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**TECHNOLOGY CORONA TREATMENT
OF POLYPROPYLENE KNITS**

**ÚPRAVA POLYPROPYLENOVÝCH PLETENIN
ZA POMOCÍ KORONY**

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Rozsah práce

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ANNOTATION

This master degree work is concerned with treatment of polypropylene knits surface using the atmospheric plasma as a purpose of hydrophility elimination and how to obtain better results for other finishing process. My work is divided into five main parts.

Introduction interprets the basic terms. What plasma is, where plasma is in the nature and where we could meet it and why exactly plasma.

The second part explains plasma history, the first pioneers are mentioned, the scientists deserving the next development and the basic data when these events were happened.

The theoretical part describes and explains the basic physical and chemical principles of plasma creation, plasma dividing after type of used parameters, using in the textile industry. It mentions Polypropylene and its physical and chemical properties. It explains the principles of softeners and its chemical composition and usage.

In the experimental part of work were the patterns washed for purpose to simulate the non-treated polypropylene properties and its next treatment with help of atmospheric plasma. By drop test was found out the hydrophility change of polypropylene knits. By using of PC and CCD camera was done the dynamic test of measuring the contact angle. Moreover the experimental part goes into the utilization of hydrophility elimination in the praxis and so, by observing the softeners quantity.

Conclusion takes measures of recorded results, discusses about plasma gain and shows the possible solutions how to improve the PP treatment with help of plasma.

Anotace

Tato diplomová práce se zabývá úpravou povrchu polypropylenových pletenin za pomoci atmosférické plasmy, za účelem snížení hydrofility, a získání lepších parametrů pro další zušlechťovací procesy. Je rozdělená na pět hlavních částí.

Úvod, kde se vysvětlují základní pojmy. Co je to plasma, kde se s ní v přírodě můžeme setkat, a proč právě plasma.

V druhé části je ozřejměná její minulost, jsou vzpomenuti první průkopníci, lidé kteří se zasloužili o její další rozvoj a základné časové data v kterých se tyto invence uskutečnili.

V teoretické části jsou popsány a vysvětleny základné fyzikální a chemické principy vzniku plasmy, dělení plasmy podle typu používaných parametrů, použití v textilním průmyslu. Zmiňuje se také o Polypropyléne o jeho fyzikálně-chemických vlastnostech. Vysvětluje principy změkčovacích prostředků jejich chemické složení a použití

V rámci experimentální části práce byly vzorky vyprány za účelem napodobení vlastností neupraveného polypropylénu a jeho následné upravení za pomoci atmosférické plasmy. Kapkovým testem byla zjištěná změna hydrofility polypropylenových pletenin. Za použití PC a CCD kamery byl proveden dynamický test měření kontaktního uhlu. Dále se experimentální část zabývá využití snížení hydrofility v praxi a to sledováním množství změkčovacích prostředků. A jejich úbytek při opakovaném praní.

Závěr, kde se hodnotí zaznamenané výsledky, diskutuje o přínose plasmy a ukazuje možná řešení jak by se dala zdokonalit úprava PP pomocí plasmy.

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V Liberci, dne . . .

.....

podpis

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REGISTER OF USED SYMBOLS

PP	Polypropylene
PET	Polyethylene
RF [Hz]	resonance frequency
Atm [Pa]	atmospheric pressure (101 325Pa)
DC [A]	direct current
AC [A]	alternate current
DBD	dielectric barrier discharge
OAUGDP	one atmosphere uniform glow discharge plasma
ELF [Hz]	extremely low frequency
VLf[Hz]	very low frequency
LF [Hz]	low frequency
MF [Hz]	medium frequency
HF [Hz]	high frequency
APT	atmospheric plasma treatment
APGD	atmospheric plasma glow discharge
p [Pa]	pressure
P [W]	power
V [m/min]	velocity
LDPE	low density polyethylene
HDPE	high density polyethylene
CA [°]	contact angle
CCD	charge-couple device
LED	light emitting diode
PS	power supply
PLC	programmable logic controller
LCD	liquid crystal display
H ₂ SO ₄	sulphuric acid
FTIR	Fourier Transformance InfraRed

1. Introduction

Plasma is by no means a human invention. It is found in the stars – including our Sun (see figure 1.), in the tails of comets and in the flashes of lightning. The Northern Lights are a plasma phenomenon, too. The word of plasma comes from Greek and means “form” or “shape” but also “that which is formed”.



Fig.1. The Sun – form of plasma

Today, there is possible to find technical plasmas in wide range of applications in the most diverse branches and manufacturing, including the production of many modern household objects. This manifold applications owe their existence to intensive research and development work in this young field of technology.

Plasma is often referred as the fourth state of matter. When a solid material is heated it typically transforms firstly into a liquid and at higher temperature into a gas. If further energy is supplied to the gas, it becomes to be electrically conducted, even though overall electrical neutrality is maintained. This is due to the fact that the electrons gain sufficient energy to be separated from atoms or molecules of the gas. The plasma consists of mixture of mainly positively charged ions, electrons and neutral particles.

When the temperature of the ions and neutral particles is usually less than one hundred degrees Celsius, the energy of the electrons in this plasma corresponds to a temperature of some 10000 degrees Celsius. Thus they serve as highly reactive tools for powerful but gentle applications without consuming great energy.

This “hotcoolness” opens the way to undreamt processing possibilities and enormous economic opportunities.

The enormous promise of plasma technology stems from its remarkable potential for friendly environment and energy saving processing. There are so many usage advantages of this new area of science in textile industry. One of the greatest advantages is its flexibility and its new wide spectrum of applications and its clear ecological advantages. Nowadays, there is set the strong accents for the best ecological parameters.

In this way, plasma technology will represent an essential starting point for technologies in the future and today, too.

1.1 History of Plasma Technology

The history of plasma technology goes back to the 18th century. It was the physicist and writer Georg Christoph Lichtenberg (1752–1799), professor of mathematics in Göttingen from 1770, who first generated and documented beautiful surface discharges.

This he did by introducing an insulating sheet between a pointed electrode and a metal plate. When fern spores were scattered onto this sheet and a voltage applied between the electrode and the metal, brush discharge patterns were formed.

Lichtenberg’s experiments merely displayed a phenomenon in 1780; the first attempts to explain it in terms of the plasma state were due to the experimental physicist from London, Michael Faraday (1791–1867). Prior to his ground-breaking discovery of electromagnetism in 1821, he spent the years 1816–1819 investigating the properties of heated matter: ‘What happens when a material is heated from the solid via the liquid to the gas phase and beyond? Is there a fourth state of matter?’

Faraday was not able to answer these questions but his compatriot Sir William Crookes (1832–1919) discovered this fourth state in 1879 as a ‘radiating matter’ in discharge tubes. The result: the remaining gas began to glow green and developed a pattern of stripes. Furthermore, at the negative electrode, the cathode, he observed a dark region, today still known as Crookes’ dark space. These observations led Crookes to postulate a fourth state which is an ‘ultra-gas-like’ and arises under high-vacuum conditions.

He correctly hypothesised that the tube had contained electrically charged gas molecules or ions. What he had discovered it was plasma. Previously, in 1887, Werner von Siemens, in fact, had already exploited the technical plasma in his apparatus for producing ozone.

However, he did not recognise this as a plasma phenomenon. A better understanding of the processing occurring in gas discharge tubes was obtained through the experiments by Sir Joseph John Thomson (1856–1940) in Cambridge. In 1897 he published a paper reporting that cathode rays undoubtedly consist of tiny negatively charged particles, which he called corpuscles. He determined the charge-to-mass ratio of these particles, which were later become to be known as electrons. On account of their tiny size in comparison with atoms, he postulated that they had been able to be quite conceivably by a constituent of the atom. This led him to the conclusion that atoms consist of positively charged mass ‘throughout which electrons are distributed’.

A few years later Thomson’s ideas about the electron and its role in the atom received confirmation: In 1886, the German chemist Eugen Goldstein proved that a gas discharge tube contained not only cathode rays (electrons) but also other rays that travel in the opposite direction towards the anode. He called them canal rays. Shortly thereafter they were shown as positively charged atomic particles, the ions; in other words, particles with missing electrons. Thus plasma had been identified as a mixture of electrons and ions. Now only the name was missing.

This was provided by the New York chemist Irving Langmuir (1881–1957). In 1923, Langmuir observed in an ionised gas, characteristic oscillations that depended on the electron density and mass. These collective oscillations in a system of many charged particles, he called ‘plasma oscillations’. They arise from random inhomogeneities in the charge distribution in plasma – local regions of higher electron or ion density – and the natural tendency of the charge to be uniformly redistributed.

The first attempt to give a full account of gas discharges was published by the German physicist Johannes Stark in 1902 with the title ‘Electricity in Gases’. As a director of the Physics Institute of the University of Greifswald, he was awarded the Nobel Prize on 10th December 1919 for his discovery of the Doppler effect in canal rays and the splitting of the spectral lines in electric fields.

At the end of 1918, Stark invited Rudolf Seeliger to Greifswald. Seeliger worked there until 1955, winning recognition as one of the pioneers of modern plasma and gas discharge physics. More recently great interest has been aroused by the generation of diamond layers.

In 1953, at the teaching university in Potsdam, Werner Schmellenmeier identified diamonds as a product of acetylene gas discharges. In the 1960s and 1970s techniques were developed in Russia for chemically precipitating diamond layers from the gas phase and, in 1983, Japanese scientists succeeded in producing diamond layers with a microwave plasma.[1]

2. Theoretical Part

2.1 Corona Discharge

A corona is a process by which a current, perhaps sustained, develops from an electrode with a high potential in a neutral fluid, usually air, by ionising that fluid so as to create plasma around the electrode. The ions generated eventually pass charge to nearby areas of lower potential, or recombine to form neutral gas molecules.

When the potential gradient is large enough at a point in the fluid, the fluid at that point ionizes and it becomes conductive. If a charged object has a sharp point, the air around that point will be at a much higher gradient than elsewhere.

Air near the electrode can become ionized (partially conductive), while regions more distant do not. When the air near the point becomes conductive, it has the effect of increasing the apparent size of the conductor. Since the new conductive region is less sharp, the ionization may not extend past this local region. Outside of this region of ionization and conductivity, the charged particles slowly find their way to an oppositely charged object and are neutralized.[2]

If the geometry and gradient are such that the ionized region continues to grow instead of stopping at a certain radius, a completely conductive path may be formed, resulting in a momentary spark, or a continuous arc. Corona discharge usually involves two asymmetric electrodes; one highly curved (such as the tip of a needle, or a small diameter wire) and one of low curvature (such as a plate, or the ground). The high curvature ensures a high potential gradient around one electrode, for the generation of plasma.

Coronas may be positive or negative. This is determined by the polarity of the voltage on the highly-curved electrode. If the curved electrode is positive with respect to the flat electrode we say we have a positive corona, if negative we say we have a negative corona.

The physics of positive and negative coronas are strikingly different. This asymmetry is a result of the great difference in mass between electrons and positively

charged ions, with only the electron having the ability to undergo a significant degree of ionizing inelastic collision at common temperatures and pressures.

An important reason for considering coronas is the production of ozone around conductors undergoing corona processes. A negative corona generates much more ozone than the corresponding positive corona.

2.2 Particle Collisions

The Maxwell-Boltzmann distribution functions discussed above are maintained by collisions among individual particles of the gas or plasma. Some of the different kinds of binary or multi-body collisions which can occur among electrons, ions, and neutral atoms or molecules of types A, B and C.

Unfortunately in industrial applications, it is necessary to consider not only binary collisions between two individual charged particles of the plasma, but also interactions of these charge particles with other forms of matter solids, liquids, and the background neutral gas in which it is imbedded. [3]

Electrons

$e + A \rightarrow A^+ + 2e$	Ionization
$e + A \rightarrow A^* \rightarrow e + A + h\nu$	Excitation
$e + A^* \rightarrow 2e + A^*$	Penning ionization
$e + A \rightarrow e + A$	Elastic scattering
$e + AB \rightarrow e + A + B$	Dissociation
$e + AB \rightarrow 2e + A^+ + B$	Dissociative ionization
$e + AB \rightarrow A^- + B$	Dissociative attachment
$e + A^+ + B \rightarrow A + B$	Recombination

Ions

$A^+ + B \rightarrow A + B^+$	Charge exchange
$A^+ + B \rightarrow A^+ + B$	Elastic scattering
$A^+ + B \rightarrow A^+ + B^+$	Ionization
$A^+ + B \rightarrow A^+ + B^* \rightarrow A^+ + B + h\nu$	Excitation
$A^+ + e + B \rightarrow A + B$	Recombination
$A^+ + BC \rightarrow A^+ + B + C$	Dissociation
$A + BC \rightarrow C + AB$	Chemical reaction

2.3 Characteristics of Industrial Plasma Sources

The plasma sources used in industry are described by their manufacturers and users in terms of small set of characteristics that define their regime of operation.

These source characteristics include the plasma type, the nature of its power supply, the operating pressure, and the mode of interaction of the source with a workpiece. Significant differences in these plasma source characteristics can, nonetheless, generate plasmas for which the active species concentrations, electron number densities, electron kinetic temperatures, sheath potential drops etc, are very similar, while the technical means of generating the plasma are quite different.

In industrial plasma sources, the active-species concentrations and electron-number densities tend to be proportional to the input plasma power density. If the input power density and other plasma parameters are the same in different plasma sources, the usual result is the same plasma-processing effect on the workpiece, achieved by the different means.

2.3.1 Plasma Type

When RF is applied to generate a plasma, the plasma behaves like a resistive circuit element below the critical sheath frequency, and like capacitor with polarizable dielectric above this frequency.

Below the critical sheath frequency at about 1 MHz, the electrode and positive column structures observable along the axis of an RF glow discharge resemble an instantaneous snapshot of the structures of a normal glow discharge that reverse each half-cycle of the RF.

Above the critical sheath frequency, the sheath structures of the RF glow discharge behave capacitively and become more uniform between the electrodes.

The time and space resolved sheath characteristics in this regime are not well understood.[4]

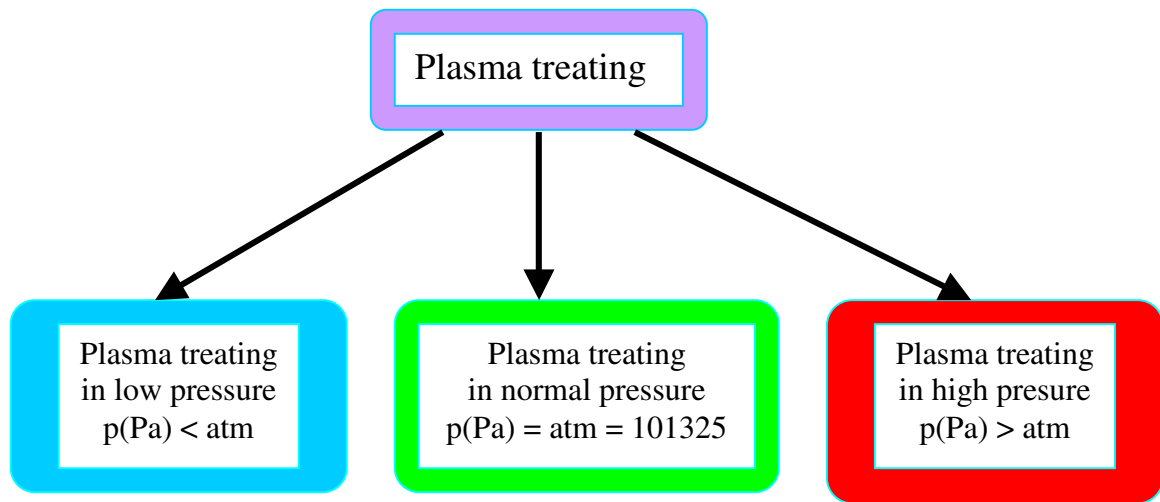
2.3.2 Operating Pressure

The operating pressure (see at scheme 1.) of the working gas is a significant factor in choosing a plasma source because restricts the choice of reactor technology and the type of source used for plasma-processing applications.

The most critical choice with respect to pressure is whether the process is to be operated at 1 atm or under vacuum. If a source is operated at 1 atm batch-processing and vacuum equipment are not required, under vacuum both are required, and their cost is relatively insensitive to the vacuum pressure.

If plasma sources are operated above 1 atm, batch-processing of workpieces are required, and above 3 atm, the enclosures are considered to be pressure vessels with regulatory restrictions that require design according to national boiler codes. For these reasons, plasma processing is rarely conducted above 1 atm.

A few applications of plasma torches and military equipment (for example aircraft) require pressures ranging from 1 atm down to 0.1 atm. At 1 atm (101 325 Pa), which we take to include a barometric range within 5% of standard atmosphere just quoted, batch processing of workpieces and vacuum pumping equipment are not necessary. This factor leads to significant cost saving in the processing of webs, films, and large numbers of low value workpieces.[5]



Scheme: 2.1. Parting by pressure.

2.3.3 Power Supply Characteristics

Industrial plasma sources operate over a wide range of excitation frequencies. Schematic diagrams of DC, power line, and RF plasma source subsystems are shown on figure 2.

Plasma sources energized by DC power supplies have advantage that DC power is relatively inexpensive. DC power supplies may, at most, require a matching network consisting of a simple ballast resistor or inductor to limit the current and stabilize non-thermal arcs or other plasma sources with negative resistance characteristic.

Arc and corona discharges operated at power line frequency (50 or 60Hz) have a very inexpensive power supply, since the final transformer before the load usually serves as current limiting ballast.[6]

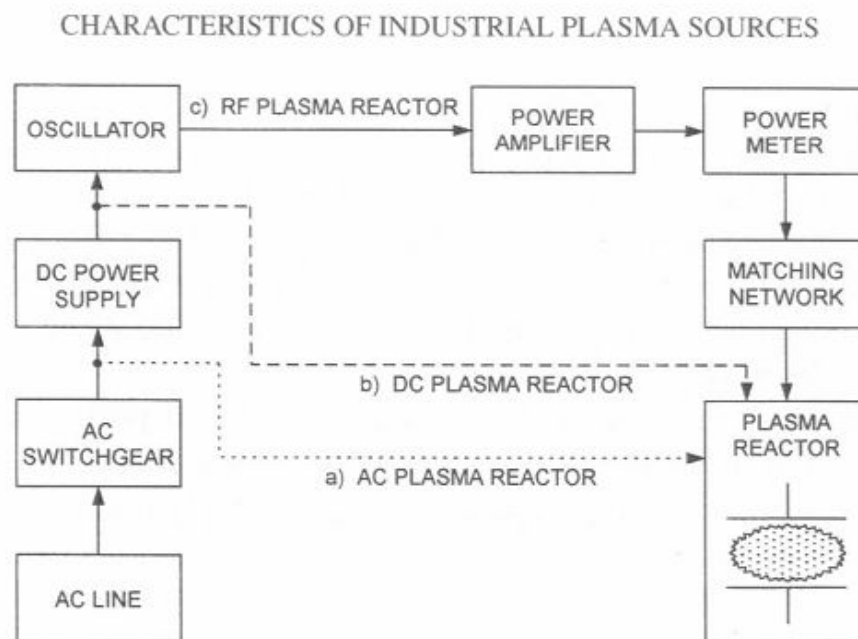


Fig.2.2: Schematic diagram of power supply components needed for plasma sources that require (a) AC line voltage only; (b) DC electrical power; and (c) RF power

The plasma sources that require RF power supplies and that dielectric barrier discharge (DBD) and the one atmosphere uniform glow discharge plasma (OAUGDP) operate in the extremely low frequency (ELF) and very low frequency (VLF) range, from approximately 500 Hz to 30kHz.

Some RF vacuum glow discharge reactors used for microelectronic deposition or etching, such as triode etching system, operate the RF power supply for one electrode below the critical sheath frequency, where the plasma appears as a resistive load to the power supply, and the second electrode and power supply above the critical sheath frequency, at 13.56 MHz. The lower range includes portions of the low frequency (LF) and medium frequency (MF) bands, from about 50 kHz to a few MHz.

Regulatory restrictions on allowed frequencies and off-site emission intensities must be considered for such sources.

The RF glow discharge plasma reactors used for microelectronic deposition and etching operate above critical sheath frequency, where the reactor behaves like a capacitive load to its power supply. Such reactors are operated in high frequency (HF) band (3 – 30 MHz) at “sacrifice frequencies” establish by regulatory bodies at 13,56 MHz, and harmonically twice and three times for this frequency. These 13,56 MHz RF power supplies have been used in such large numbers for microelectronic and other plasma-processing applications.

Most plasma sources used for surface treatments, depositions or etchings require only a few hundred watts to few kilowatts of input power. The capital cost of the plasma source subsystem and its power supply may be such a small fraction of the cost of the complete plasma-processing system or fabrication tool that factors other than cost may dominate the choice of plasma source.

