# Design and Synthesis of Flame-Retardant Recycled Styrofoam Electrospun Nanofibers

**Bachelor of Science in Mechanical Engineering**

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# DECLERATION OF AUTHORSHIP

**Project Title:** Design and Synthesis of Flame-Retardant Recycled Styrofoam Electrospun Nanofibers

**Authors:** Furkan UYSAL, Sidar YILDIRIM

**Supervisor:** Prof. Dr. Aykut KENTLİ

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**by**

**Furkan UYSAL, Sidar YILDIRIM**

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AT

MARMARA UNIVERSITY



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# ABSTRACT

The main purpose of this study is to transform waste polystyrene,which is harmful to nature,into combustion resistant nanofibers that can be used in many areas.While doing process,we first transformed PS/DMF solutions that we can created at different densities into nanofibers with an electrospining device.Then,we subjected the nanofibers we obtained to a combustion test at UL94 Standards and obtained information.The information we obtained is that the ignitation time is generally directly proportional to the PS density.

**Keywords:** Dimethyl Formamide, Electrospining, Flame Retardancy Nanofiber,Polystyrene

# ABBREVIATIONS

| | |
|---|---|
| PS | Polystrene |
| DMF | Dimethyl Formamide |

# Contents

# 1.INTRODUCTION

Polystyrene polymers used in many areas in the industry become very harmful to nature with the waste they create as a result of use. In addition, these damages bring about irreversible problems for centuries. For this reason, in our project, we aimed to produce nanofibers to be used in places exposed to heat and combustion (for example, in the electrical industry) such as electrical cables by recycling PS waste (with an electrospinning device). In this way, polystyrene waste will be transformed into useful products to be used in the industry instead of being a threat to the ecosystem.

## 1.1 Thesis Background

Since these days, with the increase in population, industrialization and changing and increasing consumption conditions, interest in and use of plastic materials has increased significantly and this situation has started to pose a great threat in terms of environmental sustainability. Polystyrene (PS), which is widely preferred especially in disposable products and packaging industry, can remain in nature for centuries without deteriorating due to its chemically stable structure. Although PS does not have structural toxicity when released into the environment, it poses a great threat to both land and marine ecosystems due to its tendency to absorb high amounts of heavy metals such as mercury. In this case, instead of directly disposing of polystyrene as waste, it is transformed into functional and value-added products, thus ensuring its great importance both environmentally and economically.

Electrospinning technology, which has gained an important place especially in the field of nanotechnology, is one of the methods developed for upcycling of plastic waste. Nanotechnology enables the processing of materials at nanoscale, enabling the obtaining of materials with very large surface area and volume ratio, light, durable, permeable and functional properties. Nanofibers combined with electrospinning can be used on a wide scale from textiles to composite materials, from filtering systems to biomedical applications.

## 1.2 History and Development of Electrospinning Device

The electrospinning method is based on a principle developed and patented by Cooley and Morton in 1902. The basic points of this method are based on the formation of thin fibers (fibers) by high-voltage electrical fields on liquid polymers. The studies developed by Formhals in 1934 led to the development of electrospinning technology to its current state. Formhals described an electrospinning system that could be considered quite advanced according to the conditions of the period and received many patents. However, this technique was limited in terms of the large-scale use of nanotechnology and microstructures in the industry, and it has become a source of attention again in nanomaterial production since the 1990s. After this date, the electrospinning method has been adopted as the primary method in many industrial and academic projects due to its ease, high efficiency and low cost in nanofiber production.

A traditional electrospinning device; It consists of an injector (syringe) or chamber containing a polymer solution, a metal needle (nozzle) connected to this chamber, a high voltage source and a collector surface. When high voltage is applied, the polymer solution at the needle tip takes a shape called a "Taylor cone" due to electrostatic forces. At this point, the polymer solution exits the needle in jet form and moves towards the collector surface thanks to the electrostatic repulsion force that exceeds the surface tension. During flight, the solvent evaporates or the melt cools and solidifies, resulting in thin, continuous and generally bead-free nanofibers. Thanks to this method, it is possible to produce micro and nano-sized fibers directly from the polymer solution. The morphological properties of nanofibers obtained by electrospinning vary depending on many parameters such as the concentration and type of polymer used, the applied voltage, the needle-collector distance, solvent properties, flow rate and ambient temperature. Each of these parameters directly affects porosity, mechanical strength, surface smoothness, fiber diameter and other performance criteria. In particular, the choice of solvent plays an

important role in determining fiber morphology. N,N-Dimethylformamide (DMF), the solvent used in this study, stands out with its high solubility capacity, low vapor pressure and boiling point; enabling the production of bead-free, small diameter nanofibers.

## 1.3 Project Description

### 1.2.1 Problem Description

Plastic waste materials have become one of the most important environmental problems of the world today. Polystyrene (PS), which has a serious place among these wastes, is a waste that is difficult to recycle and has a long lasting environment. This material, also known as Styrofoam, is widely used in insulation, packaging and consumer products; however, it generally becomes waste after use and remains in the environment for a long time without being destroyed. This situation causes both environmental pollution.

It is not possible to effectively recycle durable plastics like PS in waste management systems, and several methods such as burning or burying harm the environment. For this reason, an idea is needed that will both reduce environmental impacts and make these wastes reusable.

This project aims to process waste polystyrene into nanofibers by electrospinning and to provide flame retardant properties to these nanofibers. Thus, PS, which is harmful to the environment, will be functional and usable.

### 1.2.2 Scope and Limitations

The scope of this study will be limited to the conversion of recycled polystyrene into nanofiber form by electrospinning method and the examination of morphological, structural and thermal properties of these nanofibers. During the project process:

• Waste polystyrene (PS) was selected as the polymer to be used.

• DMF (N,N-Dimethylformamide) was used as the solvent.

• The effect of concentration was examined by keeping the parameters such as applied voltage, flow rate, needle diameter, needle-collector distance constant.

• The produced nanofibers were characterized by UL94 combustion tests.

The study covers only laboratory-scale production. Industrial production, long-term durability, cost calculation analyses and other advanced performance evaluations are not included in the scope of this study.

### 1.2.3 Importance and Impacts

This study has important scientific and social impacts. First of all, when we evaluate it in the context of waste management; It is very important to make PS, which is known to be very difficult to recycle, reusable, to reduce environmental pollution as much as possible and to prevent resource waste. The project is directly related to the idea of sustainable development.

Secondly, the properties such as high surface area, porosity and mechanical strength of nanofibers produced by electrospinning allow them to be used in many industrial applications such as flame retardant materials, filters, textiles and composite production. Especially when we consider areas such

as construction and defense industry, heat and flame resistant materials are at a very important point. For this reason, it can be said that the application potential of the study is high and possible.

Thirdly, this project provides a special knowledge accumulation on nanofiber synthesis by investigating the effects of many different variables on nanofibers, starting from the properties of the solution during production by electrospinning and up to system parameters. The data we obtained in this experiment will both contribute to the academic literature and provide support and guidance for future projects.

# 2.RESEARCH OBJECTIVE

Polystyrene (PS) is a polymer synthesized from styrene monomers by free radical addition reactions. It is a colorless and transparent thermoplastic with a glass transition temperature of 100 degrees. PS (polystyrene); is preferred due to its food compatibility, good processability, transparency, fluidity, lightness, success in insulation, resistance to solvents and many other features. The raw material, which has many areas of use, is classified in 3 ways as Crystal, Foam and Anti-Shock according to the processing method. PS materials are used instead of wood, metal and paper in many branches of industry due to their easy processability. It is highly preferred in areas such as insulation boards, washing machine and refrigerator parts, radio and television cases, film and plate production, lighting materials, paper and fabric coatings, household goods production, battery boxes and toy production.

Anti-shock Polystyrene is mostly used in sheet applications, TV Panels, Food Packaging Applications, Stationery Products, Computer Parts and picnic items such as plates, spoons and forks. Crystal Polystyrene, which is much harder and incredibly transparent compared to other raw materials, is used in CD cases, electrical appliances, cups, cassettes, home decoration products, lamps, sheet applications, shoe polish boxes and cosmetic product boxes. PS materials, which have an average melting temperature of 170-280 C degrees and a mold temperature of 30-60 C degrees, have such a wide area of use in the industry, as can be seen, but their use has ended and those that become waste become extremely harmful to nature due to their chemical and physical structures. For this reason, in our project, we aimed to recycle Polystyrenes that have become harmful to nature and how they can be used in the industry again. As a result of our studies, by producing nanofibers from the PS solutions we prepared, in areas where the temperature may be high or where there is a risk of burning such as electrical cables, our main goals are to prevent damage to other devices due to high temperatures.

## 2.1 Project Specifications

First of all, as a result of our research to recycle PS materials and provide nanofiber production, we assumed that we could achieve this with Electrospinning and advance the process within this scope. Then, by providing the necessary contacts to use this setup, we found the opportunity to work at the Istanbul Ticaret University Mechatronics Engineering Laboratory and brought together the materials for nanofiber production. The materials we will use in our main setup are; PS, solvent (DMF), precision balance, beaker, ruler and electrospinning device (with syringe, drum, oil paper, nozzle, solution advancement cable).

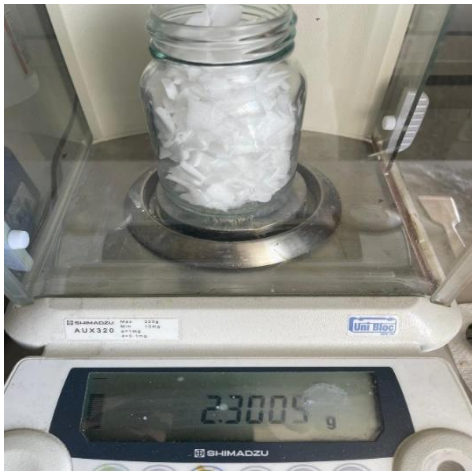



*Figure 4 Presicion Scale*

*Figure 3 Spacers*

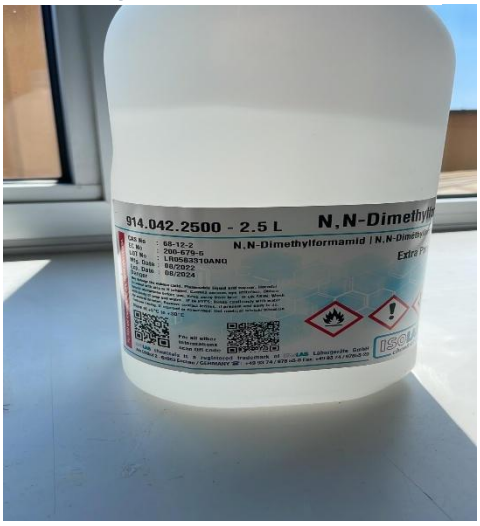



*Figure 2 N-N Dimethyl Formaldehyde*

*Figure 1 Inside Electrospining*

First, we turned the PS plates into small pieces with our hands so that they could easily dissolve in the solvent and then separated them into 2gr, 3gr, 4gr, 5gr and 6gr. Then, we put the PS pieces we separated with the precision balance into the beaker and dripped DMF on them to make a total of 20 gr. Thus, we have 10%, 15%, 20%, 25%, 30% PS solutions.

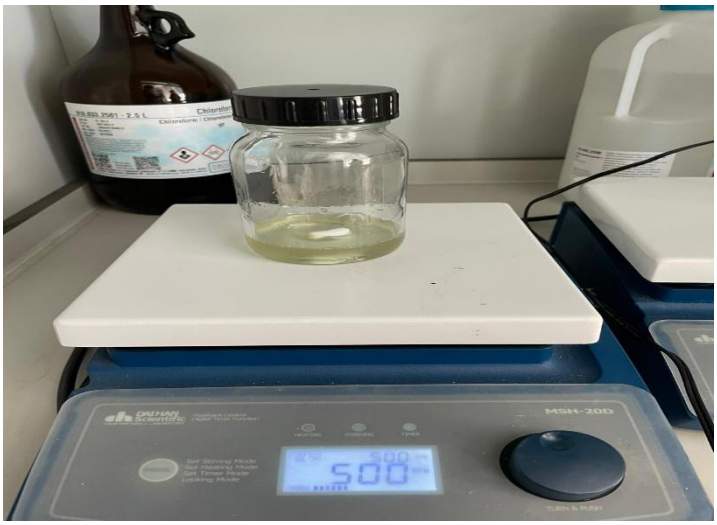



*Figure 5 Magnetic Stirrer*

If we briefly mention DMF in this section, Dimethylformamide is used as a polymer and resin solvent and as a catalyst in chemical reactions, in gas absorption, as an electrolyte solvent, as a solvent in extractions, and as a solvent in crystallizations. Dimethylformamide (DMF) is a colorless liquid that can be mixed with both water and many organic liquids. It has been called the "universal solvent" and has been used in many areas for this reason. The reason we chose DMF instead of other solvents is that, as we can see from the table below, DMF solvent is the most suitable solvent in terms of PS solubility, viscosity control, evaporation rate (appropriate boiling temperature) and stability under electric field. Thanks to these features, DMF solvent enabled us to produce homogeneous, smooth and nanofibers with the necessary diameter detection.

