



 Research Article

Collector and Dosing-Device Architectures in Electrospinning: A Classification by Product Dimensionality and Its Implications for Scale-Up

Journal Website:
<http://sciencebring.com/index.php/ijasr>

Copyright: Original content from this work may be used under the terms of the creative commons attributes 4.0 licence.

Submission Date: August 20, 2026, **Accepted Date:** September 16, 2026,

Published Date: October 10, 2026

Crossref doi: <https://doi.org/10.37547/ijasr-06-10-03>

Shohruxmirzo Mahsudov

Namangan State Technical University, Namangan, Uzbekistan

Sherzod Korabayev

Namangan State Technical University, Namangan, Uzbekistan

Fayzulla Bekchanov

Kimyo International University in Tashkent, Tashkent, Uzbekistan

Xusanxon Bobojanov

Namangan State Technical University, Namangan, Uzbekistan

ABSTRACT

The electrospinning process is physically identical in all installations, yet the products obtained from them differ radically in architecture, and the difference is determined almost entirely by the configuration of the electrodes and the dosing device rather than by the process parameters. This review classifies the reported collector and emitter architectures by the dimensionality of the product they yield — one-dimensional bundles and yarns, two-dimensional sheets and webs, and three-dimensional tubular and shaped constructs — and relates each architecture to the four intrinsic limitations of electrospinning: the polymodal distribution of fibre diameters, the occurrence of morphological defects, the disordered orientation of the deposited fibres, and the small number of capillaries that can be operated simultaneously. It is shown that the first two limitations are addressable only through the solution and the process regime, whereas the third and fourth are addressable only through hardware, so that collector and emitter design and formulation development are complementary rather than alternative routes to

improvement. A modern laboratory installation is analysed as a case study, and its configuration options are mapped onto the classification. The throughput limitation is then examined quantitatively: for a single-emitter laboratory system, the areal deposition rate implies an output that is two to three orders of magnitude below industrial requirements, and the multiplication factors available from multi-capillary, coaxial and free-surface emitters are compared.

KEYWORDS

Electrospinning; collector design; rotating drum; disc collector; coaxial emitter; multi-capillary; fibre alignment; scale-up; throughput.

1. INTRODUCTION

Electrospinning of polymer fibres is among the most effective processes for producing nanofibrous materials, and the basic diagram of the process is the same for every installation: a polymer solution is delivered through a capillary held at high potential, a charged jet is emitted

from the conical meniscus at its tip, the jet is stretched and split by electrostatic forces while the solvent evaporates, and the resulting fibres are deposited on a collecting electrode [1–3]. The schematic of this arrangement is shown in Fig. 1.

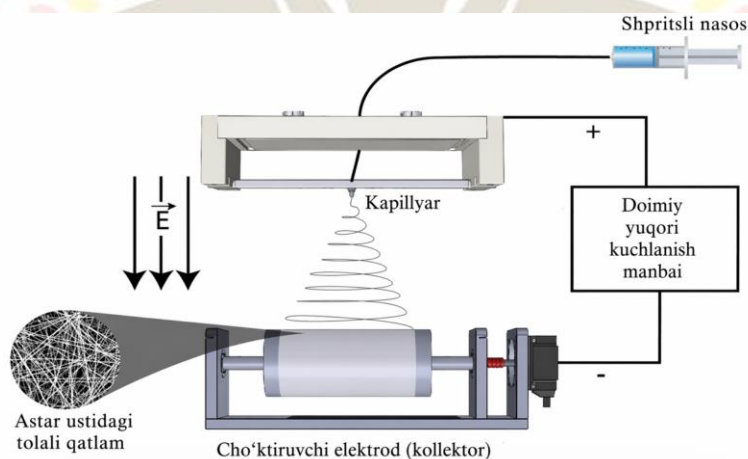


Fig. 1. Schematic diagram of the production of nanofibrous materials by electrospinning.