In thermal plasma-processing applications requiring arcjets or plasma torches, power levels ranging from a few kilowatts to more than 1 MW may be required.

In these applications, efficient and effective use of the plasma power is important. The power supply is major fraction of the overall cost of the plasma-processing system, and the electrical power is major contributor to its operating costs. [6]

2.3.4 Plasma Source Applications

Plasma sources have found an enormous range of industrial applications, including many applications when physical or chemical-processing method proved inadequate. New applications are being reported at plasma-related meetings on an almost monthly basis.

In terms of sheer numbers, plasma sources are most often found in the well-established areas of surface treatment of materials, microelectronic deposition and etching, ion-beam sources, and the thermal plasma processing of bulk materials.

2.3.4.1 Surface Treatment

Plasma surface treatment involves using direct plasma exposure to change the surface energy, wettability, wickability, and bonding of fabrics, films and solids and sterilization, cleaning and decontamination of surfaces. To achieve industrially important effects, plasmas used for surface treatment must have a sufficiently high electron number density to provide useful fluxes of active species but not so high or energetic as to damage the treated material. Especially very sensitive Polypropylene in this case.

These constraints rule out dark discharges other than coronas for most applications, because of their low production rate of active species and arc or torch plasmas, which have power densities and active species flux intensities high enough to damage exposed materials. Glow discharge plasmas, whether operated in 1 atm or under vacuum, possess the appropriate density and active-species flux for nearly all plasma surface treatment applications.

RF glow discharge plasmas can be generated by inductive, capacitive or microwave excitation using the physics and technology [7].



Fig 2.3. Treated of polypropylene by plasma discharges

2.4 Atmospheric Plasma Treatment (APT)

Plasma is an ionized form of gas and can be created using a controlled level of AC or DC power and an ionizing gas medium. It is an ensemble of randomly moving, charged atomic particles with a sufficient particle density to remain, on average, electrically neutral.

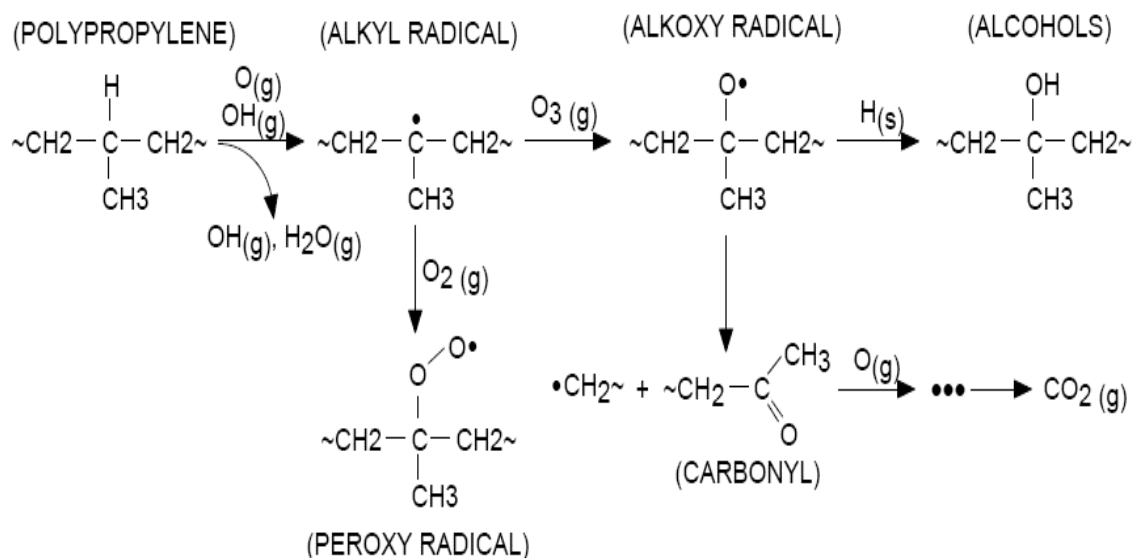
Plasmas are used in very diverse applications, ranging from manufacturing integrated circuits used in the microelectronics industry through treating polymer films to the destruction of toxic waste. Plasma processes can be grouped into two main classes — low-density and high-density — according to their electron temperature versus electron density. In low-density, direct-current and radio-frequency glow discharges, the electron and heavy particle temperatures are not equal. Low-density plasmas have hot electrons with cold ions and neutrals. Energetic electrons collide with dissociate and ionize low-temperature neutrals, creating highly reactive free radicals and ions. These reactive species enable many chemical processes to occur with low-temperature feed stock and substrates.

The atmospheric plasma system allows creation of uniform and homogenous high-density plasma at atmospheric pressure and at low temperatures using a broad range of inert and reactive gases. The APT process treats and functionalizes material surfaces in the same way as the vacuum plasma treatment process on a wide range of materials; and has unique advantages over the presently used corona, flame and priming treatment technologies. APT production equipment testing has been successfully performed for the treatment of various materials, including PP fiber, PP and polyethylene (PE) nonwovens, polyester fiber, Tyvek®, nylon, wool, textile yarn, oriented PP film, PE film, PE terephthalate (PET) film and polytetrafluoroethylene film. The surface energies of the treated materials increased substantially (without any backside treatment), thereby enhancing their wettability, printability and adhesion properties.

If APT produces a uniform discharge between electrodes, the system is defined as an APGD system. In the case of a nonuniform discharge, the system is known as a corona treating machine. Schematically, a system to treat films or textiles at atmospheric pressure has the structure of that shown in Figure 2 — from a feed roll, films are driven by the grounded roll in the plasma treatment and then to a collector.

Plasma is produced between two electrodes — one is the grounded roll and the other is the powered electrode connected to a high-voltage frequency power supply. In the case of a corona treating machine, plasma is developed in air medium. In the APGD system, the electrode is connected to gas in lets. A standard corona treating machine and an APGD system with individually designed electrodes were used for these investigations. A dielectric layer between the electrodes and an appropriate gas mixture as the plasma medium are used to obtain a uniform discharge.

Gas phase radicals abstract H from the surface and produce radical sites on the PP surface. Further reactions lead to formation of functional groups like peroxy, alkoxy, alcohols and other groups.[8]



2.5 Corona in Textile Industry

Textile manufacturers and end-users have been searching for ways to improve the surface properties of natural and man-made fibers. Specifically, there is a need to improve adhesion, wettability, printability and dyeability; as well as to reduce material shrinkage. The methods of modifying fiber properties to make polypropylene (PP) dyeable, including the process of copolymerization with polymers that can be dyed, have been evaluated.

Traditional latex systems and primers with low melt points have been used to coat fabrics to promote ink adhesion, heat-sealing and thermoforming performance. PP fibres have especially been the focus of research to enhance colorfastness properties for the material because of its excellent chemical resistance, high melting point, low cost and adaptability to many fabrication methods. To date, the poor dyeability of PP has limited optimization of its applications in the manufacturing of yarns and knit fabrics, upholstery fabrics and industrial fabrics. Fibers with polar functional groups can be dyed more easily than nonpolar fibers because polar groups will chemically bond with dye molecules. Because the molecular chains of PP are nonpolar and its surface is hydrophobic, the dye molecules will not bond chemically to the fibers. PP fiber is highly crystalline as well, which also restricts its dyeability.

Functional groups may be introduced onto the fiber surface by using gas plasma treatments, improving fiber surface properties without affecting the fiber's bulk properties. By creating a polar layer on the fiber surface, in reaction with functionality introduced, wettability of the fiber for dyeing is enhanced with hydrophylicity.

A novel atmospheric plasma treatment (APT) process has been developed using atmospheric plasma glow discharge (APGD) technology (Fig.2.3) as a result of studying the reaction mechanisms between plasma and fiber surfaces to optimize industrial system applications.

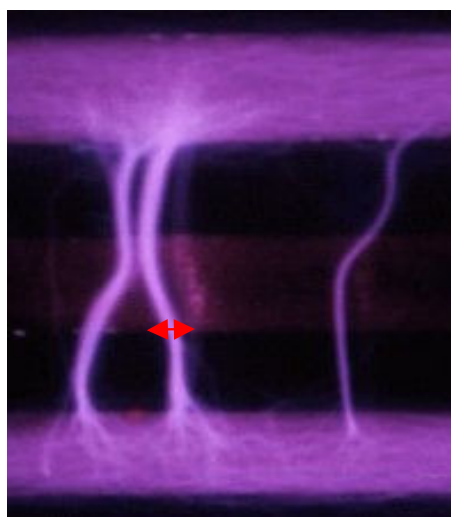


Fig. 2.3: Filamentary plasma charge 200 μm

The APT apparatus does not require any vacuum systems, produces high -density plasma and provides treatment of various fibres at low temperature while operating at atmospheric pressure. The wettability of various man-made and natural fibers has been dramatically increased by this process. Electron microscopy has shown that the surface of fibers after APT is uniformed and consistent, suggested treatment is homogeneous. APT has a cleaning effect that removes contaminants and increases the microroughness of the fiber (Fig.2.4)

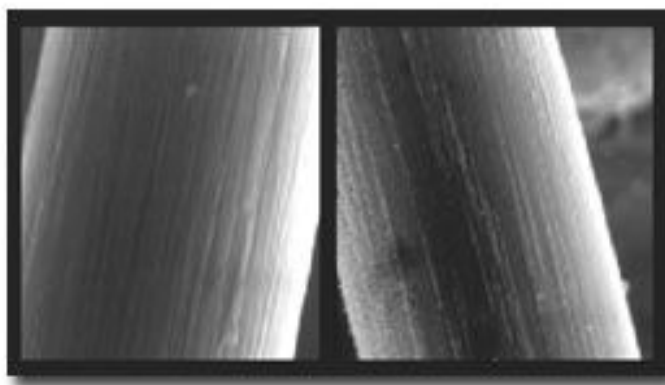


Fig.2.4: Plasma enhances the microroughness of fibers [8]

2.6 Other Methods of Plasma Treatment

Other method treated surface of textile materials is parallel electrodes corona system. It is method for treatment of internal and external surfaces of woven and nonwoven textiles and cords from organic and inorganic fibres with the aim to change surface properties of the fibres by the action of electrical plasma. The electrical plasma is produced by electrical discharges generated using a discharge electrode system that comprises at least two electrically conductive electrodes situated on the same side of the treated textile material inside of dielectric body.

The electrodes are energized by electrical voltage at a frequency from 50 Hz to 1 MHz an magnitude from 100 V to 100 kV, and electrical discharges take place in a working gas at a pressure ranging from 1 kPa to 1000 kPa above a part of the dielectric body surface, where the plasma is generated without a contact with conductive electrodes.

The conductive electrodes are situated in parallel with the part of dielectric body surface above that the plasma is generated. (See Fig.2.5)

The apparatus comprises the electrode system consisting of at least two electrically conductive electrodes, which are situated inside of a dielectric body and an auxiliary system of electrodes also is situated inside of dielectric body. (See Fig.2.6)

The electrode systems are situated on both sides of treated textile material and the electrical plasma is generated by electrical discharges in the vicinity of the dielectric body surface, where a part of the dielectric body insulating the electrodes each from other as well as from the electrical plasma is made preferably from a ferroelectric material.

The treated textile material is situated on the part of the dielectric body surface above that the plasma is generated or it is in motion along the part of the dielectric body surface above that the plasma is generated in a direct contact with this surface or in close vicinity of this surface, in such a way that the discharges electrodes of the electrode system are embedded inside the dielectric body on the same side of the treated textile material.

Such an electrode arrangement is characterized by the fact that all or the majority of electrical field lines enter and go out from the treated textile on the same side of the treated textile and by the fact that the discharge electrodes are not in contact with electrical plasma.

As a consequence, the electric field lines and the electrical discharge channels have the direction mostly parallel with the textile fibres surfaces and the electrode lifetime is not reduced by oxidation and erosion to due to a contact with the plasma and the due to the abrasion by the treated textile.

An alternating or pulsed electrical voltage of magnitude ranging from 1000 V to 100 kV and frequency ranging from 50 Hz to 1MHz is applied between the discharge electrodes serving to the discharge generation. The apparatus can operate over a wide pressure range from on the order of 1 kPa to the order of 1000 kPa, preferably at atmospheric gas pressure. [9]

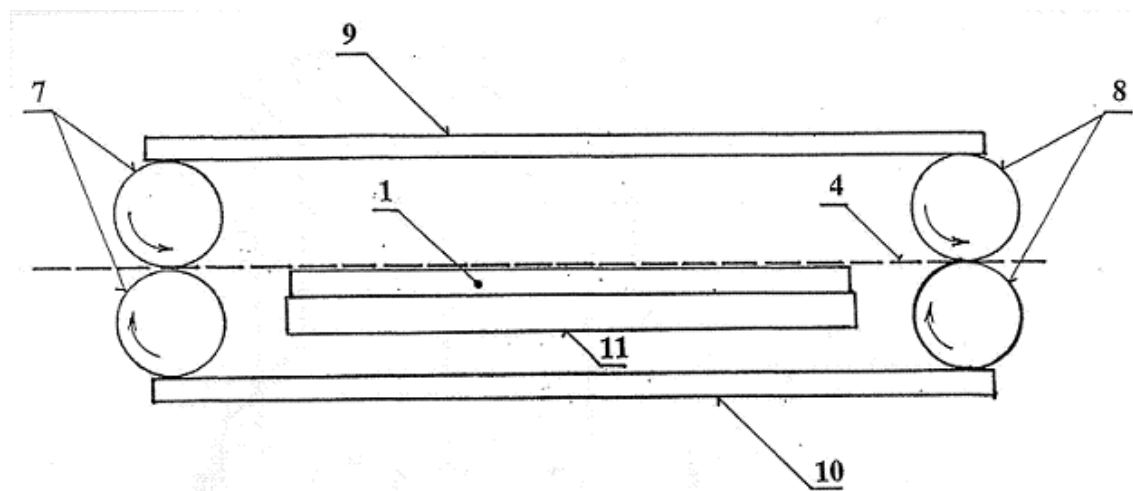


Fig.2.5: All units with parallel electrodes

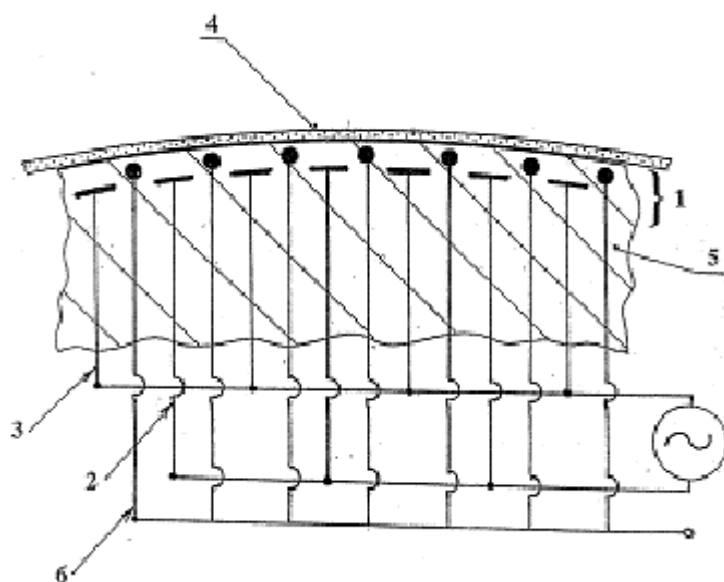


Fig.2.6: Two parallel electrodes with auxiliary electrode

2.7 Polypropylene Physical and Chemical Properties

Polypropylene or **polypropene (PP)** is a thermoplastic polymer used in a wide variety of applications (see tab.2.1), including food packaging, textiles, laboratory equipment, loudspeakers, automotive components and polymer banknotes. An addition polymer made from the monomer propylene, it is unusually resistant to many chemical solvents, bases and acids [10]. Most commercial polypropylene has a level of crystallinity intermediate between that of low density polyethylene (LDPE) and high density polyethylene (HDPE); its Young's modulus is also intermediate. Although it is less tough than LDPE, it is much less brittle than HDPE. This allows polypropylene to be used as a replacement for engineering plastics, such as ABS. Polypropylene has very good resistance to fatigue, so that most plastic living hinges, such as those on flip-top bottles, are made from this material. Very thin sheets of polypropylene are used as a dielectric within certain high performance pulse and low loss RF capacitors.

Tab 2.1: Overview of PP properties

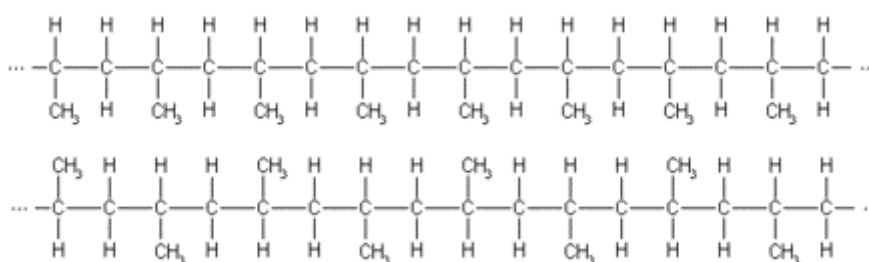
Chemical name	poly(1-methylethylene)
Synonyms	Polypropylene; Polypropene; Polipropene 25 [USAN]; Propene polymers; Propylene polymers; 1-Propene homopolymer
Chemical formula	$(C_3H_6)_x$
Monomer	Propylene (Propene)
CAS number	9003-07-0 (atactic) 25085-53-4 (isotactic) 26063-22-9 (syndiotactic)
Density	Amorphous: 0.85 g/cm^3 Crystalline: 0.95 g/cm^3
Melting point	173 °C
Degradation point	286 °C


Food containers made from it will not melt in the dishwasher and do not melt during industrial hot filling processes. For this reason, most plastic tubes for dairy products are polypropylene sealed with aluminium foil (both heat-resistant materials). After the product has cooled, the tubes are often given lids of a cheaper (and less heat-resistant) material, such as LDPE or polystyrene.

Such containers provide a good hands-on example of the difference in modulus, since the rubbery feeling of LDPE with respect to PP of the same thickness is readily apparent.

A rubbery PP can also be made by a specialized synthesis process. Traditional rubber can be melted and recycled, making it a thermoplastic elastomer.

An important concept in understanding the link between the structure of polypropylene and its properties is tacticity. (see fig. 2.7) The relative orientation of each methyl group (CH_3 in the figure at left) relative to the methyl groups on neighboring monomers has a strong effect on the finished polymer's ability to form crystals, because each methyl group takes up space and constrains backbone bending. Unlike most other vinyl polymers, useful polypropylene cannot be made by radical polymerization. The material that results from such a process has methyl groups arranged randomly, and so is called atactic. The lack of long-range order prevents any crystallinity in such a material, giving an amorphous material with very little strength and few redeeming qualities.

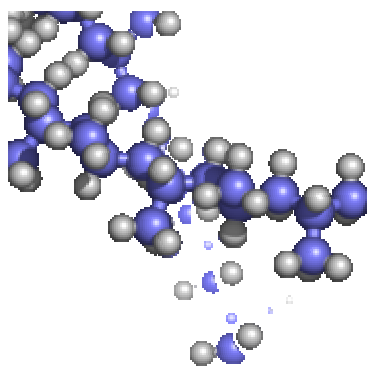


 **Fig.2.7:** Short segments of polypropylene, showing examples of isotactic (above) and syndiotactic (below) tacticity.

A Ziegler-Natta catalyst seems to be able to limit incoming monomers to a specific orientation, only adding them to the polymer chain if they face the right direction.

Most commercially available polypropylene is made with titanium chloride catalysts, which produce mostly isotactic polypropylene (the upper chain in the figure above). With the methyl group consistently on one side, such molecules tend to coil into a helical shape; these helices then line up next to one another to form the crystals that give commercial polypropylene its strength.

More precisely-engineered Kaminsky catalysts have been made, which offer a much greater level of control. Based on metallocene molecules, these catalysts use organic groups to control the monomers being added, so that a proper choice of catalyst can produce isotactic, syndiotactic (see fig.2.8), or atactic polypropylene, or even a combination of these. Aside from this qualitative control, they allow better quantitative control, with a much greater ratio of the desired tacticity than previous Ziegler-Natta techniques. They also produce higher molecular weights than traditional catalysts, which can further improve properties.



 **Fig.2.8** A ball-and-stick model of syndiotactic polypropylene.

To produce a rubbery polypropylene, a catalyst can be made which yields isotactic polypropylene, but with the organic groups that influence tacticity held in place by a relatively weak bond. After the catalyst has produced a short length of polymer which is capable of crystallization, light of the proper frequency is used to break this weak bond, and remove the selectivity of the catalyst so that the remaining length of the chain is atactic.

