

**VIGILANCIA TÉCNOLÓGICA DE NO TEJIDOS A BASE DE NYLON-6  
PRODUCIDOS POR ELECTROSPINNING PARA USO EN ENTORNOS  
HOSPITALARIOS.**

**TECHNICAL SURVEILLANCE OF NON-WOVEN BASED ON NYLON-6  
PRODUCED BY ELECTROSPINNING FOR USE IN HOSPITAL  
ENVIRONMENTS.**

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**Resumen:** En esta investigación, se considera la vigilancia tecnológica de las nanofibras no tejidas a base de Nylon-6 producidas por electrospinning, diferentes parámetros sobre el proceso de electrospun (concentración, voltaje, distancia de punta a colector de aguja y caudal), fueron analizados para su aplicación en entornos hospitalarios. Se encontró que el Nylon 6 presenta buenas propiedades mecánicas, biocompatibilidad y eficiencia como filtros de agua que permite su uso en un proceso de electrospinning para desarrollar nanofibras no tejidas con porosidad, gran área superficial por unidad de masa y alta permeabilidad, lo que lo hace un material opcional para entornos hospitalarios. La variación de los parámetros de electrospinning favorece la conformación de nanofibras no tejidas, reduce las gotas y proporciona diámetros de nanofibras más pequeños.

**Palabras clave:** Nylon-6, no tejido, nanofibra, nanotextil, electrospinning, entornos hospitalarios.

**Abstract:** In this research, we consider about the technological surveillance of non-woven nanofibers based on nylon-6 produced via electrospinning, different parameters about the process of electrospun (concentration, voltage, needle tip-to-collector distance, and flow rate), were analyzed for their application in hospital environments. We found that Nylon 6 exhibits good mechanical properties, biocompatibility, and efficiency as water filters that permits their use in a process of electrospinning to develop non-woven nanofibers with porosity, large surface area per unit mass, and high permeability, it makes a good option material for hospital environments. The variation of electrospinning parameters favors the conformation of non-woven nanofibers, reduce the drops, and provides smaller nanofiber diameters.

**Keywords:** Nylon-6, non-woven, nanofiber, nanotextil, electrospinning, hospital environments.

## 1. INTRODUCTION

According to International Standard ISO 9092, non-woven textiles are defined as a manufactured sheet, veil or fiber material oriented in a direction or randomly joined by chemical or thermal mechanical processes. The fibers may be continuous or discontinuous fibers, or be formed *in situ* (ICONTEC 1996). Non-wovens are porous and flexible products, consisting of one or more layers of fibers. Non-woven textiles can be classified as single use disposables (diapers, medical dressings, household wipes and protective clothing) or durable (the interface of clothing, automobile headliners and carpets)(Abu Sayed 2017).

Nanotechnology in non-woven textiles can improve properties to benefit textile processing; For example, adhesive properties, antibacterial properties, energy production (for solar energy) and luminescence (for color control)(Haydon 2013). Non-woven nanofibers can be developed with polymers of natural or synthetic origin, among them it's found the Nylon 6.

Nylon-6, also known as polyamide 6, is a biodegradable, biodegradable synthetic polymer material and has good mechanical properties, such as its hardness, elasticity, toughness and resistance to abrasion, wear, oils, heat, resistance chemistry and easy processing capability. It is used in automobile parts, wipes, battery separators, synthetic suede, brush bristles and protective garments (Ryu et al. 2003). The most commonly used techniques for producing non-woven fibers in general include Meltblown process, multi-component process and electrospinning(Raj et al. 2011; H. R. Pant et al. 2011; Giesecking et al. 2012; Montazer and Malekzadeh 2012; Ryu et al. 2003).

