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# Influence of secondary stretching on diameter and morphology of bicomponent polymer nanofibers produced by gas jet fiber process

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ABSTRACT

This paper focuses on the effect of addition of a secondary gas jet on diameter and morphology of bi-component nanofibers produced using the gas jet fibers (GJF) process. In GJF process, a primary turbulent gas jet is used for liquid jet initiation, liquid jet stretching, and drying of the liquid jet into nanofibers. The secondary gas jet is added to provide additional stretching of the liquid jet so that fibers of even smaller diameter can be obtained. The location of the secondary jet in relation to the liquid delivery nozzle is varied to determine an area of influence of the secondary gas jet on fiber diameter and fiber morphology. The radius of the copper loop used to deliver the secondary gas jet is also varied to assess its effect on fiber diameter. The results show almost 100% reduction in nanofiber diameter of bilobal and interpenetrating network type nanofibers with appropriate placement of the secondary gas jet. The additional stretching also creates gradient morphology promoted by incomplete phase separation of the polymers as a consequence of much faster solvent loss.



## 1. Introduction

This work evaluated the utility of secondary air jets in conjunction with production of bi-component polymer nanofibers from metastable polymer solutions using a primary gas jet in Gas Jet Fiber (GJF) process [1–6]. The GJF process does not use electrical potential and relies on the stretching of the liquid jets under the influence of a primary turbulent gas jet. GJF process produces nanofibers of equivalent diameter at significantly higher rates than in single nozzle electrospinning [6].

Nanofibers are used in a wide range of applications, such as drug delivery, tissue engineering scaffolds, filtration, and protective clothing [7–15]. Better performance is observed in these applications if the fiber diameter is a few tens to hundreds of nanometer [7,8,16,17]. A number of fiber manufacturing processes are used to obtain nanofibers, such as the GJF process [1–6], drawing [18], electrospinning [16,19–21] melt blowing [22–24], or solution blowing process [25–27] to name a few. Electrospinning is the most popular method among the methods of production of nanofibers with successful scale-up to commercial production via simple modifications [20,28–34]. Smaller diameter fibers are produced in electrospinning by tuning the spinning parameters such as applied voltage, polymer solution feeding rate, and collector to tip distance, or by changing the polymer concentration, selecting a solvent of desired surface tension and electrical conductivity [8,16,20,31,35,36]. However, not all parameters can be changed at will to obtain desired fiber diameter and often the parameters are inter-related [37].

In view of this, a secondary thinning force, decoupled from the spinning parameters presents a viable option to obtain smaller diameter fibers. One example is the addition of external air flow to the existing electrospinning process. He et al. [38] prepared polyacrylonitrile nanofibers of about 170 nm diameter by using air-jet splitting electrospinning device. Air blowing-assisted electrospinning, called electroblowing [39], is another technique for controlling the diameter and the morphology of nanofibers by combining the process of electrospinning with air blown around the spinneret. Hsiao et al. [40] produced polycarbonate nanofibers and observed reduction of average diameter of the fibers from 168 nm to 120 nm with the application of air jet in conjunction with electrospinning. Wang et al. [39] produced water resistant hyaluronic acid nanofibers of about 70 nm diameter by implementing air-blowing rate of 100 $ft^3$/h. Kong et al. [41] observed reduction of diameter of electro-spun polyvinyl alcohol nanofibers by increasing air pressure under air blowing conditions. Poly (ether sulfone) nanofibers were produced by Lin et al. [42] in gas-jet/electrospinning process where the average diameter of the fiber reduced from 424 nm to 208 nm by increasing the gas flow rate.

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The same technique was used for fabrication of nanofibers of poly (ester imide). The average diameter reduced from 4800 nm to 363 nm due to an increase of the gas flow rate from 2.5 L/min to 10 L/min [43]. Nylon 6 nanofibers of about 50 nm diameter were produced by combining electrospinning and supersonic air blowing [44]. Nanofibers of smaller diameter have also been obtained by applying additional centrifugal force to liquid jets in conjunction with electrospinning process [37].