The result is a mostly amorphous material with small crystals embedded in it. Since each chain has one end in a crystal but most of its length in the soft, amorphous bulk, the crystalline regions serve the same purpose as vulcanization.

Polypropylene fibres have such excellent properties as low specific weight (0,91g/cm³ only!), high strength (42-53 cN/Tex), and good resistance to acids and alkalis and they also possess good thermal resistance and anti-bacterial properties. PP fibres have been widely used in sports wear and industrial textiles such as for filtration, composites, biomaterials and electronics. In these applications, the surface properties of the fibres are particularly important.

The poor wettability (0,05% at 20°C) and dyeing ability have, however, limited the applications of these fibres in garments and other industries. It is of importance to improve the wettability of PP fibres for many applications. Chemical treatment has been traditionally used to modify fibre materials but it has some disadvantages, such as influence on bulk properties and environmental pollution. As a type of environmentally friendly physical surface modification technology, plasma treatment can also be used to treat textile materials. Plasma treatment is a simple process without any pollution.

Moreover, plasma modification only takes place on the upper-most surface of fibres and will not change the bulk properties [11].

2.8 Fabric Softeners

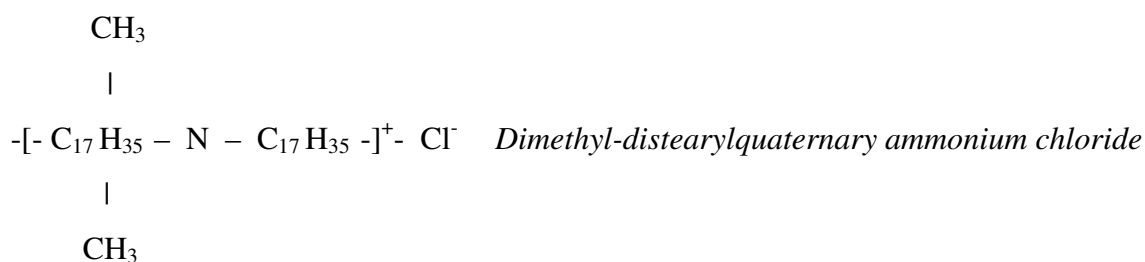
This class of textile finish was developed to improve the hand of harsh textiles such as might be produced by permanent press resins, heat setting of synthetics or the bulking of acrylics with steam. These compounds act to produce softness on textiles by their long hydrocarbon tail that penetrates the fabric interstices and allows a certain amount of slippage.

There is also an increase in the tactile sensation of hand as the skin may slide over the surface of the fabric more smoothly. There are three classes of fabric softeners, each with its own unique set characteristics.

Anionic softeners: usually sulfonated and negatively charged fatty acids and oils. They are required to be padded on because of a lack of affinity for the fiber. Used by the industry most commonly for cotton, cellulose and silk.

Cationic softeners: the most common type sold commercially for domestic use. These softeners have an affinity for the fabric and require no padding.

Tending to yellows with age, they on persentage usage, will causes a buildup of fatty acids in fabric interstices, producing water-repellency on continued use. This property may be undesirable, especially on diapers and the like, a common use for softeners. Those softeners containing quaternary ammonium compounds confer incidental antibacteriostatic properties.



Nonionic softeners: these softeners lack affinity for negatively charged fabrics. More recent nonionics, especially in spray aerosol packaging, have antistatic properties and are sold commercially. They are typical fatty acid structure.



As may be seen from softeners and their structure, the fatty acids tail has a great deal to do with the softening of textiles. In addition they like detergents, have the effect of reducing surface tension of water by virtue of their charges, thus making it easier to penetrate the fabric [11].

In addition to softening the tactile sense of the fabric, softeners by their virtue of long hydrocarbon tail structure can also reduce of presence of wrinkles by allowing the fibers to slip, thus avoiding jamming and resulting wrinkles. This is especially important in knits. In addition, they can confer an element of static resistance if they are properly terminated with sulfonated or nitrogen-containing moisture attractors.

2.9 Measuring of Contact Angle

Contact angle (CA) describes the shape of a liquid droplet resting on a solid surface. When drawing a tangent line from the droplet to the touch of the solid surface, the contact angle is the angle between the tangent line and the solid surface.

If a liquid with well-known properties is used, the resulting interfacial tension can be used to identify the nature of the solid. This technique is extremely surface sensitive, with the ability to detect properties on monolayers.

When a droplet of liquid rests on the surface of a solid, the shape of the droplet is determined by the balance of the interfacial liquid/vapor/solid forces. CA can be used to detect the presence of films, coating, or contaminants with a surface energy different from that of the underlying substrate. When a droplet of high surface tension liquid is placed on a solid of low surface energy, the liquid surface tension will cause the droplet to form a spherical shape (lowest energy shape).

The measurement provides information regarding the bonding energy of the solid surface and surface tension of the droplet. Because its simplicity, CA has been broadly accepted for material surface analysis related to wetting, adhesion, and absorption. Traditionally, CA utilizes a sample stage to hold the substrate, a string to apply a droplet of liquid, a light source to illuminate the droplet, and a set of optics for magnifying the image for observation. (An instrument such as a goniometer is typically used.)

After placing a droplet of liquid (1-25 μL) onto the surface, the outline of the droplet is studied through the magnifier. The operator positions the tangent line from the droplet to the touch of the surface. A protractor within the optics then provides a reading of the contact angle.

Unfortunately, operator subjectivity often interferes with the accuracy of the technique. Modern contact angle systems (see fig.2.9), however, adopt precision optics and charge-couple device (CCD) cameras with image processing hardware and software to enhance the performance of contact angle analysis, making it easier, quicker, and more precise.

A droplet of liquid is dispensed onto the substrate surface (manually or automatically), and a CCD camera reveals the profile of the droplet on the computer screen. Software calculates the tangent to the droplet shape and the contact angle.

Data and the image are collected, analyzed, and saved on computer. Surface preparation has become very important in a variety of industries. In many cases, surface cleanliness is a vital concern prior to finishing or processing. Modern contact angle instruments with computerized video processing offer a reliable, accurate, and repeatable method to quantify cleanliness levels of surfaces [12].

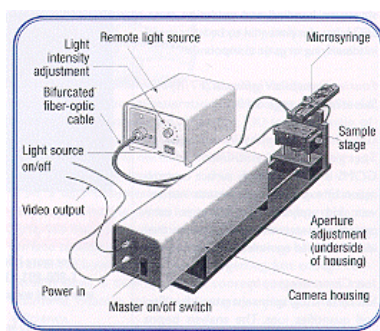
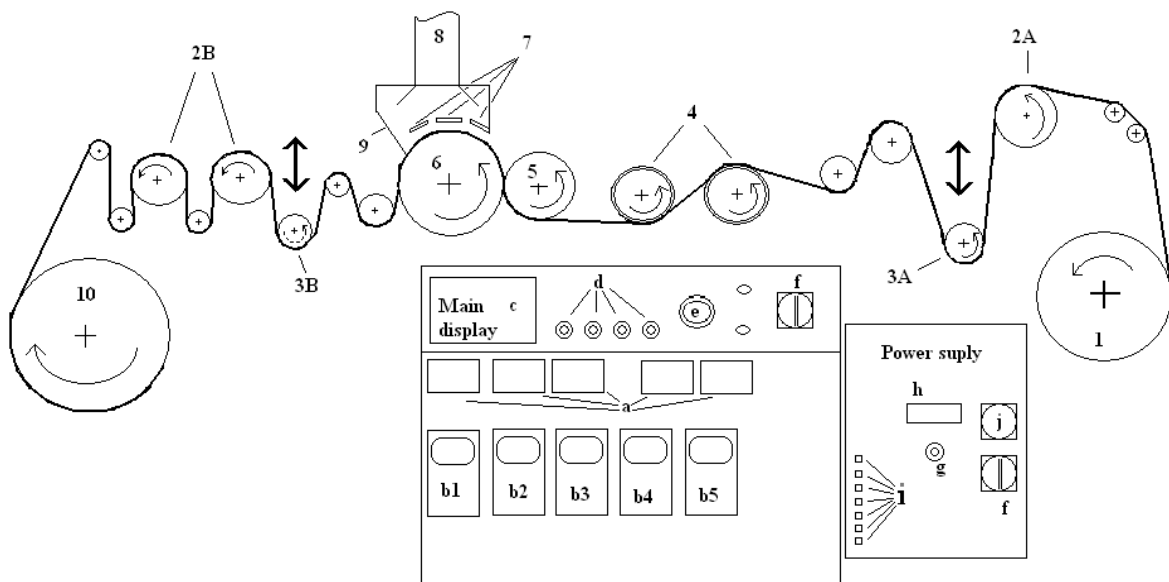


Fig.2.9: Equipment for measuring contact angle [12]

3. Sequence in Corona Unit. (see scheme 3.1)

Everything begins when 2 main switches (f) are rounded to place on. One of them is special for Power supply (PS). All LED diodes (i) signalize that all systems and functions are going well. They are informed us about high temperature of electrodes, failures of system, acceptance that machine is ready, electrodes are in use or not and exhausting.

With operating controller of PS(g) is possible to set how much power is used to treatment. Range is from 0 to 1,5 KW. It means how powerfull the treatment will be.



- 1) Cylinder with delivery of material
- 2) Regulated cylinder function
- 3) Controlling cylinder
- 4) Expansible cylinder
- 5) Pressure roller
- 6) Lower electrode

- a) PLC regulators
- b) Display for only 1
- c) Main display
- d) Operating controllers
- e) Safety quick stop
- f) Main switch on/off

- | | |
|------------------------------|----------------------------------|
| 7) Upper electrode | g) Operating controller |
| 8) Exhausting | of Power Supply |
| 9) Protective shelter | h) Controlling display of |
| PS | |
| 10) Collector | i) LED diodes |
| | j) Signalizator of errors |

Scheme 3.1 Corona discharge machine by Softal

Controlling display of PS(h) shows the real value of power. When the signalizator of errors (j) is flashing, machine automatically stops the way of power to electrodes. On the control panel is placed Operating controllers (d). Where the velocity of material is set, rotating speed of expansible cylinder (4) and other functions are optimized. Values of this function are possible to follow in real time on Display for only 1 function (b). All functions are graphically displayed in main multi functional LCD display (c).

PLC s(a) are a brain of all the systems. They are kept all functions in process, regulating drawing of the mechanism and controlling all functions. When it is necessary to stop very quickly the whole unit, there are three buttons for Safety quick stop (e) in each side of the machine. If one of these buttons is pressed the whole machine is immediately stopped.

The flowing of the material is beginning on cylinder with delivery of material (1). Next step is regulated by the cylinder RC (2) which is with controled cylinder CC (3) and with PLC (a) guardian tension of fabric material. When the CC is going down (it means that friction is less and it needs to decline the entrancy speed). PLC declines rotational speed of RC. There is the opposite process validated.

Other step is expansible roller (4). Knitted fabric has a tendency that when there is more friction, fabric has less wide in this place. Therefore it needs to prepare the constant width before coming into the electrode. Very close to these rollers is a pressure roller (5), which is aligning the material to the lower electrode (6). Between lower electrode and upper electrode (7) is plasma discharge, which is treating fabric material. By this process ozone O_3 is created, which is necessary to be exhausted. For

this purpose there is the exhausting system (8). For safety of people working with this machine there is the protective shelter (9).)

For creating plasma discharge is needed high voltage combined with high electric current. This combination is deadly dangerous. After this step is another regulation system which is regulated by output from treated part. After these all steps is the treated fabric wounded on a collecting cylinder. There is a picture of the whole corona unit for better imagination.(see fig.3.1)



Fig. 8. Whole unit of corona treating machine

4. Experimental Part

4.1 Materials

For this project were used knitted PP materials from fy. Moira (CZ), which is the producer of sports clothes and accessories for sportmen, more in www.moira.cz. For making sure that it is really PP material was used Melting test: Our testing sample was started to melt in 168°C. This temperature is shown that it can be PP. And the test with concentrate H_2SO_4 . Testing specimen was submerged to concentrate H_2SO_4 with warming up to 60°C. Most of synthetic materials have been damaged and completely dissolved but our materials were acid resistant and this shows that this is PP material again.

4.2 Treatment Testing Sample

The first step pointed out that some treatment were used on tested materials. There was used the drop test.

Drop test

Consists of the buret tube where destilated water is used. 1cm under the buret is the testing specimen. The time is measured when drop of water is fallen down to fabric. In other case the time is stopped when no water is on the surface of sample.

Drop test showed that testing sample is hydrophilic and it means that some treatment was applied. Therefore it is necessary to wash the fabric before testing.

Washing procedure

Was made according to the norm: NP EN ISO 105 C06 test C25

After washing of all samples, water was rinsed. Finally, the sample was placed to a drying machine at the temperature 50°C. All specimens were there for 24 hours. After this time the specimens were dried and prepared to use.

All samples of fabric were totally hydrophobic.(in appendix, I would say that the time of 10 minutes more was without any changes of a drop of water on fabric, only for my information. I tested it during 2 hours and there was no change of drop of water on fabric). In this moment, the fabric behavior was similar or equal as raw PP material.

4.3 Treatment by Corona Discharge Plasma

The second step was including the modification by corona discharge plasma. Firstly, parameters were set and optimized as value of power supply and velocity of fabric through plasma reactor. This step was difficult because if velocity is low and the power is too high, it is happen that the sample will be destroyed. As we know PP fibres melt in the point of 168°C. And over this temperature, the fabric is devaluated. The opposite parameters such as high velocity and low value of power supply cause that treatment is not sufficient as it can be. Therefore it is necessary to find optimal parameters. For testing PP material were found out optimal parameters 0,5 [KW] for power supply and 2,5 [m/min] for velocity.

After setting of these parameters in corona machine, the first sample was treated . The treatment was always done in face side. There were three different fabrics. (See tab. 4.1)

Tab. 4.1: Showing kind of sample, number of treatment

Name	Treatment	Called
Blue smooth	1,2,3 one side and un(treated)	mh (1..3)
	1,2,3 both side and un(treated)	mh (1..3+1..3)
White and blue	3 one side	bm (3)
	2,3,4 both side and un (treated)	bm (2..4+2..4)
Blue alteration	1,2,3 one side and un(treated)	mp (1..3)
	1,2,3 both side and un(treated)	mp (1..3+1..3)

These three samples were taken to pass by corona treatment. The number of treatments is from once on the one side to 4 times on the both sides.

Other three samples are made from the same material PP but every of these samples had another density of link. Therefore each knitted sample has another parameters. (See tab.4.2)

Tab. 4.2 Showing kind of sample, number of treatment

Name	Treatment	Called
Dark blue	1,2..5) one side and un(treated)	tmavomodry (tm)(1..5)
	1,2,3 both side and un(treated)	tmavomodry (tm)(1..3+1..3)
Blue	1,2,3...6 one side	svetlomodry (sm)(1,2...6)
	1,2,3,4 both side and un treated	svetlomodry (sm)(1..4+1..4)
Orange	4,5,6 one side and un(treated)	oranz (o)(4..6)
	2,3,4 both side and un(treated)	oranz (o)(2..4+2..4)

4.4 Problems with Treating

Few minutes after start of the corona machine, it happens that uniformity of plasma discharge is very bad. It means, that one discharge is stronger and bigger as the others. This unique discharge can cause any burning places in PP material (see Fig.4.1) and the fabric is by this way devaluated (see Fig. 4.2). Therefore it is necessary to take the unit go on. After 4-5 minutes the uniformity of discharge is much more better and these unique discharges disappeared. After this time machine is prepared to work.

The other problem is, when the machine is working longer time than one hour. The rotating electrode becomes too hot for treating the PP materials.

The material smelled after melting and the surface was hard to touch. These defects very clearly show that material started to melt on the surface. And all these changes of material properties are undesirable and nonreversible processes.



Fig. 4.1: There is uniform and homogenous plasma discharge with an atmospheric plasma surface treatment system.

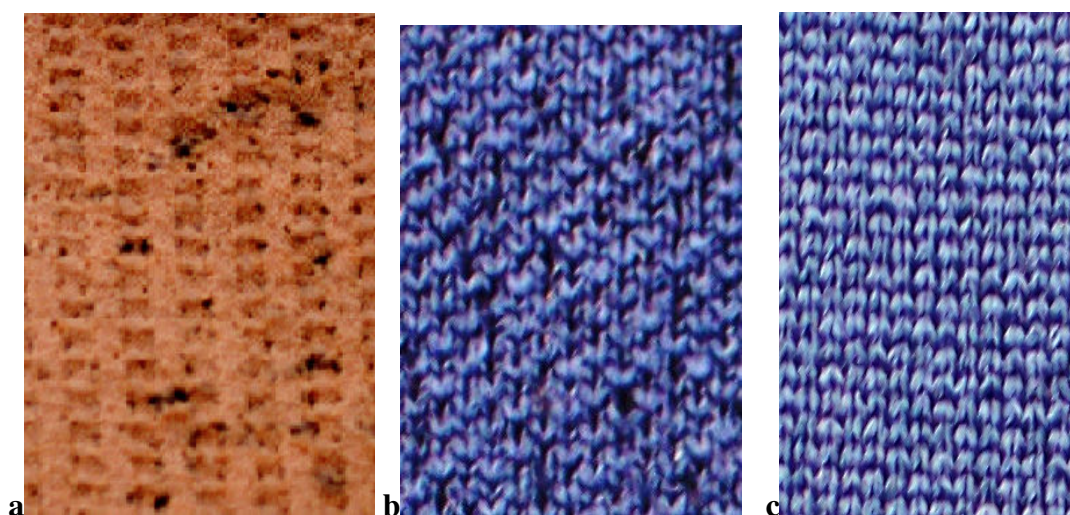


Fig. 4.2: a),b)strong devaluated knitted PP fabric by unique discharge c)treated knitted fabric without some damaging

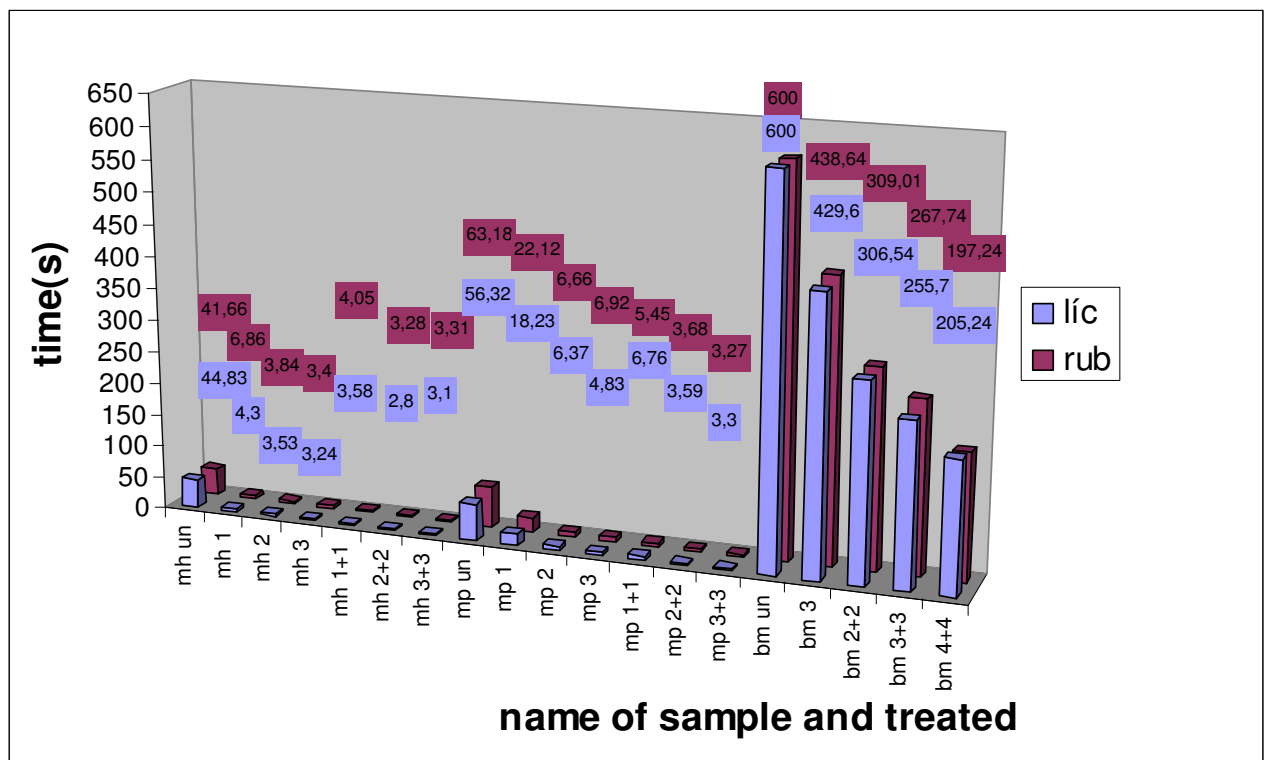
4.5 Measurement of Treated Specimens

The samples after treatment have to be measured so soon as it is possible. The effect after treatment is going to less. For punctuality of the measurement it was measured in the day of treatment. For measuring of wettability of water was used the drop test which is describes upper. Testing was done on the both sides of fabric. The results are in graph 4.1. and graph 4.2.

