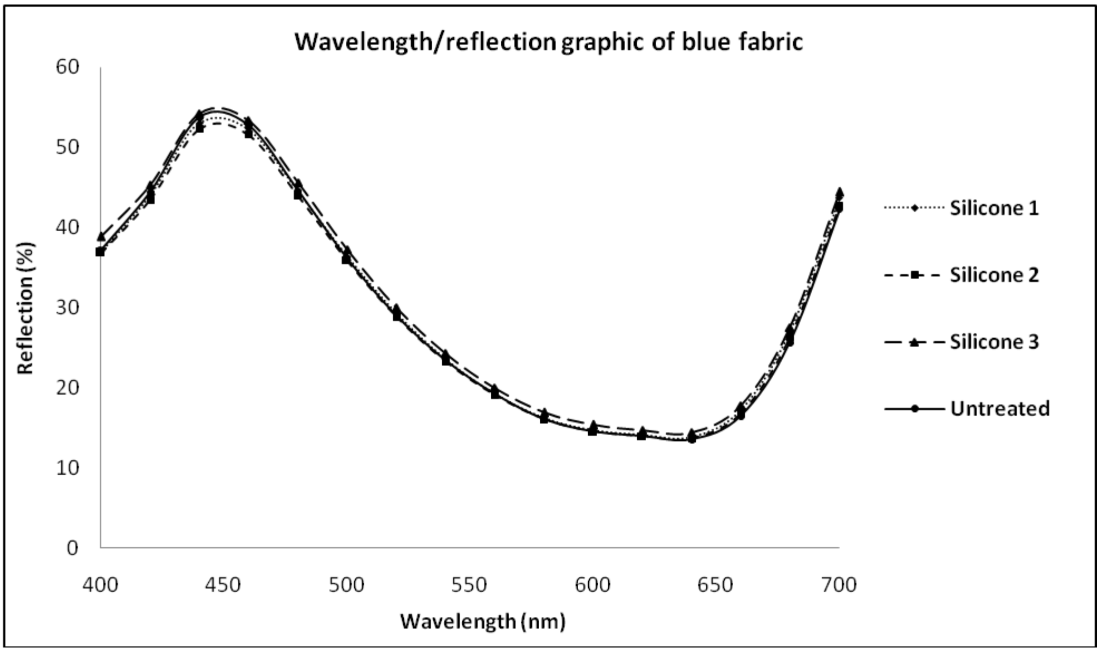

Figure 4.25 Wavelength/reflection graphic of blue fabric (ironed)

Table 4.26 Color coordinates of blue fabric (ironed)

	L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Untreated	56.11	-3.19	-34.05		49.99	249.17	-120.89
Silicone 1 treated	56.21	-3.47	-33.41	0.85	49.58	245.28	-117.89
Silicone 2 treated	55.91	-3.47	-33.25	1.12	48.95	244.86	-117.77
Silicone 3 treated	56.95	-3.42	-33.36	1.19	50.71	243.68	-115.99

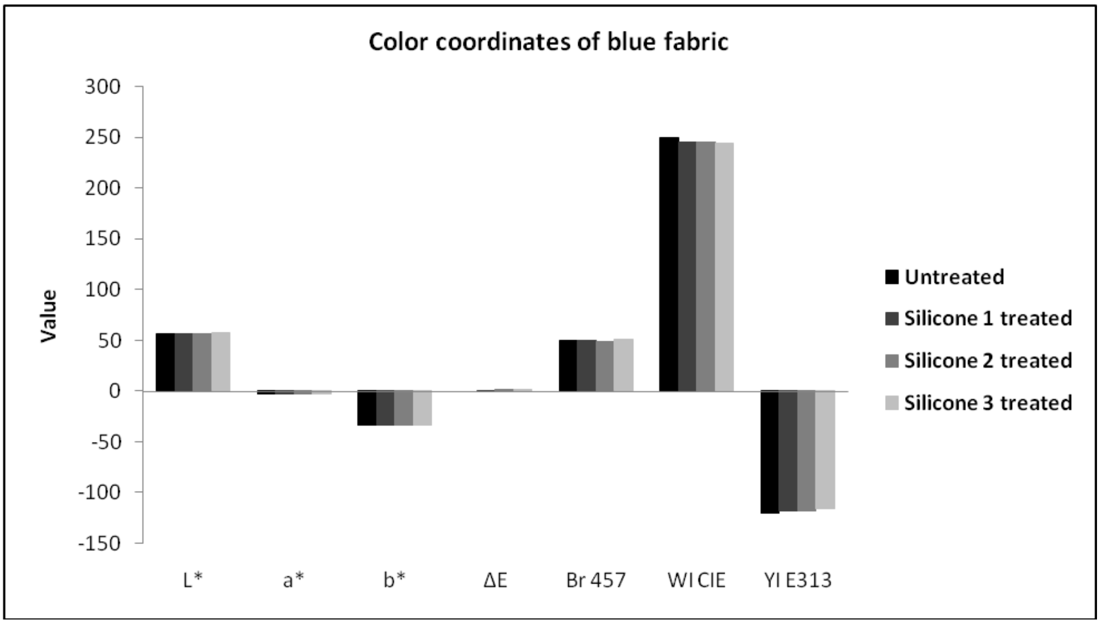

Figure 4.26 Color coordinates graphic of blue fabric (ironed)

Table 4.27 Differences of color coordinates of blue fabric (ironed)

	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated
ΔL*	0.10	-0.20	0.84
Δa*	-0.28	-0.28	-0.23
Δb*	0.64	0.80	0.69
ΔWI CIE	-3.89	-4.31	-5.49
ΔBr 457	-0.41	-1.04	0.72
ΔYI E313	3.01	3.12	4.90
ΔE	0.71	0.92	1.12

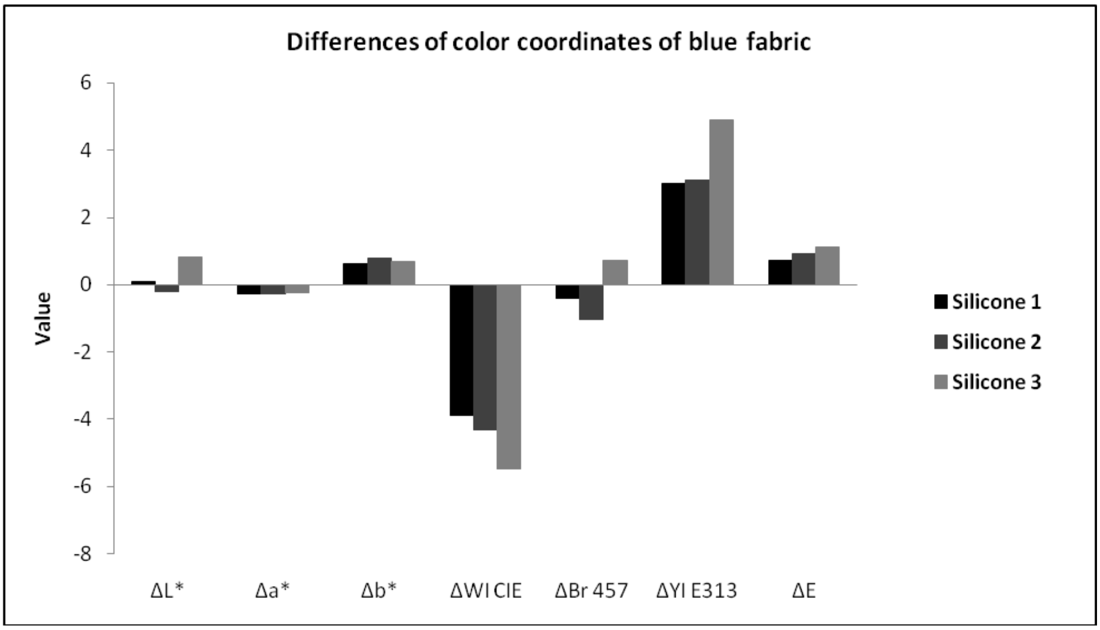

Figure 4.27 Differences of color coordinates graphic of blue fabric (ironed)

Fig 4.25 shows light absorption of all samples which treated softener decreases slightly after softening treatment so Silicone 1, Silicone 2 and Silicone 3 treated fabric samples reflection values are almost similar untreated fabric sample.

Table 4.26, Table 4.27 and Fig. 4.26, Fig. 4.27 shows color coordinates and its differences for red fabric samples. In Table 4.26 and Figure 4.26, color coordinates of Silicone 3 and Silicone 2 treated fabric samples decreases a bit according to untreated fabric sample. Whiteness indices value of Silicone 3 treated fabric samples shows increase more than Silicone 2 and Silicone 3 treated fabric samples whiteness value. Decrease in yellowness indices for Silicone 3 treated fabric samples more than decrease in yellowness indices for Silicone 2 and Silicone 1 treated samples. That causes variation of b***** value in Silicone 3 treated samples.

The result values of ironed red fabric samples which were treated with softeners given in Table 4.28, Table 4.29, Table 4.30 and Figure 4.28, Figure 4.29, Figure 4.30.