Polymeric fibers with diameter ranging from few tens of nanometers to a few micrometers were produced by applying only the hydrodynamic forces in the GJF process [1–6]. In this process, polymer solutions are driven by a syringe pump through a delivery system, such as pendent drop, flat surface, and needle-shaped nozzle and are brought in contact with the compressed gas jet. The gas delivery nozzle and the liquid delivery systems are physically separated as shown in Fig. 1. The polymer solution is converted into a continuous liquid jet and then into continuous fibers by the forces imparted by the gas jet [1,2]. The fibers are collected at a certain distance from the nozzle exit to take full advantage of the compressed gas that attenuates the liquid jet and removes the evaporated solvent. Several nanofiber morphologies, such as bi-lobal, core-shell, side-by-side, and interpenetrating network (IPN), are produced using this technique from bi-component polymer systems [4–6]. The fiber characteristics, e.g., diameter, porosity, and conglutination can be tailored to suit specific applications. Detailed descriptions of the GJF process and the

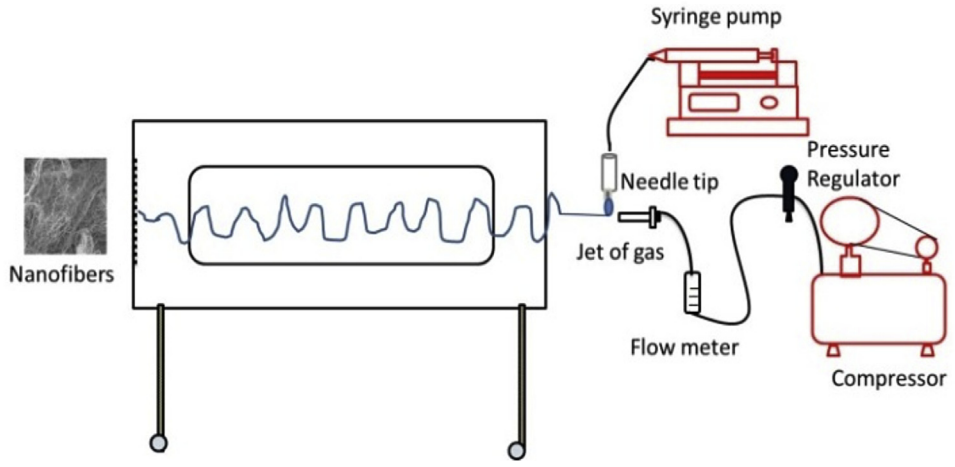


**Fig. 1.** Schematic diagram of GJF process.

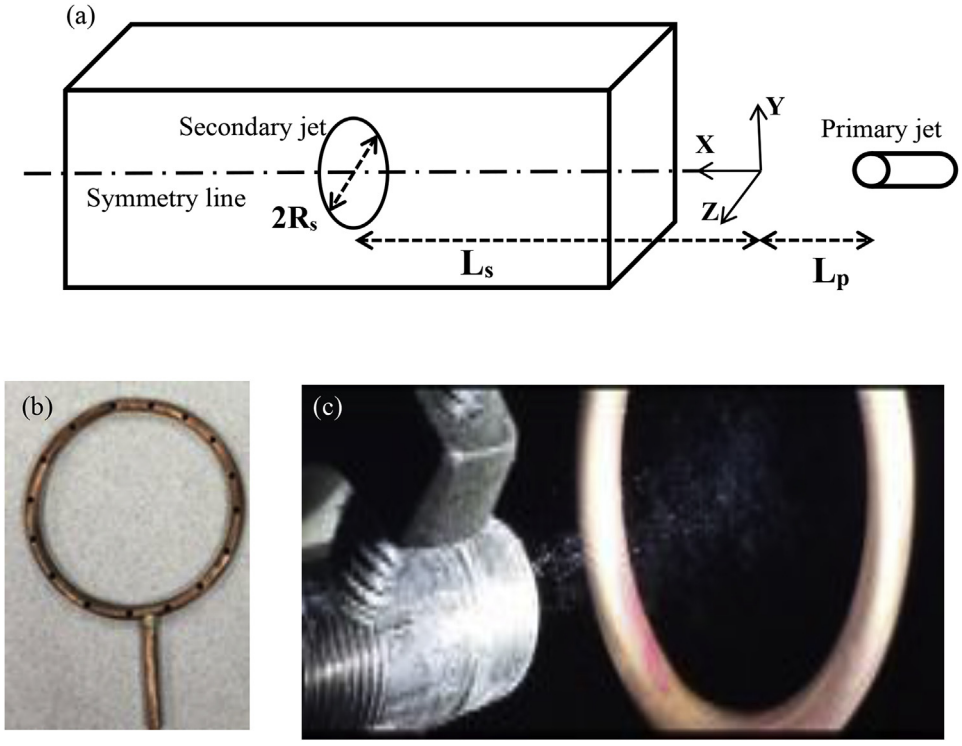


**Fig. 2.** (a) Schematic diagram showing placement of the primary gas jet, liquid delivery nozzle, and the secondary gas jet in GJF process. The distance between the primary gas jet and the liquid delivery nozzle ($L_p$) is 2 cm, (b)optical image of the copper tube loop ($R_s = 5$ cm), (c) real time image of the liquid jet passing through the circular loop at $L_s = 10$ cm, $R_s = 2$ cm.