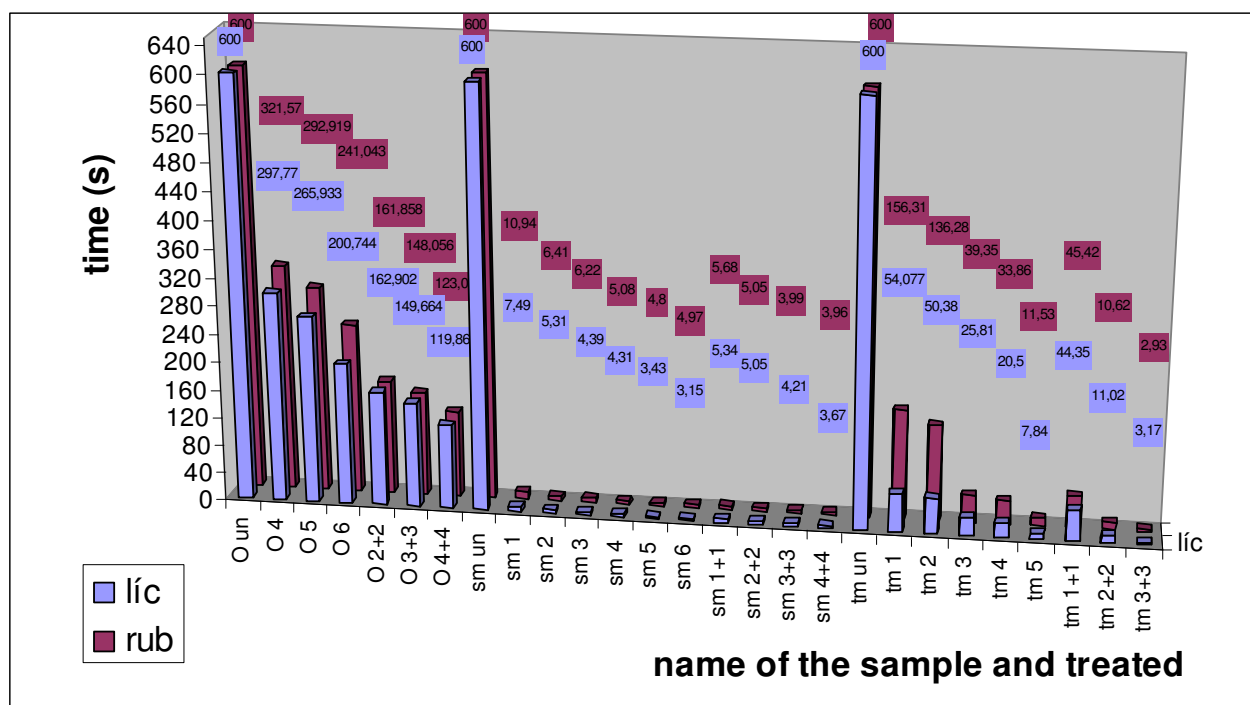
4.5.1 Wettability of Testing Sample

In axis Y is recorded the time in seconds, which a drop of the water needs for going through the fabric material. Axis X explains which fabric, single or double side and which number of treating was used. In front of row is a plotting graph of measuring face side. At the back of row is plotting graph of measuring backside. Over each column in graph there is the value of wettability. This value is average of 10-15 measurements. In blue background it is for face side and the pink background is for backside. In each sample was improved the wettability. Special attention is deserved for specimen called sm (see graph 4.2). Untreated knitted fabric has wettability more than 600 sec. After the first treatment, the average time is only 7,49 sec for treated side and 10,94 sec for untreated side.

After this measurement was done another test. All samples were washed again according the norm NP EN ISO 105 C06 test C25. Then was made the drop test. Results are that all knitted fabric had the time more than 600 sec. From this result it is clear that washing had also degraded the effect and the PP material becomes hydrophobic again.



Graph 4.1: Dependence of water wettability on time



Graph 4.2: Dependence of water wettability on time in other samples

4.5.2 Resulting Drop Test after Repeated Washing

After the resulting drop test, all samples were washed again according to standardized norm **NP EN ISO 105 C06 test C25**. Then testing samples were evaluated by the drop test. Results showed that all samples are more hydrophobic in table 4.3.

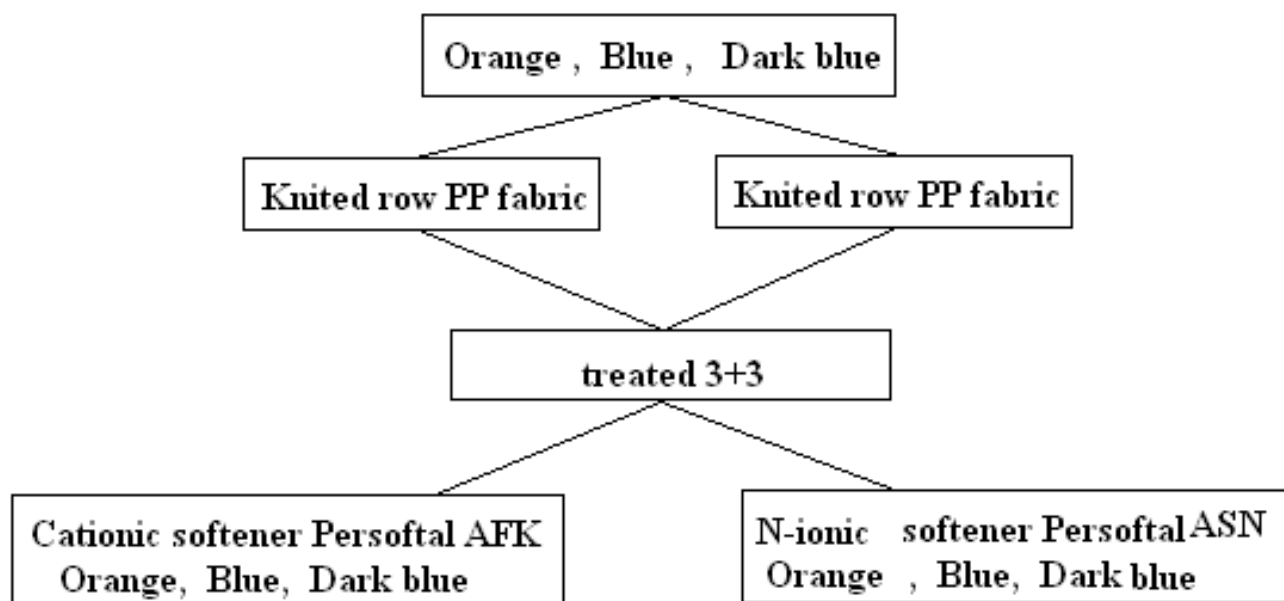
Tab. 4.3: Testing sample and its time in Drop test

Name	Treatment	Time
Dark blue	1,2..5) one side and un(treated)	> 600 sec
	1,2,3 both side and un(treated)	> 600 sec
Blue	1,2,3...6 one side	> 600 sec
	1,2,3,4 both side and un treated	> 600 sec
Orange	4,5,6 one side and un(treated)	> 600 sec
	2,3,4 both side and un(treated)	> 600 sec

4.5.3 Using of Softeners in Treated PP Knits

The first step in this experiment was to take two rows of knitted PP fabrics from each colour (dark blue, blue, orange), then we continued to treat by Corona machine.

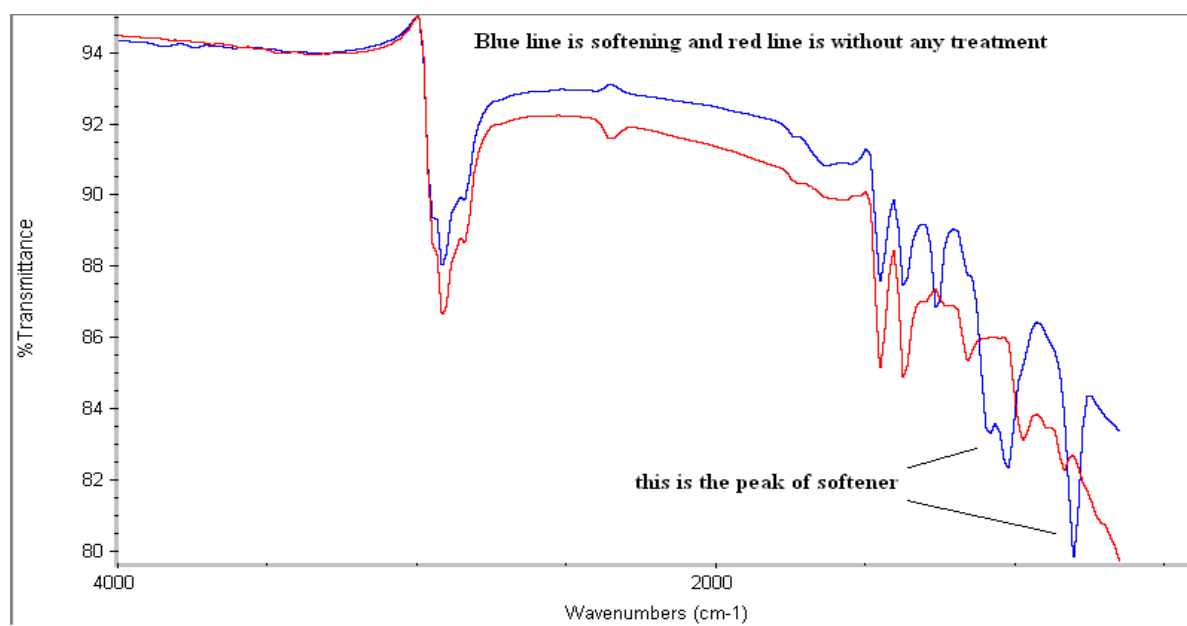
Each of samples was treated for 3 times on both sides. Now there are two groups with same samples but there is another softener. According to scheme 4.1.



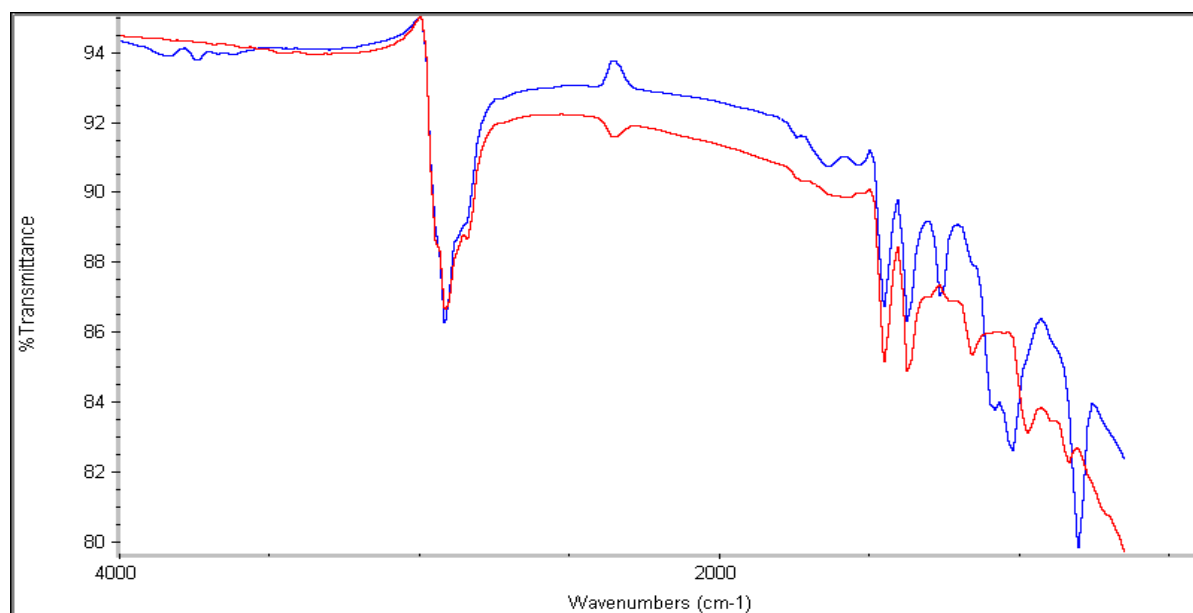
Scheme 4.1. used process

This six samples passed the drop test and the result was that each of these samples has wettability time more than 600 seconds. Another test was the test in Fourier Transformance InfraRed(FTIR).

If the graph 4.3. and graph 4.4 are compared , there is not difference. Only in graph 4.3 after washing is peak a little smaller and it means that a small amount of softener disappeared during the washing process.

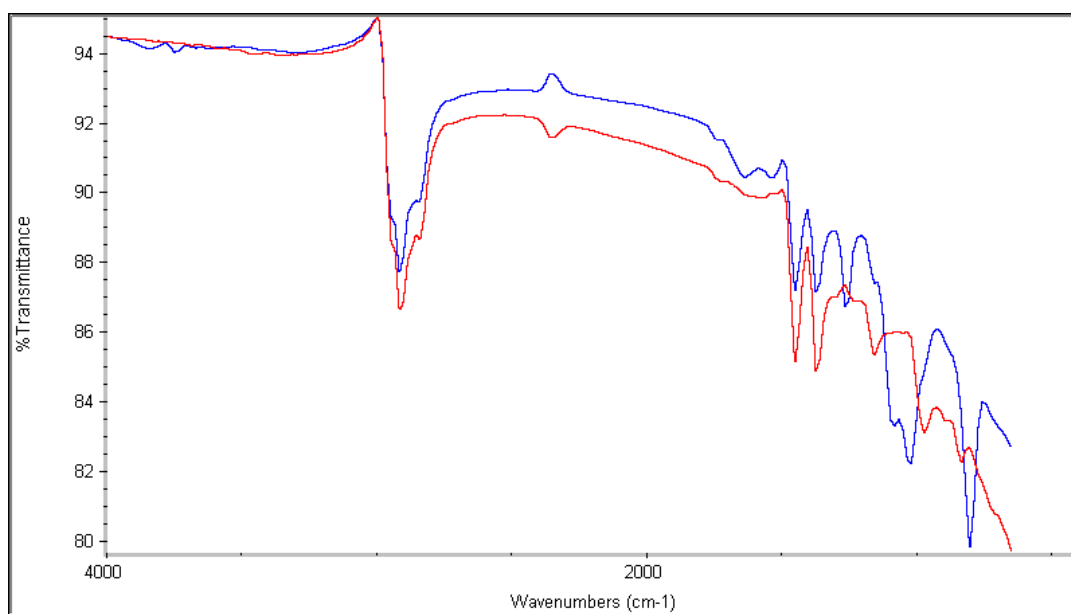


Graph 4.3: Using cationic softener before wash

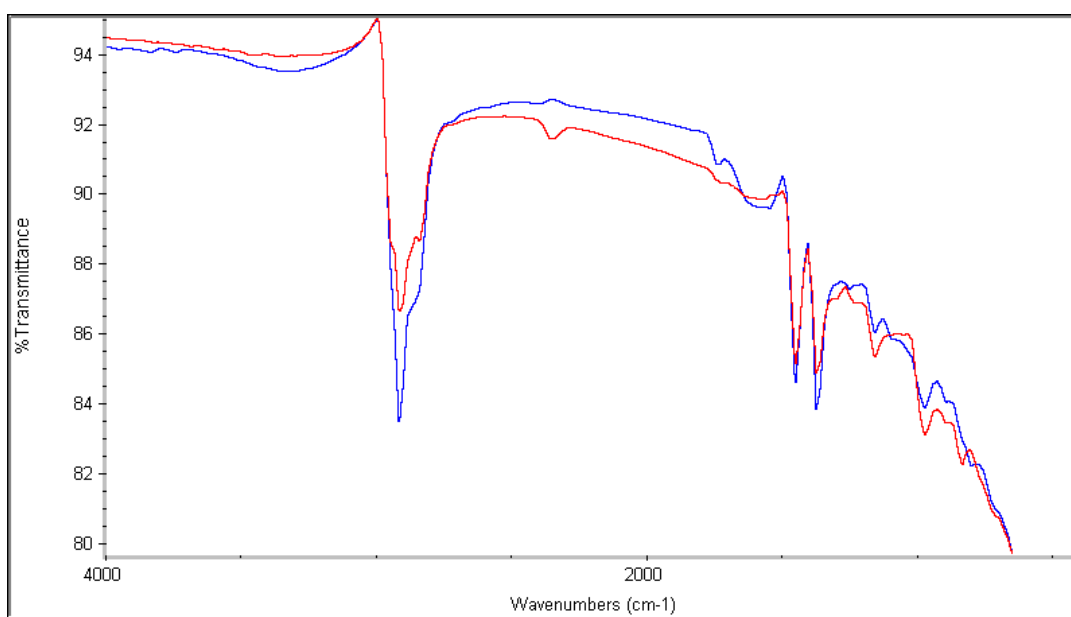


Graph 4.4: Using cationic softener after wash

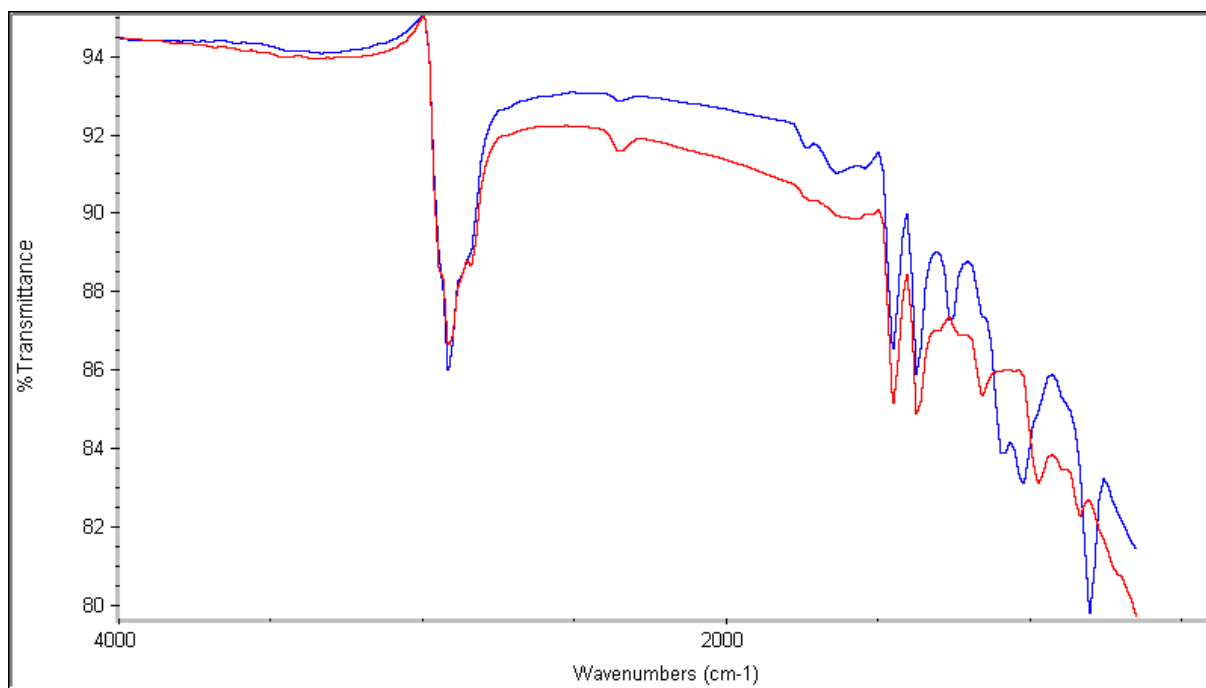
After comparing N-ionics (see graph 4.5. and graph 4.6), situation is completely opposite than in Cationic case. In graph, after one washing the peak of softener is completely removed and it means that N-ionic softener was taken out during washing process. Therefore to other experiment it is better to choose only cationic softener. Next testing is about washing of 2,3,4,5,10 times and comparing how much softener disappeared after each washing process. (See graphs 4.7, 4.8, 4.9, 4.10, 4.11).



