QATAR UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

SYNTHESIS AND CHARACTERIZATION OF THERMOCHROMIC NANOFIBER COMPOSITION FOR TEXTILE APPLICATIONS.

BY

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ABSTRACT

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Title:__SYNTHESIS AND CHARACTERIZATION OF THERMOCHROMIC NANOFIBER COMPOSITION FOR TEXTILE APPLICATIONS, Prepositions, and Articles

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This study focuses on optimizing application methods for nanofiber and thermochromic pigments on textiles, assessing their performance through instrumental analysis, and establishing scientific explanations for the observations. While previous research on thermochromic textiles has focused mainly on qualitative assessments of their functionality, this study aims to evaluate their functionality qualitatively and quantitatively using appropriate instrumental methods. The study focuses on application techniques that enhance the performance of thermochromic pigments with nanofiber on textiles and provide a technical basis and inspiration for creative design applications and other fields.

SEM analysis of the electrospun nanofibers from all samples revealed consistent and uniform diameter morphology, indicating that electrospinning is a robust and versatile technique that can produce nanofibers with consistent morphology from various materials. SEM analysis of micro- and nano-thermochromic showed that both materials exhibit a thermochromic effect, changing color from colorless to blue at high temperatures. However, nano-sized particles were found to be more sensitive to heat and reverted to their original state faster than micro-sized particles, indicating that particle size plays a crucial role in determining the thermochromic behavior of the materials.

SEM analysis of composite nanofiber + thermochromics in fabric demonstrated that the composite nanofibers were successfully produced with a smooth and uniform morphology. The nano thermochromic and spray thermochromic solutions were evenly dispersed within the matrix of cellulose acetate or PET, respectively, indicating good dispersion of the thermochromic material in the polymer matrix. Additionally, the addition of recycled fabric to the composite nanofiber did not seem to affect the morphology of the composite nanofiber, and the thermochromic material was uniformly distributed within the nanofiber.

These results suggest that composite nanofiber + thermochromic in the fabric have potential applications in various fields such as textiles, medical, sensors, and smart materials. TGA results suggest that adding nano thermochromic to cellulose acetate may impact its thermal stability, indicating the need for further analysis and testing to fully understand the nature of this effect and its potential applications. This study provides valuable insights into optimizing application methods for nanofiber and thermochromic pigments on textiles and their potential for various applications.

DEDICATION

In memory of my beloved Parents.

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CHAPTER 1: INTRODUCTION

Nanofibers refer to fibers with a diameter of less than 100 nm. Production of nanofibers occurs in various ways, one among them being through electrospinning. Electrospinning refers to a nanofiber production method in which a polymer solution is subjected to a high-voltage electric field. The high electric field forces the solution out through a tiny nozzle, and the resulting electrostatic force produced by the high voltage causes it to stretch and very thin form fiber. Nanofiber technology is used in many applications, including the production of thermochromics in the textile industry (YILDIRIM et al., 2019).

Thermochromics is a type of material that changes color in response to changes in temperature. This phenomenon occurs due to the reversible change in the structure or arrangement of molecules in the material as the temperature changes. For example, a thermochromic material may appear one color at room temperature and then change to a different color when heated or cooled. There are two main types of thermochromic materials: reversible and irreversible. Reversible thermochromic materials change color back and forth as the temperature fluctuates. On the other hand, irreversible thermochromic materials change color permanently when exposed to a certain temperature threshold (Ibrahim, 2012).

According to YILDIRIM et al. (2019), past scientific studies on electrospinning have mainly focused on characterizing nanofibers, using new thermochromic materials, and new applications for nanofibers. Other studies have also focused on applications of thermochromic pigments, smart fabrics, and the development of nanofibers from recycled materials. Thermochromic materials have many applications, including temperature-sensitive labels, food packaging, medical applications, military applications, and applications in the fashion clothing manufacturing industry.

In temperature-sensitive labels, thermochromic materials indicate whether a product has been exposed to a specific temperature range, such as in medical devices or food transport. In food packaging, thermochromic materials can show whether the food is still fresh or has been exposed to high temperatures during transport or storage. In clothing, thermochromic materials create color-changing fabrics or indicate temperature changes in sports or outdoor activities (Ibrahim, 2012).

1.2. Thermochromics Applications:

1.2.1 Thermochromic military applications:

Thermochromic materials have various military applications due to their ability to change color in response to temperature changes. Military equipment manufacturers can incorporate thermochromic materials in equipment for easier temperature monitoring during operation. These nanofibres change color as the temperature increases, allowing real-time equipment performance monitoring and preventing overheating. Thermochromic nanofibres can also be used to create thermal targets for military training. These targets change color in response to the heat of bullets or other projectiles, providing immediate feedback on the shot's accuracy. Military uniforms and equipment can be manufactured using thermochromic nanofibres to create a more effective camouflage system. The materials can change color to match the surrounding environment, making it harder for the enemy to detect the soldiers. Military equipment manufacturers can also use them to create temperature sensors for military applications. These sensors change color in response to changes in temperature, indicating the temperature without the need for complex electronic equipment. The military can use thermochromic materials to detect the presence of chemical agents in the air. The materials change color in response to the chemicals, warning soldiers of a potential chemical attack.

1.2.2. Thermochromic nanofibers medicine applications:

Thermochromic nanofibers also have several potential applications in medicine due to their ability to change color in response to temperature changes. Medical specialists can use thermochromic materials to create drug delivery systems that release medication in response to changes in temperature. This approach could allow for more precise and controlled drug delivery to specific areas of the body. They can also incorporate thermochromic materials into wound dressings to monitor the temperature of the wound site. Temperature changes could indicate inflammation, infection, or other issues, allowing for early intervention and treatment. Thermochromic materials can be used in diagnostic testing, such as pregnancy tests or glucose monitoring. The materials change color in response to specific temperatures, providing a visual indication of the presence or absence of certain substances. They can use thermochromic materials in thermotherapy, which uses heat to treat various conditions. The materials can change color to indicate when the optimal temperature has been reached, ensuring safe and effective treatment. Hyperthermia therapy is a treatment that uses heat to kill cancer cells. Thermochromic materials can be used to monitor the temperature of the tumor during treatment, ensuring that the tumor is heated to the appropriate temperature without damaging surrounding healthy tissue. Special clothing made using thermochromic material can be used to identify kidney problems. High body temperature would bring about a change in the color of the clothing, which would, in turn, raise the alarm for urgent medical attention. Medical specialists can use garments made from thermochromic materials to monitor cancer patients' health status. The clothing would detect abnormal changes in body temperature caused by inflammation of the affected body organ(s). This would call for monitoring of the patient by the doctors.

1.2.3. Thermochromics wearable fashion application:

Thermochromic materials have various applications in the fashion industry due to their ability to change color in response to temperature changes. Clothing designers and manufacturers can incorporate thermochromic materials into fabrics to create color-changing clothing. The fabric's color can change as the temperature changes, creating a unique and interactive garment. They can also use thermochromic materials to make accessories such as jewelry and bags that change color in response to temperature changes. Footwear designers can use thermochromic materials to develop and design color-changing shoes that respond to temperature changes. This can create a visually striking effect and add an element of excitement to footwear. Swimwear manufacturers can incorporate thermochromic materials into swimwear to create color-changing swimsuits. As the temperature of the water changes, the color of the swimsuit can change, adding an element of fun to beach and pool attire. Fashion industries can also use thermochromic materials to produce smart textiles, which can respond to changes in the wearer's environment. For example, a jacket made with thermochromic materials can change color to reflect temperature changes, allowing the wearer to stay comfortable and stylish in various weather conditions. Sportswear made using thermochromic material can be worn by players during sporting activities. It would be designed in such a way that it changes color when exposed to long periods of high temperature from the body. This would be used to determine whether a player needs to be replaced due to exhaustion.

1.3 The Purposes of this Research:

The primary objective of the research conducted in this study was to optimize the methods of applying nanofiber and thermochromic pigments onto textiles by using Cellulose acetate and recycled fabrics and water bottles, evaluate their instrumental performance, and establish scientific justifications for the findings. The literature primarily examines the functionality of thermochromic textiles from a qualitative perspective. However, this thesis aims to evaluate their functionality quantitatively, using appropriate instrumental methods. The study focuses particularly on application techniques that improve the performance of thermochromic pigments on textiles by using nanofiber, intending to provide a technical foundation and inspiration for innovative design applications in various fields.

CHAPTER 2: LITERATURE REVIEWS

2.1 Nanotechnology in the textile industry

Nanotechnology is a rapidly growing field of science that focuses on manipulating materials at the nanoscale level, which is one billionth of a meter. In recent years, the textile industry has embraced nanotechnology to develop new materials and improve existing ones by modifying their properties at the molecular level. This paper examines the applications of nanotechnology in the textile industry, the benefits and risks associated with its use, and its impact on the environment.

Applications of Nanotechnology in the Textile Industry

a) Self-cleaning textiles

One of the most significant applications of nanotechnology in the textile industry is the development of self-cleaning fabrics. This is achieved by coating the fabric with thin nanoparticles that repel dirt and other contaminants. Self-cleaning textiles can reduce the need for washing, thereby conserving water and reducing the energy needed to wash clothes (Bhat & Bhat, 2018).

b) UV protection

Nanotechnology has been used to enhance the UV protection of textiles. This is achieved by incorporating nanoparticles into the fabric that absorb UV radiation. Incorporating nanoparticles into textiles can increase their Ultraviolet Protection Factor (UPF) rating by up to 50% (Cai & Li, 2017).

c) Antibacterial properties

Nanotechnology has been used to develop fabrics with antibacterial properties. This is achieved by incorporating silver nanoparticles into the fabric, effectively killing bacteria. Silver nanoparticles can inhibit the growth of bacteria on fabrics, thereby reducing the risk of infection (Fathi & Norouzi, 2019).

d) Water and stain resistance

Nanotechnology has been used to develop fabrics with water and stain resistance. This is achieved by coating the fabric with thin nanoparticles that repel water and other liquids. Fabrics coated with nanoparticles are more resistant to water and oil-based stains than untreated fabrics (Ma & Liu, 2018).

Benefits of Nanotechnology in the Textile Industry

a) Improved durability

Nanotechnology has been used to develop fabrics with improved durability. This is achieved by strengthening the fibers at the molecular level, making them more resistant to wear and tear. Fabrics treated with nanoparticles were more durable than untreated fabrics (Wang et al., 2018).

b) Reduced environmental impact

Nanotechnology has the potential to reduce the environmental impact of the textile industry. This is achieved by reducing the need for washing and using harmful chemicals in manufacturing. Using self-cleaning textiles can reduce the amount of water and energy needed to wash clothes, thereby reducing the textile industry's environmental impact (Javed & Naz, 2017).

c) Improved comfort

Nanotechnology has been used to develop fabrics that are more comfortable to wear.

This is achieved by improving the fabric's breathability, which allows air to pass through the fabric more easily. This can help to reduce sweating and improve comfort (Lu et al., 2017).

Risks of Nanotechnology in the Textile Industry

While the use of nanotechnology in the textile industry offers many benefits, there are also risks associated with its use. Some of the potential risks include:

a) Environmental concerns

The use of nanoparticles in textiles could have a negative impact on the environment. The release of nanoparticles during washing clothes could pollute the water supply, and the disposal of nanoparticle-treated fabrics could lead to soil and groundwater contamination (Klaine et al., 2008).

b) Health concerns

There is also concern about the potential health risks of using nanoparticles in textiles. Nanoparticles can penetrate the skin and be absorbed into the bloodstream, which could lead to adverse health effects. There is a need for further research to fully understand the potential health risks associated with using nanoparticles in textiles (Bhat & Bhat, 2018).

c) Cost

The use of nanotechnology in textiles can be expensive, which could limit its adoption in the industry. The high cost of nanoparticles and the additional processing required to incorporate them into fabrics can make nanotechnology-based textiles more expensive than traditional textiles (Javed & Naz, 2017).

d) Lack of regulation

There is currently a lack of regulation governing the use of nanoparticles in textiles. This could lead to the development and use of nanoparticles that may pose risks to human health and the environment. There is a need for regulatory bodies to develop guidelines and regulations to ensure the safe use of nanotechnology in the textile industry (Ma & Liu, 2018).

e) Impact of Nanotechnology on the Environment

The use of nanotechnology in the textile industry has the potential to reduce the environmental impact of the industry. Self-cleaning textiles can reduce the need for washing, which conserves water and reduces energy consumption. Fabrics treated with nanoparticles can also be more durable, reducing the need for frequent replacement, which can reduce waste. However, the use of nanoparticles in textiles also poses environmental risks. The release of nanoparticles during washing clothes could pollute the water supply, and the disposal of nanoparticle-treated fabrics could lead to soil and groundwater contamination (Klaine et al., 2008).

In conclusion, nanotechnology has many applications in the textile industry, including developing self-cleaning textiles, fabrics with UV protection, antibacterial properties, and water and stain resistance. The use of nanotechnology in textiles offers many benefits, including improved durability, reduced environmental impact, and enhanced comfort. However, there are risks associated with using nanoparticles in textiles, including ecological concerns, health concerns, cost, and lack of regulation. The textile industry should work to mitigate these risks while continuing to explore the potential benefits of nanotechnology in the industry.

2.2 Electrospinning :

Electrospinning is the process of producing a polymer fiber of a size that is much smaller than a micron by pulling a polymer solution using an electrical current. It is a simple and uncomplicated process to set up. The primary elements that make up an electrospinning system are a source of high voltage, a reservoir containing dissolved polymer equipped with a conducting nozzle, and an electrically grounded plate positioned at a certain distance from the conductive nozzle (Zheng-Ming et al., 2003). The uses that electrospun fibers can be put to are extensive and varied. They have been the subject of research in biomedicine for wound dressing, tissue engineering, and protective garments. Electrospun fibers can mimic the properties of the extracellular matrix found within the body, making them useful in tissue engineering. Researchers can also explore cell adhesion, differentiation, and the impact of materials on a very tiny scale thanks to electrospun nanofibers (Esmaeili, Deymeh,& Rounaghi, 2017). Nanofibers have the potential to be effective in wound dressing due to their broad surface area and small pore size, both of which reduce the likelihood of an infection occurring. Other uses ideally suited for electrospinning include producing reinforcing fibers for composite materials, applying pesticides to plants, and constructing surfaces on textile fabrics that are not wet.

Since Antonin Formhals submitted the initial invention for electrospinning in 1934, over 60 further patents have been submitted for various forms and procedures of electrospinning. The majority of the early research that is now connected with electrospinning was carried out in other fields of study before the recent uptick in the amount of research that has been done on electrospinning because of the advent of nanotechnology. Taylor discovered that when large electric forces are applied to a polymer solution, the exposed droplet will take on the shape of a cone and transform into an electrically powered jet. The Taylor cone is a term used to describe this particular geometric feature of the droplet at the point when it is extruded. It is utilized in numerous tests nowadays as an indicator of the beginning of the electrospinning process. When scientists began focusing more on the production of nanoscale materials, they discovered that electrospinning could constantly produce material on a sub-micron scale.

After beads were deposited on the collector plate following electrospinning's use to manufacture nanofibers by an increasing number of researchers, those researchers began to notice the existence of entrained beads along the length of the fiber produced by the process. The capillary effect of the solution as it makes its way to the plate has been hypothesized to be the cause of this phenomenon. Although entrained beads are a distinctive type of morphology compared to uniform fibers, a microscopic study has been done to determine the cause of this kind of morphology (Ferahtia, 2021). The capillary effect has only been mentioned in passing. It has been postulated that as the polymer solution jet moves forward, the domains inside the jet attempt to reduce the amount of free surface energy they experience by drawing closer to one another locally and, as a result, generating entrained spheres or beads. Depending on how far away the collecting plate is, the individual spheres could not have enough time to entirely detach from one another before they reach the target plate, causing the resulting fiber to appear like a string with beads strung along it.

As Fong et al. hypothesized, the polymer solution's high surface tension may have contributed to the formation of the beads. High surface tension makes the capillary effect that was previously described much more pronounced. According to Fong's research findings, lowering the solution's surface tension will result in a smaller number of beads being generated while simultaneously increasing the diameter of the fiber produced. According to Tripatanasuwan et al., the production of beads can be attributed to the capillary effect; however, their research also demonstrates that the humidity in the surrounding air can impact the evaporation rate of the polymer jet, which in turn influences the process of bead formation. Electrospinning in a closed environment allowed researchers to notice that the number of beads entrained in the fibers rose in proportion to the relative humidity of the domain.

As Tripatanasuwan et al. showed, humidity can affect the pace at which a polymer solution evaporates; hence, the surface tension of a polymer solution is not the only component in producing beaded fibers. To demonstrate that humidity affects fiber shape, the research conducted by Tripatanasuwan et al. maintains several variables at a constant level. These variables include voltage, weight percent, density, and viscosity. However, the degree to which a solvent can evaporate during the electrospinning process can be altered in several ways. For example, the distance between the plates can be made more significant, the velocity of the jet can be adjusted, and the flow rate of the polymer solution can be changed.

