Journal of Materials and Electronic Devices 1 (2021) 16-27


# Differences and Parametric Evaluation of Centrifugal Force Spinning from Electrospinning Method

Ozge Kamaci[1*], Necla Yucel[1,2], Erdi Bulus[3,4]

[1]Nanoscience and Nanoengineering Master's Program, Graduate Education Institute, Istanbul Medeniyet University, Istanbul 34720, Turkey
[2]Istanbul Arel University, Faculty of Engineering and Architecture, Biomedical Engineering Department, Bioinspired Functional Polymers and Nanomaterials Laboratory, Istanbul 34500, Turkey
[3]Polymer Science and Technology Program, Institute of Science and Technology, Kocaeli University, Kocaeli 41000, Turkey
[4]ArelPOTKAM (Polymer Technologies and Composite Applications and Research Center), Istanbul Arel University, Istanbul 34500, Turkey

Nanotechnological products are used in many different sectors such as medical, textile, defense and electronics. Nanofibers are a different production method of nanomaterials and different techniques are used in their production. These; electrospinning, spinning with the effect of centrifugal force, self-assembly and fiber drawing from the melt are the main production techniques [1]. In this review, electrospinning and spinning with the effect of centrifugal force will be focused on and the structures of nanofibers formed as a result of these methods will be evaluated. Electrospinning method is based on nanotechnological products; It is used in academic studies and small-scale products. However, spinning with centrifugal force is a method of nanofiber production that does not take place much in academic studies, and it is mostly used in industry and large diameter nanofiber production. Since the spinning method with centrifugal force is not encountered much in academic studies, it will be explained in general terms in this review and its differences will be evaluated with electrospinning method. In addition, the paramteric properties of the spinning method with centrifugal force will be explained and its effects on nanofiber production will be discussed. Thus, it is expected that the examples in this review will guide scientists who aim to produce large-scale industrial nanofibers with industry academic cooperation, and it is aimed to introduce the centrifugal force spinning in general terms.

***Keywords:*** *Centrifugal force spinning, industry, electrospinning, nanofiber*

*Submission Date: 22 December 2020*
*Acceptance Date: 27 February 2021*

**Corresponding author: ozge.kamaci@gmail.com (Ozge Kamaci) Tel: +905372061436*

## Introduction

In this review, electrospinning and centrifugal force spinning methods will be evaluated separately. But first of all, the production methods of nanotechnological products in academia and industry,

as mentioned in the summary, are self assembly, fiber drawing from the melt and spinning with centrifugal force, which will be frequently discussed.

The dimensions of the outputs obtained using the aforementioned methods are at the nanometric level. To define the nano meter; It is used to describe structures with a scale of one billionth of a meter. The systems that enable the definition, characterization, redesign and creation of nano-sized materials are called nanotechnological applications [2].

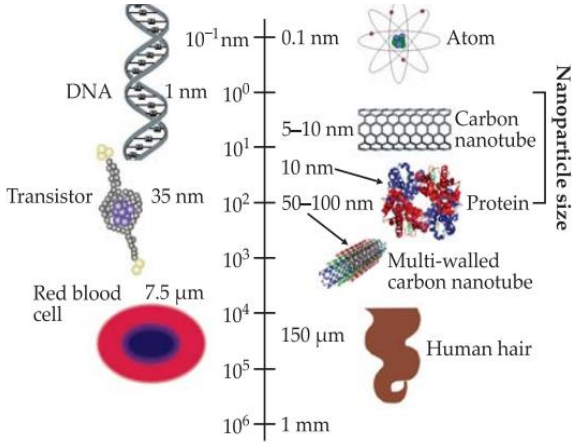


***Figure 1.*** *Comparison scale from atomic scale to millimeter scale [3]*

The nanofiber structures obtained using these methods; To define briefly, according to the definition made by the National Science Foundation (National Science Foundation), mesh-shaped structures that are at least one-dimensional and have dimensions of 100 nm and below are called nanofiber structures. Looking at the usage areas of nanofibers; medical textile products, filtration material, dental products, insulation material, energy storage units. In addition, nanofiber technologies are used in areas such as fuel cells, telecommunications, and drug release systems in the aviation sector that requires high technology [4].

## Electrospinning technology from nanofiber production methods:

It is briefly defined as the method of converting the melt polymer solutions leaving the syringe to nanofibers (fibers) by using electrostatic forces between the syringe and the collector in the electrospinning device [5].

It is a method that Willian Gilbert first introduced in the early 1600's by observing that the water drop on the dry surface was retracted under the effect of electrostatic forces and deformed into a cone. Lord Rayleigh improved the electrospinning mechanism further and made the electrospinning mechanism more understandable based on the measurements of the surface tension of liquids in polymer or liquid ejection at jet velocity when they exceed the critical level. With the solution of the mechanism of the electrospinning method, John Francis Cooley was the first to patent the device in the 1900s. In 1960, Geoffrey Taylor developed this technology and found the cone angle in electrospinning method by forming the cone shape of the solution or liquid droplet at a certain angle in the electric field. This cone angle was called the Taylor angle and recorded as 49.3 ° [6,7].

Basic working principle of electrospinning device; It consists of a syringe system with a polymer solution and a collector shaft. The polymer solution in the syringe system is charged with high voltage; It works on the principle that when the surface tension of the polymer solution exceeds the driving force of the electric field, it pulses from the tip of the syringe to the collector shaft as nanofiber [8].

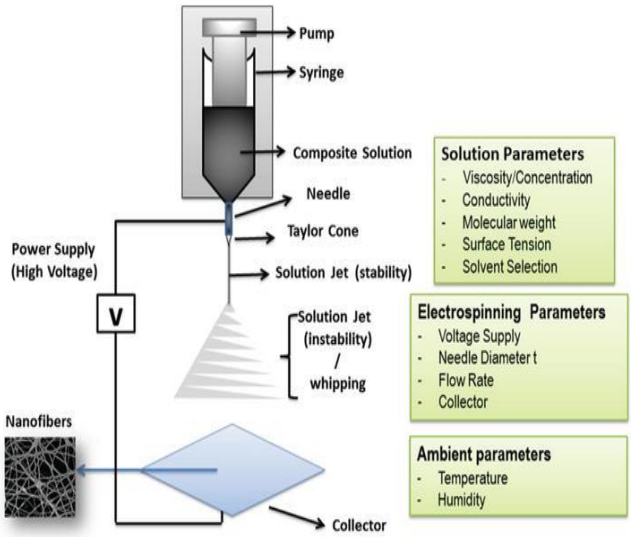


***Figure 2.*** *Electrospinning working setup [9]*

The most used method in nanofiber production has been electrospinning. Data on this; Until 2013, the term electrospinning was used in 1,891 products in the European Patent Office, and it was observed that 2,960 nanofiber terms were used. When looking at the publications, 11,973 publications around the world are related to nanofibers, and 18,679 related publications have been seen [10]. As can be understood from the data, electrospinning is a reliable and effective method of nanofiber production.

