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UNIVERSITY OF GAZIANTEP

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A STUDY ON SOME CONSTITUENTS OF ELECTROSPRAYING PROCESS DETERMINING THE DEPOSITION TIME

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BY

BİLGEN KAPAR

November 2018

A Study on Some Constituents of Electrospraying Process Determining The Deposition Time

Ph. D. Thesis

in

Textile Engineering

University of Gaziantep

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Bilgen KAPAR

ABSTRACT

A STUDY ON SOME CONSTITUENTS OF ELECTROSPRAYING PROCESS DETERMINING THE DEPOSITION TIME

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Ph.D. in Textile Engineering

Supervisor(s): Prof. Dr. Cem GÜNEŞOĞLU

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In this study, five different textile chemicals (macrosilicone, microsilicone, flame retardent, florokarbon, florokarbon+dendrimer), which are prepared with suitable solvents, are sprayed by electrospraying method on to the aluminum foil, 100% cotton knitted fabric, 100% polyamide knitted fabric and 100% polyester knitted fabric. In this spraying process, it is desired to observe how long a certain amount of solution is accumulated on the collector (deposition time), and the effecting parameters are emphasized. Environmental factors were determined as 20-23 ºC temperature and 27-32% humidity. The solution concentration, applied voltage, needle-to-collector distance parameters were also investigated. After the deposition times were observed, the relationships of the deposition times with the relevant parameters were also analyzed statistically. The effect coefficients of the parameters were obtained by these analyzes and formulas were obtained by statistical programmes. In these formulas, it is observed how parameters affect the agglomeration period (whether they are true or inverse, meaningful).Percentage errors were calculated between each formulation and each experimental result.As a result of study, deposition time shows differences according to chemical type, collector type and concentration rates.

Key Words: Electrospray, textile chemicals, deposition time, statistical analysis

ÖZET

ELEKTROSPREY İŞLEMİNİN YIĞMA SÜRESİNİ BELİRLEYEN BAZI BİLEŞENLERİ ÜZERİNE BİR ÇALIŞMA

KAPAR, Bilgen

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Kasım 2018

139 sayfa

Bu çalışmada beş farklı tekstil kimyasalı (makrosilikon, mikrosilikon, güç tutuşurluk, florokarbon-su iticilik, florokarbon+dendrimer-su iticilik) ve ilgili çözücüleri kullanılarak hazırlanan çözeltilerin elektrosprey yöntemi ile alüminyum folyo, % 100 pamuklu örgü kumaş, 100% polyester örgü kumaş ve 100% polyamid örgü kumaşlara spreylenmiştir. Bu spreyleme işleminde belirli miktardaki çözeltinin ne kadar sürede toplayıcıda yığıldığı gözlenmek istenmiş olup, bu süreye etkiyen parametrelerin üzerinde durulmuştur. Çevresel faktörler, 20-23 ºC sıcaklık ve %27-32 nem olarak belirlenmiştir. Çözelti konsantrasyonu, uygulanan voltaj, iğne ucu-toplayıcı arası mesafe parametreleri de araştırılmıştır. Yığılma süreleri gözlemlendikten sonra, yığılma sürelerinin ilgili parametrelerle olan ilişkileri de istatistiksel olarak analiz edilmiştir. Bu analizlerle parametrelerin etki katsayıları görülmüş ve istatistik programla formüller elde edilmiştir. Bu formüllerde yığılma süresine hangi parametrenin nasıl etkidiği (doğru ya da ters olup olmadığı, anlamlı olup olmadığı) gözlenmiştir. Her formülasyon ve her deney sonucu arasında yüzdelik hatalar hesaplandı. Çalışma sonucunda, yığılma süresi kimyasal tipine, konsantrasyon oranına ve toplayıcı yüzeye göre farklılıklar göstermiştir.

Anahtar Kelimeler: Elektrosprey, tekstil kimyasalları, yığılma süresi, istatistiksel analiz

To my dear husband and son;

Adil&Umut Kaan

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I also thank the members of my thesis committee, Prof. Dr. Mehmet Topalbekiroğlu and Assoc. Prof. Dr. Onur Balcı for their guidance and suggestions.

The major experiment materials for this study, 100% Polyester fabric sampleswere provided by Elvan Tekstil, Denizli. Chemicals and 100% Polyamide fabric samples were provided from Rudolf Duraner, Bursa. 100% Cotton fabric samples were provided from Fıstık Tekstil, Gaziantep.

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NOMENCLATURE

dyn/ cm	The centimeter-gram-second (cgs) unit of force/cm
$S \cdot m^{-1}$	Siemens/meter
µS/cm	Mikrosiemens/cm
mN/m	Millinewton/meter
cP	Centipoise
22 G	22 gauge
Ω	Ohm
v/v	Volume/Volume
rpm	Revolution/minute
µm	Micrometer
PES fabric	Polyester fabric
PA fabric	Polyamide fabric
PCC	Pearson correlation coefficient
p value	Calculated probability value

CHAPTER 1

INTRODUCTION

Nanotechnology is an attractive word for a while. Nanotechnology has been used in lots of different discipline in science. Textile science is one of the important fields when the literature was checked.

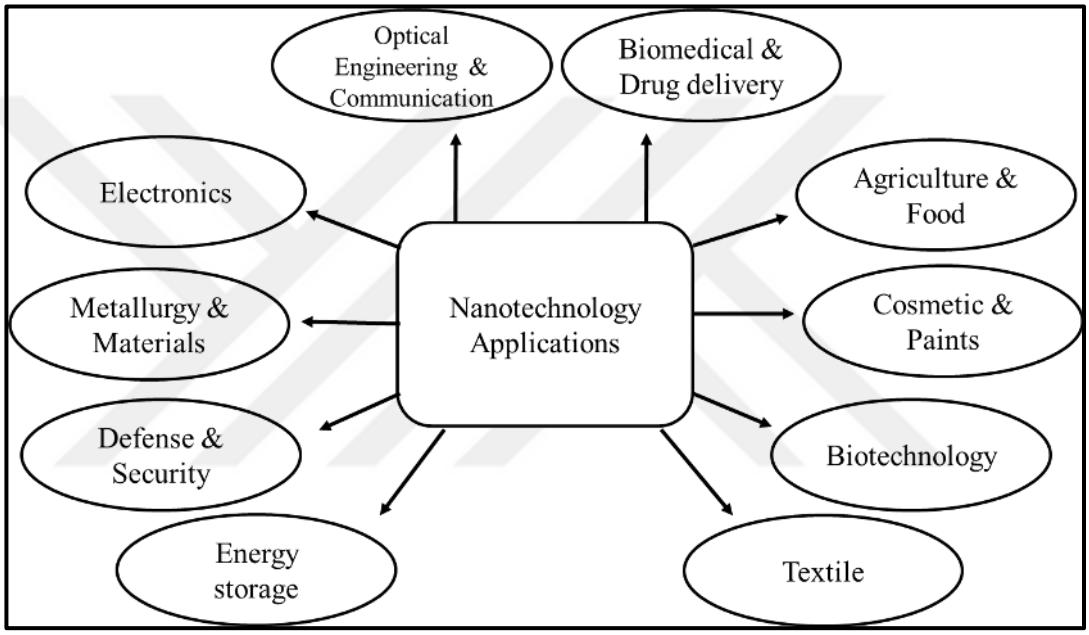

Figure 1.1 Nanotechnology Application Areas [Ramsden, Book, 2009]

Nanotechnology is generally describes as there is a matter, that is nanosized, which you can learn and control it. Physical, chemical or biological properties of materials can be synthesized or changed to enhance the materials for next generations [Patra and Gouda, 2013]. Nano means "dwarf" in Greek. Expressions defined by nano indicate any measure in one percent of a billion. For example; The nanometer refers to one billionth of a meter (1 nm = 10-9 m). Nanostructures correspond to systems of about 10 to 100 atoms (10 to 9 meters in length) [Özdoğan et. al., 2006].

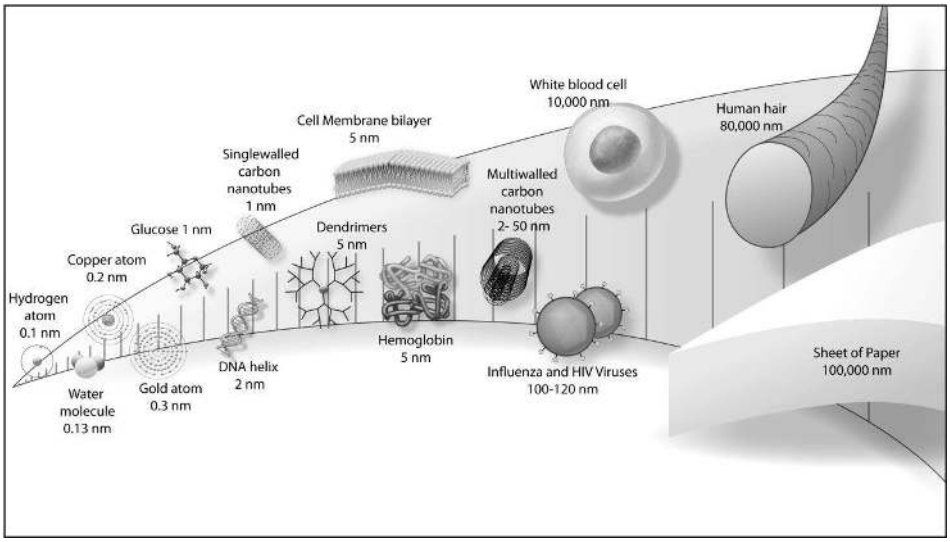

Figure 1.2 Nanoscale and nanostructure [Yokel and MacPhail, 2011]

Textile industry has been listed as one of the most significant sector in nanotechnology. Not only, the application of nanotechnology in textile industry has raised the durability, comfort and hygienic of fabrics, but also it decreases the cost of the production [Patra and Gouda, 2013]. The main reason of nanotechnology in textile industry is that conventional methods used to give desirable properties to fabrics, but generally conventional methods can not be permanent on fabric, and fabrics will loose the properties by every laundering or wearing. Nanotechnology can take part in textile industry to obtain fabric softness, durability, breathability namely water repellnecy, fire reterdancy, antimicrobial and crease resistance in fibers, yarns and fabrics [Celikturk, 2011].

It is possible to achieve to give textile materials different properties by nanotechnology. Textile surfaces can be coated by chemicals or polymers by using nanotechnology. These coatings enable following characteristics; antibacterial effect, antimicrobial effect, flame retardancy, infrared absorbing, special effects [Kut and Güneşoğlu, 2005].

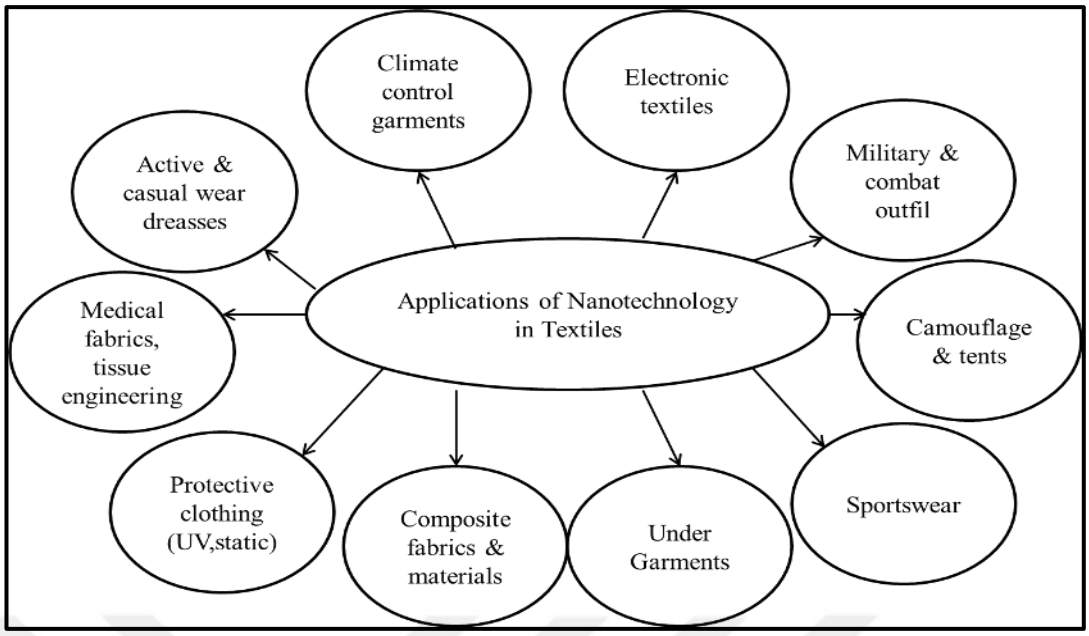

Figure 1.3 Some applications of nanotechnology in textiles [Celikturk, 2011]

1.1.Electrospraying Process

Electrospraying has given new opportunities to nanotechnology. Electrospraying process can be used for especially micro and nano thin film deposition, micro and nano particle or capsule production. Electrospraying can satisfy the needs of nanoparticle production with measureability of size, reproducibility and influent capsulation [Jaworek, 2008]. The thought of electrospraying process regarding fluids has been coined to get into detail the proper execution regarding atomization which occurs at a continuing conical meniscus as opposed to some other types of atomization. In general, a remarkably fine filament concerns through the pinnacle in the cone, which also filament and then disperses into a remarkably fine aerosol. Sometimes the real filament has shown to become outstanding continual aeroplanes, nevertheless fast-moving specific decreases, and for some liquid materials exclusively ionic types are usually released. This conical meniscus is usually established by the end of the capillary pipe and constantly given juice at a source working at near actually zero hydrostatic tension [Smith, 1986]. Electrospraying process is very a cost-effective strategy where utilizes a homogeneous electrohydrodynamic pressure to split the liquids directly into fine jets. With regards to the unique processing limitations (e.g. collector distance, voltage) these techniques can simply develop micro- and nano-scale fibers and particles composed of polymers, ceramics or possibly composites. You will find two main strategies from

the electrohydrodynamic atomization finalizing: electrospraying and electrospinning. Electrospraying recognizes a method where particles are usually produced as the appearance electrospinning can be utilized for producing fibres. Experts took observe of these systems because of their particular capacity to generate micro- in addition to nanometer architectures including useful cells scaffolds, drug delivery insurance providers, designed biochips in addition to bioactive motion pictures/coatings. Electrospinning can be an attractive probability for producing fibers from bio-polymers. It could tackle a number of wants in tissue engineering, like scaffolds for skin tone, bone tissue, blood stream in addition to vascular grafts [Wu and Clark 2008]. It is indicated above that electrohydrodynamic atomization can be seperated in two common groups; electrospraying and electrospinning. These techniques can produce particles and fibers in the range from nanometers to micrometers. Electrospraying is a process that causes the creation of tiny droplets by means of electric field. In electrospraying process, there is a solution and this solution flows from a nozzle under an electric field, which forms a jet. The jet is damaged and turns into droplets by means of electric force [Jaworek, 2007]. The basic set up (Figure 1.4) regarding electrospraying process is constructed of numerous major parts: a syringe pump electric motor, a syringe, a metallic needle providing as nozzle, a top voltage electric power origin along with a grounded substrate supplying as being a collector (Figure 1.5).

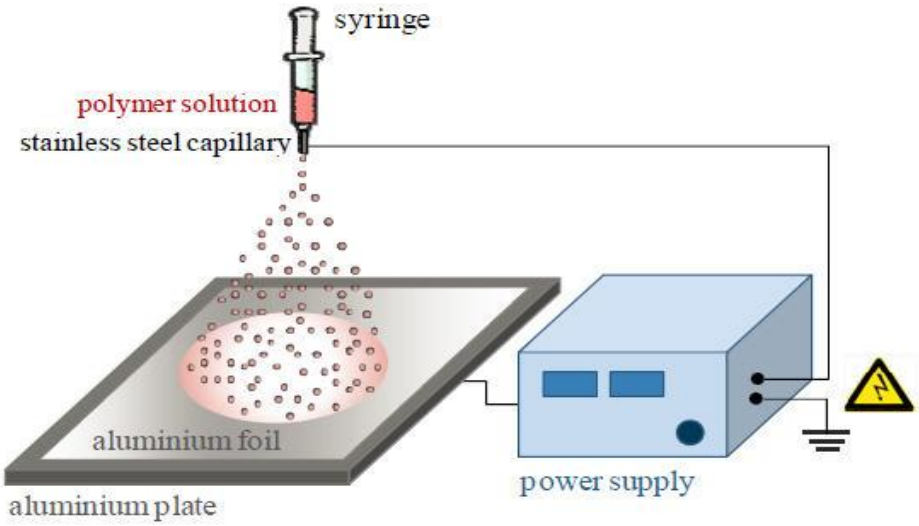

Figure 1.4 Schematic of a typical electrospraying setup [Bock et. al., 2011]

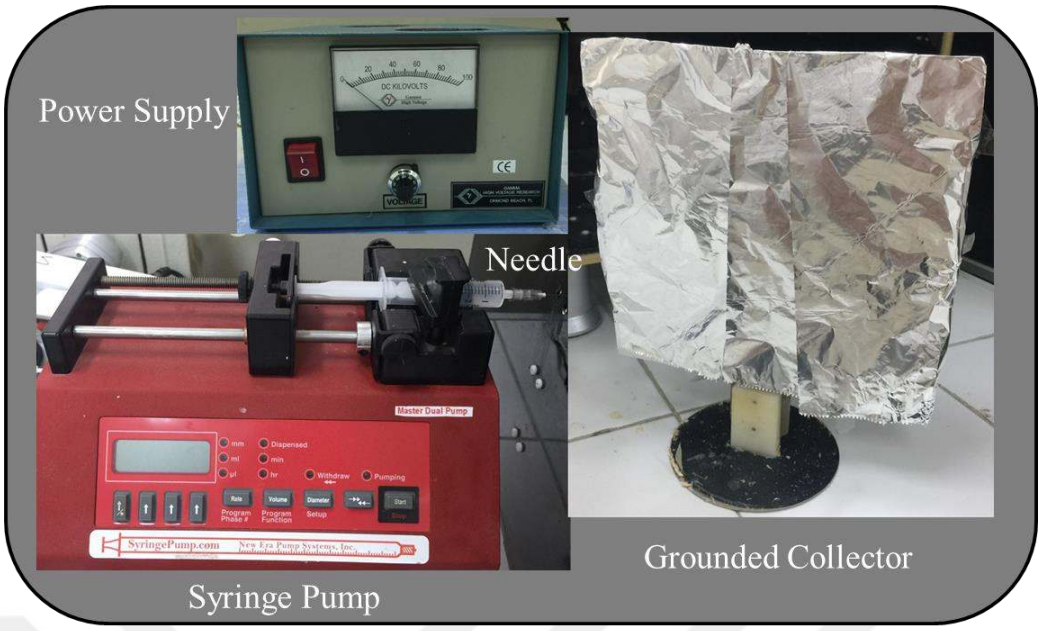

Figure 1.5 Basic components of electrospraying method

Electrospray technology causes new novelties to nanotechnology. Nanotechnology is made up the investigation of actual physical phenomena at supra atomic levels, creation of atomic compounds, generation of nanoparticles, deposition of nano webs from particles, production regarding nano structured materials. This specific technology is utilized for thin film deposition, particle manufacturing or capsule formation regarding both micro and nano size. In modern material technologies, microelectronics and health care technology, thin films and fine powders are utilized [Jaworek and Sobczyk, 2008]. Electrospray technique is capable of producing highly charged particles from nanometer to supermicrometer diameter range. In electrospray technology, generation, dispersion and deposition of particles can be controlled by users. By manipulating particle size, morphology and construction, electrospray technique can be suitable for many application areas, especially for medical, biological applications [Chen et. al., 2009].

1.2. Effective Parameters in Electrospraying Process

There are three main groups of parameters in both electrospraying and electrospinning. These are; process parameters, solution parameters and ambient parameters. Process parameters are voltage, tip-collector distance, flowrate and needle diameter [Doshi and Reneker, 1995], solution parameters are viscosity, surface tension, conductivity and concentration [Deitzel et. al., 2000] and ambient parameters include temperature, humidity, and pressure [Rodoplu and Mutlu, 2012].

Parameters can effect particle size [Chen et. al., 1995; De Juan and De La Mora, 1997, Bock et. al. 2011], particle morphology [Bock et. al. 2011], deposition time [Gunesoglu, 2011] in electrospraying, fiber diameter [Christopherson et. al. 2009, Fridrick et. al., 2013], fiber morphology [Deitzel et. al., 2001,] and spinnability [Demir et. al., 2002] in electrospinning.

1.2.1. Process Parameters

1.2.1.1. Voltage

In electrohydrodynamic atomization systems (electrospinning and electrospraying), voltage value is one of the substantial parameters. Applied voltage enables to alert the charges in the solution to transform them to the collector. Applied voltage could be positive or negative. When voltage value overcomes the critical value, Taylor's cone is occured and the process starts [Taylor, 1964]. When electrical voltage increases, the meniscus formed at the tip of the nozzle also increases. It shows that electrical voltage has an effect on the electrospraying mode at the capillary needle [Syafiza, 2013].

1.2.1.2. Tip-collector Distance

The other significant process parameter is tip collector distance. This parameter has a main effect on jet flight time and electric field strength. It means when the tip collector distance descents, flight time and solvent evaporation time become shorter and it causes an increase in the electric field strength. It can be said that the effect of decreasing tip collector distance is generally identical with increasing of voltage [Chowdhury and Stylios, 2010].

1.2.1.3. Flow rate

Generally, when flow rate of solution is chosen lower, there is enough time for polarization of solution [Li and Wang, 2013]. For example a decreses in flowrate, thin films on collector happen [Woo et. al., 2012].

1.2.1.4. Needle Diameter

Needle diameter has a significant effect on electrospraying process. If very small diameter needles have chosen, there can be coagulation problems [Mo et.al., 2004].

1.2.2. Solution Parameters

1.2.2.1. Viscosity

Solution viscosity plays a critical role in electrohydrodynamic atomization systems. In electrospraying process, the jet breaks into droplets with low viscosities. For high viscosity values jet does not break, so the jet travels to the collector and particles could not be achieved [Deitzel et. al., 2011]. In electrospinning process; continuos and smooth fibers can not be achieved with very low viscosity, while with very high viscosity causes hard ejection of jets from solution and coagulations. For the process it should be used suitable viscous solutions [Larrondo and Manley,1981; Sukigara et. al., 2003].

1.2.2.2. Surface Tension

A droplet at the tip of the needle can be occured because of surface tension [Costa et. al. 2010]. It has been concluded that a liquid cannot be electrosprayed when its surface tension is higher than 50 dyn/cm [Smith, 1986].

1.2.2.3. Conductivity

Solution conductivity is specified by the polymer type, solvent sort, and the salt [Zong et. al., 2002]. A liquid cannot be electrosprayed when its surface tension is higher than 50 dyn/cm and its conductivity does not fall within the range of 10^{-1} -10^{-11} S/m [Smith, 1986]. Conductivity affects particle size during electrospraying, Tang and Gomez [1996] showed in their study, when conductivity is increased during the electrospraying process, it is possible to get smaller droplets.

1.2.3. Ambient Parameters

Ambient parameters, humidity and temperature. Humidity influences the fiber diameter and morphology in electrospraying process [Chen et. al., 1995; Park and Lee, 2009]. It is still difficult to find any study related with temperature effect on electrospraying in literature.

1.3. Textile Chemicals

Typical process from fibers to finished goods represents the textile chain and is summarized in the following diagram.

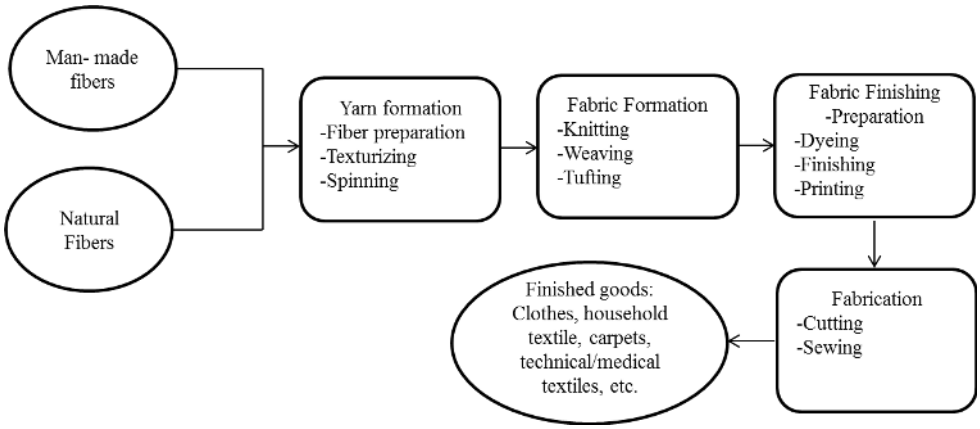

Figure 1.6 Typical textile processing flow-chart

Textile wet processing can be separated in three groups; pretreatments, coloration (dyeing or printing) and textile finishing. Finishing is the last step in the fabric manufacturing process, one more chance to provide the attributes which consumers may importance. Finishing process in the narrow perception is the final step within the fabric manufacturing process, the last possibility to supply the properties that customers will value. Finishing completes typically the fabric's performance and provides it special functional attributes such as the final 'touch'. Finishing process can be divided into two groups; mechanical and chemical finishing. Chemical finishes are often pad applied to dyed or printed fabrics after a drying out step. Within this situation, dry fabric is passed by means of the chemical finish solution and the process is known as a 'wet on dry' process. The wet pick-up of a chemical solution in a pad mangle is usually influenced by many aspects such as fabric features, machine settings and solution or emulsion properties [Schindler and Hauser, 2004]. There are different applications in chemical finishing process. These are can be listed in the following table (Table 1.1).

Table 1.1 Different applications in chemical finishing

Finishing Types	Effect of Solutions
Softening Finishes	Soft hand, some smoothness, more flexibility and better drape and pliability
Hand Building Finishes	Fullness, stiffness
Easy care and Durable Press Finishes	Easy care, minimum care, easy to iron, wash and wear,
Repellent Finishes	Self evident, the drops should stay on the surface and easily drip off.
Soil-release Finishes	Protection from soil redeposition during laundering and absorbency or transport of liquid water
Flame Retardent Finishes	Successful flame retardent product and having little or no adverse effect on textile's physical properties
Non-slip Finishes	Increase the adhesion between fibers and yarns regardless of fabric construction
Antistatic Finishes	To avoid effects of statical charges, causing materials handling problems
Anti-pilling Finishes	To avoid unsightly appearance and unpleasent handle
Elastomeric Finishes	Main effect is durable elasticity
Finishes to improve colour fastness	Improve colour fastness by chemical finishing
Ultraviolet Protection Finishes	Prevention from harmful effects of solar ultraviolet
Antimicrobial Finishes	Protection of textile user and protection of textile itself from damage caused by microorganisms
Insect Resist and Mite Protection Fnishes	Protect wool and other animal fibers from attack by the larvea of certain moths and beetles
Finishing with enzymes: bio finishes for cellulose	Removes protruding fibers and slubs from fabrics, reduces pilling, softens fabric hand and provide a smooth fabric appearance
Novel Finishes	Anti-odour finishes, fragrance finishes, plasma techniques, sol-gel finishes etc.

Textile finishing usually involves treatments such as scouring, bleaching, dyeing and/or printing, the last mechanical or chemical finishing operations, that during this stage are carried out upon textile items (staple, sliver or top, yarns or filaments, woven or knitted fabrics) to further improve their particular standard characteristics like take dye puncture, printability, wet ability, coloration, side, and also overall look. Simply by textile finishing, many of us furthermore suggest all of the finalizing functions that, even though within the so called completing point, are usually applied to the actual material to further improve their appearance, hand along with houses, at times according to the discipline involving application [Bellini et. al., 2002].

There are many studies related with several polymers used in electrospraying in literature. Textile chemical solutions are limited availability in this process. When

literature was checked, especially florocarbon chemical solution used in studies [Yonezawa et. al., 2001; Gunesoglu et. al. , 2010; Gunesoglu, 2011; Gunesoglu et. al., 2011; Xu,2011; Dasdemir and İbili, 2016].

In this study, widely used – commercially available textile finishing chemicals are selected for electrospraying process. They are macrosilicone softener (Rucofin GWE), micro silicone softener (Rucofin GWS), fluorocarbon (EEE 6), dendrimer+fluorocarbon (Ruco-Guard AFR) and flame retardant chemicals (Rucoflam CK). These chemicals were produced by Rudolf Group, Germany and they were supplied from Rudolf Duraner, Bursa, Turkey. When literature was checked except fluorocarbon, other chemicals are scarcely used in electrospraying. Election was made among the commonly used chemicals.

1.3.1. Macrosilicone softener

Softeners can be categorized by cationic softeners, anionic softeners, nonionic softeners, amphoteric softeners and silicone softeners. In textile industry, silicones are mainly used in all stages of the process, from fiber production to finished goods. Silicones are generally applied to textile materials via conventional padding system. In this study silicones applied to textile materials by electrospraying method.

