Research Papers

GREENSUSMATER

Greensusmater
Vol. 3, No. 1, 2026
https://doi.org/10.62755/gsm.2026.06
Check for updates

A Novel Fiber Collection System for Rotary Force Spinning Method

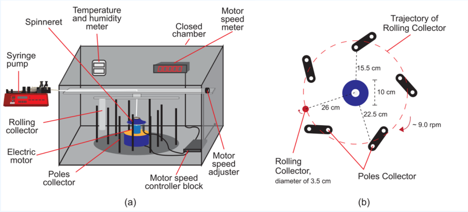
Dian Ahmad Hapidin[1,*], Elvina Ayu Ratnasari[2], Aan Priyanto[1], Khairurrijal Khairurrijal[1,3,4]

[1] *Research Group of Physics and Technology of Advanced Materials, Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Jalan Ganesa No. 10, Bandung, Jawa Barat 40132, Indonesia*
[2] *Research Center for Space, National Research and Innovation Agency (BRIN), Indonesia*
[3] *University Center of Excellence – Nutraceutical, Bioscience and Biotechnology Research Center, Institut Teknologi Bandung, Jalan Ganesa No. 10, Bandung, Jawa Barat 40132, Indonesia*
[4] *Department of Physics, Faculty of Science, Institut Teknologi Sumatera, Jalan Terusan Ryacudu, Lampung Selatan, Lampung 35365, Indonesia*

Corresponding author: dian.ahmad@itb.ac.id

ARTICLE HISTORY: Received: March 9, 2026 | Revised: May 9, 2026 | Accepted: May 14, 2026

ABSTRACT



Recent advancements in micro- to nano-scale fiber production, particularly through rotary force spinning (RFS), offer high production rates but face challenges in optimizing fiber collection efficiency. This study investigates the effect of spinneret angular speed on fiber collection performance of a novel RFS collector system. The collector system integrated zig-zag pole collectors with a rolling collector that seamlessly traverse between the poles for fiber assembly. This configuration enabled the produced fibers to be continuously assembled onto the rolling collector, thereby forming fibrous membranes directly during the spinning process. The collection performance was evaluated using polyvinylpyrrolidone (PVP) fibers fabricated at spinneret angular speeds ranging from 4000 to 11000 rpm. The results showed that the rolling collector captured up to 95.39% of the produced fibers at a high rotational speed of 11,000 rpm, whereas at lower rotational speed, most fibers were deposited onto the pole collectors, reaching 95.19% at 4000 rpm. These findings indicate that the proposed collector system effectively enhances fiber collection efficiency over a broad rotational speed range while enabling direct fibrous membrane formation in the RFS process.

Keywords: *Rotary force spinning; Fiber collection efficiency; Zig-zag pole collector; Rolling collector; Spinneret angular speed; Polyvinylpyrrolidone (PVP) fibers; Fibrous membrane*

1. INTRODUCTION

Multifunctional one-dimensional fibrous materials are extensively utilized across diverse fields. Their applications span various sectors including food, biomedicine, energy, and environmental domains. Research endeavors in fibers development persist, with researchers worldwide continuously exploring diverse strategies to achieve optimal fiber production. Several well-established methods for micro- to nano-scale fiber fabrication include electrospinning, solution blow spinning, island-in-the-sea spinning, phase separation, template synthesis, and rotary force spinning (RFS). RFS, also referred to as centrifugal jet spinning, has emerged as a prominent method for producing fibers characterized by high production rates and cost-effectiveness [1,2,3]. Typically, an RFS apparatus comprises essential components such as a spinneret, an electric motor, and a fiber collector system [2,4,5]. Utilizing centrifugal force generated by the electric motor, RFS ejects polymeric solution from the spinneret, leading to the formation of fibers collected at the collector system [2,4]. Various parameters, including polymer viscosity, surface tension, spinneret angular speed, and spinneret-to-collector distance, influence the properties of fibers produced via the RFS technique [2,5,6,7]. Additionally, process parameters such as spinneret angular speed and collector system structure are considered to significantly impact fiber collection efficiency.