*Table 1 Solvents*

| ## | Name ( abbrev.) | Formula | Mol.Wt. | B.p. C | M.p.C | density, | diel.const | refraction | b.moment | viscosity |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Acetone | CH3COCH3 | 58.08 | 56.2 | -95.4 | 0.79 | 1.3588 | 20.7 | 2.88 | 3.16 |
| 2 | Methanol | CH3OH | 32 | 65 | -98 | 0.791 | 1.3288 | 32.7 | 1.7 | 5.45 |
| 3 | Propanol | C3H7OH | 60.11 | 82.4 | -89.5 | 0.786 | 1.3776 | 18.3 | 1.66 | 17.7 |
| 4 | Butanol | C4H9OH | 74.12 | 99 | -115 | 0.806 | 1.3978 | 15.8 | 1.7 | 42.1 |
| 5 | Ethyl Ether | (C2H5)2O | 74.12 | 34.5 | -116 | 0.714 | 1.3526 | 4.34 | 1.15 | 2.22 |
| 6 | Hexane | C6H14 | 86.18 | 69 | -95 | 0.66 | 1.3751 | 1.89 | 0.08 | 2.92 |
| 7 | Methyl Ethyl Keton | CH3COC2H5 | 72.12 | 79.6 | -86 | 0.805 | 1.3788 | 18.5 | 2.5 | 36.5 |
| 8 | Carbon Disulfid | CS2 | 76.1 | 46 | -112 | 1.27 | 1.6319 | 2.64 | 0 | 3.76 |
| 9 | NN-Dimethyl Formamid (DMF) | HCON(CH3)2 | 73.1 | 152 | -61 | 0.945 | 1.4303 | 36.7 | 3.86 | 7.96 |
| 10 | Decalin | C10H18 | 138.25 | 196 | -43 | 0.9 | 1.481 | 2.2 | 0 | 33.8 |
| 11 | O-Xylene | C8H10 | 106.17 | 144.4 | -25.2 | 0,88 | 1.5055 | 2.57 | 0.62 | 7.56 |
| 12 | 1,2-Dichlorobenzene | C6H4Cl2 | 147.01 | 180.5 | -17 | 1.305 | 1.5515 | 9.93 | 2.5 | |
| 13 | Benzene | C6H6 | 78.12 | 80.1 | 5.5 | 0.879 | 1.5011 | 2.28 | 0 | 6.03 |
| 14 | Toluene | CH3-C6H5 | 92.15 | 110.6 | -95 | 0.867 | 1.4961 | 2.38 | 0.36 | 5.52 |
| 15 | Chloroform | CHCl3 | 119.38 | 61.7 | -63.5 | 1.48 | 1.4459 | 4.7 | 1.87 | 5.42 |
| 16 | Ethyl acetate | CH3CO2C2H5 | 88.12 | 77.1 | -83.6 | 0.9 | 1.3723 | 6.02 | 1.78 | 4.41 |
| 17 | Water | H2O | 18 | 100 | 0 | 0.998 | 1.33299 | 78.5 | 1.84 | 10.1 |
| 18 | Acetyl Acetone | CH3COCH2COH3 | | | | | | | | |
| 19 | Pyridine | C5H5N | 79.1 | 115.6 | -41.8 | 0.982 | 1.5095 | 12.3 | 2.19 | 9.45 |
| 20 | Dimethyl Sulfoxide | (CH3)2SO | 78.1 | 189 | -32 | 1.328 | 1.3874 | 42.6 | | |
| 21 | Cyclohexane | C6H12 | 84.16 | 80.7 | 6.55 | 0.778 | 1.4266 | 2.02 | 0 | 8.98 |
| 22 | Phenolphthalein (alcoh.0.5%) | | | | | | | | | |
| 23 | Acetonitril | CH3CN | 41.05 | 81 | -44 | 0.786 | 1.3441 | 36.2 | 3.92 | 3.45 |
| 24 | Phenolphthalein | | | | | | | | | |
| 25 | Phenol | C6H5OH | 94.11 | 181.8 | 43 | 1.072 | 1.5418 | 9.78 | 1.45 | 34.9 |
| 26 | Dimethyl Sulfate | (CH3O)2SO2 | 126.13 | 188 | -32 | 1.333 | 1.3874 | 42.6 | | |

If we go back to our project, after making sure that the solutions we obtained were completely homogeneous, we filled the syringe with 10ml. Then we closed the syringe and connected it to the pump section of the electrospinning device so that there was no air inside. After selecting the amount to be shot (10ml) from the pump assembly, we also determined the shot speed as 2ml/h. Then, we attached the carrying cable that will transmit the 32 cm solution that we cut to the tip of the syringe. We mounted the other end to the nozzle to be shot with the connection elements. Then, we advanced the solution to the tip of the nozzle by pressing the buttons on the manually adjustable screen on the pump because the electrospinning device provides shooting with electrical power. It does not advance the solution in the tube. Finally, in order to collect the fibers on the drum in an orderly manner, we placed the 25x35 cm greaseproof paper that we cut on the drum. After adjusting the 25kW electrical energy and 500rpm drum rotation speed, we pressed the power button of the electrospinning device and closed the protective cover. We handled the same processes for all solutions, but in these processes, there were both fixed parameters and variable parameters. If we talk about these;

Fixed parameters: solution amount (10ml), shooting speed (2ml/h), nozzle-drum distance (25cm, remained constant because the distance setting of the device we used was faulty), electric power (25kW)

Variable parameters: solution density and the time spent to homogenize the solution accordingly (the time required for homogeneity increased as the PS amount increased) and fiber production time. Our experiments lasted an average of 330 minutes. With the increase in density, shooting could not occur at the nozzle

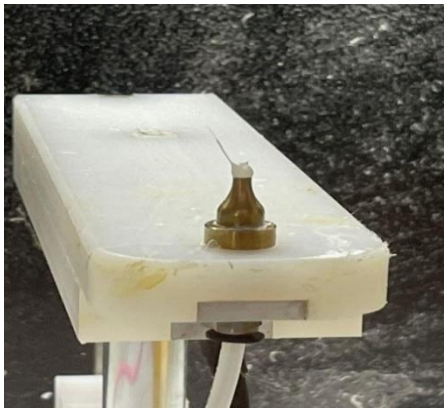


*Figure 6 Clogged nozzle*

tip at times and we had to clean it at regular intervals, so we completed the productions in 360-380 minutes.

As a result of all these waiting and studies, we put the fibers we collected on oil paper in a transparent file and preserved the samples with their properties for future studies.

# 3.REVIEWS

**Plastik Atıkların ve Yapıda Kullanım Olanaklarının İncelenmesi:**

Plastic materials (synthetic polymers are the building blocks of plastics) have been used in many sectors from past to present; food packaging, insulation, purification systems, building materials, etc. These are the materials that appear in the fields. With the increasing population rate over the years, the amount of plastic used in the industry has also increased in direct proportion. Unfortunately, although plastics are versatile in terms of applicability, after use, they reach very dangerous levels for natural habitats (such as air, water, soil). Because ordinary plastic left to nature as waste can survive for centuries without breaking down. Due to both the presence of toxic substances in their structure and their chemical properties, they can cause very harmful reactions as a result of their reactions with toxic substances. For this reason, in recent times, minimizing the use of plastic and producing useful materials (e.g. nanofibers, membranes, etc.) for use in industry from plastics that become waste as a result of use have become an important field of work for most societies. In this way, it has become a great progress in financial terms (there is no need to produce extra plastic and allocate absurd capital to materials that can be produced by recycling plastic) and it has become an excellent solution method in terms of protecting natural life.

If we briefly talk about some plastics and their usage areas;

PVC (polyvinylchloride) is frequently used in the construction industry. In addition to the construction industry, PVC has widespread uses such as electrical and telephone cables, food packaging, assembly and clothing industries and the automobile industry. It is known that dirty water pipes and various filling materials are produced from waste PVC plastic packaging.

PP (polypropylene) is lighter than other plastic types and has a higher softening temperature, so it can be used in many areas, from the healthcare sector to the construction sector. The use of polypropylene fibers is quite common in the carpet industry, especially in the USA. It also has a large share in the furniture, wall covering, packaging and automobile industries.

Another type of plastic frequently used in construction is ABS (Acrylonitrile-Butadiene-Styrene) plastics. It is frequently preferred in kitchen appliances, lighting products, radiator panels, plumbing pipes and parts due to its high temperature resistance.

In addition to the synthetic polymers (plastics) mentioned above; Many different plastic products such as PS (polystyrene), PET (polyethylene terephthalate), PPE (polyphenylene ether), EVA (ethylene vinyl acetate) are frequently used and encountered in daily life.

In addition to the information we have given about the common areas of use of plastics, I would also like to touch upon the nanomaterials obtained from plastics through timely recycling studies and their areas of use. Let's explain these with a few examples: Fareed et al. managed to use PET bottle waste in the production of polymer mortar in 2007 and stated that this mortar could be used in the production of paving stones and sewer pipes. In addition, materials such as carpet bases, sleeping bags, pillows, quilts, auto parts, paint brushes and lifeguard pillows can be produced using waste PET. In 2015, Martinez Urreaga et al. combined recycled agricultural plastic and waste HDPE (high density polyethylene) with waste cellulosic fibers and succeeded in increasing the mechanical properties of the eco-composite material they produced with various additives such as EVA (Ethyl vinyl acetate) and PP (polypropylene). . In 2014, Gonzales Sanchez et al. produced a composite material with strong mechanical properties by combining recycled agricultural plastics and waste cellulosic fibers.

As a result, within the scope of this study, plastic waste generated in construction and industry and studies aimed at reducing plastic waste were examined. The main goal is to reduce the use of plastic products and to recycle the waste plastics resulting from use and turn them into useful materials to be used in the sector. In this way, we develop the country's economy and protect natural life from the dangers of plastic waste.

**A Review on Fabrication Methods of Nanofibers and a Special Focus on Application of Cellulose Nanofibers:**

Nanofibers are the most interesting materials with measurements in the nanometric range, from ten to a thousand nanometers. Nanofibers have different outstanding qualities such as high surface area, good permeability, and enhanced physical, mechanical, and organic properties, and thus their application studies in many sectors, including energy production, various biological and medical fields, defense, food industry, water purification, and environmental protection. Is being carried out. In addition, these nanofiber materials are simple materials that can be obtained by recycling materials such as plastic and polymers, and many different methods are used in the industry to produce nanofibers/nanomaterials to be synthesized. If we count these methods; Many different methods can be used, such as electrospinning, self-assembly, phase separation, template synthesis, drawing and centrifugal spinning. While there are many methods to be applied, we had the opportunity to gain information through the articles necessary to decide which one to use. The electrospinning method, unlike others, is the most suitable method for our usage standards because it is easily applicable, low-cost, high-efficiency, and nanofibers made with this method are more advantageous due to higher surface area, less fiber diameter ranging from nano to micro scale, and good porosity. We can evaluate it as. Also, if we briefly talk about why we equalize other methods;

Self-assembly has high price and low efficiency.

Phase separation is not suitable for every polymer and is insufficient for long fiber production.

Template synthesis is again difficult to set up.

There is no drawing method, a regular process and it is very difficult to produce low diameter fibers.

Centrifugal spinning has difficulties in installation and assembly.

For this reason, the synthesis method we will use when considering the production of nanofibers by recycling PS polymer will be electrospinning.

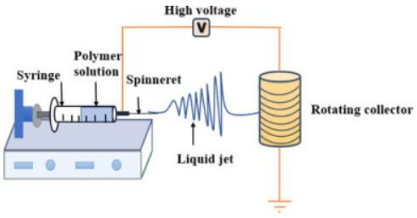



*Figure 7 Electrospining Process*

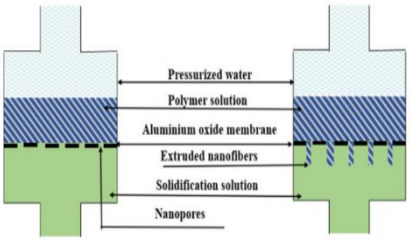



*Figure 8 Nanofiber Extrusion*

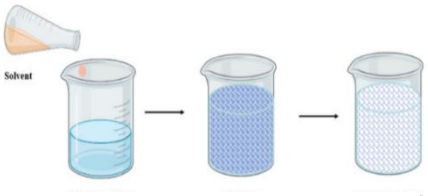



*Figure 10 Nanofiber Synthesis*

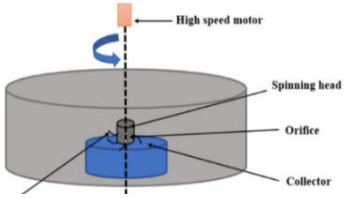



*Figure 9 Rotary Spinning*

**Recycling and Reutilizing Polymer Waste via Electrospun Micro/Nanofibers:**

Electrospinning is divided into various application techniques, but in this part we will use the traditional electrospinning method with a single nozzle. Because it is the simplest and most cost-effective method by which we can obtain the nanofibers we want to produce. In this method, installation is very simple and the main equipment used is as follows;

A spinneret (metallic needle)

High voltage power supply

Grounded collector

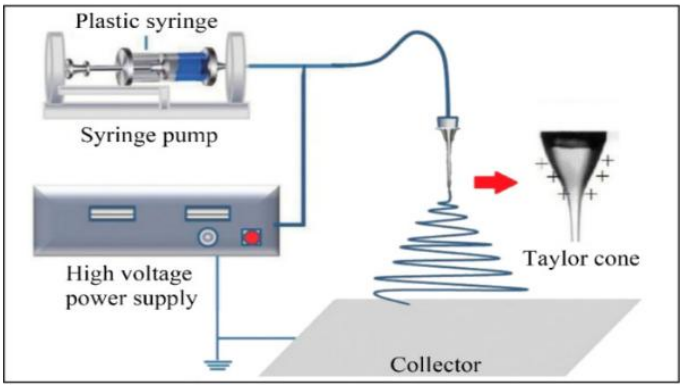



*Figure 11 Electrospining Process*

If we briefly explain how the electrospinning process takes place; The electrospinning process is accomplished by applying a high electrical voltage to the liquid droplet of polymer melt or solution at the tip of the spindle. The liquid droplet will begin to elongate into a conical shape known as a "Taylor cone" as the high voltage increases. Elongation occurs when electrostatic repulsion exceeds surface tension. After the Taylor cone is formed, the charged liquid jet is directed to the metal collector. The liquid mentioned herein may be a polymer solution, an emulsion or a melt polymer. The flapping motion that occurs during the flight from the Taylor cone to the collector will develop as the melt cools or the solution evaporates, depending on the viscosity of the liquid. As a result, a non-woven fiber mat will cover the collector.

