COAXIAL ELECTRODES FOR ELECTROSPINNING

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Abstract

Coaxial nanofibers are bi-component nanofibers produced by technology known as coaxial electrospinning. Coaxial electrospinning is a unique technique recently developed to incorporate drugs and bioactive agents in composite nanofibers with core/shell structure. This technology allows production of nanofibers with various chemical and physical properties. Three types of coaxial electrodes were developed with respect to producibility and the material used. Needle coaxial spinning electrode is used for small amounts of polymeric material and low productivity of nanofibers. Cylindrical and Cleft coaxial spinning electrodes allow to increase the productivity of nanofibers. All these electrodes and electrospinning device were developed for cluster Nanoprogres by the Technical University of Liberec.

Keywords: Coaxial nanofibers, electrospinning, coaxial electrodes.

1. INTRODUCTION

Currently, a great effort is devoted to the development of nanofibrous layers produced by electrospinning. General properties of nanofibers are its diameters in nanometer-scale and therefore large specific surface of fibers. Electrospinnng is one of the most conventional methods for producing nanofibers in different forms, such as core/shell nanofibers. Various drugs such as antibiotics, analgesics, vitamins, etc. can be incorporated in the core using coaxial electrospinning [1, 2].

With application of core/shell nanofibers, the unstable biological agents can be protected from harsh environments, deliver the bioactive molecules or drugs in a sustained way, and functionalize the surface of the nanostructures without affecting the core material [3].

Coaxial technique involves the use of a compound electrode consisting of two coaxial capillaries, through which two miscible or immiscible components can be electrospun simultaneously. In this manner, drugs or their mixtures can be encapsulated by a polymeric shell layer, leading to sustained and smooth release of these agents for an optimal period of time [4].

Core/shell structure of nanofiber could be produced by using special designs of electrodes. A coaxial jet is formed by a coaxial spinneret when two different liquids flow through outer and inner capillaries simultaneously. Both capillaries are connected to a high voltage power supply and nanofibers are consolidated during solvent evaporation. The feeding ratio of two components affects the uniformity and stability of the jet flow core.The shell thickness of the nanofiber can also be controlled by flow rates of liquids in the inner and outer capillaries during coaxial electrospinning. Other parameters, such as size of core/shell capillaries, applied electric field, volume feed rate, immiscibility of core/shell liquids, and their viscosity and conductivity, also play a crucial role in determining the uniform formation of core/shell jets and the morphology of the produced nanofibres in this electrospinning method [5]. Recently, both miscible and immiscible polymer blends have been electrospun into nanofibers by the phase separation phenomena [6]. The complex internal structure of nanofibers is formed via spontaneous phase separation during the electrospinning process [7].

Three types of coaxial electrodes were developed for cluster NANOPROGRES, z.s.p.o. by the Technical University of Liberec. NANOPROGRES, z.s.p.o. is an interest group of corporate bodies – companies, academic institutions and R&D institutions – founded to increase competitive strength and business support for nanotechnology, focusing on biomedicine. Vision of Nanoprogres, z.s.p.o is development and preparation technological procedures, products and services in the field of core/shell nanofibers for application in biomedicine. All developed coaxial electrodes will be introduced in this article.

2. APPROACH

Coaxial electrodes were designed and constructed for electrospinning device shown in Fig. 1 which was developed in cooperation with cluster Nanoprogres, z.s.p.o. This unique device for production of core/shell nanofibers allows electrospinning of a broad spectrum of materials primarily for use in medicine. Its great advantage is a versatility of choice of spinning electrodes in respect to spun materials and applications. The device construction allows easy replacement of the spinning electrode, spun materials, a collector and a substrate material for the nanofibers capture.

Needle spinning electrodes for electrospinning of a broad spectrum of liquid materials and two kinds of needleless electrodes to increase productivity of core/shell nanofibers will be introduced in the following subchapters.