**Electrospinning parameters;** The characteristics of the nanofibers taken as output are divided into two in terms of morphology and size control.

• **System parameters;** The type of polymer used, the molecular weight of the polymer used, the polarity and properties of the solvents that dissolve the polymers are important. In addition, the viscosity of the polymer solution, the conductivity of the polymer solution as it will be operated in an electrical environment, the surface tension value of the polymer when shooting from the syringe and the crosslinking functions of the polymer solution.

• **Process parameters;** The final concentration of the polymer solution, the fluidity of the polymer, the electrical potential of the device, the distance between the collector and the syringe tip, the temperature of the environment, the humidity value, the pulse rate in the device [11].

### Centrifugal force spinning, one of nanofiber production methods:

Centrifugal spinning is a technology for producing nanofibers from a wide variety of different materials. The basic technique here is based on the production of nanofibres using centrifugal force rather than electric field forces in electrospinning. Electrospinning is not suitable for large mass production due to limited material and device design restrictions. Therefore, centrifugal force technology is a method developed to produce large volumes of nanofibers [12]. In this respect, the use of the centrifugal force production method has been found to be more suitable for industrial-sized nanofiber fabrics.

The reasons why spinning is preferred in industrial type nanofiber production with centrifugal force; It is affordable in terms of price, using less solvent and obtaining a large production efficiency. In addition, as electrospinning is operated under electric field and high voltage, it can create risk factors in occupational safety [13].

In addition, the clogging factor created by the electrospinning method in the device, the sensitivity to the electric field, the limited limits to obtain effective output, the use of only conductive polymers have pushed the industries working in industrial production to use the centrifugal force method [14].

Before nanofiber production is made in the spinning device by centrifugal force to a large extent; Production steps such as the ratio of polymers and solvents, thickness of fibers, pore size of nanofibers, correct processing order of the use of selected polymers should be planned well.

### Comparison of electrospinning and centrifugal force and spinning methods:

Reasons for the production of developed nonwoven nanofibers by centrifugal force method; Risk of occupational safety due to working with high voltage (> 10 kV) source in the electrospinning device, the dielectric constant remaining in a limited range in various solvents, in other words, the sensitivity of some solvents to the electric field in the electrospinning device, most importantly, the high efficiency product is within limited ranges in the electrospinning method. .

Considering the advantages of the spinning method with centrifugal force; The centrifugal force effect can support the elongation or flexion of the fibers, and the operation of the system can continue by extending the polymers or polymer melts with and without electrical conductivity without the need for an electric field. From the beginning of the centrifugal force effect, while 1 gram of polymer solution is thrown per minute, 0.3 grams of polymer solution per minute is thrown into the collectors from the electrospinning syringe. This difference between the quantities reaches a significant number in the amount of nanofibers produced, especially in large-scale use [15].

When electrospinning and spinning systems with centrifugal force are examined, the differences in the design of the devices are striking. Spinning system with centrifugal force is based on ejecting the polymer solution based on the centrifugal force. Namely; It is a system consisting of a head called spinneret in which there is a molten or direct polymer solution, a motor connected to the spinneret, and a reservoir with collectors that collect nanofibers around it. The system is based on the logic that the angular velocity determined by the balance between the surface tension centrifugal force exceeds a certain velocity limit, and the polymer solution is thrown out of the orifice of the spinneret, which is the chamber where the polymer solution is placed, with jet velocity, that is, towards the collector [16]. The rotation speed here is provided by the motor that rotates the spinneret.

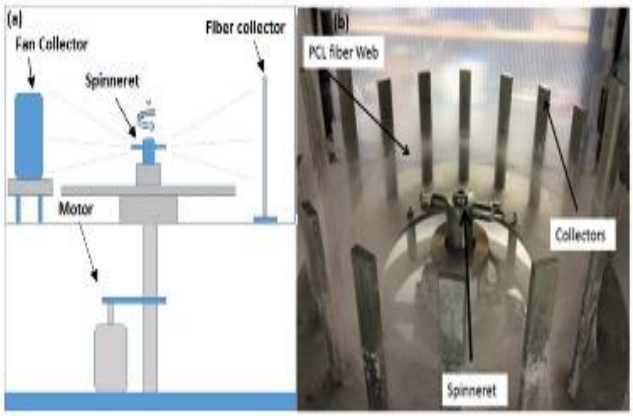


***Figure 3.*** *Centrifugal force spinning device [17]*

There are some parameters to be considered in centrifugal technology. These were determined as the angular rotation speed of the spinneret and the radii of the orifice in the spinneret, the polymer solution viscosity, the final

concentration of the polymer solution, the surface tension value, the evaporation rate of solvents, the temperature (in the molten state or solidification of the polymer), the distance between the orifice and the collector.

Namely; If the polymer concentration is below the critical value, droplets form on the fibers. In other words, the fibers from which the low concentration polymer solution is formed are thinner and have a delicate structure. When it comes to the critical value, it is the concentration value that will allow the polymer solution to exceed the surface tension and go to the collector [18].

When the surface tension of the polymer solution or polymer melt exceeds the rotor speed, the polymer solution begins to be thrown out of nanofiber. However, when the rotor rotation speed exceeds the equilibrium speed between the surface tension and the rotor too much, it creates rupture or droplets in the skipping nanofibers. In such cases, either the angular velocity is reduced, or the viscosity of the polymer solution is diluted in various arrangements [19]. It is tried to obtain the desired fine nanofibers by considering various parameters such as these.

## Comparison of two methods in terms of nanofiber structure:

Comparing the centrifugal spinning method and the electrospin method, it was seen that the centrifugal force polymer solutions were used more viscous, that is, higher concentrations, than the polymer solutions prepared in electrospinning. Also; In addition, it was observed that fiber mats formed by the centrifugal force method in laboratory scale use formed a loose (scattered winding) package. Fiber mats coming out of the electrospinning device are packed more tightly, no dispersion is observed. However, when appropriate parameters are used, it has been observed that the fiber mats formed as a result of spinning with centrifugal force are more robust and do not break [20].

## Studies using centrifugal force spinning

When the liretate studies where centrifugal spinning method is applied, it is seen that the most used polymer group is polycaprolactone (PCL). PCL is an aliphatic synthetic, biodegradable, biocompatible polymer. In the biomedical field, drug delivery systems and implants are used either alone or as a composite [21].

Kodali et al., In their study in 2020, evaluated the effects of the centrifugal force of the PCL polymer solution and the angular rotation speed of the fibers during spinning, and the effects of tension-tensile forces on the morphology of fibers [22]. Accordingly, 16% PCL polymer solution was placed in the spinnereta and pulsed at 5000 rpm, 7000 rpm and 9000 rpm. When it comes to the results, it has been observed that the homogeneity of the fibers has increased with the increase of the speed and they have become uniform. Fiber dimensions become thinner in direct proportion to the speed increase.