If we talk about styrofoam, which is our subject of study, terminologically it appears as expanded (EPS) or extruded (XPS) polystyrene. It is a thermoplastic polymer used in many fields, including the electronics and packaging industries, due to its versatility, lightness, thermal stability, cleanliness and low cost. EPS is toxic to organisms and tends to accumulate mercury compounds in the environment, leading to a drastic impact on the environment. Therefore, it is also important to convert recycled EPS into valuable products by electrospinning. In this vein, Shin et al. conducted a series of studies on recycled EPS through electrospinning, and in 2005, they obtained electrospun fibers containing recycled EPS and natural solvents, which benefit the environment. Later, Shin et al. mixed microglass fibers with electrospun EPS fibers and found that the separation efficiency of the fibers increased for filtering water-in-oil emulsions. Applications of electrospun recycled EPS are generally for filtration. For example, Khairurrijal et al. investigated electrospun recycled EPS for air filtration. In 2018, they succeeded in synthesizing nanofiber membranes from waste high-impact PS using the electrospinning method, which showed a suitable application in air filtration based on contact angle measurement and air filtration testing.

In line with this method, for example; Esmaeili and colleagues synthesized PET, PS, and PC nano/microfibers via solution electrospinning and investigated the influence of various operational parameters, especially needle diameter and spinning voltage, on the properties of the resulting fibers.

Therefore, they inspired us to examine the potential of electrospinning in the reuse of plastic waste and to explore the properties of the resulting nanofibers depending on variable parameters.

As we mentioned above, these processes affect the quality of the nanofibers produced depending on certain parameters. The main parameters we need to pay attention to in the electrospinning system we will install are; We can say these are the applied voltage, flow rate, distance between the metallic needle and the collector, needle diameter, polymer properties (concentration, viscosity, surface tension, etc.) and the solvent used.

**Electrospinning: The Technique and Applications and Article: Electrospining:**

Considering that I have given sufficient information about the electrospinning method (its application and necessary equipment, etc.) in our previous articles, I will talk about the important parameters of the electrospinning method, which I have implicitly mentioned before, thanks to the few articles I have read in this section. If we remember again, the parameters were as follows; applied voltage, flow rate, distance between the metallic needle and the collector, needle diameter, polymer properties (concentration, viscosity, surface tension, etc.) and the solvent used. Now we will examine these parameters in more detail, respectively.

Applied voltage: Voltage is a factor that affects the amount of charge carried by the jet and the degree of electrostatic repulsion. As the voltage increases, the diameter of the fibers decreases.

Flow Rate: As the flow rate increases, the amount of material passing through the needle tip increases, resulting in the formation of large-diameter nanofibers. Additionally, the flow rate has a significant impact on the formation of a smooth Taylor Cone.

Needle Tip and Collector Distance: The distance between the fibers must be calculated as the minimum gap sufficient for the solvent to evaporate before reaching the collector, and the experiment must be carried out at that range. As the distance increases, thinner fibers appear to form.

Needle Diameter: Nanofibers electrospun with small needle diameters are thinner, smoother and bead-free. It has greater fiber porosity than electrospun nanofibers with large needle diameters. As mentioned earlier, higher applied voltage, smaller spinneret diameter, and lower flow rate result in thinner electrospun nanofibers.


*Figure 12 Nozzles*

Collector Type: After solidifying during the spinning process, electrospun fibers can be collected in a wide variety of collectors, mostly consisting of stationary and rotating platforms. Stationary collectors are generally flat plates for collecting random fibers where the extent of the field can be adjusted to a desired limit.


*Figure 13 Collector Types*

Polymer Concentration: Polymer Concentration; Since it affects factors such as viscosity, electrical conductivity and surface tension, it must be adjusted to appropriate percentages.

Viscosity: Viscosity is a property that depends on the molecular weight of the polymer used and the solvent. As the viscosity increases, the solution will become more difficult to spray from the syringe tip and may even dry out before spraying occurs. As viscosity increases, fiber diameter increases.

Surface Tension: In order for electrospinning to occur, the applied electrostatic force must exceed/break the surface tension of the solvent. Otherwise the experiment will fail. Surface tension causes bead formation when the polymer concentration is low. If the surface tension is low, jet formation begins at a lower voltage. The surface tension of the polymer solution can be changed by changing solvents and adding surfactants

Conductivity: As the conductivity (charge density of the solution) increases, the production of bead-free fiber increases. Additionally, as conductivity increases, the diameters of the nanofibers formed decrease. Inorganic and organic salts, together with surfactants, can be used to selectively change the conductivity of the solution and eliminate bead formation. Without conductivity, fiber formation can never occur.

Solvent Selection: The choice of solvent to be used to create the solution during nanofiber formation by electrospinning is one of the most valuable parameters. If we give some examples of solvents that we can use during the synthesis of nanofibers with polystyrene; We can write it as dichloromethane (DCM), acetone, chloroform, N, N-Dimethylacetamide, N, N-Dimethylformamide (DMF) and Tetrahydrofuran. However, while there are many solvent examples, vapor pressure, boiling point, etc. are the most suitable and most successful solvent in fiber production. We need to pay attention to chemical properties. As will be seen in further studies, the most logical choice among the example solvers I gave above is; It will be DMF because it is useful and has the ability to dissolve solids in high amounts. Because it has properties such as high boiling point (low evaporation rate), low vapor pressure and high permeability. The higher the vapor pressure (volatility), the more distorted the morphology of the resulting fibers will be, as the fibers sprayed from the jet will solidify before reaching the collectors. Additionally, as the permeability of the solvent increases, fiber bead formation and nanofiber diameters decrease. In general, low-conductivity, low-boiling point solvents tend to form high fiber diameter and beaded nanofibers. For example, PCL fibers formed with low-boiling point solvents such as dichloromethane (DCM) or 1,1,1,3,3,3-hexafluoroisopropanol (HFIP) are obtained in micro sizes (normally nanofibers are formed in nano sizes).

**Synthesis and Characterization of Polystyrene with Embedded Silver Nanoparticle Nanofibers to Utilize as Antibacterial and Wound Healing Biomaterial:**

In this research, silver nanoparticles (Ag) embedded in polystyrene (PS) nanofiber composites were prepared by electrospinning technique using N, N-dimethylformamide (DMF (99.8% purity)) as solvent and safe reducing agent. The morphology of electrospun PS nanofibers plays an important role in the final product used in a particular application, so it is more important to produce bead-free PS nanofibers. The main items to be considered during the synthesis of beadless nanofibers are based on polymer properties (molecular weight, concentration, viscosity, conductivity, surface tension and solvent used) and correct solvent selection. In this context, we can briefly say that; To obtain uniform nanofibers using PS, many parameters need to be studied in common and at appropriate scales.

During the synthesis of nanofibers from PS polymers by electrospinning, the choice of solvent to be used in the apparatus is very important. In this regard, for polystyrene; Many solvents such as 1,2-dichloroethane, N, N-dimethylformamide (DMF), ethyl acetate, acetone, methyl ethyl ketone (MEK) and tetrahydrofuran (THF) have been investigated, and among these solvents, DMF has a higher boiling point, conductivity and It emerged as the most suitable and most preferred solvent to produce uniform PS nanofibers with a smooth surface due to its dielectric constant. For this reason, we will create solutions with DMF while carrying out our work.

*Table 2 Solvents Properties*

| Solvent name | Solvent abbreviation | Boiling point (°C) | Vapor pressure at 20°C (mmHg) | Dielectric constant | Surface tension at 20°C (mN/m) | Density at 20°C (g/mL) |
|---|---|---|---|---|---|---|
| Acetic acid | AA | 118 | 11.4 | 6.2 | 27 | 1.049 |
| Acetone | Ace | 56 | 185.5 | 21.5 | 25.2 | 0.788 |
| Chloroform | CHF | 61 | 160 | 4.8 | 27.5 | 1.489 |
| Dichloromethane | DCM | 40 | 353 | 8.93 | 26.5 | 1.326 |
| N,N-Dimethylacetamide | DMAc | 166 | 2.25 | 37.8 | 36.6 | 0.937 |
| N,N-Dimethylformamide | DMF | 152 | 2.3 | 36.7 | 37.1 | 0.945 |
| Dimethyl sulfoxide | DMSO | 189 | 0.42 | 46.7 | 43.54 | 1.096 |
| Ethanol | EtOH | 78 | 44.63 | 24.5 | 22.1 | 0.789 |
| Ethyl acetate | EA | 77 | 73 | 6.0 | 23.9 | 0.901 |
| Formic acid | FA | 101 | 42.97 | 57.9 | 37.67 | 1.221 |

To give brief information about DMF; DMF is an organic compound with the formula C_3 H_7 NO. It is a colorless, odorless liquid that is miscible with water and many organic substances and is used as an organic solvent. DMF is used as a solvent with a low evaporation rate in the production of acrylic fibers and plastics. The biggest advantage of DMF in this field is its ability to dissolve solids in high amounts. Therefore, it is more economical than many other solvents.

Coming back to the study, the PS and AgNPs-PS nanofiber composite was prepared via an electrospinning process from N,N-dimethylformamide (DMF) as a solvent and reducing agent. If we explain the work step by step;

First, the desired amount of polystyrene is weighed according to the required concentrations and allowed to dissolve in DMF at room temperature to form a homogeneous solution (made by letting the solution stand for a while or using a magnetic stirrer). Then, 1% by weight of AgNO_3 was added into the prepared 15% by weight PS solution for 1 hour, and as a result, AgNPs were formed in the solution, therefore the solution turned dark yellow. After this step, electrospinning was used to create electrospun polystyrene (PS) nanofiber and PS nanofiber composite embedded in AgNPs. Appropriate solutions were transferred to a syringe equipped with a needle, and the fiber was collected on an aluminum collection plate. The operation of this system can be achieved by turning on the power of the high voltage system and gradually increasing the voltage through a regulator, starting from 0 kV and keeping it constant at 30 kV during the electrospinning process. Polymer solutions were sprayed towards the collector, and as a result, a 30 cm x 30 cm nanofiber layer was produced on the aluminum foil.

We briefly reviewed how different experimental designs have been developed to obtain precise conditions for electrospinning of Polystyrene. The table below shows the dependent parameters and their levels for the experimental design:

| Parameters | Levels |
|---|---|
| Concentration, wt.% | 10, 15, 20, 25 and 30 |
| Extrusion Rate, ml/h | 1, 2 and 3 |
| Field, kV/cm | 2 and 3 |
| **Total Runs** | **5 × 3 × 2 = 30** |

*Figure 14 Total number of experiment*

In summary, in this experiment, nanofibers obtained by integrating metal nanoparticles into nanofibers for use in biomedical fields from PS (styrofoam) by electrospinning depending on variable parameters are mentioned. If we talk about the parameters; First, a high density (35%-40%) solution was used to determine the solution concentration, but since this density caused high viscosity, the spraying process by the pump failed (higher nozzle size and higher voltage were needed). Additionally, beads and discontinuous films were formed at low polymer concentrations of 5–8%. At such a low concentration level, solutions do not contain sufficient material to produce stable, solid continuous fibers. With increasing polymer concentration, the number of direct interchain associations of polystyrene molecules in solution increases and reaches a critical value to form a three-dimensional network structure (high viscosity gel). For this reason, 30% solution was considered as the maximum solution density. Then, the voltage to be applied and the distances between the needle and the collector were calculated at optimum rates as 25kV and 10cm, respectively.