Table 4.28 % Reflection values of the red samples within visible region (ironed)

λ (nm)	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated	Untreated
400	5.46	5.21	5.21	5.35
420	3.32	3.13	3.14	3.28
440	3.02	2.84	2.86	2.99
460	2.82	2.65	2.67	2.78
480	2.47	2.33	2.36	2.47
500	2.21	2.09	2.12	2.22
520	2.04	1.93	1.97	2.06
540	2.16	2.05	2.09	2.19
560	2.35	2.23	2.28	2.41
580	5.21	4.98	5.02	5.41
600	18.27	17.88	17.72	18.96
620	40.07	39.77	39.32	41.13
640	59.03	58.92	58.21	59.71
660	69.20	69.02	68.39	68.62
680	73.52	73.17	72.68	71.93
700	78.95	78.94	78.51	77.66

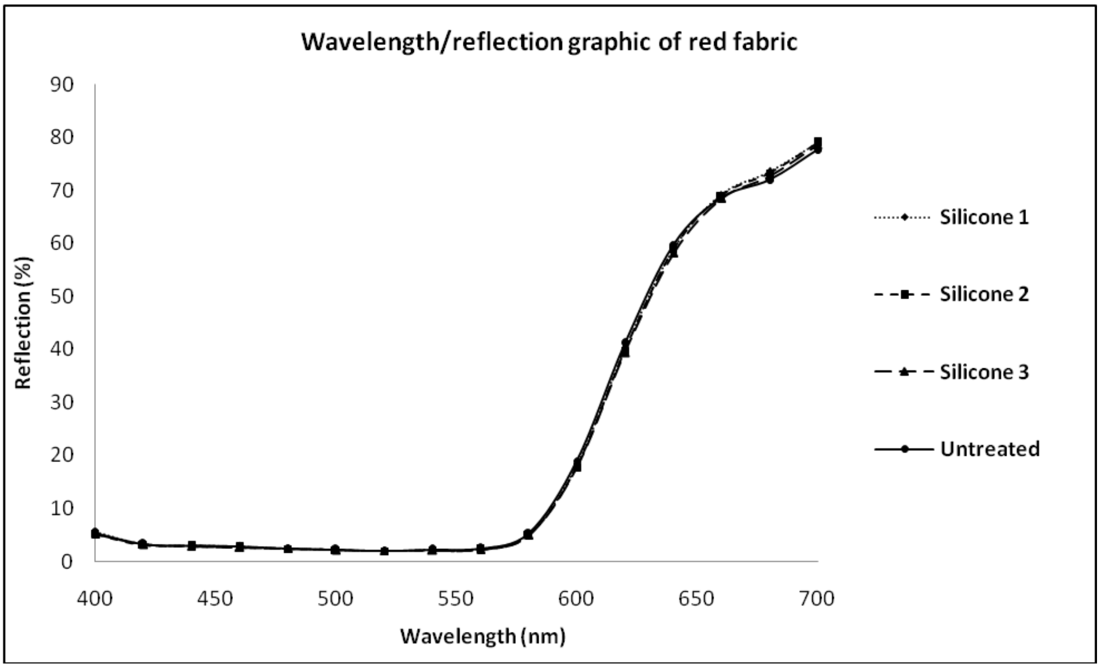

Figure 4.28 Wavelength/reflection graphic of red fabric (ironed)

Table 4.29 Color coordinates of red fabric (ironed)

	L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Untreated	35.92	53.29	28.25	--	2.80	-176.15	70.29
Silicone 1 treated	35.55	53.08	27.34	0.60	2.84	-172.29	69.26
Silicone 2 treated	35.21	53.33	27.98	0.68	2.67	-176.19	70.51
Silicone 3 treated	35.14	52.91	27.72	0.97	2.70	-175.45	70.17

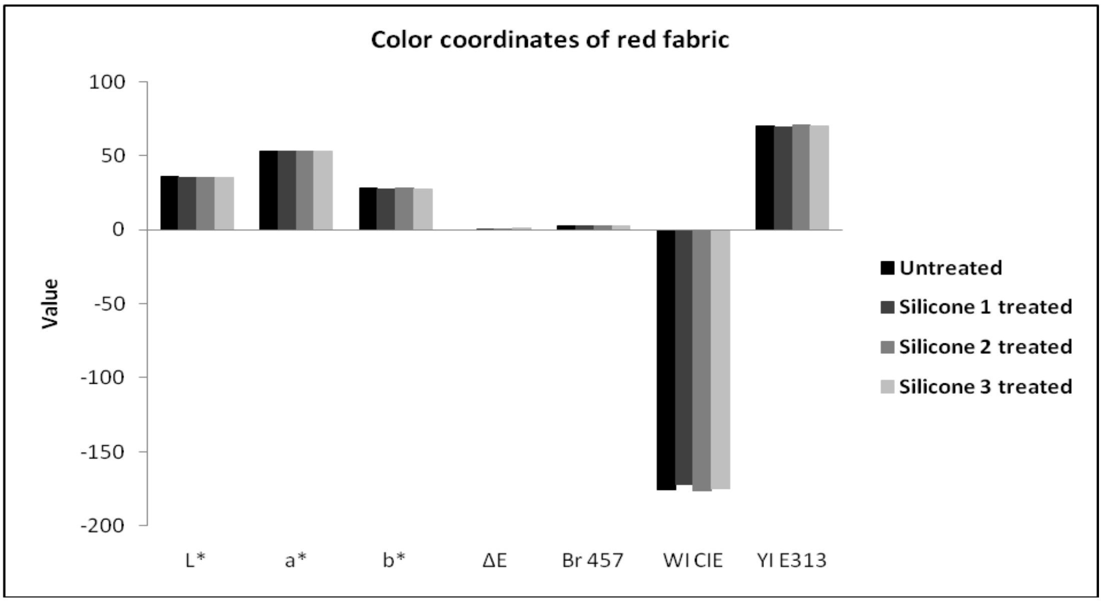

Figure 4.29 Color coordinates graphic of red fabric (ironed)

Table 4.30 Differences of color coordinates of red fabric (ironed)

	Silicone 1 treated	Silicone 2 treated	Silicone 3 treated
ΔL*	-0.37	-0.71	-0.79
Δa*	-0.21	0.04	-0.39
Δb*	-0.91	-0.27	-0.54
ΔWI CIE	3.60	-0.04	0.71
ΔBr 457	0.04	-0.13	-0.11
ΔYI E313	-1.03	0.23	-0.13
ΔE	1.03	0.76	1.03

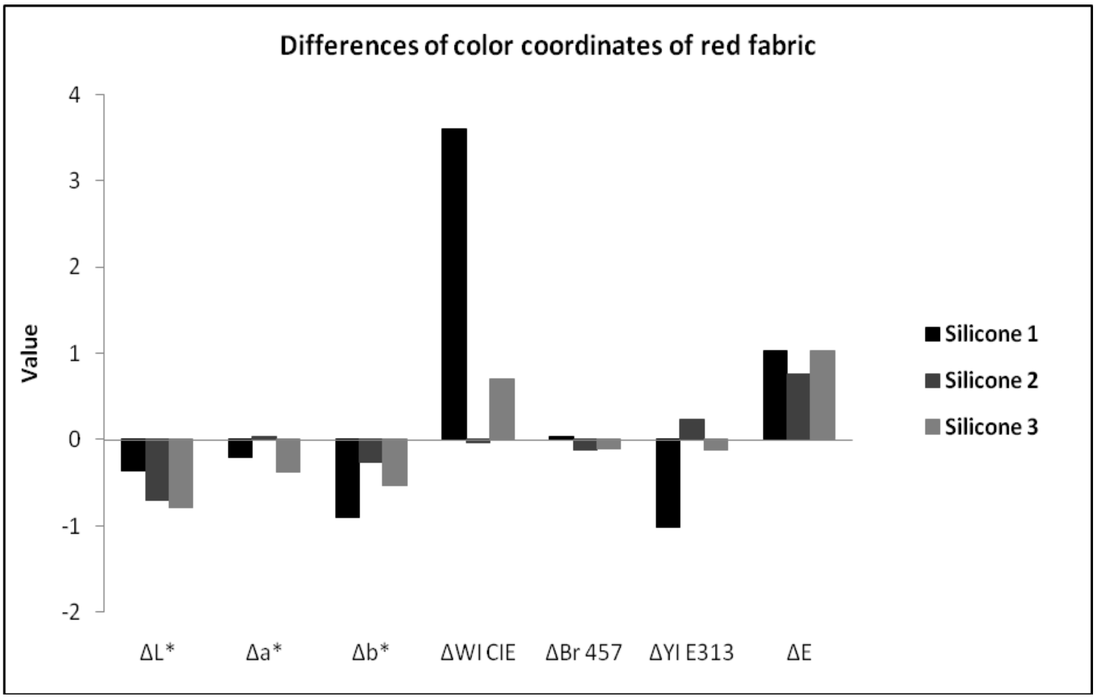

Figure 4.30 Differences of color coordinates graphic of red fabric (ironed)

Fig 4.28 shows light absorption of all samples which treated softener decreases slightly after softening treatment so Silicone 1, Silicone 2 and Silicone 3 treated fabric samples reflection values are almost similar untreated fabric sample.