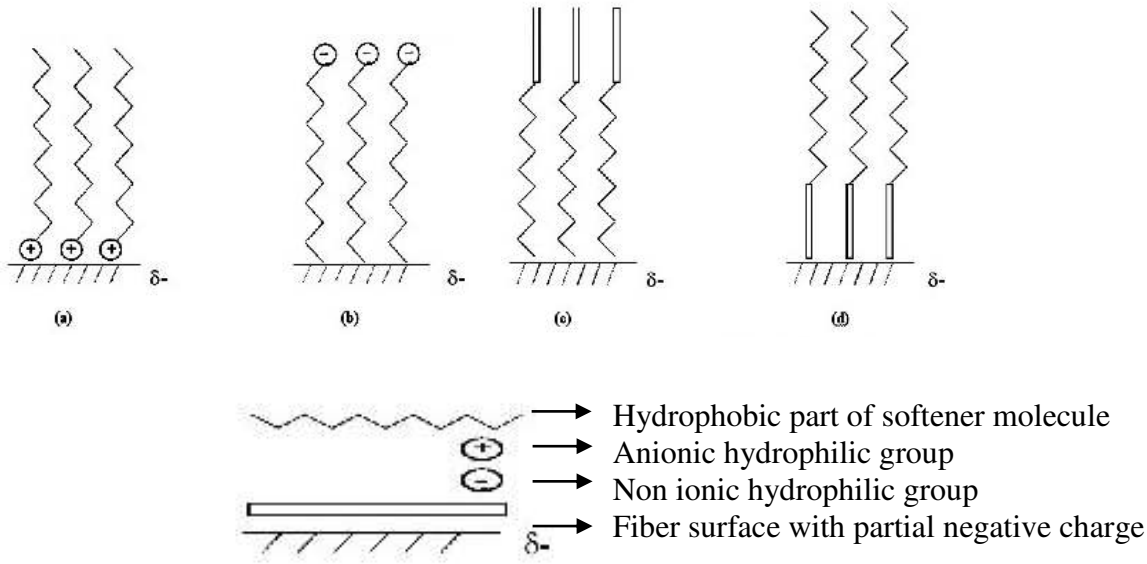

Figure 1.7 Schematic orientation of softeners on fiber surface (a) Cationic softener at fiber surface, (b) Anionic softener at fiber surface (c) Non-ionic softener at hydrophobic fiber surface (d) Non-ionic softener at hydrophilic surface [Schindler and Hauser, 2004].

With the aid of silicones textile materials gain properties such as lubrication, softening, foam control or hydrophobic coatings. The silicone emulsions are available with different particle sizes. Macro size means that the particle size is 150-300 nm [Choudhury et. al., 2012].

1.3.2. Microsilicone softener

Microsilicones can be available below 40 nm and in transparent form. The microemulsions can be selected commonly because of high shear stability [Choudhury et. al., 2012]. The amino functional silicones are generally carried out properly with microemulsions. There are some advantages when we compare microemulsions with macroemulsions. Because of small particle size, the effect can be durable [Li and Wang, 2013]. Macroemulsions can be deposited on the yarn surface. When microemulsions are examined, they penetrate into the yarn [Figure 1.8].

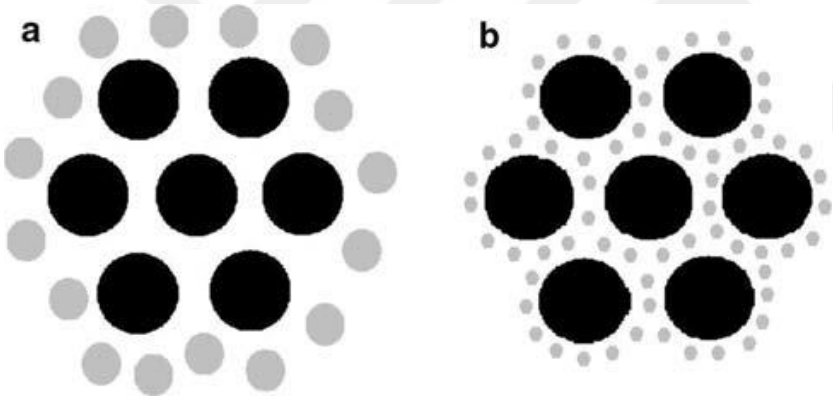

Figure 1.8 Cross section of yarns treated with silicone softeners. (a) Macroemulsion silicone particles deposited on the yarn surface. (b) Microemulsion silicone particles penetrated into the yarn [Parvinzadeh and Hajiarissi, 2008]

1.3.3. Fluorocarbon

Fluoro alkyl polymers had been started to use since 1960s. Because of perfect surface properties of fluoro alkyl polymers, they have been used in textile industry as water resistant, oil resistant and soil repellent. Water resistancy can be changeable according to polymer chain long [Uğur and Karaboyacı, 2010]. Fluorocarbons (FC) are used as repellent finishes in textile industry. Both oil and water repellency can be succeeded with fluorocarbons because of low surface energy [Černe, 2004].

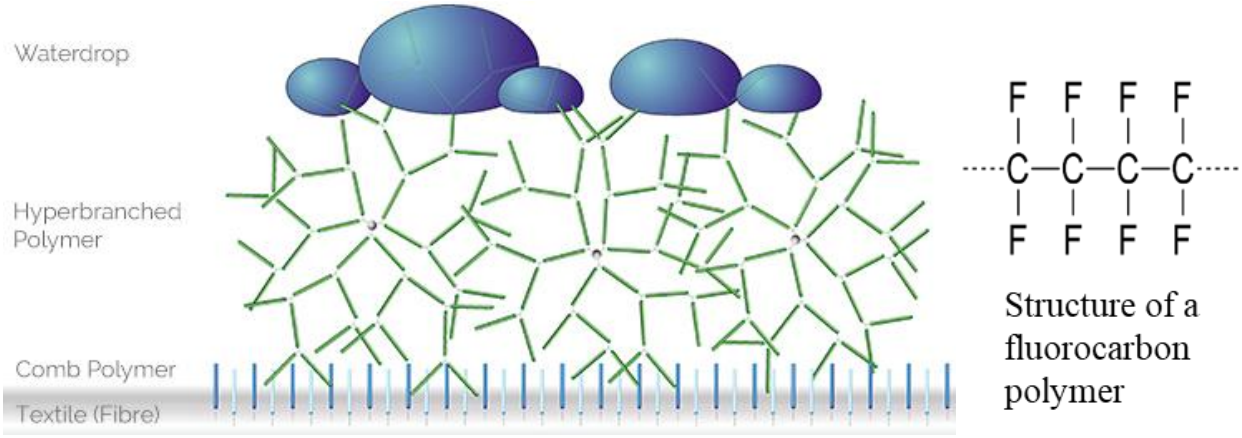

Figure 1.9 Fluorocarbon as a water resistant [Rudolf Group]

After fluorocarbon polymer is applied on the textile material, during fixation, fluorocarbon polymers combine polymer films on the surface, and this perflorated parts are oriented to the surface and this situation makes the textile surface water repellent [Çoban, 1999; Grottenmüller, 1999].

1.3.4. Dendrimer

The dendrimer derives from the Greek words "dendron" (tree) and "meros" (part) refers to tree-like branched compounds. Multi branched (dendritic) structure are frequently encountered in nature, science, art and daily life. Examples of dendritic structures that are the branches and roots of trees, blood vessels, nerve cells, rivers, lightning, corals and snowflake [Vögtle et. al., 2009]. Dendrimers are highly branched oligomers with nonpolar chains forming a star brush structure [Schindler and Hauser, 2004]. In general, dendrimers have different controllable sizes, molecular weights during the synthesis. Dendrimers can have variable molecular structures which influence the chemical structures [Khakzar 2014].

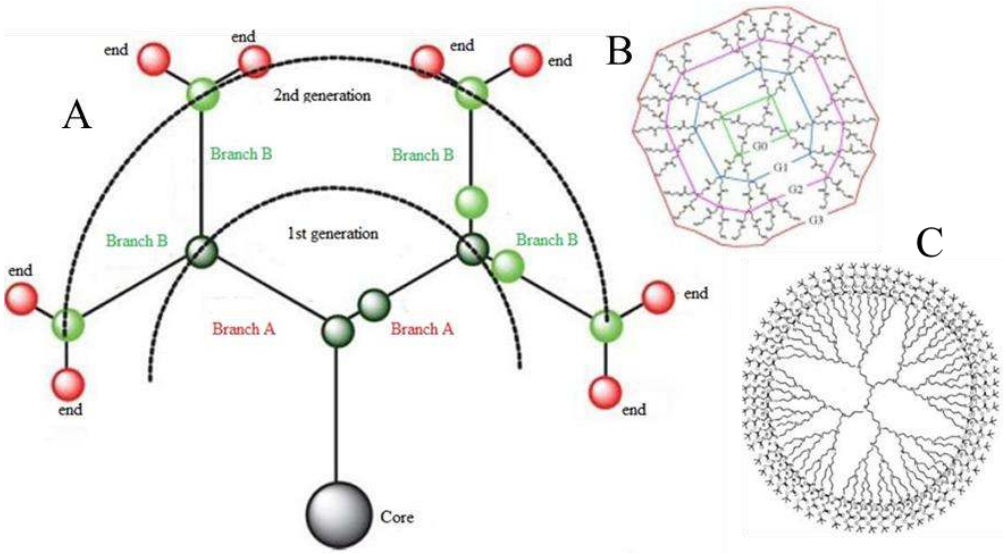

Figure 1.10 A) Dendritic unit [Vögtle et. al., 2009] B) Generation formation [Holister et. al., 2003] C) Dendrimers with tightly packed structure [Jansen et.al., 1995]

Dendrimers are frequently used in textile industry; they are used as pretreatment process before dyeing process so it is possible to progress the dyeing ability of fibers. Except this dendrimers are used as aftertreatment process as water, oil and soil resistant so the textile fibers can be durable to washing and abrasion resistance [Barış, 2012].

1.3.5. Flame retardent agent

Flame retardants enable to safe the consumer from dangerous situations. Flame retardants are textile auxiliary chemicals which give some properties to the textile materials like self-extinguishing, fire resistance or smoke retarder [SunZhang and Sun 2009]. Flame retardants can be categorized as following; brominated,chlorinated phosphorus containing nitrogen containing, and inorganic flame retardants. It can be seen from Figure 1.11. that how does a textile material burn and flame formation. When there is high temperatures, the flame retardant molecule releases bromine(Br) or chlorine (Cl) as free radicals. These radicals have a reaction with hydrocarbon molecules. After releasing HBr and HCl due to reaction, HBr and HCl then react with H+ and OH- radicals again and water is formed [Garment Techs, 2014].

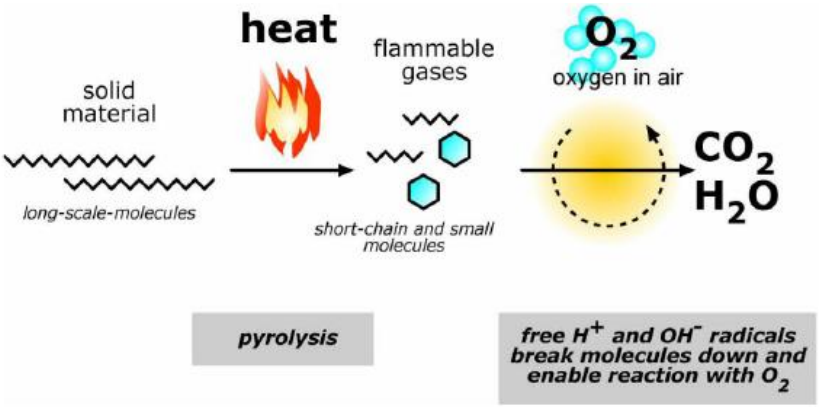

Figure 1.11 Materials burning and flame creation

In textile industry, flame retardants are generally used in furnishing and upholstery, combination flame retardant–durable press, protective garments, core-yarn fabric [Calamari, 2000].

1.4. Importance and Purpose of the Study

Electrohydrodynamic atomisation process (electrospinning and electrospraying) has been studied in recent years. Especially electrospinning process are used to produce nanofibers. But still there are a lot of problems with producing satisfactory nanofiber properties, so studies have been maintained in laboratory conditions. When literature has been checked number of electrospraying studies are less than electrospinning studies. Besides electrospraying studies are almost completely made with polymers. Textile chemicals have not been chosen for electrospraying or they have been chosen seldom. Besides, textile chemicals have not been widely chosen for electrospraying studies. There are lots of studies related with electrospraying process with other polymers, generally surface properties are examined. Different process parameters are investigated and surface properties are surveyed. With the scope of thesis widely used textile chemicals are electrosprayed and aim is to investigate the parameters affecting electrospraying process. The study deals with the relation between the deposition time and the process constituents since reducing deposition time would be the biggest challenge to have facile electrospraying. The constituents show different tendency on deposition time. It is thought that when the effect of constituents are determined on deposition time, this study will contribute greatly to the current literature. Besides when electrospraying process is commercialized, it is possible to

know which constituent effect most on the electrospray process period and which constituent has almost no effect on process period.

1.5. Scope of Thesis

Scope of thesis, solutions prepared with five different textile chemicals (macrosilicone, microsilicone, fluorocarbon, dendrimer+fluorocarbon and flame retardant) suitable solvents are electrosprayed on aluminium foil, 100% cotton fabric, 100% polyester fabric and 100% polyamide fabrics with two different distances (3 cm, 10 cm), six different voltage values (4.5 kV, 6.75 kV, 7.5 kV, 10 kV, 15 kV, 20 kV) and with three different concentrations (pure, 1:5 v/v, 1:10 v/v). Textile chemicals are chosen according to widely usage in textile industry and besides, these chemicals are not electrosprayed yet or seldomly electrosprayed. When literature was checked some chemicals could be electrosprayed and after electrospraying process the surface properties were examined. There is no study related with deposition time except the study of Gunesoglu in 2011.

In this study, solution characterizations; viscosity, electrical conductivity and surface tension values were measured. The electrospray set up was constituted and all study was done with this set up. 4 mL of solution were electrosprayed on four different collector (aluminum foil, 100% polyester fabric, 100% polyamide fabric and 100% cotton fabric) and deposition time (time needed for finishing 4 mL solution in the syringe) was measured. The effect of parameters and verification of process were identified with statistical analysis (correlation analysis and ANOVA) and the formulation of deposition time was formed with regression analysis.

1.6. Structure of Thesis

This study is composed of five chapters. These are explained below;

First chapter is related to introduction of the subject. In this chapter general informations about the subject, electrospraying process, textile chemicals, importance and purpose of the study, scope of the study and structure of the study are given. Readers can find necessary introductory information related to electrospraying technique and textile chemicals.

Second part of the thesis is completely related with state of technic. Readers can find literature survey related with technique and solvents used in thesis.

Third chapter includes material and method that used in this thesis.

Fourth chapter shows the results and discussions of the thesis.

The final chapter includes conclusion, discussion and considerations about the study. In addition, potential future works are also provided in this chapter.

CHAPTER 2

LITERATURE REVIEW

In this doctorate thesis, solutions prepared with five different textile chemicals (macrosilicone, microsilicone, fluorocarbon, dendrimer+fluorocarbon and flame retardant) suitable solvents are electrosprayed on aluminium foil, 100% cotton fabric, 100% polyester fabric and 100% polyamide fabrics with two different distances (3 cm, 10 cm), six different voltage values (4.5 kV, 6.75 kV, 7.5 kV, 10 kV, 15 kV, 20 kV) and with three different concentrations (pure, 1:5 v/v, 1:10 v/v) and the deposition time for each process was measured and the parameter effects are analysed with statistical method and formulation was done for each process by another statistical method. Literature was checked to contribute for thesis during studies and the selected studies are submitted below.

Smith (1986) made an experimental study which is called electrohydrodynamic atomization (EHD) and he dealed with the parameters (viscosity, conducitivity, capillary radius) affected on this process. He got significant results; a) if the surface tension is above 50 mN/m, the liquid could not be sprayed in this process, b) if the ocnductivity is below than 10^{-11}S/m, it is not possible to execute the EHD process, c) when viscosity increases, droplets become larger.

Chen and Pui (1997) studied to reveal the effect of liquid dielectric constant on existing scaling laws for the electrospraying process. Solvents which have high dielectric constants, the experimental data has a good fitting with the scaling laws. The results show compatibility with the studies was made before this study.

Hu and Chan (1998) studied on effect of fabric mechanical properties on drape. Sixteen different mechanical properties were selected and tested to reveal the effects of these properties on drape. Four regression models were proposed.

Hartman et. al. (1999) developed a model to estimate the shape of the liquid cone and jet, the quantitiy of electric field both inside and outside of the cone and lastly surface charge density of liquid surface. They showed the forces in liquid cone in the Figure 2.1.

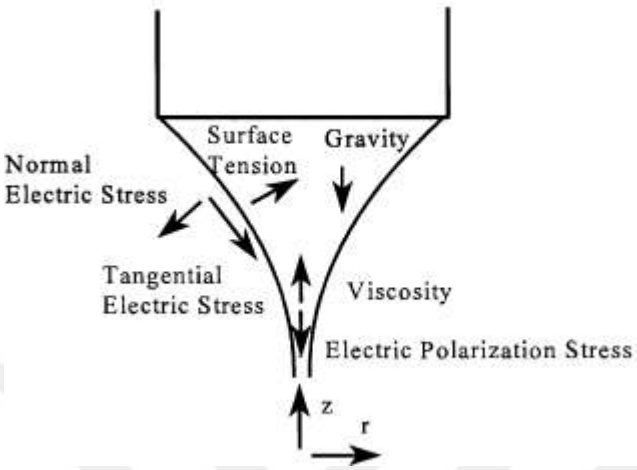

Figure 2.1 Forces in the liquid cone

Figure 2.2 shows a schematic representation of the cone-shape calculation method. By means of this calculation method, Hartman and friends achieve very similar to experiment shape by cone-shape model type.

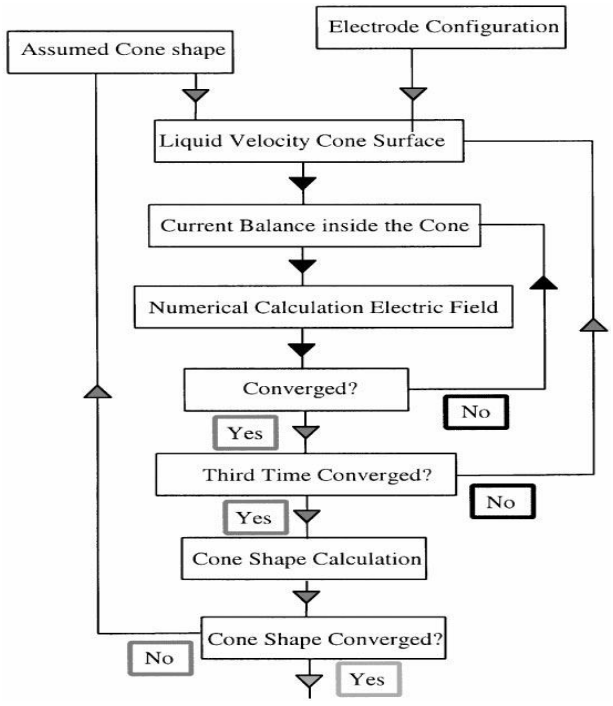

Figure 2.2 Representation of the liquid cone shape calculation.

Edirishinge and Jayasinghe (2002) electrosprayed water, glycerol and their mixtures with different viscosities range 1-1340 cP with constant voltage and flow rate. Results show that when viscosity increases mode of atomization is affected, and besides that the size and size distribution of droplets.

Ozdil et. al. [2007] studied on effect of yarn properties on thermal comfort knitted fabrics. They used different yarnd and properties to investigate the effect on thermal comfort. The results were also evaluated with statistical analysis and they found the importance levels of parameters on thermal comfort. They also constituted regression formulations of thermal properties.

Hogan and Biswas (2008) studied on fim deposition by electrospraying process by using naoparticle sols. They used zinc oxide as nanoparticles, and solution was prepared with ethanol. And they used Monte Carlo simulation for this study. Simulations were handled to detect the effects of deposition time, concentration in the sol, particle size, the dispersion of nanoparticles on film surface, roughness, porosity and lateral feature size. The thickness of films was in an increment when time is over. When the deposition time is sufficient, the porosity reached a fixed value.

Costa et. al. (2010) made a research that concentration effect on electrohydrodynamic atomisation for poly (vinylidene fluoride) (PVDF)/N,N-dimethylformamide (DMF) and PVDF/DMF/acetone solutions . When concentration is low, thin film was obtained with small droplets. When concentration increased, the droplets became larger.

Baykaldi, B. et. al. (2011) studied cotton/elasthane blended core yarns with different twist factors, linear densities. These parameters affect the splicing zone property. They made several trials and they observed the parameters affect breaking strength. They found the parameters affect according to regression analysis and they obtained formulation.

Gunesoglu (2011) studied two different fluorocarbon solutions were electrosprayed on 100% cotton fabric and he looked the relation between some parameters with deposition time. He counted time for 10 droplets on cotton fabric and then he tried to

make a comparison between changing parameters. And then statistically make a formulation by a statistical analysis programme.

Syafiza et. al. (2013) studied to show the deposition quality by changing the voltage, concentration and feed rate of TiO_2 solution. TiO_2 solution was electrosprayed on to the carbon substrate. Voltage, concentration and feed rate effects were analyzed in this study. There is an increase in particle size and in deposited area when feed rate increases. Jet formation becomes steady to unsteady when electrostatic voltage increases. The deposition morphology of TiO_2 on carbon subtrate also changes with the parameter changes.

Afzal et. al. [2015] studied statistical modeling of thermal resistance of cotton/polyester blended double layer interlock fabrics. Fabric samples produced with different fabric weights, yarn numbers, linear densities to achieve different cover factors. They used best subset regression models as a statistical model and they constituted similar results for both actual and predicted values on thermal resistace of double layer interlock fabrics.

El-Kady and Abdel Latif (2015) studied bivariate and multivariate statistical analysis of yield and agronomic characters for Egypt cotton. They used sixteen different cultivar and prepared 4x4 lattice design with five replication for nine traits. They used six different statistical methods to show the relation between yield and its components. They also showed a formulation for effective parameters.

Dasdemir and İbili (2016) studied to enhance superhydrophobic and alcohol repellent nonwovens used in medical industry by electrospraying method. Besides they also made an application to obtain superhydrophobic and alcohol repellent effect by conventional method. They compared the effectiveness of both studies. Electrospraying process results gave better results than conventional method. Both water and alcohol repellency are higher in electrospraying than conventional method.

Prabu et. al. (2016) studied to get a moisture management cotton fabric via electrospraying process. A hydrophobic polymer was electrosprayed on the back surface of the fabric. This back surface means close to the skin. So it could be obtained one face of fabric is hydrophilic (100% cotton fabric) and the other face is hydrophobic. The enhanced fabric is suitable with ecology, and commercially

scalable due to minimum chemicals usage and no effluent discharge. And also it showed that it is possible to produce cotton garments for active sportswear.

Faraji et. al. (2017) studied one of the most important parameter, conductivity and the influence of it. Apart from effect of conductivity, the droplets occured during electrospraying were examined. The study occured at room temperature. The selected polymer was KCI and suitable solutions prepared and then electrosprayed wtih high electrical voltage and flow rates. Results showed that flow kinetics are more effective on electrospraying process than conductivity. When conductivity increased, the size of droplets was decreased.

There are several studies related with silicone softener application by padding method [Chattopadhyay and Vyas [2010], Dong et. al. [2006], Habereder and Bereck [2002], Kang and Kim [2001], Parvinzadeh and Haijarissi [2008]]. They all studies different researches but same application method with silicone softeners. [Huang et al. 2005] made a research related with electrostatic spraying of silicone softeners to get nano scaled silicone. They aimed electrostatic spray deposition of nano-sized Si-HA (silicon substituted hydroxyaptite) has been performed and this represents a new way to modify the implant surface to achieve the goal of improving bone integration.

CHAPTER 3

MATERIAL AND METHOD

3.1. Materials

Scope of thesis, the materials included chemicals, solvents, collector types were expressed below.

3.1.1. Chemicals

Five different textile chemicals were used in this study. These are listed and expressed below according to properties. The chemicals were kindly supplied by Rudolf Duraner, Bursa, Turkey.

- First chemical is nonionic, polysiloxane macrosilicone (called in thesis Macrosilicone Softener).
- Second chemical is a polysiloxane based nonionic microsilicone (called in thesis Microsilicone Softener).
- Third chemical incorporates a booster with high binding mechanism for obtaining finishes with high durability and good hydrostatic head. It is cationic, and C6 fluorocarbon resin (called in thesis Fluorocarbon Softener).
- Forth chemical is a cationic, cost-effective universal product with integrated dendrimer and aromatic booster component in fluorocarbon (called in thesis Fluorocarbon&Dendrimer Softener).
- Fifth chemical is a blend of organic and inorganic salts, mild anionic flame retardant (called in thesis Flame Retardant Softener).

3.1.2. Fabric Types

The materials are 100% Cotton, 100% Polyester and 100% Polyamide knitted fabrics. Fabric weight for each type of fabric was measured with circular sample cutter with 'TS EN 12127-Determination of mass per unit area using small samples' test standard (Figure 3.1). Fabric thickness for each type of fabric was measured with

fabric thickness tester with 'TS 7128 EN ISO 5084- Determination of thickness of textiles and textile products' test standard.

Figure 3.1 Circular sample cutter

The surface electrical resistivity measurements of the fabric samples were performed by means of Charleswater 99105 Surface Resistance Meter (Figure 3.2) according to ASTM-F-150, with placing probes of the instrument along a straight line on the sample, separated from each other by a distance "s". When the electrical contact is made along a straight line on the surface of the fabric; electrical current flows through the probes, while the floating electrical potential between the probes is adjusted to 10V. Surface resistivity (ρ) is then calculated in accordance with the following Equation (1):

$$\rho = \frac{V \times 2\pi}{I \times \left(\frac{1}{s}\right)}$$

where, ''V" is the difference of potential in Volts between probes (10V), ''I" is the electrical current that flows through probes, ''s" represent the distances between the probes (20 cm).

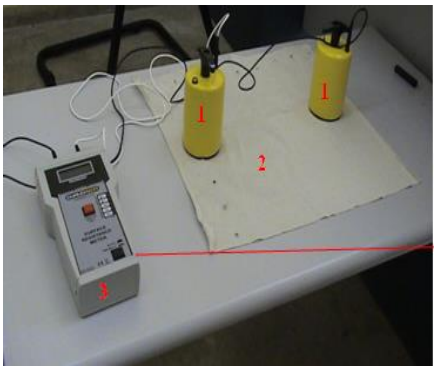

Figure 3.2 The surface resistivity measurement consisting replacing of probes (1) along a straight line on the fabric sample (2). The difference of potential

between the probes is adjusted to 10V and the surface resistance achieved when an electric current is flown between the probes is read in Ω by display (3).

The surface resistivity measurements were performed three times for each sample and the average values were obtained. And then bulk resistivity was calculated, conductivity was obtained by inverting the bulk resistivity value with respect to the impact as $S.cm^{-1}$. After the obtaining of the electrical conductivity values of the surfaces, the values were normalized by converting to logarithmic values and those values were used as statistical analyses parameter.

3.2. Method

3.2.1. Electrospraying Process Set up

Electrospraying set- up was consisted of New Era NE-1000X pump, 0-100 kV- 20 W ES100P Model Gamma high voltage power supply and a grounded collector (Figure 3.3 and Figure 3.4). During the experiment, chemical solutions at different concentrations were pumped through a syringe pump using a needle. The syringe is connected to a high DC voltage. Electrospray was collected on foil, 100% polyester knitted fabric, 100% polyamide knitted fabric and 100% cotton knitted fabric as collector. This collector was grounded. For a proper electrospraying process flow rate, concentration values, tip to collector distance values and voltage values were determined. Flow rate was determined as 20 µL/min, needle diameter was selected as 0,7 mm (22G) concentration values were determined as pure, 1:5 and 1:10 v/v, tip to collector distance values were determined as 3 cm and 10 cm, and voltage values were determined as 4.5 kV, 6.75 kV, 7.5 kV, 10 kV, 15 kV, 20 kV.