**Table 1:** Fiber dimensions based on rotational velocity

**Table 1.** Mean fiber diameter of the forcespun PCL fibers for various rotational speeds.

| Rotational speed (rpm) | Mean fiber diameter ($\mu$m) |
|---|---|
| 5000 | 1.98±0.709 |
| 7000 | 1.65±0.173 |
| 9000 | 1.4±1.393 |

As a result of the stretching tensile evaluation of PCL fiber mats produced at different speeds; As the speed increases (from 5000 rpm to 9000 rpm) the tensile pull modulus decreases. It was found to be 5.08 Mpa at 5000 rpm and 3.89 Mpa at 9000 rpm. Reason; It is the decrease of glass transition temperatures and crystallization degrees with the increase of the rotation speed of the fibers. As the size of the fibers gets thinner with the increase of speed, it has been observed that the porcelain structure properties of the membranes increase, and it has been concluded that the fibers have decreased the tensile tensile strength.

When looking at Zander's spinning study with the centrifugal force of the melt PCL and PCL polymer solution in 2014; In this study, fibers were obtained by spinning the PCL polymer in the molten state (120 ° C-250 °C) with centrifugal force [23]. As a result of the experiments, the desired amount of droplet-free uniform fibers were obtained from the PCL solution at 200 °C. According to the study, the desired fiber dimensions were obtained when the viscosity of the PCL melt was reduced at high temperature. This shows the importance of the viscous state of the polymer being studied and the temperature at which the experiment is conducted in the morphology of the fibers. However, when working with PCL solution instead of PCL solution in melt state, the rotational speed must be rotated above a certain threshold value. It is generally considered to be low at 8000 rpm PCL melt, which is considered to be the high speed in the centrifugal force spinning of the PCL polymer solution. Because the obtained PCL fiber outputs were observed as broken and broken. For this reason, it is possible to obtain uniform fibers at speeds of 14.000-18.000 rpm for polymer melts as in this study. However, here too, since the viscose of PCL melt is high at 18.000 rpm, it enters a rapid solidification process, in this case, it has been observed that the forcespinning device causes clogging in the pulses, the morphology of the resulting fibers is too droplet and undesirable quality. Apart from this, in a paramtric data, the distance between the collector and the spinneret did not show a significant difference in the efficiency of the fibers,

but when the distance was short, the quality of the fibers obtained decreased.

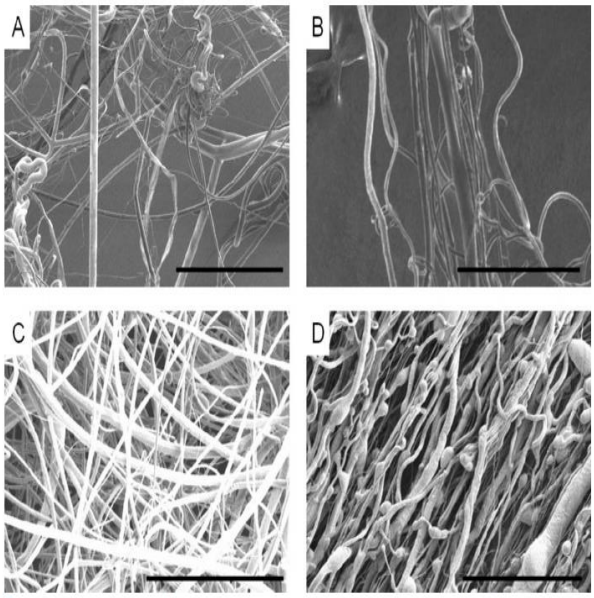


Figure 4. Scanning electron micrographs of melt-spun polycaprolactone fibers spun at various rotation speeds. (A) 8000 rpm, (B) 10,000 rpm, (C) 14,000, (D) 18,000. Scale bar denotes 300 μm. Temperature and collector distance were fixed at 200°C and 14 cm, respectively.

***Figure 4.*** *a) At 8000 rpm b) At 10.000 rpm c) At 14.000 rpm d) Fiber image at 18.000 rpm*

Apart from PCL, it is seen that polypropylene polymer is used very frequently in liters. Polypropylene is a petrochemical product that is resistant to low-density chemical agents and temperature. It is used in industrial and industrial fields such as injection molding, air pressure molding, automotive [24].

Raghavan et al. Used centrifugal force spinning method in the production of nonwoven polypropylene nanofiber mats and investigated the morphology of the output fibers according to certain variables of the device [25].

By using centrifugal force spinning method in the production of nonwoven polypropylene (PP) nanofiber mats, the morphology of the output fibers was investigated according to certain variables of the device. Accordingly, polypropylene polymer was melted at 225 °C and discharged into the collector at different flow rates. According to the results, flow rates from the melt polypropylene spinneret were determined as 500 g / 10 min, 36 g / 10 min, 1200 g / 10 min, 1550 g / 10 min, and rotational speeds were determined as 8000 rpm and 12,000 rpm. It was observed that 1550 g of molten PP polymer, which was thrown at 12000 rpm in 10 minutes, had a dispersed spreading and uniform fiber structure. The reason is that the melt PP polymer, whose firing rate is higher than grams per minute, has entered a faster cooling process and has formed the desired uniform fiber structure. In short, it has been observed that PP melt polymer crystallizes faster with high pulse rate, it cools the liquid crystal phase, which is the intermediate phase of the polymer, faster and supports the development of fibers.

Spinning with centrifugal force, as mentioned at the beginning, provides high efficiency and scaled production and enables producers to save time. Regardless of the type of polymer used in large scale production, it is a laboratory environment and limited nanofiber production is carried out because the production band is low. In order to overcome these limitations, Andjani et al., In 2018, 26 studies examining the use of PVP (polyvinylpyrrolidone) polymer in drug delivery systems; The reason why PVP polymer is generally used in drug delivery systems is that it can easily carry active drug transport agents. In the study, different concentrations of PVP polymer solutions were prepared and fibers of different morphologies were prepared by spinning method with the spinning method and the fibers that could be most suitable for the drug transport system were examined. The PVP polymer concentrations prepared were determined as 8%, 10%, 12%, 14%, 16% and 18% by weight. The flow rate of polymer solutions was determined as 30ml / s, 10 cm between spinneret and collector and rotational rotation speed 15.000 rpm. According to this; When the concentration is kept low, it has been observed that there are too many droplets on nanofibers such as 8%. The droplets decreased as the concentration increased. When the PVP polymer concentration was 16%, uniform dropletless nanofibers were obtained. The important point here is that the polymer concentration reaches a critical level, the viscosity of the solution decreases at polymer concentrations below the critical level and the binding energy of the polymer chains decreases and they cannot form a normal fiber structure. In other words, when the surface tension of the polymer is too high, the surface area per mass decreases, the polymer fibers have a problem in jumping into the collector and droplets are formed before the fibers are formed without creating sufficient surface area. When we look at the opposite of this situation, because the viscosity of highly concentrated polymer solutions is naturally high, the necessary chain bonds are formed between the polymer chains for fiber formation.