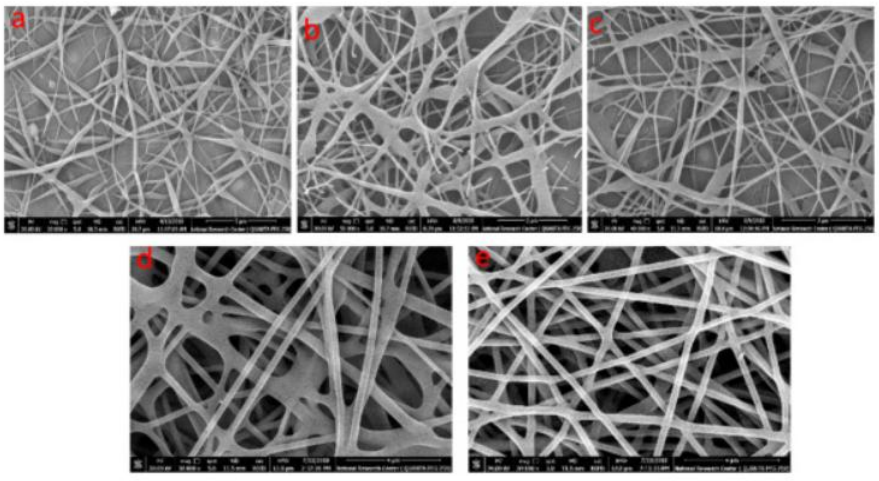



*Figure 15 SEM images*

The above figure shows the images of the fibers formed when the extrusion rate of 10%, 15%, 20%, 25% and 30% polystyrene solution by weight is 2 ml/h and the area is 3 kV/cm, respectively. In this figure, which changes from "a" shape to "e" shape, respectively, we can see that the beads and small diameter fibers turn into more regular, beadless and large diameter fibers.

| | | | | |
|---|---|---|---|---|
| Extrusion Rate 2 ml/h and Field 3 Kv/cm | 11 | 10 | *Beads + Fibers* | 63 ± 4.38 |
| | 12 | 15 | *Fibers + Beads* | 175 ± 12.11 |
| | 13 | 20 | *FibBeads + Fibersers* | 208 ± 14.43 |
| | 14 | 25 | *Fibers* | 243 ± 16.86 |
| | 15 | 30 | *Fibers* | 486 ± 33.65 |

**Fabrication of PS/PVDF-HFP Multi-Level Structured Micro/Nano Fiber Membranes by One-Step Electrospinning:**

In this section, we will examine the synthesis of PS/PVDF-HFP multilevel microfiber membranes by electrospinning. Micro/nanofiber membranes with multi-level interlocking structure provide good mechanical strength and long-term stability. Additionally, if we compare with membranes consisting only of nanofibers, the membranes we will obtain in this section appear with better permeability and durability. Additionally, it allows us to achieve higher selectivity and a larger surface area compared to microfiber membranes alone.

PS/PVDF-HFP membranes exploit dual micro/nanoscale fiber morphology to combine the advantages of both domains. Nanofibers provide high porosity and a larger surface area; these are beneficial in terms of selectivity, permeability and antifouling properties. Depending on the variable system parameters we mentioned in the previous sections, e.g. We will systematically investigate the effects of key electrospinning parameters, including solution concentration, polymer ratio, voltage, and tip-collector distance, on the morphology and multilevel structures of PS/PVDF-HFP nanofiber membranes.

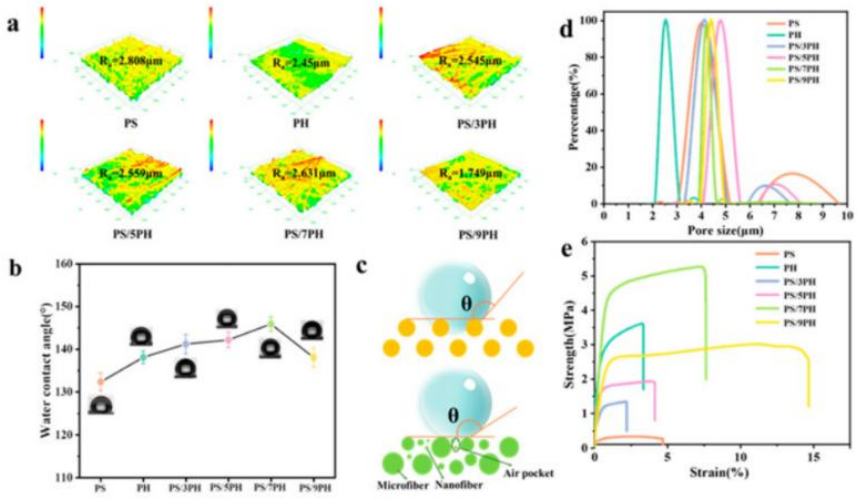
Firstly, PS/PVDF-HFP spinning solutions were produced simply and directly by different mass ratios of PS and PVDF (as solute) mixtures (PS: PVDF-HFP = 1:3, 1:5, 1:7 and 1:9) at various concentrations. It was prepared by dissolving (14 wt%, 16 wt%, 18 wt%, and 20 wt%) into DMF (as solvent). Then, the obtained PS/PVDF-HFP spinning solutions were fed into laboratory homemade electrospinning equipment used with specific electrospinning parameters (voltage of 30 kV, reception distance of 18 cm and liquid extrusion rate of 1 mL/h, and experimental temperature of 25 ± 5 °C). transferred. Micro- and nano-scale fibers, which are then synthesized by electrospinning, are formed simultaneously during spinning through micro-phase separation and are continuously deposited and solidified on the collector as an intertwined network where the two polymer phases are thoroughly mixed. In order to be suitable for the recording process, electrospun fiber membranes were prepared from PS/PVDF-HFP spinning solutions at different ratios (PS: PVDF-HFP = 1:3, 1:5, 1:7 and 1:9), respectively; They are named as PS/3PH membrane, PS/5PH membrane, PS/7PH membrane and PS/9PH membrane. For comparison purposes, the pristine PS membrane and pristine PVDF-HFP membrane, respectively; They are called PS membrane and PH membrane.

The table below gives brief information about the properties of the membranes obtained depending on variables such as voltage, collector distance, solution concentration and polymer ratio, while keeping the flow rate constant.

| Membrane | PS | PH | PS/3PH | PS/5PH | PS/7PH | PS/9PH |
|---|---|---|---|---|---|---|
| Thickness (μm) | 250 ± 20 | 250 ± 20 | 250 ± 20 | 250 ± 20 | 250 ± 20 | 250 ± 20 |
| Mean pore size (μm) | 4.52 ± 0.2 | 2.77 ± 0.10 | 4.54 ± 0.10 | 5.74 ± 0.20 | 4.38 ± 0.10 | 4.64 ± 0.20 |
| Maximum pore size (μm) | 6.32 ± 0.2 | 4.00 ± 0.10 | 5.92 ± 0.10 | 8.12 ± 0.20 | 5.26 ± 0.10 | 5.34 ± 0.20 |
| Porosity (%) | 74.1 ± 3.2 | 81.9 ± 2.1 | 76.4 ± 3.1 | 77.8 ± 3.5 | 78.9 ± 3.5 | 72.8 ± 2.3 |

Looking at the above table in terms of the porosity of these membranes, specifically, when the mass ratio of PVDF-HFP to PS increases from 3:1 to 7:1, the porosity of the fiber membrane due to the increase in the proportion of nanoscale fibers is 76.4% ± 3%. It increases from .1 to 78.9% ± 3.5%. However, when the mass ratio of PVDF-HFP to PS continues to increase up to 9:1, the porosity of the fiber membrane decreases and becomes lower than the porosity of the pure PS membrane due to the decrease of the nanofiber proportion and the slight increase in its density.

Additionally, the mechanical properties of fiber membranes affect their long-term durability. The mechanical properties of fiber membranes prepared with different spinning solution ratios are shown in the figüre below.




Fiber membranes prepared with different spinning solution ratios: (**a**) Surface three-dimensional confocal microscope images and (**b**) static water contact angle; (**c**) Schematic diagram of water droplets on different membrane surfaces; (**d**) Pore size distribution diagram and (**e**) stress–strain curve diagram.

*Figure 16 Fiber membranes with different spinning solution ratios*

As we can see in the figure, when the mass ratio of PVDF-HFP to PS increases from 3:1 to 7:1, it can be seen that the PVDF-HFP ratio increases, and the breaking strength and elongation at break of the fiber membrane also increase. This is because multilevel micro/nanostructures can improve the mechanical properties of the membrane. When the mass ratio of PVDF-HFP to PS continues to increase

up to 9:1, the elongation at break of the fiber membrane continues to increase and the breaking strength decreases due to the decrease in the proportion of nanofibers in the entire membrane.

As a result, in this section, we have described the synthesis of intertwined micro-nano scale fibers through microphase separation from the solution obtained by dissolving PS/PVDF-HFP polymers in DMF, using the electrospinning method. In this section, where we have information about the morphology of nanofibers obtained in line with variable system and operating parameters, if we talk about the system parameters in which the most suitable/optimal membranes are produced; We can say that when the concentration of the solution is 18 wt% (mass ratio of PS to PVDF-HFP is 1:7), the spinning voltage is 30 kV and the spinning take-up distance is 18 cm.

**Electrospinning of Grooved Polystyrene Fibers: Effect of Solvent Systems:**

In this experiment, it is generally explained that the secondary surface tissue provides morphological diversity. LBPS, DCM, ACE, THF, HBPS, DMF, CYC and non-solvent NS are used as solvents. Electrospinning features: Syringe 0.7 mm in diameter, distance 15 cm, temperature 22 C, Flow rate They set the voltage as 1.5ml/h to 15kV. They mix the solvents I mentioned above in the ratios of 3.1 2.1 1.1 1.2 1.3 and dissolve PS. As a result of these processes, we reach the following results.

Single solver:

Acetone alone cannot dissolve it, but it softens and swells the PS. DCM THF DMF CyCo makes electrospun successfully.Since rapid evaporation occurs in DCM and HF, the needle becomes clogged and the process is interrupted.At 15% ps it produced only dmf beaded free.DCM resulted in small pores (less than 100 nm) distributed evenly on the beads and fibersTHF caused irregular large pores (approximately 1 μm).CYCo produced wrinkled beads. They increase the psi to 30%, but it still becomes beaded (normally when the PS density is like this, smooth fibers appear). This does not happen because of the viscosity. It is necessary to reduce the viscosity in CyCo.

Binary solver:

Lbps/lbps lbps/hbps hbps/hbps ns/lbps or hbps are mixed in different proportions.The needle keeps getting clogged only in Lbps/lbps, only the lbps mix did not give the result we expected.

When Thf/dmf is 3.1, it produces single-hole fiber. When it is 2.1, a much higher number of holes are formed. When it is 1.1, smooth fiber is formed.

All mixes it one by one at 1.1. Except for Ace/CyCo, the others produce it without beads at 25 - 30%. At 1.1 and above, DMF comes out smooth and smooth. At 1.1 and below, holes begin to appear.Except for DMF, it either creates beads or holes in all of them. It is not smooth with DMF either, which is not a pleasant situation (wrinkles).

**Polymer Nanofibers Via Electrospinning: Factors Affecting Nanofiber Quality:**

In the introduction part of the article, he talks about why nanofibers are preferred and their benefits. He talks about the many uses of nanofibers and their applications in these areas. Then, the theoretical explanation of the electrospinning process is given and the processes of its parts are mentioned. When we look at the properties affecting the fiber type, viscosity is examined first. When the concentration is low. Wetness occurs in the collector, and when it is excessive, the electric field cannot overcome the polymer. As a result, as the viscosity increases, the fiber diameter increases and passes from spherical to linear. Surface tension has the effect of reducing the surface area per unit mass of a fluid. When surface tension is examined, it is understood that it gives similar results to viscosity and is proportional to the solute concentration.

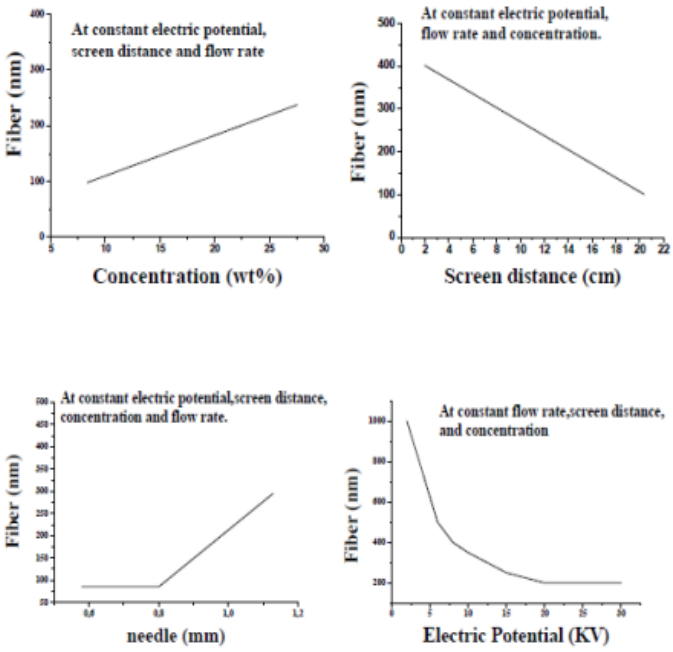



*Figure 17 Change of Fibers Diameter*

When the conductivity of the solution is increased, it causes it to be more affected by the electric field. The diameter of the fiber is directly related to the radius of the needle tip. It is said to be directly proportional. Although they say that the fiber diameter decreases as the applied voltage increases, some studies show no effect, and some even say that if the voltage increases, the fiber diameter increases. It is seen that the diameter of the fiber braids decreases as the distance between the needle and the collector increases. Moreover, if the distance increases, there will be enough time for the beads to evaporate. formation decreases. Temperature affects the evaporation rate and viscosity of the polymer. If the temperature increases, the viscosity of the polymer decreases. As the viscosity decreases, the tension increases and the diameter of the fibers decreases.

