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TRADITIONAL AND NOVEL MELT-BLOWN AND SPUNBOND TECHNOLOGIES

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Abstract

The concepts of existing spun-bond and melt-blown systems are outlined in relation to a new high capacity process allowing birth systems to operate with same equipment.

The Biax melt-blown and spun-bonded systems are base on a modular design, and existing high capacity melt-blowing lines can easily and quickly be converted into spunbonded lines making high-strength webs by addition of the drawn jet assembly, using the existing melt-blowing spinnerettes. New spinnerettes (fitting existing die block designs) of 200 orifices per inch die width are now in commercial use, and up to 800 orifices per inch have been tested.

Spunbonded webs produce by this system can further be processed into very strong webs by calendaring, spot-bonding, water-jet entanglement or needle-punching. Products described in this have been produced on Biax-Fiberfilm's 5" pilotline. A 40" commercial melt-blowing line is presently converted to a spunbonded line. This line can be used asboth, a melt-blowing and spunbonded line with only minutes of conversion time.

Introduction

The object of this presentation is the compare traditional meltblown systems (11) (Figure 1a) (20-40 orifices per inch die width) with newly developed high capacity systems (7) (Figure 1b) (200-800 spinning orifices per inch die width) and its development into a new high fiber strength spunbonded process (10).

The spunbonded processes described below are mostly processes where webs are formed from *continuous* filaments, and are constructed essentially of three elements :

a) A spinnerette consisting of a steel plate with holes where polymer is extruded out of to form a molten fiber-forming stream.
b) A draw-down device which grips the filaments and accelerates them to a certain velocity, usually by air jets, like Lurgi (1), Freudenberg (2,3). Ason Engineering (5), or roll systems, like DuPont (Reemay, Typar), and
c) in between a quench system to facilitate cooling and solidifying the molten stream into solid fibers and preventing the fibers from sticking together.

The quench efficiency and draw-down velocity determines the degree of molecular orientation within the fibers and thus filament strength, measured as gram per denier (gpd) or gram per dtex.

The exit side of the draw-down device is usually used to blow the filament bundles more or less uniformly onto a collecting screen where the filament bundles are forming a web for further processing.

The process described in this paper differs from previously known ones by way of a highly efficient quench system, a high concentration of spinning orifices(400/inch of die width), allowing a higher capacity (Kg/hr)per spinning unit, and the fact that it does not depend on gravity for the filaments to fall from the spinnerette, e.g. horizontal spinning is possible and sometimes preferred, rather than downward spinning.

High Quench Efficiency Spinnerette Design

The quenching done by previously known spunbonded systems is by air or water mist blown perpendicular to the fiber stream. This allows only for limited air velocities or the fibers would break due to the perpendicular force (1c). The low air velocities produce a relatively slow heat transfer from air to fiber surface, resulting in slow cooling, and solidifying, of the fibers. In this development, the quenching medium is directed parallel to the fiber surface at high velocity and laminar flow, leading to highly efficient heat transfer (= cooling effect) due to the high Reynold's Numbers. The spinnerette design has evolved from a previous melt-blown spinnerette (7,8) developed several years ago and in commercial operation (Figure 1c).

In this spinnerette hot air is blown circumferencially around spinning nozzles, arranged in multiple rows, parallel to the fiber stream, to blow fibers unto a collecting screen. The fibers in the melt-blowing process have essentially no molecular orientation. The difference in the spunbonded version is that air temperature inside the spinnerette is being kept cool,-but high enough so not to solidify the polymer - , the air pressure is kept high and air volume low, so as to effect a high velocity, low turbulence, and high degree of temperature drop due to adiabatic cooling.

The spinning nozzles protuding through the air plate should be long, but the length is limited by the cooling effect of the air exiting the annular exit ring around the nozzle. As air expands along the nozzle, it cools the nozzle tips and increases the melt viscosity of the polymer inside the nozzle, leading to an increase in polymer melt pressure. The optimum length for a nozzle of 0.8 mm outside diameter and 0.4 mm inside diameter has been found to be about 3 mm. As air then moves along the molten polymer stream, it accelerates and cools the polymer below its melting point.