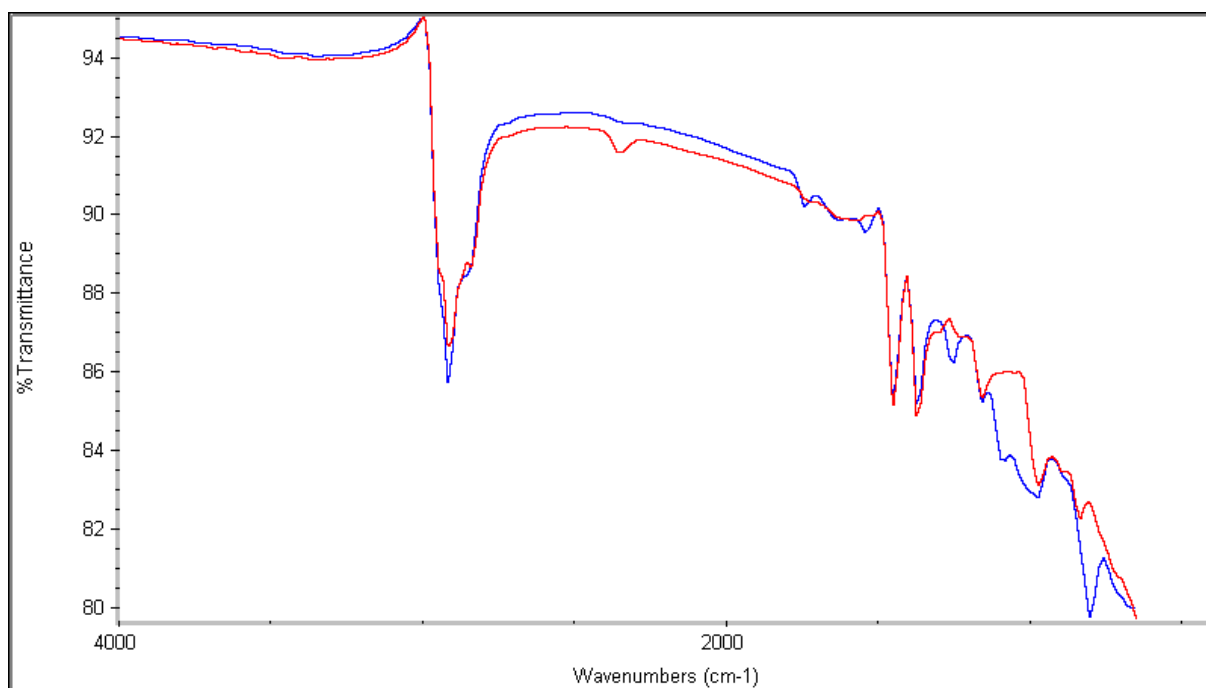
Graph 4.5: Using N-ionic softener before wash



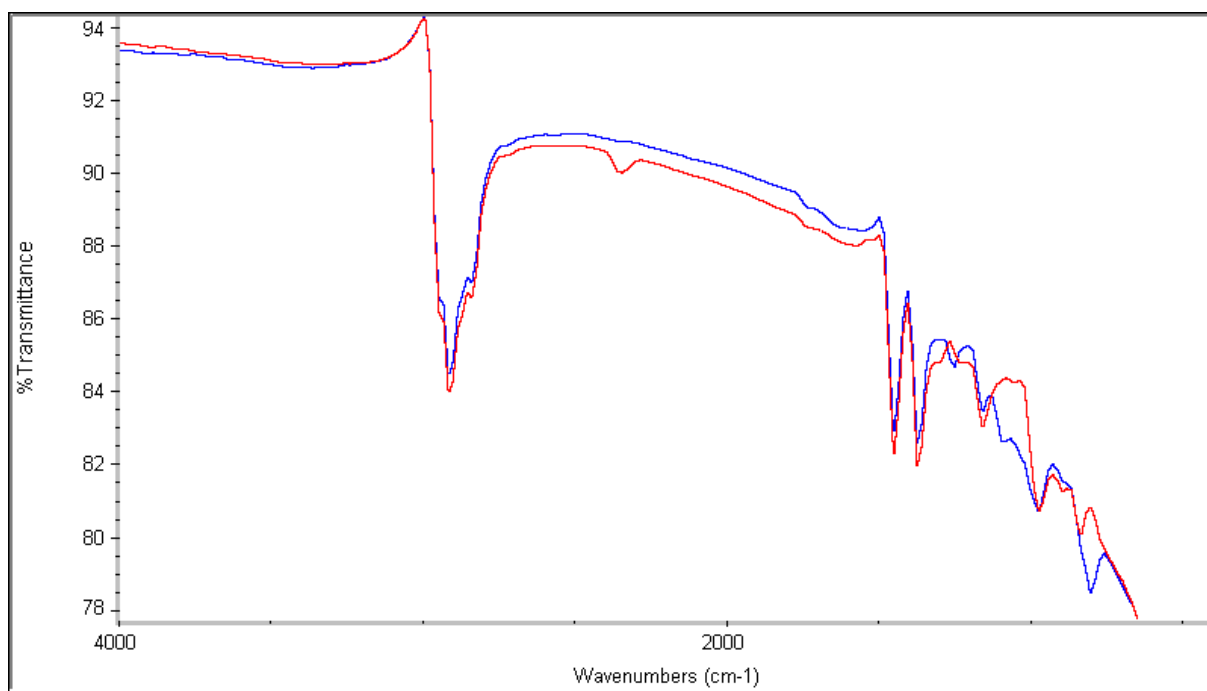
Graph 4.6: Using N-ionic softener after wash



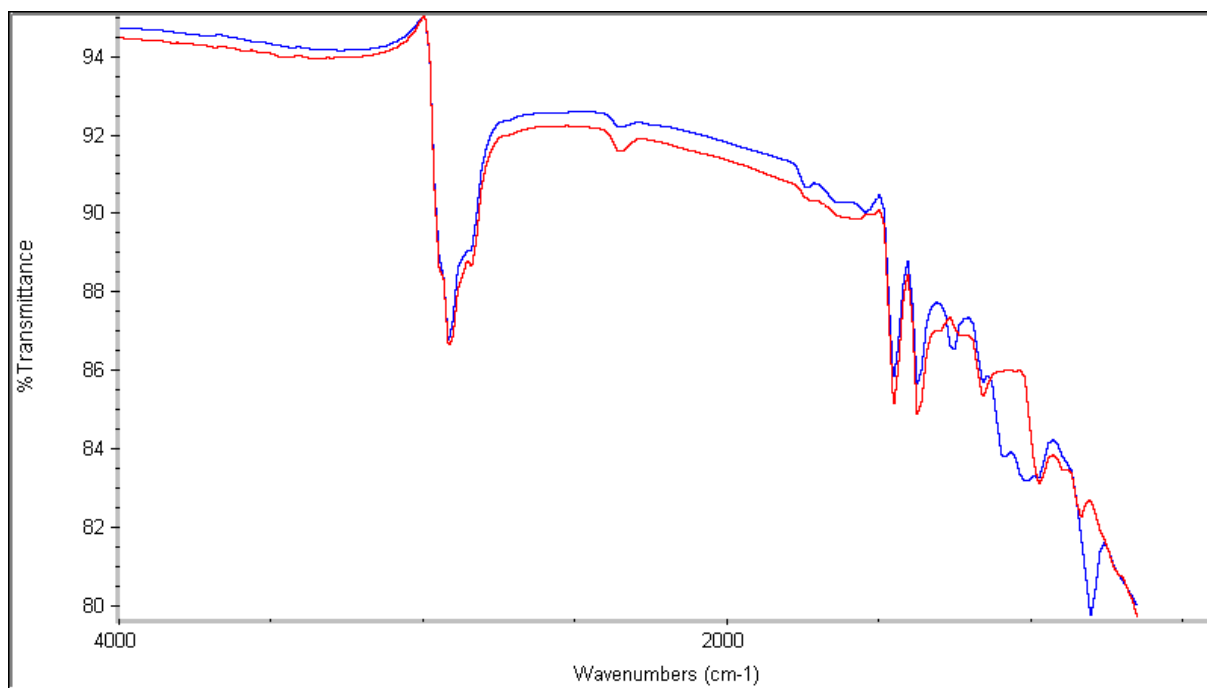
Graph 4.7: Cationic softener fabric after the second washing



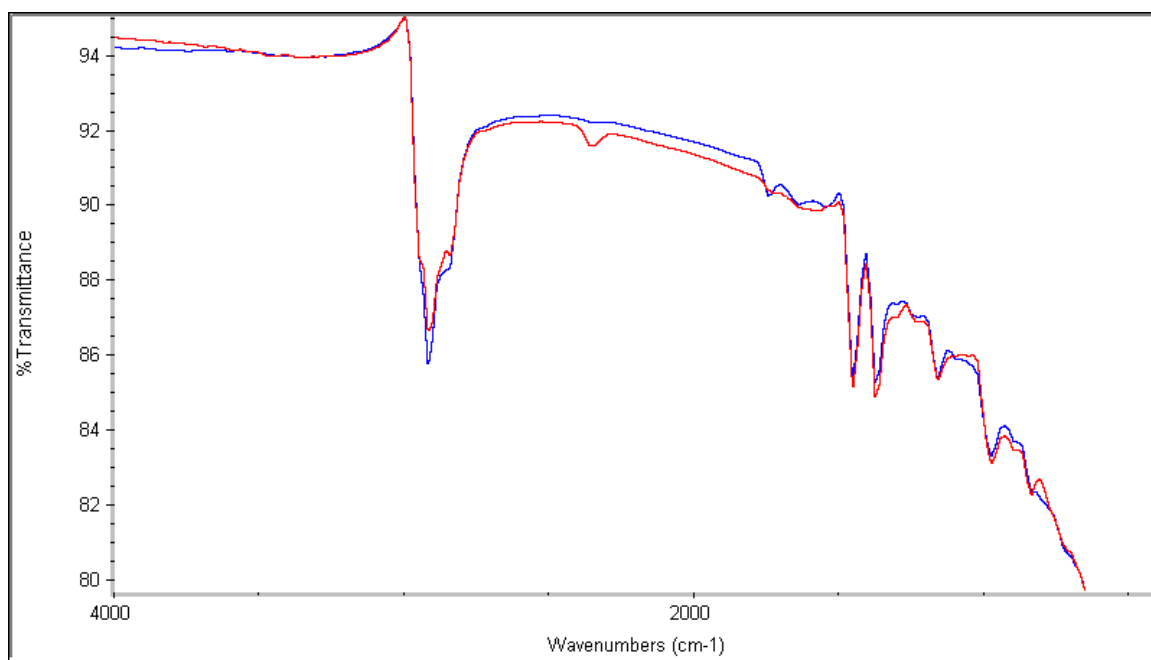
Graph 4.8: Cationic softener fabric after the third washing



Graph 4.9: Cationic softener fabric after the fourth washing



Graph 4.10: Cationic softener fabric after the fifth washing

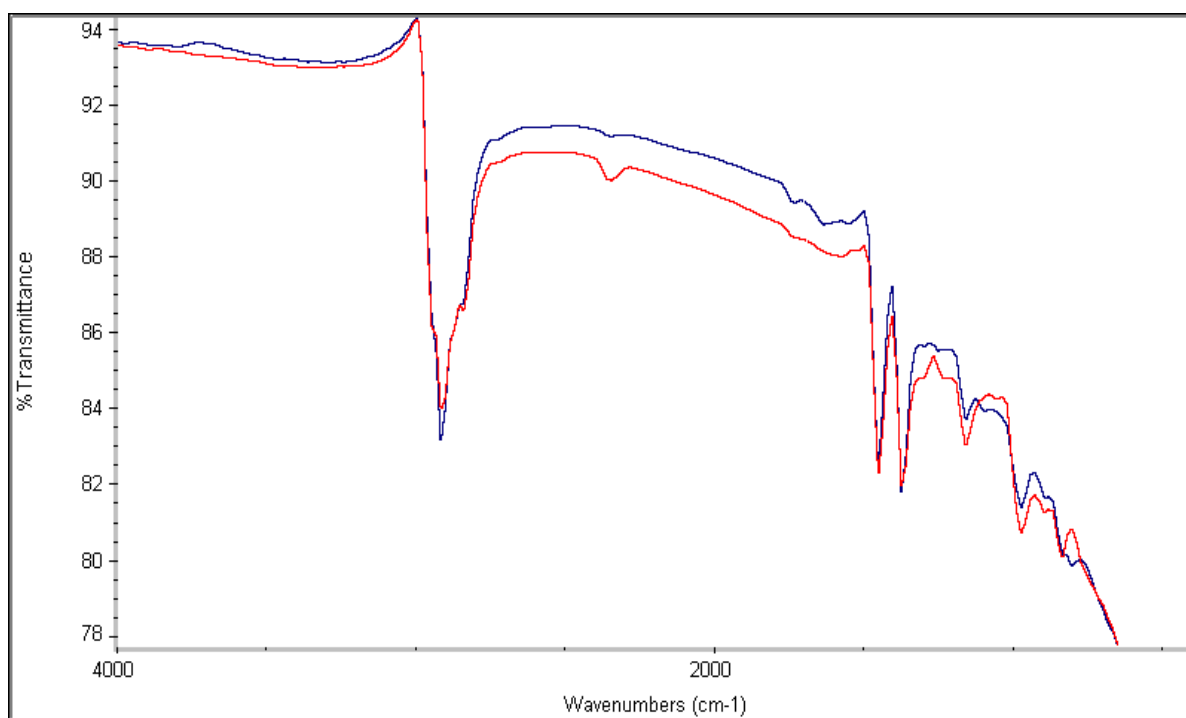


Graph 4.11: Cationic softener fabric after the tenth washing

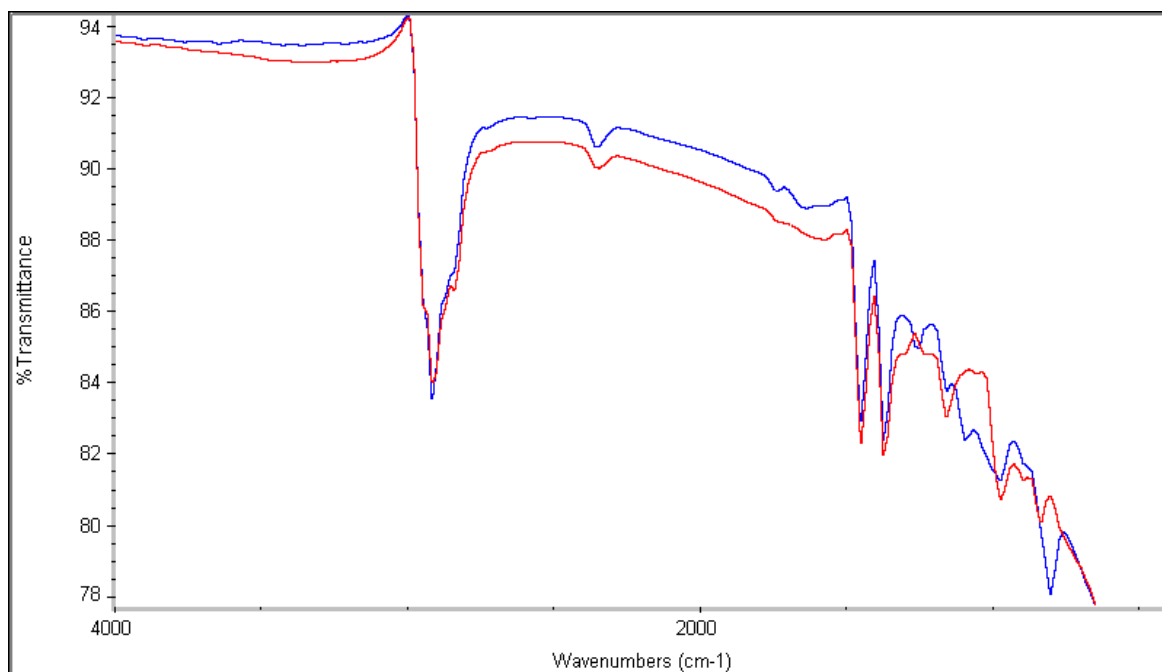
Results of other treated (orange, blue, dark blue) fabric samples were very similar therefore there is shown only one of them. This sixth graph (see graphs 4.5, 4.7, 4.8, 4.9, 4.10, 4.11) exposes sequential decrease of softener in fabric.

The next three graphs 4.12, 4.13, 4.14.) inform us about using of softener without corona treatment application. As the first graph shows the cationic softener did not catch on PP fabric. So it is clear that using of corona is the best way how to improve PP properties.

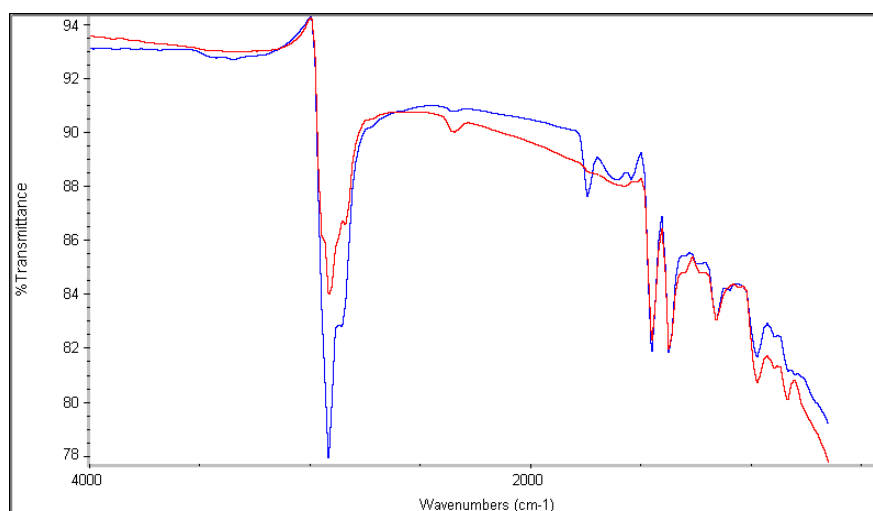
Little strange situation is in using of N-ionic softener where is a small amount of that (see graph 4.13). But it was lost during the washing process. (see graph 4.14)



Graph 4.12: Using cationic softener without corona treatment



Graph 4.13: Using N-ionic softener without corona treatment before wash



Graph 4.14: Using N-ionic softener without corona treatment after wash

4.5.4 Measuring of Contact Angle

Contact angle was measured by equipment from fy. Dataphysics OCA. (see fig. 4.3). The dynamic method was used. It means that the contact angle of a drop of water was measured after it fell on the surface of the fabric and it was measured for the next 100 seconds.

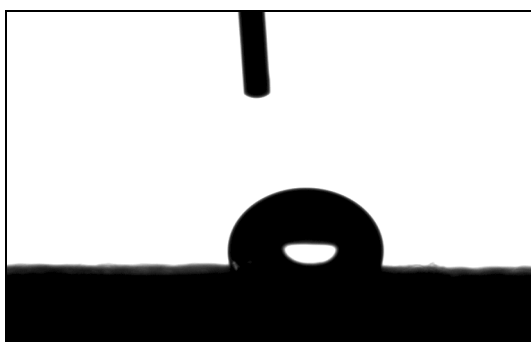


Fig.4.3 Picture by CCD camera

The whole system takes one picture for 0,08 sec. In time of 100sec it means that there are 1250 pictures. It is necessary, because a drop of water is going to fabric and this dynamic method is able to catch all changes in contact angle of drop.

System of lenses magnify the real picture and CCD camera takes pictures to Personal computer with applicable software, which is evaluation and it automatically measures the contact angle.

In graphs, there is value of contact angle and his change shown by polynomial regress, Sometimes it happens that a curve is rising, what is unreal, because the drop of water can not reduce his contact angle!!! On the other hand, the polynomial regress better caught the real function of change. This is the main point, why polynomial regress was preferred to linear regress. There is the table 4.4 where are the names of specimen, number of treatments , sides and mainly average value of Contact Angle for better overview.