A significant additional discovery that was made regarding the electrospinning process concerned the phenomena that are commonly referred to as whipping. As the polymer jet travels toward the collection plate, the solvent in the solution evaporates, leaving behind the formed polymer. This process is called polymerization. During this period, the jet will go through a procedure known as "whipping," during which it will undertake a sequence of high-speed flagellations that give the impression of being completely random. Many researchers have attempted to develop models explaining why the whipping phenomenon occurs and how to predict the unpredictable circular motion of the jet when it is electrospun. These models have been developed to shed light on these questions. These models have been constructed so that we can better understand these questions. In the study by Yarin et al., an attempt is made to predict the amount of whipping that will occur by analyzing the disturbances induced by both the electric force and the air. These disturbances are compared with one another. To do this, the disruptions caused by the electric force are compared to those caused by the atmosphere. Yarin discovered that the evaporation of the solvent and the solidification of the polymer jet both had a substantial impact on the radius of the circular pattern that was generated when the fiber first started to whip. The model provided evidence of this. The hypothesis that the whipping motion was caused by the negative charges carried by the liquid jet as it went closer to the plate was supported by the research that Reneker and his colleagues carried out. They also observed that the diameter of the nanofibers shrunk as the amount of turbulence in the jet grew. This was an exciting finding. This turned out to be a fascinating discovery. Another set of researchers, led by Hohmann and colleagues, concluded that the interaction of gravitational forces, electrical charges, and Rayleigh instability brings on the whipping of a polymer jet.

Because it attributes more variables to the causes of the whipping phenomenon, such as electrical, gravitational, and Rayleigh instability, the paper by Hohmann et al. provides a more descriptive view of the whipping phenomenon than the papers by Reneker et al. and Yarin et al. do. This is because Reneker et al. and Yarin et al. do not. This goes beyond what Reneker et al. and Yarin et al. have accomplished in their papers. Hohmann et al. elaborates on how electrospinning can be utilized despite the polymer solution's varying viscosities and charge densities. This provides an additional level of specificity to the research. They define the electrospinning process by expressing it as a formula that is a function of the two factors. Hohmann et al. also demonstrates how electrospinning can be used with polymer solutions with varying viscosities and charge densities.

Following the findings of bead formation and whipping of the polymer jet, ongoing research in the electrospinning process has led to the development of a wide variety of polymers and solvents that can be utilized to produce nanofibers. This has been made possible as a direct result of the electrospinning process. In their research, Huang and colleagues presented a comprehensive list of more than forty-four different polymers that had been electrospun successfully. This list also included the eight solvents used, the testing parameters, the applications for the particular polymer nanofibers, and the polymer concentration in the solution.

During the ongoing investigation, it was found that the voltage and the weight percent of the solution may influence the fibers' output. This was a discovery made in the course of the investigation. The efforts of scientific researchers have resulted in a significant increase in the number of factors that can affect the product that is ultimately produced by the electrospinning process. In this calculation, some factors considered include surface tension, the distance between the needle tip and the collection plate, temperature, humidity, the rate of fluid ejection, and the type of polymer being used. An analysis of these findings reveals that an increase in the voltage that is applied results in a reduction in the diameter of the electrospun fibers and an increase in the likelihood that the fibers contain beads that have become entrained. In addition, the diameter of the electrospun fibers decreases. In addition, it has been observed that polymer solutions with a high surface tension require a higher applied voltage to pull the fiber closer to the plate. In conclusion, increasing the distance separating the collector and the nozzle improves the chances that pure fibers will be spun, but doing so requires an increase in the voltage being applied.

Poly (ethylene oxide) is one polymer with significant electrospinning (PEO) application. PEO has various applications in the biomedical industry, including tissue engineering and medication delivery. It is favored over other polymers because of its high level of biocompatibility and its relative ease of electrospinning utilizing a variety of solvents and voltages. Because of its straightforward polymer structure, which consists of two carbons and one oxygen molecule attached to the backbone, and its capacity to be dissolved in water, it is relatively straightforward to generate polymer solutions with which to electrospun material. Additionally, PEO is easily mixed with other polymers to create composites for various applications.

The investigation that Dietzel and his colleagues carried out examines the particulars of the electrospinning of PEO nanofibers, concentrating on the aspects of the procedure that were considered. In this study, the effects of several electrospinning process parameters, such as voltage, surface tension, feed rate of solution, and the weight percent of polymer in the solution, are investigated to determine how the characteristics of these variables influence the production of fibers (Lee et al.,2018). These parameters include the following: The findings of this research show that an increase in voltage increases the number of beads entrained in spun PEO nanofibers. This was demonstrated by the research that was provided in this study. In addition, it has been established that an increase in the percentage of PEO present in the solution, as measured by weight, decreases the likelihood of bead formation.

The authors of Dietzel et al. do a fantastic job of explaining how the electrospinning process can be altered by a variety of factors in the environment. The electrospinning statistics provided by Dietzel et al. encompass various subjects, including the polymer solution's applied voltage, weight percent, flow rate, and surface tension. These articles comprehensively cover the electrospinning process, providing a more well-rounded perspective. In other publications, the parameters that affect electrospinning are not considered. Instead, a greater emphasis is placed on the characterization of the material that is generated and the potential applications of this material shortly. Another study that directly targets several processing parameters that affect fiber shape is the review that Huang et al. conducted on all of the polymers created using electrospinning. This review can be found here. Voltage and viscosity are the only elements that Huang et al. describe as affecting the shape of the electrospun material.

To stop the creation of beaded nanofibers, the capillary effect of a polymer solution and the processing parameters employed in electrospinning, such as voltage, distance traveled, and weight percent, are still subject to change depending on the type of polymer being used. Even though the reason for the creation of beads can be easily determined, this continues to be the case. Because there is no single, definitive formula or attribute of the material that indicates whether or not beads will be generated, it cannot be easy to exert control over the morphology of fibers (Mailley, Hebraud, & Schlatter,2021). This can make controlling the morphology of fibers challenging. One technique that has not been explored to its full potential is one in which the fundamentals of fluid mechanics are applied to explain the morphology of electrospinning. Utilizing fluid mechanics principles to describe the development and nature of the polymer jet as it makes its way to the grounded collection plate may make it easier to characterize the resulting fiber morphology of the polymer nanofiber. This may be the case if the goal is to simplify the process.

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2.2.1. Cellulose Acetate:

Cellulose is the most important structural polysaccharide and biomolecule in the world. It is also the most abundant. In 1992, Kobayashi and Shoda were the first people to successfully synthesize cellulose without making use of any enzyme with a biological origin. In terms of its composition, cellulose is a glucose polymer made up of molecules of the -type of glucose connected by glycosidic linkages. Cellulose chains have a linear structure, maintained by hydrogen bonds between each chain. These units are not arranged precisely in the system's plane but adopt a saddle conformation. This involves the successive glucose residues being rotated at an angle of 180 degrees concerning the molecule's axis and the hydroxyl groups being arranged in an equatorial position. This configuration provides a high level of mechanical resistance. Because of its structure, cellulose is amenable to extensive changes, which might form new derivative compounds. These new compounds might be more suitable than cellulose for specific purposes (Czapka eta l.,2021). There is a wide range of cellulose derivatives, the most common of which are cellulose acetate and ethyl cellulose, while methylcellulose and cellulose ethyl cellulose are also standard. Methylcellulose is another type of cellulose derivative. These chemical compounds are derived from cellulose through a process that involves altering the structure of the starting material by replacing the hydroxyl groups on the outside of the molecule with methyl, acetyl, or ethoxy groups, respectively. Much research has been done on cellulose derivatives' electrospinning in the past ten years. However, there have been enormous advancements, particularly in preparing composite materials based on the electrospinning of these derivatives. These materials have tremendous potential to turn the tide in several different industrial sectors, and these advancements have been particularly notable.

Numerous researchers have investigated electrospun nanofibers derived from cellulose derivatives using various solvent solutions. Electrospinning could be done with different solvents, including acetone, dimethylacetamide, dimethylformamide, acetic acid, chloroform, methanol, water, or a mixture of these solvents in varying concentrations; however, acetone was by far the most popular of these solvents. The primary issue is that acetone has a low boiling point (56 degrees Celsius) and evaporates quickly. This makes it challenging to conduct the long-term electrospinning necessary for the large-scale manufacture of nanostructures for various applications. Because of their high surface area, cellulose-derivative electrospun nanostructures have been used in multiple applications in recent years. These applications include serving as scaffolds for tissue regeneration, filter membranes, and catalytic processes. The textile industry has also used fibers derived from cellulose by combining various fibers with polymeric coatings to create new composite materials. However, the most common services for cellulose derivatives nanostructures are in the medical industry. Some examples of these uses include the tissue engineering discussed earlier, the production of bandages, drug-controlled release systems, medical implants, and artificial organs (Wen et al., 2018). Although the prospective benefits of cellulose derivative nanostructures have been examined, a correlation has not yet been established between the properties of the prior solutions and the properties of electrospun nanostructures. Therefore, the current study aims to establish a correlation between the solution's physicochemical properties and the electrospun nanostructures' microstructural properties. To accomplish this goal, it will be determined how the solution affects the concentration of natural and biodegradable polymers and how the solution involves the solvent utilized.

2.2.2 Recycle PET from bottles and polystyrene.

It is possible to recycle and reuse the material found in used bottles made from poly (ethylene terephthalate) (PET), which helps reduce the quantity of garbage sent to landfills. A technology known as melt-electrospinning was utilized in the production of recycled PET. The melting temperature causes an impact on the material's morphology, the applied voltage, and the distance between the die and the collector. The investigation focused on electrospun fibers. Differential scanning calorimetry (DSC) and thermal gravimetric analysis were used to investigate the thermal characteristics of recycled PET (TGA). It was discovered that recycled PET granules could be melted at 260, 290, and 310 degrees Celsius, producing the melt polymer at the highest temperature.

It was electrospun at a high voltage of 38 kV, and the distance between the spinner and the material being electrospun was 12 cm. The widths of the recycled PET electrospun ranged from 45 to 65 mm. A significant amount of the PET bottles collected worldwide will be converted to fiber for use in various applications, including textiles, fiberfill, carpet fiber, and nonwovens (López de Guereñu, 2020). The processing can be done in either more compact and smaller spinning units or the granulation path of more extensive extrusion spinning lines. Both options are available. It is also possible to include recycled melt as a side stream into constantly operating direct fiber spinning operations. This is something that can be done. In this particular research project, a method known as melt-electrospinning was utilized to generate nanofibers from recycled PET bottles. The process parameters are the distance from the die to the collector, the temperature of the melt, and the voltages applied in the control system.

Shin and Chase used electrospinning and d-limonene as natural solvents to produce nanofibers from recycled waste-expanded polystyrene. These nanofibers were obtained from waste-expanded polystyrene. They examined the differences in the diameters of the fibers that occurred in response to the use of several kinds of solvent. Strain et al. similarly produced PET nanofibers using discarded bottles and an electrospinning process; however, applying the resultant PET as a smoke filter was their primary focus. They recently investigated the relationship between the PET concentration and the fibers' diameters.

Electrospinning was used for the research that Zander and colleagues conducted on the synthesis of nanofibers from both pure and mixed waste streams. They mainly concentrated on the fiber morphologies resulting from the viscosity of the first solution utilized. Macossay et al. and Mo et al. participated in an experimental study on the production of electrospun nanofibers. They focused on some parameters, such as the syringe's needle diameter and the voltage's effect.

2.2.3 Nanofibers Variables:

For the creation of nanofibers, there are a few crucial factors. These variables directly affect how nanofibers are structured.

- The Molecular Weight:

Electrospinning's ability to create nanofibers largely depends on the solution's molecular weight. It shows how many polymer chain entanglements there are in the spinning solution. Numerous experts said in their study that high molecular weight solutions prefer to make coarse/thick nanofibers. In contrast, low molecular weight solutions tend to produce beads instead of nanofibers, Lee H, Gang X, Davood K, 2017. Therefore, the molecular weight of the polymer plays a crucial role in creating the ideal viscous solution for the production of nanofibers. It may be possible to obtain the appropriate viscosity for the spinning solution if the polymer's molecular weight is low and the researcher has combined it with nanoparticles or drugs. In some cases, even if the polymer concentration is low, the correct number of polymer chain entanglements can guarantee the proper viscosity level for electrospinning.

- Concentration:

Electrospinning for textile applications depends significantly on the polymer concentration in the spinning solution. When the concentration is extreme, the nanofiber characteristics modify, and the diameter of the nanofibers becomes thicker, which changes the scope of the investigation. If the polymer concentration in the solution is very poor, the characteristics change, and at low amounts, bead production is more likely than nanofiber creation.

- The solution Viscosity:

The electrospinning fluid viscosity is an essential parameter in the fabrication of nanofibers. Molecular weight, polymer concentration, and viscosity are all connected.

Khan et al. (2018). There is no need for either low or high viscosity to obtain nice and clear nanofibers. It is challenging to maintain the appropriate viscosity for the spinning solution. As a result, before proceeding with the experiment, the researchers experimented on an optimal situation. In general, excessive viscosity has a negative impact on nanofiber deposition because jets can become unstable, and droplets can develop.

- The Conductivity:

The electrical conductivity or density of surface charges of the solution is critical for the electrospinning manufacturing of nanofibers. It is governed by the type of polymer and solvent employed to create the solution. The diameter of nanofibers is greatly affected by conductivity; as the conductivity of the solution increases, the diameter of the nanofibers decreases; nevertheless, electrospinning of highly conductive solution has a detrimental influence on the bending stability and diameter distributions of nanofibers. Nanofiber-based scaffold fabrication is required to reduce nanofiber diameter dispersion and provide bending stability. As a result, a suitable or adequate conductivity of the electrospinning solution is needed to fabricate the nanofibers. Khan et al. (2018).

- The Applied Voltage:

Khan et al. (2018). Applied Voltage it is a more critical parameter in the manufacturing of nanofibers. The applied voltage has a significant impact on both electrospinning and the characteristics of nanofibers. The initiative voltage for electrospinning is affected by the material's characteristics, the distance between the nozzle tip and the collector, humidity, and ambient temperature. When the viscosity of the polymer solution increases or its concentration in solution increases, considerable voltage is necessary to form the nanofiber scaffolds. The voltage is also greatly affected by the collector distance. When the distance between the nozzle tip and the collector increases, a large electric force is required to construct and collect the nanofibers on the collector.

- The Flow Rate of the polymer Solution:

The flow velocity of the solution during electrospinning is critical for fabricating the correct shape for nanofibers. If the flow rate is modest, it might aid in evaporating the solvent from the solution during nanofiber ejection.

- The Nozzle and Collector Distance:

The distance of collecting is a critical variable in the fabrication of noticeable solid nanofibers. To make solid nanofibers, the distance between the nozzle tip and the collector must be large enough to allow the solvents in the jet to evaporate before collection. The material qualities and electrospinning geometry determine the minimum collecting distance.

- The Temperature and Humidity:

Temperature and humidity have been found to significantly impact the manufacturing of nanofibers for textile products/applications. For improved electrospinning of textile nanofibers, the solution temperature should be raised to 25 Celsius. When the temperature rises, nanofibers' morphology, mechanical characteristics, and structure are altered.

2.1.4 Recycle Abaya Fabrics:

The abaya is a traditional garment worn by women in many Muslim countries. Abayas are typically made from lightweight and breathable fabrics like cotton or polyester. Using nanofibers in abaya fabric can improve its properties, such as durability, water repellency, and UV protection. CA and rPET nanofibers can be incorporated into abaya fabric to enhance its functional properties. The textile industry is one of the most polluting industries globally, accounting for a significant portion of carbon emissions and waste generation. The concept of circularity has emerged as a promising approach to mitigate the environmental impact of textiles, aiming to minimize waste and maximize resource efficiency through reuse, repair, and recycling. Recycling has received significant attention for achieving circularity in the textile industry. This literature review will focus on recycling for the life cycle circularity of textiles.

2.3 Recycling:

Recycling is the process of converting waste materials into new products. Recycling can take various forms in the textile industry, including mechanical, chemical, and upcycling. Mechanical recycling involves breaking down textiles into smaller fibers that can be used to produce new products. Chemical recycling consists of breaking textiles into their chemical components, which can be used to make new materials.

Upcycling involves transforming waste textiles into higher-value products.

2.3.1 Life Cycle Circular Economy:

Life cycle circular economy (LCCE) is a framework that aims to optimize resource use and minimize waste throughout the life cycle of a product. LCCE focuses on three main strategies: reduce, reuse, and recycle. The textile industry can benefit from LCCE by implementing sustainable design, improving the durability of products, and optimizing recycling processes.

2.3.2 Challenges and Opportunities:

Recycling in the textile industry faces several challenges, such as the complexity of textile products, the difficulty of separating fibers, and the presence of hazardous chemicals. However, recycling also presents opportunities, such as reducing waste and greenhouse gas emissions, conserving resources, and creating new business models. The circular economy approach can provide economic benefits to the industry by creating new revenue streams and reducing costs associated with waste management.

2.3.3 Recycling Bottles:

Recycling bottles is an essential aspect of environmental conservation. According to Geyer et al. (2017), over 8.3 billion metric tons of plastics have been produced since 1950, of which only 9% have been recycled, 12% incinerated, and 79% have accumulated in landfills and the natural environment. In this context, recycling bottles can help mitigate the negative impact of plastics on the environment. Recycling bottles has been shown to reduce greenhouse gas emissions, save energy, and reduce waste in landfills (Geyer et al., 2017).

In addition, recycling bottles can also create economic benefits by generating job opportunities and reducing costs associated with producing new bottles. Many studies have explored the different ways in which bottles can be recycled, such as mechanical recycling, chemical recycling, and feedstock recycling (Soroudi et al., 2021). However, challenges remain in increasing the recycling rates of bottles, such as the lack of infrastructure, low public awareness, and the complex nature of plastic waste management (Geyer et al., 2017).