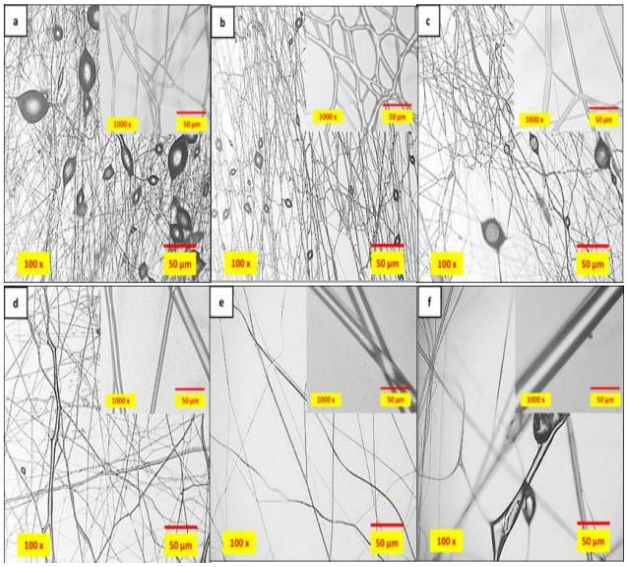

***Figure 5.*** *a) 8% PVP-nanofiber, b) 10% PVP-nanofiber, c) 12% PVP-nanofiber d) 14% PVP-nanofiber e) 16% PVP-nanofiber, f) 18 PVP-nanofiber*

When looking at the applications related to spinning different polymers with centrifugal force, Vazquez et al. Conducted a study with Polyvinylidine Fluoride (PVDF) in 2012, investigated the morphology of nanofibers by changing the radius of the orifice attached to the spinnereta (the accent from which the polymers were thrown) and the angular velocity of the spinneret [27]. PVDF is used as a polymer in the medical sector in suture production, hernia mesh and in the development of artificial cornea [28].

Vazquez et al. In their study; PVDF solutions were prepared by weight (18%, 21.5%, 25%). The speeds of the spinneret are determined as 4000 rpm, 8000 rpm and 10.000 rpm. Fiber outputs at different speeds and concentrations were evaluated in SEM.

Again, as described in other studies, fiber sizes obtained from low-concentration polymer solutions are small, and fiber size expands as concentration increases.

Again, as described in other studies, fiber dimensions obtained from low-concentration polymer solutions are small, and the fiber size expands as the concentration increases. In addition, as the rotation speed of the spinnert increases, the concentration should be increased in direct proportion so that the fibers do not droplet and have a uniform structure. The purpose of this study is that even in polymers with different crystal phase structure such as PVDF, when appropriate conditions are provided, the centrifugal force spinning method can be used easily.

Researchers are curious about how centrifugal force spinning studies will affect fiber morphologies with the polymer prepared as a composite. One of these studies; Padron et al. Was the study of fibers consisting of conjugated polymers and composites by using centrifugal force spinning method in 2011 [29].

First of all, conjugated polymers have side chains with unsaturated bond structure in the main polymer chain. Thanks to these side chains, the polymer has gained semiconductivity [30]. Conjugated polymers contain metal oxides and organic viologen groups as content. It provides structural changes such as the ability to manipulate the color, electrochemical properties of materials or composites made with conjugated polymers, and provide structural modifications [31]. Conjugated polymers are versatile sensor materials. It gives inorganic materials properties such as optical and electrical (insulation or conductivity). With the conjugated polymer, the inherent photophysical properties of electronic materials can change. Usage areas; It is frequently encountered in devices and machines such as LED lamps, photovaltic devices, chemical sensors, biosensors, transistors, laser devices [32].

Considering the study of Padron et al. In 2011; Composite nano-fiber morphologies of PPV-BEH and PEO, a conjugated polymer, were investigated. First of all, PPV was made into a hybrid polymer with Poly (2,5-bis (20-ethyl-hexyl)-1,4-phenylenevinylene) in order to be a conjugated polymer that can dissolve easily in solvents and can shine at 590 nm wavelength. In the study, BEH-PPV polymer, PEO and different concentrations of nanofiber structures were investigated. As mentioned before, problems are encountered during nanofiber production as a result of the sensitivity of some polymers to electrostatic force. In this study, spinning method with centrifugal force was used because the conjugated polymer, BEH-PPV, could not produce fiber with the desired efficiency under electrostatic force and showed weakness in throwing. Prepared polymer solutions were taken as in Table 2. The rotational speed of the device in spinning with centrifugal force was kept between 2000 rpm and 7000 rpm.

**Table 2:** Fixed PEO 1.5% polymer solution concentration versus eBEH-PPV concentrations

**Concentrations of Solutions Prepared with a Constant 1.5 wt % of PEO to Chloroform**

| Sample | PEO (wt %) | BEH-PPV (wt %) |
|---|---|---|
| 1 | 100 | 0 |
| 2 | 99.5 | 0.5 |
| 3 | 99.0 | 1.0 |
| 4 | 97.5 | 2.5 |
| 5 | 95.0 | 5.0 |
| 6 | 90.0 | 10.0 |

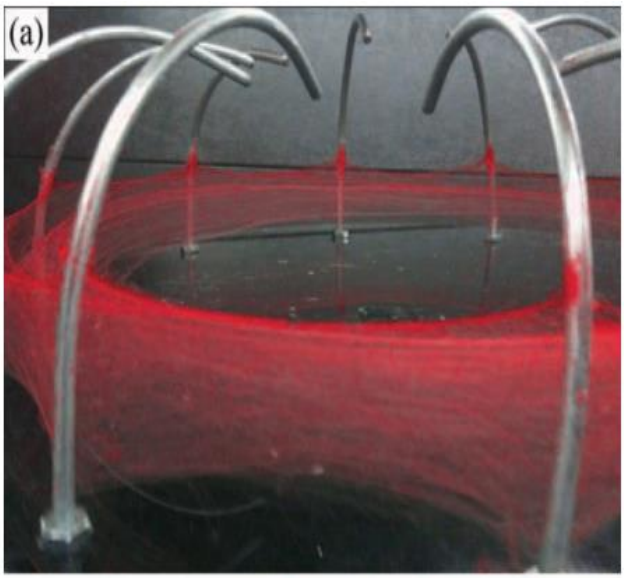


***Figure 6.*** *Nanofibers formed in the spinning device by centrifugal force*

Since the product efficiency is taken as basis in this study, the aim is to produce more nanofibers unlike electrospinning. For this purpose, when the speed of the spinning device is increased with the centrifugal force, the fiber dimensions become thinner, but a high rate of nanofiber has been obtained. As important as obtaining nanofibers in desired sizes is the type and percentage of use of solvents that open the polymers used. For this purpose, it has been observed that when chloroform and water are used together as an opener in pure polyethylene oxide (PEO) use, the nanofiber thickness is avarage thickness, but the diameter of the fibers increases twice as only chloroform opener. It was observed that when the evaporation capacity of the solvent was reduced by mixing with water with chloroform, thinner fibers were formed. Another important point is; For fibers obtained from composite polymers, the mixture concentration must be at a certain threshold. As a reason, its rotational speed has to exceed the heavy surface tension of the composite mixture due to viscosity and facilitate the output as nanofibres to the collector. In other words, the angular velocity must exceed the viscosity and surface tension of the solution to obtain fiber. In this study, it was determined that the appropriate BEH-PPV concentration was between 5% and 10%, and the desired rate of nanofiber was obtained.

