Improvement of fiber twisting and crimping in the melt-blowing process

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Abstract

This paper suggests a new apparatus for the melt-blowing process, whereby an air vortex is applied to the pneumatic chamber, causing the fibers to have a tendency to twist and crimp. Fabrics so produced can have improved mechanical characteristics; in addition, their web strength, softness, and feel can be mechanically controlled. A simple analytical model for the present invention is established to determine the strength of the air vortex twist acting on the fibers during melt-blowing spinning as a function of nozzle pressure, flow rate, jet orifice angle, and diameter of the jet orifice, so that the mechanical characters can be controlled.

Keywords: Melt-blown apparatus; Air vortex; Fiber; Air-jet spinning

1. Introduction

The melt-blowing process [1,2] is a process that produces a micro-fiber web. The produced microfibers of polymer can find wide applications in various areas, such as air filtration, water filtration, insulation, and absorbent materials. Melt-blowing is used commercially as a one-step process for converting polymer resin directly into a nonwoven mat. In the process a very high velocity gas impacts a molten polymer stream, as illustrated in Fig. 1. As a result, the polymer stream is attenuated rapidly by gas jets, and the resultant fibers are collected on a screen as a nonwoven mat. The fiber diameter can be reduced from 700 to 1 μm in 50 μs [1], but this dramatic change in diameter significantly weakens its mechanical strength and other fiber characteristics such as loft, drape, and feel.

Most polymer fibers spun today, such as nylon used in clothing, are produced through mechanical processes, and the diameters and strength of the produced fibers can easily be determined without any calculation. Recently, microfibers or superfine fibers have been produced by either electrospinning [3,4,5,6] or melt spinning. The former uses a high voltage to pull down the charged polymer stream, while the latter uses the motion generated by air jets to spin fibers, so it is difficult to predict the size of the produced fibers as well as their strength. This paper aims to reduce the attenuation of the polymer stream, and to improve its mechanical strength by air vortex twist acting on the fibers to produce self-crimping fibers.

2. New melt-blowing apparatus

Figure 1 illustrates a traditional melt-blowing apparatus. Melt-blown nonwovens play key roles in many

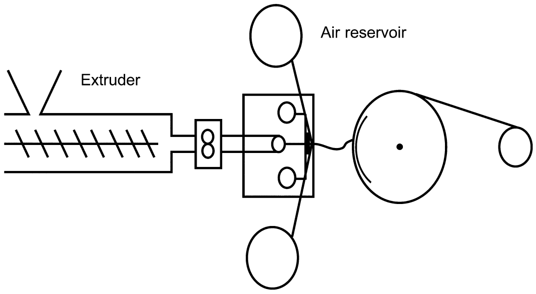

Fig. 1. Schematic of the traditional melt-blowing process.

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everyday products due to the large fiber surface area and the exceptional absorbency of the webs. However, because the strength of the web is not high enough, their applications are seriously limited. To overcome this shortcoming, Triebes et al. [7] invented a new apparatus, which has a pneumatic chamber with many spaced protrusions on both opposing walls, which cause, controlled lateral flow near the chamber walls. This lateral flow causes drag on the fibers, which is imparted with rotational energy derived from the lateral component of the two turbulent airflow fields that oppose one another.

It is known that fabrics composed of twisted fibers exhibit greater strength characteristics and higher loft than fabrics composed of untwisted fibers. Twisting is not achieved in the common melt-blowing process. It would be desirable to have a process for producing twisted fibers during its initial attenuation stage. Triebes et al. [7] investigated the turbulence effect of protrusions in the walls in their invention, and found that it was the spaced protrusions that caused turbulence, and thus a rotational flow. The idea was new and heuristical, but the turbulence was difficult to control.

Accordingly, it is an objective of the present paper to provide a nonwoven fabric that is produced in a novel controllable way so that the web strength, softness, and feel can be increased and controlled.

Air vortex twist is a very effective approach to this problem and has been successfully applied in air-jet spinning [8,9,10]. The process is illustrated in Fig. 2.

We will first apply the air vortex to the melt-blowing process, wherein the rotational flow can increase web softness and feel for the self-crimping fibers.

Figure 3 illustrates the schematic of our new melt-blowing process, wherein two mechanically produced rotational flows flow along the two symmetric walls. When the two rotating airs converge at the nozzle, a

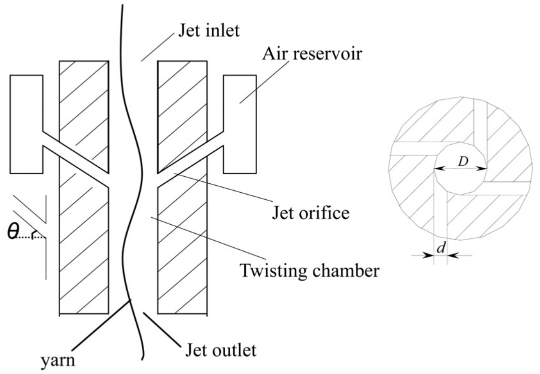

Fig. 2. Air vortex in air-jet spinning. The principle can be applied to the welt-blowing process to produce self-crimping fibers or webs.