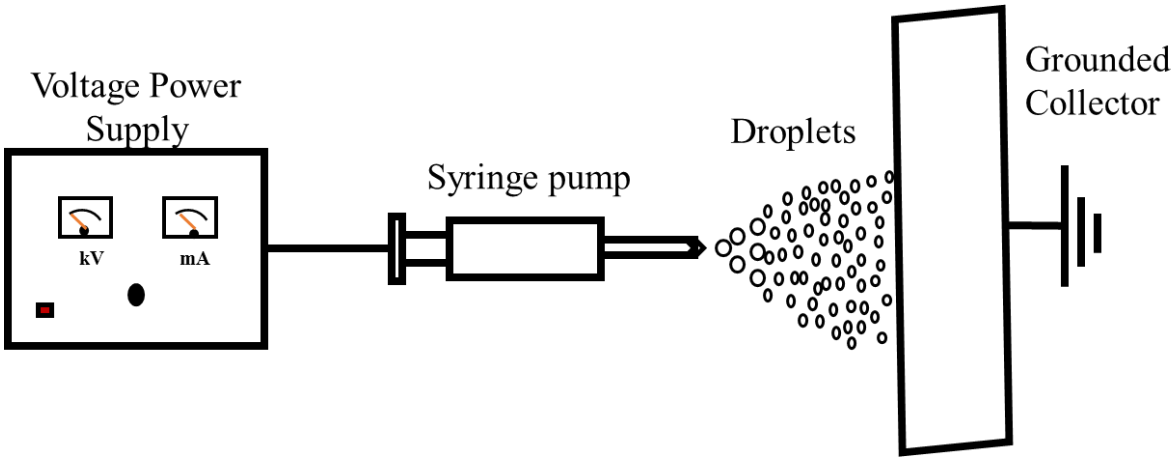

Figure 3.3 Schematic of electrospraying set up

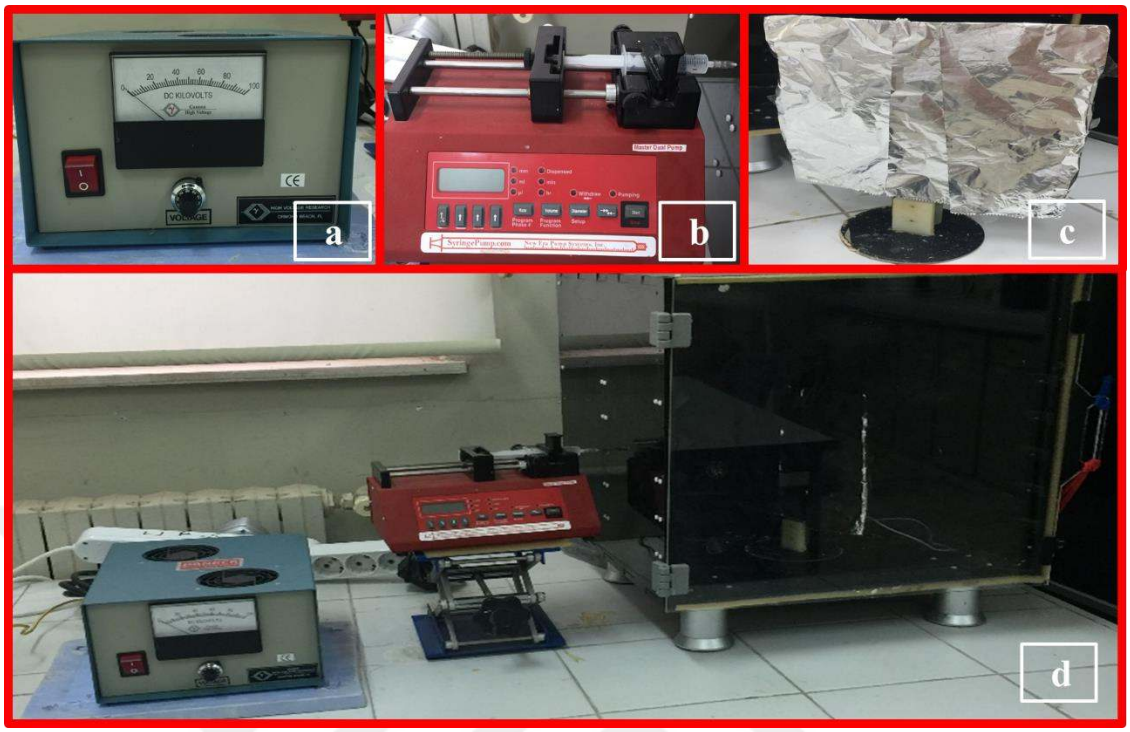

Figure 3.4 a) Picture of the power supply positioned outside the electrospraying box, b) Picture of the syringe pump outside the electrospraying box, c) Picture of aluminum foil collector inside the electrospraying box, d) Picture of electrospraying set up

3.2.2. Preparation of Chemical Solutions

In this thesis, some prestudies were done to determine optimum concentrations for all kind of chemicals. First 1:20, 1:50 and 1:100 v/v concentrations were selected to make electrospraying process. The trials gave unsuitable results and then it was decided to select lower concentrations to perform electrospraying process regularly. Three different concentrations were selected and prestudies with these concentrations gave suitable results, so the optimum concentrations were determined as pure, 1:5 v/v and 1:10 v/v.

3.2.2.1. Macrosilicone Softener Solution

This chemical solution was prepared according to pure, 1:5 and 1:10 dilutions with distilled water. In Figure 3.5 the prepared Macrosilicone Softener solution can be seen.

Figure 3.5 Macrosilicone Softener Solution and Preparation; a) Pure concentration Macrosilicone Softener solution, b) 1:5 concentration Macrosilicone Softener solution c) 1:10 concentration Macrosilicone Softener solution

3.2.2.2. Microsilicone Softener Solution

This chemical solution was prepared according to pure, 1:5 and 1:10 dilutions with distilled water. In Figure 3.6 the prepared Microsilicone Softener solution can be seen.

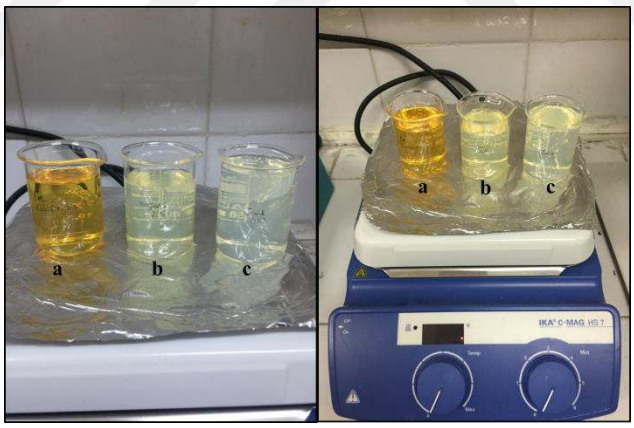

Figure 3.6 Microsilicone Softener Solution and Preparation; a) Pure concentration Microsilicone Softener solution, b) 1:5 concentration Microsilicone Softener solution c) 1:10 concentration Microsilicone Softener solution

3.2.2.3. Fluorocarbon Solution

This chemical solution was prepared according to pure, 1:5 and 1:10 dilutions with distilled water. In Figure 3.7 the prepared Fluorocarbon solution can be seen.

Figure 3.7 Fluorocarbon Solution and Preparation; a) Pure concentration Fluorocarbon solution, b) 1:5 concentration Fluorocarbon solution c) 1:10 concentration Fluorocarbon solution

3.2.2.4. Fluorocarbon&Dendrimer Solution

This chemical solution was prepared according to pure, 1:5 and 1:10 dilutions with distilled water. In Figure 3.8 the prepared Fluorocarbon&Dendrimer solution can be seen.

Figure 3.8 Fluorocarbon&Dendrimer Solution and Preparation; a) Pure concentration Fluorocarbon&Dendrimer solution, b) 1:5 concentration Fluorocarbon&Dendrimer solution c) 1:10 concentration Fluorocarbon&Dendrimer solution

3.2.2.5. Flame Retardant Solution

This chemical solution was prepared according to pure, 1:5 and 1:10 dilutions with distilled water. But when the pure, 1:5 and 1:10 emulsions could not have been electrosprayed as described in the results section, 1:5 and 1:10 dilutions with

water/ethanol mixture was also prepared. These dilutions were occurred with high speed stirrer, the solutions were mixed about 5000 rpm and 45-60 minutes to get a homogenous solution. In Figure 3.9 the prepared Flame Retardant solution can be seen.

Figure 3.9 Flame Retardant Solution and Preparation; a) 1:5 concentration Fluorocarbon&Dendrimer solution b) 1:10 concentration Fluorocarbon&Dendrimer solution

3.2.3. Characterization of Chemical Solutions

For the characterization of the prepared solutions, viscosity, conductivity and surface tension measurements were used.

3.2.3.1. Viscosity

Brookfield DV III Ultra Programmable Rheometer device was used to measure viscosity. Viscosity measurements were done for 50 rpm with using spindle number 18 at room temperature. In Figure 3.10, rheometer was demonstrated.

Figure 3.10 Viscosity measurement device (Brookfield DV-3 Ultra®)

For viscosity measurements, 50 mL measuring tubes were used. All measurements were done when the solution temperature was 20ºC ± 1 ºC.

3.2.3.2. Conductivity

Conductivity measurements were taken with using Orion 4 star Plus pH meter. Three measurements were made for each concentration of all chemicals, and average of the three measurements was taken. In Figure 3.11, conductivity device was demonstrated. All measurements were done when the solution temperature was 20ºC ± 1 ºC.

Figure 3.11 Conductivity measurement device (Orion 4 Star Plus®)

3.2.3.3. Surface Tension

Surface tension measurements were performed with Attension Theta Optical Tensiometer according to 'pendant drop' technique. Four measurements were taken for each concentration for each chemical. Optical tensiometer was shown in Figure 3.12. All measurements were done when the solution temperature was 20ºC ± 1 ºC.

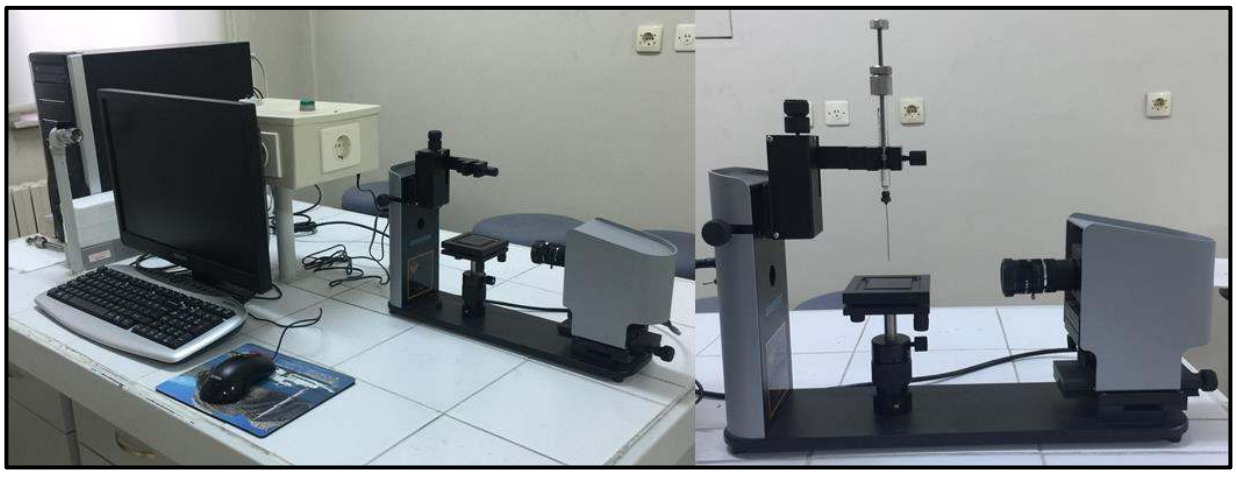

Figure 3.12 Surface tension measurement device (Attension Theta®)

3.2.4. Electrospraying Process for Chemical Solutions

All five chemicals were electrosprayed at three different (pure, 1:5, 1:10 volume/volume) concentrations except flame retardant agent Flame Retardant solution. Flame Retardant was electrosprayed at 1:5 and 1:10 dilution rates only. Electrosprayed samples were collected to all grounded collectors (aluminum foil, 100% PES fabric, 100% PA fabric and 100% Cotton fabric). The process parameters were flow rate (20µl/min) applied voltage (4.5 kV, 6.75 kV, 7.5 kV, 10 kV, 15 kV and 20 kV), tip to collector distance (3 cm and 5 cm) and needle size (22 gauge). Applied electric field values were 1 kV/cm, 1.5 kV/cm, 2 kV/cm, 2.5 kV/cm and 5kV/cm. During experiments, the ambient temperature was measured as 20-23 ° C and the humidity value was measured as 27-32%. For each applied electric field, deposition time was recorded for electrospraying of 4ml solution. In normal conditions, 4 ml solution should be poured in 20 minutes, because the set up is horizontally arranged and there isn't any forces acting on liquid droplet. When electrospraying process was performed, voltage was applied and by means of electric field and some blockages 4 ml solution didn't finish in 20 minutes.

Table 3.1 Electrospraying process parameters applied on all chemical solutions

Chemical Solution	Concentration (v/v)	Voltage (kV)	Tip to collector distance (cm)	Applied solution amount(mL)	Collector Type
Macrosilicone Softener	Pure-1:5-1:10	4.5 - 6.75 -7.5 -10 -15 -20	3-10	4	Aluminum Foil-100% PES Fabric-100%PA Fabric-100%CO Fabric
Microsilicone Softener	Pure-1:5-1:10	4.5 - 6.75 -7.5 -10 -15 -20	3-10	4	Aluminum Foil-100% PES Fabric-100%PA Fabric-100%CO Fabric
Fluorocarbon	Pure-1:5-1:10	4.5 - 6.75 -7.5 -10 -15 -20	3-10	4	Aluminum Foil-100% PES Fabric-100%PA Fabric-100%CO Fabric
Fluorocarbon& Dendrimer	Pure-1:5-1:10	4.5 - 6.75 -7.5 -10 -15 -20	3-10	4	Aluminum Foil-100% PES Fabric-100%PA Fabric-100%CO Fabric
Flame Retardant	1:5-1:10	4.5 - 6.75 -7.5 -10 -15 -20	3-10	4	Aluminum Foil-100% PES Fabric-100%PA Fabric-100%CO Fabric

3.2.5. Variance Analysis

3.2.5.1. Correlation Analysis

Correlation analysis is a method that shows whether there is a relationship between variables, and if there is a relation, it enables to indicate the direction and power [Alpar, 2003]. Correlation analyses were done to deposition time with solution parameters (viscosity, surface tension, conductivity, concentration) and process parameters (voltage, distance, collector type). Correlation analyses were done with Minitab® 16 Statistical Software. In this study, correlation analyses were done to

learn if there is a relation and extent between two numerical parameters. But this analysis can't give cause effect relationship alone. So analysis of variance (ANOVA) should be applied to the parameters.

3.2.5.2. Generalized Linear Method (Factorial ANOVA)

Effects of viscosity, voltage and tip to collector distance on deposition time were subjected to analysis of variance (ANOVA) for statistical evaluation and correlation. The variance analysis were done in order to find out the relation between each parameters by IBM SPSS Statistics 21- Software; IBM, Chicago, USA. ANOVA was made after correlation analysis, and some parameters didn't take into the analysis of variance because of highly correlated. ANOVA was made to obtain the relationship between one dependent variable (deposition time) with independent variables (voltage, distance, viscosity). In all statistical analyses, level of significance was chosen $p \leq 0{,}05$. All independent variables used for statistical analysis in the study were taken as numerical factors. Experimental design set up was shown in the Table 3.2.

Table 3.2 Experimental design set up

Chemical Solution	Independent Variable	Levels		Collector Type	Dependent Variable
Macrosilicone Softener	Concentration (v/v)	3	Pure, 1:5, 1:10	Aluminum foil, PES fabric, PA fabric, Cotton fabric	Deposition Time (minute)
	Voltage (kV)	6	4.5, 6.75, 7.5, 15, 17.5, 20		
	Tip collector distance (cm)	2	3, 10		
Microsilicone Softener	Concentration (v/v)	3	Pure, 1:5, 1:10	Aluminum foil, PES fabric, PA fabric, Cotton fabric	Deposition Time (minute)
	Voltage (kV)	6	4.5, 6.75, 7.5, 15, 17.5, 20		
	Tip collector distance (cm)	2	3, 10		
Fluorocarbon	Concentration (v/v)	3	Pure, 1:5, 1:10	Aluminum foil, PES fabric, PA fabric, Cotton fabric	Deposition Time (minute)
	Voltage (kV)	6	4.5, 6.75, 7.5, 15, 17.5, 20		
	Tip collector distance (cm)	2	3, 10		
Fluorocarbon& Dendrimer	Concentration (v/v)	3	Pure, 1:5, 1:10	Aluminum foil, PES fabric, PA fabric, Cotton fabric	Deposition Time (minute)
	Voltage (kV)	6	4.5, 6.75, 7.5, 15, 17.5, 20		
	Tip collector distance (cm)	2	3, 10		
Flame Retardant	Concentration (v/v)	3	1:5, 1:10	Aluminum foil, PES fabric, PA fabric, Cotton fabric	Deposition Time (minute)
	Voltage (kV)	6	4.5, 6.75, 7.5, 15, 17.5, 20		
	Tip collector distance (cm)	2	3, 10		

3.2.5.3. Regression Analysis

Regression analysis is used as a method to demonstrate the relation between the variables. Regression analysis is used commonly to show how the dependent variable is affected when the independent variable changes. When choosing independent variables, it is important to pick only one of the independent variables with high correlation between them [Orhunbilge, 2002]. For example although viscosity and concentration are like different from each other, in fact two of the parameter are

closely linked. Only one such variable should be selected in the multiple regression analysis. For this, it is necessary to look at the correlation matrix of all variables before starting the analysis and to choose one of the highly correlated fields. Regression analyses were done by Minitab 16 to get a formulation of electrospraying process with variable parameters and to see the effect of parameters. In this study, regression analysis were done to constitute a formulation of dependent variable (deposition time) with independent variables.

For this study Best Subset Regression analysis was used to obtain the most effective independent variables on dependent variables. Best subsets regression analysis determines the best fitting regression models, built with the remarked variables. The main significant aim of the best subset regression is to express models, which achieve the target, with minimum variables as possible. 'The model with the highest adjusted R and low Mallows' value is assumed as the best model for determination of best predicted characters'. It is important to choose best fitting result with lowest value of Mallows' Cp and highest value of adjusted R^2 [El-Kady et. al., 2015]. Minitab® 16 Statistical Software was used to make both regression analysis and best subset regression analysis.

CHAPTER 4

RESULTS AND DISCUSSION

It is possible to compare deposition time results for Macrosilicone Softener and Microsilicone Softener. Because Macrosilicone Softener and Microsilicone Softener are both silicone softener, nonionic polysiloxane mixtures. When solution parameters were stated, viscosity results for pure concentrations considered, Macrosilicone Softener (dry matter content is 49.5-51.5%) and Microsilicone Softener (dry matter content is 48.5%-49.5%) have viscosity values at 50 rpm 35.6 cP and 35.4 cP, the viscosity values were almost identical. Conductivity results showed differences for pure chemical, 1:5 v/v and 1:10 v/v dilutions. Surface tension results also showed differences for each concentration. If deposition time values were examined, there were differences between deposition times. It can be explained that deposition time differences can be caused by conductivity and surface tension differences.

Fluorocarbon (dry matter content is 23.3-27.7%) is cationic, and C6 fluorocarbon resin, Fluorocarbon&Dendrimer (dry matter content is 22-24%) is a cationic, cost-effective universal product with integrated dendrimer and aromatic booster component in fluorocarbon. Deposition time results can be compared for these two chemical solutions. Pure Fluorocarbon has 3.40 cP viscosity value at 50 rpm, besides pure Fluorocarbon&Dendrimer has 28.60 cP viscosity value at 50 rpm. Dry matter contents of these two chemical solutions are almost identical but viscosity values are so different from each other. It can be explained that Fluorocarbon&Dendrimer has bigger particle size than Fluorocarbon. Conductivity and surface tension values of these two chemical solutions are different. It can be explained that deposition time differences can be caused by different viscosity, conductivity and surface tension values. Sato and Cunha [2009] studied and they disclosed that when particle size increased to 64 μm to 550 μm, viscosity increased linearly from 60 cP to 40 cP.

If we compare Macrosilicone Softener, Microsilicone Softener and Fluorocarbon&Dendrimer according to viscosity values, Macrosilicone Softener and Microsilicone Softener have nearly 50% dry matter and have a viscosity value nearly 35 cP. Fluorocarbon&Dendrimer has 22-24% dry matter and has a viscosity value 28.6 cP. Dry matter content of Fluorocarbon&Dendrimer is nearly half of Macrosilicone Softener and Microsilicone Softener, but viscosity difference of Fluorocarbon and Macrosilicone Softener, Microsilicone Softener is less than half. It can be explained Macrosilicone Softener and Microsilicone Softener have lower molecular weight than Fluorocarbon&Dendrimer.

Flame Retardant is a blend of organic-inorganic salt. All organic molecules contain carbon, nearly all contain hydrogen, and many also contain oxygen. Inorganics include salts, metals, substances made from single elements and any other compounds that don't contain carbon bonded to hydrogen [ToughtCo, 2018]. Flame Retardant (dry matter content 48-50%) has viscosity value at 50 rpm 5.12 cP. It shows that Flame Retardant contains inorganic salts more than organic salts because inorganic salts are single atoms, they don't have chain structure. All chemicals couldn't be compared all together because of different content, molecular weigth, and solution parameters. So the results are examined in five groups according to chemical solution types.

4.1. Macrosilicone Softener Results

In this study, three different fabric types were used. Fabric features were given in Table 4.1. 100% bleached polyester fabric was kindly supplied by Elvan Tekstil, Denizli, Turkey. 100% bleached polyamide fabric was kindly supplied by Rudolf Duraner, Bursa, Turkey and 100% bleached cotton fabric was kindly supplied by Fıstık Tekstil, Gaziantep, Turkey.

Table 4.1 Fabric properties

Fabric Type	Stitch Density (wales/course)	Fabric Weight (gsm)	Bulk Resistivity (Ω.cm)	Electrical Conductivity ($S.cm^{-1}$)
100% knitted polyester	17x26	223	$1.66*10^{12}$	$2.7382*10^{-13}$
100% knitted polyamide	14x20	98	$1.83*10^{13}$	$2.627*10^{-14}$
100% knitted cotton	15x15	210	$10.82*10^{13}$	$2.734*10^{-15}$

4.1.1. Macrosilicone Softener Solution Characterization

In this thesis, some prestudies were done to determine optimum concentrations. First 1:20, 1:50 and 1:100 v/v concentrations were selected to make electrospraying process. The trials gave unsuitable results and then it was determined to select lower concentrations to perform electrospraying process regularly. Three different concentrations were selected and prestudies with these concentrations gave suitable results, so the optimum concentrations were determined as pure, 1:5 v/v and 1:10 v/v. Concentration, viscosity, conductivity and surface tension values of these concentrations were given Table 4.2.

Table 4.2 Viscosity, conductivity and surface tension values of Macrosilicone Softener chemical solutions with different concentrations

Chemical solution	Concentration (%)	Viscosity (cP)	Conductivity (µS/cm)	Surface Tension (mN/m)
Macrosilicone Softener	Pure	35.6	1336,33	22,64
	1:5 v/v	2,56	594,33	25,05
	1:10 v/v	2,13	290,67	26,06

Viscosity, conductivity and surface tension measurements were done for different concentration values (pure, 1:5 v/v, 1:10 v/v) to specify the suitability of chemical solutions for electrospraying process. Viscosity measurements of Macrosilicone Softener solutions (pure, 1:5 v/v and 1:10 v/v) were shown in Figure 4.1. When the results were examined, it was seen that when concentration of chemical decreases the viscosity decreases too. Viscosity of solutions is increased when concentration of chemical is increased [Edirisinghe and Jayasinghe, 2002; Wu et. al. 2014]. The viscosity values of Macrosilicone Softener ranged from 2,13cP to 35,56cP when concentration ranged from 1:10 v/v to 100% pure chemical. When Figure 4.1 was drawn according to viscosity and concentration values, the relation between viscosity and concentration could be seen clearly. Concentration 0.10 indicated 1:10 v/v chemical solution, concentration 0.20 indicated chemical solution 1:5 v/v and concentration 1.00 indicated pure chemical solution.

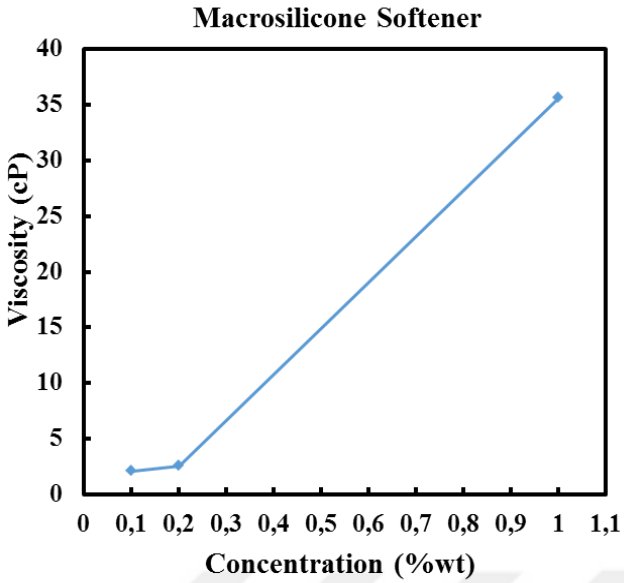

Figure 4.1 Viscosity measurements of Macrosilicone Softener chemical solution with different concentrations

Conductivity is another important characteristic of solutions to perform electrospraying process. The conductivity results were given in Figure 4.2. The results were changed between 290.67 µS/cm to 1336.33 µS/cm. When the literature was checked, Faraji [2017] indicated that if the conductivity is lower than 10^{-6} µS/cm, the liquid can not be electrosprayed. When the conductivity of chemicals was examined the conductivity values were higher than this value. So it showed that these conductivity values enabled us to perform electrospraying process.

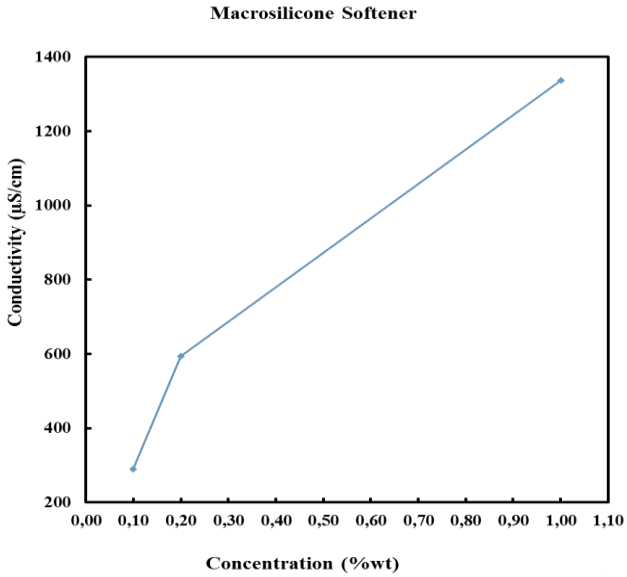

Figure 4.2 Conductivity measurements of Macrosilicone Softener chemical solutions with different concentrations

Surface tension results were given in Figure 4.3. The surface tension values were changed between 22.64 mN/m to 26.06 mN/m. Smith [1986] reported that when the surface tension value is higher than 50 mN/m, polymer or chemical can't be electrosprayed.

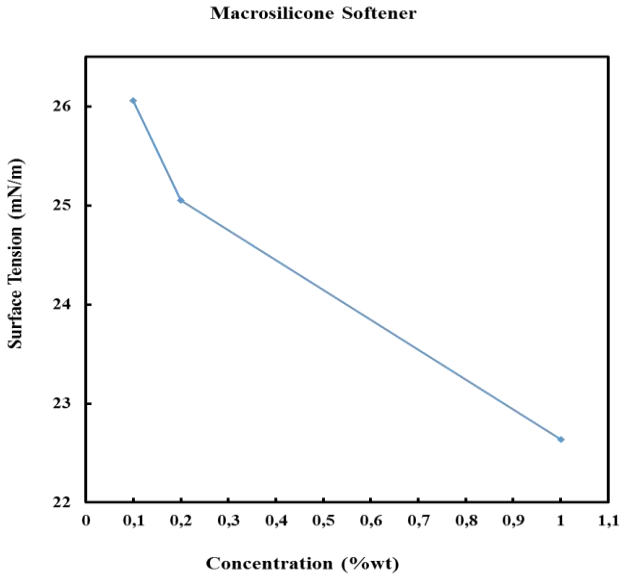

Figure 4.3 Surface tension measurements of Macrosilicone Softener chemical solutions with different concentrations

4.1.2. Electrospraying Process for Macrosilicone Softener Solution

The trails for each concentration and for each five electric field were done three times and the average of the results was calculated for aluminum foil, 100% polyester fabric, 100% polyamide fabric and 100% cotton fabric. Macrosilicone Softener chemical solutions were electrosprayed at three different (pure, 1:5, 1:10 volume/volume) concentrations. The process parameters were flow rate (20µl/min) applied voltage (4.5 kV, 6.75 kV, 7.5 kV, 10 kV, 15 kV and 20 kV), tip to collector distance (3 cm and 5 cm) and needle size (22 gauge). Applied electric field values were 1 kV/cm, 1.5 kV/cm, 2 kV/cm, 2.5 kV/cm and 5kV/cm. For each applied electric field, deposition time was recorded for electrospraying of 4ml solution. The deposition time was measured for each situation and then statistical analysis was done to determine the contribution of the parameters.

4.1.3. Deposition Time Results of Macrosilicone Softener Solution

4.1.3.1. Deposition Time Results of Macrosilicone Softener Solution on Aluminum Foil

Deposition time results were examined for pure concentration for Macrosilicone Softener chemical solution electrosprayed on aluminum foil. Expected result is that the smaller deposition time, easier the process [Gunesoglu, 2011]. Increasing in applied voltage causes increasing the height of the meniscus at the end of the nozzle [Syafiza et. al., 2013]. At a critical voltage form of liquid meniscus at capillary end will be a conical shape (known as cone-jet mode). When voltage value exceeds the critical value, electrospraying process couldn't be achieved. Increasing voltage by not exceeding critical voltage value would help the electrospray become faster [Chen et. al., 2009]. When the electric field (kV/cm) increases, the speed of the droplet increases also [Wilhelm et. al., 2003]. When Table 4.3 was assessed, applied electric field increases and deposition time decreases and expected results were obtained for pure concentration.

Table 4.3 Deposition Time of Electrospraying Macrosilicone Softener pure concentration solution on aluminum foil

Macrosilicone Softener	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
Pure chemical	4,5	3	1,5	23,3	23,33
Pure chemical	4,5	3		23,37	
Pure chemical	4,5	3		23,33	
Pure chemical	15	10	1,5	23,26	23,26
Pure chemical	15	10		23,28	
Pure chemical	15	10		23,25	
Pure chemical	17,5	10	1,75	23,2	23,21
Pure chemical	17,5	10		23,23	
Pure chemical	17,5	10		23,19	
Pure chemical	20	10	2	23,01	23,01
Pure chemical	20	10		23,02	
Pure chemical	20	10		23,01	
Pure chemical	6,75	3	2,25	22,54	22,54
Pure chemical	6,75	3		22,56	
Pure chemical	6,75	3		22,53	
Pure chemical	7,5	3	2,5	22,48	22,47
Pure chemical	7,5	3		22,47	
Pure chemical	7,5	3		22,47	

Results were examined for 1:5 concentration for Macrosilicone Softener (Table 4.4), expected results were obtained like pure concentration results.