**Table 3:** Product yield according to speed and BEH-PPV / PEO composite mixtures used

Yield production of BEH-PPV/PEO Fibers in Chloroform Solvent for 1 mL Samples

| Speed (RPM) | Pure PEO | 0.5 wt % BEH-PPV | 1.0 wt % BEH-PPV | 2.5 wt % BEH-PPV | 5.0 wt % BEH-PPV | 10 wt % BEH-PPV |
|---|---|---|---|---|---|---|
| 2000 | High | Medium | Medium | Medium | - | - |
| 2500 | High | Medium | Medium | Medium | High | High |
| 3000 | Medium | Medium | Medium | Medium | High | High |
| 4000 | Poor | Medium | Low | Low | High | Medium |
| 5000 | Poor | Low | Low | Low | Medium | Poor |
| 6000 | - | Low | Low | Poor | Poor | - |
| 7000 | - | Poor | Poor | - | - | - |

The spinning method with centrifugal force, as mentioned at the very beginning, is a method that is generally used for industry and used in textiles and woven products, as a large amount of output is obtained with low cost. However, it has been observed that it has been used in tissue engineering applications in recent years, besides industrial production. There are models and applications of the spinning device adapted to the laboratory environment with centrifugal force. Recently, there are studies in the literature showing that it is also used in making biodegradable dressings. One of them is Loordhuswamy et al, conducted in 2014; A wound dressing study consisting of a PCL / gelatin (Gel) composite [33]. In the study, 15% PCL was knitted with different gelatin concentrations and tried to obtain a porous, soft-textured, smooth-fiber wound dressing that would allow the desired cells to adhere. Polymer mixtures were prepared in the ratios of PCL / Gel constructs (100/0, 70/30, 50/50, 30/70) and spinning at 5000 rpm with centrifugal force was performed. Then, the formed dressings were subjected to SEM, cell tests and mechanical tests. According to this; In the PCL / Gel composite, it was observed that the size of the fibers decreased when the ratio of soft gelatin was increased. The reason for this is that the viscosity of gelatin is lower than PCL and it makes the composite less viscous by increasing the percentage of gelatin. In this way, it has been found that the percent folding of the polymer chains is reduced. However, on the other hand, the pore diameters of the wound dressings formed by the increase in the percentage of gelatin were enlarged and this provided a suitable environment for the adhesion of the cells. In mechanical measurements, it was observed that the stretch-shrinkage ratios and the elasticity coefficients started to decrease with the increase of gelatin concentration. Gelatin is a protein that is not resistant to stretching due to its structure. In the tensile-tensile strength tests, the decrease in values with gelatin is thought to be due to the interactional connections between hydrophobic PCL and hydrophilic gelatin.

**Table 4:** Mechanical test results of PCL / Gel covers

Porosity, mechanical properties and contact angle measurement of C-Spun PCL/gel matrices, mean ± SD.

| C-Spun PCL/gel matrices | Porosity (%) | $T_m$ (°C) | ΔHf (J/g) | Young's modulus (MPa) | Tensile strength (MPa) | Contact angle | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 0 s | 3 s | 6 s |
| 100/0 | 86 ± 0.95 | 64.4 | 72.67 | 40.76 ± 11.26 | 3.14 ± 0.36 | 85° | 85° | 85° |
| 70/30 | 88 ± 0.81 | 63.7 | 52.99 | 84.87 ± 24.31 | 2.91 ± 0.60 | 74° | 16° | 0° |
| 50/50 | 91 ± 0.91 | 63.3 | 38.49 | 82.70 ± 35.83 | 1.7 ± 0.61 | 61° | 0° | 0° |
| 30/70 | 93 ± 1.03 | 62.1 | 19.91 | 72.757 ± 6.23 | 1.22 ± 0.11 | 45° | 0° | 0° |

With the increase of the hydrophilic gelatin percentage, the desired structure was obtained in the dressing. However, it has been observed that when the desired hydrophilic property in the dressing morphology is increased, it limits cell adhesion. That is, with the increase in the percentage of gelatin in the composite, in the cell cultivation environment, the gelatin absorbs the liquid at a high rate due to its hydrophilic surface structure and causes swelling in the wound dressing, resulting in cell death. For this reason, it has been found that the optimum PCL / gelatin percentage is 70/30. Later, when the cell growth rates at this rate were examined, it was observed that the cells were aligned, adhered and multiplied in parallel with the fiber structure they formed at this PCL / Gel: 70/30 ratio.

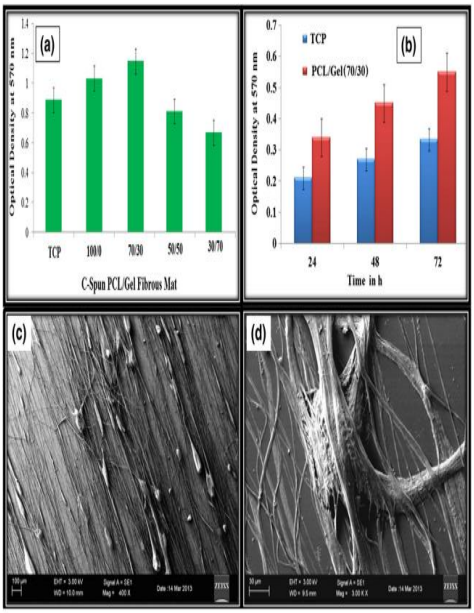


Fig. 8. (a) MTT assay of fibroblast (NIH 3T3) on different ratios of C-Spun PCL/gel matrices. (b) Growth kinetics of NIH 3T3 on C-Spun PCL/gel (70/30) matrices.(c) SEM micrograph of C-Spun PCL/gel (70/30) matrices.(d) Magnified SEM images of a cell on C-Spun PCL/gel 70/30 matrices depicting the orientation of the cell inline with fiber orientation.

***Figure 7.*** *a) Distribution of fibroblast cells in different proportions of composites b) PCL / Gel: 70/30 cell growth kinetics c) PCL / Gel: 70/30 SEM dressing d) PCL / Gel: 70/30 matte cell placement*

It is clear from this study that proper fiber alignment must meet both cell adhesion and mechanically the requirements of the dressing. In other words, even if protein-based polymer that is easy to break down is used, ultra-thin fibers can be formed thanks to the appropriate composite ratios. It has been found that cell growth in fiber dressings formed in this way is possible. It has been shown that the centrifugal force spinning method can also be used easily in biomedical applications.