The specific technical implementation of this scheme, however, determines the type and, in large measure, the quality of the resulting product. The geometry of the electrodes, their relative arrangement, their velocity of motion, and the number or absence of capillaries

determine the orientation of the fibres in the product, their length and the dimensions of the product — sheet, continuous tape, tube or yarn [3]. A process description that specifies only voltage, distance and feed rate is therefore incomplete: two installations operating at

identical parameters but with different collectors will produce materials that are not interchangeable.

Despite this, hardware configuration is reported far less systematically than the electrical parameters, and comparative treatments are scarce. Reviews of electrospinning generally devote extensive space to solution and process variables and treat the collector as a boundary condition.

The aim of this review is to classify the reported collector and dosing-device architectures according to the dimensionality of the product they yield, to relate each architecture to the intrinsic limitations of the process, and to examine quantitatively the throughput limitation that determines whether a given architecture can be scaled to industrial output.

2. Intrinsic limitations of the electrospinning process

Electrospinning has a number of intrinsic shortcomings that any hardware configuration must be judged against [3]:

- a polymodal distribution of fibre diameters, that is, the diameter within a single specimen is represented across a range of values rather than at a single value;
- the presence of various defects in the fibres: branching points or fusion of fibres, distortion of the cylindrical shape of the fibre through necking or thickening, and flattening of the fibres;
- a disordered, non-oriented arrangement of the deposited fibres;
- the relatively small number of capillary nozzles that can be operated simultaneously in a single installation.

The first two shortcomings can be partly eliminated by correct preparation of the spinning solution and by selection of the process regime. With appropriate choice of solvent, polymer

concentration, solution flow rate, voltage, capillary-to-collector distance, and the temperature and solvent vapour pressure in the deposition zone, the process can be carried out up to the limit of fibre splitting; in this case the spread of fibre diameters and the occurrence of the defects listed above are minimal.

The third and fourth shortcomings can be partly eliminated only by hardware means. This division is the organising principle of the present review: formulation work and hardware design address disjoint sets of limitations, so that neither can substitute for the other. A laboratory that has optimised its solution to the point of minimal diameter spread has done nothing about orientation or throughput, and vice versa.

3. Classification of collector architectures

3.1. Basis of the classification

Collector architectures are classified here by the dimensionality of the product they yield. A zero-dimensional or isotropic product is a web in which no direction is preferred; a one-dimensional product is a bundle, tow or yarn in which the fibres are collinear; a two-dimensional product is a sheet or tape in which the fibres lie predominantly along one direction within the plane; and a three-dimensional product is a tube or shaped construct whose geometry is imposed by the collector.

This basis is preferred to a classification by mechanical form (plate, drum, disc) because it is the product architecture, not the hardware form, that determines fitness for a given application; two different hardware forms yielding the same product dimensionality are interchangeable from the designer's point of view.

3.2. Isotropic and two-dimensional collectors

The simplest collector is a stationary plate, on which fibres deposit in a random, non-oriented arrangement. It yields an isotropic web and is

used where the extracellular matrix of a tissue is to be imitated, since a random arrangement mimics that structure closely, or where the material is intended as a dressing or a cosmetic film.

A rotating cylindrical drum is the most widely used collector for two-dimensional products. A substrate is fixed to the drum surface and the deposited fibres are drawn along the peripheral direction. Standard laboratory dimensions are a diameter of 100 mm and a length of 200 mm; combined with a scanning motion of the emitter, such a drum permits the production of uniform coatings or electrospun sheets up to 200 × 310 mm. The degree of alignment achieved is governed by the peripheral velocity, which for a drum of diameter D rotating at n revolutions per minute is

$$v = \pi \cdot D \cdot n / 60. \quad (1)$$

For a 100 mm drum, rotational speeds of 100–2000 min^{-1} correspond to peripheral velocities of 0.52–10.5 m s^{-1} , which covers the range from random to strongly aligned deposition.

A disc collector with a sharpened edge concentrates the electric field at the rim and collects fibres into an aligned band; maximum diameters of about 100 mm are typical for laboratory units. Wire-drum and knife-electrode arrangements achieve the same end by structuring the field rather than by mechanical drawing: fibres bridge between adjacent conductors and are therefore laid down parallel to one another. These arrangements yield higher degrees of alignment than a plain drum at a given

speed, at the cost of a more complex design and of a deposition area limited by the electrode spacing.

