Electrospun Nanofibers: Basic Principles

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Electrospun nanofibers had been gaining importance in several areas such as the biomedical, environmental, food, textile, and biotechnology industries, amongst others. The fabrication of three-dimensional membranes through the electrospinning technique confers several characteristics that are important in the above industrial approaches such as high-to-volume radio, high surface area, controllable porosity, thickness, and mechanical properties, also the non-toxicity, biocompatibility, and biodegradability can be conferred to the scaffolds by choosing the adequate polymeric formulation. This entry discusses the characteristics and importance of electrospun nanofibers in industry.

Keywords: Parameters ; Polymers ; Tissue engineering ; Biomaterials ; Drug delivery systems ; Electrospun nanofibers ; Electrospinning

1. Electrospinning Technique

Electrospinning is a technique used for the fabrication of fibers and manufacture of fibrous scaffolds [1][2][3][4][5][6][7][8][9][10][11][12][13]; its applications have increased substantially in recent years; particularly in the fields of medicine and engineering (R&D). The electrospinning technology is based on the injection of a conductive polymer solution, electrically charged and directed towards a collector, against an electrode that is grounded closing the circuit. The solution then passes through a field of electrostatic forces ranging from 15 to 50 kV, which produces a stretching effect that forms fibers from a nanometer to a micrometer range (Figure 1)[9], the solvent then evaporates and is deposited in the collector.

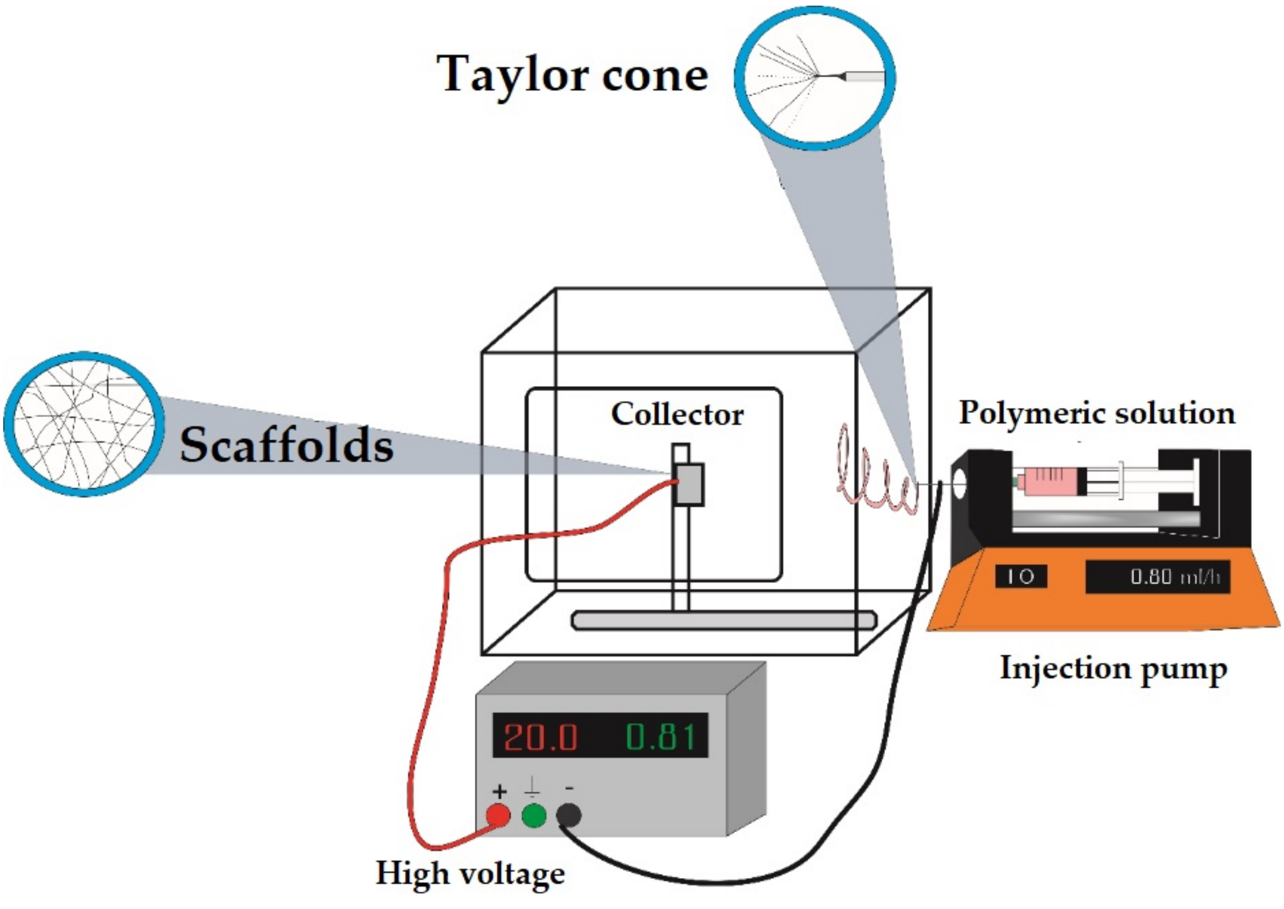

Figure 1. Electrospinning device set up (based on [4][8]).