**Fabrication of Flame-Retardant and Superhydrophobic Electrospun Nanofibers:**

In this article, ale retardation and superhydrophobicity were focused on and their effects were discussed. Inflammability and water repellency are two of the important properties desired for nanofibers. Pure polystyrene could not pass the inflammability test when it weighed 5% and failed. fWhen the weight percentage was increased, this created a pressure and increased coal production. These coal residues help protect the polymer from flame like a shield. Micro-

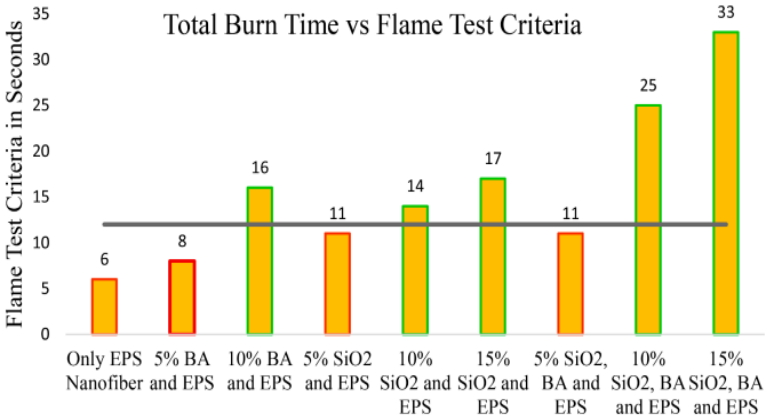



*Figure 18 Total Burn Time vs Test Criteria*

nano (BA-SiO2) particles are included in the EPS for the superhydrophobicity test. And this ensures a successful electrospinning process. In general, it must be at least 10% to pass the burning test. It has to be a micro-nano concentration because the others are below the desired criterion. They are tried separately and by mixing, but none of them work. In addition, we can say that SiO2 gives more burning resistance than BA because when the concentrations are equal, the burning time is longer.

**Fly Ash-Incorporated Polystyrene Nanofiber Membrane as a Fire-Retardant Material: Valorization of Discarded Materials**

He talks about the benefits of reducing the damage caused by waste to the environment and reducing environmental pollution by reducing the number of waste. He mentions that we can do this by

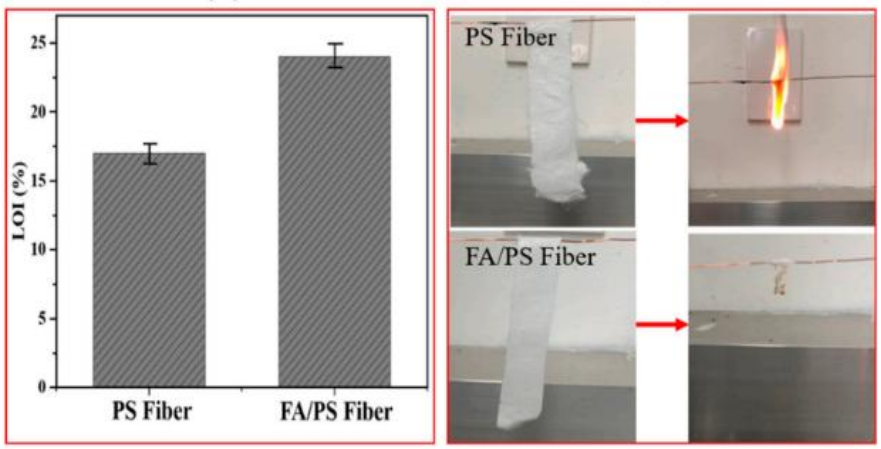



*Figure 19 PS vs FA/PS fiber*

recycling waste. He uses waste PS and Fly-ash in the experiment. He recycles these two both individually and together with electrospinning. It clarifies the type and properties of the fibers they produce. First, PS is electrospinned alone and put into the burning test. Then, the FA/PS composite is formed and put into the burning test. It is observed that these two are more successful in the burning test when they are together. It is also observed that the fiber radius decreases. Its small size is an important criterion for smoother fibers. It is stated that the reason for this is that FA is very well hidden in PS particles and is docked with PS particles. This shows that waste materials can actually be very functional and give positive results.

**Electrospinning of Polymers, Their Modeling and Applications:**

He starts the article by explaining nanotechnology and nanofibers. He explains why nanotechnology is important and what its advantages are. The basis of nanotechnology is that if the size decreases to nanometer dimensions, the substances gain many good properties such as hardness, tensile strength, and a significant increase in the surface/volume ratio. Let us briefly explain electrospinning. He introduces the main parts we use. He says that thanks to the voltage, the polymer coming out of the tip of the needle evaporates and this evaporated polymer collects in the collector load and produces fibers. He says that these processes can be examined with microscopes such as SEM, TEM, AFM. Then, the PS polymer is dissolved in three separate solvents: THF, CHCL3 and DMF.

He puts it into the electrospinning process. He compares the morphological properties of the resulting fibers. While the fibers formed in THF and CHCL3 solvents are formed with beads, it is observed that beadless fibers can be formed when DMF is used as a solvent. And it is decided that the optimal solvent is DMF. He also says that increasing the solution conductivity reduces the number of beads. He tests this by adding salt and It works, but he states that we need to be careful that the fibers rise above the desired radius when the salt concentration exceeds a certain value. He states that high voltage causes fibers with higher diameters.

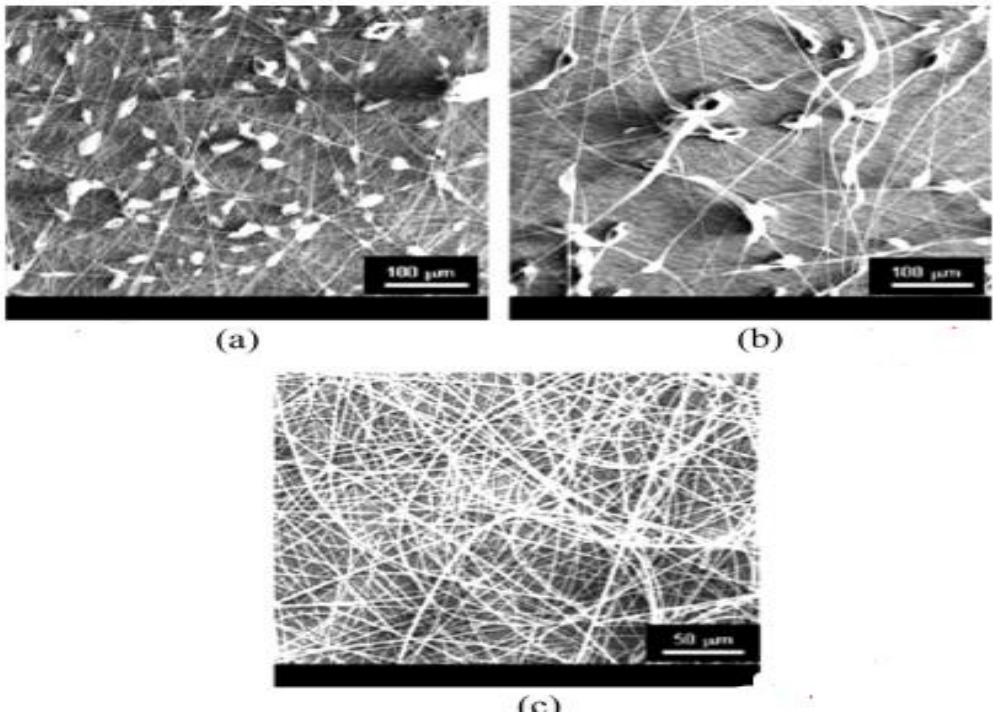



*Figure 20 a) THF b) CHCL3 c)DMF*

**Electrospinning of Uniform Polystyrene Fibers: The Effect of Solvent Conductivity:**

In this experiment, he transforms polymers into nanofibers by electrospinning. He says that even very small changes in the experiment cause large changes in the morphology of nanofibers. He focuses on solution conductivity and polymer concentration, which are the most important of these. He supplies DMF solvent from five different suppliers. Each of these solvents has different density. While doing this, he observes the results obtained by mixing DMFs purchased from the same supplier in different PS concentrations to see the effect they have on the PS density. PS concentration is generally below 25%, except for DMF1-A99–PS20. In other words, if we want bead-free fiber, we need to have a minimum PS concentration of 25%. However, if we increase the PS concentration further, the diameters of the resulting fibers increase significantly and this is not a situation we want. Likewise, when we increase the PS concentration, the viscosity also increases and the conductivity decreases significantly. This Therefore, we deduce that the initial conductivity of our solvent is high and that we need to increase it in a balanced way as the conductivity will decrease as the PS concentration increases. In the experiment, the images of the nanofibers that emerged as a result of the solutions we created with DMFs purchased from each supplier have been shared. Thanks to these images, we can clearly see whether they are beaded or not. Like the ones supplied from Fluka98. The electrospinning process is performed again by adding tetrabutylammonium to DMFs with low initial conductivity. We observe that TBAB significantly increases the solution conductivity. In this way, smaller diameter nanofibers are obtained.

| Name | DMF grade | % PS (w/v) | Fiber morphology | Fiber diameter (nm) | Bead size (l/w) (micron) | Bead aspect ratio (micron) | Viscosity (cP) | Conductivity (μS/cm) |
|---|---|---|---|---|---|---|---|---|
| *DMF1-Aldrich99* | Aldrich, 99% | 0 | – | – | – | – | – | 15.9 |
| DMF1-A99–PS10 | Aldrich, 99% | 10 | Nano-fibers with few beads | 481 ± 93 | 8.43 ± 1.48/3.60 ± 0.79 | 2.41 ± 0.51 | 21.2 ± 0.1 | 10.1 |
| DMF1-A99–PS15 | Aldrich, 99% | 15 | Nano-fibers, very few beads | 958 ± 200 | 17.27 ± 5.83/5.18 ± 1.37 | 3.39 ± 1.16 | 60.0 ± 0.7 | 8.6 |
| DMF1-A99–PS20 | Aldrich, 99% | 20 | Micro-fibers only | 1470 ± 256 | – | – | 139.7 ± 0.7 | 7.3 |
| *DMF2-Aldrich99* | Aldrich, 99% | 0 | – | – | – | – | – | 5.6 |
| DMF2-A99–PS10 | Aldrich, 99% | 10 | Nano-fibers with many beads | 373 ± 112 | 9.39 ± 1.62/4.60 ± 1.42 | 2.18 ± 0.63 | 22.9 ± 0.1 | 2.5 |
| DMF2-A99–PS15 | Aldrich, 99% | 15 | Micro-fibers with beads | 1229 ± 319 | 15.42 ± 2.62/6.36 ± 1.11 | 2.48 ± 0.49 | 59.9 ± 0.5 | 1.35 |
| DMF2-A99–PS20 | Aldrich, 99% | 20 | Micro-fibers with few beads | 2370 ± 445 | 21.70 ± 2.34/6.86 ± 1.24 | 3.23 ± 0.60 | 129.8 ± 0.4 | 1.1 |
| DMF2-A99–PS25 | Aldrich, 99% | 25 | Micro-fibers only | 1882 ± 277 | – | – | 342.6 ± 1.8 | 1.1 |
| *DMF-Sigma998* | Sigma, 99.8% | 0 | – | – | – | – | – | 1.3 |
| DMF-S998–PS10 | Sigma, 99.8% | 10 | Nano-fibers with many beads | 367 ± 120 | 10.76 ± 2.80/6.01 ± 1.59 | 1.87 ± 0.52 | 21.6 ± 0.2 | 0.9 |
| DMF-S998–PS15 | Sigma, 99.8% | 15 | Nano-fibers with beads | 922 ± 274 | 15.92 ± 4.36/9.85 ± 1.28 | 1.62 ± 0.39 | 62.5 ± 0.5 | 0.8 |
| DMF-S998–PS20 | Sigma, 99.8% | 20 | Micro-fibers with few beads | 2788 ± 374 | 26.01 ± 3.56/10.77 ± 0.30 | 2.46 ± 0.30 | 136.4 ± 0.5 | 0.8 |
| DMF-S998–PS25 | Sigma, 99.8% | 25 | Micro-fibers only | 1872 ± 223 | – | – | 338.9 ± 1.1 | 0.8 |
| *DMF-Fluka98* | Fluka, 98% | 0 | – | – | – | – | – | 0.5 |
| DMF-F98–PS10 | Fluka, 98% | 10 | Nano-fibers with many beads | 351 ± 97 | 7.87 ± 1.86/3.38 ± 1.22 | 2.50 ± 0.72 | 21.2 ± 0.1 | 0.5 |
| DMF-F98–PS15 | Fluka, 98% | 15 | Nano-fibers with beads | 942 ± 171 | 21.66 ± 3.91/10.47 ± 2.52 | 2.12 ± 0.38 | 55.3 ± 0.2 | 0.4 |
| DMF-F98–PS20 | Fluka, 98% | 20 | Micro-fibers with beads | 1376 ± 272 | 21.69 ± 5.74/11.88 ± 2.72 | 1.87 ± 0.52 | 122.8 ± 0.6 | 0.4 |
| DMF-F98–PS25 | Fluka, 98% | 25 | Micro-fibers with few beads | 2661 ± 529 | 32.57 ± 6.05/14.74 ± 3.10 | 2.28 ± 0.53 | 336.3 ± 3.5 | 0.4 |
| DMF-F98–PS30 | Fluka, 98% | 30 | Micro-fibers only | 4284 ± 413 | – | – | 604 | 0.4 |
| *DMF-Fluka998* | Fluka, 99.8% | 0 | – | – | – | – | – | 1.0 |
| DMF-F998–PS10 | Fluka, 99.8% | 10 | Nano-fibers with many beads | 292 ± 48 | 12.85 ± 2.56/6.60 ± 1.20 | 2.01 ± 0.51 | 22.2 ± 0.1 | 0.7 |
| DMF-F998–PS15 | Fluka, 99.8% | 15 | Nano-fibers with beads | 942 ± 248 | 16.97 ± 3.27/8.48 ± 1.72 | 2.01 ± 0.58 | 62.5 ± 0.7 | 0.7 |
| DMF-F998–PS20 | Fluka, 99.8% | 20 | Micro-fibers with beads | 1534 ± 366 | 27.34 ± 5.21/13.49 ± 2.09 | 2.04 ± 0.37 | 129.6 ± 0.7 | 0.7 |
| DMF-F998–PS25 | Fluka, 99.8% | 25 | Micro-fibers with few beads | 1656 ± 218 | 14.93 ± 1.51/5.42 ± 0.64 | 2.78 ± 0.37 | 354.8 ± 2.8 | 0.7 |
| DMF-F998–PS30 | Fluka, 99.8% | 30 | Micro-fibers only | 3803 ± 596 | – | – | 666 | 0.7 |