3.3. One-dimensional collectors

Where the product is to be a continuous bundle or yarn rather than a sheet, the collecting electrode is reduced to a narrow disc or to a pair of parallel linear knife electrodes, and the collected fibres are drawn off continuously. The principal advantage of these schemes is simplicity together with the ability to produce long continuous bundles in which the fibres are highly aligned; the principal limitation is low throughput, since the deposition area is by design very small.

3.4. Three-dimensional collectors

A rod or mandrel collector produces tubular structures with nanofibre walls. Rods of different diameters, typically 1–15 mm, can be mounted, with a maximum rod length of about 200 mm. This is the standard route to vascular grafts and nerve conduits, and it is the configuration used in the bilayer vascular constructs reported in the tissue-engineering literature, where an inner layer of randomly arranged fibres is followed by an outer layer deposited at a different rotational speed [4, 5].

More elaborate three-dimensional collectors — structured deposition electrodes carrying a relief, or rotating tubular collectors with knife electrodes — impose a patterned architecture on the deposited web. Their advantage is the ability to obtain two-dimensionally oriented fibres or patterned constructs in a single operation; their limitation is a complex design and a degree of ordering that falls as the deposited layer thickens and screens the underlying field.

Table 1 summarises the classification.

**Table 1. Classification of collector architectures by product dimensionality.**

Collector architecture	Product	Typical dimensions	Principal advantage	Principal limitation
Stationary plate	isotropic web	limited by field spread	simplicity; mimics native ECM	no alignment; small area
Rotating drum	2D sheet or tape	ø100 × 200 mm; up to 200 × 310 mm with emitter scanning	alignment adjustable via peripheral velocity	alignment limited at low speeds
Disc with sharpened edge	aligned band	ø up to 100 mm	high alignment	very small deposition area
Wire drum / knife electrodes	2D aligned sheet	set by electrode spacing	high alignment at low speed	complex design; ordering falls with thickness
Narrow disc / linear knives	1D bundle, yarn	continuous length	long continuous aligned tows	very low throughput
Rod or mandrel	3D tube	ø1–15 mm, length ≤200 mm	tubular walls in one operation	diameter limited; wall uniformity
Structured 3D electrode	patterned construct	design-dependent	patterned architecture in one step	field screening as layer thickens

4. Dosing-device architectures

The design of the dosing device determines not only whether uniform fibres are obtained but also whether the fibre can be given an internal structure. Depending on its configuration, it is possible to produce not only homogeneous fibres but also bilayer, porous or two- and three-component fibres, as well as materials made from mixed fibres of different composition. The throughput of the electrospinning process also depends on the design of the dosing device [3].

Four families are distinguished. A single-phase emitter consists of one capillary and yields

homogeneous fibres; its construction normally allows the capillary needle to be removed and replaced, so that needles of different sizes can be used, with external diameters from 0.15 to 3.2 mm and internal diameters from 0.08 to 2.6 mm. A coaxial emitter delivers two solutions through concentric capillaries and yields fibres or particles with a core-shell structure. It has a secondary but practically important function: by supplying pure solvent through the outer needle, it prevents the clogging of the needle tip that occurs when solutions are formed with volatile solvents, since the tip is kept wetted.

Two- and three-component capillaries placed side by side yield fibres of Janus or multi-sectional



cross-section, and are used where two materials with different degradation rates must be combined within a single fibre.

Multi-capillary systems and free-surface (needleless) emitters address the fourth intrinsic limitation, that of throughput. Their advantage is a high process output; their limitations are a wide spread of fibre diameters and sizes in the multi-

capillary case, and, in the free-surface case, the absence of the clogging problem at the cost of much less precise control over the emission points.

Table 2 summarises the dosing-device architectures against the fibre structure they yield and their throughput implications.

Table 2. Dosing-device architectures, fibre structure and throughput.