Fiber collection efficacy is closely linked to the structure of the collector system. Unlike electrospinning systems that eject jets toward a specific spot on the collector, RFS systems eject jets radially, causing the fabricated fibers to disperse over a wider area around the spinneret. Consequently, RFS systems generally face greater difficulty in obtaining collected fibers in the form of membranes with high fiber density. Conventionally, RFS devices are equipped with various types of collector systems, such as pole collectors [2,6,8], rolling charged-drums [9], and wall-like collector systems [10] to facilitate fiber assembly. While poles and wall-like collector systems can achieve fiber assembly, they necessitate further processing to obtain collected fibers in the form of fibrous membranes. Conversely, the rolling charged-drum collector can produce fibrous membranes directly but involves high voltage operation, rendering it inefficient. Thus, there is a pressing need for an RFS collector system capable of achieving high collection efficiency and directly yielding fibrous membranes without additional processing steps.

This study aims to develop a novel collector system for the RFS apparatus and investigate the impact of spinneret angular speed on fiber collection efficiency. The newly devised collector system integrates poles and a rolling collector, with the poles arranged in a zig-zag configuration around the spinneret at specific intervals. This arrangement enables the

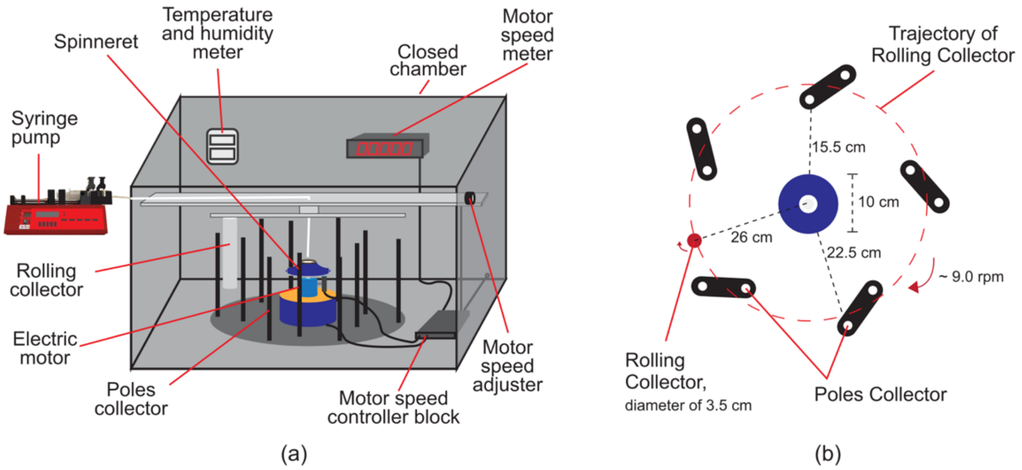


Figure 1. (a) Setup of RFS device, ILMI-N301 with modified collector system; (b) Schematic of a new collector system.