*Table 3 Table of Different DMF solvents*

**Fabrication of Two- and Three- Dimensional Fibrous Mats by Electrospinning Method:**

He mentions that nanofibers produced with the electrospinning technique have a much better surface area/volume ratio than other methods. Another good feature of the electrospinning method is that it has an easily controllable pore structure and fiber diameter.

Production of two-dimensional fiber braids:

In a simple electrospinning method, the fibers cannot go beyond 2 dimensions. The fibers are collected in a fixed or mobile collector.

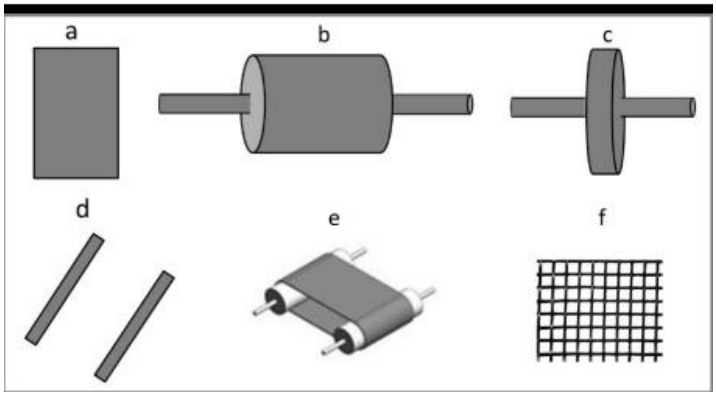



*Figure 21 Drum Types*

Formation of jets from a single end, Formation of jets from multiple ends, Formation of multiple jets with independent systems from the ends. In the 2D electrospinning method, these three different processes are mentioned.

Production of 3D fiber braids:

He talks about the importance of 3-D fiber production in many fields, especially tissue engineering. Post-electrospinning processing, Mold-assisted electrospinning, Self-assembly, Liquid-assisted electrospinning, Porogen addition are mainly examined under these headings in 3-D fiber mesh production.

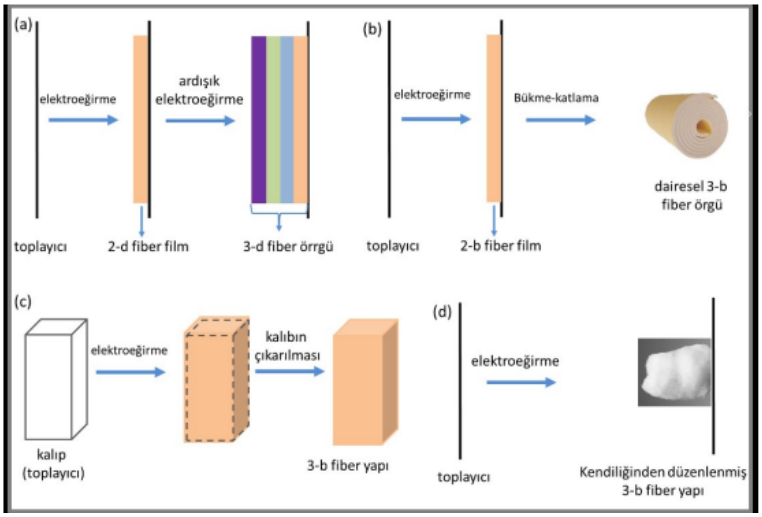



*Figure 22 Different fiber formed*

**Effect of Processing Conditions on the Electrospinning Behavior of Polyvinylpyrrolidone with Lower Toxicity Solvents:**

The aim of this study was to dissolve PVP using low-toxicity solvents and perform the electrospinning process. In the experiment, ethyl alcohol, dimethylsulfoxide (DMSO) were used as single solvents, and DMSO/ethyl alcohol and DMSO/acetone binary solvents were also used. In the electrospinning process, 17.5kV voltage is applied, the needle The distance between the tip and the collector is kept constant as 15 cm, and the flow rate is kept constant as 1.25 ml/s.

| Distance(cm) | Flow Rate(mL/h) | Voltage(kV) | Observation |
|---|---|---|---|
| 15 | 1.00 | 17,5 | Electrospraying / droplets/beads |
| 15 | 1.25 | 17,5 | Homogeneous fibers |
| 15 | 1.50 | 17,5 | Electrospraying / droplets/beads |

After keeping these values constant, other features affecting the morphology of the fiber braids are examined. As the PVP concentration in the PVP/ethanol solution increased, the homogeneity deteriorated. While it was not homogeneous at 1.0 and 1.70 flow rates, Homogeneous fibers are formed at a flow rate of 1.25. We want the solutions to evaporate a little while reaching the collector. If the wetness is too much, it cannot evaporate sufficiently and wetness occurs in the collector. An aluminum collector is used in the experiment. When dissolving with DMSO, wetness occurs and to reduce this wetness, DMSO is mixed with ethanol or acetone, but neither of them changes the volatility, so the wetness continues.

**Synthesis of High-Impact Polystyrene Fibers Using Electrospinning:**

Fiber synthesis from waste high impact polystyrene (HIPS) was successfully carried out using the electrospinning method. The main solvents are purchased dimethylformamide (DMF) and d-limonene, and additionally non-solvent acetone. First, DMF and d-limonene are applied one by one (15, 20, 25, 30, and 35 wt.%). Then DMF and The experiment is continued by mixing d-limonene 75:25, 50:50 and 25:75. Finally, to observe the effect of acetone, a HIPS/d-limonene solution is created and acetone is added into it. Only DMF is only d-limonene, the mixture of this binary and acetone added states, HIPS electrospinning process was carried out successfully. As the polymer density increased, the diameter of the resulting fibers also increased. When the concentration was 20%, beaded fibers were formed, although the average diameter was low. When we increased the concentration to 25%, the diameter of the fibers increased, but fibers without beads were formed.

| Solution | Concentration (wt.%) | Viscosity (centi Poise) | Surface Tension (dyne/cm) |
|---|---|---|---|
| HIPS/d-limonene/DMF(75:25) | 20 | 309 | 34.2 |
| HIPS/d-limonene/DMF(50:50) | 20 | 312 | 33.5 |
| HIPS/d-limonene/DMF(25:75) | 20 | 325 | 32.8 |

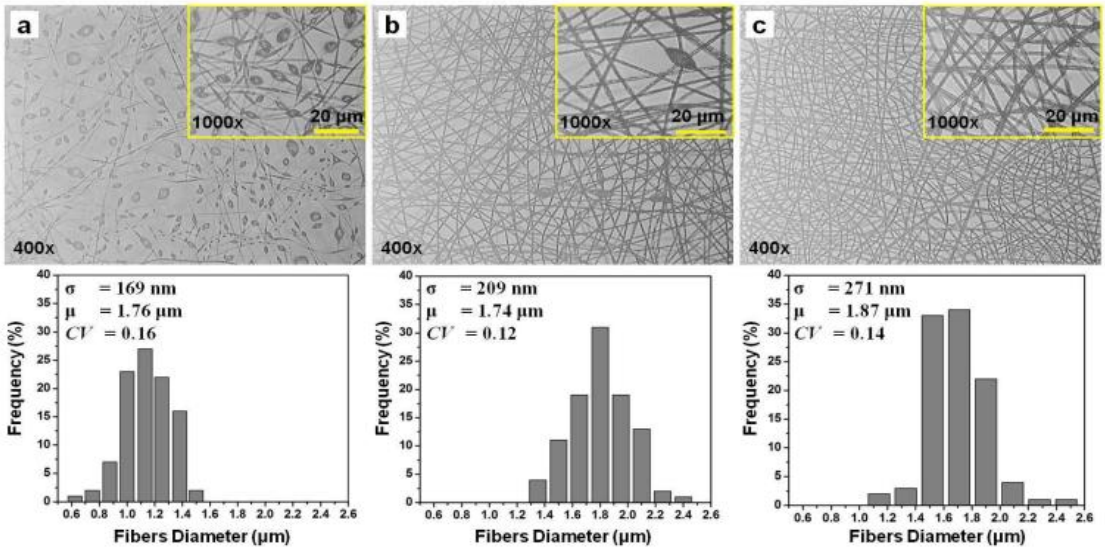



*Figure 23 a) 75:25% b) of 50:50% c) of 25:75%.*

**Review Article: Recycling of Polystyrene:**

He mentions that polystyrene is a very important polymer that can be used in packaging and many things needed by the consumer. It is underlined that polystyrene, which has an indestructible structure, causes significant damage to the environment when released into the environment. He says that there are many different methods of recycling, these are the main ones.

Mechanical Recycling, Chemical Recycling, Thermal Recycling, mechanical recycling can yield both solid and liquid PS without losing the properties of PS, and this PS can be used over and over again. If we want to use the chemical recycling method, we need to use an extra catalyst and this must be chosen carefully, not randomly. He says that, in general, catalysts with a solid base structure are a more effective choice than catalysts with a solid acid structure. In thermal decomposition, we first need to determine the decomposition temperature of plastics. Because the weight of liquid products decreases or increases depending on this, this is an important feature for us. Catalyst If we have to make a choice, we should choose FCC because FCC gives the most efficiency. PS can be separated into styrenes by mixing with other aromatics. With this method, it is possible to obtain PHA, a biodegradable substance that has little harm to the nature. If we design a fermentor and add bacteria, we can increase the PHA yield. Finally, we can add an enzymatic catalyst to this fermentor. If you add it, we will significantly positively affect the polymerization of PHA.

**Studies on the controlled morphology and wettability of polystyrene surfaces by electrospinning or electrospraying:**

He says that when we obtain nanofibers from PS polymer by electrospinning or electrospraying method, the morphology of these fibers may differ depending on both the solvent and the electrospinning test values. The number of beads, the size of these beads, the size and smallness of the diameters of the fibers are some of these features. The water contact angle was measured and as a result of these measurements, the wettability of the CA value in the surface morphology. We realized that it plays an important role in the experiment. Two different solvents, DMF and THF, are used in the experiment. First, to see the effect of the PS concentration, different data are obtained by increasing it from 5% to 30%. As the PS concentration increases, the viscosity of the solutions increases when both DMF and THF solvents are used. It is determined that the solution using THF has a higher viscosity than DMF. During the same process, surface tensions are measured and it is observed that the surface tension of the solution with DMF increases, but the solution with THF does not draw a smooth graph. When we look at their conductivity, since the PS polymer is not conductive, the conductivity of the solution increases as the PS concentration increases. While decreasing, the THF solution gives us the value 0. These nanofibers are shown to us in pictures. Then, by mixing DMF and THF solvents in certain proportions, new solvent properties are obtained. As the THF concentration in this solvent increases, it is seen that the bead size, fiber diameter and aspect ratio increase. CA value It changes irregularly.

| DMF/THF | Fiber diameter (nm) | Bead size (μm) | Aspect ratio | CA (°) |
|---|---|---|---|---|
| 100/0 | 50–200 | 5/3 | 1.7 | 151.2 ± 1.9° |
| 75/25 | 50–200 | 5/3 | 1.7 | 151.3 ± 1.7° |
| 50/50 | 200–500 | 10/3 | 3.3 | 151.2 ± 1.6° |
| 25/75 | 300–600 | 15/3 | 5.0 | 146.3 ± 1.9° |
| 0/100 | – | 20 | – | 153.3 ± 0.9° |

In addition, it has been observed that the size of the beads formed decrease as the ambient temperature increases. The reason for this is that as the temperature increases, thf evaporates very quickly, which causes the fiber surface to cool rapidly. This causes condensation and then we carry out the drying process. Meanwhile, marks form on the fibers. When the ambient temperature increases. Condensation will become difficult and the size of the pores will decrease.