Dosing device	Fibre structure obtained	Relative throughput	Principal limitation
Single capillary	homogeneous	1 (reference)	low output
Coaxial (core-shell)	core-shell; hollow after core removal	≈ 1	two solutions must be compatible
Two- or three-component capillary	Janus / multi-sectional	≈ 1	alignment of the streams
Multi-capillary array	homogeneous, per capillary	proportional to capillary count	wide diameter spread; interference between jets
Free-surface (needleless)	homogeneous	high	poor control of emission points
Emitter with gas blowing	homogeneous, finer	≈ 1	additional gas supply and control

5. Case study: configuration options of a laboratory installation

A modern laboratory system illustrates how the architectures of Sections 3 and 4 are combined in practice. The installation considered here is equipped with a stainless steel, aluminium and glass chamber chemically resistant to organic solvents, with transparent front door, ceiling and rear panel; the chamber is sealed, thermally

insulated and airtight, which permits rapid cooling [6].

Its electrical configuration provides a high-frequency voltage source for polarisation of the emitter, adjustable from 0 to 30 kV and protected against arcing and short circuits, together with a second adjustable negative supply for the collector in the range 0 to -10 kV. The second supply allows the maximum potential difference between emitter and collector to be increased beyond the rating of a single source — up to +30 kV and -10 kV — which is important when multi-

emitter rotating heads are used, and it increases the efficiency with which atomised particles and fibres are collected.

Solution delivery is by syringe pump with a volume of up to 140 mL and a flow rate from 0.1 to 1000 mL h⁻¹; a second syringe pump is provided for the coaxial head. The emitter-to-collector distance is set manually from 0 to 290 mm. A universal rotating collector platform accepts interchangeable drum, mandrel or disc collectors up to 200 mm in length, with rotational speeds from 100 to 2000 min⁻¹, which by Eq. (1) corresponds to peripheral velocities of 0.52–10.5 m s⁻¹ for a 100 mm drum.

Auxiliary systems include an emitter scanning stage, which in combination with the rotating drum permits uniform micro- and nanofibre sheets up to 200 × 310 mm and allows two stages to be installed for the simultaneous deposition of two materials; a passive or actively regulated extraction system with inlet and outlet pressure sensors maintaining a slight negative pressure inside the chamber for operator safety;

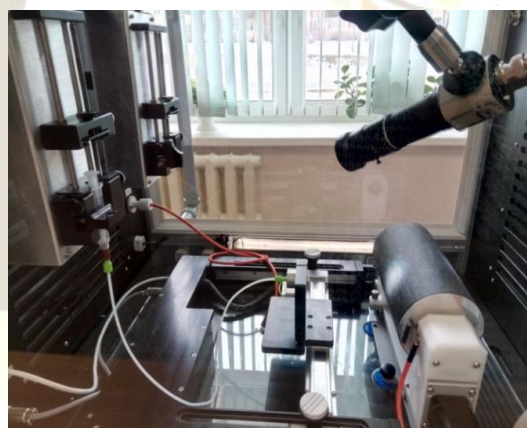
temperature and humidity sensors displaying ambient conditions in real time; a camera with an objective lens for detailed observation of the Taylor cone and of the rotating jet; remote diagnostics over Ethernet; and automatic recording and export of all processing parameters.

Mapping these options onto Table 1 shows that a single installation of this class can produce isotropic webs, aligned two-dimensional sheets, aligned bundles and tubular constructs without modification beyond exchanging the collector — but that it remains a single-emitter machine, and therefore addresses the third intrinsic limitation while leaving the fourth untouched.

The external appearance and internal arrangement of the installation are shown in Fig. 2 and Fig. 3. The internal view makes the geometric relationships explicit: the emitter is mounted on a horizontal axis facing the rotating collector, and the working distance is the adjustable parameter that couples the electrical and kinematic configurations.



a)



b)

Fig. 2. Laboratory electrospinning system used as the case study: a) external view; b) internal arrangement of the working chamber.

Two observations follow from the configuration list. First, the provision of a second, negative supply for the collector is not merely a convenience: it decouples the achievable potential difference from the rating of the emitter supply, which becomes the binding constraint as soon as several emitters share one chamber. Second, the automatic recording and export of all processing parameters addresses directly the reproducibility problem identified in Section 7, since it removes the dependence on manual transcription of the regime.