Table 4.4 Deposition Time of Electrospraying Macrosilicone Softener 1:5 concentration solution on aluminum foil

Macrosilicone Softener	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:5	4,5	3	1,5	22,58	22,57
1:5	4,5	3		22,57	
1:5	4,5	3		22,56	
1:5	15	10	1,5	22,57	22,58
1:5	15	10		22,59	
1:5	15	10		22,57	
1:5	17,5	10	1,75	22,51	22,52
1:5	17,5	10		22,54	
1:5	17,5	10		22,52	
1:5	20	10	2	22,23	22,24
1:5	20	10		22,25	
1:5	20	10		22,25	
1:5	6,75	3	2,25	22,15	22,14
1:5	6,75	3		22,13	
1:5	6,75	3		22,13	
1:5	7,5	3	2,5	22,06	22,06
1:5	7,5	3		22,05	
1:5	7,5	3		22,06	

Results were examined for 1:10 concentration for Macrosilicone Softener (Table 4.5), expected results were obtained like pure and 1:5 concentration results.

Table 4.5 Deposition Time of Electrospraying Macrosilicone Softener 1:10 concentration solution on aluminum foil

Macrosilicone Softener	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:10	4,5	3	1,5	23,09	23,08
1:10	4,5	3		23,06	
1:10	4,5	3		23,08	
1:10	15	10	1,5	23,06	23,06
1:10	15	10		23,06	
1:10	15	10		23,07	
1:10	17,5	10	1,75	22,59	22,58
1:10	17,5	10		22,58	
1:10	17,5	10		22,58	
1:10	20	10	2	22,4	22,38
1:10	20	10		22,37	
1:10	20	10		22,36	
1:10	6,75	3	2,25	22,18	22,20
1:10	6,75	3		22,22	
1:10	6,75	3		22,21	
1:10	7,5	3	2,5	22,13	22,15
1:10	7,5	3		22,15	
1:10	7,5	3		22,16	

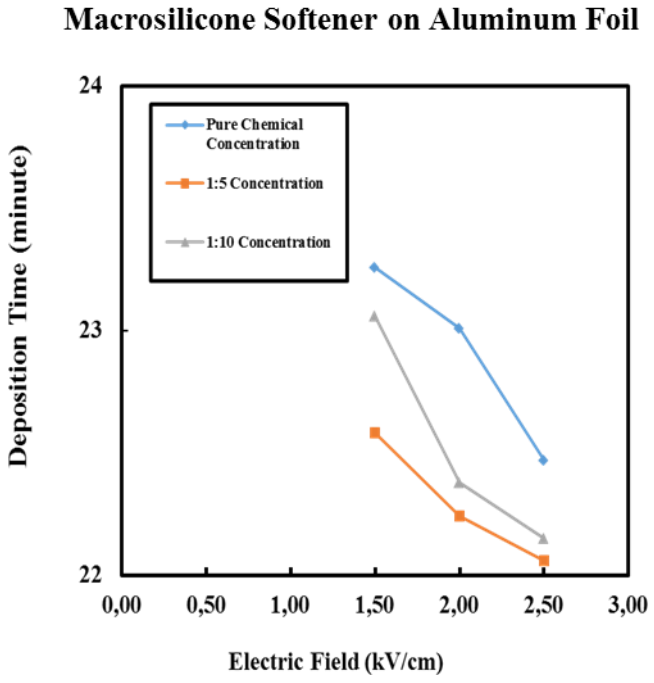

Figure 4.4 Deposition Time- Electric Field Graphic of Macrosilicone Softener on Aluminum Foil

When Figure 4.4 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.1.3.2. Electrospraying Process for Macrosilicone Softener Solution on 100% Polyester Fabric

Deposition time results were examined for pure concentration for Macrosilicone Softener chemical solution electrosprayed on 100% Polyester fabric. When Table 4.6 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. Aluminum foil and 100% PES fabric had different electrical resistivity values. 100% PES fabric has 2.7382 x 10^{-13} S·cm-^{1} conductivity. When the collector was selected as 100% PES fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process coudn't be achieved.

Table 4.6 Deposition Time of Electrospraying Macrosilicone Softener pure concentration solution on 100% Polyester Fabric

Macrosilicone Softener	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
Pure chemical	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,58	23,56
Pure chemical	15	10		23,55	
Pure chemical	15	10		23,54	
Pure chemical	17,5	10	1,75	23,45	23,44
Pure chemical	17,5	10		23,42	
Pure chemical	17,5	10		23,44	
Pure chemical	20	10	2	23,22	23,23
Pure chemical	20	10		23,24	
Pure chemical	20	10		23,24	
Pure chemical	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	22,6	23,00
Pure chemical	7,5	3		22,58	
Pure chemical	7,5	3		22,61	

Results were examined for 1:5 concentration for Macrosilicone Softener (Table 4.7), expected results were obtained like pure concentration results.

Table 4.7 Deposition Time of Electrospraying Macrosilicone Softener 1:5 concentration solution on 100% Polyester fabric

Macrosilicone Softener	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,3	23,29
1:5	15	10		23,27	
1:5	15	10		23,29	
1:5	17,5	10	1,75	23,18	23,19
1:5	17,5	10		23,2	
1:5	17,5	10		23,20	
1:5	20	10	2	23,07	23,05
1:5	20	10		23,04	
1:5	20	10		23,05	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	22,37	22,37
1:5	7,5	3		22,35	
1:5	7,5	3		22,38	

Results were examined for 1:10 concentration for Macrosilicone Softener (Table 4.8), expected results were obtained like pure and 1:5 concentration results.

Table 4.8 Deposition Time of Electrospraying Macrosilicone Softener 1:10 concentration solution on 100% Polyester Fabric

Macrosilicone Softener	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,29	23,27
1:10	15	10		23,26	
1:10	15	10		23,27	
1:10	17,5	10	1,75	23,13	23,14
1:10	17,5	10		23,16	
1:10	17,5	10		23,13	
1:10	20	10	2	22,59	22,60
1:10	20	10		22,61	
1:10	20	10		22,59	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	22,24	22,22
1:10	7,5	3		22,22	
1:10	7,5	3		22,21	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% PES fabric, because at 7.5 kV it was possible to perform electrospraying process.

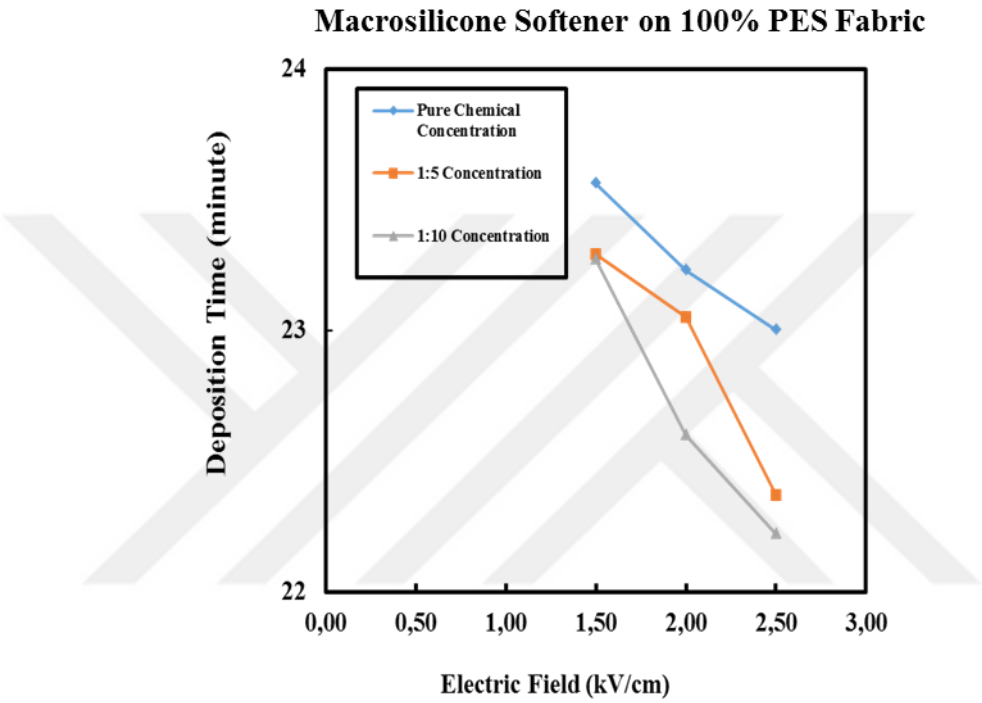

Figure 4.5 Deposition Time- Electric Field Graphic of Macrosilicone Softener on 100% Polyester Fabric

When Figure 4.5 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.1.3.3. Electrospraying Process for Macrosilicone Softener Solution on 100% Polyamide Fabric

Deposition time results were examined for pure concentration for Macrosilicone Softener chemical solution electrosprayed on 100% Polyamide fabric. When Table 4.9 was evaluated, applied electric field increased and deposition time decreased and it meant expected results were obtained for pure concentration. 100% polyamide fabric has $2,627*10^{-14}$ $S \cdot cm^{-1}$ conductivity. When the collector was selected as 100%

PA fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process coudn't be achieved like collector as 100% PES fabric.

Table 4.9 Deposition Time of Electrospraying Macrosilicone Softener pure concentration solution on 100% Polyamide Fabric

Macrosilicone Softener	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
Pure chemical	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,56	23,55
Pure chemical	15	10		23,54	
Pure chemical	15	10		23,56	
Pure chemical	17,5	10	1,75	23,47	23,45
Pure chemical	17,5	10		23,44	
Pure chemical	17,5	10		23,45	
Pure chemical	20	10	2	23,35	23,34
Pure chemical	20	10		23,32	
Pure chemical	20	10		23,34	
Pure chemical	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	23,26	23,26
Pure chemical	7,5	3		23,27	
Pure chemical	7,5	3		23,25	

Results were examined for 1:5 concentration for Macrosilicone Softener (Table 4.10), expected results were obtained like pure concentration results.

Table 4.10 Deposition Time of Electrospraying Macrosilicone Softener 1:5 concentration solution on 100% Polyamide fabric

Macrosilicone Softener	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,3	23,31
1:5	15	10		23,32	
1:5	15	10		23,32	
1:5	17,5	10	1,75	23,2	23,20
1:5	17,5	10		23,22	
1:5	17,5	10		23,19	
1:5	20	10	2	23,1	23,08
1:5	20	10		23,07	
1:5	20	10		23,08	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	22,56	22,55
1:5	7,5	3		22,54	
1:5	7,5	3		22,56	

Results were examined for 1:10 concentration for Macrosilicone Softener (Table 4.11), expected results were obtained like pure and 1:5 concentration results.

Table 4.11 Deposition Time of Electrospraying Macrosilicone Softener 1:10 concentration solution on 100% Polyamide Fabric

Macrosilicone Softener	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,14	23,16
1:10	15	10		23,18	
1:10	15	10		23,15	
1:10	17,5	10	1,75	23,05	23,06
1:10	17,5	10		23,07	
1:10	17,5	10		23,07	
1:10	20	10	2	22,54	22,53
1:10	20	10		22,53	
1:10	20	10		22,53	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	22,41	22,39
1:10	7,5	3		22,38	
1:10	7,5	3		22,39	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% PA fabric, because at 7.5 kV it was possible to perform electrospraying process. For pure chemical, there was just some time difference between polyester fabric and polyamide fabric about 1-4 seconds, for 1:5 concentration; like pure concentration there were just a few time differences between polyester and polyamide fabric about 2-3 seconds. For 1:10 concentration the deposition time difference was a bit more than pure and 1:5 concentrations, about 8-9 seconds.

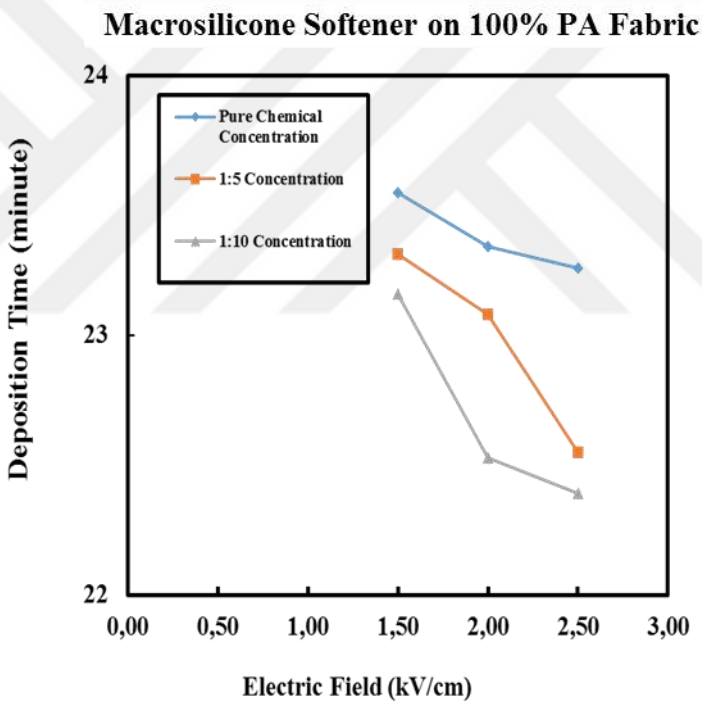

Figure 4.6 Deposition Time- Electric Field Graphic of Macrosilicone Softener on 100% Polyamide Fabric

When Figure 4.6 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.1.3.4. Electrospraying Process for Macrosilicone Softener Solution on 100% Cotton Fabric

Deposition time results were examined for pure concentration for Macrosilicone Softener chemical solution electrosprayed on 100% Cotton fabric. When Table 4.12 was evaluated, applied electric field increased and deposition time decreased and it meant expected results were obtained for pure concentration. 100% Cotton fabric has $2.734*10^{-14}$ $S \cdot cm^{-1}$ conductivity. When the collector was selected as 100% cotton fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process coudn't be achieved like collector as 100% PES fabric.

Table 4.12 Deposition Time of Electrospraying Macrosilicone Softener pure concentration solution on 100% Cotton Fabric

Macrosilicone Softener	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
Pure chemical	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,56	23,55
Pure chemical	15	10		23,55	
Pure chemical	15	10		23,53	
Pure chemical	17,5	10	1,75	23,45	23,43
Pure chemical	17,5	10		23,41	
Pure chemical	17,5	10		23,44	
Pure chemical	20	10	2	23,33	23,31
Pure chemical	20	10		23,3	
Pure chemical	20	10		23,31	
Pure chemical	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	23,15	23,17
Pure chemical	7,5	3		23,18	
Pure chemical	7,5	3		23,17	

Results were examined for 1:5 concentration for Macrosilicone Softener (Table 4.13), expected results were obtained like pure concentration results.

Table 4.13 Deposition Time of Electrospraying Macrosilicone Softener 1:5 concentration solution on 100% Cotton fabric

Macrosilicone Softener	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,51	23,49
1:5	15	10		23,49	
1:5	15	10		23,47	
1:5	17,5	10	1,75	23,37	23,36
1:5	17,5	10		23,35	
1:5	17,5	10		23,35	
1:5	20	10	2	23,29	23,28
1:5	20	10		23,26	
1:5	20	10		23,28	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	22,58	22,57
1:5	7,5	3		22,56	
1:5	7,5	3		22,56	

Results were examined for 1:10 concentration for Macrosilicone Softener (Table 4.14), expected results were obtained like pure and 1:5 concentration results.

Table 4.14 Deposition Time of Electrospraying Macrosilicone Softener 1:10 concentration solution on 100% Cotton Fabric

Macrosilicone Softener	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,47	23,46
1:10	15	10		23,45	
1:10	15	10		23,47	
1:10	17,5	10	1,75	23,38	23,36
1:10	17,5	10		23,35	
1:10	17,5	10		23,36	
1:10	20	10	2	23,25	23,25
1:10	20	10		23,24	
1:10	20	10		23,26	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	22,46	22,48
1:10	7,5	3		22,5	
1:10	7,5	3		22,47	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% cotton fabric, because at 7.5 kV it was possible to perform elecrrospraying process. For pure chemical, there was just some time difference between cotton fabric and polyester fabric, polyamide fabric about 1-4 seconds, for 1:5 concentration; like pure concentration there were some time differences between cotton and polyester fabric, polyamide fabric about 16-20 seconds. For 1:10 concentration the deposition time difference was more than pure and 1:5 concentrations, about 28-30 seconds.

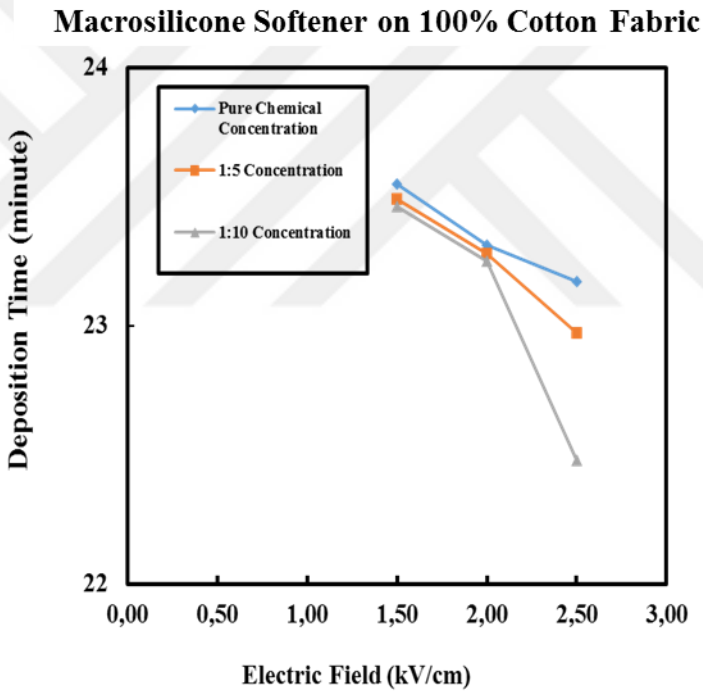

Figure 4.7 Deposition Time- Electric Field Graphic of Macrosilicone Softener on 100% Cotton Fabric

When Figure 4.7 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.1.4. Variance Analysis for Macrosilicone Softener Solution

4.1.4.1. Correlation Analysis of Macrosilicone Softener Solution

Correlation analysis were done to deposition time with solution parameters (viscosity, surface tension, conductivity, concentration) and process parameters (voltage, distance, collector type) via Minitab® 16 Statistical Software. Table 4.15 showed the Pearson Correlation Coefficients (PCC) between deposition time and different process and solution parameters. It could be seen that from Pearson correlation coefficient, the parameters were correlated with deposition time. According to positivity and negativity of coefficients, surface tension had negative correlation coefficient which means when surface tension increases deposition time decreases or vice versa. The other parameters had positive correlation coefficient which indicates when parameters increases deposition time increases too. The p value obtained for all parameters were less than 0.05 expressing statistically significant effect on deposition time.

Table 4.15 Correlation Analysis of Macrosilicone Softener Solution

Parameter	PCC	p value
Concentration (v/v)	0,413	0,000
Viscosity (cP)	0,413	0,000
Surface Tension (mN/m)	-0,402	0,000
Conductivity (µS/cm)	0,403	0,000
Voltage (kV)	0,455	0,000
Distance (cm)	0,596	0,000
Collector Type (aluminum foil, 100% PES, 100% PA and 100% Cotton Fabric	0,476	0,000

PCC values should be in a range between +1 and −1, including the end values +1 or −1 [Ratner, 2009], the p-value less than 0.05 means that the effect of the parameter on deposition time is meaningful [Afzal et. al., 2015]. In addition, it was observed that distance has highest effect on deposition time with PCC value 0.596, at p-value 0.000. When surface tension value is observed, the effect on deposition time is negatively with PCC value -0.402, at p-value 0.000. It means when surface tension increases deposition time decreases or vice versa.

4.1.4.2. Generalized Linear Method (Factorial ANOVA) for Macrosilicone Softener Solution

Macrosilicone Softener solutions were prepared with three different concentrations (pure, 1:5 and 1:10). ANOVA was done for Macrosilicone Softener solution by IBM

SPSS Statistics 21- Software; IBM, Chicago, USA. The ANOVA table is shown (Table 4.16) for study of Macrosilicone Softener solution.

Table 4.16 ANOVA Table for Macrosilicone Softener Solution

Source	Type III Sum of Squares	df	Mean Square	F	p value
Corrected Model	26,940[a]	6	4,49	117,08	0,000
Intercept	4511,135	1	4511,14	117633,3	0,000
Viscosity (a)	4,654	1	4,654	121,348	0,000
Voltage (b)	4,993	1	4,993	130,202	0,000
Distance (c)	6,979	1	6,979	181,98	0,000
Collector Type (d)	0,268	1	0,268	6,988	0,009
a*b*c*d	0,582	1	0,582	15,172	0,000
Error	5,944	155	0,038		
Total	85310,959	162			
Corrected Total	32,884	161			
a. R Squared = ,819 (Adjusted R Squared = ,812)					

According to variance analysis (ANOVA) results, viscosity, voltage, distance and collector type were statistically significant on deposition time both seperately and together ($p \leq 0.05$). When process parameters (voltage, distance and collector type) were considered together, the effect on deposition time was again significant. Again all parameters (viscosity, voltage, distance and collector type) were considered together, the effect on deposition time of all parameters was significant.

4.1.4.3. Regression Analysis for Macrosilicone Softener Solution

When choosing independent variables, it is important to pick only one of the independent variables with high correlation between them [Orhunbilge, 2002]. For example although viscosity and concentration were like different from each other, in fact two of the parameter were closely linked. Only one such variable should be selected in the multiple regression analysis. For this, it was necessary to look at the correlation matrix of all variables before starting the analysis and to choose one of the highly correlated fields. After all variables correlated with each other and were within the same property group, the final equations contained just three or four parameters. Viscosity and concentration were in same property group, so concentration was removed from the regression analysis [Hu and Chan, 1998]. Final variables were selected for regression analysis to release the effective parameters on

deposition time. The effects of conductivity and surface tension couldn't be expressed because these parameters weren't added to the regression analysis since Minitab programme showed also that these parameters are highly correleated and removed from analysis. According to the regression analysis, the affecting parameters and significance values were shown in Table 4.17.

Table 4.17 Results for regression analysis of deposition time of Macrosilicone Softener Solution

Parameters	**Coeeficient**	**T**	**P (Significance value)**
Constant	22,209	423,04	0,0000
Viscosity	0,011873	10,91	0,0000
Voltage	-0,093036	-9,64	0,0000
Distance	0,20917	13,56	0,0000
Collector Type	0,43004	10,11	0,0000
R^2 = 77,5% R^2(adj) = 76,9%			

Analysis of Variance					
Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	4	25,4799	6,37	135,1	0,0000
Residual Error	157	7,4038	0,0472		
Total	161	32,8837			

Viscosity, voltage, distance and collector type parameters were effective on deposition time; according to coefficient value collector type had biggest effect on deposition time. According to these results; the regression analysis for deposition time was below:

Deposition time = 22.2 + 0.0119 viscosity – 0.0930 voltage + 0.209 distance + 0.430 collector type

Increasing of viscosity causes an increase on deposition time. Voltage value has negative effect on deposition time, it can be expressed that when voltage increases deposition time decreases or vice versa. Deposition time increases with increasing distance. When collector type is chosen according to the conductivity, more conductive collector type causes less deposition time. When correlation and ANOVA results were examined, distance value had the biggest effect on deposition time, but according to regression analysis collector type was the highest effective parameter. It should be noted that correlation analysis and ANOVA just gave us the relation

between the parameters; both analyses could not decide the relation on their own. Regression analysis is an equation of parameters relation.

Best subset regression is that the subset of predictors is selected to fit the well defined criterion with largest adjusted R^2, lowest Mallows' value and lowest S value. MINITAB examines all possible subsets of variables as shown in Table 4.18.

Table 4.18 Models consisting of different combinations of variables selected using all possible regressions from predictors of deposition time for Macrosilicone Softener Solution

Predictors	R²	Adjusted R²	Mallows' Cp	S	Viscosity	Voltage	Distance	Collector Type
1	35,6	35,2	291,2	0,36386			X	
1	22,7	22,2	381,0	0,39859				X
2	52,6	52,1	174,2	0,32194	X		X	
2	47,1	46,4	213,0	0,33083			X	X
3	64,1	63,5	96,0	0,27316	X		X	X
3	62,8	62,1	105,1	0,27810	X	X	X	
4	77,5	76,9	5,0	0,21716	X	X	X	X

The model with the higher R^2 value, the smaller Mallows' Cp and the smaller S value should be selected for best subset model. According to Table 4.17, when all predictors participate in the model, the highest R^2 value (77.5), the smallest Mallows' Cp (5.0) and the smallest S (0.21716) value can be obtained. And regression analysis and best subset regression analysis gave us the same parameters effect on deposition time.

4.2. Microsilicone Softener Results

4.2.1. Microsilicone Softener Solution Characterization

In this thesis, some prestudies were done to determine optimum concentrations. Concentration, viscosity, conductivity and surface tension values of these concentrations were given Table 4.19.

Table 4.19 Viscosity, conductivity and surface tension values of Microsilicone Softener chemical solutions with different concentrations

Chemical solution	Concentration (%)	Viscosity (cP)	Conductivity (µS/cm)	Surface Tension (mN/m)
Microsilicone Softener	Pure	35.4	706.00	24.31
	1:5 v/v	2.77	473.00	30.32
	1:10 v/v	2.56	299.67	30.74

Viscosity, conductivity and surface tension measurements were done for different concentration values (pure, 1:5 v/v, 1:10 v/v) to specify the suitability of chemical solutions for electrospraying process. Viscosity measurements of Microsilicone Softener solutions (pure, 1:5 v/v and 1:10 v/v) were shown in Table 4.19. When the results were examined, it was seen that when concentration of chemical decreases the viscosity decreases too similar to Microsilicone Softener solution results. The viscosity values of Microsilicone Softener ranged from 2.56 cP to 35.4 cP when concentration ranged from 1:10 v/v to 100% pure chemical. When Figure 4.8 was drawn according to viscosity and concentration values, the relation between viscosity and concentration could be seen clearly.

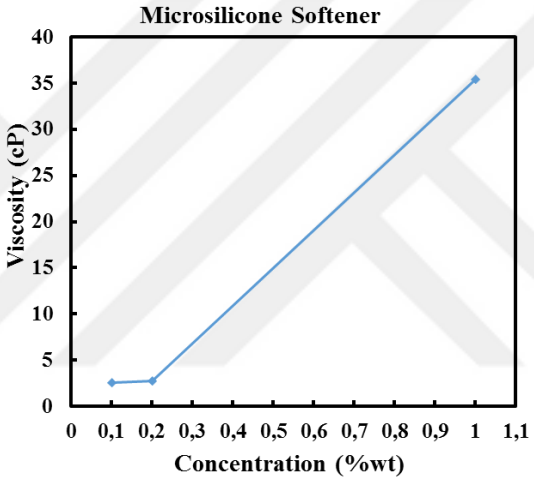

Figure 4.8 Viscosity measurements of Microsilicone Softener chemical solutions with different concentrations.

Conductivity is another important characteristic of solutions to perform electrospraying process. The conductivity results were given in Figure 4.9. The results were changed between 299.67 µS/cm to 706.00 µS/cm.

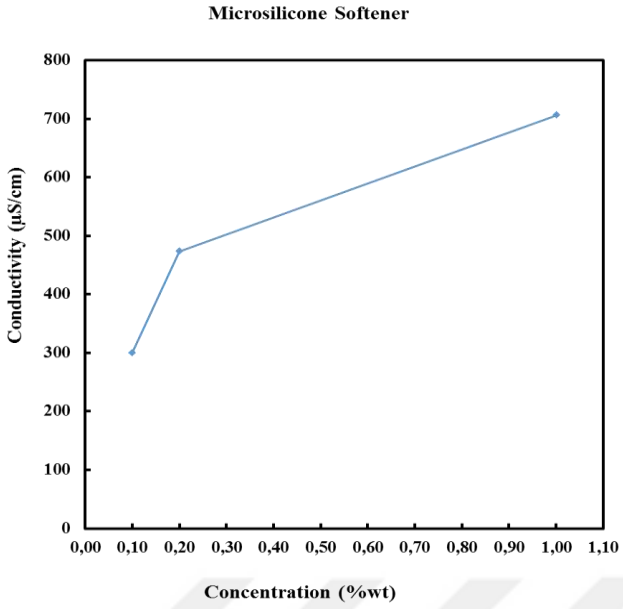

Figure 4.9 Conductivity measurements of Microsilicone Softener chemical solutions with different concentrations.

Surface tension results were given in Figure 4.10. The surface tension values were changed 24.31 to 30.74 mN/m.

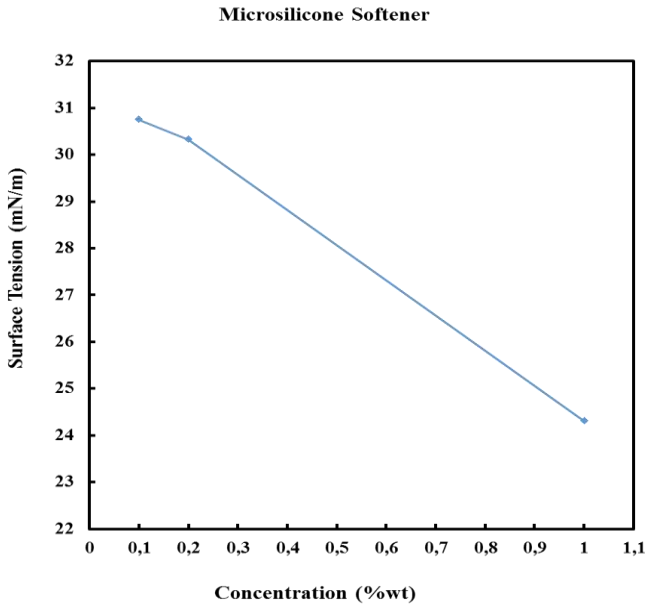

Figure 4.10 Surface tension measurements of Microsilicone Softener chemical solutions with different concentrations

4.2.2. Electrospraying Process for Microsilicone Softener Solution

The trails for each concentration and for each five electric field were done three times and the average of the results was calculated for aluminum foil, 100% polyester fabric, 100% polyamide fabric and 100% cotton fabric. Microsilicone Softener chemical solutions were electrosprayed at three different (pure, 1:5, 1:10 volume/volume) concentrations. The process parameters were flow rate (20µl/min) applied voltage (4.5 kV, 6.75 kV, 7.5 kV, 10 kV, 15 kV and 20 kV), tip to collector distance (3 cm and 5 cm) and needle size (22 gauge). Applied electric field values were 1 kV/cm, 1.5 kV/cm, 2 kV/cm, 2.5 kV/cm and 5kV/cm. For each applied electric field, deposition time was recorded for electrospraying of 4ml solution. The deposition time was measured for each situation and then statistical analyses were done to determine the contribution of the parameters.