2.3.4 Abaya Fabric:

Abaya is a traditional Islamic garment that women in the Middle East widely wear. Abayas are typically made from various fabrics, including cotton, silk, and polyester. There has been growing interest in using recycled materials to produce abayas, such as recycled polyester (rPET) and post-consumer textile waste (PCTW).

According to Islam et al. (2020), using recycled materials in abaya production can have significant environmental benefits, such as reducing the carbon footprint and conserving natural resources. Using rPET has been shown to reduce greenhouse gas emissions and energy consumption compared to virgin polyester production (Kurian et al., 2020). Furthermore, using PCTW can divert textile waste from landfills and reduce the need for virgin materials (Islam et al., 2020).

Despite the potential benefits, there are challenges in using recycled materials in abaya production, such as the availability and quality of recycled materials and the consumer preference for traditional materials (Islam et al., 2020). Therefore, further research and development are needed to overcome these challenges and promote the use of recycled materials in abaya production.

2.4 Thermochromic pigment application in textile application

Thermochromic pigments are specialized colorants that change color as they are subjected to changes in temperature. These pigments can be used in various applications, including textiles. In the textile industry, thermochromic pigments are being used to create innovative fabrics that can change color in response to changes in temperature (Ibrahim, 2012).

The major application of thermochromic pigments is to indicate temperature. For instance, if a thermochromic pigment turns green at a particular temperature, the eye may see the color change, allowing the temperature to be determined. Various thermochromic pigments, painted or coated on a strip, can be used to grade temperature and the thermochromic pigments can be precisely calibrated to change color at certain temperatures. Strip-type thermometers, used to measure body temperature, are a typical illustration of this. Even asleep youngsters or patients under anesthesia can have their body temperatures measured with this. To determine the food or drink's proper cold or heating temperature, thermochromic pigments are frequently used in food containers, such as bottles, cans, mugs, kettles, etc.

One of the most common uses of thermochromic pigments in the textile industry is in the production of t-shirts and other types of clothing. These pigments can be added to the fabric during the dyeing process, allowing the fabric to change color when exposed to different temperatures. For example, when exposed to heat, a t-shirt might be dyed with thermochromic pigments that cause it to turn from black to white. This effect can create unique designs only visible when the fabric is heated, such as a logo or message that appears when the wearer works up a sweat (Bamfield, 2001).

Liquid crystals and leuco-dye-based thermochromic pigments have been used in textiles as thermochromic materials. Before application, each of these kinds of thermochromic materials requires microencapsulation. Due to a lack of affinity and water insolubility, thermochromic compounds have difficulty applying dyes to textile fibers, whether natural or synthetic. For these reasons, they are typically used as pigments on the surface of fabrics and some binder systems (Morales-Espinoza et a.,2020). It has also been reported to coat filaments and fabrics with some polymeric binder systems that contain thermochromic elements that are encapsulated. Compared to other commercially available pigments, these pigments' color strength is less. This is because there is only a tiny amount of dye in the final formulation, which weighs roughly 2% before microencapsulation and less in the finished product. These pigments are therefore utilized at 15–30% by weight in the coating to prevent the usage of pale hues. The significant pigmentation impacts the feel and handle of the cloth.

In 1991, T-shirts sold under the Global Hypercolor brand featured printed and coated thermochromic pigments with permanent color. Instead of using colorless, the permanent color was used to create a change in color from one to another. These items' fastness qualities, particularly their wash fastness, were subpar. Some children's clothing with thermochromic properties has also been recorded to visualize changes in body temperature. With the aid of a binder system, the thermochromic material is applied either before or after the garment's creation in the form of coating and printing. Similarly, thermochromic pigments based on leuco dye have been utilized in jeans that change color with body temperature. The goal was to use thermochromic pigments to mimic the indigo-faded appearance of jeans.

During the filament manufacturing, thermochromic pigments comprising colorants were added to artificial cellulose fibers. For this, the wet spinning technique was employed. When cellulose and leuco-dye-based thermochromic pigments were combined in a spinning bath, the resulting filaments displayed thermochromism (Uncuoğlu, 2019). During melt spinning, thermochromic compounds have also been combined with other polymers. In this manner, thermochromic acrylic fibers have been created. For heat profiling of thermal processes, industrial fabrics integrating thermochromic polymers have been created. Using a melt spinning technique, nonwoven fabrics with thermochromic pigments based on leuco dye have also been created (Huang et al.,2022). There have been reports of waterproof clothing manufactured from flexible PVC sheets or other polymers. These materials contain thermochromic components, whose color changes as the surrounding temperature changes. A multilayer polymer composite with additional polymer layers and one or more thermochromic components has been created. A melt extrusion method has been used in the creation of this composite.

Another application of thermochromic pigments in textiles is in producing mood-changing fabrics. These fabrics are designed to change color in response to the wearer's emotional state, such as when they become excited, nervous, or happy. This is achieved by embedding the thermochromic pigments in the fabric and then designing the fabric to respond to changes in body temperature or other physiological cues. Thermochromic pigments can also create fabrics that respond to environmental changes, such as sunlight or temperature. For example, a shirt might be designed to change color when exposed to sunlight, allowing the wearer to stay cool and comfortable in hot weather.

Similarly, a jacket might be designed to change color when exposed to cold temperatures, providing the wearer with an additional layer of warmth. In addition to their aesthetic applications, thermochromic pigments can also be used in functional textiles. For example, these pigments can be incorporated into fabrics used in medical applications, such as temperature-sensitive bandages that change color to indicate a change in body temperature. They can also be used in sports textiles, such as running shoes that change color when the wearer's foot strikes the ground, indicating where the wearer is putting the most pressure (Ibrahim, 2012).

Research on performance evaluation and enhancement has been done to create new techniques for using thermochromic materials in textiles. The initial method utilized was the subjective color perception of color change. Bryant created a method for instrumentally measuring thermochromic liquid crystals. A spectrophotometer and a hot stage were put up to measure color at various temperature intervals. A peristaltic pump circulates ice-chilled water for measurements lower than room temperature (Crosby & Netravali, 2022). The cholesteric liquid crystals, typically needing a black background for color play, were also tested against other colored backgrounds. The samples that had been coated and printed had their film thickness, reversibility, hysteresis, and different fastness parameters assessed.

Leuco dye-based thermochromic pigments have also been the subject of inquiry; in this case, the thermochromic pigments were screen-printed and UV cured for evaluation. Using a spectrophotometer, the color measurements were made at various temperature intervals. These samples underwent testing for toughness, reversibility, color combinations, and pigment activation temperature. Metallic and textile fibers have been treated with nitrogen plasma, allowing for the application of irreversible thermochromic pigments to detect the presence of density atomic species visually (Karshalev, 2020). Diagnostic procedures are also accessible, albeit more expensive, because the plasma treatment process depends on the density of active species on the substrate's surface. The irreversible thermochromic materials utilized in this work can be purchased for less money, and detection can be done without the aid of a highly skilled staff.

The potential of thermochromic materials in textiles employed with electronic heat profiling circuitry has also been investigated, in the opinion of a textile designer. The various possible uses of thermochromic materials—leuco dye-based and liquid crystal-based—were discussed from a designer's perspective. In a study at the intersection of design and technology, indoor textile design was the main focus of this examination.

Overall, using thermochromic pigments in the textile industry has opened up new avenues for designers and manufacturers to create unique and innovative products. These pigments allow for many creative possibilities, from clothing that changes color with the wearer's mood to functional textiles that respond to environmental changes or the wearer's body temperature. However, it is essential to note that using thermochromic pigments in textiles also comes with some challenges. For example, the pigments can be expensive and may require specialized equipment to incorporate into fabrics. They can also be sensitive to washing and other types of wear, which can cause the color-changing effect to fade over time. Another challenge is ensuring that the pigments are safe for use in textiles. Some thermochromic pigments contain heavy metals or other toxic substances that can harm human health or the environment. Therefore, manufacturers must carefully select pigments that are free of these substances and meet strict safety standards.

In conclusion, using thermochromic pigments in the textile industry can revolutionize our thinking about fabrics and clothing. From mood-changing t-shirts to temperature-sensitive bandages, these pigments offer a range of creative and functional possibilities. However, as with any new technology, there are challenges to overcome, such as cost and safety concerns. However, with careful attention to these issues, the future of thermochromic textiles looks bright.

Purpose & Research Questions:

In this study, we attempted to handle it from two different angles. This experimental part's initial goal was to investigate an alternative nanofiber for textile applications by utilizing recycled water bottles, cellulose acetate, and abaya cloth. The recycling technique combines electrospinning technology with chemical recycling procedures for fiber separation to produce improved recovered textiles. The proposed idea of recycling for the circular life cycle of textiles is the subject of this purpose. Although chemical techniques offer low fiber damage through repeated recycling, electrospinning has the ability to minimize fiber mixes while keeping better fiber qualities. To further this research's objective, the following research questions were created:

Objective of the study:

1) What techniques and rations are needed to formulate a successful fiber blend?

a) What chemical-to-textile percentage ratio is necessary for blends made of plastic bottles to dissolve successfully?

b) How long should it take for polyester fiber mixes used in abaya fabrics to dissolve successfully?

2) What conditions must be met for both quantity and timing for electrospinning to be successful?

a) How much solution is needed to spin a certain size and thickness while maintaining the preliminary textile's similarity? 16 hr

b) How long does spinning a given size and thickness take to keep the final textile similar?

3) Is it feasible to create content that matches the Qatari culture?

4) Does this procedure work with fabric and fiber?

5) Thermochromic nanofiber based on composite mechanisms are shown?

6) How do you illustrate the reduction of micro-thermochromic to nano-thermochromic?

7) Enhancing Qatar's temperature's composite chromatic effects?

8) Purposes to respond to the stated research questions, the following objectives have been determined:

1. Select the type of polyester that need to be tested for recycling.
2. Select the type of polyester that need to be tested for recycling.
3. Use trifluoracetic acid to treat blended textiles to blend the fiber mix constituents chemically.
4. successfully electrospun recycled PET samples to achieve good nanofiber sheets.

Report the following findings:

a) The ideal chemical ratios for separating fiber blends.

b) The ideal period for dissolving fiber mixtures.

c) The duration needs to spin the material at the proper weight and thickness using electrospinning.

CHAPTER 3: METHODOLOGY

The major goal of this research was to investigate an alternative textile recycling approach that combined chemical recycling procedures and electrospinning technologies. A two-step procedure was used to identify the methods and percentages needed for effective fiber blend separation and electrospinning.

In this exploratory study, the following questions were addressed:

1) What techniques and rations are needed to formulate a successful fiber blend?

a) What chemical-to-textile percentage ratio is necessary for blends made of plastic bottles to dissolve successfully

b) How long should it take for polyester fiber mixes used in abaya fabrics to dissolve successfully?

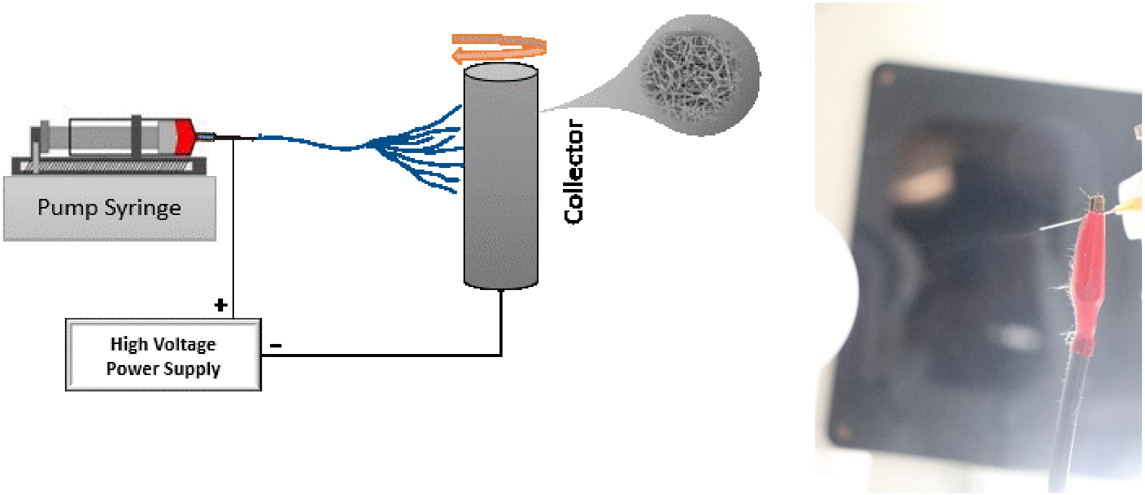


FIGURE 1. Schematic and real figure representation of the electrospinning setup.

3.1. MATERIALS AND METHODS:

Polyester fabric composition was chosen for this study because of its environmental effect, widespread market use, and industry and academic research gaps. When purchasing materials for this investigation, fiber content was prioritized. However, weave structure and weight were meticulously considered throughout the material selection process. This was done in an attempt to maintain material uniformity and commonality for proper comparative analysis across fabrications. Water bottles, polyester fabrics, and mixes were obtained from local merchants to guarantee a quick turnaround time for testing.

(CELLULOSE ACETATE AVERAGE M N ~50,000 BY GPC), ACETONE PURISS. MEETS THE ANALYTICAL SPECIFICATION OF BP, NF, AND PH. EUR., ≥99% (GC), ETHANOL (UNTAXED) PURISS. P.A., ABSOLUTE, ≥99.8% (GC), METHANOL CHROMASOLV™, FOR HPLC, ≥99.9%, DMSO, DIMETHAYLE SULFOXID were bought from Aldrich. THERMOCHROMIC was purchased from Shenzen Xiangcai Chemical Co., Ltd company. QATAR OISES BOTTOLE, TRIFLOROACITIC ACID, ≥99.0%. CHLOROFORM. ELECTROSPINNING (SHANDONG AME ENERGY CO., LIMITED, China).

3.2. Synthesis of Nano-fiber through Electrospinning.

3.2.1. Preparation of Cellulose acetate Solution:

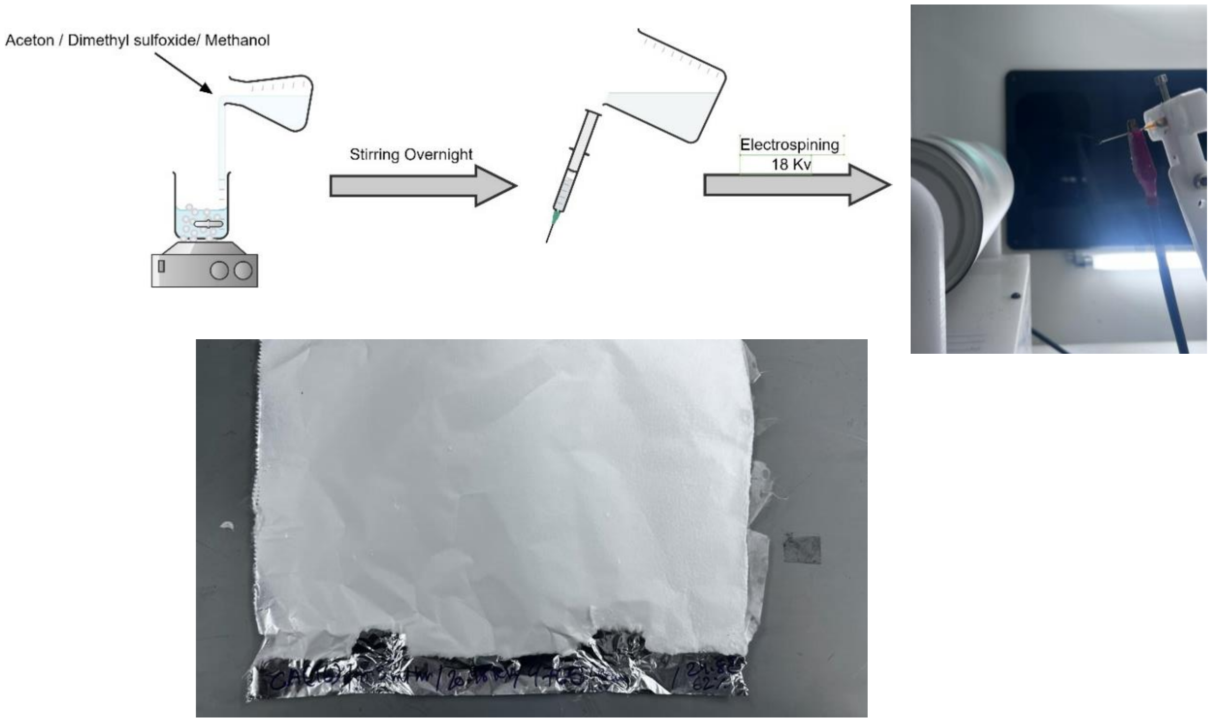


FIGURE 2. Schematic representation of the cellulose acetate nano fiber solution.

To create a CA solution with a concentration of 16% w/v, a specific quantity of CA powder was dissolved in a mixture of Acetone, DMSO, and Methanol with a volume ratio of 2:2:1. For the conventional method, as well as the core solution of coaxial and sandwich methods, CA solutions were prepared by dissolving CA powder in an Acetone/DMSO/Methanol mixture in a weight ratio of 5:1. The solution was then stirred using a magnetic stirrer overnight.