6. The throughput limitation

The fourth intrinsic limitation deserves quantitative treatment, because it is the one that determines whether a laboratory result can become a product.

Consider a single-emitter system operating at a feed rate of 5 mL h^{-1} with a solution containing 11 wt% of polymer at a density of 1.235 g cm^{-3} . The dry polymer output is then

$$\dot{m} = Q \cdot \rho \cdot w = 5 \times 1.235 \times 0.11 \approx 0.68 \text{ g h}^{-1}. \quad (2)$$

If this output is deposited over a substrate of $34 \times 19 \text{ cm}$, that is 0.065 m^2 , the areal density accumulated in one hour is approximately 10.5 g m^{-2} , which is a realistic value for a functional nanofibre mat. The corresponding areal production rate is thus of the order of $0.065 \text{ m}^2 \text{ h}^{-1}$ per emitter.

A semi-industrial line producing a continuous nanofibre tape 3 m wide at even a modest line speed of 1 m min^{-1} would require $180 \text{ m}^2 \text{ h}^{-1}$, that is a factor of about 2.8×10^3 above the single-emitter figure. Multi-capillary heads reported in the literature provide multiplication factors of the order of 10–100; free-surface emitters provide more, at the cost of diameter control. The gap between laboratory and industrial output is therefore not closed by any single measure, and

realistic scale-up requires the combination of a multi-emitter head, emitter scanning and continuous substrate transport.

This quantitative gap also explains an observation made in the economic analysis of laboratory-scale nanofibre production: because the throughput is set by the emitter and the staffing and depreciation are set by the machine, fixed costs dominate the unit cost, and the single most effective economic intervention is to multiply the number of emitters rather than to reduce material costs [7].

7. DISCUSSION

The classification proposed here has two practical consequences. The first is that collector selection should follow from the required product architecture and not from what is available: a rotating drum used because it is the standard fitting, in an application where an isotropic web is required, wastes both the alignment capability and the additional process variability that a rotating collector introduces. The second is that the four intrinsic limitations partition cleanly between formulation and hardware, so that a development programme that addresses only one of the two will reach a ceiling.

A further observation concerns reporting. Since the product architecture is determined by the collector, a process description that omits the collector type and, for rotating collectors, the peripheral velocity, is not reproducible. The practice of reporting rotational speed alone is particularly problematic, because the same speed on drums of different diameter produces different degrees of alignment; Eq. (1) should be applied before the value is reported.

The present review has limitations. It is based on the architectures described in a defined body of work rather than on an exhaustive survey of the

patent literature, where many further collector geometries have been proposed. Quantitative comparisons of alignment quality between architectures are not possible from the available sources, because alignment is reported variously as a mean deviation angle, as the fraction of fibres within a stated angular window, or only qualitatively. The throughput estimate of Section 6 uses a single representative formulation and should be scaled with the polymer content of any other solution considered.

8. CONCLUSIONS

Collector and dosing-device architectures reported for electrospinning were classified by the dimensionality of the product they yield — isotropic webs, one-dimensional bundles, two-dimensional sheets and three-dimensional tubular or patterned constructs — and each architecture was related to its typical dimensions, advantages and limitations.

The four intrinsic limitations of electrospinning partition into two groups: the polymodal diameter distribution and the morphological defects are addressable through the solution and the process regime, whereas disordered orientation and low throughput are addressable only through hardware. Formulation development and hardware design are therefore complementary and neither can substitute for the other.

A modern laboratory installation was analysed as a case study and shown to cover the full range of product architectures by collector exchange alone, while remaining a single-emitter machine that does not address the throughput limitation. The throughput gap was quantified: a single emitter operating at 5 mL h^{-1} with an 11 wt% solution yields approximately 0.68 g h^{-1} of dry polymer over 0.065 m^2 , whereas a 3 m wide semi-

industrial line at 1 m min^{-1} would require some $180 \text{ m}^2 \text{ h}^{-1}$ — a factor of about 2.8×10^3 . Closing this gap requires the combination of multi-emitter heads, emitter scanning and continuous substrate transport rather than any single measure.