The technique of electrospinning "electrostatic spinning" or "electrospun" is a method of manufacturing scaffolds composed of continuous non-woven fibers (Braghirolli, Steffens, and Pranke 2014; Agarwal, Wendorff, and Greiner 2008; Joshi 2011). This technique has proven to be simple, versatile, cost-effective and reproducible (Montero et al. 2012; Okutan, Terzi, and Altay 2014; Y. Zhang et al. 2005; Kharaziha et al. 2013). The electrospinning process involves the use of an electric field to convert or melt a polymer solution into a fiber form (Y. Zhang et al. 2005; Zhuo, Hu, and Chen 2008). It consists of three main components: a high voltage source with a positive and negative polarity that guarantees a continuous

electric field, an electrically conductive metal collector (usually a fixed aluminum plate, or a rotary drum), in which The resulting fibers and an pump to adjust the feed rate of the polymer solution contained in a syringe with a capillary or needle diameter of 0.1 to 1 mm (Montero et al. 2012; Sill and Recum 2008; Sun et al. 2013).

To achieve fiber deposition an electrical potential is applied between a drop of a polymer solution located at the end of the needle nozzle and a fixed or grounded metallic collector plate which serves as a counter-electrode, the Electro-silking is carried out by controlling temperature and humidity (Rogina 2014; Okutan, Terzi, and Altay 2014; Y. Zhang et al. 2005). Depending on the location and design in which the equipment is available, the produced nanofibers will be deposited vertically or horizontally. When the applied electric field exceeds the surface tension of the drop, it is deformed into a conical shape (Taylor's cone) and a stream of polymer solution, which is controlled by the electric field, is drawn into the collector. The jet becomes longer and thinner constantly, meanwhile, the solvent evaporates quickly. Finally the nanofibers are collected in the collector plate (Montero et al. 2012; Okutan, Terzi, and Altay 2014; Y. Zhang et al. 2005; Qin and Chronakis 2010).

Many parameters may influence the electrospinning process, including the properties of the solution (e.g., concentration, viscosity, electrical conductivity, surface tension and dielectric properties), which regulate the variables (e.g. electric force, flow rate, distance to the collector plate) and environmental parameters such as humidity and temperature. These directly affect the formation and structure of the fibers and may facilitate the presence of gout defects (Okutan, Terzi, and Altay 2014)(Chong et al. 2007).

The electrospinning processes allow the production of nanofibers with a diameter of less than 500 nm (Raj et al. 2011; H. R. Pant et al. 2011; Giesecking et al. 2012; Montazer and Malekzadeh 2012). The Nylon 6 nanofibers, produced by electrospinning are practical, efficient, with high surface relation, under electric field, with spiderlike appearance, hard, elastic and with gloss(Li, Huang, and Lü 2006; S. Zhang, Shim, and Kim 2009; Kim et al. 2013), these have been reported as an effective means of water filtration due to their porosity (Raj et al. 2011; H. R. Pant et al. 2011).

## 2. METHODOLOGY

A technological surveillance was developed using the search equation with the terms "non-woven" and "electrospinning" and "nano" through the use of the Scopus database, these contains the largest bibliographical references of scientific literature, with over 18,000 titles from 5,000 international publishers (ELSEVIER 2017). The term "non-woven", and the term "electrospinning" and the term "nano" produces 132 results, between 2005 and 2017.

### 2.1 Documents per year

Between 2005 and 2017 (Fig. 1) there is a production of 132 papers, with 2011 being the year with the highest number of publications (SCOPUS 2017).

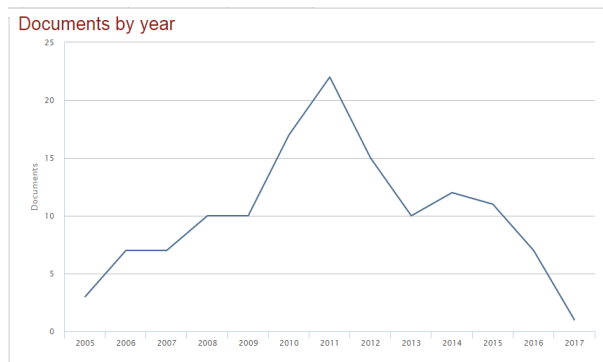


Fig. 1. Documents per year (SCOPUS 2017).