Also, Xu et al. Conducted a wound dress preparation study with centrifugal force spinning method in 2015 [34]. Cellulose acetate-based fibers prepared in the determined concentrations in the study were asked to show extra antimicrobial properties. For this purpose, the wound dressings were subjected to hydrolysis process, and cellulose-silver composite wound dressings were prepared by absorbing silver nanoparticles solution. In the study, cellulose acetate compound between 16% and 20% was dissolved in the determined DMSO / acetone-based solvent to obtain a celluleose acetate polymer solution. In the study, fibers with different morphologies were obtained by both polymer concentration and by being carved with rotational speed. The aim of the study is to keep the nanosilver material between and above the fibers in the gap that can create a gap, as the fibers formed will be subjected to hydrolysis and covered with nanosilver. Thus, it is aimed to provide a sterile environment to the wound with the release of silver depending on time in antimicrobial dressing.

According to this; It is seen that when fibers with cellulose acetate between 16% and 20% are spun with centrifugal force, the polymer solution of 16% cannot be knitted due to its low viscosity, and the process starts with only 18% cellulose acetate solution. It was revealed that the cellulose acetate concentration of 18% is approximated to the critical solution concentration in spinning with centrifugal force. Polymer chains are connected with each other starting from this concentration, forming fibers by folding. When the rotational speed was evaluated, it was seen that increasing the speed from 7000 rpm to 9000 rpm did not affect the size of the fibers much, but increased the density of the fiber formed.

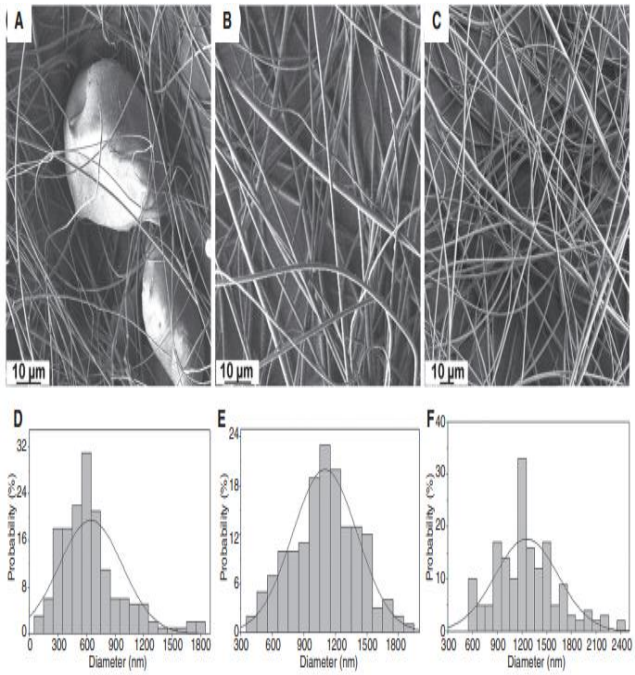


***Figure 8.*** *A-C: SEM image of fibers formed as a result of different concentrations of cellulose acetate polymer from 18% to 20%. A-D: SEM image and dimensions of 18% fibers, B-E: SEM image and dimensions of 19% fibers, C-F: SEM image and dimensions of 20% fibers*

Another important point is that when cellulose acetate fibers are subjected to hydrolysis process for coating with nanosilver, it has been observed that there is no change in the structure of the fibers and they maintain their homogeneity. Another important point is that when cellulose acetate fibers are subjected to the hydrolysis process for coating with nanosilver, it has been observed that there is no change in the structure of the fibers and they maintain their homogeneity (Figure 9.). In the hydrolysis process, the acetyl groups in cellulose acetate were destroyed by chemical process and conversion to pure cellulose was achieved. Cellulose silver composite dressings were obtained. It has been proved by SEM images that the woven fibers in cellulose silver composite wound dressings have silver particles placed both inside them and on the surface. Thus, ultra-fine fibers that are properly aligned at the desired intervals and are not affected even by hydrolysis were obtained. With this practice, it has been shown that polymers spun with centrifugal force can be easily used in the medical field.

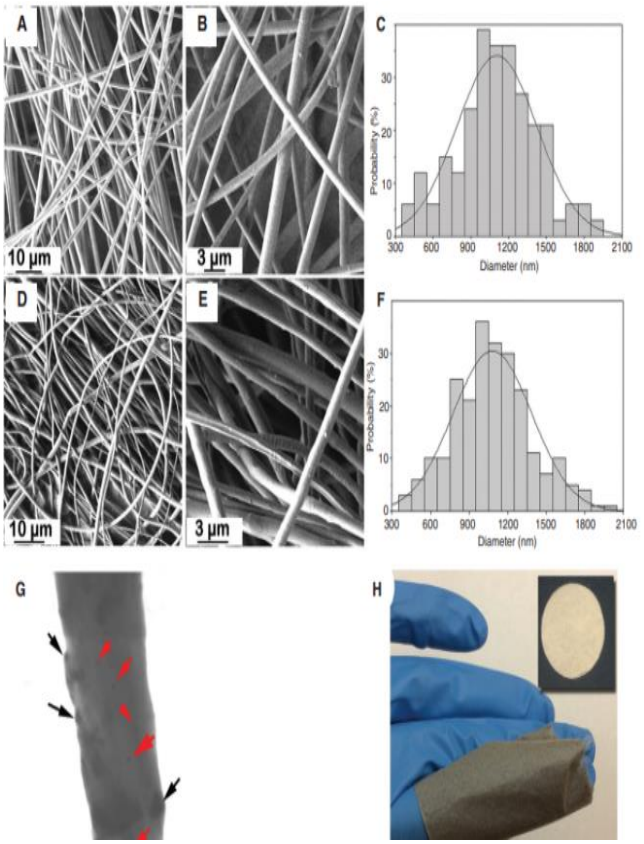


***Figure 9.*** *AC: Woven cellulose acetate composite membrane SEM image and fiber size analysis, DF: SEM image of cellulose-silver composite membrane exposed to hydrolysis process and fiber dimensions, G: Placement of silver nanoparticles in fiber H: Membrane structure without knitting process is silver color change to gray due to*

When we look at the literature studies on the centrifugal force spinning method, it has been seen that studies have been carried out with polyamide groups other than biodegradable polymer groups. Studies have been carried out with polyamide groups, which are hard in structure and have a lot of usage areas. It is known that the fibers obtained as a result of knitting polyamide groups with electrospinning method are resistant to tensile shrinkage. Since polyamide groups are hard materials, it is seen that they are used as composites with mechanically weak polymers [35].