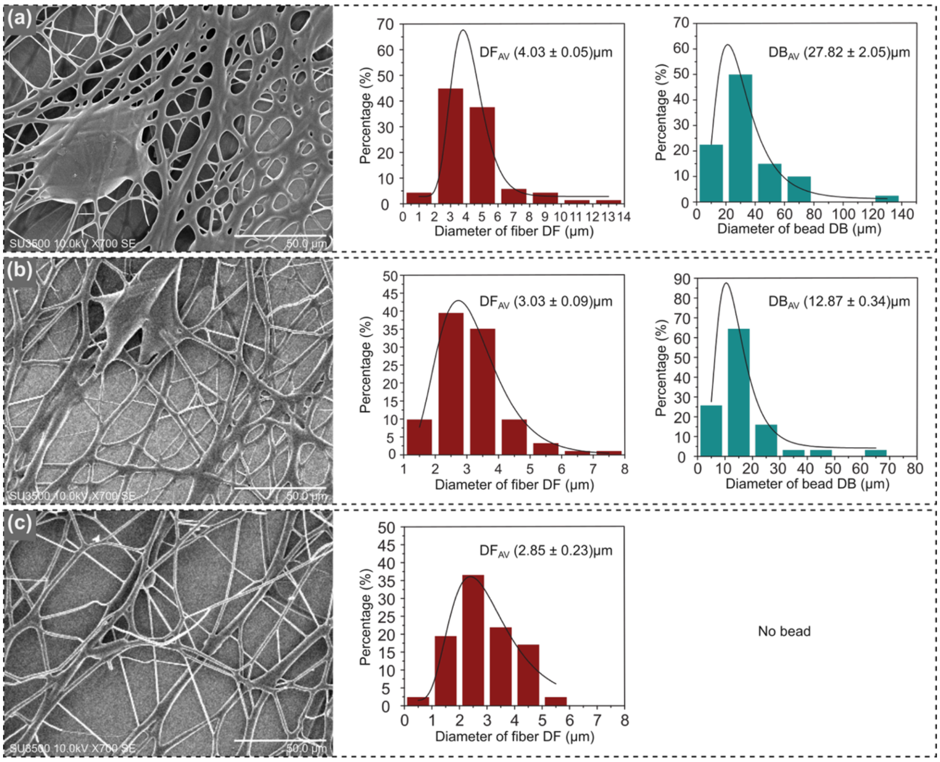


Figure 2. Morphology and diameter distribution of fibers and beads produced at: (a) 4500 rpm, (b) 6500 rpm, and (c) 10000 rpm.

rolling collector to seamlessly traverse between the poles for directly assembling fibers into membranes.

2. MATERIALS AND METHOD

Polymeric solutions for the spinning process were prepared by dissolving polyvinylpyrrolidone (PVP) with an average molecular weight (Mw) of 1,300,000 at a concentration of 10% in absolute ethanol. Both PVP and absolute ethanol were procured from Sigma-Aldrich Chemicals. The PVP solutions were subsequently spun utilizing the RFS apparatus (ILMI-N301) [2,5,7] (depicted in Figure 1a), equipped with a modified collector system as schematically illustrated in Figure 1b. The novel collector system comprised poles and a rolling collector, with the poles arranged in a zig-zag pattern next to each other at a specific distance around the spinneret. This arrangement enabled the rolling collector to continuously pass between the poles along a circular trajectory, thereby improving fiber collection efficiency.

The fibers production process was executed at various spinneret angular speeds ranging from 4000 to 11000 rpm. The fiber collection efficiency of the collector system was evaluated by comparing the mass of fibers deposited on both the poles and the rolling collector with the total mass of fibers produced during the spinning process. Fiber fabrication was conducted under constant parameters, including a PVP solution flow rate of 20 ml/min, a temperature of 25°C, and a relative humidity of 58%. Subsequently, the morphology of the fibers was examined utilizing a Scanning Electron Microscope (SEM) (SU3500, HITACHI, Japan). Fiber and bead