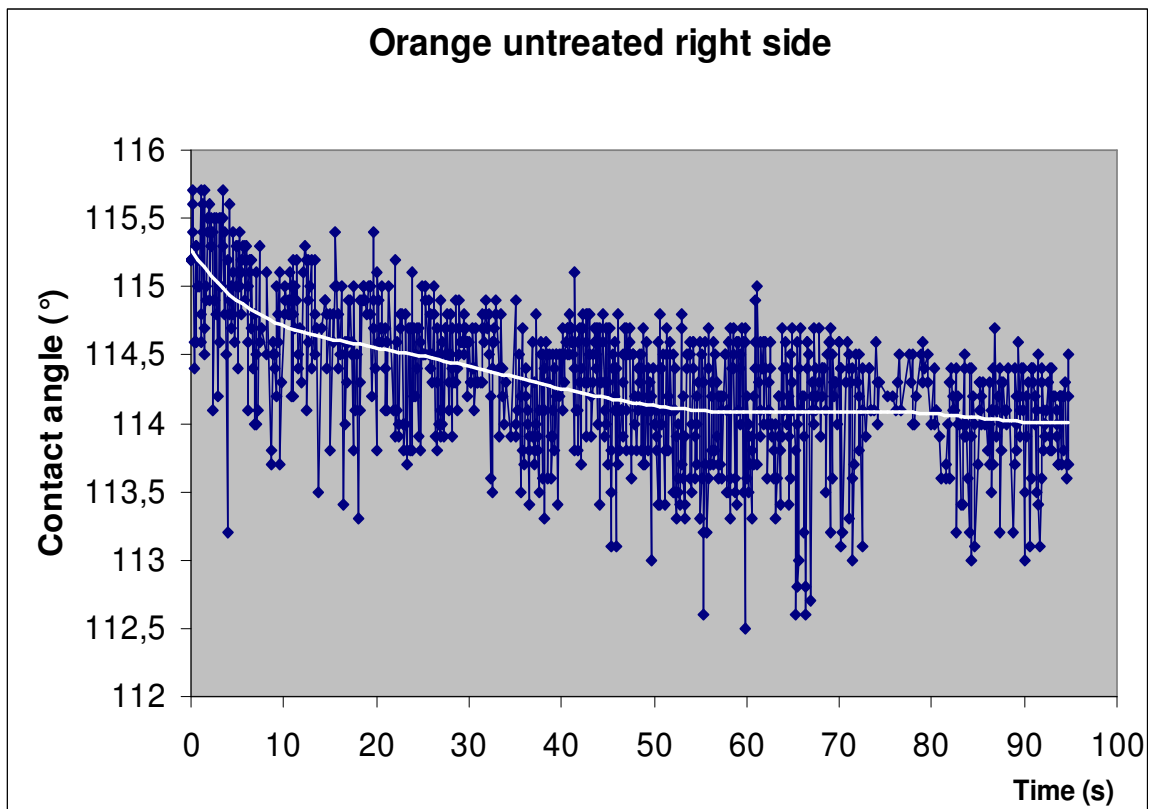
Tab.4.4: Overview contact angle and testing specimens

Name	Treated	Side	Avarage Contact Angle (°)
Orange	Untreated	Right	114,3
Orange	Untreated	Back	127,76
Orange	1 Time	Right	90,6
Orange	1 Time	Back	90,04
Orange	2 Times	Right	95,88
Orange	2 Times	Back	122,27
Orange	1+1 Times	Right	96,65
Orange	1+1 Times	Back	96,55
Orange	2+2 Times	Right	89,64
Orange	2+2 Times	Back	85,45
Blue	Untreated	Right	113,01
Blue	Untreated	Back	126,77
Blue	1 Time	Right	95,09
Blue	1 Time	Back	102
Blue	1+1 Times	Right	94,58
Blue	1+1 Times	Back	114,75
Dark blue	Untreated	Right	126,46
Dark blue	Untreated	Back	118,93
Dark blue	1 Time	Right	107,29
Dark blue	1 Time	Back	121,15
Dark blue	1+1 Times	Right	91,77
Dark blue	1+1 Times	Back	87,12

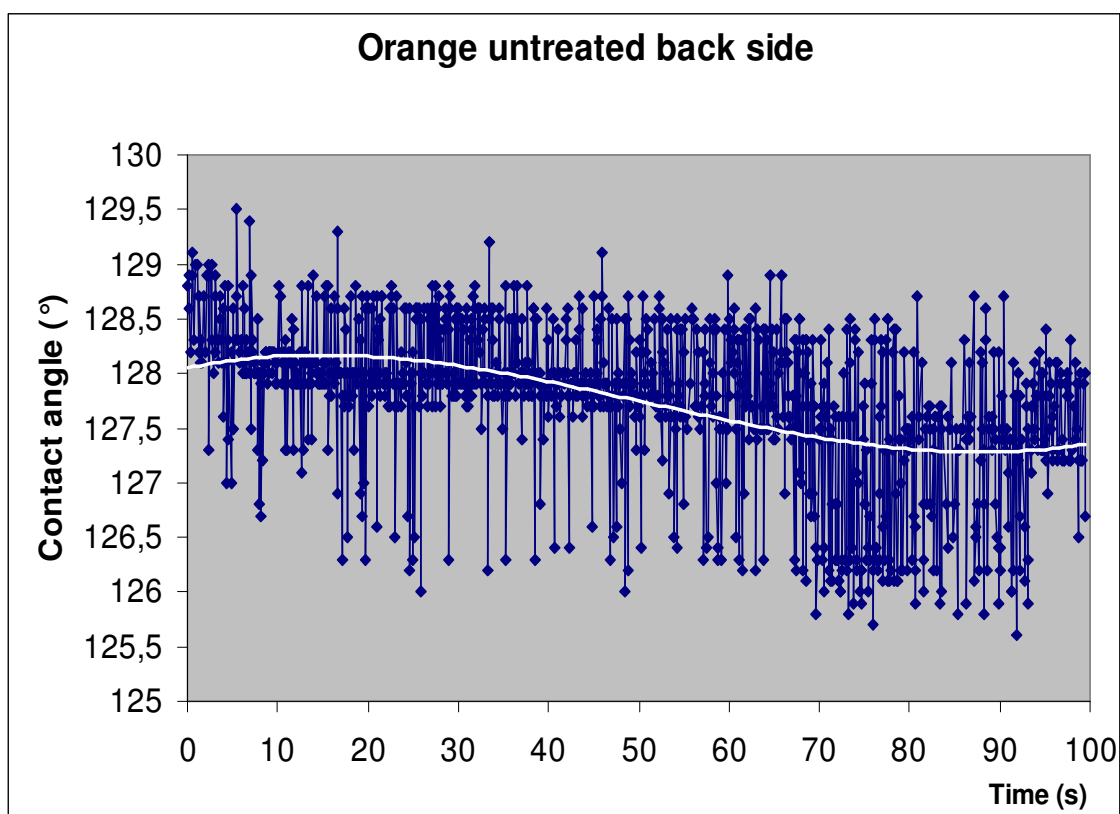
The graph 4.15, for right side orange untreated specimen shows that contact angle started on 115,2 (°) and was going down to 114 (°). On this value was stayed more than 100 seconds.

The graph 4.16, for back side orange untreated specimen gives the information about CA on value 127,76 (°).

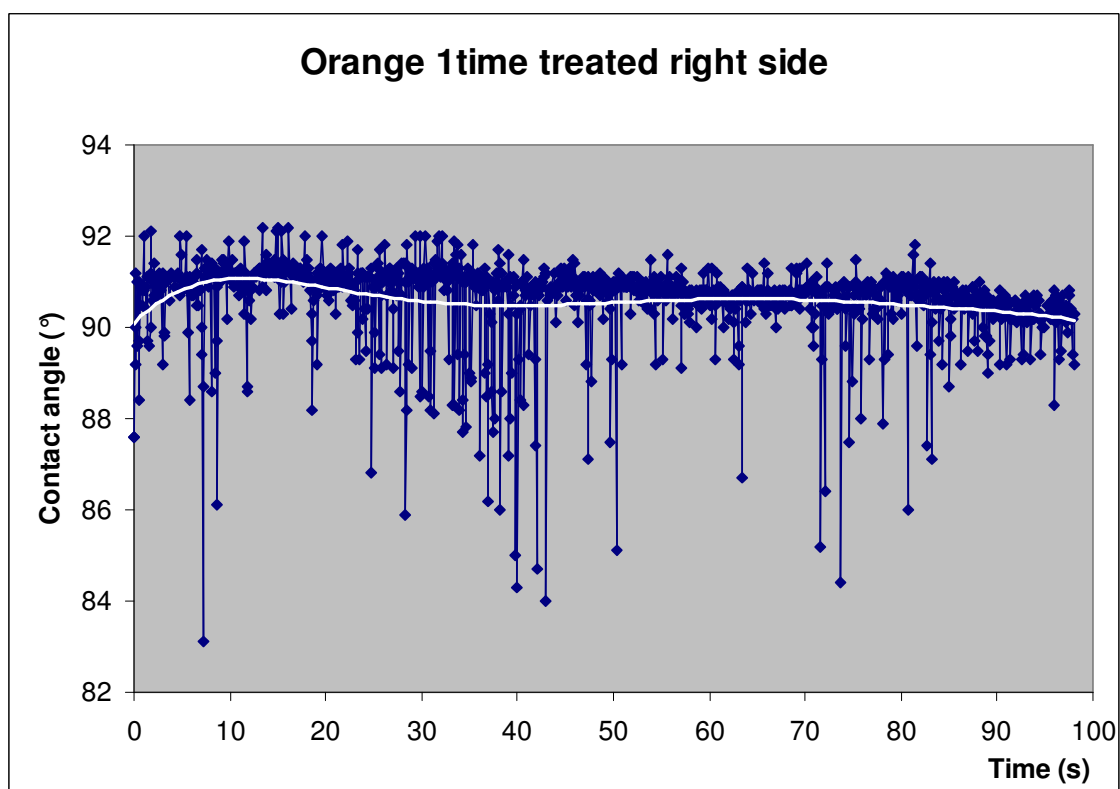
Why this value is so high (should be similar to right side approx. 115 (°)) depends mainly on place of impact of water drop and structure of knit, where every place has little difference and this place can radically change energy of surface. (Butterfly effect)