Table 4.29, Table 4.30 and Fig. 4.29, Fig. 4.30 shows color coordinates and its differences for red fabric samples. In Table 4.29 and Figure 4.29, color coordinates of Silicone 3 and Silicone 2 treated fabric samples decreases a bit according to untreated fabric sample. Whiteness indices value of Silicone 1 treated fabric samples shows high increase in whiteness value. Decrease in yellowness indices for Silicone 1 treated fabric samples more than decrease in yellowness indices for Silicone 2 and Silicone 3 treated samples. That causes variation of b***** value in Silicone 3 treated samples.

An over-all evaluation of (%) changes at color coordinates of the samples are given in Table 4.31. in this table, L measures lightness and varies from 100 for perfect white to zero for black, approximately as the eye would evaluate it. The chromaticity dimensions (a and b) give understandable designations of color as follows:

a measures redness when positive, gray when zero, and greenness when negative.

b measures yellowness when positive, gray when zero, and blueness when negative.

Table 4.31 (%) changes of color coordinates of fabric samples

Fabric samples / (%) changes of color coordinates		L*	a*	b*	ΔE	Br 457	WI CIE	YI E313
Blue fabric sample (std rec.)	**Silicone 1**	0.44	3.44	0.61	0.58	0.46	0.69	1.25
	Silicone 2	3.95	1.88	3.64	2.91	9.30	1.33	0.78
	Silicone 3	3.11	8.64	3.37	2.47	7.74	1.52	1.43
Red fabric sample (std rec.)	**Silicone 1**	0.22	1.46	0.95	0.93	1.78	1.45	0.55
	Silicone 2	1.36	1.16	0.07	0.69	5.00	0.73	0.62
	Silicone 3	2.17	0.07	0.24	0.72	6.78	1.13	1.13
Blue fabric sample (acidic pH)	**Silicone 1**	6.39	34.16	4.55	4.52	14.82	0.95	1.12
	Silicone 2	6.05	40.43	4.88	4.53	14.52	1.49	0.10
	Silicone 3	6.16	44.51	5.19	4.64	14.76	1.49	0.13
Red fabric sample (acidic pH)	**Silicone 1**	2.69	0.72	10.55	1.35	22.85	10.19	7.39
	Silicone 2	1.44	1.23	10.73	1.19	18.56	9.66	6.95
	Silicone 3	1.39	1.23	10.90	1.20	18.21	9.77	7.01
Blue fabric sample (alkali pH)	**Silicone 1**	5.39	35.72	10.46	6.00	17.00	5.89	7.40
	Silicone 2	4.93	37.92	11.16	6.13	16.62	6.60	8.83
	Silicone 3	5.30	36.35	11.07	6.21	17.30	6.37	8.28
Red fabric sample (alkali pH)	**Silicone 1**	3.36	2.15	7.16	1.90	20.71	8.41	5.55
	Silicone 2	2.61	2.50	5.36	1.87	15.35	6.62	4.08
	Silicone 3	2.83	2.56	5.25	1.95	15.71	6.64	4.11
Blue fabric sample (washed)	**Silicone 1**	0.07	13.47	1.61	0.83	0.84	1.27	2.00
	Silicone 2	1.12	9.40	0.49	0.99	1.76	0.80	1.68
	Silicone 3	1.35	5.01	0.02	0.86	2.42	0.48	1.32
Red fabric sample (washed)	**Silicone 1**	3.41	1.81	6.45	1.75	19.64	7.68	5.12
	Silicone 2	3.75	1.83	6.28	1.84	20.71	7.69	5.16
	Silicone 3	3.44	1.38	6.95	1.59	20.71	8.00	5.48
Blue fabric sample (ironed)	**Silicone 1**	0.17	8.77	1.87	0.85	0.82	1.55	2.46
	Silicone 2	0.35	8.77	2.34	1.12	2.08	1.72	2.55
	Silicone 3	1.49	7.20	2.02	1.19	1.44	2.19	4.01
Red fabric sample (ironed)	**Silicone 1**	1.02	0.39	3.21	0.60	1.42	2.01	1.46
	Silicone 2	1.97	0.07	0.95	0.68	4.64	0.02	0.32
	Silicone 3	2.19	0.72	1.90	0.97	3.92	0.39	0.18

Table 4.32 Correlation table between color coordinates

Correlation	(a*-DE)	(b*-DE)	(L*-DE)	(b*-YI)	(a*-YI)
Blue fabric sample (std rec.)	0.122	0.995	0.999	-0.327	0.851
Red fabric sample (std. rec.)	0.577	0.998	-0.857	-0.436	-0.995
Blue fabric sample (acidic pH)	0.842	0.893	-0.273	-0.862	-0.910
Red fabric sample (acidic pH)	-0.998	-0.846	0.996	-0.806	-0.992
Blue fabric sample (alkali pH)	0.406	0.875	-0.317	0.963	0.931
Red fabric sample (alkali pH)	0.276	-0.193	0.145	0.998	-0.988
Blue fabric sample (washed)	-0.155	-0.398	0.507	0.965	1.000
Red fabric sample (washed)	0.948	-0.993	0.722	0.940	-0.990
Blue fabric sample (ironed)	-0.659	0.601	0.749	-0.154	-0.999
Red fabric sample (ironed)	0.751	-0.294	0.789	0.862	-0.109

If we consider the CIELAB color space (Fig. 4.31), the CIELAB color space is organized in a cube form. The L* axis runs from top to bottom. The maximum for L* is 100, which represents a perfect reflecting diffuser. The minimum for L* is zero, which represents black. The a* and b* axes have no specific numerical limits. Positive a* is red. Negative a* is green. Positive b* is yellow. Negative b* is blue [28].

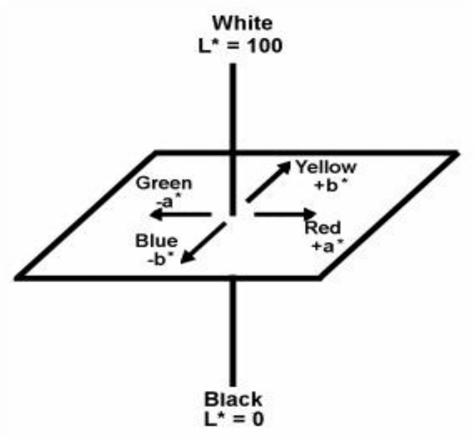

Figure 4.31 CIELAB color space

The Table 4.31 shows that all softeners in different particle sizes, cause yellowing at softener treated fabric samples. Yellowing is seen more clearly in blue fabric samples. The most important factor of effecting yellowing is the change in b* axis. Other important difference is redness. Redness influenced by a* value and the difference is seen more clearly in red fabric samples. ΔE value difference affected a* value in red fabric samples and b* value in blue fabric samples. Particle size of softeners is important for whiteness. Whiteness indices change relates to the change in the value of L*. With the combined effects of L* and b* values, the effect of particle size should be taken into account at softening treatment of blue tint fabrics.

The Table 4.32 shows that both red and blue fabric samples treated with the standard recipe, influenced by the use of fabric softener. Observed that the change of b* axis more noticeable than the change of a* axis. b* axis changes in the use of fabric softener should be monitored more carefully. The change of both a* and b* values clearly observed in acidic pH. a* and b* axis changes in acidic pH should be monitored thoughtfully. Looking at the values after washing, samples of red fabric has been effected only.

4.1.2 Costat analysis measurements

Costat analysis measurements used for statistically evaluation. Costat was used to assess the contribution of particle size of softener and the color values. The results were evaluated using a completely randomized two ways. Analyze of variance (ANOVA) and Student-Newman-Keuls (SNK) range test. The results were marked in accordance with mean values and any levels marked by same letter showed that they were not significantly different.

Variance analysis of blue and red fabric samples treated with standard recipe for ΔE, ΔWI, ΔYI and Brightness values are given in tables. When we look at the MS (mean square) value we see that the "Softener" values are higher than "Error" value. It shows that we choose right parameter and there are not any other parameters which more effected from Softener for these samples. Student-Newman-Keuls tests for softener particle size in blue and red fabric samples treated with standard recipe for ΔE, ΔWI, ΔYI and Brightness values are given in tables. "Mean" value shows which silicone softener type caused the lowest color difference. The lowest color difference is caused by the softener which has the lowest numeric value. "Non-significant Range" values shows that there is a significant or non-significant difference between ΔE ΔWI, ΔYI and Brightness values and the particle size. For blue fabric samples the difference is more significant compared to red fabric samples.