When spinning works with the centrifugal force of polyamide 6 and polyamide 6,6, which are frequently used in the industry; It is seen that the centrifugal force and the needle diameters connected to the spinneret, one of the spinning parameters, are also an important difference in spinning. Looking at the study of Hammami et al, in 2013 [36]; Polyamide 6 was prepared by dissolving in formic acid to form 15% and 25% final polymer solutions. Rotation speeds are also stated to be varied between 4000 rpm-9000 rpm. Accordingly, the working draft in Table 5 was created.

**Table 5:** Working draft created

| Concentration (wt.%) | Spinneret speed (rpm) | Mean diameter (µm) | Min. | Max. | % Sub-micron fibers | % Fibers <500 nm |
|---|---|---|---|---|---|---|
| 15 | 4000 | 0.224 | 0.123 | 0.533 | 100 | 97 |
| | 6000 | 0.233 | 0.088 | 0.643 | 100 | 95 |
| | 9000 | 0.188 | 0.067 | 0.487 | 100 | 100 |
| 20 | 4000 | 0.435 | 0.097 | 1.511 | 96 | 73 |
| | 6000 | 0.617 | 0.178 | 1.823 | 89 | 50 |
| | 9000 | 0.448 | 0.113 | 1.316 | 99 | 74 |
| 25 | 4000 | 0.751 | 0.268 | 1.929 | 76 | 24 |
| | 6000 | 0.825 | 0.267 | 4.415 | 76 | 21 |
| | 9000 | 0.801 | 0.297 | 2.80 | 82 | 23 |

The morphology of the fibers was deduced according to the speed trials at the specified concentrations. Another important point of the study is the use of intra-needle radii, which is another parametric data mentioned in the review. In the study, the radii of polymer shooting needles attached to Spinnereta were determined as 27 ga and 30 ga. It was observed that 15% low viscosity polyamide 6 polymer solution could not be collected in the collector since it could not exceed the surface tension in a 27-gal large diameter needle. However, it has been observed that the 15% polymer solution ejected from the 30-gal narrower needle and collected in the collector. For both needle types, the diameter of the needle should be reduced in order to spin a 15% solution. Or it should be spun at a concentration at the threshold value, otherwise the polymer solution is exposed to shear stress. To high viscous. When it comes to (20% and 25%), it must be spun at high speeds as seen in other studies. Again, considering the relationship between velocity needle diameter and viscosity, large diameter needles should be used, even at low speed, in order to shoot in high viscosity solutions. Thinner inner diameter needles should be used to pulse low viscosity polymer solutions. As a result; Accordingly, it has been found that it is suitable to work with highly concentrated polymer solutions to increase the spinning process. Accordingly, a certain concentration must be at a threshold for the folding of the polymer chain in the macromolecular structure. If it is diluted like 15% at a low concentration, fine needles should be used to perform the spinning process.

In the method of spinning polyamide 6.6, which is frequently encountered in daily life with its different applications in many industrial fields, this time, in addition to the parameters examined in other studies, nanofiber size variations due to temperature-related changes were mentioned in the study of Bazrafshan et al, 2020 [37].

In the method of spinning polyamide 6.6, which is frequently encountered in daily life with its different applications in many industrial areas, this time, in addition to the parameters examined in other studies, nanofiber size variations due to temperature-related changes were mentioned in the study of Bazrafshan et al, 2020 [37]. According to this; The concentration of the polymer solution and the rotational rotation speed of the device were kept constant, and polyamide 6.6 was dissolved in formic acid separately at 70 ° C, 90 ° and 110 °C, respectively. Prepared polymer solutions were subjected to spinning process by using centrifugal force method. The dimensions of the obtained fibers were examined. Results; The dimensions of the fibers were measured as 148 nm, 118 nm and 114 nm, in the order of temperature. Accordingly, while polyamide 6.6 was mixed with formic acid, it was observed that the dimensions of the fibers formed as a result of spinning with centrifugal force decreased with the increase in temperature. It is understood that while the polymer solution goes to the collector as a fiber, the formic acid, in other words the solvent, evaporates and reduces the fiber dimensions.

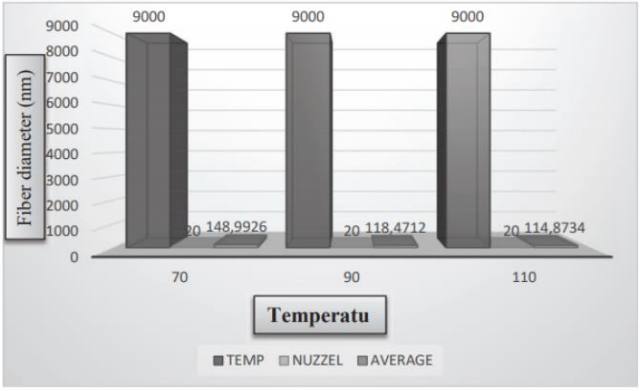


**Figure 10.** Temperature dependent nanofiber size

## Conclusion

In general, according to the purpose of the review, the introduction and facilities of spinning with centrifugal force, which has not been used much and has not been used much in academic research, has been tried to be explained. The advantages of the centrifugal spinning method over other nanofiber production techniques have been tried to be explained with examples. Accordingly, the most striking difference is that the efficiency of the product obtained from spinning with centrifugal force is higher than that of the electrospinning method. The proof that this method, which is used in industry and industrial areas producing nanofibers in larger scales, can be integrated into academic studies in the laboratory environment has been tried to be shown in the studies in the compilation. Another important advantage is that the limitations experienced in electrospinning method due to the sensitivity of some studied polymers to electrostatic forces, it has been tried to explain that this problem can be overcome by spinning with centrifugal force. One topic discussed in this review is the centrifugal force and nanofiber production parameters. Viscosity, surface tension and rotational speed values of the polymer worked in spinning with centrifugal force have been tried to be explained one by one for an efficient operation. Another

important point is that the centrifugal force spinning method, which has been used in industry for many years, has been proven by recent studies in the review of academic studies for biomedical textile products, artificial tissue products and drug release systems. The most important feature sought in nanotechnological products is the high ratio of surface area to volume. It is a technique that needs to be more prominent for nanotechnological product designs, since ultra-fine single-form fibers obtained in spinning with centrifugal force meet this feature to a great extent. The aim of this review is to make scientists realize that spinning with centrifugal force is an ideal method that should be used in academic studies in terms of obtaining nanotechnological products.

## References

**[1]** Alghoraibi, Ibrahim, and Sandy Alomari. "Different methods for nanofiber design and fabrication." *Handbook of nanofibers* (2018): 1-46.

**[2]** Anbusagar, N. R. R., K. Palanikumar, and A. Ponshanmugakumar. "Preparation and properties of nanopolymer advanced composites: A review." *Polymer-based Nanocomposites for Energy and Environmental Applications*. Woodhead Publishing, 2018. 27-73.