### 2.2 Documents by subject area

Between 2005 and 2017 (Fig. 2) has increased the diversity of areas in which the non-woven presents applications, mainly materials science, engineering, chemistry, chemical engineering and others (SCOPUS 2017, Moreno et al., 2013).

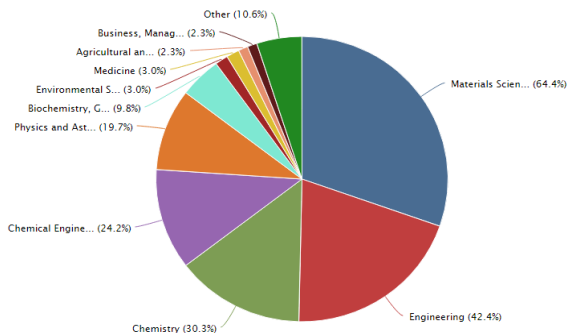


Fig. 2. Documents by subject area (SCOPUS 2017).

### 2.3 Electrospinning parameters analyzed per author

The technological surveillance is developed from the 10 authors with the largest number of publications on the subject of non-woven products produced by means of electrospinning for use in hospital environments because it is pertinent to consider the parameters of electrospinning to obtain more defined nanofibres, of smaller size, and with droplet reduction (TABLE I).

Table I. Electrospinning Parameters

| Parameters                                      | Effect on fiber morphology  |
|---|---|
| <b>Processing Parameters</b>                    |   |
| Voltage applied ↑                               | ↓ diameter of the fiber initially, then ↑ diameter                                      |
| Flow rate ↑                                     | ↑ diameter of the fiber, generation of drops with very high speeds                      |
| Distance between the nozzle and the collector ↑ | ↓ diameter of the fiber, generation of drops with distances or very small or very large |
| <b>Solution Parameters</b>                      |   |
| Concentration of polymer ↑                      | ↑ diameter of the fiber   |
| Molecular weight of the polymer ↑               | ↑ diameter of the fiber   |
| Viscosity ↑                                     | ↑ diameter of the fiber, disappearance of drops   |
| <b>Environmental Parameters</b>                 |   |
| Humidity ↑                                      | Circular pores in the fibers  |
| Temperature ↑                                   | ↓ diameter of the fibers  |

## 3. RESULTS AND DISCUSSION

For the synthesis of non-woven nanofibres of Nylon 6 by means of electrospinning the following parameters were found used by several authors.

### 3.1 Solution parameters

The solvents used by the authors to dissolve the nylon 6 synthetic polymer are formic acid (Ryu et al. 2003; S. Zhang, Shim, and Kim 2009; Faccini, Vaquero, and Amantia 2012; H. R. Pant et al. 2010; Heikkilä et al. 2007; Montazer and Malekzadeh 2012; B. Pant et al. 2012; Shi et al. 2011; Park et al. 2009; Kim et al. 2013; Raj et al. 2011; H. R. Pant et al. 2011; Yin, Krifa, and Koo 2015) acetic acid (Faccini, Vaquero, and Amantia 2012; H. R. Pant et al. 2010; Montazer and

Malekzadeh 2012; B. Pant et al. 2012; Kim et al. 2013; Raj et al. 2011; H. R. Pant et al. 2011), and 2,2,2-trifluoroethanol (TFE)(Li, Huang, and Lǔ 2006; Giesecking et al. 2012; Francis et al. 2010; Vitichuli et al. 2011)(Table II).