3.2.1.2 Electrospinning of the CA solutions.

The solutions underwent electrospinning after being sonicated for five minutes. Between the nozzle tip and the outside of the drum, a distance of 8.0 cm was covered by an electrical potential that ranged from 15 KV to 23 KV. The drum's rotating speed was set to 476 rpm, and the solutions were fed at a rate of 0.5 ml/h. The temperature used for the electrospinning procedure was 246±°C.

FIGUER 3: Representation of the nanofiber Cellulose acetate membrane

3.2.2. Preparation of R-PET Solution:

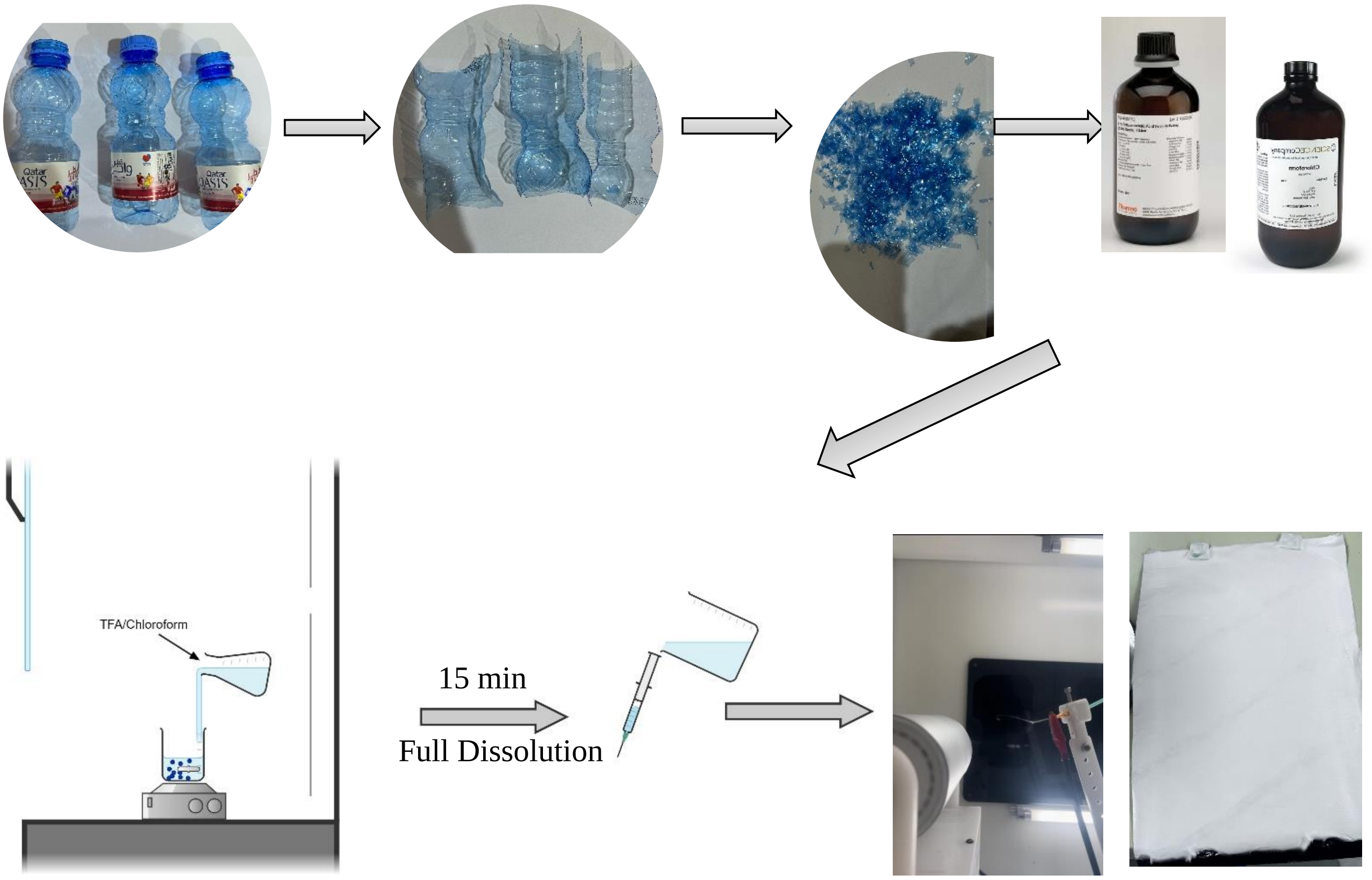


FIGURE 4: Schematic representation of the PET dissolution and fabrication of the r-PET nano fiber sheets.

Use the Qatar Oasis water bottle, shredding to small pieces, clean it with ethanol, then drying overnight. Then a certain amount of r-PET pieces were dissolved in 1:3 v/v TFA/Chloroform to obtain an r-PET solution at the concentration of 15% w/v. An r-PET solution for the usual method was provided by dissolving r-PET in the weight ratio of 1:3 in a TFA/Chloroform mixture, then putting it in the magnetic stirring for 1-2 hr.

3.2.2.1 Electrospinning of the R-PET Solutions.

The r-PET solutions were magnetically stirred and subsequently electrospun. The distance between the nozzle tip and the drum's outside surface was 8.0 cm, and a variable electrical potential of (15–25) KV was applied over that area. The rotating drum's rotational speed was set to 511 rpm. The solutions were fed at a controlled rate of 0.5 ml/h. At room temperature (24–6°C), electrospinning was performed.

Figure 5: R-PET nanofiber.

3.2.3 . Preparation of R-fabric Solution:

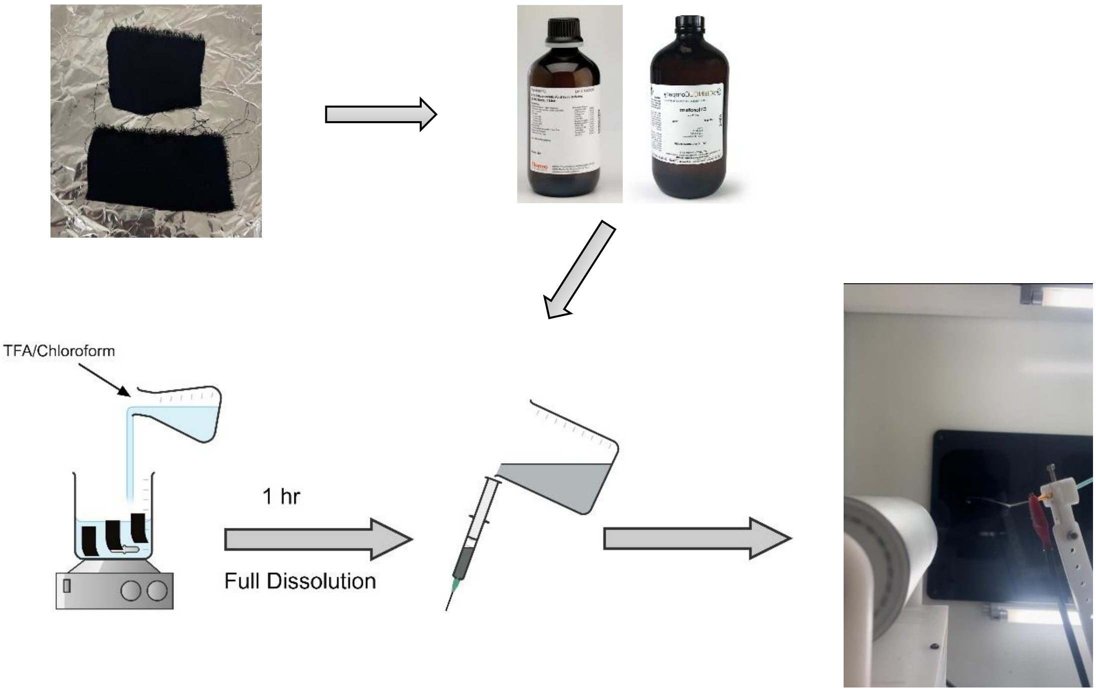


FIGURE 6: Schematic representation of the Abaya Fabric dissolution and the recycled fabric nano-fiber sheets fabrication.

We used the Qatari brand fabric, shredded it into small pieces, cleaned it with ethanol, and dried it overnight. Then a certain amount of fabric pieces were dissolved in 1:3 v/v TFA/Chloroform to obtain an r-fabric solution at the concentration of 15% w/v, put in the magnetic stirring the complete dissolution was done from 30 min -1 hr.

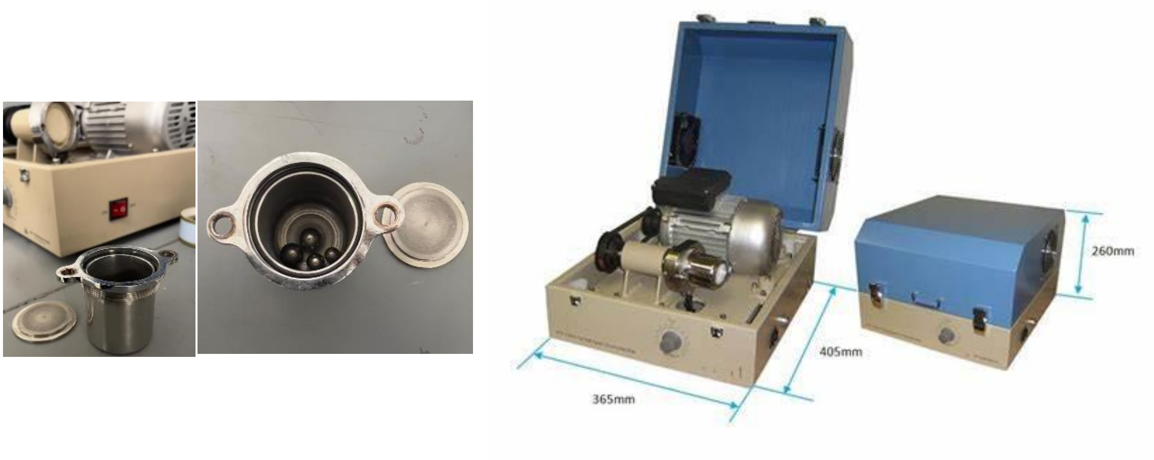
3.2.3.1 Electrospinning of the r-abaya Fabric solutions.

The r-abaya fabric solutions were subjected to magnetic stirring before electrospinning. An electrical potential of 17.56 KV was applied across a distance of 8.0 cm between the nozzle tip and the drum's outer surface. The rotational speed of the drum was set to 479± rpm, while the feed rate of the solutions was maintained at 0.5 ml/h. The electrospinning process was conducted at a temperature of 22±6°C.

Part 2:

3.3 Synthesis OF the Composite Nanofiber with Thermochromic.

3.3.1. Micro-Thermochromic to nano Thermochromic:



Figuer7: represent the ball milling deviceand the ball millimg models used in this study.

Convert the micro-size thermochromic purchased from (Shenzen Xiangcai Chemical Co., Ltd company, china) to nano-size using a ball milling machine, adding the micro thermochromic powder to the jar with four different balls, closing the jar in the device, and adjusting the milling time to 30 min.

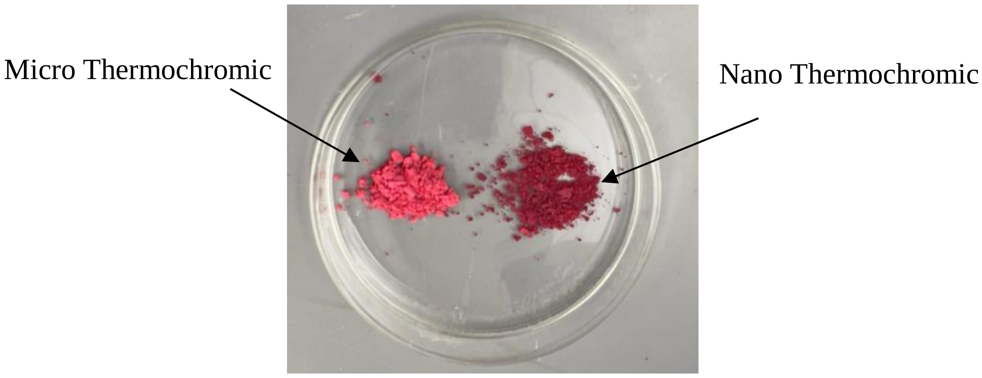


Figure 8: Showing the thermochromic in Micro size and nano size.

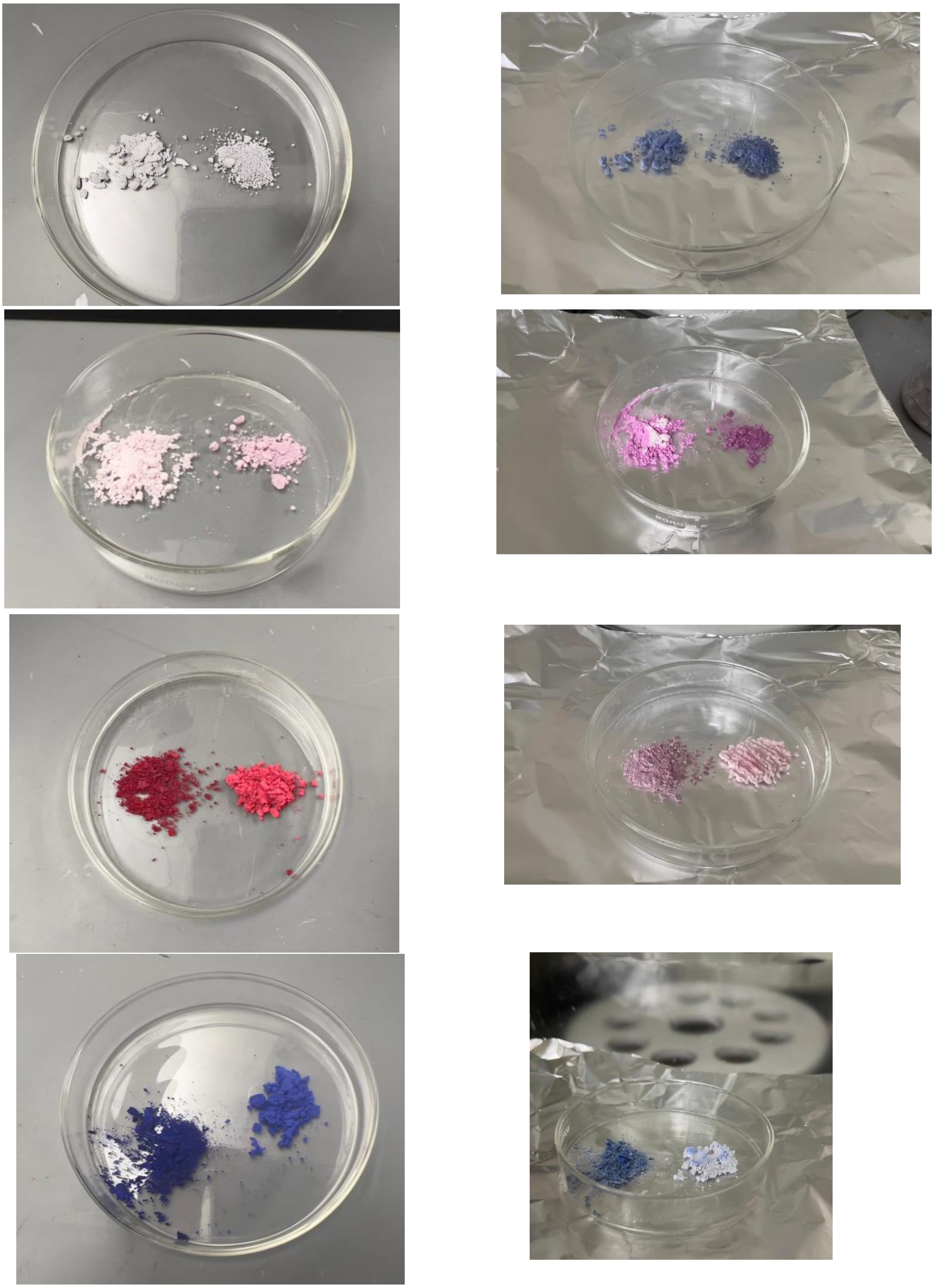


Figure 9: Images of the thermochromic in micro and nano sizes at different temperatures.

3.3.2. Preparation of cellulose acetate with Thermochromic solution:

To create a CA solution with a concentration of 15-16% w/v and 0.5-2% nano-sized thermochromic, a specific amount of CA powder and nano-thermochromic were dissolved in a mixture of Acetone, DMSO, and Methanol in a ratio of 2:2:1 v/v. The CA solution for the standard and sandwich methods was obtained by dissolving CA powder and thermochromic in an acetone/DMSO/Methanol mixture with a weight ratio of 5:1. The solution was left to stir magnetically overnight.

Add the solution to the 10 ml syringe, and adjust it in the pump machine. The flow rate was 0.5ml/hr by applied voltage 17.89 Kv.

3.3.3. Preparation of r-PET with Thermochromic solution:

Use the Qatar Oasis water bottle, shredding to small pieces, clean it with ethanol, then drying overnight. Then a certain amount of r-PET pieces and nano- Thermochromic were dissolved in 1:3 v/v TFA/Chloroform to obtain an r-PET solution at the concentration of 13 to 15% w/v with 2% of nano-size of thermochromic. An r-PET solution for the usual method was provided by dissolving r-PET and Thermochromic in the weight ratio of 1:3 in a TFA/Chloroform mixture, then putting it in the magnetic stirring for 1-2 hr. Add the solution to the 10 ml syringe and adjust it in the pump machine. The flow rate was 0.5ml/hr by an applied voltage of 15 Kv.