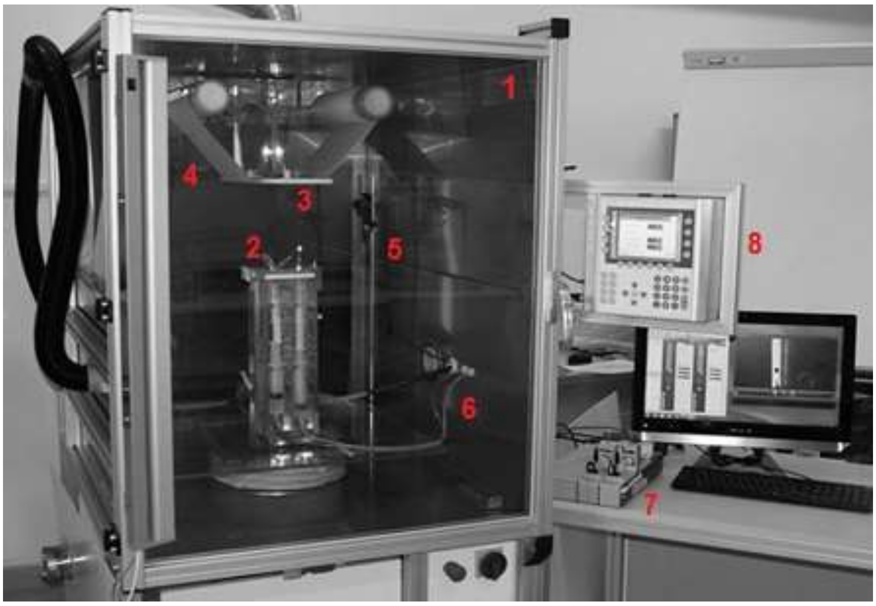
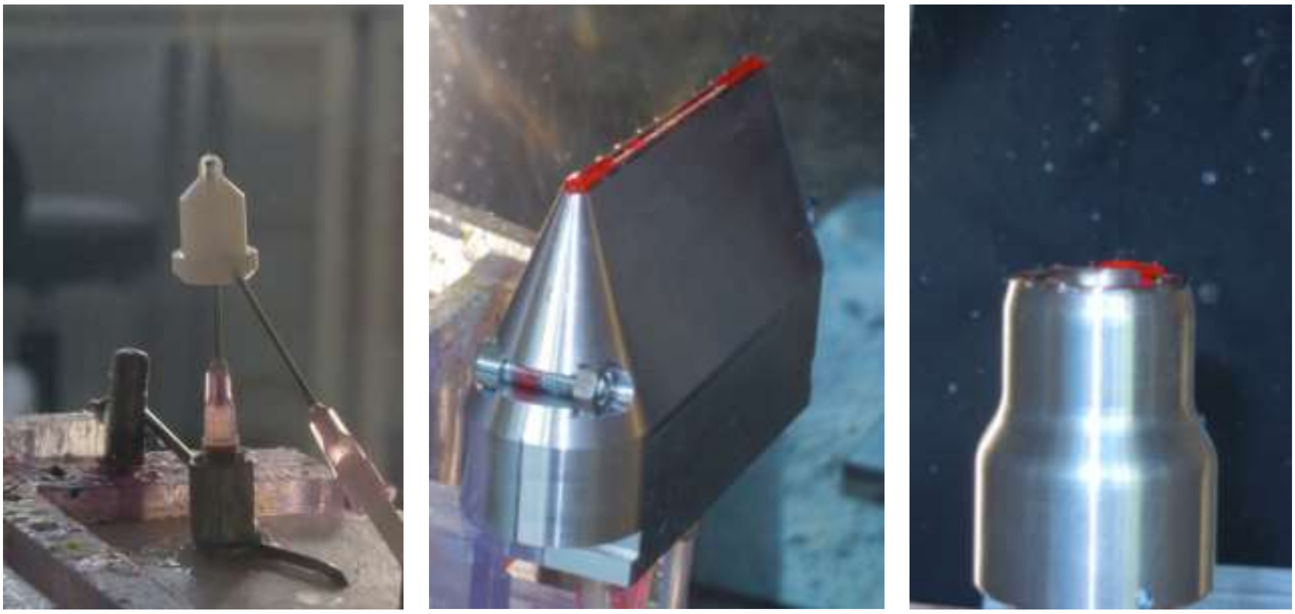


Fig. 1 Electrospinning device which is suitable for commercial use: (1) coaxial electrospinning device, (2) spinning electrode, (3) the collector, (4) the substrate material, (5) webcam for process control, (6) dosing system, (7) dosing pump, (8) the control panel.