4.2.3. Deposition Time Results of Microsilicone Softener Solution

4.2.3.1. Deposition Time Results of Microsilicone Softener Solution on Aluminum Foil

Deposition time results were examined for pure concentration for Microsilicone Softener chemical solution electrosprayed on aluminum foil. Expected result was that the smaller deposition time, easier the process [Gunesoglu, 2011]. When Table 4.20 was assessed, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration.

Table 4.20 Deposition Time of Electrospraying Microsilicone Softener pure concentration solution on aluminum foil

Microsilicone Softener	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
Pure chemical	4,5	3	1,5	23,07	23,07
Pure chemical	4,5	3		23,07	
Pure chemical	4,5	3		23,06	
Pure chemical	15	10	1,5	23	23,01
Pure chemical	15	10		23,01	
Pure chemical	15	10		23,01	
Pure chemical	17,5	10	1,75	22,54	22,52
Pure chemical	17,5	10		22,51	
Pure chemical	17,5	10		22,52	
Pure chemical	20	10	2	22,44	22,45
Pure chemical	20	10		22,46	
Pure chemical	20	10		22,45	
Pure chemical	6,75	3	2,25	22,35	22,35
Pure chemical	6,75	3		22,35	
Pure chemical	6,75	3		22,34	
Pure chemical	7,5	3	2,5	22,33	22,32
Pure chemical	7,5	3		22,32	
Pure chemical	7,5	3		22,3	

Results were examined for 1:5 concentration for Microsilicone Softener (Table 4.21), expected results were obtained like pure concentration results.

Table 4.21 Deposition Time of Electrospraying Microsilicone Softener 1:5 concentration solution on aluminum foil

Microsilicone Softener	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:5	4,5	3	1,5	23,02	23,02
1:5	4,5	3		23,02	
1:5	4,5	3		23,01	
1:5	15	10	1,5	23,06	23,05
1:5	15	10		23,05	
1:5	15	10		23,03	
1:5	17,5	10	1,75	22,56	22,54
1:5	17,5	10		22,53	
1:5	17,5	10		22,54	
1:5	20	10	2	22,48	22,46
1:5	20	10		22,45	
1:5	20	10		22,46	
1:5	6,75	3	2,25	22,22	22,24
1:5	6,75	3		22,24	
1:5	6,75	3		22,25	
1:5	7,5	3	2,5	22,2	22,20
1:5	7,5	3		22,18	
1:5	7,5	3		22,21	

Results were examined for 1:10 concentration for Microsilicone Softener (Table 4.22), expected results were obtained like pure and 1:5 concentration results.

Table 4.22 Deposition Time of Electrospraying Microsilicone Softener 1:10 concentration solution on aluminum foil

Microsilicone Softener	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:10	4,5	3	1,5	23,06	23,04
1:10	4,5	3		23,01	
1:10	4,5	3		23,04	
1:10	15	10	1,5	23,02	23,03
1:10	15	10		23,03	
1:10	15	10		23,03	
1:10	17,5	10	1,75	22,59	22,57
1:10	17,5	10		22,56	
1:10	17,5	10		22,57	
1:10	20	10	2	22,52	22,52
1:10	20	10		22,54	
1:10	20	10		22,51	
1:10	6,75	3	2,25	22,48	22,47
1:10	6,75	3		22,47	
1:10	6,75	3		22,47	
1:10	7,5	3	2,5	22,32	22,30
1:10	7,5	3		22,28	
1:10	7,5	3		22,31	

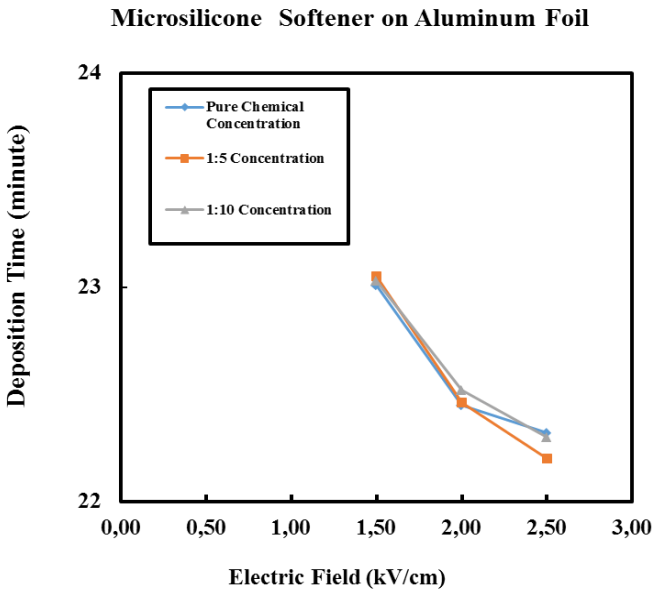

Figure 4.11 Deposition Time- Electric Field Graphic of Microsilicone Softener on Aluminum Foil

When Figure 4.11 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.2.3.2. Electrospraying Process for Microsilicone Softener Solution on 100% Polyester Fabric

Deposition time results were examined for pure concentration for Microsilicone Softener chemical solution electrosprayed on 100% Polyester fabric. When Table 4.23 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. Aluminum foil and 100% PES fabric have different electrical resistivity values. Aluminum foil has 29×10^{-2} S·cm-^{1}, 100% PES fabric has 2.7382 x 10^{-13} S·cm-^{1} conductivity. When the collector was selected as 100% PES fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process coudn't be achieved.

Table 4.23 Deposition Time of Electrospraying Microsilicone Softener pure concentration solution on 100% Polyester Fabric

Microsilicone Softener	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
Pure chemical	4,5	3	1,5	INSUFICIENT VOLTAGE	INSUFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	24,66	24,62
Pure chemical	15	10		24,62	
Pure chemical	15	10		24,59	
Pure chemical	17,5	10	1,75	23,17	23,15
Pure chemical	17,5	10		23,15	
Pure chemical	17,5	10		23,12	
Pure chemical	20	10	2	22,56	22,54
Pure chemical	20	10		22,53	
Pure chemical	20	10		22,53	
Pure chemical	6,75	3	2,25	INSUFICIENT VOLTAGE	INSUFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	22,33	22,35
Pure chemical	7,5	3		22,34	
Pure chemical	7,5	3		22,38	

Results were examined for 1:5 concentration for Microsilicone Softener (Table 4.24), expected results were obtained like pure concentration results.

Table 4.24 Deposition Time of Electrospraying Microsilicone Softener 1:5 concentration solution on 100% Polyester fabric

Microsilicone Softener	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,25	23,25
1:5	15	10		23,23	
1:5	15	10		23,26	
1:5	17,5	10	1,75	23,11	23,11
1:5	17,5	10		23,12	
1:5	17,5	10		23,10	
1:5	20	10	2	23,04	23,03
1:5	20	10		23,02	
1:5	20	10		23,04	
1:5	6,75	3	2,25	22,44	22,46
1:5	6,75	3		22,48	
1:5	6,75	3		22,45	
1:5	7,5	3	2,5	22,4	22,38
1:5	7,5	3		22,39	
1:5	7,5	3		22,36	

Results were examined for 1:10 concentration for Microsilicone Softener (Table 4.25), expected results were obtained like pure and 1:5 concentration results.

Table 4.25 Deposition Time of Electrospraying Microsilicone Softener 1:10 concentration solution on 100% Polyester Fabric

Microsilicone Softener	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,14	23,13
1:10	15	10		23,12	
1:10	15	10		23,14	
1:10	17,5	10	1,75	23,12	23,10
1:10	17,5	10		23,09	
1:10	17,5	10		23,09	
1:10	20	10	2	23,06	23,06
1:10	20	10		23,06	
1:10	20	10		23,06	
1:10	6,75	3	2,25	22,6	22,60
1:10	6,75	3		22,6	
1:10	6,75	3		22,59	
1:10	7,5	3	2,5	22,58	22,57
1:10	7,5	3		22,58	
1:10	7,5	3		22,56	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. When pure chemical solution was evaluated for 100% PES fabric, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, but when 1:5 v/v and 1:10 v/v dilution concentrations were evaluated, at 6.75 kV electrospraying performance could be achieved. Zeta potential values of Macrosilicone Softener and Microsilicone Softener were measured to clarify why electrospraying process couldn't be achieved although very identical chemicals. Zeta potential values (Table 4.26) could explain the difference.

Table 4.26 Zeta potential values of Macrosilicone Softener and Microsilicone Softener

Sample Name	**ZP (mV)**
Rucofin GWE pure chemical	12813,33
Rucofin GWE 1:5 v/v	269000,00
Rucofin GWE 1:10 v/v	690000,00
Rucofin GWS pure chemical	14086,67
Rucofin GWS 1:5 v/v	20,13333
Rucofin GWS 1:10 v/v	34,83333

Zeta potential values of Microsilicone Softener with concentrations of 1:5 v/v and 1:10 v/v decreased dramatically when compared with pure chemical. But for Macrosilicone Softener zeta potential values increased with decreasing concentration [Okutan et. al., 2014]. It could be said that if the zeta potential value for these chemicals were lower than 12813.33 mV, electrospraying process could be achieved for 6.75 kV. When the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% PES fabric, because at 7.5 kV it was possible to perform electrospraying process.

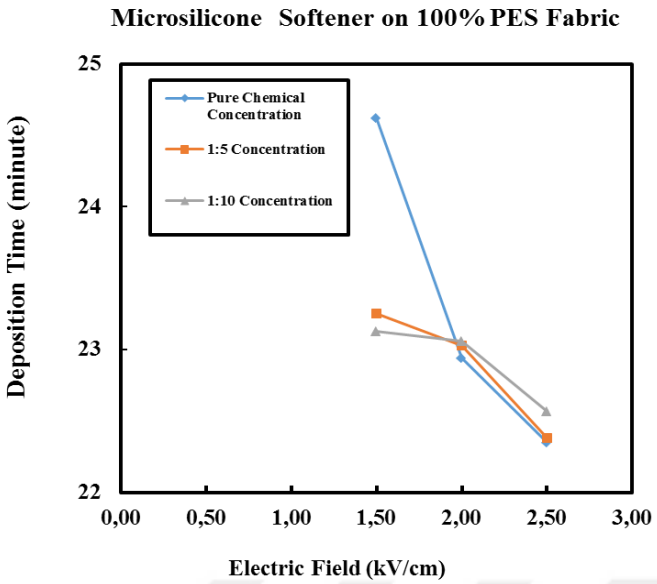

Figure 4.12 Deposition Time- Electric Field Graphic of Microsilicone Softener on 100% Polyester Fabric

When Figure 4.12 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.2.3.3. Electrospraying Process for Microsilicone Softener Solution on 100% Polyamide Fabric

Deposition time results were examined for pure concentration for Microsilicone Softener chemical solution electrosprayed on 100% Polyamide fabric. When Table 4.27 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. Aluminum foil and 100% PA fabrics have different electrical resistivity values. 100% Polyamide fabric has $2.627*10^{-14}$ $S \cdot cm^{-1}$ conductivity. When the collector was selected as 100% PA fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process couldn't be achieved.

Table 4.27 Deposition Time of Electrospraying Microsilicone Softener pure concentration solution on 100% Polyamide Fabric

Microsilicone Softener	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
Pure chemical	4,5	3	1,5	INSUFICIENT VOLTAGE	INSUFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,35	23,33
Pure chemical	15	10		23,32	
Pure chemical	15	10		23,33	
Pure chemical	17,5	10	1,75	23,24	23,23
Pure chemical	17,5	10		23,22	
Pure chemical	17,5	10		23,24	
Pure chemical	20	10	2	23,11	23,10
Pure chemical	20	10		23,08	
Pure chemical	20	10		23,1	
Pure chemical	6,75	3	2,25	INSUFICIENT VOLTAGE	INSUFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	22,6	22,59
Pure chemical	7,5	3		22,59	
Pure chemical	7,5	3		22,58	

Results were examined for 1:5 concentration for Microsilicone Softener (Table 4.28), expected results were obtained like pure concentration results.

Table 4.28 Deposition Time of Electrospraying Microsilicone Softener 1:5 concentration solution on 100% Polyamide Fabric

Microsilicone Softener	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,24	23,24
1:5	15	10		23,23	
1:5	15	10		23,25	
1:5	17,5	10	1,75	23,18	23,17
1:5	17,5	10		23,15	
1:5	17,5	10		23,17	
1:5	20	10	2	23,03	23,03
1:5	20	10		23,04	
1:5	20	10		23,03	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	22,5	22,52
1:5	7,5	3		22,54	
1:5	7,5	3		22,52	

Results were examined for 1:10 concentration for Microsilicone Softener (Table 4.29), expected results were obtained like pure and 1:5 concentration results.

Table 4.29 Deposition Time of Electrospraying Microsilicone Softener 1:10 concentration solution on 100% Polyamide Fabric

Microsilicone Softener	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,31	23,29
1:10	15	10		23,26	
1:10	15	10		23,3	
1:10	17,5	10	1,75	23,16	23,14
1:10	17,5	10		23,12	
1:10	17,5	10		23,15	
1:10	20	10	2	22,57	22,57
1:10	20	10		22,55	
1:10	20	10		22,58	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	22,45	22,43
1:10	7,5	3		22,4	
1:10	7,5	3		22,43	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% PA fabric, because at 7.5 kV it was possible to perform electrospraying process. For pure chemical, there was just time big difference between polyester fabric and polyamide fabric about 8-90 seconds, for 1:5 concentration, time difference decreases 1-14 seconds. For 1:10 concentration the deposition time difference was 4-16 seconds. For Microsilicone Softener chemical solution time difference for all concentrations is more than Macrosilicone Softener chemical solution.

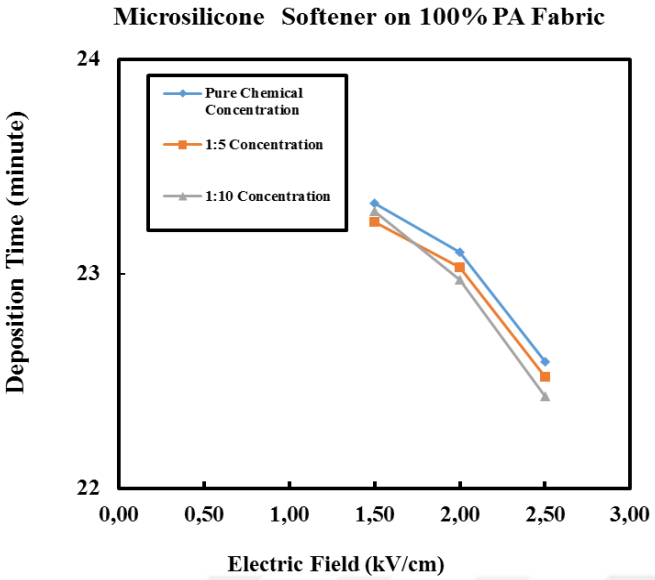

Figure 4.13 Deposition Time- Electric Field Graphic of Microsilicone Softener on 100% Polyamide Fabric

When Figure 4.13 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.2.3.4. Electrospraying Process for Microsilicone Softener Solution on 100% Cotton Fabric

Deposition time results were examined for pure concentration for Microsilicone Softener chemical solution electrosprayed on 100% Cotton fabric. When Table 4.30 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. Aluminum foil and 100% Cotton fabrics have different electrical resistivity values. 100% Cotton fabric has $2.734*10^{-14}$ $S \cdot cm^{-1}$ conductivity. When the collector was selected as 100% cotton fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process coudn't be achieved.

Table 4.30 Deposition Time of Electrospraying Microsilicone Softener pure concentration solution on 100% Cotton Fabric

Microsilicone Softener	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
Pure chemical	4,5	3	1,5	INSUFICIENT VOLTAGE	INSUFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,5	23,48
Pure chemical	15	10		23,47	
Pure chemical	15	10		23,46	
Pure chemical	17,5	10	1,75	23,4	23,42
Pure chemical	17,5	10		23,43	
Pure chemical	17,5	10		23,42	
Pure chemical	20	10	2	23,35	23,35
Pure chemical	20	10		23,34	
Pure chemical	20	10		23,35	
Pure chemical	6,75	3	2,25	INSUFICIENT VOLTAGE	INSUFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	22,63	23,00
Pure chemical	7,5	3		22,56	
Pure chemical	7,5	3		22,6	

Results were examined for 1:5 concentration for Microsilicone Softener (Table 4.31), expected results were obtained like pure concentration results.

Table 4.31 Deposition Time of Electrospraying Microsilicone Softener 1:5 concentration solution on 100% Cotton fabric

Microsilicone Softener	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,42	23,43
1:5	15	10		23,44	
1:5	15	10		23,42	
1:5	17,5	10	1,75	23,33	23,35
1:5	17,5	10		23,36	
1:5	17,5	10		23,35	
1:5	20	10	2	23,25	23,26
1:5	20	10		23,28	
1:5	20	10		23,26	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	22,48	22,51
1:5	7,5	3		22,54	
1:5	7,5	3		22,52	

Results were examined for 1:10 concentration for Microsilicone Softener (Table 4.32), expected results were obtained like pure and 1:5 concentration results.

Table 4.32 Deposition Time of Electrospraying Microsilicone Softener 1:10 concentration solution on 100% Cotton Fabric

Microsilicone Softener	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D.Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,36	23,35
1:10	15	10		23,34	
1:10	15	10		23,34	
1:10	17,5	10	1,75	23,27	23,27
1:10	17,5	10		23,28	
1:10	17,5	10		23,25	
1:10	20	10	2	23,23	23,24
1:10	20	10		23,24	
1:10	20	10		23,26	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	22,39	22,40
1:10	7,5	3		22,4	
1:10	7,5	3		22,42	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% cotton fabric, because at 7.5 kV it was possible to perform elecrrospraying process. For pure chemical, there was just some time difference between cotton fabric and polyester fabric, polyamide fabric about 1-25 seconds, for 1:5 concentration; like pure concentration there were some time differences between cotton and polyester fabric, polyamide fabric about 1-23 seconds. For 1:10 concentration the deposition time difference was more than pure and 1:5 concentrations, about 3-27 seconds. 100% Cotton fabric results were closer to 100% Polyamide fabric results than 100% Polyester fabric results.

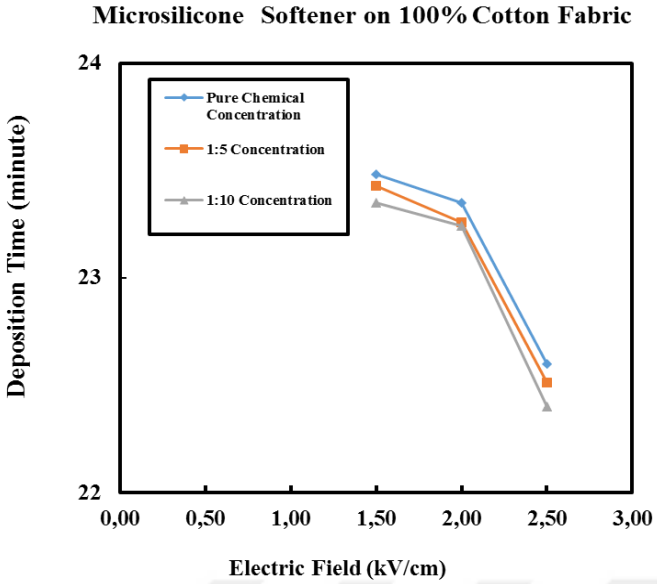

Figure 4.14 Deposition Time- Electric Field Graphic of Microsilicone Softener on 100% Cotton Fabric

When Figure 4.14 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.2.4. Variance Analysis for Microsilicone Softener Solution

4.2.4.1. Correlation Analysis of Microsilicone Softener Solution

It was observed that distance has highest effect on deposition time with PCC value 0.614, at p-value 0.000. When voltage value was observed, the effect on deposition time was with PCC value 0.445, at p-value 0.000. And lastly, collector type value had PCC value 0.408, at p-value 0.000.

Table 4.33 Correlation Analysis of Microsilicone Softener Solution

Parameter	PCC	p value
Concentration (v/v)	0,124	0,108
Viscosity (cP)	0,124	0,109
Surface Tension (mN/m)	-0,124	0,108
Conductivity (µS/cm)	0,115	0,137
Voltage (kV)	0,445	0,000
Distance (cm)	0,614	0,000
Collector Type (aluminum foil, 100% PES, 100% PA and 100% Cotton Fabric	0,408	0,000

4.2.4.2. Generalized Linear Method (Factorial ANOVA) for Microsilicone Softener Solution

ANOVA results were shown in Table 4.34.

Table 4.34 ANOVA Table for Microsilicone Softener Solution

Source	Type III Sum of Squares	df	Mean Square	F	p value
Corrected Model	25,036a	4	6,259	117,2	0,000
Intercept	5124,848	1	5124,85	95961,272	0,000
Voltage (b)	8,365	1	8,365	156,629	0,000
Distance (c)	9,312	1	9,312	174,357	0,000
Collector Type (d)	0,001	1	0,001	0,014	0,906
b*c*d	2,432	1	2,432	45,537	0,000
Error	8,705	163	0,053		
Total	88050,827	168			
Corrected Total	33,742	167			
a. R Squared = ,742 (Adjusted R Squared = ,736)					

According to variance analysis (ANOVA) results; voltage and distance were statistically significant on deposition time ($p \leq 0.05$). Collector type was not significant on deposition time alone.

4.2.4.3. Regression Analysis for Microsilicone Softener Solution

According to the regression analysis, the affecting parameters and significance values were shown in Table 4.35.

Table 4.35 Results for regression analysis of deposition time of Microsilicone Softener solution

Parameters	**Coeeficient**	**T**	**P (Significance value)**
Constant	22,3662	377,3	0,0000
Voltage	-0,11713	-10,13	0,0000
Distance	0,25075	13,57	0,0000
Collector Type	0,38504	7,75	0,0000
R^2 = 67,0% R^2(adj) = 66,4%			

Analysis of Variance					
Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	3	22,6046	7,5349	111	0,0000
Residual Error	164	11,137	0,0679		
Total	167	33,7416			

Voltage, distance and collector type parameters are effective on deposition time; according to coefficient value collector type has biggest effect on deposition time. According to these results; the regression analysis for deposition time is below:

Deposition time = 22.4 – 0.117 voltage + 0.251 distance + 0.385 collector type

Voltage value has negative effect on deposition time, it can be expressed that when voltage increases deposition time decreases or vice versa. Deposition time increases with increasing distance. When collector type is chosen according to the conductivity, more conductive collector type causes less deposition time. MINITAB examines all possible subsets of variables as shown in Table 4.36.

Table 4.36 Models consisting of different combinations of variables selected using all possible regressions from predictors of deposition time for Microsilicone Softener solution

Predictors	R^2	Adjusted R^2	Mallows' Cp	S	Voltage	Distance	Collector Type
1	37,7	37,3	145,8	0,35599		X	
1	19,8	19,4	234,3	0,40366	X		
2	54,9	54,4	62,1	0,30368	X	X	
2	46,4	45,7	104,5	0,33121		X	X
3	67,0	66,4	4,0	0,26059	X	X	X

According to Table 4.36, when all predictors participate in the model, the highest R^2 value (67.0), the smallest Mallows' Cp (4.0) and the smallest S (0.26059) value can be obtained. And regression analysis and best subset regression analysis gave us the same parameters effect on deposition time.

4.3. Fluorocarbon Results

4.3.1. Fluorocarbon Solution Characterization

In this thesis, some prestudies were done to determine optimum concentrations. Concentration, viscosity, conductivity and surface tension values of these concentrations were given Table 4.37.

Table 4.37 Viscosity, conductivity and surface tension values of Fluorocarbon chemical solutions with different concentrations

Chemical solution	Concentration (%)	Viscosity (cP)	Conductivity (µS/cm)	Surface Tension (mN/m)
Fluorocarbon	Pure	3.40	2195.33	30.71
	1:5 v/v	2.35	721.33	39.47
	1:10 v/v	2.13	396.67	40.35

Viscosity, conductivity and surface tension measurements were done for different concentration values (pure, 1:5 v/v, 1:10 v/v) to specify the suitability of chemical solutions for electrospraying process. Viscosity measurements of Fluorocarbon solutions (pure, 1:5 v/v and 1:10 v/v) were shown in Figure 4.35. When the results were examined, it was seen that when concentration of chemical decreases the viscosity decreases too. The viscosity values of Fluorocarbon ranged from 2,13cP to 3,40cP when concentration ranged from 1:10 v/v to 100% pure chemical. When Figure 4.15 was drawn according to viscosity and concentration values, the relation between viscosity and concentration could be seen clearly.

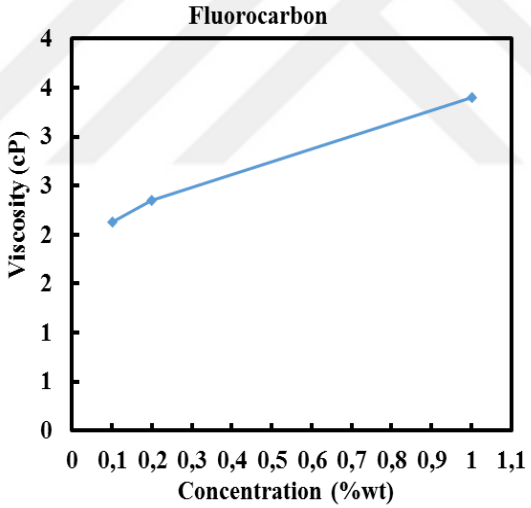

Figure 4.15 Viscosity measurements of Fluorocarbon solutions with different concentrations

The conductivity results were given in Figure 4.16. The results were changed between 396.67 µS/cm to 2195.33 µS/cm.

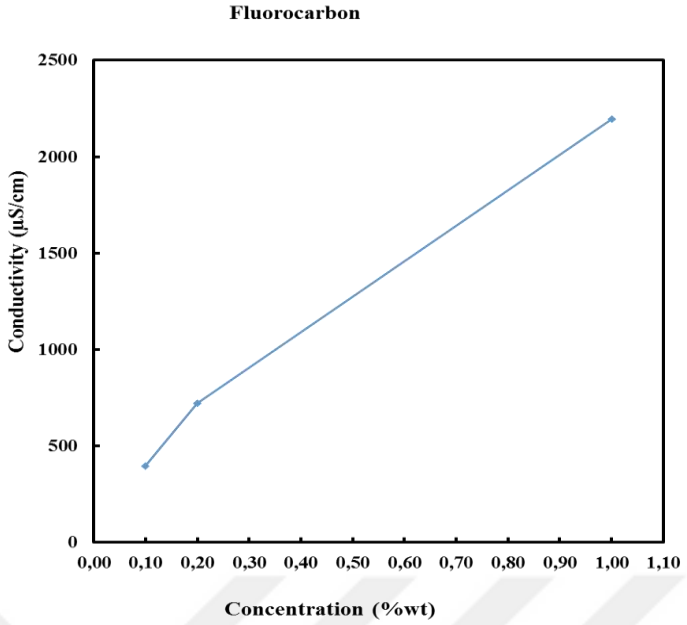

Figure 4.16 Conductivity measurements of Fluorocarbon chemical solutions with different concentrations

Surface tension results were given in Figure 4.17. The surface tension values were changed between 30.71 mN/m to 40.35 mN/m.

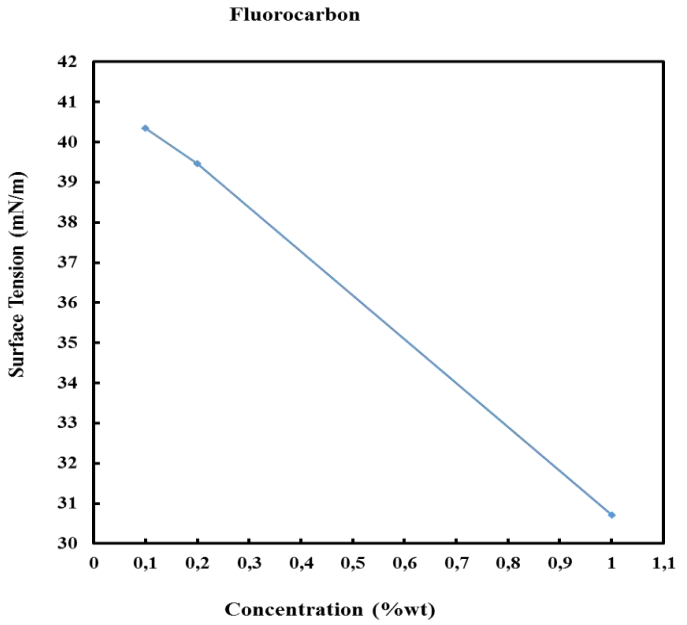

Figure 4.17 Surface tension measurements of Fluorocarbon chemical solutions with different concentrations

4.3.2. Electrospraying Process for Fluorocarbon Solution

The trails for each concentration and for each five electric field were done three times and the average of the results was calculated for aluminum foil, 100% polyester fabric, 100% polyamide fabric and 100% cotton fabric. Fluorocarbon chemical solutions were electrosprayed at three different (pure, 1:5, 1:10 volume/volume) concentrations. The process parameters were flow rate (20µl/min) applied voltage (4.5 kV, 6.75 kV, 7.5 kV, 10 kV, 15 kV and 20 kV), tip to collector distance (3 cm and 5 cm) and needle size (22 gauge). Applied electric field values were 1 kV/cm, 1.5 kV/cm, 2 kV/cm, 2.5 kV/cm and 5kV/cm. For each applied electric field, deposition time was recorded for electrospraying of 4ml solution. The deposition time was measured for each situation and then statistical analysis was done to determine the contribution of the parameters.