Table 4.33 Variance analysis of blue fabric sample treated with standard recipe (ΔE)

Variation Source	SS	Df	MS	F	P
Softener	7.58	2	3.78	73.65	0.000
Error	0.30	6	0.05		
Total	7.88	8			

Table 4.34 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated with standard recipe (ΔE)

Variation Source	Mean	n	Non-significant Range		
Silicone 2	2.63	3	a		
Silicone 3	2.15	3		b	
Silicone 1	0.49	3			c

Table 4.35 Variance analysis of blue fabric sample treated with standard recipe (ΔWI)

Variation Source	SS	df	MS	F	P
Softener	67.60	2	33.80	302.19	0.000
Error	0.67	6	0.11		
Total	68.27	8			

Table 4.36 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated with standard recipe (ΔWI)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	2.83	3	a	
Silicone 2	-2.76	3		b
Silicone 3	-3.17	3		b

Table 4.37 Variance analysis of blue fabric sample treated with standard recipe (Brightness)

Variation Source	SS	df	MS	F	P
Softener	37.58	2	18.79	100.02	0.000
Error	1.12	6	0.18		
Total	38.70	8			

Table 4.38 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated with standard recipe (Brightness)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	-0.09	3	a	
Silicone 3	-3.94	3		b
Silicone 2	-4.78	3		b

Table 4.39 Variance analysis of blue fabric sample treated with standard recipe (ΔYI)

Variation Source	SS	df	MS	F	P
Softener	20.85	2	10.42	195.19	0.000
Error	0.32	6	0.05		
Total	21.17	8			

Table 4.40 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated with standard recipe (ΔYI)

Variation Source	Mean	n	Non-significant Range		
Silicone 3	1.17	3	a		
Silicone 2	0.41	3		b	
Silicone 1	-2.37	3			c

Table 4.41 Variance analysis of red fabric sample treated with standard recipe (ΔE)

Variation Source	SS	df	MS	F	P
Softener	9.55	2	4.77	0.06	0.930
Error	0.04	6	0.00		
Total	0.04	8			

Table 4.42 Student-Newman-Keuls Test for softener particle size in red fabric samples treated with standard recipe (ΔE)

Variation Source	Mean	n	Non-significant Range
Silicone 3	0.89	3	a
Silicone 1	0.88	3	a
Silicone 2	0.86	3	a

Table 4.43 Variance analysis of red fabric sample treated with standard recipe (ΔWI)

Variation Source	SS	df	MS	F	P
Softener	32.31	2	16.15	6.04	0.030
Error	16.04	6	2.67		
Total	48.35	8			

Table 4.44 Student-Newman-Keuls Test for softener particle size in red fabric samples treated with standard recipe (ΔWI)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	1.94	3	a	
Silicone 2	-1.31	3	a	b
Silicone 3	-2.55	3		b

Table 4.45 Variance analysis of red fabric sample treated with standard recipe (Brightness)

Variation Source	SS	df	MS	F	P
Softener	0.09	2	0.04	6.37	0.030
Error	0.04	6	0.00		
Total	0.13	8			

Table 4.46 Student-Newman-Keuls Test for softener particle size in red fabric samples treated with standard recipe (Brightness)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	0.02	3	a	
Silicone 2	-0.14	3	a	b
Silicone 3	-0.22	3		b

Table 4.47 Variance analysis of red fabric sample treated with standard recipe (ΔYI)

Variation Source	SS	df	MS	F	P
Softener	2.43	2	1.21	5.04	0.050
Error	1.44	6	0.24		
Total	3.87	8			

Table 4.48 Student-Newman-Keuls Test for softener particle size in red fabric samples treated with standard recipe (ΔYI)

Variation Source	Mean	n	Non-significant Range
Silicone 3	0.96	3	a
Silicone 2	0.77	3	a
Silicone 1	-0.22	3	a

Variance analysis of blue and red fabric samples treated with acidic pH for ΔE, ΔWI, ΔYI and Brightness values are given in tables. When we look at the MS (mean square) value we see that the "Softener" values are higher than "Error" value for red fabric samples. It shows that we choose right parameter and there are not any other parameters which more effected from Softener for these samples but for blue fabric samples "Error" values are higher than "Softener" values in ΔE and Brightness tables. It shows that there are some other parameters which more effected from Softener for these samples, for example pH level. Student-Newman-Keuls tests for softener particle size in blue and red fabric samples treated with acidic pH for ΔE, ΔWI, ΔYI and Brightness values are given in tables. The lowest color difference is caused by the softener which has the lowest numeric "Mean" value. "Non-significant Range" values shows that there is a significant or non-significant difference between ΔE ΔWI, ΔYI and Brightness values and the particle size. For red fabric samples the difference is significant but for blue fabric samples the difference is non-significant.

Table 4.49 Variance analysis of blue fabric sample treated in acidic pH (ΔE)

Variation Source	SS	df	MS	F	P
Softener	0.07	2	0.03	1.36	0.320
Error	0.14	6	0.02		
Total	0.21	8			

Table 4.50 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated in acidic pH (ΔE)

Variation Source	Mean	n	Non-significant Range
Silicone 3	4.14	3	a
Silicone 1	3.99	3	a
Silicone 2	3.94	3	a

Table 4.51 Variance analysis of blue fabric sample treated in acidic pH (ΔWI)

Variation Source	SS	df	MS	F	P
Softener	12.31	2	6.15	3.72	0.080
Error	9.91	6	1.65		
Total	22.22	8			

Table 4.52 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated in acidic pH (ΔWI)

Variation Source	Mean	n	Non-significant Range
Silicone 3	4.55	3	a
Silicone 2	3.78	3	a
Silicone 1	1.77	3	a

Table 4.53 Variance analysis of blue fabric sample treated in acidic pH (Brightness)

Variation Source	SS	df	MS	F	P
Softener	0.14	2	0.07	0.50	0.620
Error	0.85	6	0.14		
Total	0.99	8			

Table 4.54 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated in acidic pH (Brightness)

Variation Source	Mean	n	Non-significant Range
Silicone 3	7.39	3	a
Silicone 1	7.23	3	a
Silicone 2	7.08	3	a

Table 4.55 Variance analysis of blue fabric sample treated in acidic pH (ΔYI)

Variation Source	SS	df	MS	F	P
Softener	8.98	2	4.49	3.58	0.090
Error	7.51	6	1.25		
Total	16.49	8			

Table 4.56 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated in acidic pH (ΔYI)

Variation Source	Mean	n	Non-significant Range
Silicone 1	1.80	3	a
Silicone 2	-1.15	3	a
Silicone 3	-0.53	3	a

Table 4.57 Variance analysis of red fabric sample treated in acidic pH (ΔE)

Variation Source	SS	df	MS	F	P
Softener	0.08	2	0.04	3.49	0.090
Error	0.08	6	0.01		
Total	0.15	8			

Table 4.58 Student-Newman-Keuls Test for softener particle size in red fabric samples treated in acidic pH (ΔE)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	3.35	3	a	
Silicone 2	3.22	3	a	
Silicone 3	3.11	3	a	

Table 4.59 Variance analysis of red fabric sample treated in acidic pH (ΔWI)

Variation Source	SS	df	MS	F	P
Softener	3.59	2	1.79	39.03	0.000
Error	0.27	6	0.04		
Total	3.86	8			

Table 4.60 Student-Newman-Keuls Test for softener particle size in red fabric samples treated in acidic pH (ΔWI)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	18.60	3	a	
Silicone 3	17.28	3		b
Silicone 2	17.25	3		b

Table 4.61 Variance analysis of red fabric sample treated in acidic pH (Brightness)

Variation Source	SS	df	MS	F	P
Softener	0.02	2	0.01	5.74	0.040
Error	0.01	6	0.00		
Total	0.03	8			

Table 4.62 Student-Newman-Keuls Test for softener particle size in red fabric samples treated in acidic pH (Brightness)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	0.61	3	a	
Silicone 3	0.52	3		b
Silicone 2	0.50	3		b

Table 4.63 Variance analysis of red fabric sample treated in acidic pH (ΔYI)

Variation Source	SS	df	MS	F	P
Softener	0.43	2	0.21	66.56	0.000
Error	0.01	6	0.00		
Total	0.44	8			

Table 4.64 Student-Newman-Keuls Test for softener particle size in red fabric samples treated in acidic pH (ΔYI)

Variation Source	Mean	n	Non-significant Range	
Silicone 3	-4.88	3	a	
Silicone 2	-4.91	3	a	
Silicone 1	-5.36	3		b

Variance analysis of blue and red fabric samples treated with alkali pH for ΔE, ΔWI, ΔYI and Brightness values are given in tables. When we look at the MS (mean square) value we see that the "Softener" values are higher than "Error" value for red and blue fabric samples. It shows that we choose right parameter and there are not any other parameters which more effected from Softener for these samples. Student-Newman-Keuls tests for softener particle size in blue and red fabric samples treated with alkali pH for ΔE, ΔWI, ΔYI and Brightness values are given in tables. The lowest color difference is caused by the softener which has the lowest numeric "Mean" value. "Non-significant Range" values shows that there is a significant or non-significant difference between ΔE ΔWI, ΔYI and Brightness values and the particle size. For both red and blue fabric samples the difference is significant.