2.1 Needle coaxial spinning electrode

The needle coaxial electrode consists of two coaxially arranged needles for feed of shell and core liquid material to the spinneret orifice (see Fig. 2 (a)). An advantage is a choice of a needle diameter in depending on the spun materials. We can also choose the height of the protruding inner needle from the orifice of the outer one. A great advantage is a spinneret material. We don’t use metal spinneret causing the loss of electrically energy, but spinneret consists from polymeric nonconductive materials. A maximum energy of process is focused on the bi-component polymeric droplet. Next advantage is easy process control. We can focus on the polymeric droplet and on the one Taylor cone during coaxial electrospinning. A disadvantage of this technology is low productivity of core/shell nanofibers.



(a) (b) (c)

Fig. 2 Types of coaxial electrodes: (a) Needle coaxial spinning electrode, (b) Cleft coaxial spinning electrode, (c) Cylindrical coaxial spinning electrode.

2.2 Cleft coaxial spinning electrode

The cleft coaxial spinning electrode, vide (Fig. 2 (b)) is a variant of needleless technology to increase the productivity of core/shell nanofibers. The first needleless coaxial electrode was developed at Technical University in Liberec and patented in 2009 under the name "Weir spinner" [8]. A principle is electrospinning from a free liquid surface of a polymeric two-layer. The cleft coaxial spinning electrode consists of three chambers. Two lateral chambers are supplied by a shell polymer solution and the inner one is feeding with a core material. The polymeric two-layer is created at the spinneret orifice. Many Taylor cones are formed on the top of the shell polymer solution (upper layer) and they pull up bottom layer like as their core part. Then, both polymer solutions are drawn and elongated together by the electrospinning jets and collected on the grounded collector.

The cleft coaxial spinning electrode has a special construction with a tiny orifice. The electric energy is concentrated on the polymeric two-layer and it isn't lost by metal spinneret. The unique construction of feeding chambers causes uniform creating of thin polymeric two-layer over the entire length of the spinner orifice. High production of core/shell nanofibers is advantage of this electrode.

2.3 Cylindrical coaxial spinning electrode

The cylindrical coaxial spinning electrode (see (Fig. 2 (c)) is a new variant of the needleless coaxial electrode consists of two lateral shell chambers and the inner core chamber. This special shape of needleless electrode with a smooth surface allows electrospinning without a lost energy. The electric energy is concentrated to places with sharp edges and these drain away energy from the electrospinning process. A special construction of the cylindrical coaxial spinning electrode without sharp edges (see Fig. 3 (a)) allows focusing the energy on the polymeric two-layer. A problem of this construction was a lower productivity of core/shell nanofibers because the orifice of electrode was too massive. The next step was a new construction of this electrode. The new cylindrical coaxial spinning electrode with a tiny orifice was developed (see Fig. 3 (b)). The productivity in this case was comparable with the cleft coaxial spinning electrode.

Fig. 3 Modification of the cylindrical coaxial spinning electrode (a) previous construction, (b) new construction.

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3. RESULTS AND DISCUSSION

Three types of coaxial electrodes were developed for electrospinning device. Needle, cylindrical and cleft coaxial spinning electrodes are able to produce of core/shell nanofibers but each of them has different advantage. Nonconductive material used for the needle spinneret doesn't cause the loss of electrically energy. Another advantage is the possibility follow the formation of the one Taylor cone on the polymeric droplet. Low productivity of core/shell nanofibers is disadvantage of this technology.

The construction of the cleft coaxial spinning electrode causes a creating of Taylor's cones along the entire length of the electrodes slot. An advantage of this electrode is a higher productivity. Difficult following the formation of individual Taylor cones and process control are disadvantages of this electrode.

The productivity cylindrical coaxial spinning electrode with a tiny orifice is comparable with the cleft coaxial spinning electrode. A great advantage of the cylindrical coaxial spinning electrode is its shape without sharp edges. This electrode with a smooth surface allows electrospinning without a lost energy. The electric energy is focusing on the polymeric two-layer. The choice of an electrode depends on the purpose the nanofibers are produced for.

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