# 4. SYSTEM DESIGN

## 4.1 Realistic Constraints and Conditions

In this study, various realistic environmental constraints and conditions were taken into consideration in the design and application parts of the nanofiber synthesis process.

• *Environmental Concerns*: Polystyrene is a harmful material that can remain in nature for hundreds of years. Recycling this material by electrospinning method provides waste reduction and positive contribution to the environment.

• *Sustainability:* This project provides sustainable material production by converting waste polystyrene into high-value nanofibers. The single-nozzle electrospinning system used consumes less energy compared to high-capacity industrial systems, which is very important in terms of continuity.

• *Manufacturability:* The proposed system has a structure that can be easily reproduced in university or industrial laboratories. Thanks to the use of standard injector pumps, collectors and voltage sources, production conditions can be changed according to the person and the need, and it is flexible and repeatable.

• *Health and Safety:* Since the hazards of organic solvents such as DMF are known, all experiments were carried out in accordance with laboratory safety procedures. Protective gloves, glasses and laboratory coats were used. In addition, high voltage devices were operated in accordance with electrical safety rules.

## 4.2 Engineering Standards

The design and implementation processes of this project were carried out in accordance with relevant engineering and laboratory standards:

• *ASTM D5439* – Standard guide for recycling of plastics.

• *ISO 10993-5* – Biological evaluation of materials (guidance for future biomedical applications).

• *IEEE High Voltage Laboratories Electrical Safety Standard* – Applied during use of 25 kV systems.

• *TS EN 60529* – IP protection standards were taken as reference for equipment safety and insulation.

In addition, university laboratory rules regarding working with chemicals, flammable solvents and electrical systems were read and observed.

## 4.3 System Design Details

The system was designed for the purpose of synthesizing polystyrene nanofibers by electrospinning. The system components and process are as follows:

• *Polymer Solution Preparation*: Recycled polystyrene was dissolved in DMF at 10-15-20-25-30% by weight. A homogeneous solution is needed for the smooth shooting process. The solutions were stirred in a magnetic stirrer for the required time (1-2 hours) to obtain the desired homogeneous mixture.

*Figure 26 PS plate*

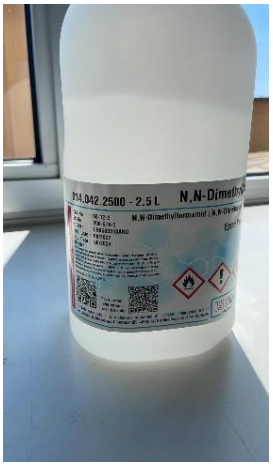



*Figure 27 DMF*

*Figure 24 Precision Scale*

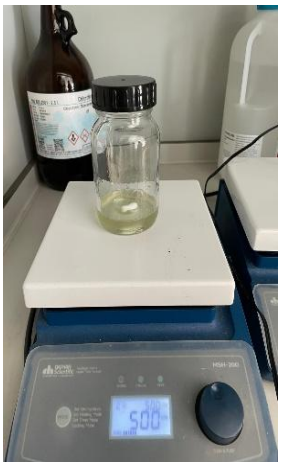


*Figure 25 Magnetic Stirrer*

• Electrospinning Unit Setup:

o The injector pump in the laboratory was used to keep the solution constant and controllable (2 mL/hour).

o The steel needle (0.41 mm) was connected to a 25 kV high voltage source.

o A cylindrical aluminum collector was placed 15 cm away from the needle tip.

o The ambient temperature was kept constant at room temperature of 22–25 °C.

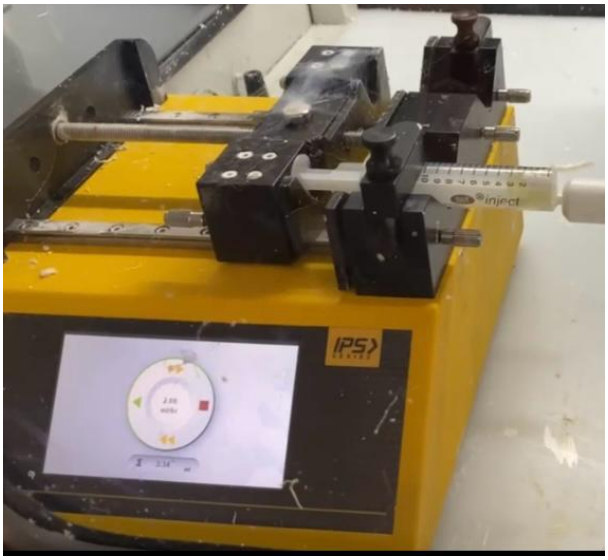


*Figure 28 Pump Device*

**Spacers :**

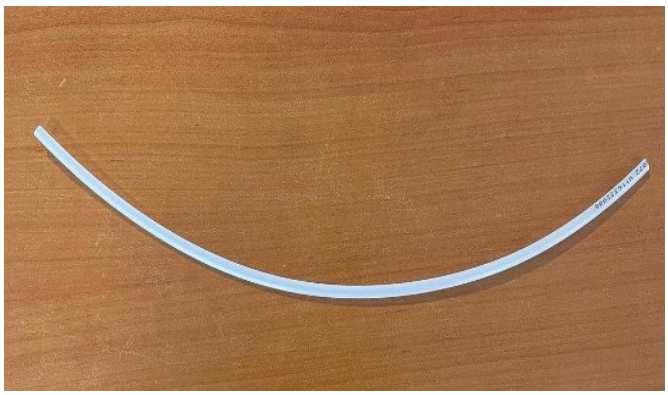


*Figure 30 32 cm pipe*

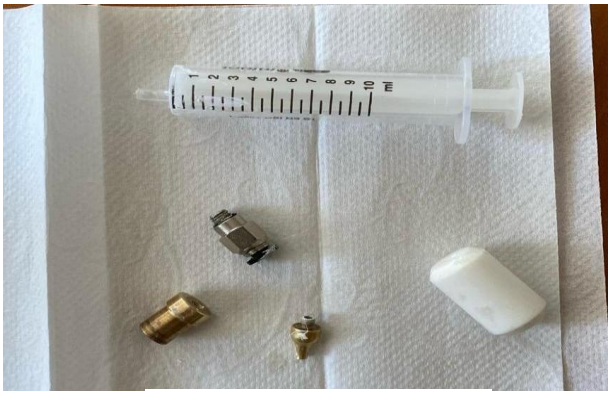


*Figure 29 Spacers*

• **Thread Formation Process:** The voltage was gradually increased from 0 to 25 kV to initiate jet formation. The nanofibers formed in the air were collected as a uniform layer on an aluminum plate rotating at 500 RPM as follows.

*Figure 31 Drum*

• **Parameter Optimization:** In order to reduce bead formation as much as possible and to obtain uniform fiber morphology, variables were considered and the Ps concentration was changed while keeping some of the following parameters constant.

o Flow rate: 2 mL/hour

o Voltage: 25 kV

o Needle-collector distance: 15 cm

o Polymer concentration: 10-15-20-25-30% (by weight) in DMF

*Figure 32 Setup*


*Figure 33 Electrospining Settings*

• **Characterization:** The nanofiber sheets collected at different densities were subjected to the following tests.

o Burning test according to UL94 flame retardant classes.

# 5. METHODS

In this section, the system setup and experimental steps required for the experiment we will conduct are explained in detail. The procedures, materials needed and test conditions are explained in detail. The reasons and results of each step are explained and imposed on a scientific reality.

## 5.1 Experimental Setup

The electrospinning system we used in this study is a vertical electrospinning device with a single needle and a cylindrical aluminum collector, NE 200 Nano spinner. The main components of the system and what they provide are as follows.

• **High voltage power supply (0–30 kV):** It creates an electrostatic field within the device and ensures that the liquid solution coming out of the needle tip reaches the collector.

• **Syringe pump:** It ensures the flow of the polymer solution at a constant and desired speed.

• **Needle (metal type):** A metal needle with an inner diameter of 0.41 mm made of stainless steel was used. Its effect on the diameters of the formed nanofibers is known.

• **Cylindrical aluminum collector surface**: It is a grounded metal surface connected to the collector electrode. Oil paper is placed on it and the nanofibers are collected on the oil paper. In this way, the nanofibers can be separated from the device more smoothly and easily. The RPM level can be adjusted to the desired level.

**Intermediate parts:** They are used to ensure the smooth flow of the liquid solution from the tip of the syringe to the needle. For a smooth flow, attention should be paid to their cleanliness and it should be ensured that they do not leak.

## 5.2 Preparation of the Polymer Solution

Polystyrene (PS), used as raw material, was obtained from waste tablecloths made of waste PS. It was broken down and reduced to small sizes for easier dissolution before use.

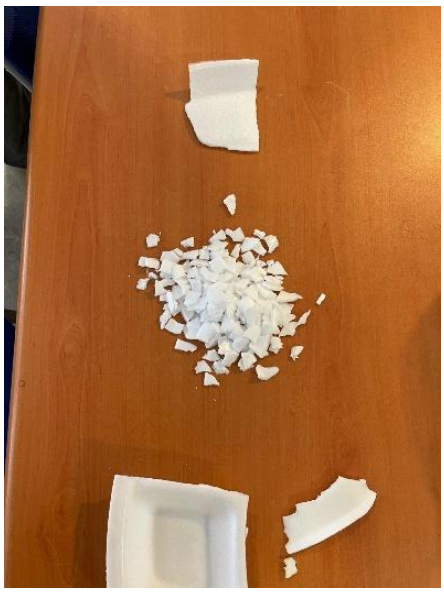


*Figure 34 Crumbled PS*

• **Solvent used:** N,N-Dimethylformamide (DMF). It provides the desired fiber formation thanks to its high boiling point and low evaporation rate compared to other solvents.

• **Polymer concentration:** PS solution was prepared in DMF at 10%, 15%, 20%, 25% and 30% by weight ratios.

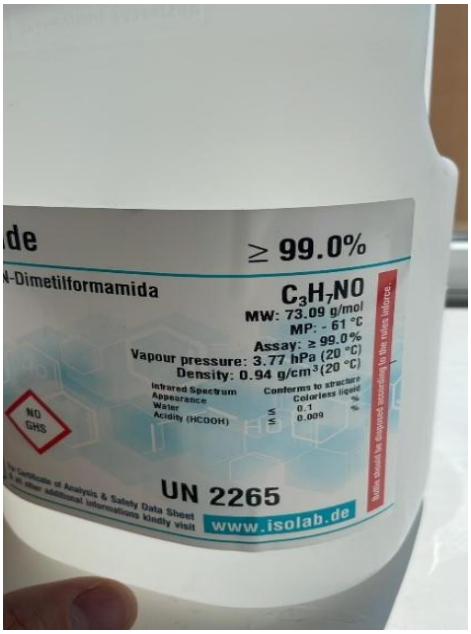



*Figure 35 %99 DMF*

*Figure 36 Weight Measurement*

• **Mixing process:** The solution was mixed with a magnetic stirrer at 300-500 RPM for 2 hours at room temperature, trying to obtain a solution as homogeneous as possible.

## 5.3 Electrospinning Procedure

The optimum parameters of the electrospinning device were determined as follows, thanks to the other articles read, considering the smoothness of the surface of the nanofibers and both the bead formation and the size of the formed beads.

• **Applied voltage:** 25 kV (15 kV and 20 kV values were tried in the first trial, but due to the continuous liquid accumulation at the needle tip, it caused the needle tip to block. This caused the liquid not to reach the collector and prevented the formation of nanofibers.)

• **Flow rate:** 2 mL/hour

• **Needle-collector distance:** 25 cm (this parameter is fixed for the NE200 electrospinning device we used.)

• **Ambient temperature:** 22–25 °C

The polymer solution obtained was placed in a 10 mL capacity syringe. The syringe was placed in a pump device with a flow rate of 2 ml/hour. The solution reaching the needle tip thanks to the spacers reached the collector metal thanks to the electric field in the device and nanofiber formation was observed. No matter how much we tried to keep the spacers and the system clean, the needle tip can occasionally get blocked and need to be cleaned, as in the picture below, due to both the long hours of the process and the fact that it has too many variable parameters. While the shooting process alone takes about 5 hours, if we take into account the solution preparation and homogenization, it takes about 7-8 hours. At the end of this period, the 25cm x35cm nanofibers we removed from the aluminum collector and produced are as follows. All of these processes were done in the mechatronics laboratory provided to us by the İstanbul Ticaret University.

*Figure 37 Solidified solution at the nozzle tip*

*Figure 38 Nanofiber*

## 5.4 Flame Retardancy Test

A flame retardancy test similar to the UL94 standard was applied. 5 different nanofibers with different densities were subjected to a total of 15 burning tests, each 3 times. When we did this process, M5-B01 Advanced Manufacturing Processes Laboratory, which is a windless and safe environment since it is a burning process, was used to prevent the nanofibers, which are quite light, from moving and to ensure a successful experiment.