Table 4.65 Variance analysis of blue fabric sample treated in alkali pH (ΔE)

Variation Source	SS	df	MS	F	P
Softener	0.02	2	0.01	4.14	0.070
Error	0.01	6	0.00		
Total	0.03	8			

Table 4.66 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated in alkali pH (ΔE)

Variation Source	Mean	n	Non-significant Range
Silicone 3	4.92	3	a
Silicone 1	4.83	3	a
Silicone 2	4.80	3	a

Table 4.67 Variance analysis of blue fabric sample treated in alkali pH (ΔWI)

Variation Source	SS	df	MS	F	P
Softener	4.87	2	2.43	6.22	0.030
Error	2.35	6	0.39		
Total	7.22	8			

Table 4.68 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated in alkali pH (ΔWI)

Variation Source	Mean	n	Non-significant Range	
Silicone 2	16.41	3	a	
Silicone 3	15.64	3	a	b
Silicone 1	14.61	3		b

Table 4.69 Variance analysis of blue fabric sample treated in alkali pH (Brightness)

Variation Source	SS	df	MS	F	P
Softener	0.40	2	0.20	11.79	0.000
Error	0.10	6	0.01		
Total	0.50	8			

Table 4.70 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated in alkali pH (Brightness)

Variation Source	Mean	n	Non-significant Range	
Silicone 3	8.68	3	a	
Silicone 1	8.54	3	a	
Silicone 2	8.18	3		b

Table 4.71 Variance analysis of blue fabric sample treated in alkali pH (ΔYI)

Variation Source	SS	df	MS	F	P
Softener	4.99	2	2.49	7.00	0.020
Error	2.13	6	0.35		
Total	7.12	8			

Table 4.72 Student-Newman-Keuls Test for softener particle size in blue fabric samples treated in alkali pH (ΔYI)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	-8.90	3	a	
Silicone 3	-9.84	3	a	b
Silicone 2	-10.72	3		b

Table 4.73 Variance analysis of red fabric sample treated in alkali pH (ΔE)

Variation Source	SS	df	MS	F	P
Softener	0.47	2	0.23	112.61	0.000
Error	0.01	6	0.00		
Total	0.48	8			

Table 4.74 Student-Newman-Keuls Test for softener particle size in red fabric samples treated in alkali pH (ΔE)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	2.68	3	a	
Silicone 3	2.20	3		b
Silicone 2	2.20	3		b

Table 4.75 Variance analysis of red fabric sample treated in alkali pH (ΔWI)

Variation Source	SS	df	MS	F	P
Softener	27.63	2	13.81	134.02	0.000
Error	0.62	6	0.10		
Total	28.25	8			

Table 4.76 Student-Newman-Keuls Test for softener particle size in red fabric samples treated in alkali pH (ΔWI)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	15.26	3	a	
Silicone 3	11.70	3		b
Silicone 2	11.40	3		b

Table 4.77 Variance analysis of red fabric sample treated in alkali pH (Brightness)

Variation Source	SS	df	MS	F	P
Softener	0.06	2	0.03	75.81	0.000
Error	0.00	6	4.22		
Total	0.06	8			

Table 4.78 Student-Newman-Keuls Test for softener particle size in red fabric samples treated in alkali pH (Brightness)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	0.59	3	a	
Silicone 3	0.42	3		b
Silicone 2	0.41	3		b

Table 4.79 Variance analysis of red fabric sample treated in alkali pH (ΔYI)

Variation Source	SS	df	MS	F	P
Softener	2.76	2	1.38	136.30	0.000
Error	0.06	6	0.01		
Total	2.82	8			

Table 4.80 Student-Newman-Keuls Test for softener particle size in red fabric samples treated in alkali pH (ΔYI)

Variation Source	Mean	n	Non-significant Range	
Silicone 2	-2.74	3	a	
Silicone 3	-2.86	3	a	
Silicone 1	-3.97	3		b

Variance analysis of blue and red washed fabric samples for ΔE, ΔWI, ΔYI and Brightness values are given in tables. When we look at the MS (mean square) value we see that the "Softener" values are higher than "Error" value for red fabric samples but for blue fabric samples "Error" values are higher than "Softener" values. It shows that there are some other parameters which more effected from Softener for these samples, for example washing cycles, temperature, period etc. Student-Newman-Keuls tests for softener particle size in blue and red fabric samples treated with acidic pH for ΔE, ΔWI, ΔYI and Brightness values are given in tables. The lowest color difference is caused by the softener which has the lowest numeric "Mean" value. "Non-significant Range" values shows that there is a significant or non-significant difference between ΔE ΔWI, ΔYI and Brightness values and the particle size. For both red and blue fabric samples the difference is non-significant.

Table 4.81 Variance analysis of blue washed fabric samples (ΔE)

Variation Source	SS	df	MS	F	P
Softener	0.08	2	0.04	0.72	0.520
Error	0.33	6	0.05		
Total	0.41	8			

Table 4.82 Student-Newman-Keuls Test for softener particle size in blue washed fabric samples (ΔE)

Variation Source	Mean	n	Non-significant Range
Silicone 2	1.04	3	a
Silicone 3	0.97	3	a
Silicone 1	0.81	3	a

Table 4.83 Variance analysis of blue washed fabric samples (ΔWI)

Variation Source	SS	df	MS	F	P
Softener	9.71	2	4.85	0.96	0.43
Error	30.33	6	5.05		
Total	40.04	8			

Table 4.84 Student-Newman-Keuls Test for softener particle size in blue washed fabric samples (ΔWI)

Variation Source	Mean	n	Non-significant Range	
Silicone 3	-1.63	3	a	
Silicone 2	-1.88	3	a	
Silicone 1	-3.95	3	a	

Table 4.85 Variance analysis of blue washed fabric samples (Brightness)

Variation Source	SS	df	MS	F	P
Softener	7.57	2	3.78	6.34	0.030
Error	3.57	6	0.59		
Total	11.14	8			

Table 4.86 Student-Newman-Keuls Test for softener particle size in blue washed fabric samples (Brightness)

Variation Source	Mean	n	Non-significant Range	
Silicone 3	1.42	3	a	
Silicone 2	1.21	3	a	
Silicone 1	-0.61	3		b

Table 4.87 Variance analysis of blue washed fabric samples (ΔYI)

Variation Source	SS	df	MS	F	P
Softener	1.70	2	0.84	0.27	0.76
Error	18.34	6	3.05		
Total	20.04	8			

Table 4.88 Student-Newman-Keuls Test for softener particle size in blue washed fabric samples (ΔYI)

Variation Source	Mean	n	Non-significant Range
Silicone 1	2.99	3	a
Silicone 2	2.08	3	a
Silicone 3	2.06	3	a

Table 4.89 Variance analysis of red washed fabric samples (ΔE)

Variation Source	SS	df	MS	F	P
Softener	0.04	2	0.02	2.76	0.14
Error	0.05	6	0.00		
Total	0.09	8			

Table 4.90 Student-Newman-Keuls Test for softener particle size in red washed fabric samples (ΔE)

Variation Source	Mean	N	Non-significant Range
Silicone 3	2.49	3	a
Silicone 2	2.48	3	a
Silicone 1	2.33	3	a

Table 4.91 Variance analysis of red washed fabric samples (ΔWI)

Variation Source	SS	df	MS	F	P
Softener	2.67	2	1.33	4.83	0.050
Error	1.65	6	0.27		
Total	4.32	8			

Table 4.92 Student-Newman-Keuls Test for softener particle size in red washed fabric samples (ΔWI)

Variation Source	Mean	n	Non-significant Range	
Silicone 3	14.66	3	a	
Silicone 2	14.03	3	a	b
Silicone 1	13.33	3		b

Table 4.93 Variance analysis of red washed fabric samples (Brightness)

Variation Source	SS	df	MS	F	P
Softener	0.01	2	0.00	3.23	0.110
Error	0.00	6	0.00		
Total	0.01	8			

Table 4.94 Student-Newman-Keuls Test for softener particle size in red washed fabric samples (Brightness)

Variation Source	Mean	n	Non-significant Range	
Silicone 3	0.59	3	a	
Silicone 2	0.58	3	a	
Silicone 1	0.53	3	a	

Table 4.95 Variance analysis of red washed fabric samples (ΔYI)

Variation Source	SS	df	MS	F	P
Softener	0.36	2	0.18	6.56	0.030
Error	0.16	6	0.02		
Total	0.52	8			

Table 4.96 Student-Newman-Keuls Test for softener particle size in red washed fabric samples (ΔYI)

Variation Source	Mean	n	Non-significant Range	
Silicone 1	-3.49	3	a	
Silicone 2	-3.72	3	a	b
Silicone 3	-3.98	3		b

Variance analysis of blue and red washed fabric samples for ΔE, ΔWI, ΔYI and Brightness values are given in tables. When we look at the MS (mean square) value we see that the "Softener" values are higher than "Error" value for red fabric samples but for blue fabric samples "Error" values are higher than "Softener" values. It shows that there are some other parameters which more effected from Softener for these samples, for example ironing cycles, temperature, period etc. Student-Newman-Keuls tests for softener particle size in blue and red fabric samples treated with acidic pH for ΔE, ΔWI, ΔYI and Brightness values are given in tables. The lowest color difference is caused by the softener which has the lowest numeric "Mean" value. "Non-significant Range" values shows that there is a significant or non-significant difference between ΔE ΔWI, ΔYI and Brightness values and the particle size. For both red and blue fabric samples the difference is non-significant.