4.3.3. Deposition Time Results of Fluorocarbon Solution

4.3.3.1. Deposition Time Results of Fluorocarbon Solution on Aluminum Foil

Deposition time results were examined for pure concentration for Fluorocarbon chemical solution electrosprayed on aluminum foil. Expected result is that the smaller deposition time, easier the process [Gunesoglu, 2011]. When Table 4.38 was assesed, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration.

Table 4.38 Deposition Time of Electrospraying Fluorocarbon pure concentration solution on aluminum foil

Fluorocarbon	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
Pure chemical	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	22,48	22,46
Pure chemical	15	10		22,46	
Pure chemical	15	10		22,45	
Pure chemical	17,5	10	1,75	22,42	22,44
Pure chemical	17,5	10		22,45	
Pure chemical	17,5	10		22,46	
Pure chemical	20	10	2	22,4	22,39
Pure chemical	20	10		22,4	
Pure chemical	20	10		22,37	
Pure chemical	6,75	3	2,25	22,16	22,18
Pure chemical	6,75	3		22,2	
Pure chemical	6,75	3		22,17	
Pure chemical	7,5	3	2,5	22,15	22,12
Pure chemical	7,5	3		22,1	
Pure chemical	7,5	3		22,12	

Results were examined for 1:5 concentration for Fluorocarbon (Table 4.39), expected results were obtained like pure concentration results.

Table 4.39 Deposition Time of Electrospraying Fluorocarbon 1:5 concentration solution on aluminum foil

Fluorocarbon	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	22,45	22,43
1:5	4,5	3		22,44	
1:5	4,5	3		22,4	
1:5	15	10	1,5	22,39	22,41
1:5	15	10		22,4	
1:5	15	10		22,43	
1:5	17,5	10	1,75	22,27	22,29
1:5	17,5	10		22,29	
1:5	17,5	10		22,30	
1:5	20	10	2	22,31	22,34
1:5	20	10		22,35	
1:5	20	10		22,37	
1:5	6,75	3	2,25	22,28	22,28
1:5	6,75	3		22,29	
1:5	6,75	3		22,28	
1:5	7,5	3	2,5	22,32	22,33
1:5	7,5	3		22,31	
1:5	7,5	3		22,35	

Results were examined for 1:10 concentration for Fluorocarbon (Table 4.40), expected results were obtained like pure and 1:5 concentration results.

Table 4.40 Deposition Time of Electrospraying Fluorocarbon 1:10 concentration solution on aluminum foil

Fluorocarbon	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	23,13	23,15
1:10	4,5	3		23,17	
1:10	4,5	3		23,14	
1:10	15	10	1,5	23,13	23,15
1:10	15	10		23,15	
1:10	15	10		23,16	
1:10	17,5	10	1,75	23,09	23,08
1:10	17,5	10		23,08	
1:10	17,5	10		23,06	
1:10	20	10	2	22,59	22,59
1:10	20	10		22,59	
1:10	20	10		22,58	
1:10	6,75	3	2,25	23,02	23,03
1:10	6,75	3		23,02	
1:10	6,75	3		23,05	
1:10	7,5	3	2,5	22,56	22,55
1:10	7,5	3		22,56	
1:10	7,5	3		22,54	

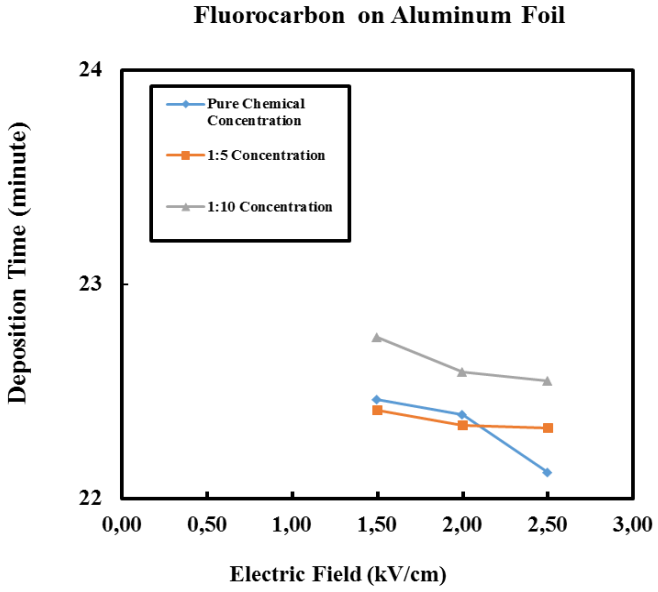

Figure 4.18 Deposition Time- Electric Field Graphic of Fluorocarbon on Aluminum Foil

When Figure 4.18 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.3.3.2. Electrospraying Process for Fluorocarbon Solution on 100% Polyester Fabric

Deposition time results were examined for pure concentration for Fluorocarbon chemical solution electrosprayed on 100% Polyester fabric. When Table 4.41 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. Aluminum foil and 100% PES fabric have different electrical resistivity values. Aluminum foil has 29×10^{-2} S·cm-^{1}, 100% PES fabric has 2.7382 x 10^{-13} S·cm-^{1} conductivity. When the collector was selected as 100% PES fabric, at low voltage (4.5 kV, 6.75 kV and 7.5 kV) distance values (3 cm), the electrospraying process coudn't be achieved. The critical voltage value for this study was between 7.5 kV and 10 kV. Because when voltage value was selected as 10 kV, electrospraying process occurred.

Table 4.41 Deposition Time of Electrospraying Fluorocarbon pure concentration solution on 100% Polyester Fabric

Fluorocarbon	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
Pure chemical	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,22	23,21
Pure chemical	15	10		23,21	
Pure chemical	15	10		23,21	
Pure chemical	17,5	10	1,75	23,15	23,14
Pure chemical	17,5	10		23,14	
Pure chemical	17,5	10		23,12	
Pure chemical	20	10	2	23,07	23,06
Pure chemical	20	10		23,05	
Pure chemical	20	10		23,05	
Pure chemical	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	7,5	3			
Pure chemical	7,5	3			

Results were examined for 1:5 concentration for Fluorocarbon (Table 4.42), expected results were obtained like pure concentration results.

Table 4.42 Deposition Time of Electrospraying Fluorocarbon 1:5 concentration solution on 100% Polyester Fabric

Fluorocarbon	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,02	23,01
1:5	15	10		23,01	
1:5	15	10		23	
1:5	17,5	10	1,75	22,53	22,53
1:5	17,5	10		22,52	
1:5	17,5	10		22,54	
1:5	20	10	2	22,45	22,44
1:5	20	10		22,44	
1:5	20	10		22,44	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	7,5	3			
1:5	7,5	3			

Results were examined for 1:10 concentration for Fluorocarbon (Table 4.43), expected results were obtained like pure and 1:5 concentration results.

Table 4.43 Deposition Time of Electrospraying Fluorocarbon 1:10 concentration solution on 100% Polyester Fabric

Fluorocarbon	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,35	23,34
1:10	15	10		23,35	
1:10	15	10		23,33	
1:10	17,5	10	1,75	23,26	23,25
1:10	17,5	10		23,24	
1:10	17,5	10		23,26	
1:10	20	10	2	23,17	23,18
1:10	20	10		23,18	
1:10	20	10		23,2	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	7,5	3			
1:10	7,5	3			

It can be said that when we studied with fabric, there could be some differences from aluminum foil. When the collector was selected as 100% PES fabric, at low voltage (4.5 kV, 6.75 kV and 7.5 kV) distance values (3 cm), the electrospraying process couldn't be achieved. The critical voltage value for this study was between 7.5 kV and 10 kV. Because when voltage value was selected as 10 kV, electrospraying process occurred. It showed that the critical voltage value was between 7.5 kV and 10 kV when the collector was chosen as 100% PES fabric, because at 10 kV it was possible to perform electrospraying process.

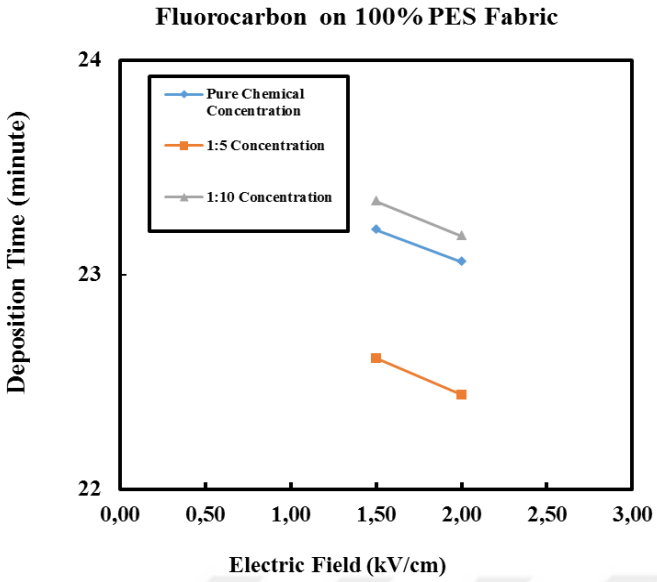

Figure 4.19 Deposition Time- Electric Field Graphic of Fluorocarbon on 100% Polyester Fabric

When Figure 4.19 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.2.3.3. Electrospraying Process for Fluorocarbon Solution on 100% Polyamide Fabric

Deposition time results were examined for pure concentration for Fluorocarbon chemical solution electrosprayed on 100% Polyamide fabric. When Table 4.44 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. 100% Polyamide fabric has $2.627*10^{-14}$ $S \cdot cm^{-1}$ conductivity. When the collector was selected as 100% PA fabric, the results were similar to 100% PES fabric results. At low voltage (4.5 kV, 6.75 kV and 7.5 kV) distance values (3 cm), the electrospraying process coudn't be achieved. The critical voltage value for this study was between 7.5 kV and 10 kV. Because when voltage value was selected as 10 kV, electrospraying process occurred.

Table 4.44 Deposition Time of Electrospraying Fluorocarbon pure concentration solution on 100% Polyamide Fabric

Fluorocarbon	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
Pure chemical	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,3	23,31
Pure chemical	15	10		23,33	
Pure chemical	15	10		23,31	
Pure chemical	17,5	10	1,75	23,22	23,21
Pure chemical	17,5	10		23,21	
Pure chemical	17,5	10		23,21	
Pure chemical	20	10	2	23,13	23,13
Pure chemical	20	10		23,12	
Pure chemical	20	10		23,15	
Pure chemical	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	7,5	3			
Pure chemical	7,5	3			

Results were examined for 1:5 concentration for Fluorocarbon (Table 4.45), expected results were obtained like pure concentration results.

Table 4.45 Deposition Time of Electrospraying Fluorocarbon 1:5 concentration solution on 100% Polyamide Fabric

Fluorocarbon	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,14	23,15
1:5	15	10		23,16	
1:5	15	10		23,14	
1:5	17,5	10	1,75	23,05	23,07
1:5	17,5	10		23,08	
1:5	17,5	10		23,09	
1:5	20	10	2	22,6	22,57
1:5	20	10		22,57	
1:5	20	10		22,55	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	7,5	3			
1:5	7,5	3			

Results were examined for 1:10 concentration for Fluorocarbon (Table 4.46), expected results were obtained like pure and 1:5 concentration results.

Table 4.46 Deposition Time of Electrospraying Ruco-Guard 1:10 concentration solution on 100% Polyamide Fabric

Fluorocarbon	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,11	23,08
1:10	15	10		23,06	
1:10	15	10		23,08	
1:10	17,5	10	1,75	22,57	22,57
1:10	17,5	10		22,58	
1:10	17,5	10		22,55	
1:10	20	10	2	22,51	22,51
1:10	20	10		22,51	
1:10	20	10		22,5	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	7,5	3			
1:10	7,5	3			

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage (4.5 kV, 6.75 kV and 7.5 kV) and low distance (3 cm) values electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 10 kV, electrospraying could be achieved. It showed that the critical voltage value was between 7.5 kV and 10 kV when the collector was chosen as 100% PA fabric, because at 7.5 kV it was possible to perform electrospraying process. For pure chemical, there was just some time difference between polyester fabric and polyamide fabric about 6-7 seconds, for 1:5 concentration; like pure concentration there were just some time differences between polyester and polyamide fabric about 13-16 seconds. For 1:10 concentration the deposition time difference was more than pure and 1:5 concentrations, about 26-27 seconds. It showed that when concentration increased deposition time difference increased between 100% PES and 100 % PA Fabric.

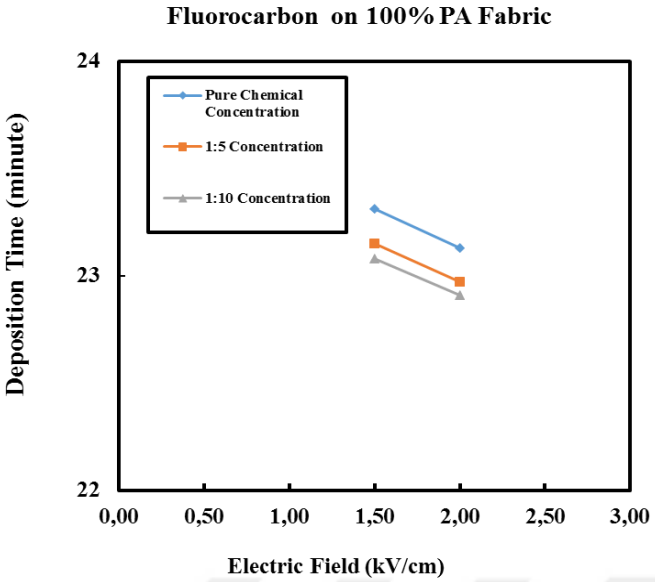

Figure 4.20 Deposition Time- Electric Field Graphic of Fluorocarbon on 100% Polyamide Fabric

When Figure 4.20 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.2.3.4. Electrospraying Process for Fluorocarbon Solution on 100% Cotton Fabric

Deposition time results were examined for pure concentration for Fluorocarbon chemical solution electrosprayed on 100% Cotton fabric. When Table 4.47 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. 100% Cotton fabric has $2.734*10^{-14}$ $S \cdot cm^{-1}$ conductivity. When the collector was selected as 100% cotton fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process coudn't be achieved.

Table 4.47 Deposition Time of Electrospraying Fluorocarbon pure concentration solution on 100% Cotton Fabric

Fluorocarbon	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
Pure chemical	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,57	23,56
Pure chemical	15	10		23,56	
Pure chemical	15	10		23,54	
Pure chemical	17,5	10	1,75	23,42	23,42
Pure chemical	17,5	10		23,43	
Pure chemical	17,5	10		23,4	
Pure chemical	20	10	2	23,33	23,29
Pure chemical	20	10		23,33	
Pure chemical	20	10		23,21	
Pure chemical	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	23,22	23,22
Pure chemical	7,5	3		23,2	
Pure chemical	7,5	3		23,23	

Results were examined for 1:5 concentration for Fluorocarbon (Table 4.48), expected results were obtained like pure concentration results.

Table 4.48 Deposition Time of Electrospraying Fluorocarbon 1:5 concentration solution on 100% Cotton fabric

Fluorocarbon	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,51	23,49
1:5	15	10		23,48	
1:5	15	10		23,47	
1:5	17,5	10	1,75	23,39	23,39
1:5	17,5	10		23,37	
1:5	17,5	10		23,40	
1:5	20	10	2	23,3	23,31
1:5	20	10		23,37	
1:5	20	10		23,25	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	23,16	23,15
1:5	7,5	3		23,15	
1:5	7,5	3		23,13	

Results were examined for 1:10 concentration for Fluorocarbon (Table 4.49), expected results were obtained like pure and 1:5 concentration results.

Table 4.49 Deposition Time of Electrospraying Fluorocarbon 1:10 concentration solution on 100% Cotton Fabric

Fluorocarbon	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,39	23,37
1:10	15	10		23,36	
1:10	15	10		23,37	
1:10	17,5	10	1,75	23,3	23,29
1:10	17,5	10		23,27	
1:10	17,5	10		23,29	
1:10	20	10	2	23,23	23,21
1:10	20	10		23,21	
1:10	20	10		23,2	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	23,15	23,12
1:10	7,5	3		23,1	
1:10	7,5	3		23,12	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% cotton fabric, because at 7.5 kV it was possible to perform elecrrospraying process. For pure chemical, there was just some time difference between cotton fabric and polyester fabric, polyamide fabric about 24-25 seconds, for 1:5 concentration; like pure concentration there were some time differences between cotton and polyester fabric, polyamide fabric about 24-34 seconds. For 1:10 concentration the deposition time difference was similar to pure and 1:5 concentrations, about 26-30 seconds. Time differences for each fabric type were close to each other.

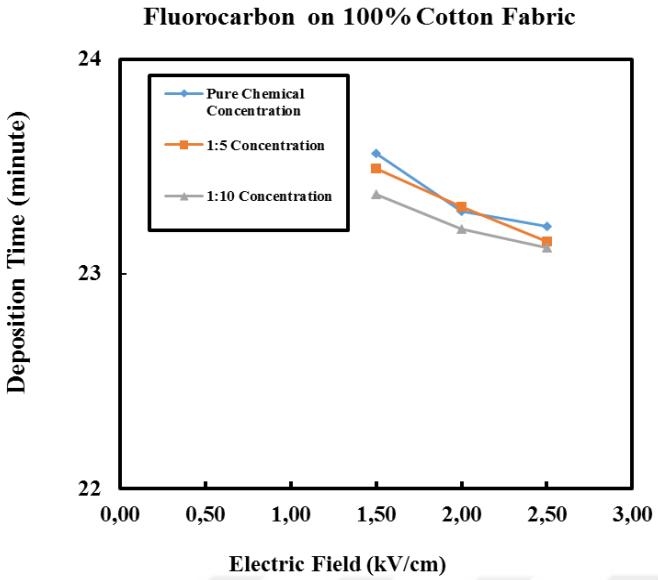

Figure 4.21 Deposition Time- Electric Field Graphic of Fluorocarbon on 100% Cotton Fabric

When Figure 4.21 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.3.4. Variance Analysis for Fluorocarbon Solution

4.3.4.1. Correlation Analysis of Fluorocarbon Solution

Table 4.50 showed the Pearson Correlation Coefficients (PCC) between deposition time and different process and solution parameters. The Pearson correlation coefficients (PCC) deposition time and different process and solution parameters were given in Table 4.50. It could be seen that from Pearson correlation coefficient, all parameters were not correlated with deposition time. Concentration, viscosity, surface tension and conductivity values were not correlated with deposition time. Voltage, distance and collector type were correlated, but correlation for voltage was very low. These parameters had positive correlation coefficient which indicates when parameters increases deposition time increases too.

In addition, it was observed that collector type has highest effect on deposition time with PCC value 0,670, at p-value 0,000. When voltage value was observed, the effect

on deposition time was with PCC value 0,182, at p-value 0,031. And lastly, distance value had PCC value 0,298, at p-value 0,000.

Table 4.50 Correlation Analysis of Fluorocarbon Solution

Parameter	PCC	p value
Concentration (v/v)	0,025	0,765
Viscosity (cP)	0,008	0,921
Surface Tension (mN/m)	-0,031	0,718
Conductivity (µS/cm)	0,006	0,940
Voltage (kV)	0,182	0,031
Distance (cm)	0,298	0,000
Collector Type (aluminum foil, 100% PES, 100% PA and 100% Cotton Fabric	0,670	0,000

4.3.4.2. Generalized Linear Method (Factorial ANOVA) for Fluorocarbon Solution

The ANOVA table was shown (Table 4.51) for study of Fluorocarbon solution.

Table 4.51 ANOVA Table for Fluorocarbon Solution

Source	Type III Sum of Squares	df	Mean Square	F	p value
Corrected Model	12,949a	4	3,237	38,991	0,000
Intercept	4315,038	1	4315,04	51973,543	0,000
Voltage (b)	1,434	1	1,434	17,274	0,000
Distance (c)	1,729	1	1,729	20,831	0,000
Collector Type (d)	2,927	1	2,927	35,253	0,000
b*c*d	0,128	1	0,128	1,537	0,217
Error	11,291	136	0,083		
Total	74034,308	141			
Corrected Total	24,24	140			
a. R Squared = ,534 (Adjusted R Squared = ,520)					

According to variance analysis (ANOVA) results; voltage, distance and collector type values were statistically significant on deposition time ($p \leq 0.05$). When process parameters (voltage, distance and collector type) were considered together, the effect on deposition time was not significant.

4.3.4.3. Regression Analysis for Fluorocarbon Solution

According to the regression analysis, the affecting parameters and significance values were shown in Table 4.52.

Table 4.52 Results for regression analysis of deposition time of Fluorocarbon solution

Parameters	Coeeficient	T	P (Significance value)
Constant	22,6287	289,73	0,0000
Voltage	-0,06288	-4,82	0,0000
Distance	0,09857	4,52	0,0000
Collector Type	0,66281	10,5	0,0000
R^2 =52,9% R^2(adj) = 51,9%			

Analysis of Variance					
Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	3	12,8211	4,2737	51,27	0,0000
Residual Error	137	11,4189	0,0833		
Total	140	24,24			

Voltage, distance and collector type parameters are effective on deposition time; according to coefficient value collector type has biggest effect on deposition time. According to these results; the regression analysis for deposition time is below:

Deposition time = 22.6 – 0.0629 voltage + 0.0986 distance + 0.663 collector type

Voltage value had negative effect on deposition time, it can be expressed that when voltage increased deposition time decreased or vice versa. Deposition time increased with increasing distance. When collector type was chosen according to the conductivity, more conductive collector type caused less deposition time. MINITAB examines all possible subsets of variables as shown in Table 4.53.

Table 4.53 Models consisting of different combinations of variables selected using all possible regressions from predictors of deposition time for Fluorocarbon solution

Predictors	R^2	Adjusted R^2	Mallows' Cp	S	Voltage	Distance	Collector Type
1	44,9	44,5	23,3	0,31004			X
1	8,9	8,2	128,0	0,39861		X	
2	45,9	45,1	22,5	0,30839	X		X
2	44,9	44,1	25,2	0,31105		X	X
3	52,9	51,9	4,0	0,28870	X	X	X

According to Table 4.52, when all predictors participated in the model, the highest R^2 value (52.9), the smallest Mallows' Cp (4.0) and the smallest S (0.28870) value can be obtained. And regression analysis and best subset regression analysis gave us the same parameters effect on deposition time.

4.4. Fluorocarbon&Dendrimer Results

4.4.1. Fluorocarbon&Dendrimer Solution Characterization

In this thesis, some prestudies were done to determine optimum concentrations. Concentration, viscosity, conductivity and surface tension values of these concentrations were given Table 4.54.

Table 4.54 Viscosity, conductivity and surface tension values of Fluorocarbon&Dendrimer chemical solutions with different concentrations

Chemical solution	Concentration (%)	Viscosity (cP)	Conductivity (µS/cm)	Surface Tension (mN/m)
Fluorocarbon& Dendrimer	Pure	28.60	936.67	31.14
	1:5 v/v	2.56	583.33	36.26
	1:10 v/v	2.35	406.00	38.74

Viscosity, conductivity and surface tension measurements were done for different concentration values (pure, 1:5 v/v, 1:10 v/v) to specify the suitability of chemical solutions for electrospraying process. Viscosity measurements of Fluorocarbon&Dendrimer solutions (pure, 1:5 v/v and 1:10 v/v) were shown in Figure 4.22. When the results were examined, it was seen that when concentration of chemical decreases the viscosity decreases too. Viscosity of solutions is increased when concentration of chemical is increased [Edirisinghe, 2002; Wu et. al. 2014]. The viscosity values of Fluorocarbon&Dendrimer ranged from 2.35cP to 28.60cP when concentration ranged from 1:10 v/v to 100% pure chemical. When Figure 4.22 was drawn according to viscosity and concentration values, the relation between viscosity and concentration could be seen clearly. Concentration 0.10 indicates 1:10 v/v chemical solution, concentration 0.20 indicates chemical solution 1:5 v/v and concentration 1.00 indicates pure chemical solution.

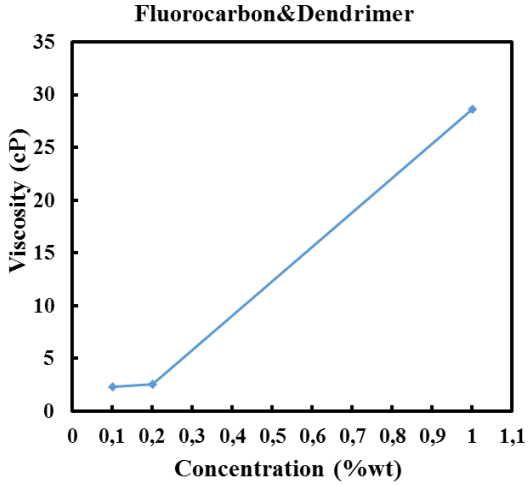

Figure 4.22 Viscosity measurements of Fluorocarbon&Dendrimer chemical solutions with different concentrations.

The conductivity results were given in Figure 4.23. The results were changed between 406.00 µS/cm to 936.67 µS/cm.

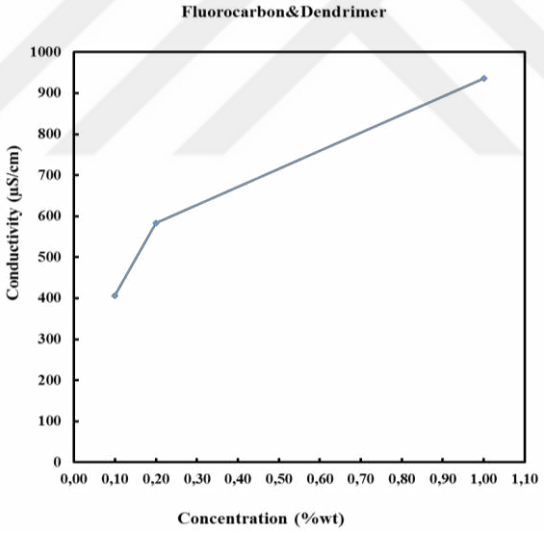

Figure 4.23 Conductivity measurements of Fluorocarbon&Dendrimer chemical solutions with different concentrations

Surface tension results were given in Figure 4.24. The surface tension values were changed between 31.14 mN/m to 38.74 mN/m.

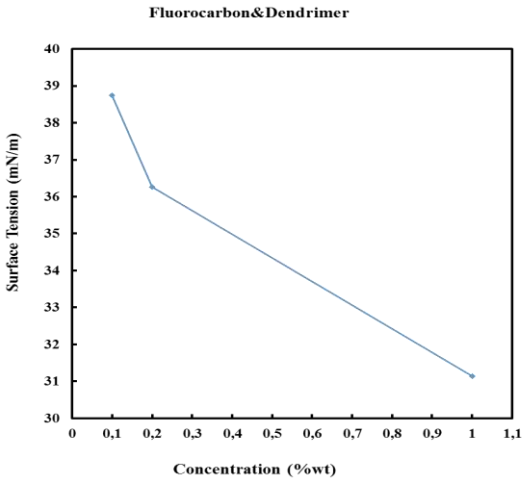

Figure 4.24 Surface tension measurements of Fluorocarbon&Dendrimer chemical solutions with different concentrations

4.4.2. Electrospraying Process for Fluorocarbon&Dendrimer Solution

The trails for each concentration and for each five electric field were done three times and the average of the results was calculated for aluminum foil, 100% polyester fabric, 100% polyamide fabric and 100% cotton fabric. Fluorocarbon&Dendrimer chemical solutions were electrosprayed at three different (pure, 1:5, 1:10 volume/volume) concentrations. The process parameters were flow rate (20µl/min) applied voltage (4.5 kV, 6.75 kV, 7.5 kV, 10 kV, 15 kV and 20 kV), tip to collector distance (3 cm and 5 cm) and needle size (22 gauge). Applied electric field values were 1 kV/cm, 1.5 kV/cm, 2 kV/cm, 2.5 kV/cm and 5kV/cm. For each applied electric field, deposition time was recorded for electrospraying of 4ml solution. The deposition time was measured for each situation and then statistical analyses were done to determine the contribution of the parameters.

4.4.3. Deposition Time Results of Fluorocarbon&Dendrimer Solution

4.4.3.1. Deposition Time Results of Fluorocarbon&Dendrimer Solution on Aluminum Foil

Deposition time results were examined for pure concentration for Fluorocarbon&Dendrimer chemical solution electrosprayed on aluminum foil. Expected result was that the smaller deposition time, easier the process [Gunesoglu,

2011]. When Table 4.55 was assesed, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration.

Table 4.55 Deposition Time of Electrospraying Fluorocarbon&Dendrimer pure concentration solution on aluminum foil

Fluorocarbon &Dendrimer	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
Pure chemical	4,5	3	1,5	22,45	22,47
Pure chemical	4,5	3		22,49	
Pure chemical	4,5	3		22,48	
Pure chemical	15	10	1,5	22,5	22,50
Pure chemical	15	10		22,51	
Pure chemical	15	10		22,5	
Pure chemical	17,5	10	1,75	22,47	22,47
Pure chemical	17,5	10		22,48	
Pure chemical	17,5	10		22,47	
Pure chemical	20	10	2	22,45	22,44
Pure chemical	20	10		22,43	
Pure chemical	20	10		22,45	
Pure chemical	6,75	3	2,25	22,42	22,42
Pure chemical	6,75	3		22,43	
Pure chemical	6,75	3		22,4	
Pure chemical	7,5	3	2,5	22,39	22,39
Pure chemical	7,5	3		22,38	
Pure chemical	7,5	3		22,39	

Results were examined for 1:5 concentration for Fluorocarbon&Dendrimer (Table 4.56), expected results were obtained like pure concentration results.