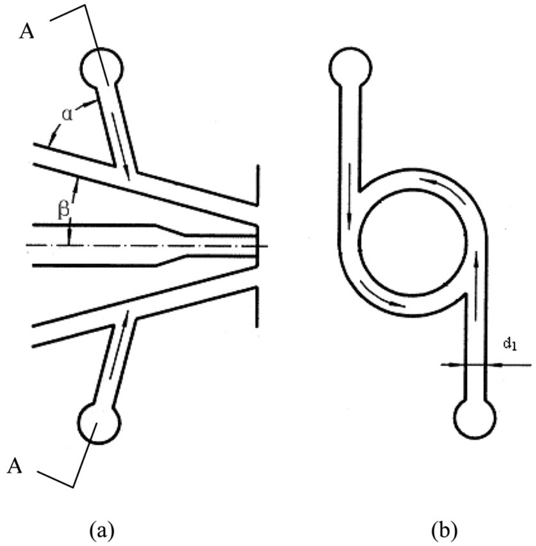

Fig. 3. Our novel new melt-blowing apparatus. (Original idea first suggested by J.H. He.)

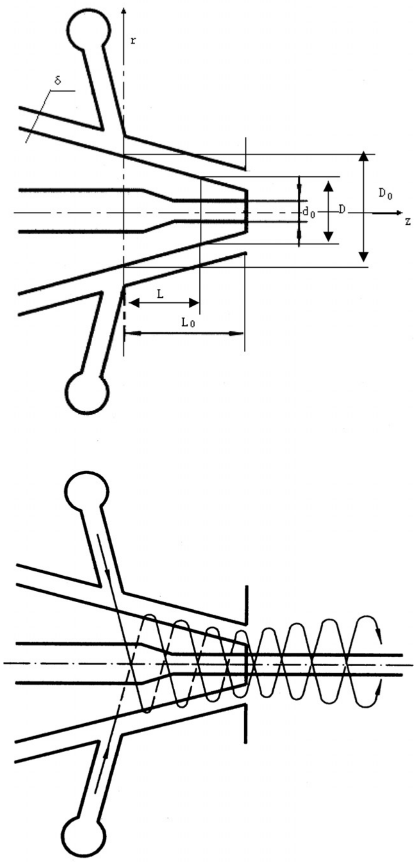

Fig. 4. Controllable rotating flow.

resultant rotating flow in the horizontal direction is achieved as illustrated in Fig. 4.

When the fibers are ejected from the nozzle, they exhibit a degree of self-crimping and twisting, which results in a stronger, softer fabric.

3. Mathematical model

In this section we will present an analytical model for the forces that determine the strength, loft, and feel of the produced fibers as a function of air pressure, air flow rate, and jet orifice angle.

The system must obey the basic laws of mechanics. The conservation of momentum in the vertical direction (Fig. 3), ignoring the energy loss, gives

$$N\pi\left(\frac{d_1}{2}\right)^2 \rho u_0 \cos\alpha \frac{D_0+\delta-d_1}{2} = \int_0^{L_0}\int_0^{2\pi}\int_{D_0/2}^{d_0/2} \rho u r^2 \, dr\, d\gamma\, dl \tag{1}$$

where ρ is the air density, u_0 is the velocity at the jet orifice, u is the vortex velocity, and N is the number of the orifices. Other parameters are illustrated in Figs. 3 and 4.

Assuming the flow is incompressible, Eq. (1) becomes

$$\frac{N(D_0+\delta-d_{1_0})}{16} d_1^2 u_0 \cos\alpha = \int_0^{L_0}\int_{D_0/2}^{d_0/2} u r^2 \, dr\, dl \tag{2}$$

We assume that the vortex velocity (u) in a vertical plane in the melt-blowing process scales as

$$u = kr^n \tag{3}$$

where k and n are constants.

Assuming that the vortex velocity at $r = (D_0 + \delta - d_1)/2$ remains approximately constant through the nozzle we have

$$u(r)|_{r=(D_0+\delta-d_1)/2} = u_0 \cos\alpha \tag{4}$$

Combining Eqs. (2), (3) and (4), we can determine the value of k and n easily.

The strength of the vortex twist, (T) acting on the fiber can be expressed as

$$T = \mu d_f \frac{\partial u}{\partial r}\bigg|_{r=(d_0+\delta)/2} \tag{5}$$

where d_f is the fiber diameter.

4. Conclusion

We have successfully invented a new apparatus for the melt-blowing process. Experimental verification is now under way to evaluate our theory.

Acknowledgment

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