3.4. CHARACTERIZATIONS:

The SEM was used to scanning electron microscopy images and the sizes of individual fibers in as-spun fiber matting directly from the obtained images. A MATTSON 1000 FTIR spectrometer was used to perform Fourier-transformed infrared spectroscopy (FTIR) with a 400–4000 cm–1 scanning range and a 16 cm–1 resolution. Thermogravimetric Analysis (TGA) was also performed using the Pyris 6 TGA from PerkinElmer. This is a sort of thermal analysis in which the mass of a sample is measured over time as the temperature varies.

Scanning electron microscope (SEM)

Figure 10: Nova NanoSEM™, (FEI, USA).

It was used to obtain the morphology and roughness changes in the surface of the modified LDP and investigates the samples after surface modification.

Fourier-transform infrared spectroscopy (FTIR)

Figure 11: **FTIR Spectrometer, Spectrum 400 Perkin Elmer.**

It is used to analyze the chemical composition of modified LDPE surface.

ThermoGravimetric Analyzer (TGA);

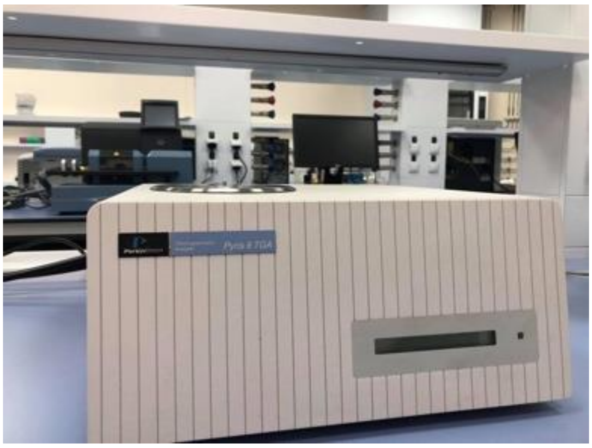


Figure 12: TGA Perkin Elmer Pyris 6 TGA

Instruments were used to measure the original weight percentage of the nanoparticles used to produce the cellulose acetate fibers.

CHAPTER 4 : RESULT.

4.1 Celloluse acetat nanofiber in different voltage

Figuer13: Actual image of Cellulose acetate nanofiber with different applied voltage. (A) 17.89 Kv/ (B) 20 KV / (C) 23 KV.

Part one of this study discovered that electrospinning is a resilient technique that can manufacture nanofibers with consistent shapes from a wide range of materials. It employs Cellulose acetate to create nanofiber that may be utilized in various applications, including textiles and medicine. Furthermore, the nanofiber is made from recycled polyester, which has a detrimental influence on the environment. The figure shows three samples of CA solution (16% wt/vol) in a 2:2:1 volume ratio. As described in the experimental section, acetone/DMSO/Methanol were electrospun with different an applied electrostatic field intensity of (17.89 - 23 kV) at a constant flow rate of 5ml/hr and distance between needle to collectors 8cm to study the fiber membrane. In Figure 13: The actual picture of the nanofiber membrane demonstrates that the CA nanofiber was created in a continuous and uniform diameter—however, Figure 1: exhibits samples of SEM images of the fibers collected. Clearly, the SEM picture of the electrospun nanofiber mats shows a lot of crossovers between them. These fibers are smooth and consistent due to the generated fibers' smoothnes.

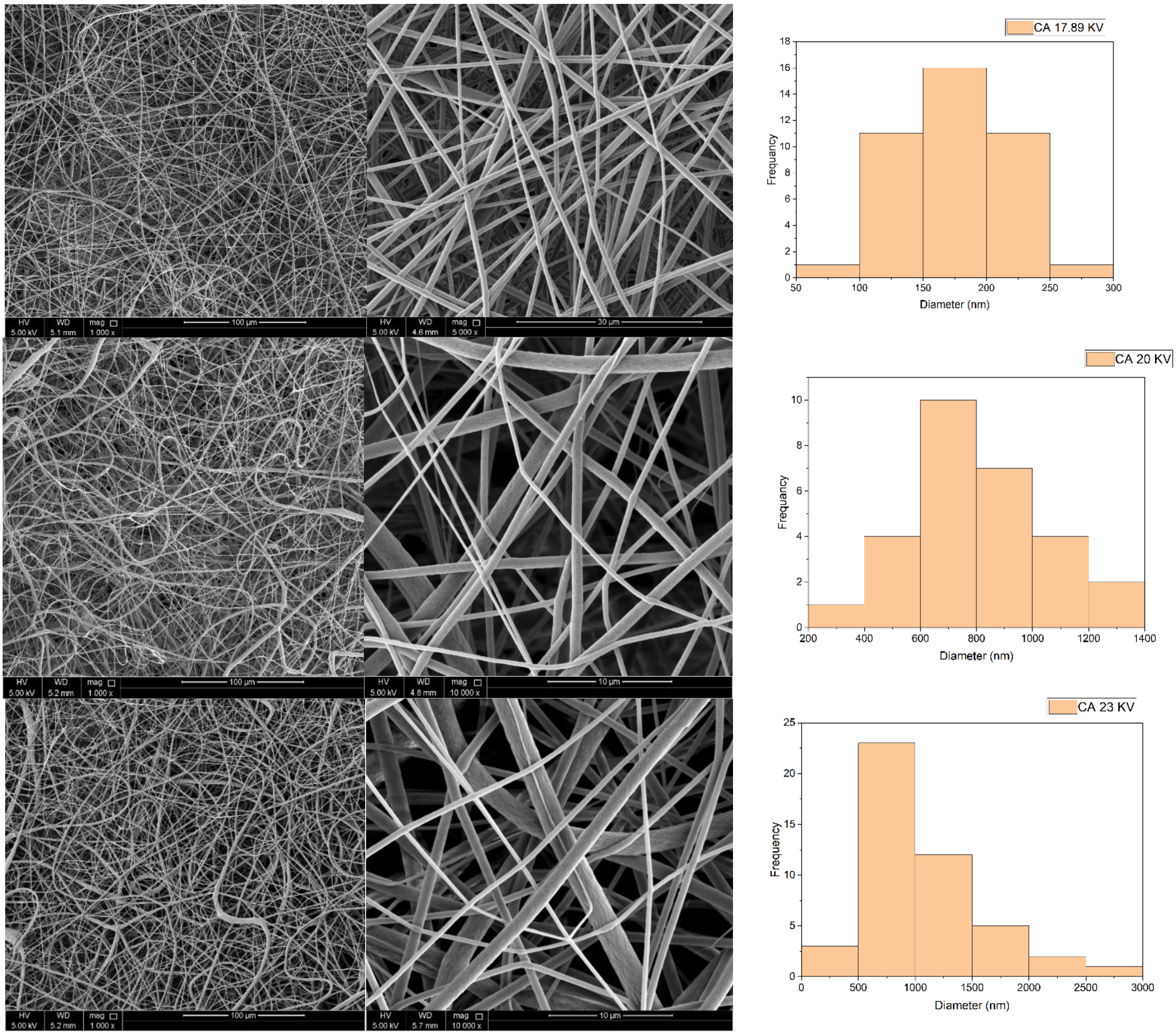


Figure 14: Scanning electron micrographs of Cellulose Acetate nanofiber with different voltage and constant The flow rate and the distance between the needle and the collection.

As shown in figures 13 and 14 the images from (A to C). In (A) were used 17.98Kv, (B) 20Kv, (C) 23KV. The SEM images in figure 14, shows that the fibers in (A) with the humidity were 65% produced were continuous and uniform in average diameter equals 178 nm. (B) humidity 62% had smoothness with little bet beads with an average diameter of 757.9 nm. Image (C) with the humidity of 64% shows that with the crossover with little difference in fiber diameters. The average diameter of this sample equals 908 nm. So, there are significant differences in fiber morphology between the three samples. This suggests that the voltage used in the electrospinning process significantly impacted the fiber morphology. According to the Average diameter, investigate that the Cellulose acetate that's applied voltage equal to 17.89 Kv. was

Based on the information provided, it appears that the TGA analysis was performed on various samples of cellulose acetate with and without the addition of nano thermochromic at different experimental conditions.

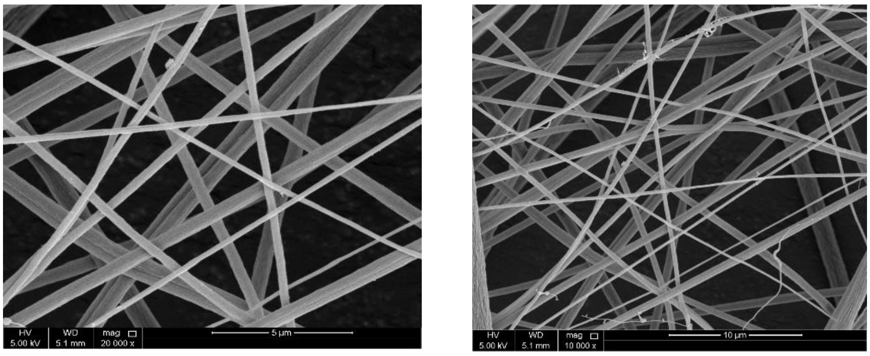


Figure 15: Cellulose Acetate (16%) in fabric /17.89 K.volt/ humidity: 71% (26 C) / distance between needle and collector 8 cm.

As shown in Figure 15, the sample was prepared using CA polymer mixed with fabric. The SEM images show that the fibers produced were continuous and uniform in diameter. The nanofiber's average diameter was roughly 32 nm, while most nanofibers were smaller than 100 nm. However, no significant differences in fiber morphology compared to Samples 1-3. This indicates that incorporating fabric into the electrospinning process did not significantly impact the fiber morphology. To be more uniform in the fabrics, it should be more stick to the fabric, which needs adjusting chemicals like silica aerogel.

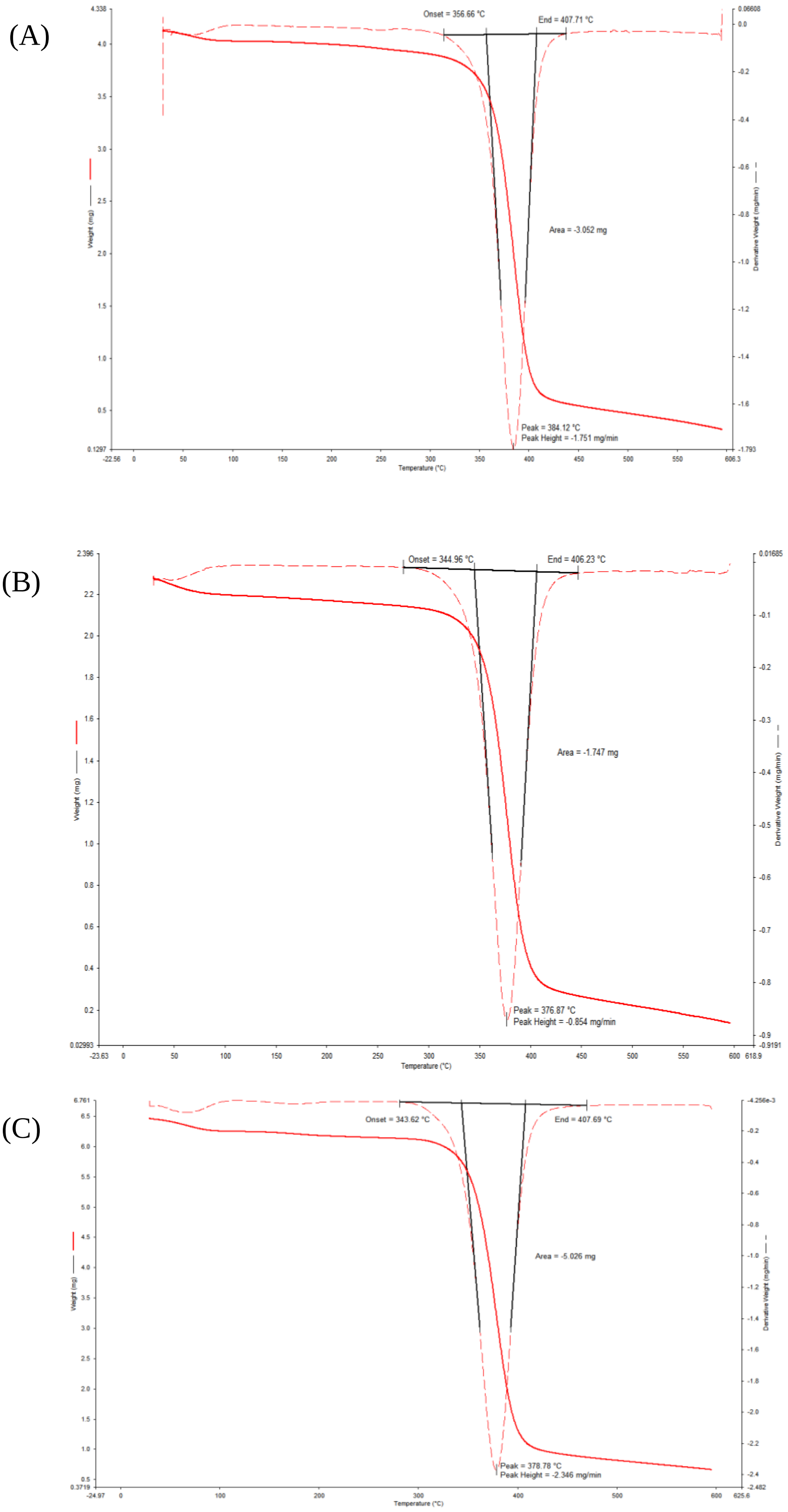


Figure 16: Represent the TGA analysis results of Cellulose Acetate nanofibers of different voltages.

In Figure 16: The TGA data for each previous sample indicates the change in weight as a function of temperature or time. The results can be used to analyze the samples' thermal stability and decomposition behavior.

All TGA samples exhibit two distinct stages of weight loss. The first stage occurs at lower temperatures and correlates to moisture loss from the samples. The second stage, which occurs at higher temperatures, corresponds to the thermal degradation of the cellulose acetate of the three samples.

Furthermore, the TGA findings for the three sample of Cellulose Acetate nanofiber at various voltages. The TGA displays the weight loss brought on by different chemical processes, including composition and decomposition. Figure 16 represents the TGA analysis results of Cellulose Acetate nanofibers. Each graph's area under the derivate curve represents the weight reduction.

Graph (A) represents the TGA analysis result of Cellulose Acetate (16%)/ 17.98 K.volt. Humidity: 65% (24.7C)/ distance between needle and collector 8 cm. The thermal treatment started from the onset at 356.66C to end at 407. 71C, so the weight reduction was equal to - 3.052 mg. Graph (B) shows the TGA analysis results of cellulose acetate (16%)/ 20 K.volt./ humidity: 62% (24.8 C) / distance between needle and collector 8 cm, and from the graph, the (B) sample’s weight has a reduction. So, The thermal treatment started from the onset at 344.96 C to end at 406.23 C as the weight reduction equals -1.747mg. Graph (C) represents the TGA analysis result of Cellulose Acetate (16%)/ 23 K.volt. Humidity: 64% (25.3) / distance between needle and collector 8 cm. The thermal treatment started from the onset at 343.62 C to end at 407.69 C, so the weight reduction was equal to - 5.026 mg. Figure 16 (graphs A, B, C) it showed that nanofibers are quite similar in the onset temperature. Sample (A) has a higher onset temperature than (B) by 11.7 C and then (C) by 13.04 C. Also, there is no noticeable difference in the temperature of the decomposition rate of both sample (B) and sample (C), where sample (A) has a higher decomposition rate at 384.12 C, which shows that sample (A) has thermal stability at a higher temperature than (B) and (C). however, (B) and (C) showed that both samples have a little bit similar thermal stability at higher temperatures Zhang et al. (2010).

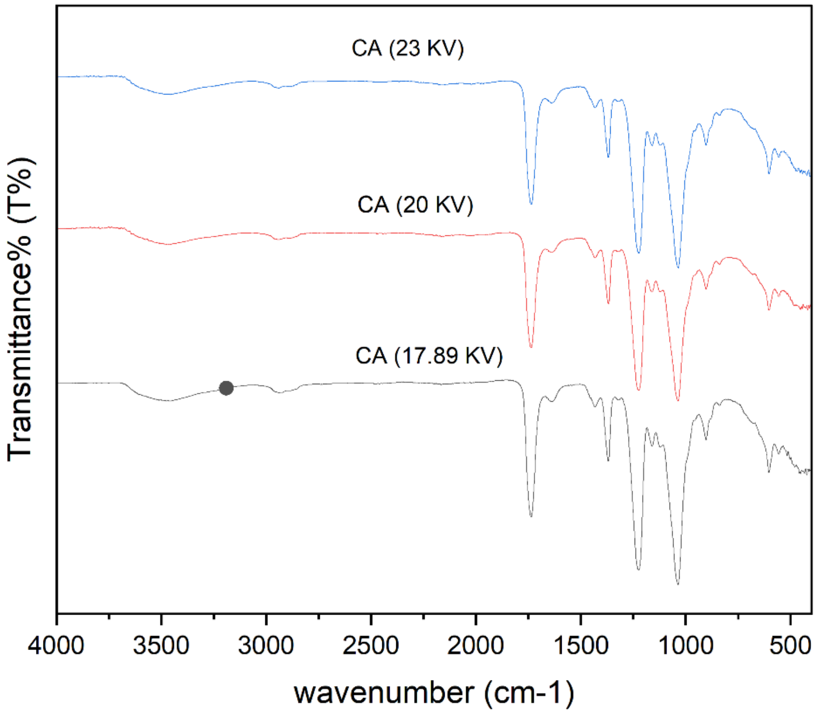


Figure 17: Represent the FTIR spectroscopy of the CA nanofiber prepared by different voltages.