Finally, it is recommended that process descriptions report the collector type and, for rotating collectors, the peripheral velocity computed from Eq. (1), since rotational speed alone is not reproducible across drums of different diameter.

Funding. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

1. Doshi J, Reneker DH. Electrospinning process and applications of electrospun fibers. *J Electrostat.* 1995;35(2-3):151-60.
2. Reneker DH, Chun I. Nanometre diameter fibres of polymer, produced by electrospinning. *Nanotechnology.* 1996;7(3):216-23.
3. Filatov YuN. Electroforming of fibrous materials (EFV process). Kirichenko VN, editor. Moscow: Karpov Institute of Physical Chemistry; 1997.
4. Vaz CM, van Tuijl S, Bouten CVC, Baaijens FPT. Design of scaffolds for blood vessel tissue engineering using a multi-layering

- electrospinning technique. *Acta Biomater.* 2005;1(5):575–82.
5. Ju YM, Choi JS, Atala A, Yoo JJ, Lee SJ. Bilayered scaffold for engineering cellularized blood vessels. *Biomaterials.* 2010;31(15):4313–21.
 6. Bionicia. Fluidnatek LE-50 electrospinning system: technical description. Valencia; 2020.
 7. Petrov AV, Simonov-Emelyanov ID, Filatov YuN. Criterial parameters for the evaluation of polymer solutions for the electrospinning of fibres. *Vestnik MITHT.* 2012;7(5):103–7.
 8. Katta P, Alessandro M, Ramsier RD, Chase GG. Continuous electrospinning of aligned polymer nanofibers onto a wire drum collector. *Nano Lett.* 2004;4(11):2215–8.
 9. Lei T, Peng Q, Chen Q, Xiong J, Zhang F, Sun D. Alignment of electrospun fibers using the whipping instability. *Mater Lett.* 2017;193:248–50.
 10. Dorati R, Chiesa E, Pisani S, Genta I, Modena T, Bruni G, et al. The effect of process parameters on alignment of tubular electrospun nanofibers for tissue regeneration purposes. *J Drug Deliv Sci Technol.* 2020;58:101781.
 11. Shin YM, Hohman MM, Brenner MP, Rutledge GC. Experimental characterization of electrospinning: the electrically forced jet and instabilities. *Polymer.* 2001;42(25):9955–67.
 12. Hohman MM, Shin M, Rutledge G, Brenner MP. Electrospinning and electrically forced jets. I. Stability theory. *Phys Fluids.* 2001;13(8):2201–20.
 13. Taylor GI. Electrically driven jets. *Proc R Soc Lond A.* 1969;313(1515):453–75.
 14. Deitzel JM, Kleinmeyer J, Harris D, Beck Tan NC. The effect of processing variables on the morphology of electrospun nanofibers and textiles. *Polymer.* 2001;42(1):261–72.
 15. Fong H, Chun I, Reneker DH. Beaded nanofibers formed during electrospinning. *Polymer.* 1999;40(16):4585–92.
 16. Sill TJ, von Recum HA. Electrospinning: applications in drug delivery and tissue engineering. *Biomaterials.* 2008;29(13):1989–2006.
 17. Agarwal S, Wendorff JH, Greiner A. Use of electrospinning technique for biomedical applications. *Polymer.* 2008;49(26):5603–21.
 18. Pozzobon LG, Sperling LE, Teixeira CE, Malysz T, Pranke P. Development of a conduit of PLGA-gelatin aligned nanofibers produced by electrospinning for peripheral nerve regeneration. *Chem Biol Interact.* 2021;348:109621.
 19. Zhang X, Reagan MR, Kaplan DL. Electrospun silk biomaterial scaffolds for regenerative medicine. *Adv Drug Deliv Rev.* 2009;61(12):988–1006.
 20. Ayutsede J, Gandhi M, Sukigara S, Micklus M, Chen HE, Ko F. Regeneration of Bombyx mori silk by electrospinning. Part 3: characterization of electrospun nonwoven mat. *Polymer.* 2005;46(5):1625–34.