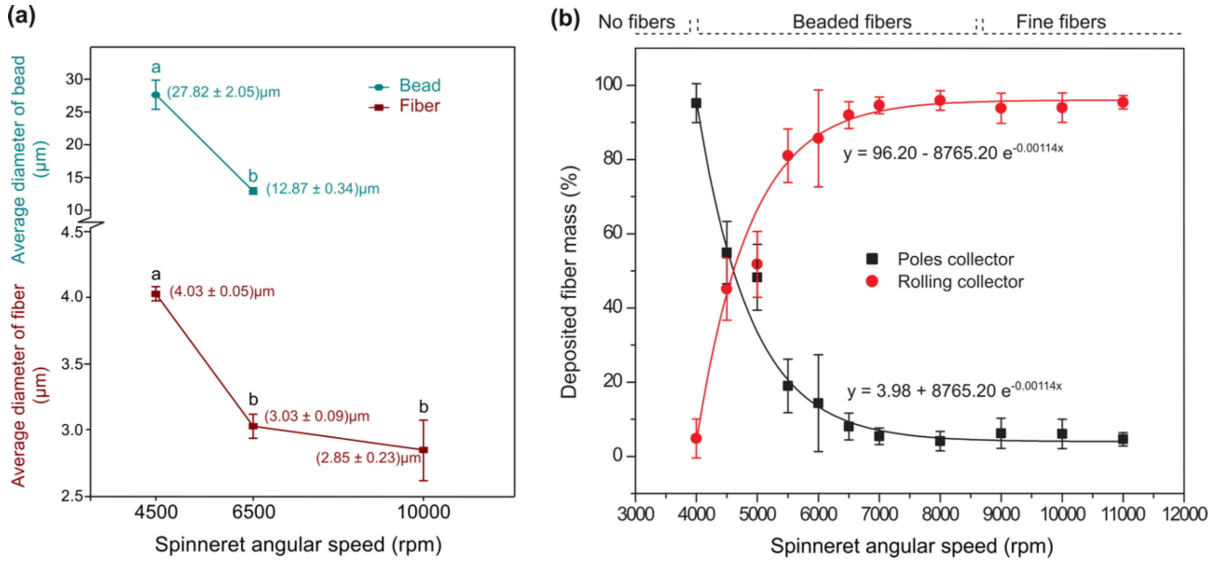


Figure 3. (a) The effect of spinneret angular speed on the average diameter of bead and fiber, (b)The effect of spinneret angular speed on the deposited fiber mass on poles and rolling collectors. The differences in letters reflect the outcomes of Tukey's one-way ANOVA statistical analysis, showing a significant difference with $p < 0.05$.

diameters were determined from SEM images utilizing ImageJ processing software provided by the National Institute of Health (USA) [11]. One-way ANOVA followed by Tukey's post hoc test was employed to evaluate the statistical significance of the effects of spinneret angular speed on fiber and bead diameters.

3. RESULTS AND DISCUSSION

PVP fibers on a micrometer scale were successfully fabricated using the RFS system equipped with a new rolling collector system. Figure 2 presents SEM images of the developed PVP fibers at various spinneret angular speeds. In general, bead formation became more pronounced at lower spinneret angular speeds. As depicted in Figure 2, the majority of beads were observed at 4500 rpm, appeared rarely at 6500 rpm, and almost disappeared entirely at 10000 rpm. The elevated angular speed of the spinneret, and consequently the increased centrifugal force, enhances the stretching of PVP jets, leading to a reduction in both bead and fiber diameters [1,2,4]. For instance, at spinneret angular speeds of 4500 rpm and 6500 rpm, beads with average diameters of (27.82 ± 2.05) μm and (12.87 ± 0.34) μm, respectively, were observed. At 10000 rpm, beads were no longer visible, and the developed fibers exhibited a smooth structure. Furthermore, spinneret angular speeds of 4500 rpm, 6500 rpm, and 10000 rpm produced microfibers with diameters of (4.03 ± 0.05) μm, (3.03 ± 0.09) μm, and (2.85 ± 0.23) μm, respectively.

The statistical analysis presented in Figure 3(a) further demonstrates the significant influence of the spinneret angular speed on both bead diameter and fiber diameter. The different statistical letters ("a" and "b") indicate a significant difference between these conditions according to Tukey's one-way ANOVA test ($p < 0.05$). The figure suggests that increasing spinneret angular speed from 4500 to 6500 rpm enhanced the centrifugal stretching force acting on the polymer jet, thereby reducing bead size significantly as indicated by different letter "a" and "b" for both conditions. A similar trend was observed for the average fiber diameter. Statistical analysis revealed that the fiber diameter at 4500 rpm was significantly different from those at 6500 and 10000 rpm, whereas no significant difference was observed between 6500 and 10000 rpm, as indicated by the identical statistical letter ("b"). These findings indicate that increasing spinneret angular speed up to 6500 rpm substantially reduced fiber diameter, while further increases in angular speed produced only marginal changes, suggesting the onset of a stabilization regime in fiber thinning behavior.

The disappearance of beads and the decrease in bead and fiber diameters with increasing spinneret angular speed are attributed to a parameter known as the critical angular speed of the spinneret for producing fine fibers. It is understood that the critical speed of the RFS system is intricately linked to the rheological properties of the spinning solution, environmental conditions, and inherent characteristics of the rotating system. Spinneret speeds below this critical threshold result in imperfectly formed fibers, often exhibiting bead formation. In extreme cases of low speed, the system may fail to produce fibers entirely [6].