FTIR spectroscopy is a powerful analytical technique used to study the vibrational modes of molecules in a sample. In this analysis, we have three samples with similar spectral features. All the samples have two long and sharp peaks at 1000 and 1200 cm^{-1}, attributed to the stretching vibrations of C–O bonds in the sample.

Another long sharp peak at 1736 cm^{-1} is observed in all samples, corresponding to the stretching vibrations of C=O bonds. The presence of this peak suggests the presence of a carbonyl group in the samples. The intensity of this peak may vary in different samples depending on the type of carbonyl group present and its location in the molecule.

A short sharp peak at 1360 cm^{-1} is also observed in all samples, attributed to the bending vibrations of the C–H bond. This peak is typically seen in alkanes and alkyl groups. The presence of this peak in our samples suggests the presence of these functional groups.

Samples CA (17.89 KV) has two weak peaks at 2900 and 3450 cm^{-1}, which are assigned to the stretching vibrations of C–H bonds in alkanes and/or the O–H bonds in alcohols. The presence of these peaks suggests the presence of these functional groups in the samples.

Sample CA (20 KV) has only one weak peak at 3450 cm^{-1}, attributed to the stretching vibrations of O–H bonds in alcohols. This peak suggests the presence of an alcohol functional group in the sample.

Sample CA (23 KV) has only one weak peak at 3450 cm^{-1}, also attributed to the stretching vibrations of O–H bonds in alcohols. The absence of the weak peak at 2900 cm^−1 suggests the absence of alkanes in the sample.

Lastly, all samples have similar spectral features, indicating the presence of C–O, C=O, and C–H functional groups. The presence of weak peaks at 2900 and 3450 cm^{-1} suggests the presence of alkanes and/or alcohols in some of the samples. The peak intensity at 1736 cm^{-1} varies in different samples, indicating differences in the type and location of the carbonyl group. Overall, FTIR spectroscopy provides valuable information about the functional groups present in the samples, which can be useful in identifying the sample components and their properties.

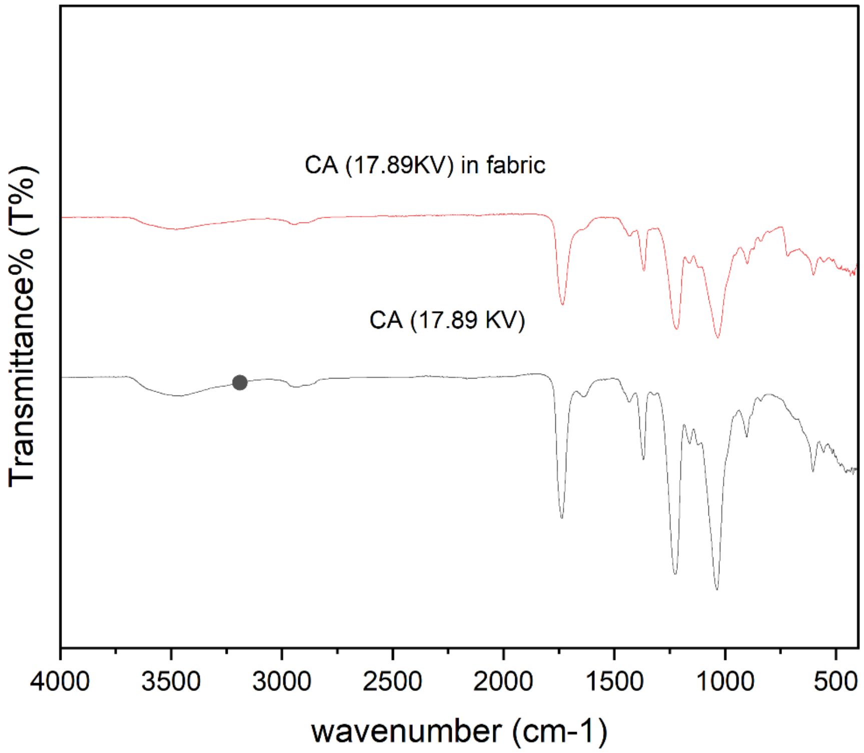


Figure 18: Represent the FTIR spectroscopy of the CA nanofiber and CA composite to the fabric.

According to the graph, the CA where composite to the fabric slightly shifts to the right with some weak peaks. Moreover, CA (17.89) have more long and sharper peaks than CA (17.89) in fabric. That means the nanofiber, when composed into fabric, will affect the nanofiber which successfully composed the nanofiber in the fabric.

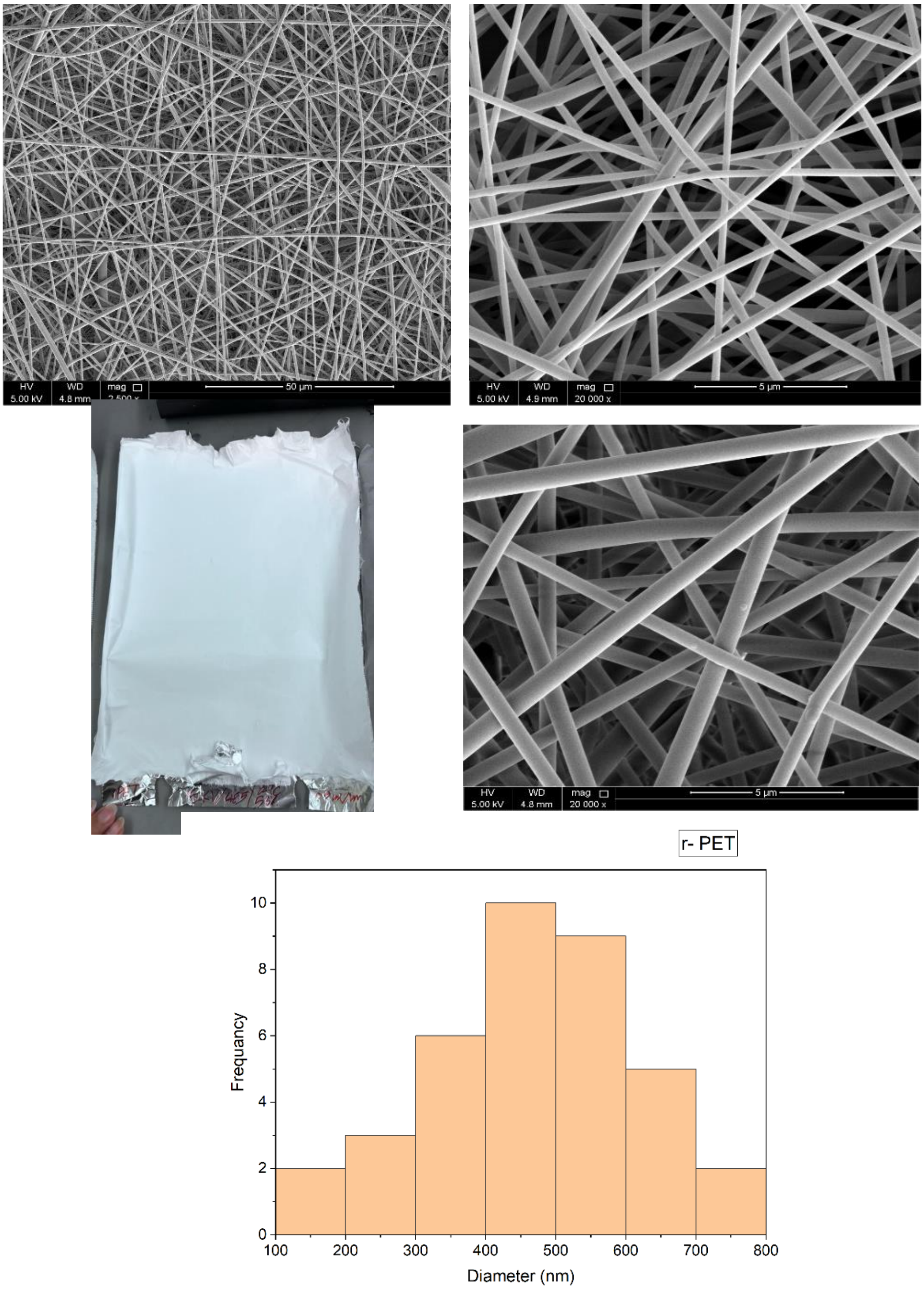


Figure 19: Recycle-PET (15 %) /15 K.volt/ humidity: 53% (26 C) / distance between needle and collector 8 cm.

We successfully recycled the water bottle and fabricated the r-PET nanofiber, as shown in Figure 19, making the white flat uniform membrane of r- PET nanofiber. Moreover, the SEM analysis proved that as showing the uniform and continues nanofiber with average diameter equal (483.5 nm). The r-PET can help for sustainability and git rid of the polyester they used in water bottles, boxes and Etc. which save the environment from the polyester that have huge impact in the word.

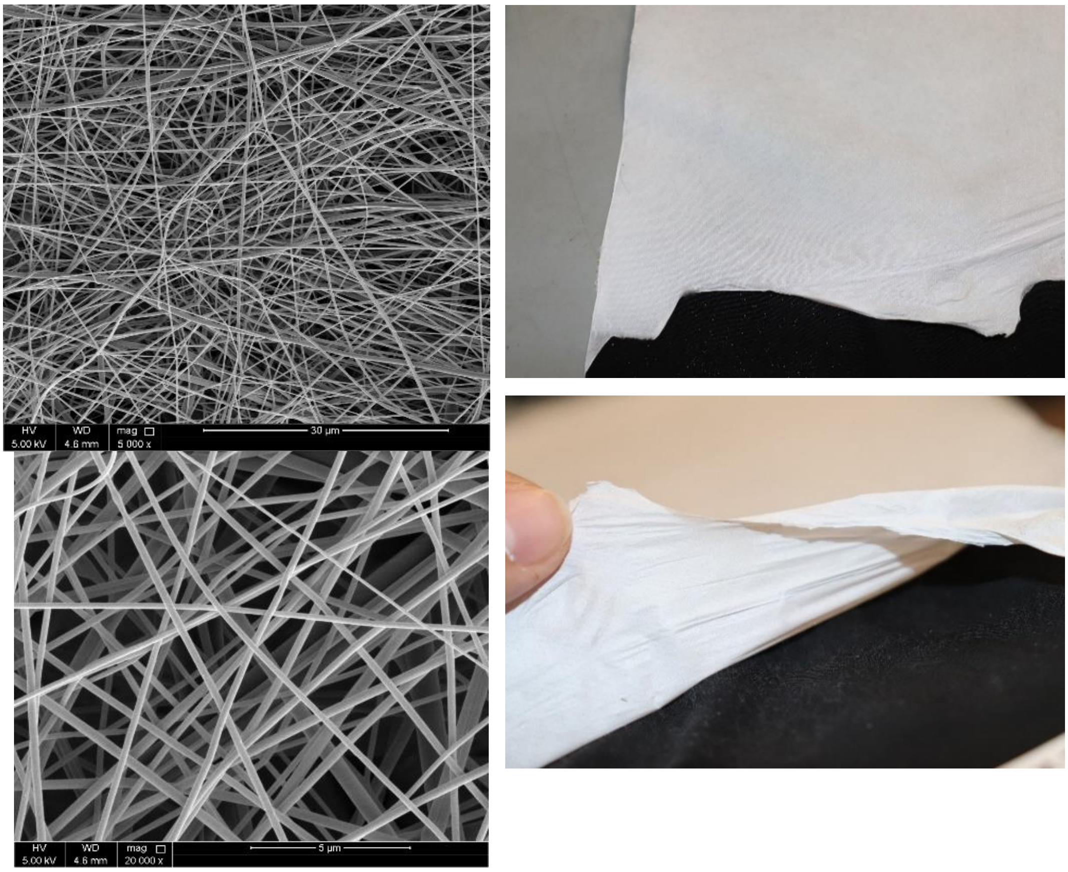


Figure 20: Represent actual and SEM images of the Recycle-PET in fabric (15 %) /15 K.volt/ humidity: 75% (26 C) / distance from needle to collector 8 cm.

According to the figure above were prepared using recycled PET (rPET) polymer. The SEM images show that the fibers produced were continuous and uniform in diameter, with no significant differences in fiber morphology from previous samples. Also, it gives the fabric more strength and soothes to the fabric. Also, specific analysis needs to know more information about the composites.

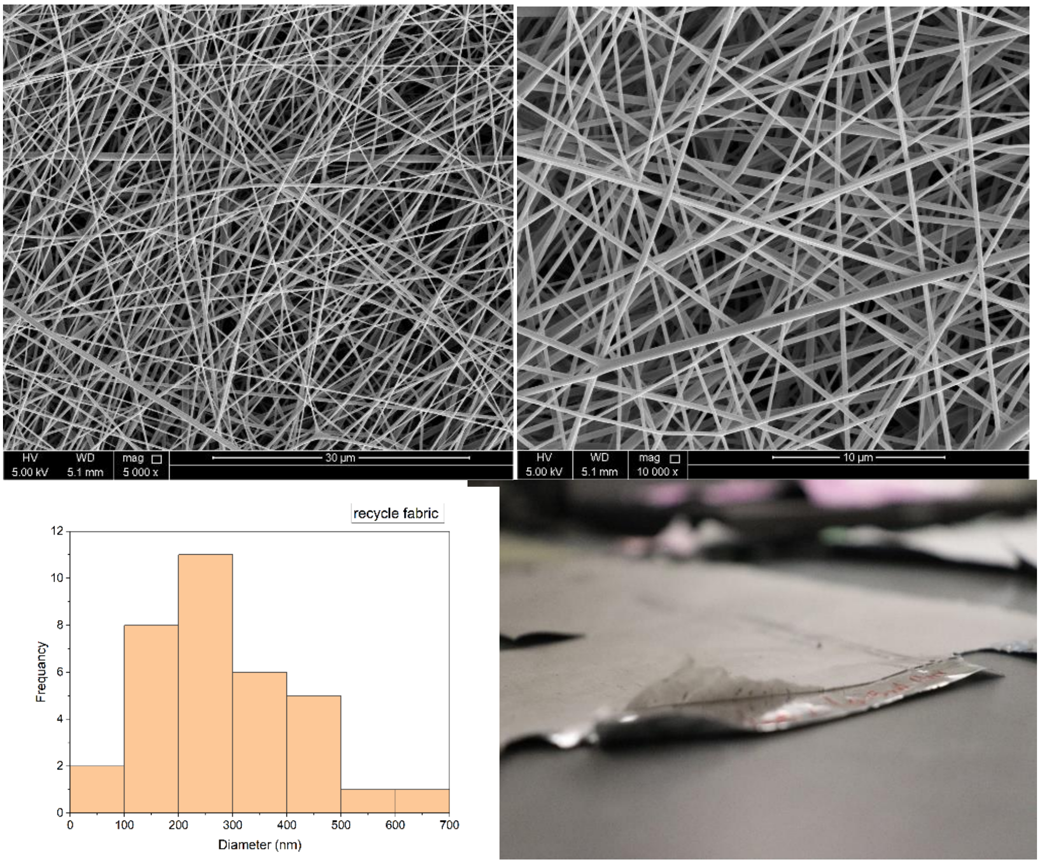


Figure 21: The actual image and SEM of nanofiber of Recycle fabric (16%) /15 K.volt/ humidity: 55% (26 C) / distance from needle to collector 8 cm.

According to the figure, this is the challenge to dissolve the fabric containing polyester and recycle it to the nanofiber. As shown above, it was successfully dissolved with 1:3 TFA and Chloroform, giving the uniform and smoothing nanofiber with an equal average diameter. This result helps to recycle the fabrics with polyester to develop sustainability. Also, it can provide new textile properties such as thermal resistance, UV protection, smooth fabrics, and strength.

In part 2:

Fabrication of nanofiber with thermochromic nanoparticles.

We used a ball milling device to convert the size of thermochromic to Nano-size.