Key Operating Variables to Produce Optimum Fibers for Spunbonded Webs

The ultimate goal in a spunbonded process is to produce fine fibers of high molecular orientation and uniformity, laid down as a perfect random web. Molecular orientation in a spunbonded process occurs in the melt just prior to solidification, which is the weakest point of the fiber under tension between the spinnerette exit and the drag force in the draw jet. The melt-orientation is then arrested by rapid cooling and solidification. If solidification is too slow (like in the melt-blowing process), the oriented polymer molecules have time to relax and become partially de-oriented.

The primary variables affecting fiber diameter are :

Q = polymer throughput (gram/nozzle/minute), and
V = ultimate fiber velocity in draw jet (334 m/sec maximum)

which are related as

$$\pi r^{2} = (Q/V\,d) \text{ or } {}^{1/2}$$

$$\text{Fiber Diameter} = 2\,(Q/\pi V\,d)^{1/2} \qquad d = \text{polymer density } (\text{g/cm}^{3})$$

Molecular orientation is affected by :

V (a minimum velocity is required to develop any orientation), and Cooling efficiency, which in tern is affected by air temperature, velocity and quantity.

While air temperature and pressure inside the spinnerette can be adjusted continuously, air quantity and velocity is also influenced by the air opening around the nozzles (not continuously adjustable) In the following Tables we have described what is happening to molecular fiber orientation between two extremes:

A: no quench air used, drag force in air jet is the only force acting on fiber,
B: maximum quench air : air from spinnerette is accelerating fibers faster than draw jet (= melt blowing conditions).

As can be seen from Table 1 and 2, optimum orientation is achieved when the fiber acceleration due to the quench air exiting the spinnerette (as determined from fiber diameter and polymer throughput) is about 40 % of final velocity V-2 , and fiber velocity in draw jet is at least 100 m/sec.

Cooling of Filaments in High Velocity Air

In cross-flow quench like in Dorschner (1) air velocities , and therefore heat transfer are limited because the air stream would tear apart the fiber bundle. Therefore long quench chambers are necessary. Draw jets are placed several meters below the spinnerettes. In the present system, air flow around each nozzle at velocities up to 100 m/sec in a laminar fashion, reaching Reynold's Numbers up to 12,000, where heat transfer is near the ideal case of the Fourier equation (9)(see Figure 3).

As the expanding air is exiting around the spinning nozzle, it cools the filament rapidly below its solidifying point. It is just before this area, where most of the fiber draw-down and molecular orientation occurs, and is done in about 2 mm length (Figure 3). Since most of the mechanical work of fiber draw-down or elongation is performed by the draw jets, and the spinnerette-air is used mainly for cooling, much higher melt-viscosities can be spun compared to melt-blowing; this means that higher molecular weight polymers (lower MFR) can be used leading to very strong fibers, about 6 gram per denier.

According to Figure 3, only 1.9 mm is used for cooling below the melting point, so that the draw jets can be placed very close to the spinnerette. Since the spinnerette-air (=melt-blowing air) is propelling the fibers into the draw jet, the process is not dependent on gravity for the fibers to fall into the draw jet, like in most other spunbonded processes, and can be spun horizontally against a vertically moving screen, which has some advantages in production.

Sub-Micron Fibers

The production of sub-micron fibers requires special spinnerette design, polymer viscosity and operating conditions. First, a very low polymer throughput (less than 0.02 gram/minute/nozzle) at maximum draw jet velocity is required to reach one micron fiber diameter or less. Polymer pressure in the spinning nozzle has to be above a certain minimum (300 psi) for fiber formation, requiring high molecular weight polymer (35 MFR polypropylene or +0.7 Intrinsic Viscosity PET polyester).

From the data presented in Table 3 it can be seen that there is a significant difference in orientation whether air quench from the spinnerette is used or not, according to % shrinkage and tenacities of fiber bundles.