Table 4.97 Variance analysis of blue ironed fabric samples (ΔE)

Variation Source	SS	df	MS	F	P
Softener	0.17	2	0.08	0.99	0.460
Error	0.25	3	0.08		
Total	0.42	5			

Table 4.98 Student-Newman-Keuls Test for softener particle size in blue ironed fabric samples (ΔE)

Variation Source	Mean	n	Non-significant Range
Silicone 3	1.12	2	a
Silicone 2	0.91	2	a
Silicone 1	0.71	2	a

Table 4.99 Variance analysis of blue ironed fabric samples (ΔWI)

Variation Source	SS	df	MS	F	P
Softener	2.75	2	1.37	0.47	0.66
Error	8.66	3	2.88		
Total	11.41	5			

Table 4.100 Student-Newman-Keuls Test for softener particle size in blue ironed fabric samples (ΔWI)

Variation Source	Mean	n	Non-significant Range
Silicone 1	-3.89	2	a
Silicone 2	-4.31	2	a
Silicone 3	-5.49	2	a

Table 4.101 Variance analysis of blue ironed fabric samples (Brightness)

Variation Source	SS	df	MS	F	P
Softener	3.18	2	1.59	8.58	0.05
Error	0.55	3	0.18		
Total	3.73	5			

Table 4.102 Student-Newman-Keuls Test for softener particle size in blue ironed fabric samples (Brightness)

Variation Source	Mean	n	Non-significant Range
Silicone 3	0.72	2	a
Silicone 1	-0.41	2	a
Silicone 2	-1.04	2	a

Table 4.103 Variance analysis of blue ironed fabric samples (ΔYI)

Variation Source	SS	df	MS	F	P
Softener	4.28	2	2.14	0.85	0.500
Error	7.48	3	2.49		
Total	11.76	5			

Table 4.104 Student-Newman-Keuls Test for softener particle size in blue ironed fabric samples (ΔYI)

Variation Source	Mean	n	Non-significant Range
Silicone 3	4.90	2	a
Silicone 2	3.12	2	a
Silicone 1	3.09	2	a

Table 4.105 Variance analysis of red ironed fabric samples (ΔE)

Variation Source	SS	df	MS	F	P
Softener	0.09	2	0.04	7.59	0.060
Error	0.02	3	0.00		
Total	0.11	5			

Table 4.106 Student-Newman-Keuls Test for softener particle size in red ironed fabric samples (ΔE)

Variation Source	Mean	n	Non-significant Range
Silicone 1	1.02	2	a
Silicone 3	1.02	2	a
Silicone 2	0.76	2	a

Table 4.107 Variance analysis of red ironed fabric samples (ΔWI)

Variation Source	SS	df	MS	F	P
Softener	14.74	2	7.37	6.31	0.08
Error	3.50	3	1.16		
Total	18.24	5			

Table 4.108 Student-Newman-Keuls Test for softener particle size in red ironed fabric samples (ΔWI)

Variation Source	Mean	n	Non-significant Range
Silicone 1	3.59	2	a
Silicone 3	0.70	2	a
Silicone 2	-0.04	2	a

Table 4.109 Variance analysis of red ironed fabric samples (Brightness)

Variation Source	SS	df	MS	F	P
Softener	0.03	2	0.01	6.31	0.08
Error	0.01	3	0.00		
Total	0.04	5			

Table 4.110 Student-Newman-Keuls Test for softener particle size in red ironed fabric samples (Brightness)

Variation Source	Mean	n	Non-significant Range
Silicone 1	0.04	2	a
Silicone 3	-0.11	2	a
Silicone 2	-0.13	2	a

Table 4.111 Variance analysis of red ironed fabric samples (ΔYI)

Variation Source	SS	df	MS	F	P
Softener	1.67	2	0.83	9.12	0.050
Error	0.27	3	0.09		
Total	1.94	5			

Table 4.112 Student-Newman-Keuls Test for softener particle size in red ironed fabric samples (ΔYI)

Variation Source	Mean	n	Non-significant Range
Silicone 2	0.23	2	a
Silicone 3	-0.12	2	a
Silicone 1	-1.02	2	a

4.3 Particle Size Analysis Results:

The particle size distribution graphs of silicone softeners used according to intensity (%), volume (%), and number (%) are given in Figure 4.32 – 4.34. In this graphs the positions and areas of peaks observed give useful data. In all graphs a single and narrow peak was found which means that the softeners have low variation of particle size distribution (PDI). PDI is a function of polydispersity of the emulsions and for homogeneous emulsions this value approaches zero, so the lower the PDI the higher the homogeneity of the particle size of the silicone softeners. The average particle size in micrometer and PDI values of softeners used are given in Table 4.113. The results of Table 4.113 are mean values of two measurements and it showed that the softeners differ in particle size and the most homogeneous emulsion belongs to macro silicone softener.

Table 4.113 PDI Values of Silicone Softeners

Name	**Average Measurement**	
	Size (µm)	**PDI**
Silicone 3	25.05	0.0795
Silicone 2	20.71	0.1245
Silicone 1	14.515	0.235

Table 4.114 Particle Size Distribution of the Silicone Softeners

Name	**Average Measurement (µm)**					
	Intensity		**Volume**		**Number**	
	Radius	**Int.**	**Radius**	**Vol.**	**Radius**	**Number**
Silicone 3	27.445	100	21.345	100	17.665	100
Silicone 2	23.455	100	16.61	100	13.31	100
Silicone 1	16.62	94.1	9.85	99.8	7.619	100