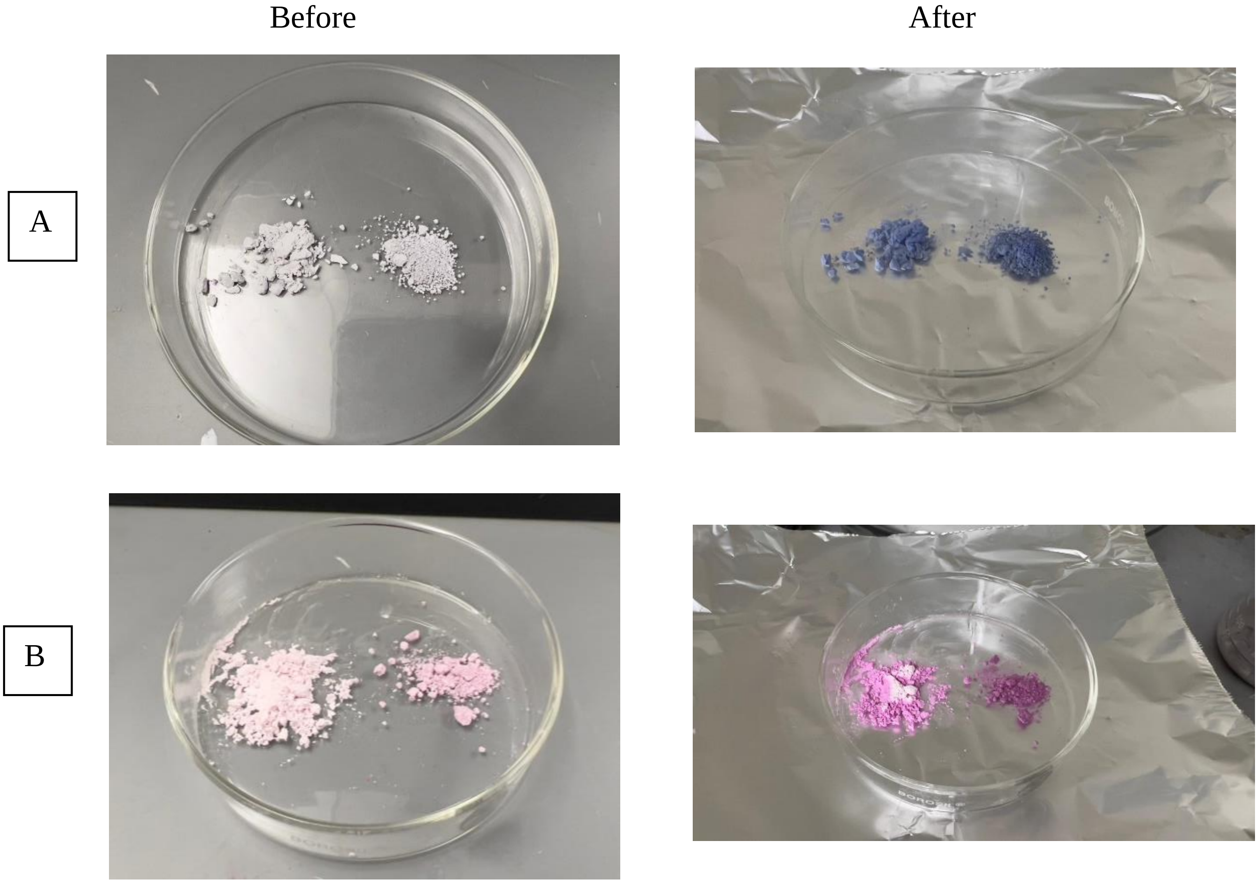
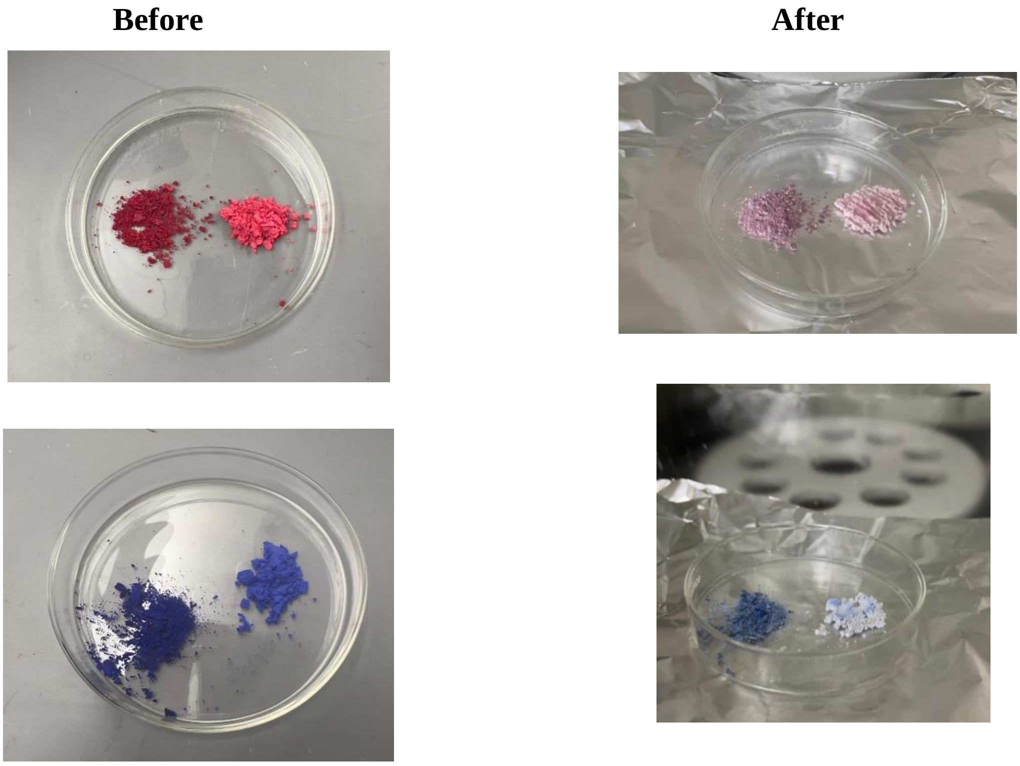


Figure 22: Thermochromic of the micro and nano size before and after exposure to heat.

Figure 22 left shows the micro-thermochromic, and on the right, the nano-thermochromic. As in the figure, they change their color from colorless to blue and reversely back to colorless. Investigate that the procedure was successfully approached due to the color of the micro- thermochromic after change it to the nano-size was changed to darker, which means that the particles were changed and the surface area became bigger. Furthermore, after exposure to the source of heat, the color changes faster in the nano size and reverses back slower than in the micro size. Which means the thermochromic have more sensitivity in nano size more than micro size. The color change observed in thermochromic materials can be attributed to the change in the size of particles and the resulting increase in surface area. When exposed to high temperatures, the particles undergo a structural change, leading to a shift in their absorption spectrum and resulting in a color change.

Interestingly, the nano-sized particles were more heat-sensitive than the micro-sized particles. This can be explained by the fact that the nano-sized particles have a larger surface area to volume ratio, which makes them more reactive to external stimuli such as heat. Additionally, the nano-sized particles were observed to revert to their original state faster than the micro-sized particles. This can be attributed to their larger surface area, allowing for faster heat dissipation. To be sure will be tested through the TEM device after they are fixed.



Before

After

Figure 23: Represent color to colorless thermochromic the micro and nano size before and after exposure to heat.

SEM of Different Concentrations of Thermochromic in Cellulose Acetate:

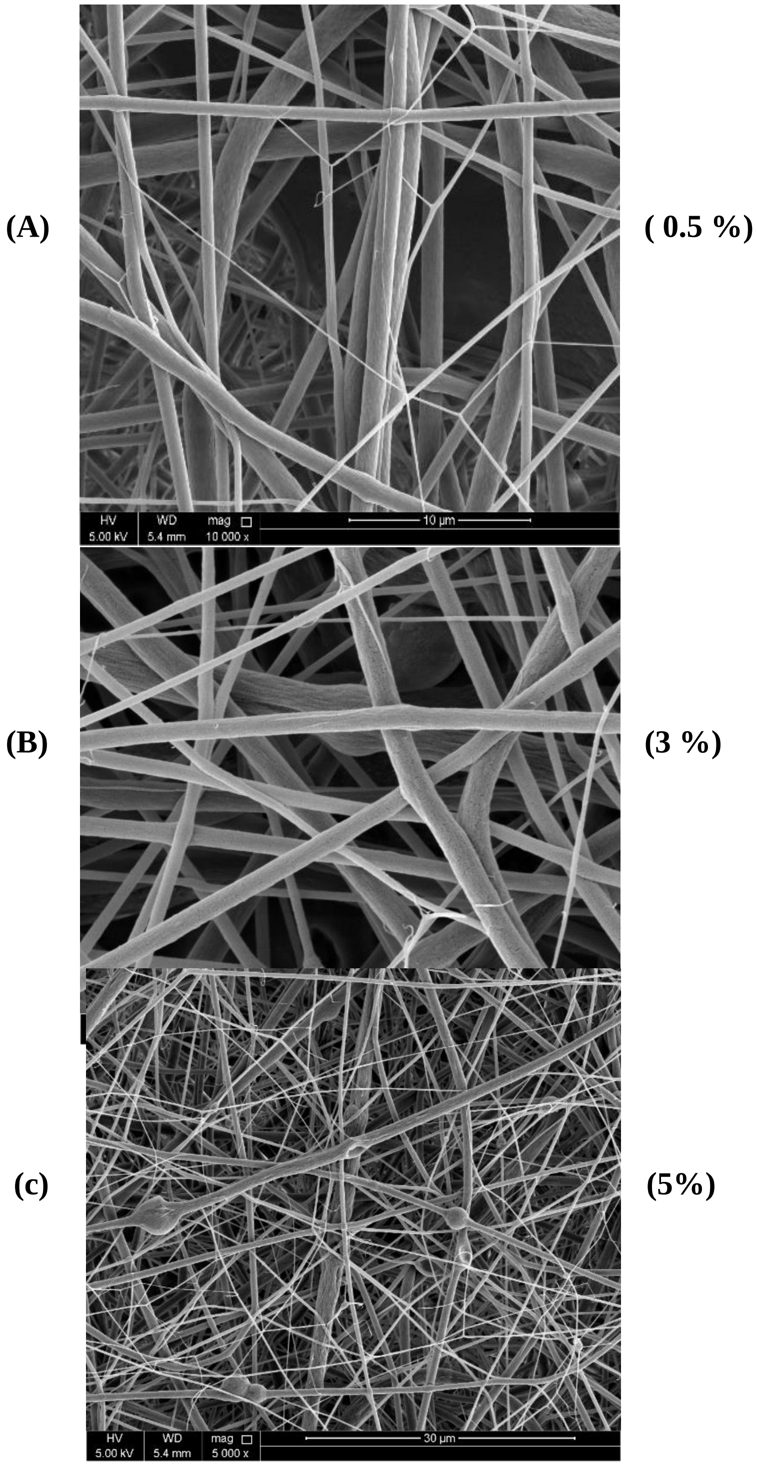
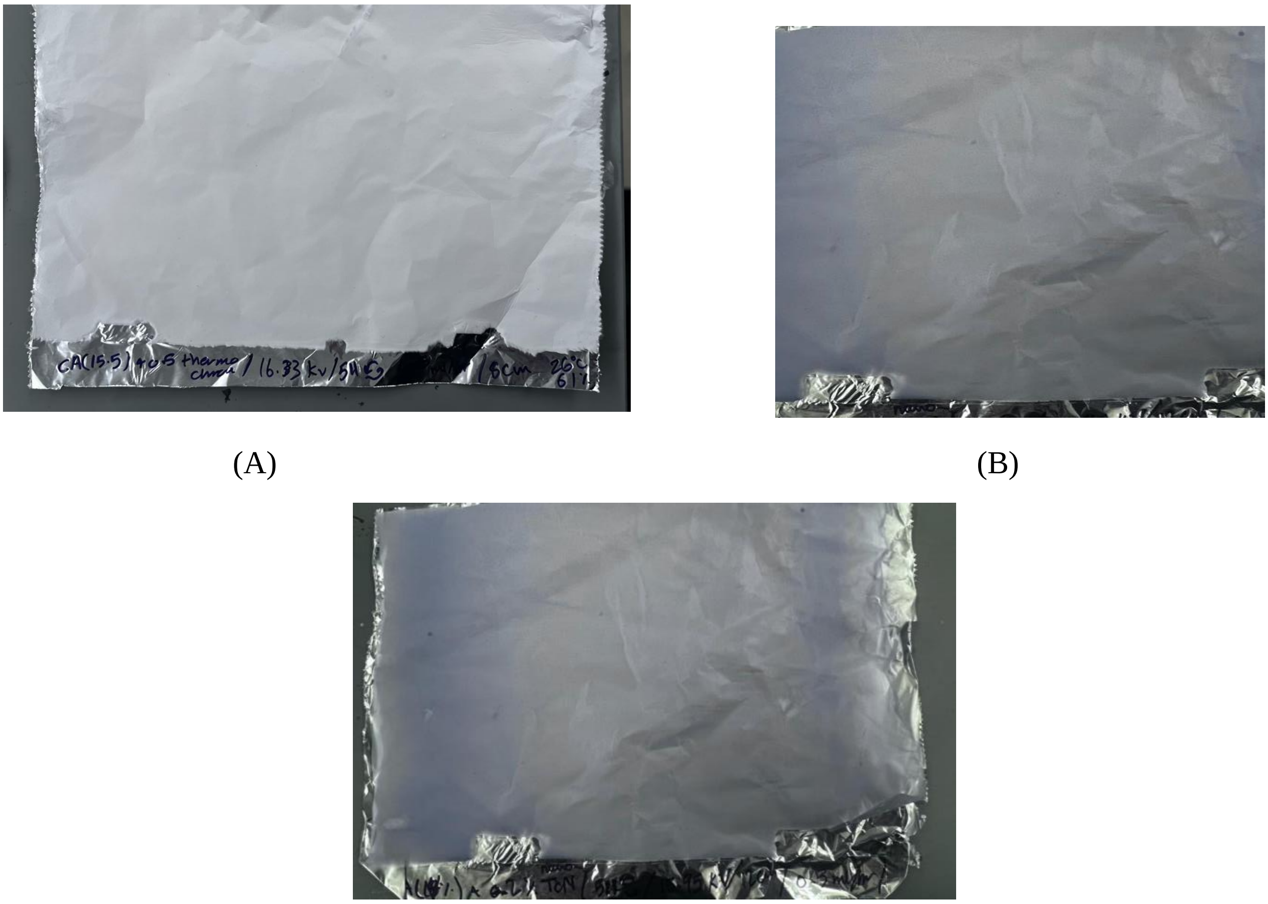


Figure 24: Cellulose Acetate (16%) with different concentrations of nanothermochroic /15.95 K.volt/ humidity: 61% (26 C) / distance between needle and collector 8 cm.



(A) (B)

(C)

Figure 25: Cellulose Acetate (16%) nanofiber with different concentrations of nano thermochromic.

Based on the SEM analysis of the composite nanofiber + thermochromic in fabric, several samples were examined under varying conditions.

Samples (A, B, and C) consisted of Cellulose Acetate (16%) and nano thermochromic (5-0.5%) with a voltage of 15.95 K.volt and a humidity of 63-61% at 25.9-26°C. in (A) the amount of nano thermochromic it was tiny so no little effect can be observed. In (B) and (C), The SEM analysis revealed that the composite nanofibers were successfully produced with a smooth and uniform morphology. The nano thermochromic was evenly distributed throughout the nanofiber, suggesting an excellent thermochromic material dispersion in the cellulose acetate matrix.

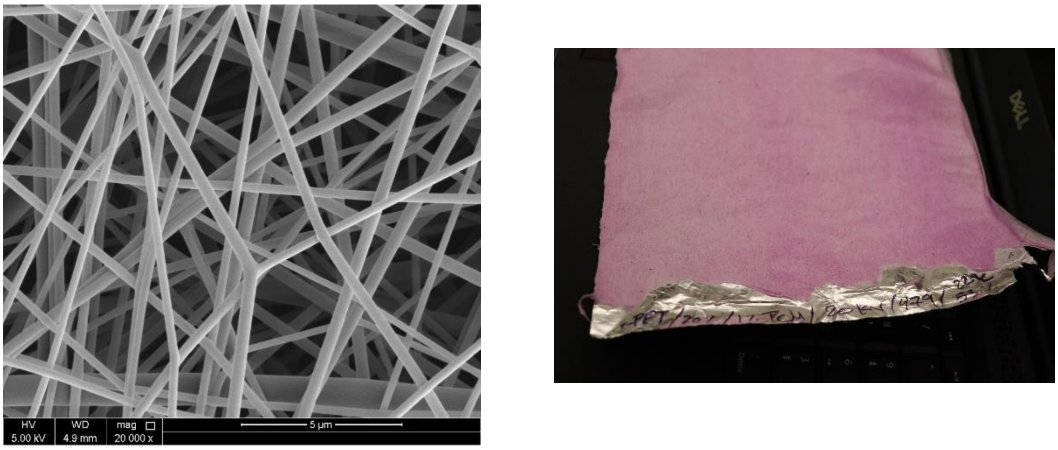


Figure 26: r-PET with 2% of nano thermochromic.

As represented in Figure 26, where notes no nanothermochromic appeared in the nanofibers and it shows clear fiber, not as in CA where the nano- thermochromic was distribute through the nanofiber which means that the nanofiber disappeared through mixing them with the solution of r-PET. This is due to the strong chemicals we used to dissolve the bottle of water. However, we saw the a good of thermochromics when we make the R-PET nanofiber then spray it with the nanothermochromics as showed in figure 27, but the its not penetrate through the nano fiber. In future work, will try to do this experiment with the same concentration of thermochromics with coaxial tool.