**[3]** Sturm, Robert. "Inhaled nanoparticles." *Phys Today* 69 (2016): 70-1.

**[4]** Hasan, Md Mahabub, AKM Mashud Alam, and Khandakar Abu Nayem. "Application of electrospinning techniques for the production of tissue engineering scaffolds: a review." *European Scientific Journal* 10.15 (2014).

**[5]** Kong, Chang Suk, et al. "Electrospinning mechanism for producing nanoscale polymer fibers." *Journal of Macromolecular Science®, Part B: Physics* 49.1 (2010): 122-131.

**[6]** Niu, Haitao, Hua Zhou, and Hongxia Wang. "Electrospinning: an advanced nanofiber production technology."

**[7]** Tucker, Nick, et al. "The history of the science and technology of electrospinning from 1600 to 1995." *Journal of engineered fibers and fabrics* 7.2_suppl (2012): 155892501200702S10.

**[8]** Park, Jun-Seo. "Electrospinning and its applications." *Advances in Natural Sciences: Nanoscience and Nanotechnology* 1.4 (2011): 043002.

**[9]** Al-Hazeem, Nabeel Zabar Abed. "Nanofibers and Electrospinning Method." *Nov. Nanomater.-Synth. Appl* (2018)

**[10]** LF Nascimento, Marcio, et al. "A literature investigation about electrospinning and nanofibers: historical trends, current status and future challenges." *Recent Patents on Nanotechnology* 9.2 (2015): 76-85.

**[11]** Asmatulu, R., and W. S. Khan. "Historical background of the electrospinning process." *Synthesis and applications of electrospun nanofibers* (2018): 17-39.

**[12]** Sarkar, Kamal, et al. "Electrospinning to merkezkaç kuvveti ™." *Materials today* 13.11 (2010): 12-14.7

**[13]** Agubra, Victor A., et al. "Forcespinning: A new method for the mass production of Sn/C composite nanofiber anodes for lithium ion batteries." *Solid State Ionics* 286 (2016): 72-82.

**[14]** Zhang, Zhi-Ming, et al. "A review on nanofiber fabrication with the effect of high-speed centrifugal force field." *Journal of Engineered Fibers and Fabrics* 14 (2019): 1558925019867517.

**[15]** McEachin, Zachary, and Karen Lozano. "Production and characterization of polycaprolactone nanofibers via merkezkaç kuvveti ™ technology." *Journal of Applied Polymer Science* 126.2 (2012): 473-479.

**[16]** Zhang, Zhiming, and Jun Sun. "Research on the development of the centrifugal spinning." *MATEC Web of Conferences*. Vol. 95. EDP Sciences, 2017.

**[17]** Obregon, Nancy, et al. "Effect of polymer concentration, rotational speed, and solvent mixture on fiber formation using merkezkaç kuvveti ®." *Fibers* 4.2 (2016): 20.

**[18]** Naghibzadeh, Majid, et al. "Evaluation of the effective forcespinning parameters controlling polyvinyl alcohol nanofibers diameter using artificial neural network." *Advances in Polymer Technology* 37.6 (2018): 1608-1617.

**[19]** Padron, Simon, et al. "Experimental study of nanofiber production through forcespinning." *Journal of applied physics* 113.2 (2013): 024318.

**[20]** Zhang, Xiangwu, and Yao Lu. "Centrifugal spinning: an alternative approach to fabricate nanofibers at high speed and low cost." *Polymer Reviews* 54.4 (2014): 677-701.

**[21]** Azimi, Bahareh, et al. "Poly (∈-caprolactone) Fiber: an overview." *Journal of Engineered Fibers and Fabrics* 9.3 (2014): 155892501400900309.

**[22]** Kodali, Deepa, et al. "Fabrication and characterization of forcespun polycaprolactone microfiber scaffolds." *Materials Research Express* (2020).

**[23]** Zander, Nicole E. "Formation of melt and solution spun polycaprolactone fibers by centrifugal spinning." *Journal of Applied Polymer Science* 132.2 (2015).

**[24]** Maddah, Hisham A. "Polypropylene as a promising plastic: A review." *Am. J. Polym. Sci* 6.1 (2016): 1-11.

**[25]** Raghavan, Bharath, Haidy Soto, and Karen Lozano. "Fabrication of melt spun polypropylene nanofibers by

forcespinning." *Journal of Engineered Fibers and Fabrics* 8.1 (2013): 155892501300800106

**[26]** Andjani, D., et al. "Fabrication of Polyvinylpyrrolidone Fibers by Means of Rotary Forcespinning Method." *MS&E* 367.1 (2018): 012044.

**[27]** Vazquez, Beny, Horacio Vasquez, and Karen Lozano. "Preparation and characterization of polyvinylidene fluoride nanofibrous membranes by forcespinning™." *Polymer Engineering & Science* 52.10 (2012): 2260-2265.

**[28]** Houis, S., et al. "Application of polyvinylidene fluoride (PVDF) as a biomaterial in medical textiles." *Medical and Healthcare Textiles*. Woodhead Publishing, 2010. 342-352

**[29]** Padron, Simon, et al. "Production and characterization of hybrid BEH-PPV/PEO conjugated polymer nanofibers by forcespinning™." *Journal of applied polymer science* 125.5 (2012): 3610-3616

**[30]** Anguera, Gonzalo, and David Sánchez-García. "Conjugated polymers: Synthesis and applications in optoelectronics." *Afinidad* 71.568 (2014).

**[31]** Neo, Wei Teng, et al. "Conjugated polymer-based electrochromics: materials, device fabrication and application prospects." *Journal of Materials Chemistry C* 4.31 (2016): 7364-7376.

**[32]** Upadhyay, Anjali, and Subramanian Karpagam. "Movement of new direction from conjugated polymer to semiconductor composite polymer nanofiber." *Reviews in Chemical Engineering* 35.3 (2019): 351-375.

**[33]** Loordhuswamy, Amalorpava Mary, et al. "Fabrication of highly aligned fibrous scaffolds for tissue regeneration by centrifugal spinning technology." *Materials Science and Engineering: C* 42 (2014): 799-807

**[34]** Xu, Fenghua, et al. "Fabrication of cellulose fine fiber based membranes embedded with silver nanoparticles via Forcespinning." *Journal of Polymer Engineering* 36.3 (2016): 269-278.

**[35]** iang, Shaohua, et al. "Tough and transparent nylon-6 electrospun nanofiber reinforced melamine–formaldehyde composites." *ACS applied materials & interfaces* 4.5 (2012): 2597-2603.

**[36]** Hammami, Mohamed Amen, Mourad Krifa, and Omar Harzallah. "Centrifugal force spinning of PA6 nanofibers–processability and morphology of solution-spun fibers." *the Journal of the Textile Institute* 105.6 (2014): 637-647.

**[37]** Bazrafshan, Vahid, Ardeshir Saeidi, and Afshin Mousavi. "The effect of different process parameters on polyamide 66 nano fiber by force spinning method." *AIP Conference Proceedings*. Vol. 2205