**Installation of the plane and process:**

We cut 5 x 12.5 cm pieces from the 25 cm x 35 cm nanofibers we had. We hung the cut nanofiber pieces on the wire we stretched with the help of a paper clip. We placed cotton pieces at the bottom of the nanofibers we hung to observe whether there was any dripping during the burning process and whether the dripping part continued to burn and burn. When this preparation process was completed, heat was applied to the nanofiber with the help of a blowtorch at a 45-degree angle in the first step so that the flame would not touch the nanofiber, and in the 2nd and 3rd steps so that the flame would touch the nanofiber. We applied the heat for 10 seconds, then waited for 10 seconds, if it did not catch fire, we applied heat again for 10 seconds. When these processes were completed, if the nanofiber did not catch fire, we examined the size of the remaining piece, if it did, we examined the dripping piece and whether it burned or not.

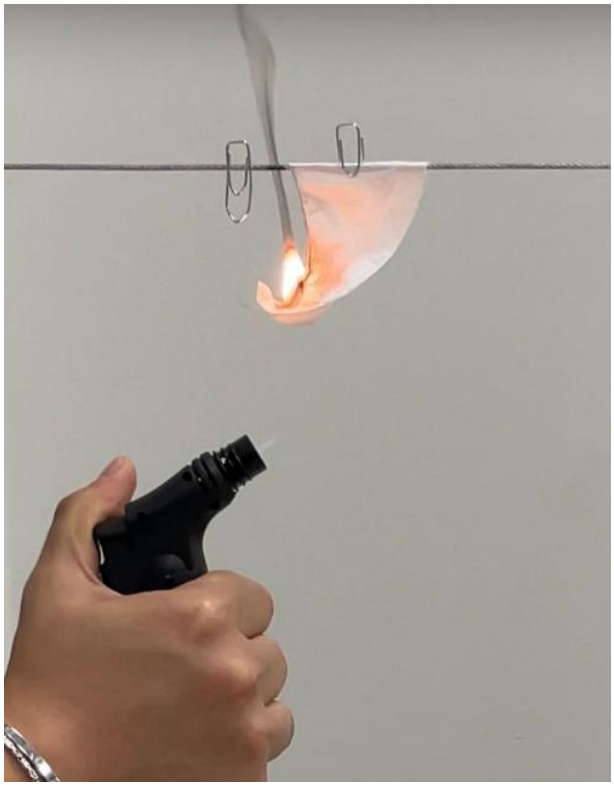


*Figure 39 Ignited Nanofiber*

*Figure 40 Flame retardancy setup*

# 6. RESULT AND DISCUSSION

In the previous steps, we talked about the installation and process steps of the electrospinning system where we converted our PS-DMF solution into nanofibers. Then, we explained the installation and application of the burning test that we applied to these fibers in Ul94 standards. In this section, we observed and detailed that different fibers have different heat resistance as a result of these two processes.

**Test 1**

In this step, we heated the nanofibers with a blowtorch at a 45-degree angle, then waited for 10 seconds and heated again for 10 seconds, but we did not touch the nanofibers with the flame during these processes and examined the results. The results we encountered according to different densities are as follows.

*Table 4 Table of Test 1*

| %PS concentration with DMF | First 10 second | | | Second 10 second | | | Remaining Part Size(cm) |
|---|---|---|---|---|---|---|---|
| | Ignition(s) | Falling Pieces | The Falling Pieces Continues to Burn | Ignition(s) | Falling Pieces | The Falling Pieces Continues to Burn | |
| 10% | x | x | x | x | x | x | 8 |
| 15% | x | x | x | x | x | x | 3,80 |
| 20% | x | x | x | x | x | x | 4,1 |
| 25% | x | x | x | x | x | x | 7,1 |
| 30% | x | x | x | x | x | x | 6 |

Nanofibers of any density did not ignite in the first burning or the second burning and naturally did not drip, so we cannot make any inferences from these properties. The physical properties of the nanofibers we compared with heat changed and became smaller. The only property we can infer is the final dimensions of the nanofibers. When we compared their dimensions, we could not find a smooth curve. While the least loss in size was at 10% PS, the most loss occurred at 20% PS.

**Test 2**

In this step, we heated the nanofibers with a blowtorch at a 45-degree angle, then waited 10 seconds and heated them again for 10 seconds, but unlike test 1, we touched the nanofibers with the flame and examined the results. The results we encountered according to different densities are as follows.

*Table 5 Table of Test 2*

| %PS concentration with DMF | First 10 second | | | Second 10 second | | | Remaining Part Size(cm) |
|---|---|---|---|---|---|---|---|
| | Ignition(s) | Falling Pieces | The Falling Pieces Continues to Burn | Ignition(s) | Falling Pieces | The Falling Pieces Continues to Burn | |
| 10% | x | x | x | 0,11 | yes | yes | x |
| 15% | x | x | x | 0,13 | x | x | x |
| 20% | x | x | x | 0,36 | yes | yes | x |
| 25% | x | x | x | 0,63 | yes | yes | x |
| 30% | x | x | x | 1,2 | yes | yes | x |

At this stage, unlike the first test, we kept the flame touching the nanofiber. Although the structures of all nanofibers changed in the first 10 seconds, none of them ignited. However, immediately after the second flame, the nanofibers started to ignite and pieces were observed falling from the ignited nanofibers (except 10%). The falling pieces continued to burn and burned the cotton we placed under the apparatus. All nanofibers burned completely and no hanging pieces remained. As a result of the test, we observed that as the PS density increased, the ignition time increased and their flame resistance increased.

**Test 3**

Test 2 was repeated in this step.

*Table 6 Table of Test 3*

| %PS concentration with DMF | First 10 second | | | Second 10 second | | | Remaining Part Size(cm) |
|---|---|---|---|---|---|---|---|
| | Ignition(s) | Falling Pieces | The Falling Pieces Continues to Burn | Ignition(s) | Falling Pieces | The Falling Pieces Continues to Burn | |
| 10% | x | x | x | 0,16 | yes | x | x |
| 15% | x | x | x | 0,2 | yes | yes | x |
| 20% | x | x | x | 0,43 | yes | yes | x |
| 25% | x | x | x | 0,46 | yes | yes | x |
| 30% | 0,36 | yes | yes | - | - | - | x |

At this stage, we applied a similar test to test 2 and examined the results. Again, while we thought that no nanofiber would ignite in the first flame process, the nanofiber with 30% PS density ignited quickly, giving an irregular result. The other nanofibers started to ignite in the second flame process, and again the ignition time increased in direct proportion to the PS density.

## 6.1 General Evaluation

It was a successful nanofiber production process like the articles we took as an example. Although we did not have the opportunity to examine the nanofibers we produced with SEM devices, we can say that the nanofiber with 30% PS density was more beaded and its surface was more irregular than the others. In the burning test, our expectations were partially met and as the %PS density increased, its heat resistance increased and it was determined as a suitable nanofiber. However, the nanofiber with 30% Ps density revealed irregular results as a result of our tests. Therefore, considering both surface smoothness and flame resistance, the most suitable fiber was the nanofiber with 25% PS density.

# 7. CONCLUSION

As a result, in order to prevent PS materials that have reached the end of their life from becoming waste and to be used in many areas in the industry (for us, being resistant to burning is essential), we produced nanofibers from recycled polystyrenes in this project, and we learned how the electrospinning device works. Depending on the parameters, we had the opportunity to see the changes in the structure of the fibers with the naked eye at some points. For example, when we examined the nanofibers, we produced a solution with a density of 30%, we observed that the fibers were produced in more beaded structures and had a more unbalanced distribution on the oil paper. In addition, with the burning experiments we conducted at the Marmara University Mechanical Engineering M5-B01 laboratory, we observed how much of the fibers burned, whether there was dripping on the cotton or how much the fibers' structures deteriorated depending on the distance we performed the burning.

# 8. APPENDIX

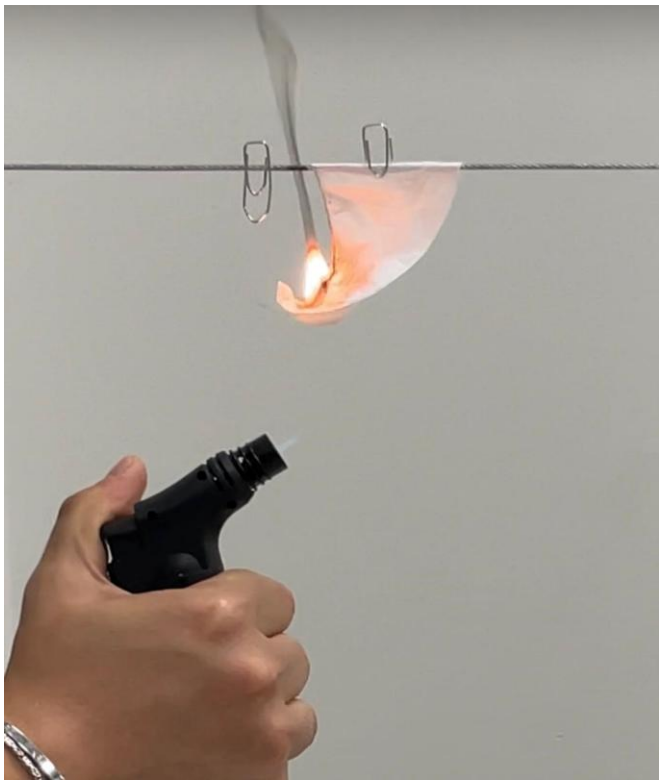


*Figure 42 Ignition Nanofiber*

*Figure 41 The Remaining Parts After Burning*

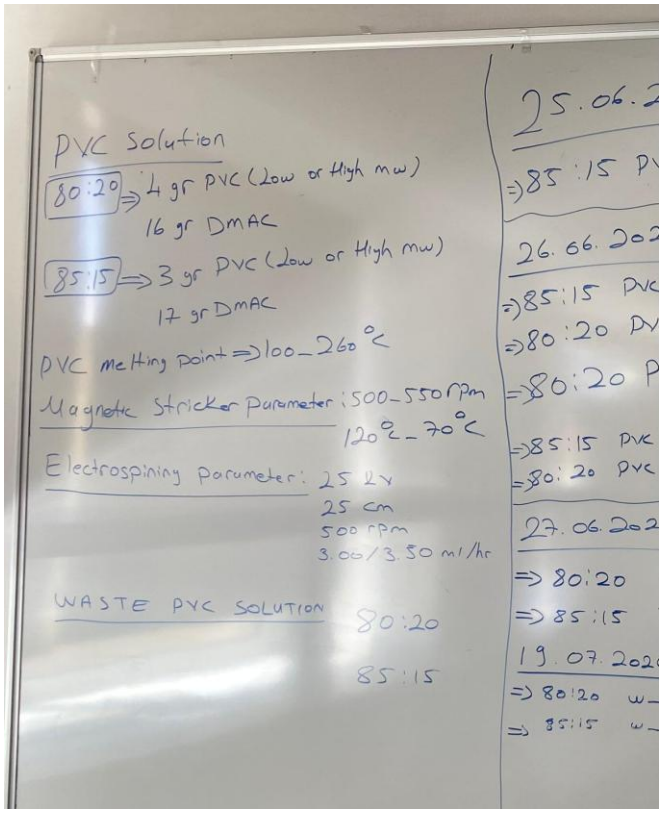



*Figure 44 Electrospining Datas*


*Figure 43 M5-B01 Laboratory*


*Figure 45 A) %25 Weight PS B) %10 Weight PS C) %15 Weight PS D) %20 Weight PS*

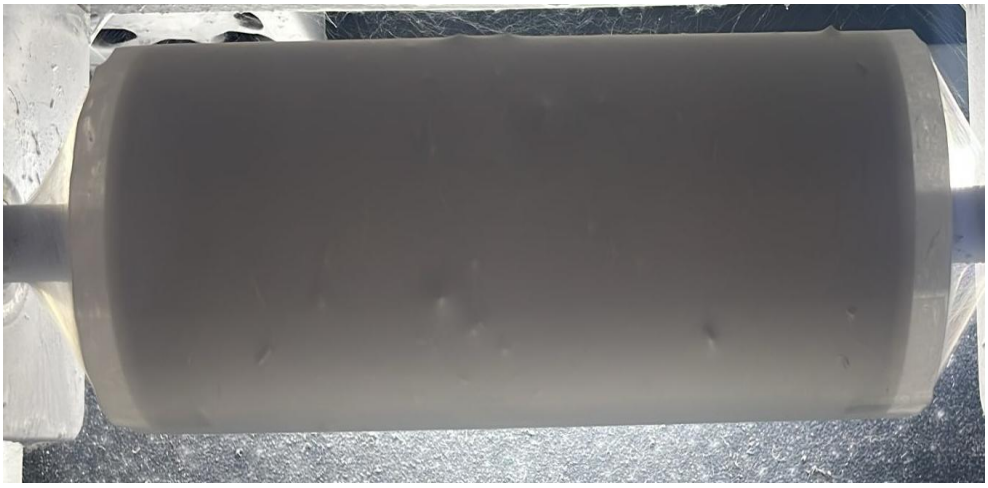


*Figure 46 %30 PS accumulated on the drum (Beaded is seen)*

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