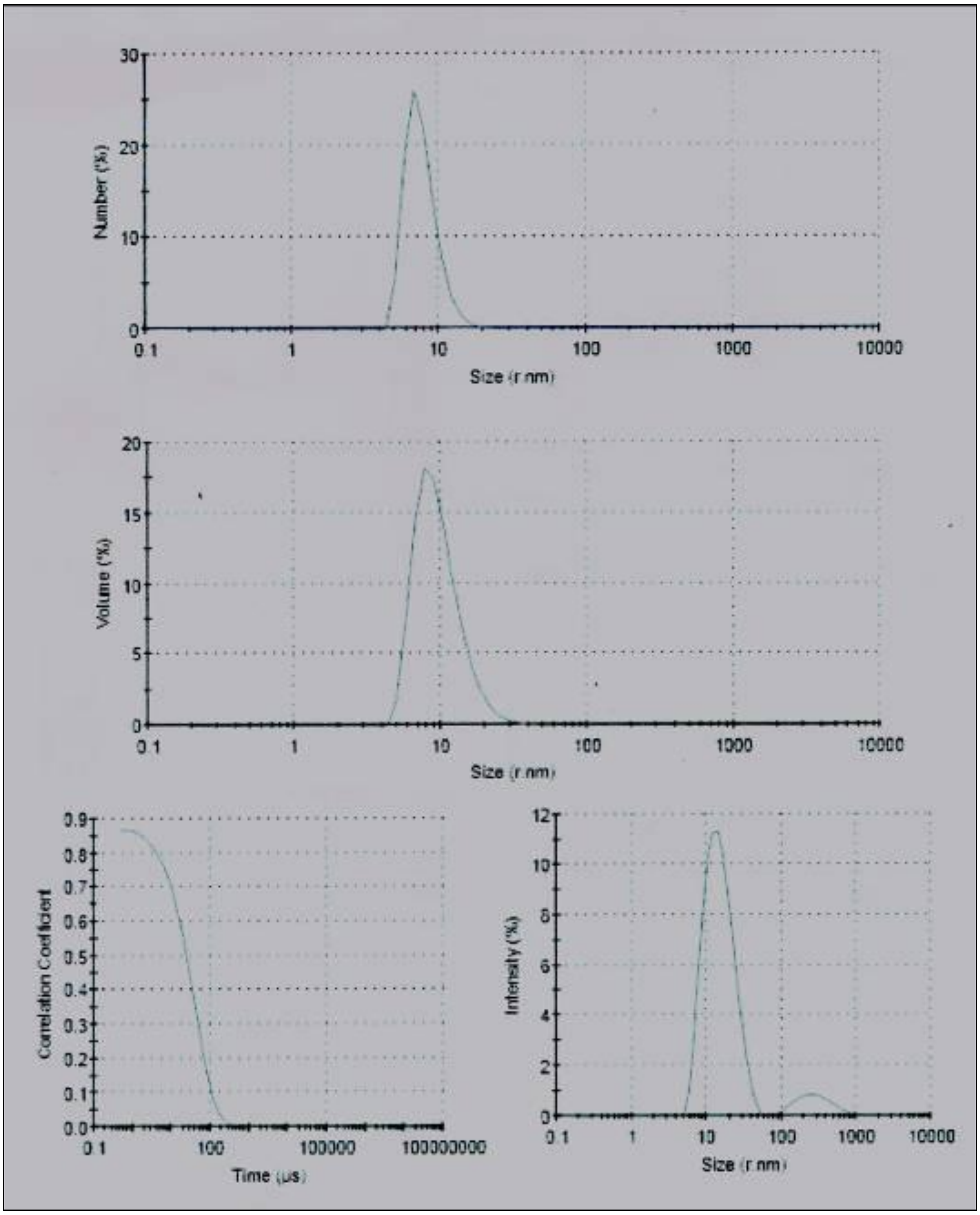

Figure 4.32 Silicone 1 Softener Graphs

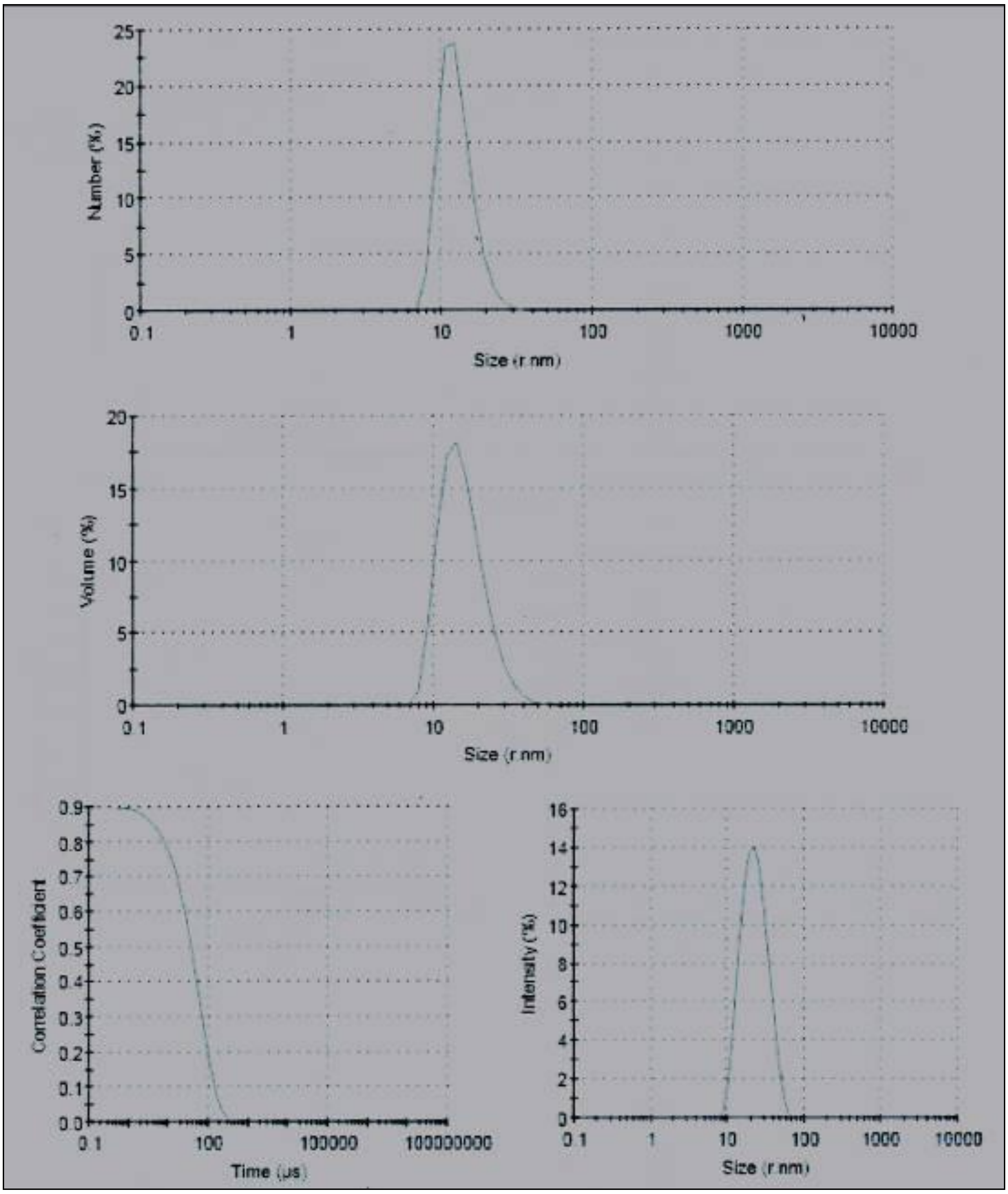

Figure 4.33 Silicone 2 Softener Graphs

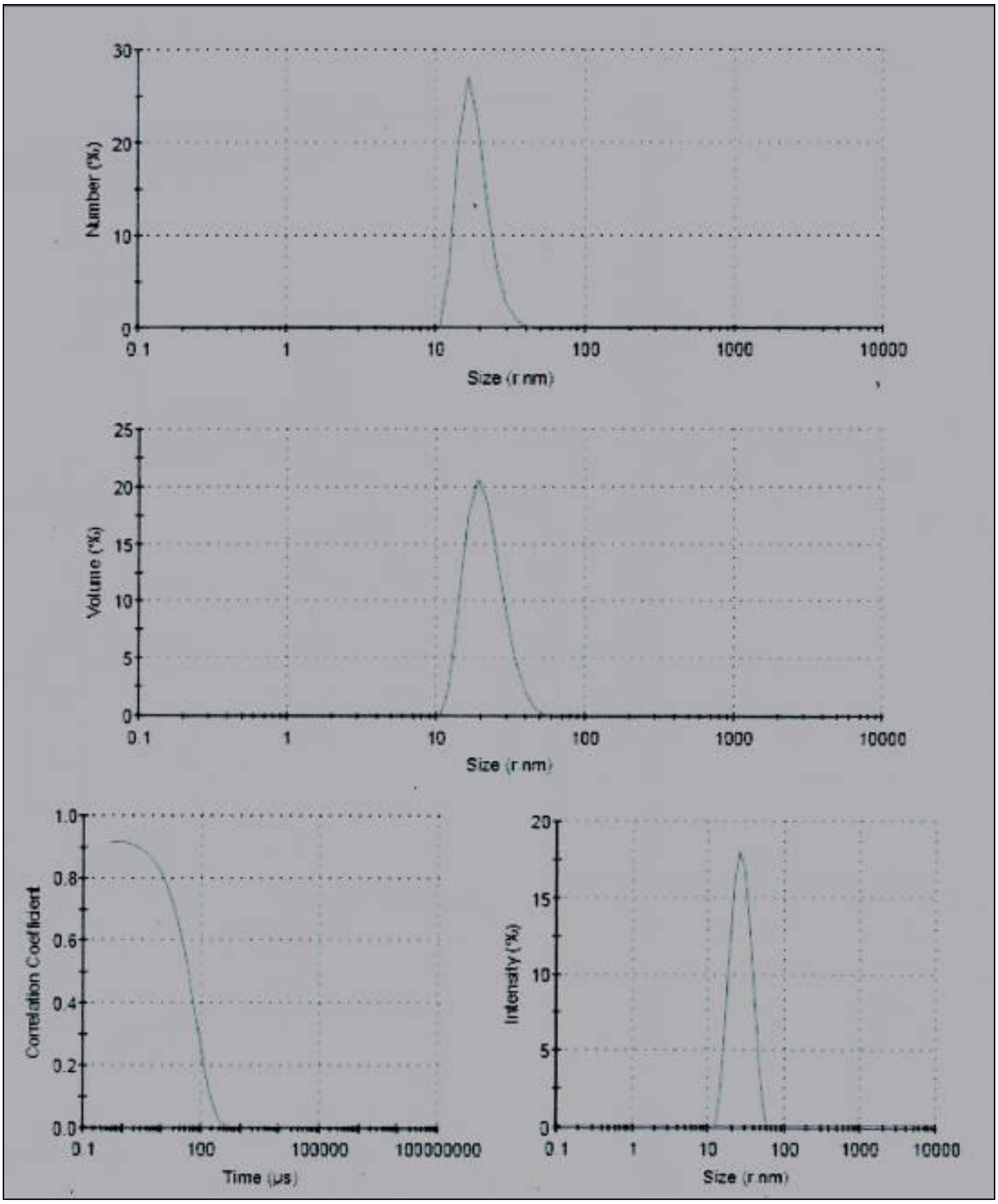

Figure 4.34 Silicone 3 Softener Graphs

4.2 Discussions

When the previous studies were examined, there are different studies related with softening treatment or different textile finishing processes.

Zia et al. studied preparation of rich handles soft cellulosic fabric using amino silicone based softener, surface smoothness and softness properties. A series of amino silicone based softeners with different emulsifiers were prepared and adsorbed onto the surfaces of cotton and blends of cotton/polyester fabrics. Factors affecting the performance properties of the finished substrate such as post-treatment with amino functional silicone based softener varying different emulsifiers in their formulations and its concentration on different processed fabrics were studied. Fixation of the amino-functional silicone softener onto/or within the cellulose structure is accompanied by the formation of semi-inter-penetrated network structure thereby enhancing both the extent of crosslinking and networking as well as providing very high softness. The results of the experiments indicate that the amino silicone can form a hydrophobic film on both cotton and blends of cotton/polyester fabrics and its coating reduces the surface roughness significantly. Furthermore, the roughness becomes lesser with an increase in the applied strength of amino silicone based softener. [14].

Parvinzadeh and Hajiraissi studied about macro- and microemulsion silicone softeners on polyester fibers: evaluation of different physical properties. Polyester fabrics were treated with three concentrations (10, 20 and 30 g/L) of macroand microemulsions of silicones in water at 30 _C by the padding method. The treated fabrics were then dried/ cured at 130 _C for 40 s. The drapeability of treated samples was lower and found to depend on the silicone particle size. Moisture absorbency of treated samples was also lower. Colorimetric properties of softener treated fabrics were evaluated with a reflectance spectrophotometer. Scanning electron microscope (SEM) examinations showed an aggregation of silicone particles on the fiber surface [17].

Çelik et al. studied to get results of effect of nano-silicone softener on abrasion and pilling resistance and color fastness of knitted fabrics. Silicone softeners are classified into three groups according to particle size; macro, micro and nano-silicones. Nano-silicone softeners penetrate the fabric inner structure more easily than others. Due to the fact that nano-silicone softener application area widens rapidly in commercial use, they gave a comparison with respect to performance and color fastness properties of knitted fabrics with and without nano-silicone softener in this study. They obtained and evaluated the properties as abrasion and pilling resistance, rubbing, dry cleaning, and washing fastness using four different knitted samples. Fabrics with nano-silicone softener exhibited poor abrasion but beter pilling resistance. Nano-silicone softener treatment does not have significant effect on color fastness properties of knitted fabrics [18].