*Table II. Solution Parameters*

| Solvent                      | Solvent concentration   | Nylon 6 concentration  |
|------------------------------|---|--|
| Formic acid                  | 98% (Heikkilä et al. 2007)  | 10% wt, 12% wt and 15% wt (S. Zhang, Shim, and Kim 2009), 10% wt (Heikkilä et al. 2007), 15-30% wt (Ryu et al. 2003) (Park et al. 2009), 15% wt (Shi et al. 2011),   |
| Formic acid – Acetic Acid    | 1:1 (Faccini, Vaquero, and Amantia 2012), 4:1 (H. R. Pant et al. 2010; B. Pant et al. 2012; Kim et al. 2013; Raj et al. 2011; H. R. Pant et al. 2011), 1:4 (Montazer and Malekzadeh 2012) | 10-20% wt (Faccini, Vaquero, and Amantia 2012), 22% wt (H. R. Pant et al. 2010), 22gr (Montazer and Malekzadeh 2012), 25 gr (B. Pant et al. 2012), 20% wt (Kim et al. 2013; Raj et al. 2011; H. R. Pant et al. 2011) |
| 2,2,2-trifluoroethanol (TFE) | --  | 6-14% wt (Li, Huang, and Lǔ 2006), 6.5, 8, 9, 10 % wt (Francis et al. 2010), 10% wt (Vitichuli et al. 2011).   |

### 3.2 Processing Parameters

The electrospinning process parameters for the development of nonwoven nanofibers analyzed by different authors are applied voltage, flow velocity, and distance between the needle and the collector (TABLE III) (Ryu et al. 2003; S. Zhang, Shim, and Kim 2009; Faccini, Vaquero, and Amantia 2012; H. R. Pant et al. 2010; Heikkilä et al. 2007; Montazer and Malekzadeh 2012; B. Pant et al. 2012; Shi et al. 2011; Park et al. 2009; Kim et al. 2013; Raj et al. 2011; H. R. Pant et al. 2011; Yin, Krifa, and Koo 2015; Li, Huang, and Lǔ 2006; Giesecking et al. 2012; Francis et al. 2010; Vitichuli et al. 2011).

*Table III Processing Parameters*

| Processing Parameters                         | Value                                    |
|---|--|
| Applied voltage                               | 8, 12, 15, 18, 20, 21, 22, 25, 30, 32 kV |
| Flow velocity                                 | 0.1, 0.3, 0.5, 0.8, 1, 1.5 ml/h          |
| Distance between the needle and the collector | 5, 6, 10, 14, 15, 16, 18, 20, 25, 30 cm  |

### 3.3 Environmental Parameters

The environmental parameters (temperature and relative humidity) can influence the results of the formation of nanofiber non-woven, so a proper control must be performed (Table IV) (Ryu et al. 2003; S. Zhang, Shim, and Kim 2009; Faccini, Vaquero, and Amantia 2012; H. R. Pant et al. 2010; Heikkilä et al. 2007; Montazer and Malekzadeh 2012; B. Pant et al. 2012; Shi et al. 2011; Park et al. 2009; Kim et al. 2013; Raj et al. 2011; H. R. Pant et al. 2011; Yin, Krifa, and Koo 2015; Li, Huang, and Lǔ 2006; Giesecking et al. 2012; Francis et al. 2010; Vitichuli et al. 2011, Caballero A. et al., 2013).

*Table IV. Environmental Parameters*

| Environmental Parameters | Value   |
|--------------------------|---|
| Temperature              | 22°C (Serbezeanu et al. 2015), 25°C (Li, Huang, and Lǔ 2006), Ambience (Ryu et al. 2003), (Park et al. 2009). |
| Relative humidity        | Controlled (Francis et al. 2010).   |

## 4. CONCLUSION

For the development of a non-woven nanofiber

based on Nylon-6, through the use of electrospinning, a technological surveillance was performed in which a large number of publications and areas were found around the subject, the influence they have been studied extensively the parameters in the electrospinning process, at a higher concentration or viscosity of Nylon-6 in the solution, lower distance between the nozzle and the collector, and higher flow velocity produces a smaller pressure normalized by the diameter of the larger sized fibers, droplet reduction. By varying the collection time, nanofibers are obtained with higher thickness and better air permeability. The diameter of the nanofibers decreases slightly with increasing tension, relative humidity and tip distance to needle collector, attributed to the rate of evaporation of the solvent during electrospinning. The efficiency of filtration increases with the decrease of concentration of the solution and the increase of the applied voltage.

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