Table 4.56 Deposition Time of Electrospraying Fluorocarbon&Dendrimer 1:5 concentration solution on aluminum foil

Fluorocarbon &Dendrimer	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	23,42	23,42
1:5	4,5	3		23,43	
1:5	4,5	3		23,42	
1:5	15	10	1,5	23,46	23,44
1:5	15	10		23,44	
1:5	15	10		23,43	
1:5	17,5	10	1,75	23,4	23,40
1:5	17,5	10		23,39	
1:5	17,5	10		23,41	
1:5	20	10	2	23,38	23,37
1:5	20	10		23,38	
1:5	20	10		23,35	
1:5	6,75	3	2,25	23,37	23,37
1:5	6,75	3		23,36	
1:5	6,75	3		23,38	
1:5	7,5	3	2,5	23,15	23,16
1:5	7,5	3		23,16	
1:5	7,5	3		23,16	

Results were examined for 1:10 concentration for Fluorocarbon&Dendrimer (Table 4.57), expected results were obtained like pure and 1:5 concentration results.

Table 4.57 Deposition Time of Electrospraying Fluorocarbon&Dendrimer 1:10 concentration solution on aluminum foil

Fluorocarbon &Dendrimer	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	23,49	23,47
1:10	4,5	3		23,47	
1:10	4,5	3		23,45	
1:10	15	10	1,5	23,5	23,48
1:10	15	10		23,48	
1:10	15	10		23,47	
1:10	17,5	10	1,75	23,24	23,21
1:10	17,5	10		23,21	
1:10	17,5	10		23,19	
1:10	20	10	2	23,12	23,14
1:10	20	10		23,15	
1:10	20	10		23,14	
1:10	6,75	3	2,25	23,08	23,09
1:10	6,75	3		23,1	
1:10	6,75	3		23,08	
1:10	7,5	3	2,5	22,59	23,00
1:10	7,5	3		22,59	
1:10	7,5	3		22,58	

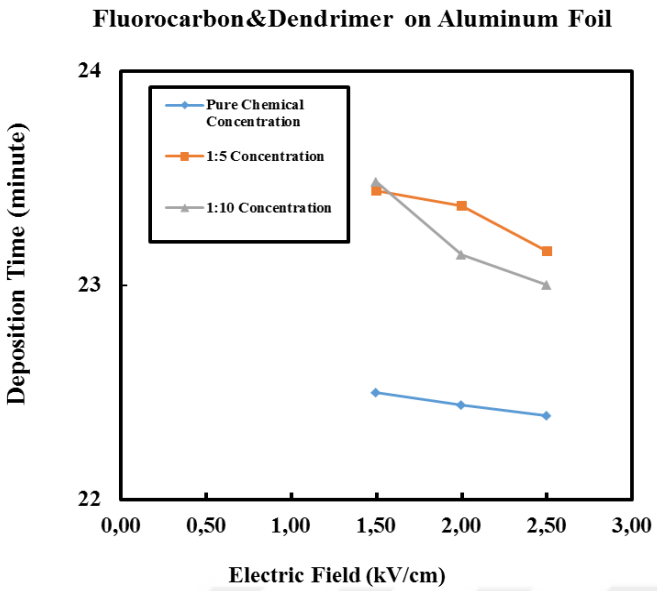

Figure 4.25 Deposition Time- Electric Field Graphic of Fluorocarbon&Dendrimer on Aluminum Foil

When Figure 4.25 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.4.3.2. Electrospraying Process for Fluorocarbon&Dendrimer Solution on 100% Polyester Fabric

Deposition time results were examined for pure concentration for Fluorocarbon&Dendrimer chemical solution electrosprayed on 100% Polyester fabric. When Table 4.58 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. But there are some unexpected results for this study. Aluminum foil and 100% PES fabric have different electrical resistivity values. Aluminum foil has 29×10^{-2} S·cm-^{1}, 100% PES fabric has 2.7382 x 10^{-13} S·cm-^{1} conductivity. When the collector was selected as 100% PES fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process coudn't be achieved.

Table 4.58 Deposition Time of Electrospraying Fluorocarbon&Dendrimer pure concentration solution on 100% Polyester Fabric

Fluorocarbon &Dendrimer	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
Pure chemical	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,07	23,07
Pure chemical	15	10		23,09	
Pure chemical	15	10		23,04	
Pure chemical	17,5	10	1,75	22,56	22,56
Pure chemical	17,5	10		22,55	
Pure chemical	17,5	10		22,58	
Pure chemical	20	10	2	22,45	22,46
Pure chemical	20	10		22,47	
Pure chemical	20	10		22,47	
Pure chemical	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	7,5	3			
Pure chemical	7,5	3			

Results were examined for 1:5 concentration for Fluorocarbon&Dendrimer (Table 4.59), expected results were obtained like pure concentration results.

Table 4.59 Deposition Time of Electrospraying Fluorocarbon&Dendrimer 1:5 concentration solution on 100% Polyester fabric

Fluorocarbon &Dendrimer	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	24,09	24,09
1:5	15	10		24,08	
1:5	15	10		24,09	
1:5	17,5	10	1,75	23,59	23,58
1:5	17,5	10		23,57	
1:5	17,5	10		23,57	
1:5	20	10	2	23,38	23,37
1:5	20	10		23,36	
1:5	20	10		23,36	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	7,5	3			
1:5	7,5	3			

Results were examined for 1:10 concentration for Fluorocarbon&Dendrimer (Table 4.60), expected results were obtained like pure and 1:5 concentration results.

Table 4.60 Deposition Time of Electrospraying Fluorocarbon&Dendrimer 1:10 concentration solution on 100% Polyester Fabric

Fluorocarbon &Dendrimer	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	24,15	24,15
1:10	15	10		24,17	
1:10	15	10		24,13	
1:10	17,5	10	1,75	23,36	23,37
1:10	17,5	10		23,37	
1:10	17,5	10		23,38	
1:10	20	10	2	23,23	23,25
1:10	20	10		23,25	
1:10	20	10		23,26	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	7,5	3			
1:10	7,5	3			

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage values (4.5 kV, 6.75 kV and 7.5 kV) and distance values (3 cm) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 10 kV, electrospraying could be achieved. It showed that the critical voltage value was between 7.5 kV and 10 kV when the collector was chosen as 100% PES fabric, because at 10 kV it was possible to perform electrospraying process.

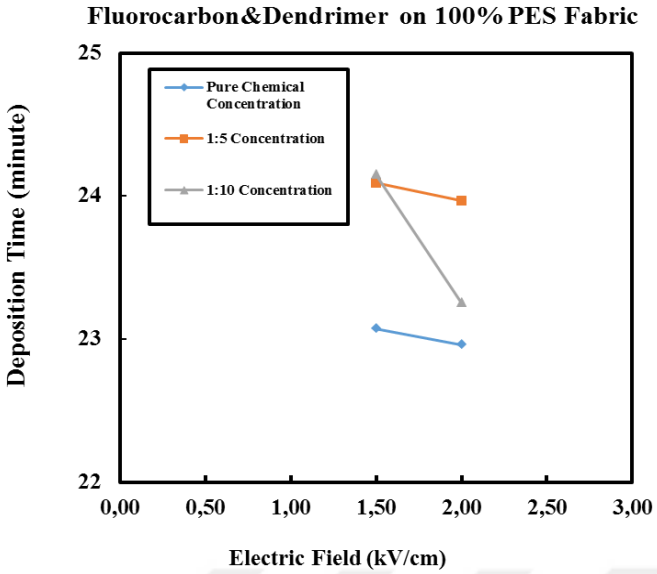

Figure 4.26 Deposition Time- Electric Field Graphic of Fluorocarbon&Dendrimer on 100% Polyester Fabric

When Figure 4.26 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.4.3.3. Electrospraying Process for Fluorocarbon&Dendrimer Solution on 100% Polyamide Fabric

Deposition time results were examined for pure concentration for Fluorocarbon&Dendrimer chemical solution electrosprayed on 100% Polyamide fabric. When Table 4.61 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. 100% Polyamide fabric has $2.627*10^{-14}$ $S \cdot cm^{-1}$ conductivity. When the collector was selected as 100% PA fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process coudn't be achieved.

Table 4.61 Deposition Time of Electrospraying Fluorocarbon&Dendrimer pure concentration solution on 100% Polyamide Fabric

Fluorocarbon &Dendrimer	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
Pure chemical	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,68	23,67
Pure chemical	15	10		23,67	
Pure chemical	15	10		23,65	
Pure chemical	17,5	10	1,75	23,53	23,54
Pure chemical	17,5	10		23,54	
Pure chemical	17,5	10		23,54	
Pure chemical	20	10	2	23,4	23,41
Pure chemical	20	10		23,43	
Pure chemical	20	10		23,41	
Pure chemical	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	23,35	23,33
Pure chemical	7,5	3		23,31	
Pure chemical	7,5	3		23,32	

Results were examined for 1:5 concentration for Fluorocarbon&Dendrimer (Table 4.62), expected results were obtained like pure concentration results.

Table 4.62 Deposition Time of Electrospraying Fluorocarbon&Dendrimer 1:5 concentration solution on 100% Polyamide Fabric

Fluorocarbon &Dendrimer	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,55	23,57
1:5	15	10		23,59	
1:5	15	10		23,58	
1:5	17,5	10	1,75	23,44	23,45
1:5	17,5	10		23,46	
1:5	17,5	10		23,44	
1:5	20	10	2	23,34	23,33
1:5	20	10		23,33	
1:5	20	10		23,31	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	23,22	23,24
1:5	7,5	3		23,25	
1:5	7,5	3		23,25	

Results were examined for 1:10 concentration for Fluorocarbon&Dendrimer (Table 4.63), expected results were obtained like pure and 1:5 concentration results.

Table 4.63 Deposition Time of Electrospraying Fluorocarbon&Dendrimer 1:10 concentration solution on 100% Polyamide Fabric

Fluorocarbon &Dendrimer	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,47	23,46
1:10	15	10		23,45	
1:10	15	10		23,45	
1:10	17,5	10	1,75	23,39	23,37
1:10	17,5	10		23,36	
1:10	17,5	10		23,35	
1:10	20	10	2	23,26	23,26
1:10	20	10		23,25	
1:10	20	10		23,27	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	23,15	23,15
1:10	7,5	3		23,14	
1:10	7,5	3		23,15	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved for 100% PA fabric. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% PA fabric, because at 7.5 kV it was possible to perform electrospraying process. But when the fabric sample was chosen as 100% PES fabric, the critical voltage value was between 7.5 kV and 10 kV, because at low voltage (4.5 kV, 6.75 kV and 7.5 kV) and low distance (3 cm) values, electrospraying process couldn't be achieved. For pure chemical, there was just some time difference between polyester fabric and polyamide fabric about 60 seconds, for 1:5 concentration; like pure concentration there were just a few time differences between polyester and polyamide fabric about 4-5 seconds. For 1:10 concentration the deposition time difference was a bit more than 1:5 concentrations, about 9-17 seconds.

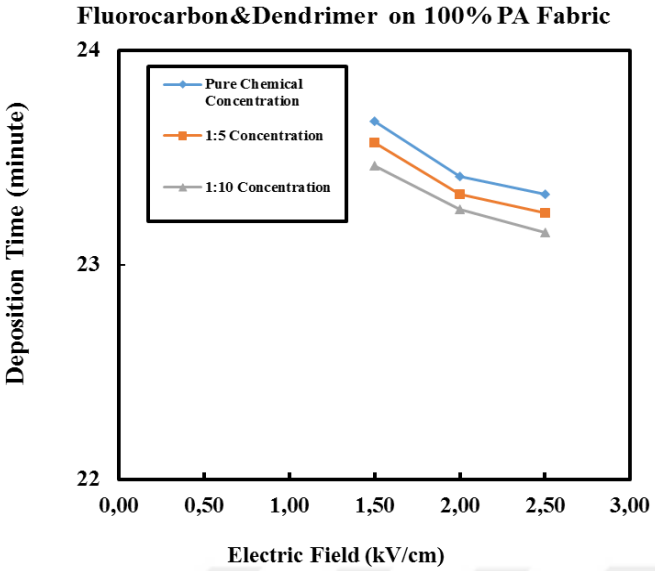

Figure 4.27 Deposition Time- Electric Field Graphic of Fluorocarbon&Dendrimer on 100% Polyamide Fabric

When Figure 4.27 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.4.3.4. Electrospraying Process for Fluorocarbon&Dendrimer Solution on 100% Cotton Fabric

Deposition time results were examined for pure concentration for Fluorocarbon&Dendrimer chemical solution electrosprayed on 100% Cotton fabric. When Table 4.64 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. 100% Cotton fabric has $2.734*10^{-14}$ $S \cdot cm^{-1}$ conductivity. When the collector was selected as 100% cotton fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process coudn't be achieved.

Table 4.64 Deposition Time of Electrospraying Fluorocarbon&Dendrimer pure concentration solution on 100% Cotton Fabric

Fluorocarbon &Dendrimer	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
Pure chemical	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	4,5	3			
Pure chemical	4,5	3			
Pure chemical	15	10	1,5	23,12	23,14
Pure chemical	15	10		23,15	
Pure chemical	15	10		23,16	
Pure chemical	17,5	10	1,75	23	23,03
Pure chemical	17,5	10		23,04	
Pure chemical	17,5	10		23,05	
Pure chemical	20	10	2	22,59	22,59
Pure chemical	20	10		22,59	
Pure chemical	20	10		22,58	
Pure chemical	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
Pure chemical	6,75	3			
Pure chemical	6,75	3			
Pure chemical	7,5	3	2,5	22,59	22,58
Pure chemical	7,5	3		22,58	
Pure chemical	7,5	3		22,57	

Results were examined for 1:5 concentration for Fluorocarbon&Dendrimer (Table 4.65), expected results were obtained like pure concentration results.

Table 4.65 Deposition Time of Electrospraying Fluorocarbon&Dendrimer 1:5 concentration solution on 100% Cotton fabric

Fluorocarbon &Dendrimer	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,31	23,31
1:5	15	10		23,32	
1:5	15	10		23,3	
1:5	17,5	10	1,75	23,26	23,24
1:5	17,5	10		23,24	
1:5	17,5	10		23,23	
1:5	20	10	2	23,19	23,17
1:5	20	10		23,17	
1:5	20	10		23,15	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	22,55	22,55
1:5	7,5	3		22,56	
1:5	7,5	3		22,53	

Results were examined for 1:10 concentration for Fluorocarbon&Dendrimer (Table 4.66), expected results were obtained like pure and 1:5 concentration results.

Table 4.66 Deposition Time of Electrospraying Fluorocarbon&Dendrimer 1:10 concentration solution on 100% Cotton Fabric

Fluorocarbon &Dendrimer	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,3	23,28
1:10	15	10		23,27	
1:10	15	10		23,28	
1:10	17,5	10	1,75	23,21	23,20
1:10	17,5	10		23,19	
1:10	17,5	10		23,2	
1:10	20	10	2	23,16	23,17
1:10	20	10		23,17	
1:10	20	10		23,18	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	23,16	23,16
1:10	7,5	3		23,16	
1:10	7,5	3		23,15	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% cotton fabric, because at 7.5 kV it was possible to perform elecrrospraying process. For pure chemical, there was just some time difference between cotton fabric and polyester fabric, polyamide fabric about 35-50 seconds, for 1:5 concentration; like pure concentration there were some time differences between cotton and polyester fabric, polyamide fabric about 16-20 seconds. For 1:10 concentration the deposition time difference was more than pure and 1:5 concentrations, about 17-18 seconds. 100% Cotton fabric results were closer to 100% Polyamide fabric results than 100% Polyester fabric results.

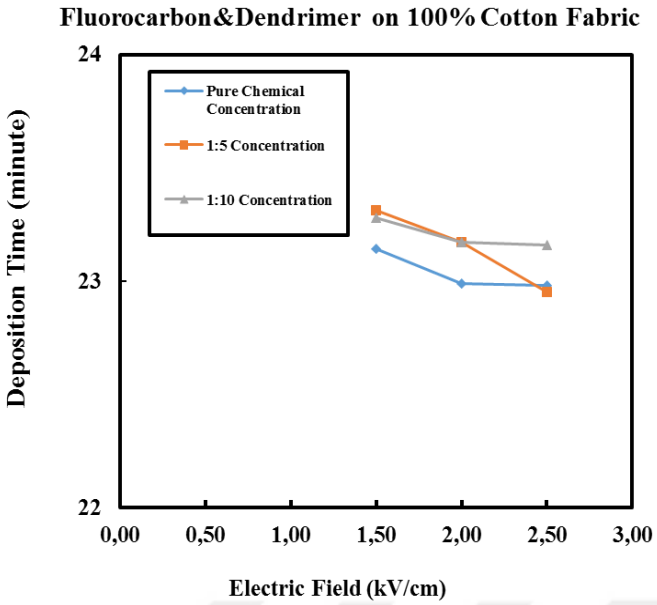

Figure 4.28 Deposition Time- Electric Field Graphic of Fluorocarbon&Dendrimer on 100% Cotton Fabric

When Figure 4.28 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.4.4. Variance Analysis for Fluorocarbon&Dendrimer Solution

4.4.4.1. Correlation Analysis of Fluorocarbon&Dendrimer Solution

Table 4.67 showed the Pearson Correlation Coefficients (PCC) between deposition time and different process and solution parameters. Voltage, distance and collector type were correlated in moderately. These parameters had positive correlation coefficient which indicates when parameters increases deposition time increases too. In addition, it was observed that viscosity has highest effect on deposition time with PCC value -0.545, at p-value 0.000. When voltage value was observed, the effect on deposition time was with PCC value 0.178, at p-value 0.028. Distance value was observed, the effect on deposition time was with PCC value 0.306, at p-value 0.000. And lastly, collector type value had PCC value 0.279, at p-value 0.000.

Table 4.67 Correlation Analysis of Fluorocarbon&Dendrimer Solution

Parameter	PCC	p value
Concentration (v/v)	-0,545	0,000
Viscosity (cP)	-0,555	0,000
Surface Tension (mN/m)	0,503	0,000
Conductivity (µS/cm)	-0,500	0,000
Voltage (kV)	0,178	0,028
Distance (cm)	0,306	0,000
Collector Type (aluminum foil, 100% PES, 100% PA and 100% Cotton Fabric	0,279	0,000

4.4.4.2. Generalized Linear Method (Factorial ANOVA) for Fluorocarbon& Dendrimer Solution

The ANOVA table is shown (Table 4.68) for study of Fluorocarbon&Dendrimer solution.

Table 4.68 ANOVA Table for Fluorocarbon&Dendrimer Solution

Source	Type III Sum of Squares	df	Mean Square	F	p value
Corrected Model	14,789a	6	2,465	30,534	0,000
Intercept	4728,287	1	4728,29	58572,3	0,000
Viscosity (a)	5,397	1	5,397	66,861	0,000
Voltage (b)	2,817	1	2,817	34,9	0,000
Distance (c)	3,845	1	3,845	47,628	0,000
Collector Type (d)	0,258	1	0,258	3,19	0,076
a*b*c*d	0,338	1	0,338	4,19	0,042
Error	11,786	146	0,081		
Total	82058,372	153			
Corrected Total	26,575	152			
a. R Squared = ,557 (Adjusted R Squared = ,538)					

According to variance analysis (ANOVA) results, viscosity, voltage, distance and collector type are statistically significant on deposition time both seperately and together ($p \leq 0.05$). When process parameters (voltage, distance and collector type) are considered together, the effect on deposition time is again significant. Again all parameters (viscosity, voltage, distance and collector type) are considered together, the effect on deposition time of all parameters is significant.

4.4.4.3. Regression Analysis for Fluorocarbon&Dendrimer Solution

According to the regression analysis, the affecting parameters and significance values were shown in Table 4.69.

Table 4.69 Results for regression analysis of deposition time of Fluorocarbon& Dendrimer solution

Parameters	Coeeficient	T	P (Significance value)
Constant	23,1551	322,26	0,0000
Viscosity	-0,018754	-9,98	0,0000
Voltage	-0,07567	-5,94	0,0000
Distance	0,14548	7,00	0,0000
Collector Type	0,2299	3,89	0,0000
R^2 = 54,3% R^2(adj) = 53,1%			

Analysis of Variance					
Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	4	14,4359	3,609	44,00	0,0000
Residual Error	148	12,1392	0,082		
Total	152	26,575			

Viscosity, voltage, distance and collector type parameters are effective on deposition time; according to coefficient value collector type has biggest effect on deposition time. According to these results; the regression analysis for deposition time is below:

Deposition time = 23.2 – 0.0188 viscosity – 0.0757 voltage + 0.145 distance + 0.230 collector type

Increasing of viscosity caused a decrease on deposition time. Voltage value has negative effect on deposition time, it can be expressed that when voltage increases deposition time decreases or vice versa. Deposition time increases with increasing distance. When collector type is chosen according to the conductivity, more conductive collector type causes less deposition time. MINITAB examines all possible subsets of variables as shown in Table 4.70.

Table 4.70 Models consisting of different combinations of variables selected using all possible regressions from predictors of deposition time for Fluorocarbon&Dendrimer

Predictors	R^2	Adjusted R^2	Mallows' Cp	S	Viscosity	Voltage	Distance	Collector Type
1	30,8	30,3	75,3	0,34908	X			
1	9,3	8,7	144,8	0,39946			X	
2	40,1	39,3	47,1	0,32578	X		X	
2	38,5	37,7	52,2	0,33005	X			X
3	49,7	48,6	18,1	0,29963	X	X	X	
3	43,4	42,3	38,3	0,31763	X		X	X
4	54,3	53,1	5,0	0,28639	X	X	X	X

According to Table 4.70, when all predictors participate in the model, the highest R^2 value (53.1), the smallest Mallows' Cp (5.0) and the smallest S (0.28639) value can be obtained. And regression analysis and best subset regression analysis gave us the same parameters effect on deposition time.

4.5. Flame Retardant Results

4.5.1. Flame Retardant Solution Characterization

In this thesis, some prestudies were done to determine optimum concentrations. Elecrospraying process couldn't be achieved with pure chemical solution. It is related with Flame Retardant has a high surface tension (49.96 mN/m). Smith [1986] reported that when the surface tension value was higher than 50 mN/m, it couldn't be electrosprayed. When Flame Retardant solution was prepared with water as 1:5 and 1:10, the surface tension values were still high. Surface tension results of Flame Retardant prepared with 100% distilled water was shown in Table 4.71.

Table 4.71 Surface tension measurements of Flame Retardant chemical solutions prepared with 100% distilled water with different concentrations

Chemical Solution	Solvent	Surface Tension (mN/m)
Flame Retardant pure	100 % Water	47,96
Flame Retardant 1:5		50,32
Flame Retardant 1:10		52,66
Flame Retardant 1:20		57,38
Flame Retardant 1:50		78,39
Flame Retardant 1:100		87,36

So to decrease surface tension values of Rucoflam-CK solutions diluted with water-ethanol (50/50 v/v) mixture. Ethanol has a lower surface tension (22.39mN/m) [Adamson and Gast, 1997] and ethanol also used as an auxiliary chemical to reduce surface tension [Salinas, 2008]. So the optimum concentrations were determined as 1:5 v/v and 1:10 v/v. Rucoflam-CK diluted with water-ethanol (50%-50%) by means of high-speed mixer at 2500 rpm about 30 minutes. Surface tension results of Flame Retardant prepared with 50%- 50% water-ethanol was shown in Table 4.72.

Table 4.72 Surface tension measurements of Flame Retardant chemical solutions prepared with 50%- 50% water-ethanol with different concentrations

Chemical Solution	Solvent	Surface Tension (mN/m)
Flame Retardant pure	50% Water- 50% Ethanol	47,96
Flame Retardant 1:5		36,09
Flame Retardant 1:10		24,12

Concentration, viscosity, conductivity and surface tension values of these concentrations were given Table 4.73.

Table 4.73 Viscosity, conductivity and surface tension values of Flame Retardant chemical solutions with different concentrations

Chemical solution	Concentration (%)	Viscosity (cP)	Conductivity (µS/cm)	Surface Tension (mN/m)
Flame Retardant	Pure	5.12	53000.00	47.96
	1:5 v/v	3.63	42815.00	36.09
	1:10 v/v	3.41	32613.33	24.12

Viscosity measurements of Flame Retardant solutions (pure, 1:5 v/v and 1:10 v/v) were shown in Figure 4.29. When Figure 4.29 was drawn according to viscosity and concentration values, the relation between viscosity and concentration could be seen clearly.

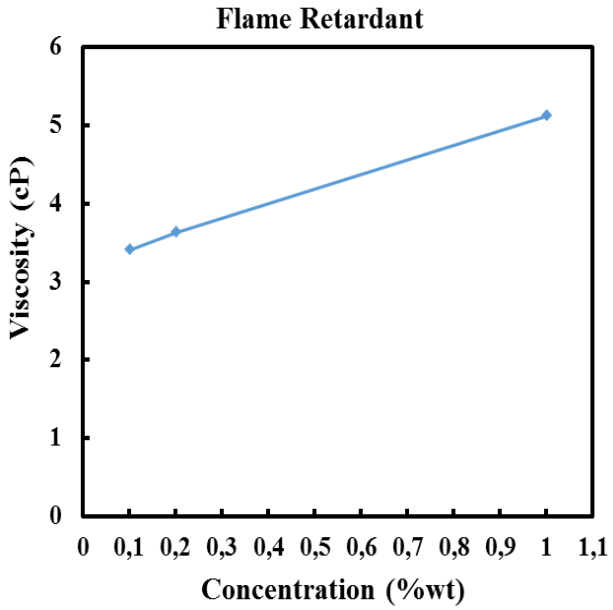

Figure 4.29 Viscosity measurements of Flame Retardant chemical solutions with different concentrations

The conductivity results were given in Figure 4.30. The results were changed between 32613.33 µS/cm to 53000.00 µS/cm.

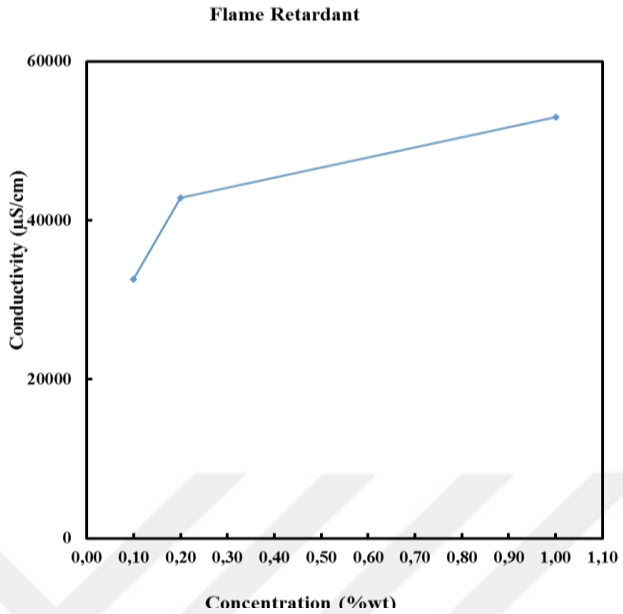

Figure 4.30 Conductivity measurements of Flame Retardant chemical solutions with different concentrations

Surface tension results were given in Figure 4.31. The surface tension values were changed between 24.12 mN/m to 47.96 mN/m.

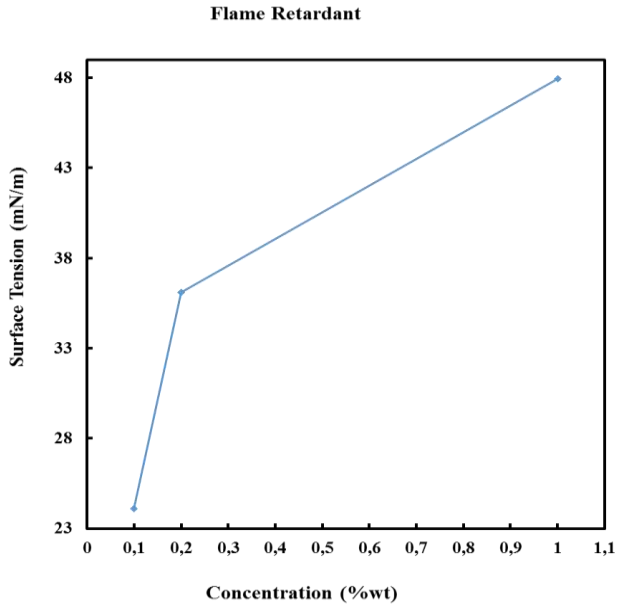

Figure 4.31 Surface tension measurements of Flame Retardant chemical solutions with different concentrations

4.5.2. Electrospraying Process for Flame Retardant Solution

The trails for two concentration and for each five electric field were done three times and the average of the results was calculated for aluminum foil, 100% polyester fabric, 100% polyamide fabric and 100% cotton fabric. Flame Retardant chemical solutions were electrosprayed at two different (1:5, 1:10 volume/volume) concentrations. The process parameters were flow rate (20µl/min) applied voltage (4.5 kV, 6.75 kV, 7.5 kV, 10 kV, 15 kV and 20 kV), tip to collector distance (3 cm and 5 cm) and needle size (22 gauge). Applied electric field values were 1 kV/cm, 1.5 kV/cm, 2 kV/cm, 2.5 kV/cm and 5kV/cm. For each applied electric field, deposition time was recorded for electrospraying of 4ml solution. The deposition time was measured for each situation and then statistical analysis was done to determine the effect size of the parameters.

4.5.3. Deposition Time Results of Flame Retardant Solution

4.5.3.1. Deposition Time Results of Flame Retardant Solution on Aluminum Foil

Deposition time results were examined for 1:5 concentration for Flame Retardant chemical solution electrosprayed on aluminum foil. Expected result is that the smaller deposition time, easier the process [Gunesoglu, 2011]. When Table 4.74 was assesed, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration.