The samples described in Table 3 were made by a 14 cm wide spinnerette having 1250 spinning nozzles arranged in 10 rows, with a 1 mm spacing between nozzles and rows.

Summary

The Biax melt-blown and spun-bonded systems are based on a modular design (Figure 2), and existing high capacity melt-blowing lines can easily and quickly be converted into spunbonded lines making high-strength webs by addition of the draw jet assembly, using the existing melt-blowing spinnerettes (Figure 1)(7,8).New spinnerettes (fitting existing die block designs) of 200 orifices per inch die width are now in commercial use, and up to 800 orifices per inch have been tested.

Spunbonded webs produced by this system can further be processed into very strong webs by calendering, spot-bonding, water-jet entanglement or needle-punching. Products described in this paper have been produced on Biax-Fiberfilm's 5" and 20" pilot line. A 40" commercial melt-blowing line is presently converted to a spunbonded line. This line can be used as both, a melt-blowing and spunbonded line with only minutes of conversion time.

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Table 1. Fiber Orientation Using Quench Air (hot) and Draw Air (cold).

Air Temp.	**Air Pressure**	**Fiber Velocity-1**	**Fiber Diameter**	**Fiber Velocity-2**	**Birefringence**
C	**PSI**	**m/sec.**	**micron**		
230	0	---		310	0.012
230	5	30	21	310	0.018
230	10	105	11	310	0.028
230	15	180	8	310	0.012
230	25	310	6	310	0.008

Polypropylene, MFR 800, Air orifice opening= 0.0064 sq.cm per nozzle, Throughput /nozzle :0.6g/min, final fiber diameter :6 micron; Nozzles : 0.81 mm OD, 0.51 mm ID.

Table 2. Fiber Orientation Using Quench Air (hot) and Draw Air (cold).

Air Temp	**Air Pressure**	**Fiber Velocity-1**	**Fiber Diameter**	**Fiber Velocity-2**	**Birefringence**
C	**psi**	**m/sec**	**micron**	**m/sec**	
230	0	---	5.2	240	0.018
190	0	---	5.2	240	0.022
230	5	15	21	240	0.027
190	5	11	24	240	0.022
230	10	22	17	240	0.030
190	10	15	21	240	0.023
230	20	48	12	240	0.045
190	20	34	14	240	0.034
230	27	95	8	240	0.060
190	27	55	11	240	0.045

Polypropylene, MFR 70, Air orifice Opening = 0.0034 sq.cm, throughput : 0.3g/min, final fiber diameter : 5.2 micron; Nozzles : 0.81 mm OD, 0.51 mm ID.

*Fiber velocities"V" (m/sec)are calculated from polymer throughput "Q"(g/min/nozzle) and fiber diameter "D"(micron);

Air temperature and pressure measured inside spinnerette.

Table 3. Process Conditions For Sub-Micron Fibers.

Run #	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Polymer	PP	PP	PP	PP	PET	PET	PET
Melt Temp, in spinnerette (C) =air Temperature	200	200	210	220	285	285	295
Air pressure in spinnerette (psi)	---	8	8	8	---	8	8
Polymer pressure in spinnerette (psi)	1500	1500	800	400	300	300	150
Polymer throughput (g/nozzle/min.)	0.01	0.01	0.01	0.01	0.015	0.015	0.015
Fiber diameter without draw jet (m)	---	5	2.5	1.5	---	1.5	1.2
Fiber velocity without draw jet (m/sec)	---	10	30	80	---	80	120
Fiber diameter after draw jet (m)	0.8-1	0.8-1	0.8-1	0.8-1	0.8-1	0.8-1	0.8-1
Fiber elongation (%)	80	30	40	48	70	40	60
Fiber tenacity (gpd)	3.5	5.5	5.0	4.5	2.5	5.0	4.2

Air Orifice Opening = 0.0020 sq.cm; Nozzle length = 30 mm; ID = 0.254 mm; OD = 0.508 mm; Polypropylene = 35 MFR; PET polyester = 0.7 IV.