In addition to affecting the fiber diameter, the spinning angular speed also influenced the percentage of fiber mass deposited on the poles and rolling collectors. Higher spinneret angular speeds resulted in a greater deposition of fibers on the rolling collector, as depicted in Figure 3. At lower speeds (4000 rpm), the pole collector captured 95.19% of fibers, while at higher speeds (11,000 rpm), the rolling collector captured 95.39%. At spinneret angular speeds exceeding 6500 rpm, more than 90% of the fibers were directed towards the rolling collector, indicating a predominant yield of fine fibers within this range. Hence, the integration of the novel rolling collector within this system has demonstrated improved fiber collection efficiency, especially at higher spinneret angular speed.

To elucidate the relationship between spinneret angular speed and the mass deposition on the rolling and pole collectors, Figure 4 illustrates the calculation of centrifugal force generated by a rotating spinneret. Centrifugal force (FC) was determined using Equation (1) [2,12]:

$$F_C = \frac{m\omega^2 D_R}{2} \tag{1}$$

where F_C is the centrifugal force (N), m is the mass of PVP solution (kg), ω is the spinneret angular speed (m/s), D_R is the diameter of solution reservoir (m).

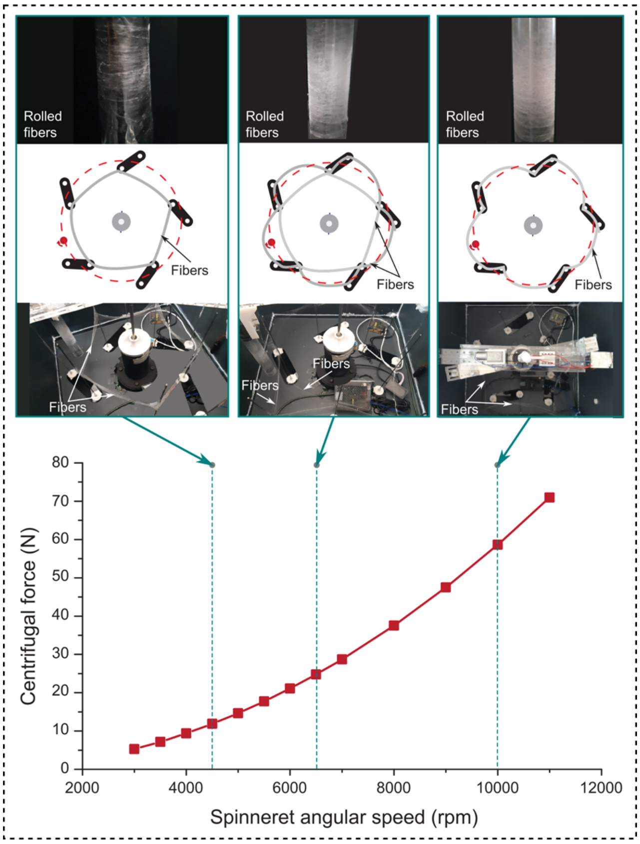


Figure 4. Magnitude of centrifugal forces resulting from various spinneret angular speeds and their effect to fiber formation and deposition on the collectors.

This force is directly proportional to the square of the spinneret angular speed, thus, an increase in spinneret angular speed correlates with an increase in centrifugal force. In RFS systems, centrifugal force constitutes the primary force governing fiber formation. It significantly propels the spinning solution within the spinneret, elongating it to form a jet. Increasing centrifugal force results in the fiber jets exhibiting more distant and consistent trajectories, leading to deposition onto the two collector poles, subsequently collected by the rolling collector traversing between them. This process is schematically depicted in Figure 4.