1.1. Parameters and conditions of electrospinning

The parameters that are mainly considered to perform an optimal electrospinning process and obtain homogeneous nanofibers are as follows: applied voltage, flow velocity rate, type of collector, and distance between the collector and the tip of the dispenser of the polymeric solution. The experimental conditions are ideally carried out in a controlled atmosphere (pressure, temperature, and percentage humidity) in the electrospinning system[4].

1.1.1. Polymer solution

The molecular weight of the chosen polymer, the concentration used of the polymer solution, and the final viscosity are the main parameters that determine fiber formation[4]. Moreover, the final characteristic of the fibers comes from the intrinsic properties of the base polymer. This polymer solution is then loaded to a normal syringe which is mounted in a syringe pump that injects the polymeric solution to a certain rate (volume/time). The injected solution creates a drop that is charged to a high potential between 15 and 50 kV. When the voltage is applied, free electrons, ions, or ion pairs are produced and are attracted to the formed electrical field. This stimulation is adequate for conductive solutions. However, for non-conducting solutions, the voltage may be directly applied to the fluids by incorporating salts[14].

1.1.2. Fiber formation

The polarization of the polymeric solutions depends upon the applied voltage, generating the propulsion of a polymeric jet, this voltage works to break the surface tension and promote the fluid elasticity in the polymer solution to distort the droplet into a conical-shaped structure known as the Taylor cone[15].

The formed jet falls to the ground creating a slight continuous polymeric filament. Then, before reaching the ground, the charged fluid is speeded in the presence of the electrostatic field[16].

The falling fluid is charged and accelerated, and thus stretched and succumb to one or more fluid instabilities which distort, then many spirals and distorted paths are formed, before being collected at the collector electrode. This region of variability is also known as the whipping region[17]

Diverse kinds of collectors can be used, including static collector, rotating drum collectors, rotating wheel with a beveled edge, moving belt collector, multifilament thread, parallel bars, and simple mesh collector[3]

A variety of parameters can be optimized in order to generate nanofibers with controlled morphology, such as:

1.2. Solution-related parameters

Polymer molecular weight: Higher molecular weight, less probability of droplet filling the collector
Polymer concentration: Higher concentration, less dripping, and increased fiber diameter
Solution conductivity: Increasing conductivity reduces defects in the fiber and reduces its diameter
Surface tension: Lower tension favors fiber production

1.3. Processing parameters

Applied voltage: Higher voltage, higher probability of dripping
Distance to collector: Greater distance, smaller diameter in the fibers, and less humidity in them
Flow rate: Higher speed, higher fiber moisture
Collectors: Different collectors, different fiber arrangement

1.4. Environmental parameters

Temperature: Higher temperature, smaller diameter in the fiber
Humidity: Low humidity, fast solvent evaporation[18]

Respecting the fiber morphology, among the electrospinning parameters that affect the fiber morphology, the low concentrations/viscosities yield defects in the form of beads and junctions; this last effect can be avoided by increasing concentration/viscosity which reduces the defects. Fiber diameters can be increased when the concentration/viscosity is incremented. Moreover, the increase of conductivity helps in the production of uniform bead-free fibers. Finally, higher conductivities yield smaller fibers in general[19].

It has been discussed, that a conclusive relationship established between surface tension and fiber morphology does not exist. Increasing polymer molecular weight reduces the number of beads and droplets. On the other hand, successful spinning occurs in solvents with a high dielectric constant. Lower flow rates yield fibers with smaller diameters, and high flow rates may produce fibers that are not dry upon reaching the collector. At extreme high voltage, beading is observed.

Nevertheless, the correlation between voltage and fiber diameter is ambiguous. A minimum distance is required to obtain dried fibers. At distances, either too close or too far, beading is observed. Nanofibers can be synthesized with a great variety of specific secondary structures using different strategies: nanofiber with core/shell structures, hollow interiors, and porous structures[20].

On the other hand, using the coaxial electrospinning technique, hollow fibers are obtained. Multiple needle tips are employed to increase the throughput. Smoother fibers result from metal collectors; highly porous fiber structures are obtained using porous collectors. Aligned fibers are obtained using a conductive frame, rotating drum, or a wheel-like bobbin collector. Finally, increasing temperatures cause a decrease in the solution's viscosity, thus resulting in smaller fibers; while increasing humidity results in the appearance of circular pores on the fibers[21].

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