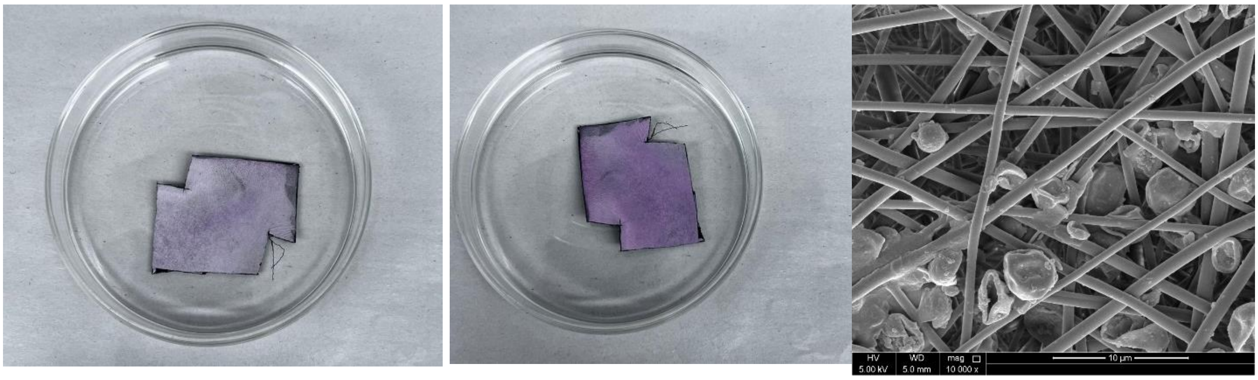


Figure 27: R-PET sprayed with nano thermochromic.

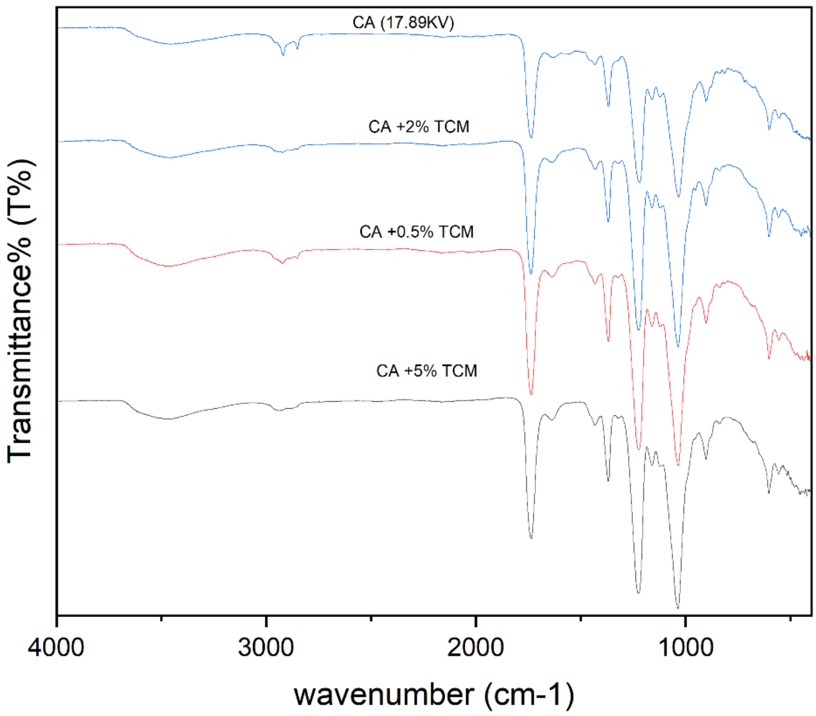


Figure 28: FTIR OF Cellulose Acetate (16%) nanofiber with different concentrations of nanothermochromic.

According to the figure, FTIR spectroscopy is used to study the vibrational modes of molecules in a sample. In this analysis, we have four samples with similar spectral features. All the samples have two long and sharp peaks at 1000 and 1200 cm^{-1}, attributed to the stretching vibrations of the C–O bonds in the sample**.** Another long sharp peak at 1736 cm^{-1} is observed in all samples, corresponding to the stretching vibrations of C=O bonds. The presence of this peak suggests the presence of a carbonyl group in the samples. The intensity of this peak may vary in different samples depending on the type of carbonyl group present and its location in the molecule. A short sharp peak at 1360 cm^{-1} is also observed in all samples, attributed to the bending vibrations of the C–H bond. This peak is typically seen in alkanes and alkyl groups.

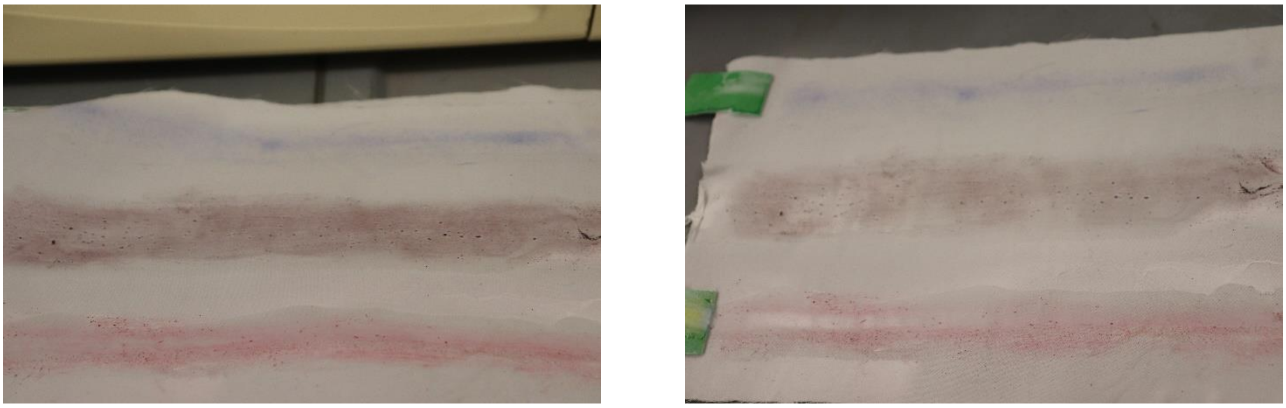
The presence of this peak in our samples suggests the presence of these functional groups.

Samples CA (16%), 0.5%TCM, and 2%TCM have two weak peaks at 2900 and 3450 cm^{-1}, assigned to the stretching vibrations of C–H bonds in alkanes and/or the O–H bonds in alcohols. The presence of these peaks suggests the presence of these functional groups in the samples.

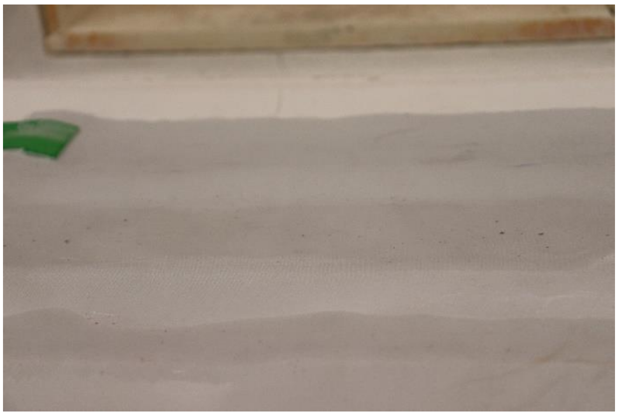
Sample 5%TCM has three weak peaks at 2900, 2890, and 3450 cm^{-1}, which are assigned to the stretching vibrations of C–H bonds in alkanes and/or the O–H bonds in alcohols. The presence of these peaks suggests the presence of these functional groups in the sample.

As the figure shows, the peaks with different concentrations have more sharp and long peaks than CA (16%) because of the thermochromic effect.

All samples have similar spectral features, indicating the presence of C–O, C=O, and C–H functional groups. The presence of weak peaks at 2900 and 3450 cm^{-1} suggests the presence of alkanes and/or alcohols in some of the samples. The peak intensity at 1736 cm^{-1} varies in different samples, indicating differences in the type and location of the carbonyl group. Overall, FTIR spectroscopy provides valuable information about the functional groups present in the samples, which can be useful in identifying the sample components and their properties.



Before **Gradually change**



After

Figure 29: Color to colorless thermochromic nanofiber with different temperatures when exposed to gradual temperature.

Figure 29 shows three different temperatures used in reversible thermochromic after conversion to nano size. It was successfully produced by cellulose acetate through electrospinning. The figure shows that the nanofiber was exposed to the temperatures before and after. The blue color had 25C, the pink color had 30C, and brownish-black had 35C. They successfully change their color gradually with increased temperature from colored to colorless.

Before

After

Figure 30: color to colorless of composite nano thermochromic and nanofiber in fabric.

According to the figure, Successfully created the uniform nanofiber sheet with nano-thermochromic, (A) the thermochromic nanofiber after being exposed to temperatures clear color nanofiber. After being exposed to heat in (B), the color appears as designed in spots in a different color.

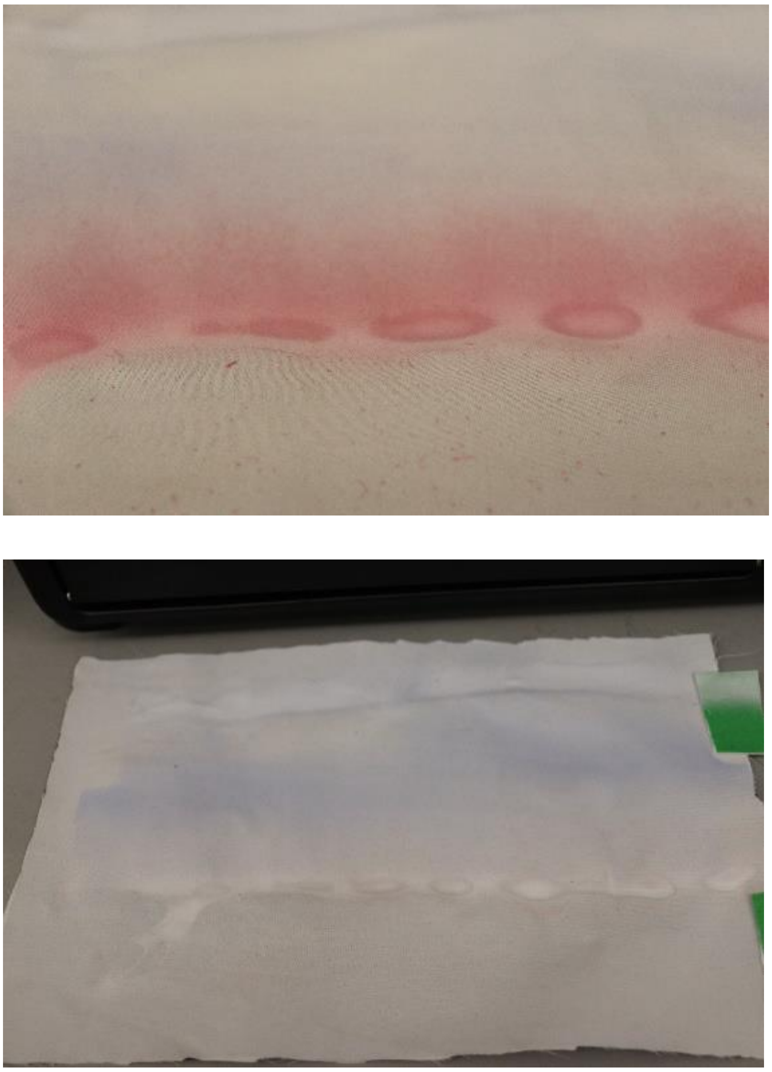


Figure 31: samples of two different types of nano thermochromic, colorless-to-color and color-to-colorless, were composed to fabric by electrospinning.

In Figure 31, We used two different kinds of nano- thermochromic produced with cellulose acetate nanofiber through electrospinning used as a creative design in clothing by changing the color differently. The pink color to colorless, and the blue color to color as both exposed to 35 C from body temperature or sun rays change opposite each other. Furthermore, it can be used to monitor temperature for food delivery to know if the food is warm or to store the food to avoid mistakes in storage.

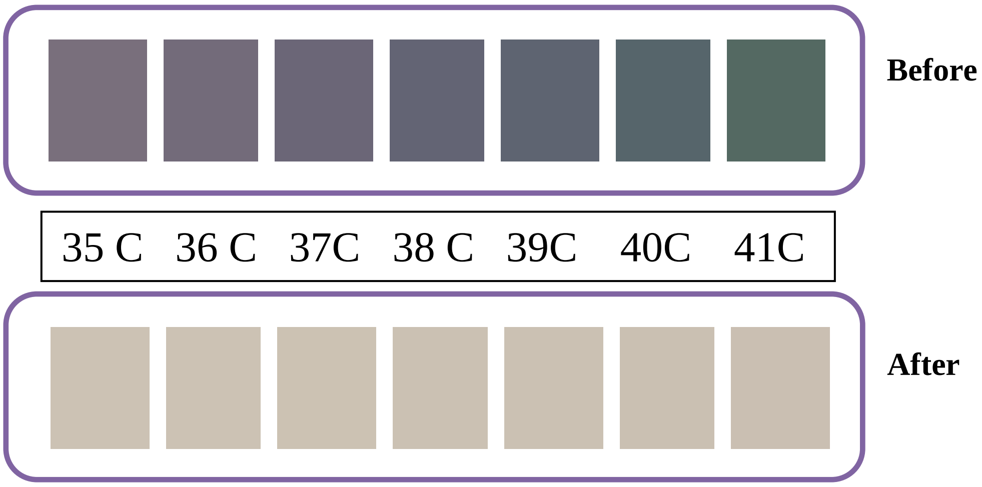


Figure 32: schemed of medical plaster with different temperatures from 36 C to 40.

As shown in the image above, a scheme of medical plaster can be used to monitor the patient's temperature rises in a hospital or at home for adults and kids. Also, it can be used for different medical applications, such as monitoring the body temperature behind many severe medical conditions like kidney problems, and it’s one of the secret symptoms of kidney disease. Also, it can be used the thermochromic nanofiber for cancer monitoring.

Thermochromics in Smart Fashion Creative.

Figure 33: management of temperature in TCS textiles. The Diagram represents the thermochromic textiles in a hot-to-cold climate. (Yang Wang1, October 2021).

These benefits enabled TCSs to be used in a variety of contexts. For instance, during outdoor activities or summer sports, the temperature is high enough to cause the TCS materials to turn light in color. (Fig. 31). Wearing light-colored clothing in this situation results in relatively modest levels of heat radiation and a cool sensation. Wearing dark clothing would be warmer in a cold area; the dark hue will absorb more heat. By regulating the dark and light will change colors in the thermochromic behavior, thermochromic materials may be used to achieve a potential application of temperature management. (Yang Wang1, October 2021).

In addition, Camouflage designs for military protective equipment are now made with thermochromic colorants. With external heat, this pattern may shift from colorless to color form that reflects the surrounding environment (Yutaka Shibahashi, 1987).

CHAPTER 5: CONCLUSION

Recent research has focused on improving nanofiber and thermochromic pigment application processes on textiles. The purpose of this research was to evaluate the performance of these pigments using Acceptable instrumental methods and scientific interpretations for the findings. The literature on thermochromic fabrics focuses mostly on their usefulness. However, this study aimed to quantify the usefulness of these pigments. The research also concentrated on strategies for improving the performance of thermochromic pigments with nanofiber on textiles, offering a technological foundation and inspiration for innovative design applications. The study produced composite nanofiber + thermochromic in fabric, which was analyzed using scanning electron microscopy (SEM) and thermogravimetric analysis (TGA). The SEM analysis of the electrospun fibers from all the samples indicated that the morphology of the fibers produced was consistent and uniform in diameter. The SEM analysis of the micro- and nano-thermochromic revealed that both materials exhibited a thermochromic effect, with the color changing from colorless to blue when exposed to high temperature. The composite nanofibers were successfully produced with a smooth and uniform morphology. The nanothermochromic and spray thermochromic solutions were observed to be evenly dispersed within the matrix of cellulose acetate or PET, respectively. The TGA results suggested that adding nanothermochromic to cellulose acetate may impact its thermal stability.

The findings of this study suggest that electrospinning is a robust and versatile technique that can produce nanofibers with consistent morphology from various materials. The uniform morphology of the nanofibers ensures that the thermochromic material is evenly distributed within the composite nanofiber, leading to a more consistent and predictable thermochromic behavior. The size of the thermochromic particles plays a crucial role in determining the thermochromic behavior of the materials, with nano-sized particles being more sensitive to heat and reverting to their original state faster than micro-sized particles. The composite nanofiber + thermochromic into fabric produced in this study has potential applications in various fields, such as textiles, sensors, and smart materials.

This study's results have significantly contributed to advancing the scientific understanding of the behavior of thermochromic pigments in textiles. The study provides a detailed characterization of the morphology, dispersion, and thermal stability of composite nanofiber + thermochromic in fabric, providing valuable insights into the mechanisms behind the thermochromic effect in textiles. The findings of this study can be used to guide the development of new and innovative products in the future, focusing on sustainability and eco-friendliness.

The study has successfully optimized application methods for nanofiber and thermochromic pigments on textiles and assessed their performance instrumentally. The findings of this study suggest that electrospinning is a versatile technique that can be used to produce nanofibers from various materials. The size of the thermochromic particles plays a crucial role in determining the thermochromic behavior of the materials. The composite nanofiber + thermochromic in fabric produced in this study have potential applications in various fields, such as textiles, sensors, and smart materials. The results of this study provide a technical basis and inspiration for creative design applications of nanofiber and thermochromic pigments on textiles, focusing on sustainability and eco-friendliness.

Future work:

After the extraordinary combination of thermal sensitivity and nanofiber and the properties that investigated high nanofiber, the discussion leads to several plans for future work to extend the analysis methods for advanced characterization to better understand the detailed nanostructure of these thermochromic nanofibers. Such could be an excellent candidate for medical application and fashion impact. Thus, the properties of thermochromic nanofiber would be of significant interest in smart textiles. Also, complete analysis of the recycled nanofiber to investigate new nanofiber properties.

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