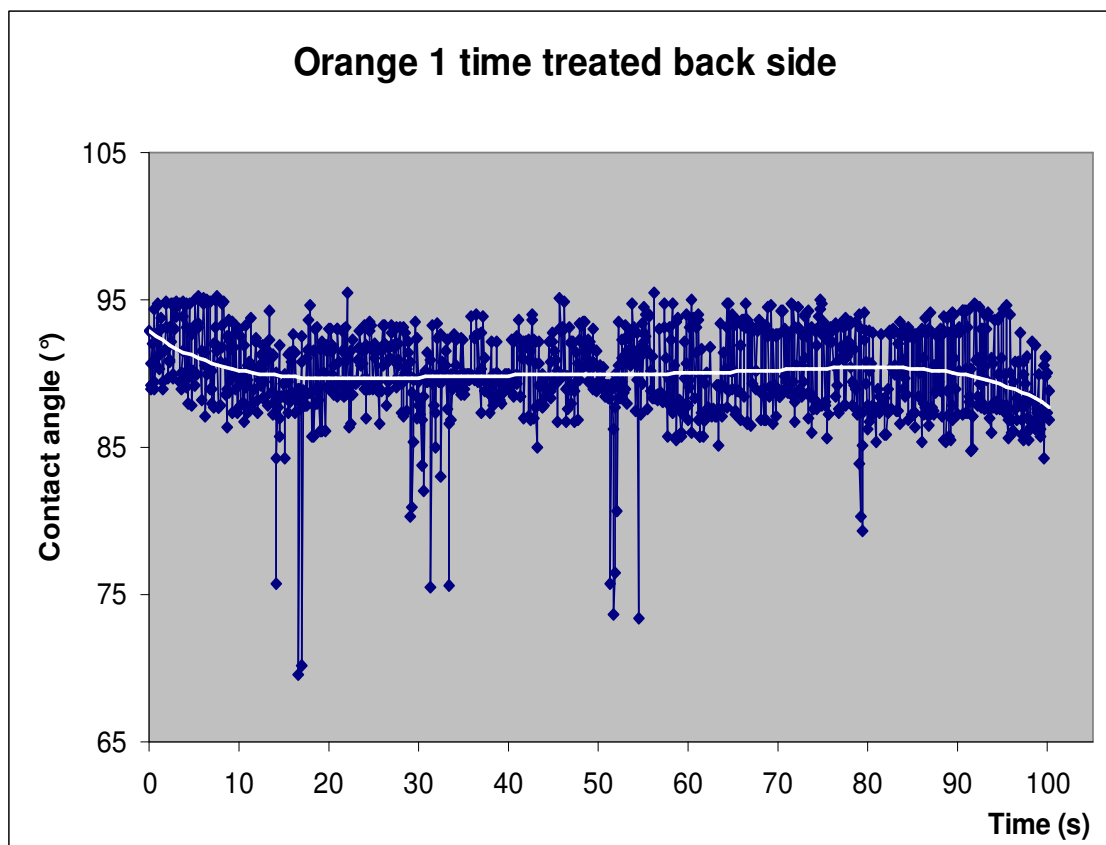
Graph 4.15



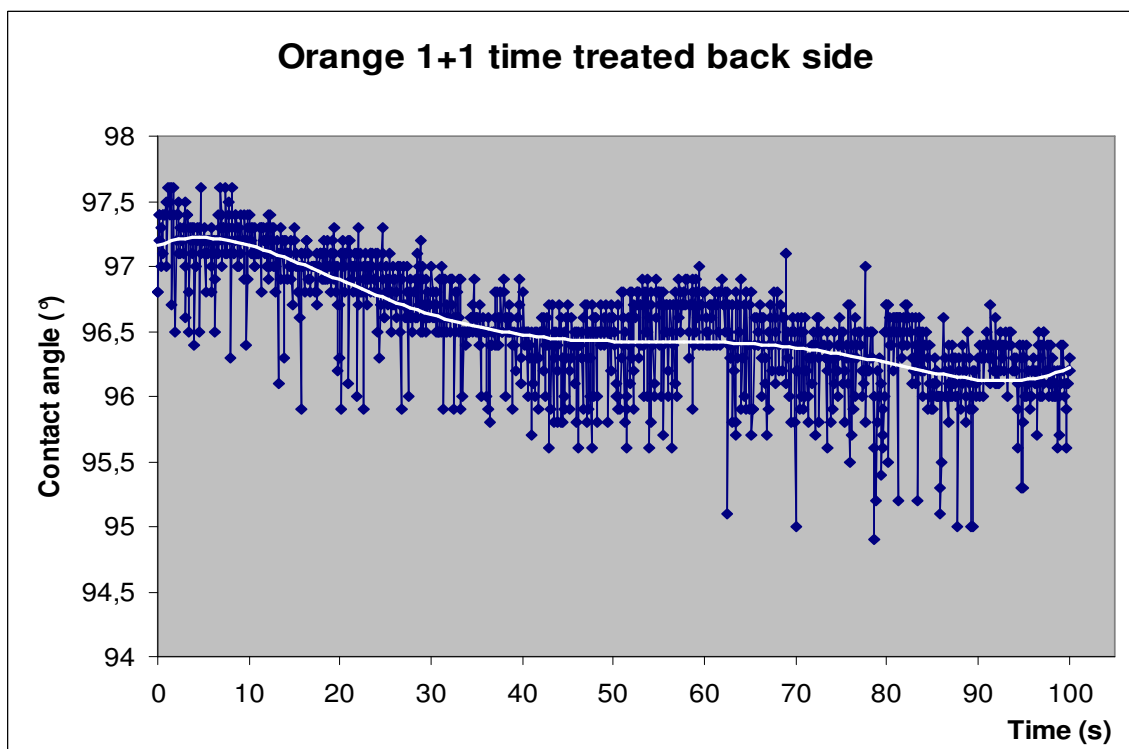
Graph 4.16



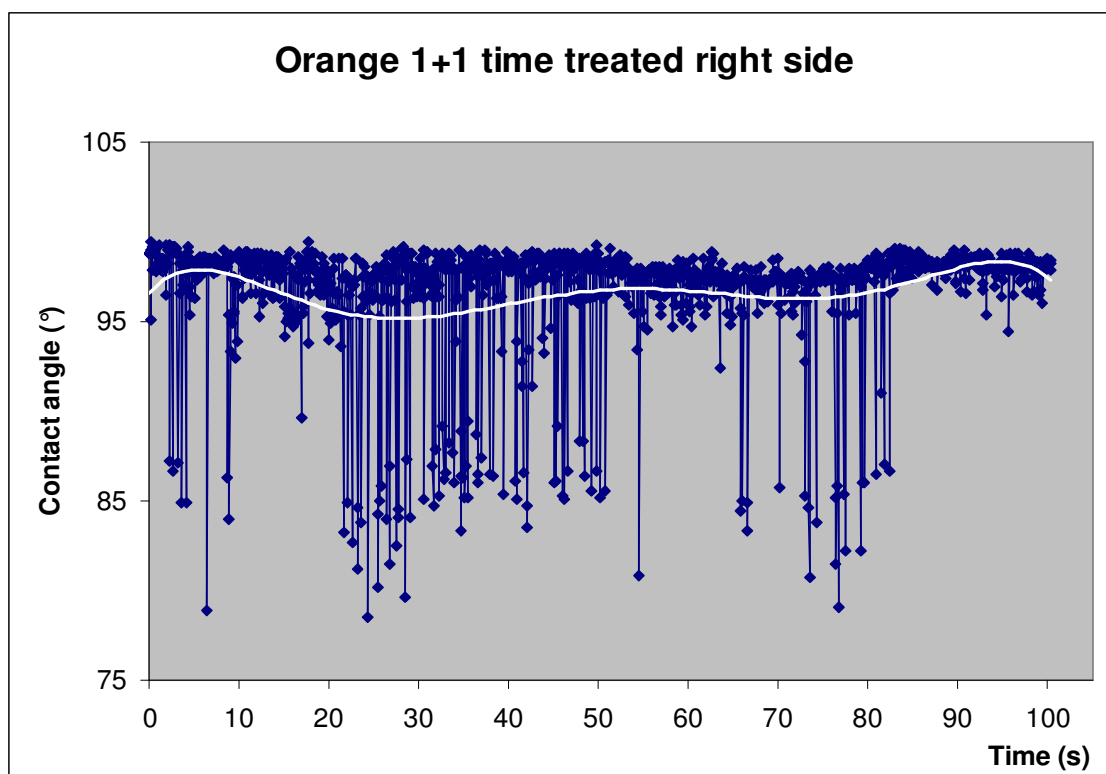
Graph 4.17



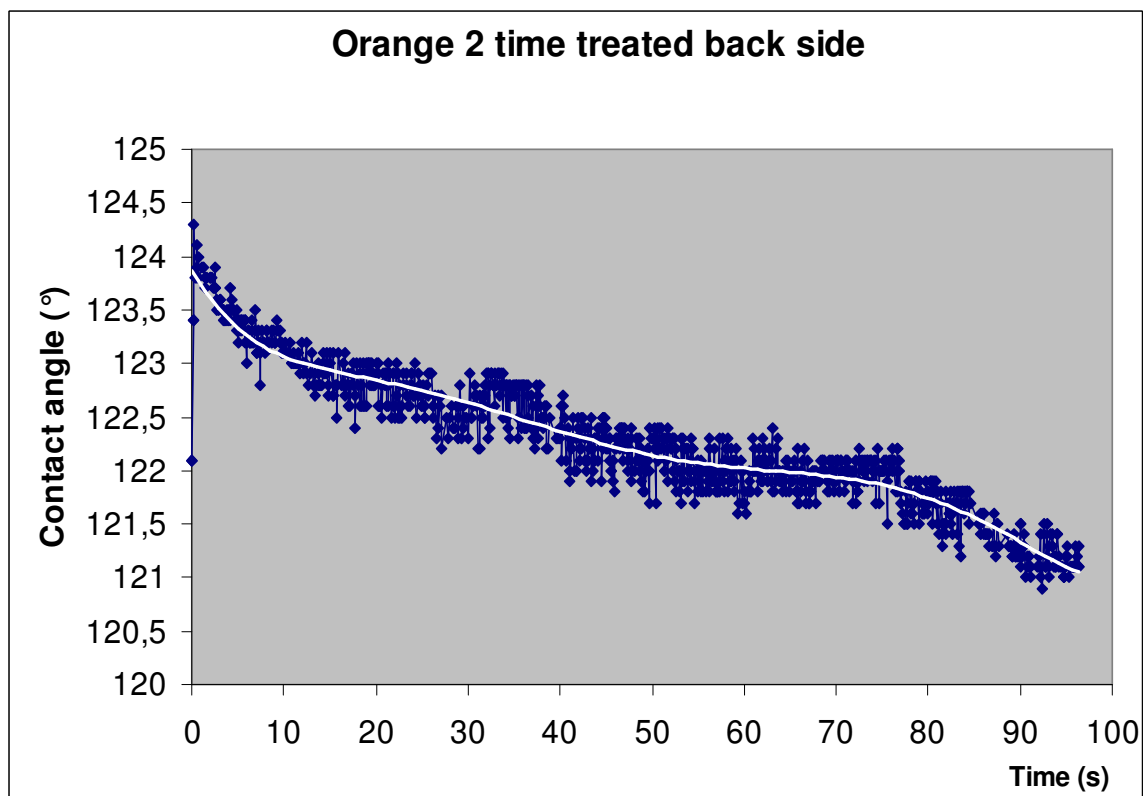
Graph 4.18



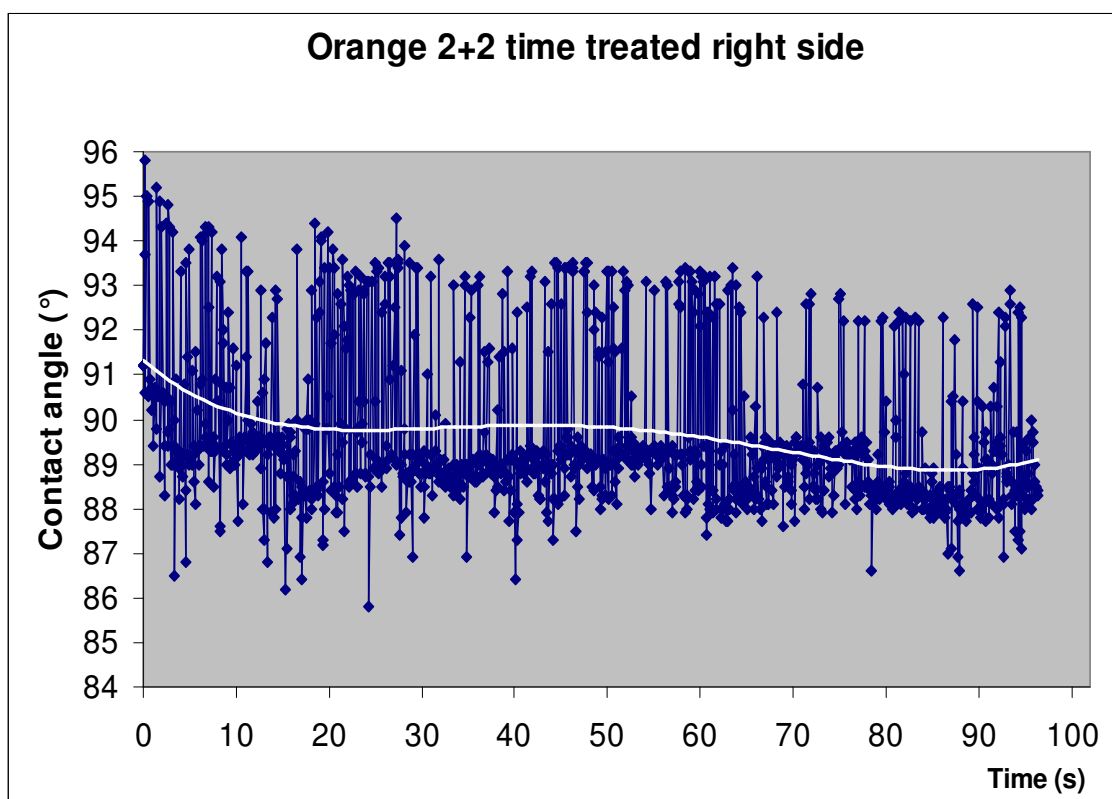
Graph 4.19



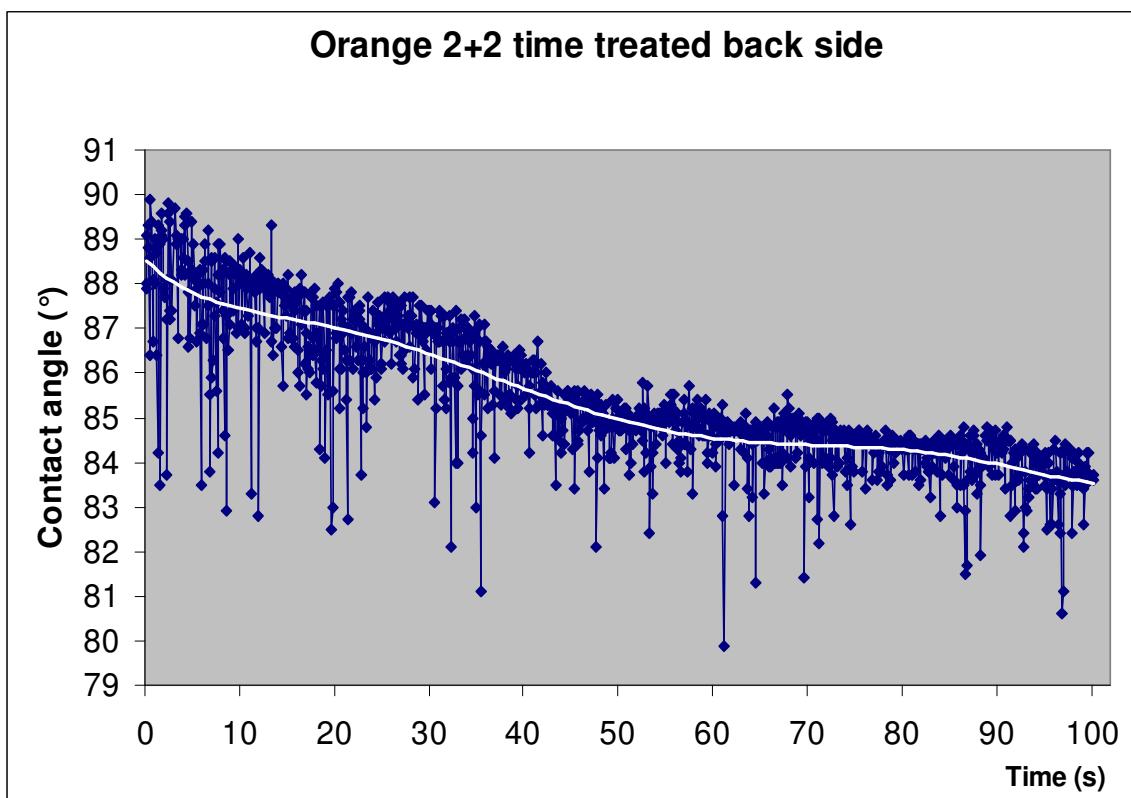
Graph 4.20



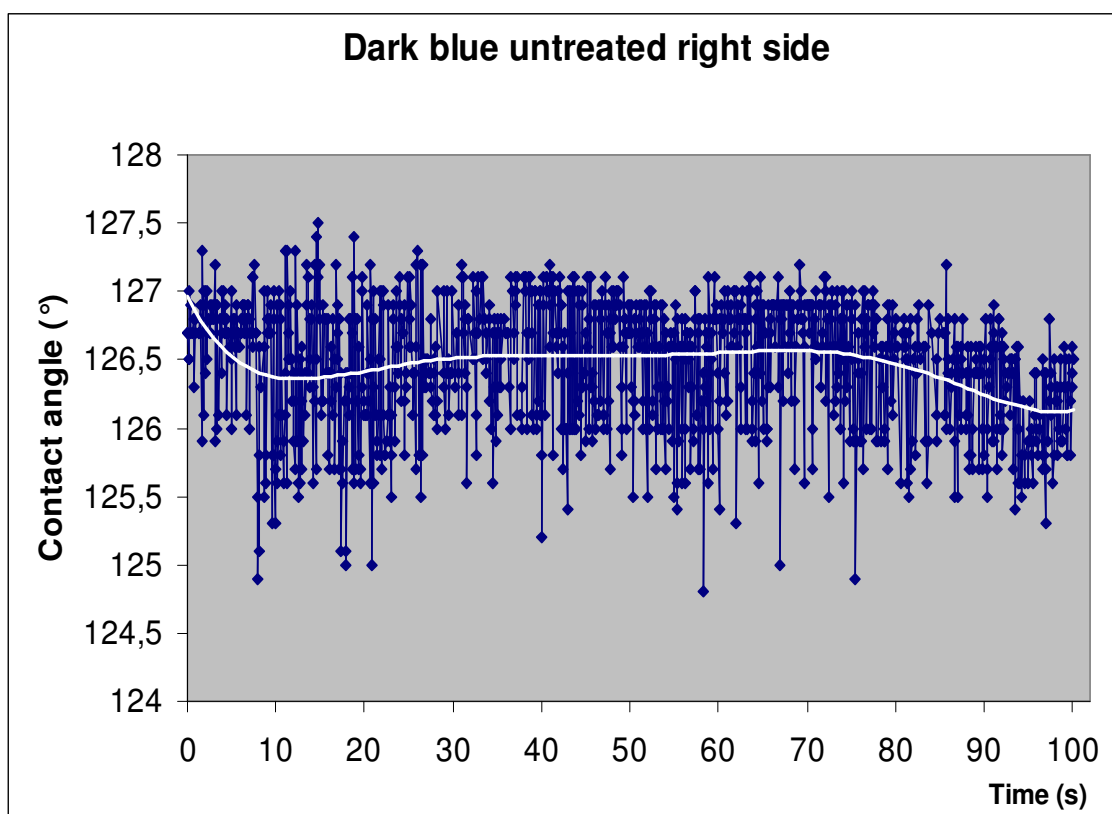
Graph 4.21



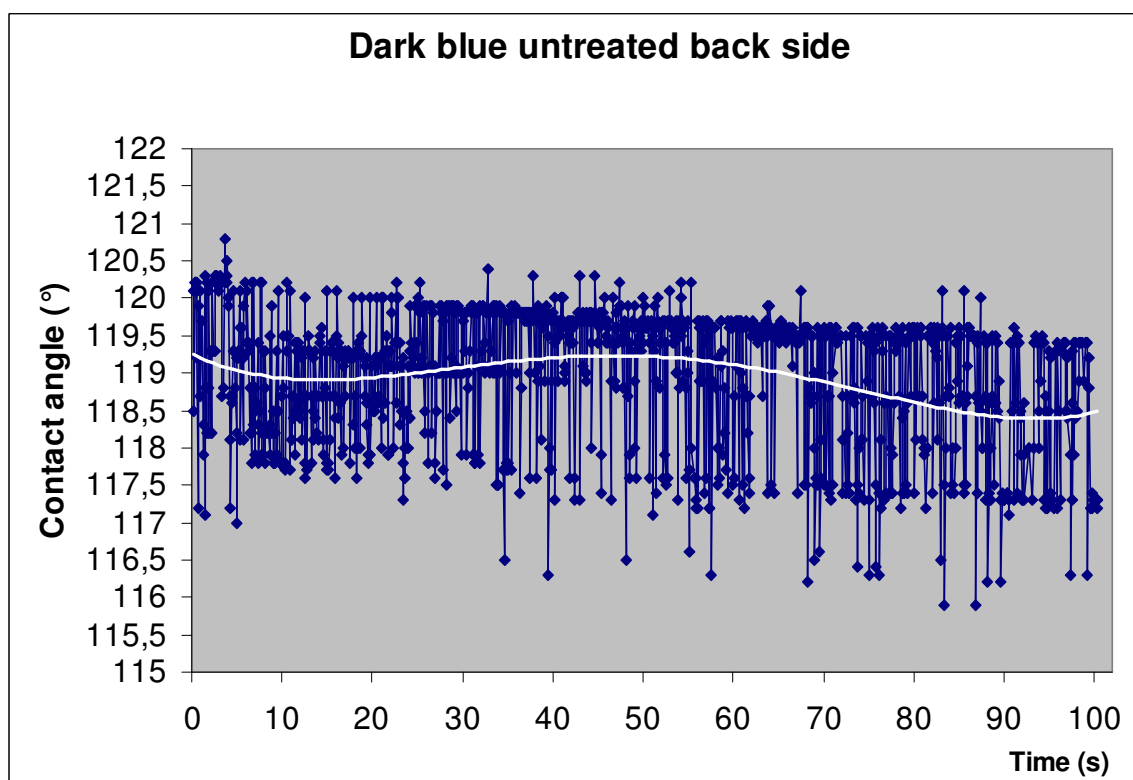
Graph 4.22



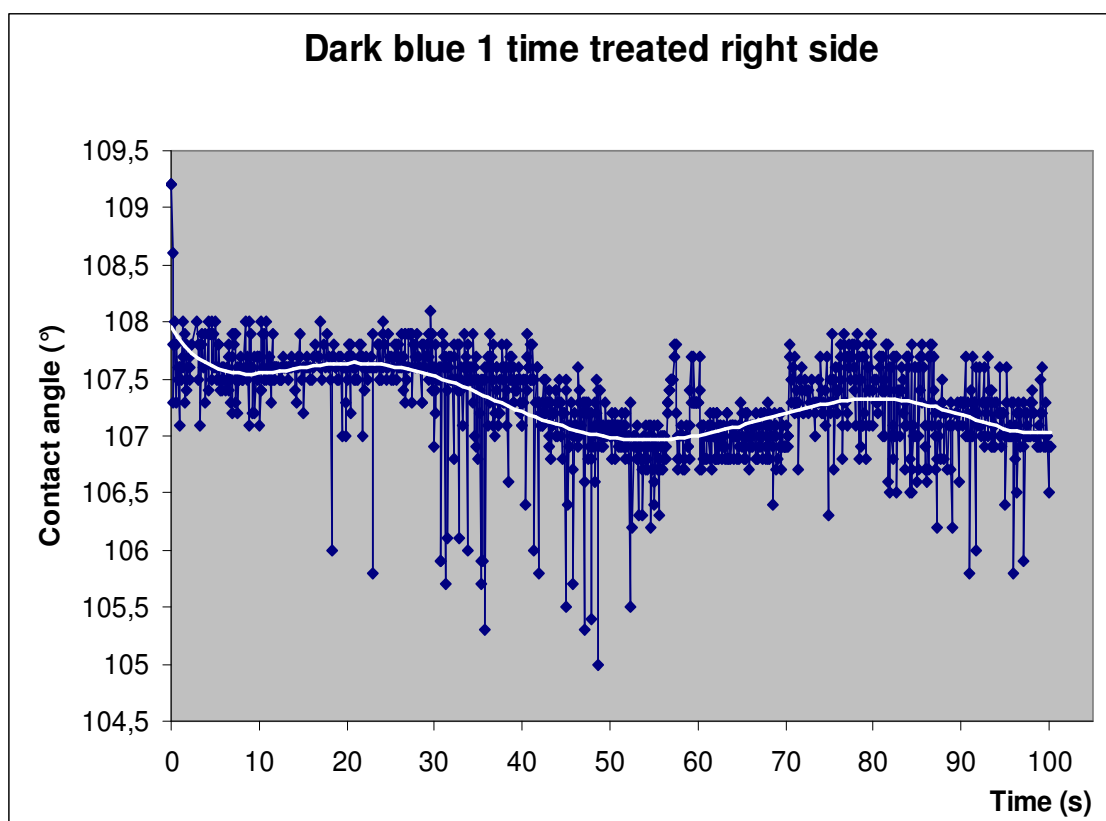
Graph 4.22



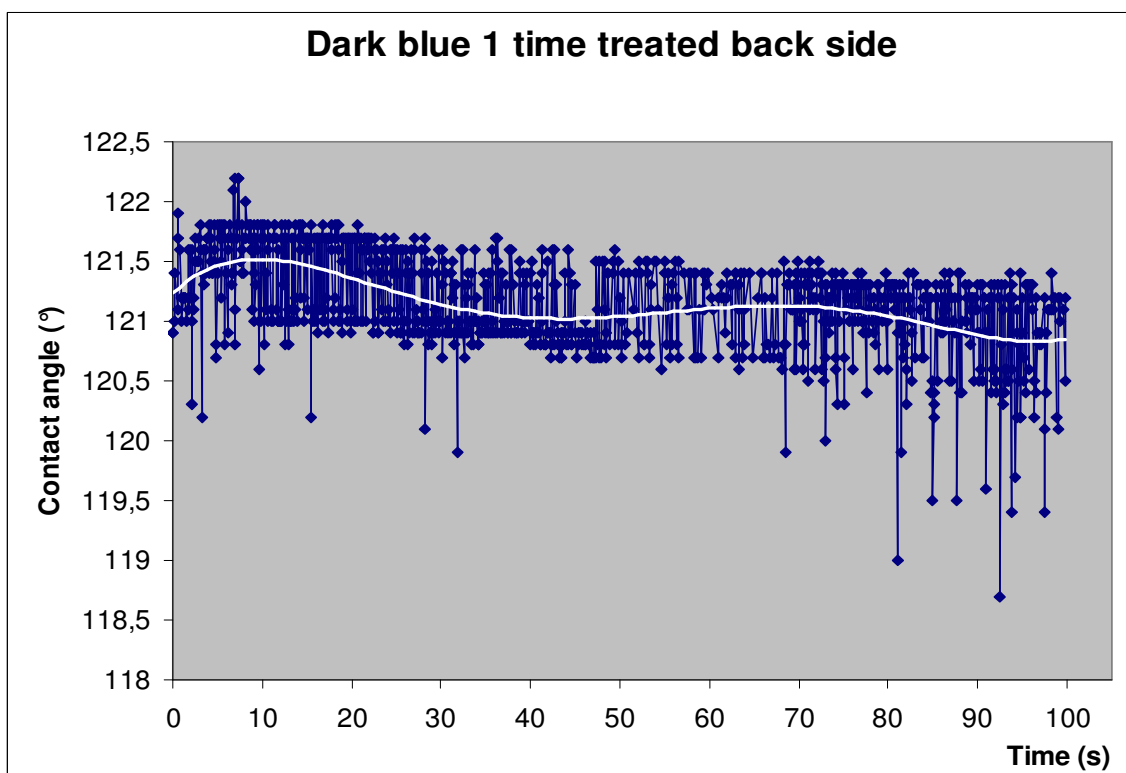
Graph 4.23



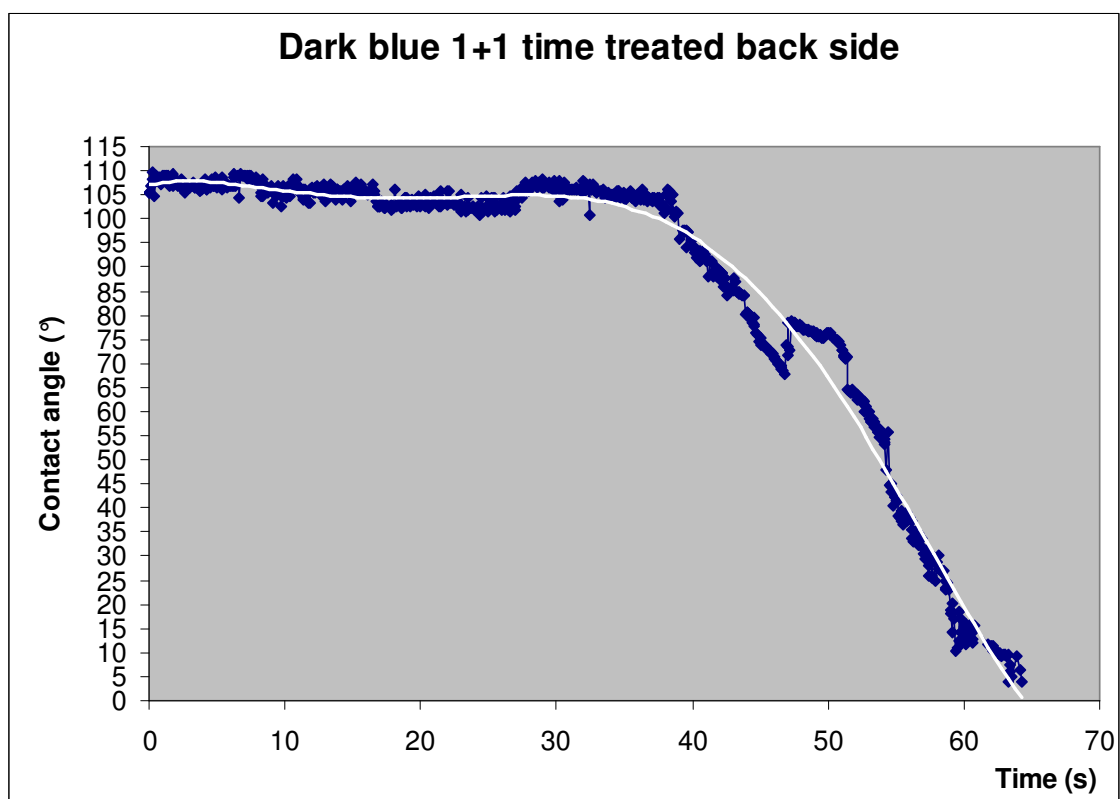
Graph 4.24



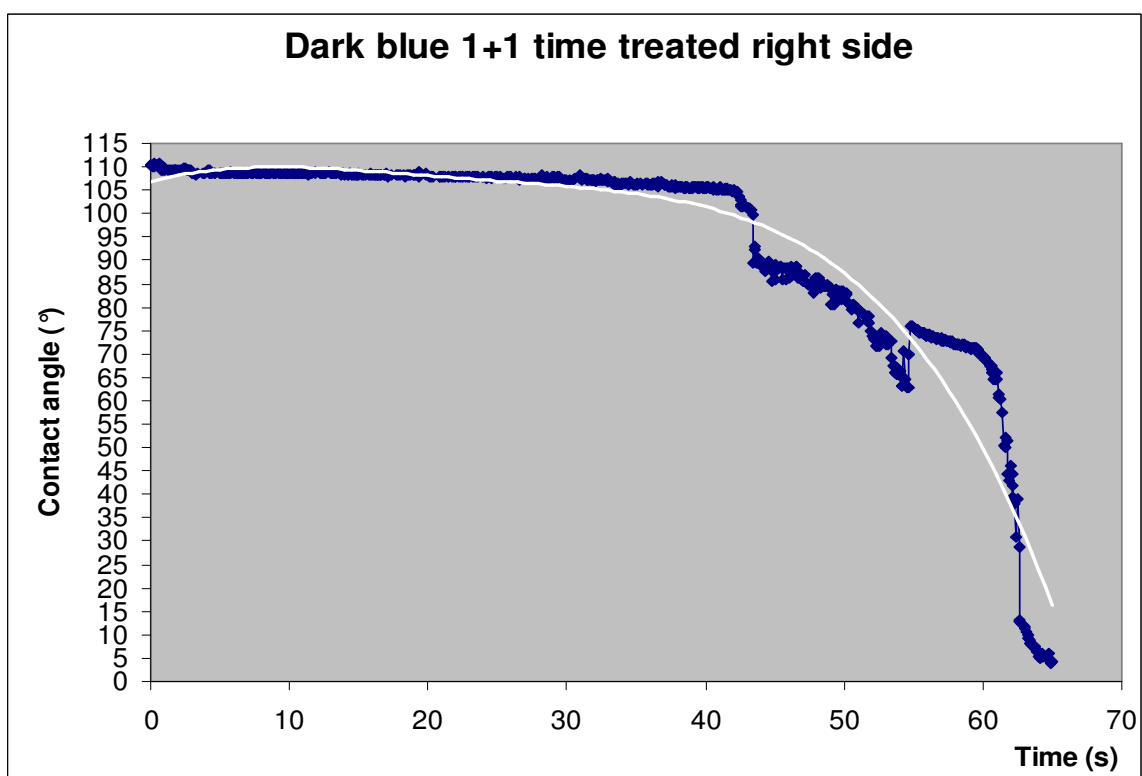
Graph 4.25



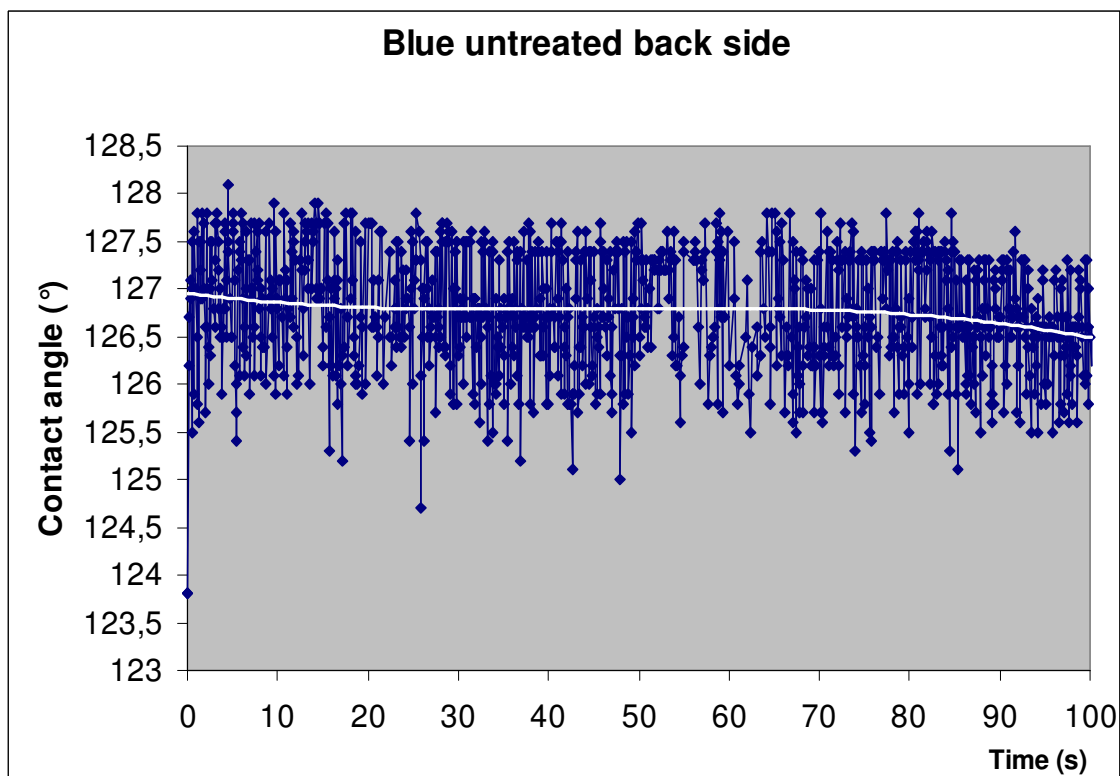
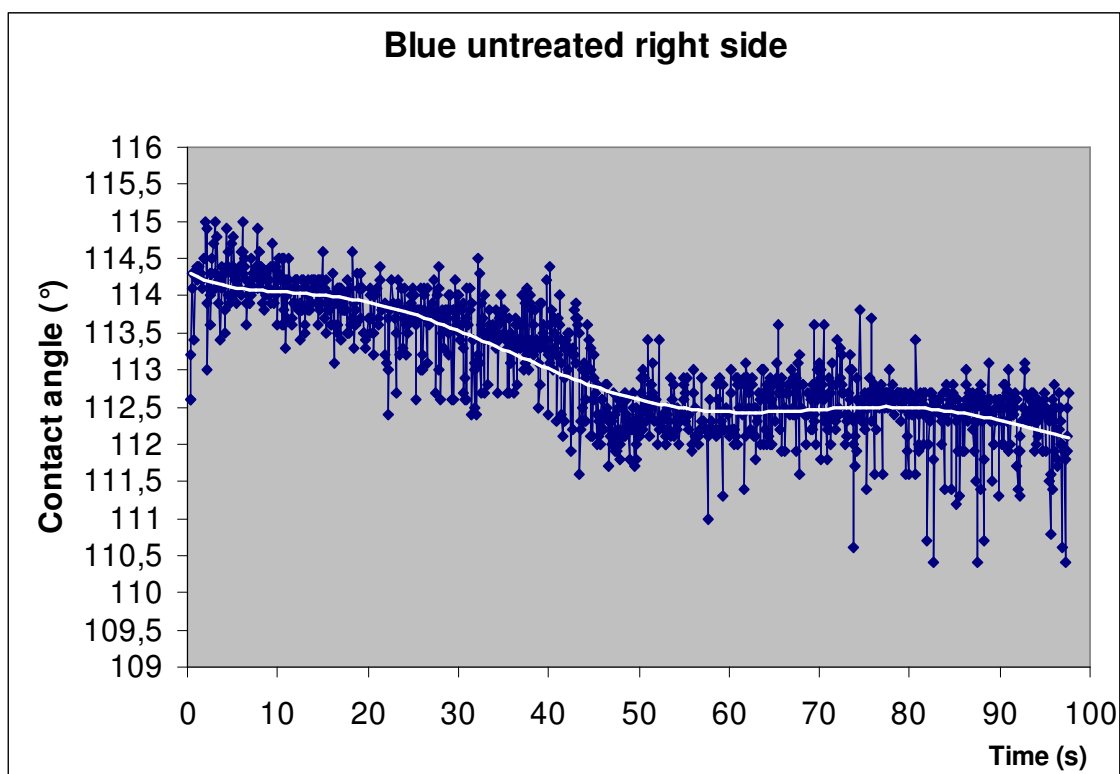
Graph 4.26

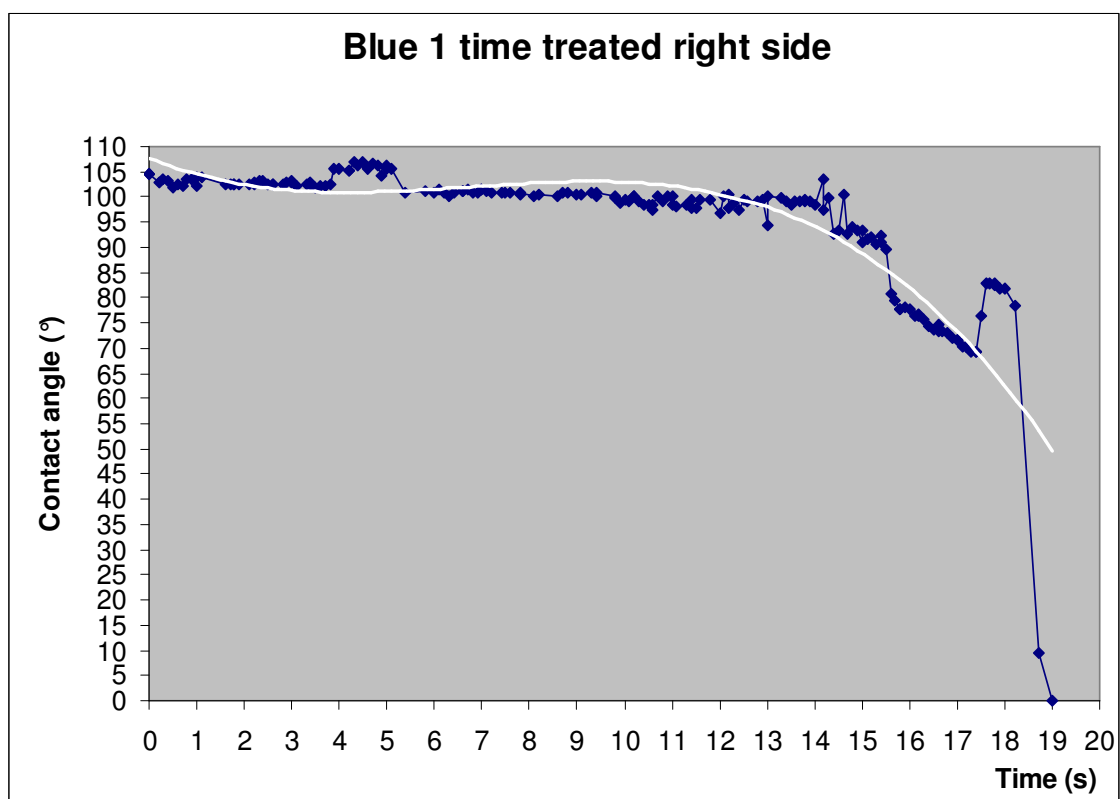


Graph 4.27

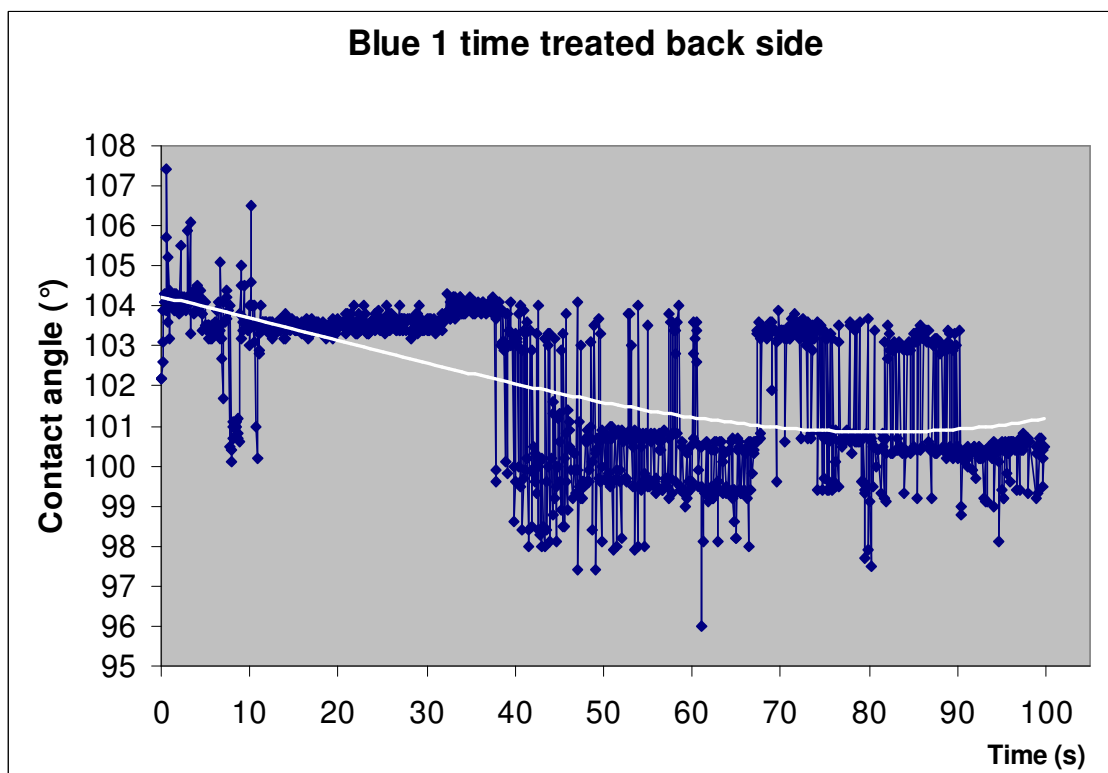


Graph 4.28

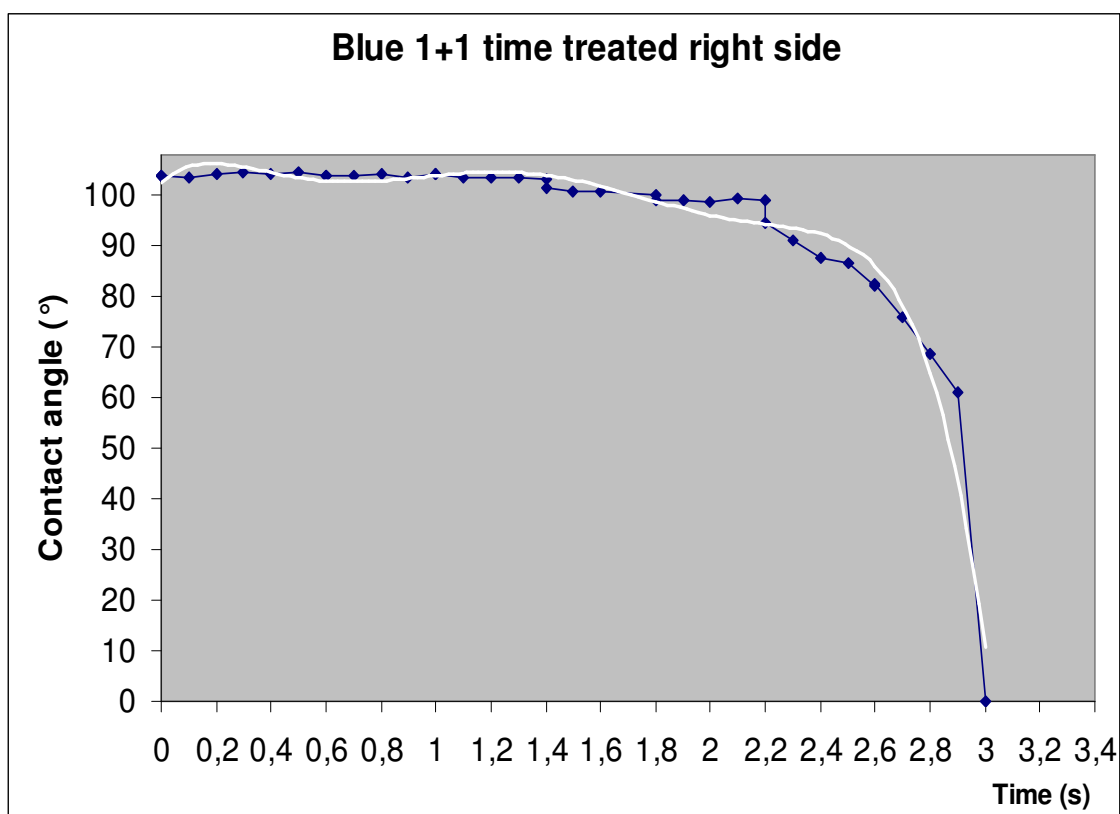




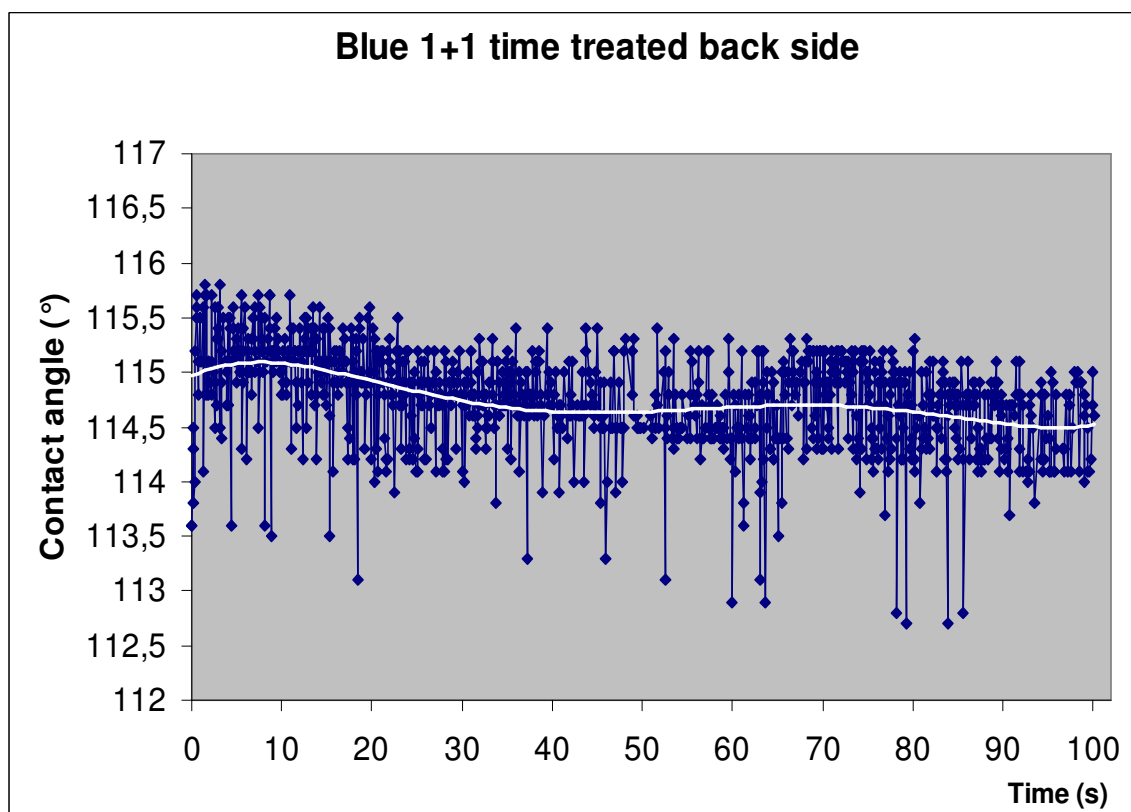
Graph 4.31



Graph 4.32



Graph 4.33



Graph 4.34

We compare the results taken by OCA. Corona treatment was useful for reduction of contact angle. It can seem that, especially in orange sample, the contact angle is bigger after 2 treatments on the right side as after a treatment, but on the back side! Reason is that very strong factor is structure of fabric.

For objective measurement of contact angle is necessary a flat surface. In this measurement was used randomly choice to place fall of drop. In unhomogenous surface very depends on holes and peaks, but in generally Plasma treatment in all cases of testing fabric decrease the contact angle.

5. Conclusion and Discussion

In this project was shown that Corona treatment increases wettability of PP knitted fabric. In drop test it is clearly confirmed that corona has positively affected increasing of wettability.

When the fabric is treated only on one side this part is increasing hydrophylity of water, other side becomes partially hydrophylic, too. But not so much as the treated side. One of the disadvantages of PP fibres is the hard touch which can be removed by using of softeners.

FTIR gives the results that in area from 1000 to 1100 cm^{-1} is inherence of NH group what is group of softeners. And this knowledge gives information about inherence of softeners in fabric. But applying of softeners without corona is very difficult. Problem is also removing the softeners after washing. In case of Cationic softener after ten washings and in case of N-ionic after first. But corona has improved the possibility of applying of this finishing process. Measurement of contact angle shows the decreasing of contact angle between surface and drop. This is demonstrated in increase of wettability of PP fabric. Such in the drop test, there is the same valid rule, when the number of treatments is higher. The fabrics become more hydrophylic.

During applied corona treatment to PP has to work with low electric current because PP fibres are sensitive to burning and sequential damaging. Therefore the treatment is not so effectively then can be. The possible way is to treat for more times, or connect to more treated stations in series.

Another problem was high temperature of rolling electrode. The solution could be to cool the electrode by some medium (water).

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