4. CONCLUSIONS

A novel collector system integrating zig-zag pole collectors and a rolling collector was successfully developed for RFS applications. The proposed system enabled direct formation of fibrous membranes on the rolling collector without requiring additional post-processing steps. The spinneret angular speed significantly affected the collection efficiency of the collector system, where higher angular speeds promoted greater fiber deposition onto the rolling collector. The rolling collector achieved the highest collection efficiency of up to 95.39% at 11000 rpm, demonstrating its effectiveness in collecting fibers at high spinneret angular speeds. Overall, the developed collector system shows strong potential for improving the practicality and efficiency of large-scale fibrous membrane fabrication using RFS technology. The high collection efficiency of the proposed collector system can minimize material loss during the spinning process and reduce production waste in large-scale fiber manufacturing.

ACKNOWLEDGMENTS

This research is funded by the ITB 3P Research Program 2026 (Pengembangan Unggulan Scheme) through the Directorate of Research and Innovation, Institut Teknologi Bandung (Project ID: DRI.PN-6-45-2026)

REFERENCES

[1] Rogalski J J, Bastiaansen C W M, Peijs T. PA6 Nanofibre Production: A Comparison between Rotary Jet Spinning and Electrospinning. *Fibers*. 2018;6(2):1-13. doi:10.3390/fib6020037.

[2] Priyanto A, Hapidin D A, Suciati T, Khairurrijal K. Current developments on rotary forcespun nanofibers and prospects for edible applications. *Food Engineering Reviews*. 2022;14:435-461. doi:10.1007/s12393-021-09304-w.

[3] Zhang Z-M, Duan Y-S, Xu Q, Zhang B. A review on nanofiber fabrication with the effect of high-speed centrifugal force field. *Journal of Engineered Fibers and Fabrics*. 2019;14:1-11. doi:10.1177/1558925019867517.

[4] Mellado P, McIlwee H A, Badrossamay M R, Goss J A, Mahadevan L, Parker K K. A simple model for nanofiber formation by rotary jet-spinning. *Applied Physics Letters*. 2011;99:203107. doi:10.1063/1.3662015.

[5] Priyanto A, Hapidin D A, Khairurrijal K. Potential loading of virgin coconut oil into centrifugally spun nanofibers for biomedical applications. *ChemBioEng Reviews*. 2022;9:393-408. doi:10.1002/cben.202100043.

[6] Lu Y, Li Y, Zhang S, Xu G, Fu K, Lee H, Zhang X. Parameter study and characterization for polyacrylonitrile nanofibers fabricated via centrifugal spinning process. *European Polymer Journal*. 2013;49:3834-3845. doi:10.1016/j.eurpolymj.2013.08.011.

[7] Priyanto A, Rohman Y M, Hapidin D A, Edikresnha D, Khairurrijal K. Rotary Forcespun Polyvinylpyrrolidone Fibers Matrix Loaded with Virgin Coconut Oil: Physicochemical Characterization, In Vitro Antioxidant Assessment, and Release Profile. *Food and Bioprocess Technology*. 2024;17:1926-1941. doi:10.1007/s11947-023-03237-4.

[8] Li Y, Mei S, Dong Y, She F, Kong L. The effect of centrifugal force on the fiber morphology in centrifugal spinning. *Polymers*. 2019;11:1-13. doi:10.3390/polym11010017.

[9] Muniz N O, Vechietti F A, Anesi G R, Guinea G V, Santos L A L dos. A review of centrifugal spinning for nanofiber production. *Journal of Materials Research*. 2020;35:2905-2916. doi:10.1557/jmr.2020.234.

[10] Edmondson D, Cooper A, Jana S, Wood D, Zhang M. Centrifugal electrospinning of highly aligned polymer nanofibers over a large area. *Journal of Materials Chemistry*. 2012;22:18646-18652. doi:10.1039/C2JM33812A.

[11] W. S. Rasband, ImageJ, U.S. National Institutes of Health, Bethesda, MD, USA, 1997–2018. Available at: https://imagej.nih.gov/ij/.

[12] Zhang X, Lu Y. Centrifugal spinning: An alternative approach to fabricate nanofibers at high speed and low cost. *Polymer Reviews*. 2014;54:677-701. doi:10.1080/15583724.2014.935853.