Another study Montazer and Hashemikia was studied about application of polyurethane/citric acid/silicone softener composite on cotton/polyester knitted fabric producing durable soft and smooth surface. This research was conducted to use various chemicals to reduce pilling with reasonable softness on the cotton/polyester knitted fabric. Diverse composites of the water-based polyurethane resin (PU), citric acid (CA) as a crosslinking agent and silicone-based softener were selected and applied on the fabric through conventional pad-dry-cure method. The characteristics of the treated fabrics including pilling rate, pilling density, water droplet adsorption time, bending length, crease recovery angle, tensile strength, and water contact angle were examined and reported. Application of the polyurethane resin along with citric acid reduced the fabric pilling. However, co-application of resin, CA, and softener improved the fabric crease recovery angle, bending length, and water droplet adsorption time. This leads to producing a fabric with acceptable low pilling performance and desirable handle properties. The obtained properties were durable to repeated washings, and the treated fabrics had a better resistance against creasing [19].

CHAPTER 5
CONCLUSIONS

In this study, we investigated the effect of different particle sizes of silicone softeners in color difference of selected colors for knitted cotton fabric samples. We used three different particle sized silicone softeners. For more detailed results we investigated the effect of acidic and alkali pH in softening bath, washing and ironing after softening treatment on color difference.

The information generated from the study;

-For blue fabrics which treated with standard recipe, softeners particle sizes effective in color difference. The change in b* axis in color space effected YI and caused yellowing. The smallest particle sized silicon softeners gave the best performance in terms of yellowing and it affected the brightness at the lowest level.

-For red fabrics which treated with standard recipe, fabric samples were influenced by the use of fabric softener in different particle size but there was no significant difference caused by particle size.

-When the blue fabrics were treated with acidic pH recipe, the color differences were found to be non-significant which an important difference from the standard recipe was.

-For red fabrics which treated with acidic pH, WI, YI and Brightness affected from the particle size. The smallest particle sized silicon softeners gave the best softener performance in terms of WI, YI and Brightness.

-For blue fabrics which treated with alkali pH, the smallest particle sized softener caused a decrease in the WI value and the moderate sized silicone softener (Silicone 2) caused yellowing by a decrease in YI value.

-For red fabrics which treated with alkali pH, WI, YI and Brightness affected from softener particle size. The smallest particle sized silicon softener gave the highest softener effect.

-According to correlation table for blue fabric samples, the b* value should be well considered to evaluate the yellowness but it was the a* value for red fabrics to prevent change of color. Both red and blue color fabric samples, whiteness index were found to be correlated with the L* value which promotes the importance of screening of this value to assess the changes in the whiteness.

-For red and blue fabrics which were washed and ironed, the effect of softener on color change were no well-evaluated by only changing the particle size but there should be other important parameters like washing / ironing cycles, temperature, period etc.

Future trend:

In this experimental study, particle size differences in silicone softeners were studied. In future some other parameters can be included or the parameters that used in this experimental study can be changed.

Softeners can be separated into some groups; silicone softeners, anionic softeners, cationic softeners, nonionic softeners. This experimental study can be continued with these softeners. So there will be different results and there will be comparison between all softeners and best recipe can be chosen.

Other parameter, pH, can be changed. In this experimental study, acidic media adjusted at pH 2.5, alkali media adjusted at 12.5. In future studies, the effect of pH value can be researched, the maximum alkali pH can be found, and the minimum acidic pH can be set. So the study should comprise different pH values and effects.

In this experimental study, color differences, yellowness indices, whiteness indices and brightness parameters were studied. Besides this analysis, mechanical tests can be done for future. Particle size effect can cause differences in tensile strength, tear strength or abrasion, so these parameters should be researched.

Ironing effect can be researched also; the study can be varied with different ironing temperatures and ironing time.

REFERENCES

[1] Schindler, W.D. , Hauser, P. J. 2004. Chemical Finishing of Textiles. Woodhead Publishing in Textiles. Cambridge England: CRC Press, 21-43.

[2] Juodsnukytė, D., Gutauskas, M., Krauledas, S. (2005). Influence of Fabric Softeners on Performance Stability of the Textile Materials. *Materials Science (Medžiagotyra)*, **11**, 179-182

[3] Özsoy, E. (2008). Klasik Silikon Emülsiyonları ve Hiderofil Silikonların Kumaş tutumu, Renk Değişimi ve Haslıklar Üzerindeki Etkilerinin Karşılaştırılması, Yüksek Lisans Tezi, Tekstil Mühendisliği Anabilim Dalı, Uludağ Üniversitesi

[4] Das, M.R. (2010). Study of Various Types of Softener (character, pH, application process) in Finishing on Cotton Knitted Goods, Senior Project, City University

[5] Agarwal, G. (2011). Interaction of Textile Parameters, Washageing and Use of Fabric Softener During the Laundry With Mechanical Properties of the Knitted Fabrics and Correlation With Textile Hand, Ph. D. Thesis, In Mechanic Energetic and Materials Science, University of Science and Technology, Lille 1

[6] Guo, J. (2003). The Effects of Household Fabric Softeners on the Thermal Comfort and Flammability of Cotton and Polyester Fabrics, M. Sc. Thesis, In Clothing and Textiles, Virginia Polytechnic Institute and State University

[7] http://www.textiletoday.com.bd/magazine/printable.php?id=177

[8] http://ebookbrowse.com/05-finishing2-troficolor-denim-makers-pdf-d266492103

[9] Nostadt, K., Zyschka, R. (1997). Softeners in the Textile Finishing Industry. *Colourage*, **44**, 53-58

[10] Imtiazuddin, S.M. (2009). Textile Chemical Finishing and Its Mechanism. *Pakistan Textile Journal*, **April, 2009**, 48, 49

[11] O'Lenick, A.J. (2009). Basic Silicone Chemistry - A Review. *Silicone Spectator*, **January, 2009**, 1-2

[12] Chattopadhyay, D.P., Vyas, D.D. (2009). Effect of Silicone Nano-emulsion Softener on Physical Properties of Cotton Fabric. *Indian Journal of Fibre & Textile Research*, **35**, 68-71

[13] Cotton Incorporated. 2004. Technical Bulletin. ISP1011 Methods of Imparting Softness to Cotton Products. North Carolina, 2-5.

[14] Zia, K.M., Tabassum, S., Barkaat-ul-Hasin, S., Zuber, M., Jamil, T., Jamal, M.A. (2011). Preparation of Rich Handles Soft Cellulosic Fabric Using Amino Silicone Based Softener. Part-I: Surface Smoothness and Softness Properties. *International Journal of Biological Macromolecules,* **48**, 482-487

[15] Manickam, M.M. (2009). Silicone Chemistry for Fabric Care. *Colourage,* **56**, 86

[16] Mohamed, A.L.O. (2011). Changing the Properties of Natural Fibres by Coating and of Synthetic Fibres by Infiltration, M. Sc. Thesis, From the Faculty of Mathematics, Computer Science and Natural Sciences, RWTH-Aachen University

[17] Parvinzadeh, M., Hajiraissi, R. (2008). Macro and Microemulsion Silicone Softeners on Polyester Fibers: Evaluation of Different Physical Properties. *Journal of Surfactants and Detergents*, **11**, 269–273

[18] Çelik, N., Değirmenci, Z., Kaynak, H.K. (2010). Effect of Nano-silicone Softener on Abrasion and Pilling Resistance and Color Fastness of Knitted Fabrics. *Tekstil ve Konfeksiyon*, **20**, 41-47

[19] Montazer, M., Hashemikia, S. (2011). Application of Polyurethane/Citric Acid/Silicone Softener Composite on Cotton/Polyester Knitted Fabric Producing Durable Soft and Smooth Surface. *Journal of Applied Polymer Science,* **124**, 4141-4148

[20] http://www.sarex.com/sarexnew/textile/articles/pdf/ART118.pdf

[21] Tomasino, C. (1992). Chemistry & Technology of Fabric Preparation & Finishing. Department of Textile Engineering, Chemistry and Science College of Textiles, North Caroline State University

[22] Habereder, P., Bereck A. (2002). Silicone Softeners. *Review of Progress in Coloration and Related Topics*, **32**, 125-137

[23] Broadbent, A.D. 2001. Basic Principles of Textile Coloration. Society of Dyers and Colourists

[24] Gunesoglu C., Kut D., Orhan M. (2010). Performing the Electrospraying Process for Application of Textile Nano Finishing Particles. *Textile Research Journal*, **80**, 106-115

[25] Manual Instructions for 90Plus. (1995). Brookhaven Instr, Holtsville, Newyork

[26] Grabowski, E.F., Morrison, J. D., (1983). Particle Size Distributions from Analysis of Quasi-Elastic Light Scattering Data. Wiley, New York

[27] http://www.brookhaveninstruments.com/products/particle_sizing/p_PS_90Plus.html

[28] Hunterlab Applications Note. (2008). CIE L*a*b* Color Scale, Vol. 8 No.7