Table 4.74 Deposition Time of Electrospraying Flame Retardant 1:5 concentration solution on aluminum foil

Flame Retardant	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time	Average D. Time (min)
1:5	4,5	3	1,5	22,46	22,45
1:5	4,5	3		22,45	
1:5	4,5	3		22,45	
1:5	15	10	1,5	22,46	22,48
1:5	15	10		22,48	
1:5	15	10		22,49	
1:5	17,5	10	1,75	22,43	22,42
1:5	17,5	10		22,41	
1:5	17,5	10		22,41	
1:5	20	10	2	22,37	22,36
1:5	20	10		22,36	
1:5	20	10		22,36	
1:5	6,75	3	2,25	22,24	22,26
1:5	6,75	3		22,28	
1:5	6,75	3		22,25	
1:5	7,5	3	2,5	22,2	22,18
1:5	7,5	3		22,19	
1:5	7,5	3		22,16	

Results were examined for 1:10 concentration for Flame Retardant (Table 4.75), expected results were obtained like 1:5 concentration results.

Table 4.75 Deposition Time of Electrospraying Flame Retardant 1:10 concentration solution on aluminum foil

Flame Retardant	Aluminum Foil				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,17	23,17
1:10	15	10		23,16	
1:10	15	10		23,18	
1:10	17,5	10	1,75	23,14	23,13
1:10	17,5	10		23,11	
1:10	17,5	10		23,13	
1:10	20	10	2	23,09	23,06
1:10	20	10		23,04	
1:10	20	10		23,06	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	22,41	22,41
1:10	7,5	3		22,43	
1:10	7,5	3		22,4	

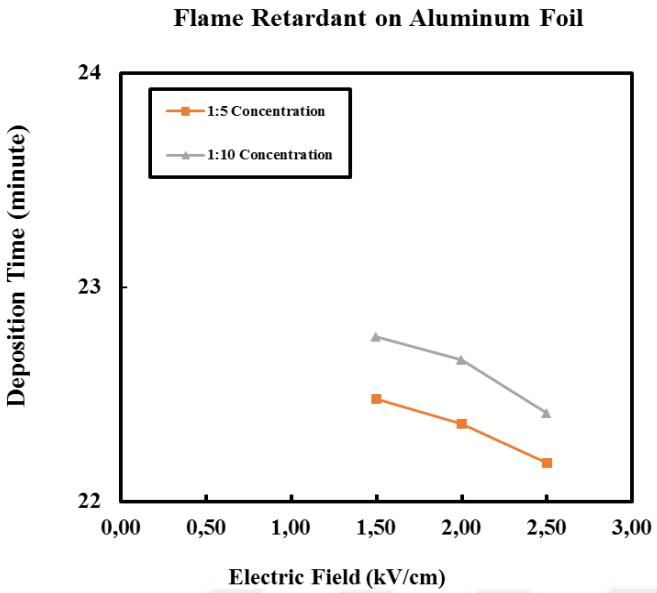

Figure 4.32 Deposition Time- Electric Field Graphic of Flame Retardant on Aluminum Foil

When Figure 4.32 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.5.3.2. Electrospraying Process for Flame Retardant Solution on 100% Polyester Fabric

Deposition time results were examined for 1:5 concentration for Flame Retardant chemical solution electrosprayed on 100% Polyester fabric. When Table 4.76 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. Aluminum foil and 100% PES fabric have different electrical resistivity values. Aluminum foil has 29×10^{-2} S·cm-^{1}, 100% PES fabric has 2.7382 x 10^{-13} S·cm-^{1} conductivity. When the collector was selected as 100% PES fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process coudn't be achieved.

Table 4.76 Deposition Time of Electrospraying Flame Retardant 1:5 concentration solution on 100% Polyester Fabric

Flame Retardant	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,3	23,28
1:5	15	10		23,26	
1:5	15	10		23,27	
1:5	17,5	10	1,75	23,1	23,09
1:5	17,5	10		23,08	
1:5	17,5	10		23,10	
1:5	20	10	2	22,58	22,58
1:5	20	10		22,59	
1:5	20	10		22,58	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	22,51	22,52
1:5	7,5	3		22,53	
1:5	7,5	3		22,53	

Results were examined for 1:10 concentration for Flame Retardant (Table 4.77) expected results were obtained like pure and 1:5 concentration results.

Table 4.77 Deposition Time of Electrospraying Flame Retardant 1:10 concentration solution on 100% Polyester Fabric

Flame Retardant	100% PES Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,34	23,32
1:10	15	10		23,32	
1:10	15	10		23,3	
1:10	17,5	10	1,75	23,23	23,21
1:10	17,5	10		23,2	
1:10	17,5	10		23,21	
1:10	20	10	2	23,14	23,15
1:10	20	10		23,15	
1:10	20	10		23,15	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	23,05	23,05
1:10	7,5	3		23,03	
1:10	7,5	3		23,06	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, for 1:5 concentration for aluminum foil, at every voltage values it was possible to achieve electrospraying process, but for 100% PES fabric, it couldn't be possible to achieve electrospraying process at low voltge values (4.5 kV and 6.75 kV). For 1:10 concentration, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75 kV and 7.5 kV when the collector was chosen as 100% PES fabric, because at 7.5 kV it was possible to perform electrospraying process.

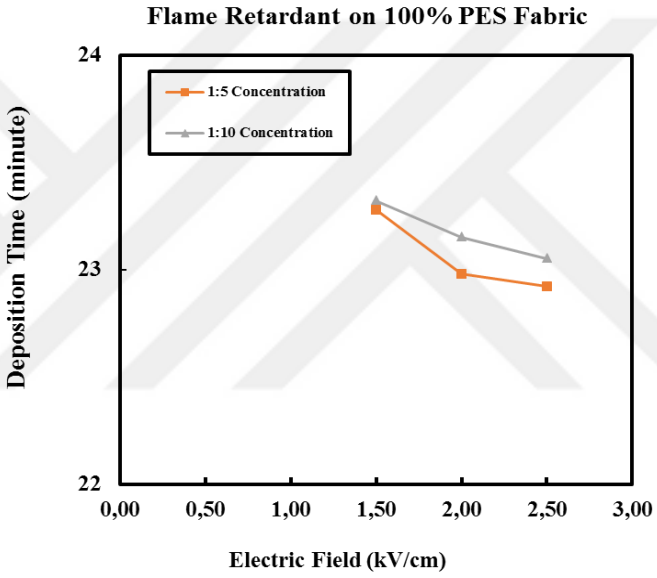

Figure 4.33 Deposition Time- Electric Field Graphic of Flame Retardant on 100% Polyester Fabric

When Figure 4.33 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.5.3.3. Electrospraying Process for Flame Retardant Solution on 100% Polyamide Fabric

Deposition time results were examined for 1:5 concentration for Flame Retardant chemical solution electrosprayed on 100% Polyamide fabric. When Table 4.78 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for pure concentration. 100% Polyamide fabric has

$2.627*10^{-14}$ $S \cdot cm^{-1}$ conductivity. When the collector was selected as 100% PA fabric, at low voltage values (4.5 kV and 6.75 kV), the electrospraying process couldn't be achieved.

Table 4.78 Deposition Time of Electrospraying Flame Retardant 1:5 concentration solution on 100% Polyamide Fabric

Flame Retardant	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,36	23,33
1:5	15	10		23,31	
1:5	15	10		23,33	
1:5	17,5	10	1,75	23,25	23,25
1:5	17,5	10		23,23	
1:5	17,5	10		23,27	
1:5	20	10	2	23,16	23,18
1:5	20	10		23,19	
1:5	20	10		23,2	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	23,11	23,11
1:5	7,5	3		23,13	
1:5	7,5	3		23,1	

Results were examined for 1:10 concentration for Flame Retardant (Table 4.79), expected results were obtained like 1:5 concentration results.

Table 4.79 Deposition Time of Electrospraying Flame Retardant 1:10 concentration solution on 100% Polyamide Fabric

Flame Retardant	100% PA Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,41	23,39
1:10	15	10		23,38	
1:10	15	10		23,37	
1:10	17,5	10	1,75	23,31	23,31
1:10	17,5	10		23,3	
1:10	17,5	10		23,32	
1:10	20	10	2	23,19	23,18
1:10	20	10		23,17	
1:10	20	10		23,19	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	23,09	23,07
1:10	7,5	3		23,06	
1:10	7,5	3		23,07	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. Similar to 100% PES fabric at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% PA fabric, because at 7.5 kV it was possible to perform electrospraying process. For pure chemical, there was just some time difference between polyester fabric and polyamide fabric about 5-20 seconds, for 1:5 concentration. For 1:10 concentration the deposition time difference was about 2-10 seconds.

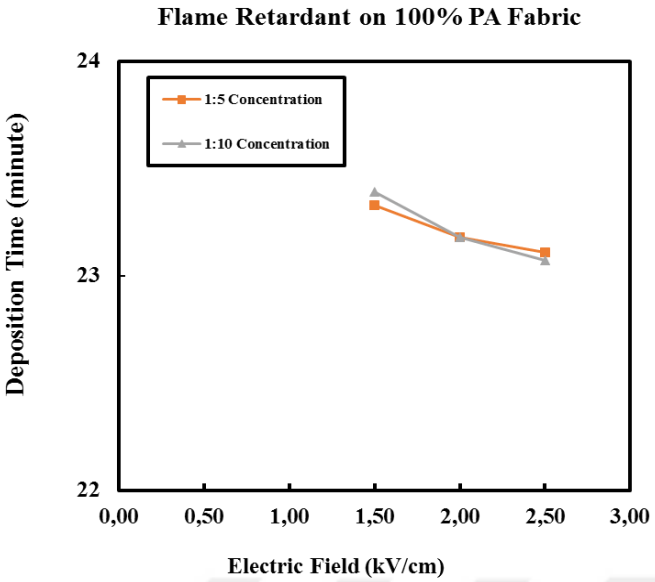

Figure 4.34 Deposition Time- Electric Field Graphic of Flame Retardant on 100% Polyamide Fabric

When Figure 4.34 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.5.3.4. Electrospraying Process for Flame Retardant Solution on 100% Cotton Fabric

Deposition time results were examined for 1:5 concentration for Flame Retardant chemical solution electrosprayed on 100% Cotton fabric. When Table 4.80 was evaluated, applied electric field increases and deposition time decreases and it means expected results were obtained for 1:5 concentration. 100% Cotton fabric has $2.734*10^{-14}$ $S \cdot cm^{-1}$ conductivity. When the collector was selected as 100% cotton fabric, electrospraying process couldn't be achieved at low voltage values (4.5 kV and 6.75 kV).

Table 4.80 Deposition Time of Electrospraying Flame Retardant 1:5 concentration solution on 100% Cotton Fabric

Flame Retardant	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:5	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	4,5	3			
1:5	4,5	3			
1:5	15	10	1,5	23,34	23,36
1:5	15	10		23,38	
1:5	15	10		23,37	
1:5	17,5	10	1,75	23,25	23,26
1:5	17,5	10		23,27	
1:5	17,5	10		23,25	
1:5	20	10	2	23,15	23,17
1:5	20	10		23,17	
1:5	20	10		23,18	
1:5	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:5	6,75	3			
1:5	6,75	3			
1:5	7,5	3	2,5	23,07	23,09
1:5	7,5	3		23,09	
1:5	7,5	3		23,1	

Results were examined for 1:10 concentration for Flame Retardant (Table 4.81), expected results were obtained like 1:5 concentration results.

Table 4.81 Deposition Time of Electrospraying Flame Retardant 1:10 concentration solution on 100% Cotton Fabric

Flame Retardant	100% Cotton Fabric				
Concentration	Voltage (kV)	Distance (cm)	Electric Field (kV/cm)	Deposition Time (min)	Average D. Time (min)
1:10	4,5	3	1,5	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	4,5	3			
1:10	4,5	3			
1:10	15	10	1,5	23,34	23,32
1:10	15	10		23,3	
1:10	15	10		23,31	
1:10	17,5	10	1,75	23,2	23,19
1:10	17,5	10		23,19	
1:10	17,5	10		23,17	
1:10	20	10	2	23,13	23,11
1:10	20	10		23,11	
1:10	20	10		23,1	
1:10	6,75	3	2,25	INSUFFICIENT VOLTAGE	INSUFFICIENT VOLTAGE
1:10	6,75	3			
1:10	6,75	3			
1:10	7,5	3	2,5	23,03	23,05
1:10	7,5	3		23,06	
1:10	7,5	3		23,07	

It can be said that when we studied with fabric, there could be some differences from aluminum foil. First, at low voltage values (4.5 kV and 6.75 kV) electrospraying performance couldn't be achieved, the voltage values were insufficient. But when the voltage value increased to 7.5 kV, electrospraying could be achieved. It showed that the critical voltage value was between 6.75kV and 7.5 kV when the collector was chosen as 100% cotton fabric, because at 7.5 kV it was possible to perform electrospraying process. For 1:5 concentration; there were little time differences between cotton and polyamide fabric about 1-2 seconds, polyester fabric about 8-17 seconds. For 1:10 concentration the deposition time difference was similar to 1:5 concentrations, about 1-3 seconds between cotton and polyamide fabric, 2-12 seconds between cotton and polyamide fabric. 100% Cotton fabric results were closer to 100% Polyamide fabric results when concentration was 1:5. Cotton fabric results were closer to 100% Polyester fabric results when concentration was 1:10.

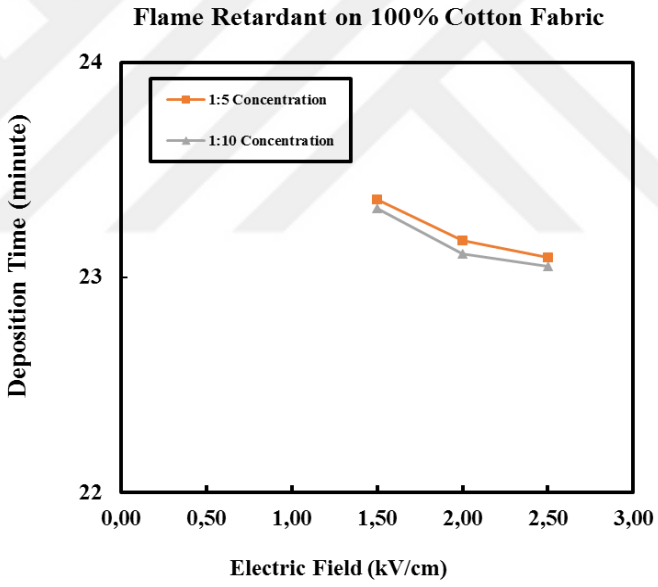

Figure 4.35 Deposition Time- Electric Field Graphic of Flame Retardant on 100% Cotton Fabric

When Figure 4.35 was examined, it could be seen clearly that when electric field increased deposition time decreased. This trend showed that increasing voltage with decreasing distance caused less deposition time.

4.5.4. Variance Analysis for Flame Retardant Solution

4.5.4.1. Correlation Analysis of Flame Retardant Solution

Table 4.82 showed the Pearson Correlation Coefficients (PCC) between deposition time and different process and solution parameters. It could be seen that from Pearson correlation coefficient, the parameters were correlated with deposition time. According to positivity and negativity of coefficients, surface tension had negative correlation coefficient which means when surface tension increases deposition time decreases or vice versa. The other parameters had positive correlation coefficient which indicates when parameters increases deposition time increases too. The p value obtained for all parameters were less than 0.05 expressing statistically significant effect on deposition time.

Table 4.82 Correlation Analysis of Flame Retardant Solution

Parameter	PCC	p value
Concentration (v/v)	-0,383	0,000
Viscosity (cP)	-0,383	0,000
Surface Tension (mN/m)	-0,383	0,000
Conductivity (µS/cm)	-0,383	0,000
Voltage (kV)	0,386	0,028
Distance (cm)	0,472	0,000
Collector Type (aluminum foil, 100% PES, 100% PA and 100% Cotton Fabric	0,667	0,000

In addition, it was observed that collector type had significant effect on deposition time with PCC value 0.667, at p-value 0.000. When distance value was observed, the effect on deposition time with PCC value 0.472, at p-value 0.000. Voltage value had an effect on deposition time with PCC value 0.386, at p-value 0.000. Concentration, viscosity, surface tension, conductivity values had same negative effect on deposition time with PCC value -0.383, at p-value 0.000. Negativity means when surface tension increases deposition time decreases or vice versa.

4.5.4.2. Generalized Linear Method (Factorial ANOVA) for Flame Retardant Solution

The ANOVA table is shown (Table 4.83) for study of Flame Retardant solution.

Table 4.83 ANOVA Table for Flame Retardant Solution

Source	Type III Sum of Squares	df	Mean Square	F	p value
Corrected Model	9,910a	6	1,652	44,599	0,000
Intercept	37,247	1	37,247	1005,755	0,000
Viscosity (a)	1,022	1	1,022	27,605	0,000
Voltage (b)	0,067	1	0,067	1,82	0,181
Distance (c)	0,069	1	0,069	1,857	0,176
Collector Type (d)	1,903	1	1,903	51,379	0,000
a*b*c*d	0,208	1	0,208	5,611	0,020
Error	3,518	95	0,037		
Total	53902,91	102			
Corrected Total	13,428	101			
a. R Squared = ,738 (Adjusted R Squared = ,721)					

According to variance analysis (ANOVA) results, viscosity and collector type were statistically significant on deposition time seperately ($p \leq 0.05$). Voltage and distance values had nonsignificant effect on deposition time, but according to correlation analysis, these two parameters had significant effect. When process parameters (voltage, distance and collector type) were considered together, the effect on deposition time was not significant. All parameters (viscosity, voltage, distance and collector type) were considered together, the effect on deposition time of all parameters was significant at p-value 0.020.

4.5.4.3. Regression Analysis for Flame Retardant Solution

According to the regression analysis, the affecting parameters and significance values were shown in Table 4.84.

Table 4.84 Results for regression analysis of deposition time of Flame Retardant solution

Parameters	Coeeficient	T	P (Significance value)
Constant	26,0029	40,62	0,0000
Viscosity	-1,0137	-5,68	0,0000
Voltage	-0,04492	-4,1	0,0000
Distance	0,10682	6,19	0,0000
Collector Type	0,54167	11,09	0,0000
R^2 = 72,2% R^2(adj) = 71,0%			

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	9,691	2,4228	62,88	0,0000
Residual Error	97	3,7373	0,0385		
Total	101	13,4283			

Viscosity, voltage, distance and collector type parameters were effective on deposition time; according to coefficient value viscosity had biggest effect in negative way on deposition time. According to these results; the regression analysis for deposition time was below:

Deposition time = 26.0 – 1.01 viscosity – 0.0449 voltage + 0.107 distance + 0.542 collector type

Increasing of viscosity caused a decrease on deposition time. Voltage value had negative effect on deposition time, it could be expressed that when voltage increases deposition time decreases or vice versa. Deposition time increases with increasing distance. When collector type was chosen according to the conductivity, more conductive collector type caused less deposition time. MINITAB examined all possible subsets of variables as shown in Table 4.85.

Table 4.85 Models consisting of different combinations of variables selected using all possible regressions from predictors of deposition time for Flame Retardant solution

Predictors	R^2	Adjusted R^2	Mallows' Cp	S	Viscosity	Voltage	Distance	Collector Type
1	44,4	43,9	95,6	0,27313				X
1	22,2	21,5	173,0	0,32315			X	
2	58,6	57,8	48,2	0,23687			X	X
2	54,9	54,0	61,1	0,24724	X			X
3	67,3	66,3	19,8	0,21156	X		X	X
3	62,9	61,8	35,3	0,22544		X	X	X
4	72,2	71,0	5,0	0,19629	X	X	X	X

According to Table 4.83, when all predictors participate in the model, the highest R^2 value (72.2), the smallest Mallows' Cp (5.0) and the smallest S (0.19629) value can be obtained. And regression analysis and best subset regression analysis gave us the same parameters effect on deposition time.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1. Summary of Study

The idea behind this thesis is to study deposition time and try to compose a formulation for factories when they produce textile surfaces with much-used textile chemicals (macrosilicone, microsilicone, fluorocarbon, dendrimer+fluorocarbon and flame retardant) via electrospraying process. This formulation will help factories to most effective parameter on electrospraying process speed. In this study, five different textile chemicals were used; macrosilicone, microsilicone, fluorocarbon, dendrimer+fluorocarbon and flame retardant. The procedure of study was given below:

1- In this study, all experimental studies were done at ambient temperature 20-23 ° C and the humidity 27-32% in order to avoid different results.
2- Textile chemicals were selected as frequency of usage. Macrosilicone, microsilicone, fluorocarbon, dendrimer+fluorocarbon and flame retardant chemicals were used for this study, water was used as solvent for macrosilicone, microsilicone, fluorocarbon, dendrimer+fluorocarbon and water/ethanol mixture was used as solvent for flame retardent agent. According to literature survey, textile chemicals haven't been used for electrospraying process, so using textile chemical solutions for electrospraying causes novelties for literature.
3- All chemicals were supplied by Rudolf Duraner, Bursa, Turkey.
4- After chemical selection, surface types were selected as aluminum foil, 100% Polyester Fabric, 100% Polyamide Fabric and 100% Cotton Fabric. These fabric types were selected because of the frequency of usage like textile chemicals

5- For a proper electrospraying process; flow rate, concentration values, voltage values, and tip to collector distance values were determined. Flow rate was adjusted 20 μL/min, concentration was selected three different values pure, 1:5 and 1:10 v/v, voltage values were adjusted as 4.5 kV, 6.75 kV, 7.5 kV, 10 kV, 15 kV and 20 kV and tip to collector distance values were selected as 3 cm and 10 cm.
6- These five different textile chemicals were prepared with solvents to be electrosprayed. And all chemical solution characterizations and electrospraying process were done at Textile Engineering Department, Gaziantep University.
7- During electrospraying process, 4 mL chemical solution was put into the syringe and time was recorded until the end of syringe. In normal conditions, 4 ml solution should finish in 20 minutes, because the set up is horizontally arranged and there isn't any forces acting on liquid droplet. When electrospraying process was performed, voltage was applied and by means of electric field and some blockages 4 ml solution didn't finish in 20 minutes. For each voltage and distance values, process was done three times to avoid statistical error.
8- After time record, all parameters effect on deposition time was statistically evaluation and confirmation; correlation analysis, variance analysis (ANOVA) and regression analysis were done. According to regression analysis, formulations were done and effect size of parameters was certained. Correlation and regression analysis were done with Minitab® 16 Statistical Software, variance analysis (ANOVA) were done with IBM SPSS Statistics 21- Software; IBM, Chicago, USA.

5.2. Results of Study

The results were given according to chemical type.

5.2.1. Macrosilicone Softener

- All studies could be achieved with each concentration, voltage and distance values when the surface type was selected as aluminum foil.
- For 100% Polyester fabric, for all concentrations at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.

- For 100% Polyamide fabric, like 100% Polyester fabric, for all concentrations at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.
- For 100% Cotton fabric, similar to 100% Polyester and Polyamide fabrics, for all concentrations at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.
- When electric field (voltage/distance, kV/cm) increased, deposition time decreased or vice versa for each concentration.
- Correlation analysis, variance analysis (ANOVA) and regression analysis were done for each concentration results, and the effective parameters were ranged as following according to effect intensity::
    - Surface type in positive way; when electrical conductivity increases, deposition time increases too.
    - Distance in positive way; when distance increases, deposition time increases too.
    - Voltage in negative way; when voltage increases, deposition time decreases.
    - Viscosity in positive way; when viscosity increases, deposition time increases too.
- The formulation is;

Deposition time = 22.2 + 0.0119 viscosity – 0.0930 voltage + 0.209 distance + 0.430 collector type

5.2.2. Microsilicone Softener

- All studies could be achieved with each concentration, voltage and distance values when the surface type was selected as aluminum foil.
- For 100% Polyester fabric when concentration selected as pure, at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved. But when concentration was selected as 1:5 v/v and 1:10 v/v, at 4.5 kV electrospraying process couldn't be achieved.
- For 100% Polyamide fabric, at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.
- For 100% Cotton fabric, similar to 100% Polyester and Polyamide fabrics, at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.

- When electric field (voltage/distance, kV/cm) increased, deposition time decreased or vice versa for each concentration.
- Correlation analysis, variance analysis (ANOVA) and regression analysis were done for each concentration results, and the effective parameters were ranged as following according to effect intensity::
    - Surface type in positive way; when electrical conductivity increases, deposition time increases too.
    - Distance in positive way; when distance increases, deposition time increases too.
    - Voltage in negative way; when voltage increases, deposition time decreases.
- The formulation is;

Deposition time = 22.4 – 0.117 voltage + 0.251 distance + 0.385 collector type

5.2.2. Fluorocarbon

- All studies could be achieved with each concentration, voltage and distance values when the surface type was selected as aluminum foil.
- For 100% Polyester fabric for all concentrations, at 4.5 kV, 6.75 kV and 7.5 kV, electrospraying process couldn't be achieved.
- For 100% Polyamide fabric for all concentrations, at 4.5 kV, 6.75 kV and 7.5 kV, electrospraying process couldn't be achieved.
- For 100% Cotton fabric, different from 100% Polyester and Polyamide fabrics, for all concentrations at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.
- When electric field (voltage/distance, kV/cm) increased, deposition time decreased or vice versa for each concentration.
- Correlation analysis, variance analysis (ANOVA) and regression analysis were done for each concentration results, and the effective parameters were ranged as following according to effect intensity::
    - Surface type in positive way; when electrical conductivity increases, deposition time increases too.

- Distance in positive way; when distance increases, deposition time increases too.
- Voltage in negative way; when voltage increases, deposition time decreases.

- The formulation is;

Deposition time = 22.6 – 0.0629 voltage + 0.0986 distance + 0.663 collector type

5.2.2. Fluorocarbon&Dendrimer

- All studies could be achieved with each concentration, voltage and distance values when the surface type was selected as aluminum foil.
- For 100% Polyester fabric for all concentrations, at 4.5 kV, 6.75 kV and 7.5 kV, electrospraying process couldn't be achieved.
- For 100% Polyamide fabric, different from 100% Polyester fabric for all concentrations, at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.
- For 100% Cotton fabric, similar to 100% Polyamide fabric, for all concentrations at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.
- When electric field (voltage/distance, kV/cm) increased, deposition time decreased or vice versa for each concentration.
- Correlation analysis, variance analysis (ANOVA) and regression analysis were done for each concentration results, and the effective parameters were ranged as following according to effect intensity::
  - Surface type in positive way; when electrical conductivity increases, deposition time increases too.
  - Distance in positive way; when distance increases, deposition time increases too.
  - Voltage in negative way; when voltage increases, deposition time decreases.
  - Viscosity in negative way; when viscosity increases, deposition time increases too.
- The formulation is;

Deposition time = 23.2 – 0.0188 viscosity – 0.0757 voltage + 0.145 distance + 0.230 collector type

5.2.2. Flame Retardant

- For aluminum foil, when concentration was selected as 1:5 v/v, electrospraying process could be achieved at all voltage and distance values. When concentration was selected as 1:10 v/v, at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.
- For 100% Polyester fabric, for two concentrations at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.
- For 100% Polyamide fabric, like 100% Polyester fabric, for two concentrations at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.
- For 100% Cotton fabric, similar to 100% Polyester and Polyamide fabrics, for two concentrations at 4.5 kV and 6.75 kV, electrospraying process couldn't be achieved.
- When electric field (voltage/distance, kV/cm) increased, deposition time decreased or vice versa for each of two concentrations.
- Correlation analysis, variance analysis (ANOVA) and regression analysis were done for each of two concentrations results, and the effective parameters were ranged as following according to effect intensity:
    - Viscosity in negative way; when viscosity increases, deposition time increases too.
    - Surface type in positive way; when electrical conductivity increases, deposition time increases too.
    - Distance in positive way; when distance increases, deposition time increases too.
    - Voltage in negative way; when voltage increases, deposition time decreases.
- The formulation is;

Deposition time = 26.0 – 1.01 viscosity – 0.0449 voltage + 0.107 distance + 0.542 collector type

When considering the deposition time equations of all chemicals studied, it's observed that the effect of viscosity has positive contribution on deposition time for Macrosilicone softener, but negative for the rest. This phenomenon is contributed to the numeric value of constant in the equations. The Macrosilicone softener trials gave the lowest constant so the contribution of viscosity was found positive. It's also accepted that the constant of the equations include the interactions of the parameters therefore any other formula which shows the interactions in it will also be used.

5.3. Recommendations for Future Studies

In this study, deposition time of five different chemical solution electrospraying processes was measured with different process parameters and tried to make a formulation according to effective parameters on deposition time. These studies were done on three different textile surface, 100% polyester fabric, 100% polyamide fabric and 100% cotton fabric. Based on this study, further studies can be carried out in the following proposals.

- In this study, ambient parameters (humidity, temperature) were constant. For future studies different ambient parameters can be used for electrospraying process.
- Different most used chemical types can be used for future studies.
- The overall evaluation for all chemicals, the effective parameters are common; voltage, distance, collector type. For macrosilicone softener, fluorocarbon& dendrimer and flame retardant viscosity is also effective parameter. But for microsilicone softener and fluorocarbon viscosity is not shown as an effective parameter. When particle sizes were measured for microsilicone softener and fluorocarbon, sizes are so close to each other and more different from the others. So for future studies particle size effect can be studied.
- After electrospraying process, physical properties can be measured and it is possible to compare the results before and after of the process.
- Different fabric types, fabric blends can be used for future studies.
- Due to the experimental setup, short-term production has been carried out in the study. On the subject of future work, the development of a system for long-term production can be emphasized.

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PUBLICATIONS

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KAPAR Bilgen, GÜNEŞOĞLU Cem, "Crease Recovery Treatment Via Pad and Chemical Foam System with Different pH Values",2013, Cilt: 20, No:90, Sayfa: 25-31.

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FOREIGN LANGUAGE KNOWLEDGE

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