An Overview of Spunbonding and Meltblowing Technologies

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ABSTRACT

This paper overviews the spunbonding and meltblowing technologies. The paper addresses the differences between the two processes, product characteristics, process economics, and process equipment.

BACKGROUND

In the past thirty years, the nonwoven industry has observed a phenomenal growth mainly because of a close alliance among nonwoven producers, fiber producers, binder producers, and machinery manufacturers. There are many nonwoven manufacturing processes and products that have been developed and commercialized in the past thirty years to address a variety of end-use markets. As an example, in the late 1950's, polymer laid systems were developed. Since then many researchers have perfected polymer laid technologies in order to make an increasingly varied range of products. Although, the research work on this technology was started in the late 1950's, and an extensive number of processing and products patents were developed, there has been a dramatic resurgence of research and developmental work in the past few years.

In recent years, the increased acceptance of polymer laid fabrics in many end-use products has sparked an interest in this process from both a commercial and a scientific point of view. This paper describes the two of the most important polymer laid systems: spunbonding process and meltblowing process.

SPUNBONDING PROCESS

The concept of spunbond process was developed simultaneously in Europe and the United States in late 1950's, but it was later--in the mid 1960's to early 1970's-that the strength and potential of the spunbond technology was recognized for commercial applications. A large number of patents on spunbond process design were filed during this period of time and a few of them were used for commercial production processes.

Process Description

A primary factor in the production of spunbonded webs is control of four simultaneous integrated operations: filament extrusion, drawing, lay down, and bonding. The first three operations are directly adapted from conventional man-made fiber spinning and constitute the *spun* or web formation phase of the process, while the last operation is the web consolidation or *bond* phase of the process--hence the generic term *spunbond* [1].

In its simplest form, a spunbond line consists of the following elements: an extruder for forming filaments; a metering pump; a die assembly; a filament spinning, drawing and deposition system; a belt for collecting the filaments; a bonding zone; and, a winding unit. A generic schematic of the spunbonding process is shown in Figure 1.

The extruder and metering pump provide uniform polymer melt delivery to the die assembly. The die block assembly is one of the most important element of the spunbond process. The die assembly has two distinct components: polymer feed distribution and spinneret. The polymer feed distribution system delivers uniform polymer melt to the spinneret block.

The filament spinning, drawing, and deposition are the three most critical steps in a spunbonding process. Basically, these three steps are performed using a single integrated system. The main function of this integrated system is to solidify, draw, and entangle the extruded filaments from the spinneret and deposit them onto a conveyor belt [2].

Spinning. The one of the three generic types of spinning techniques is employed in a spunbonding process. The concept of these three generic spinning techniques is directly adapted from the conventional filament fiber spinning techniques. The three generic spinning techniques are: Melt, Dry, and Wet. Any of the above spinning techniques can be used in the spunbond process. However, the melt spinning technique is widely used mainly because of its simplicity and economics.

Drawing. The drawing of the filaments follows the spinning. In conventional fiber spinning, drawing of the filaments is achieved using draw rollers. While, in a spunbonding process it is achieved using a specially designed aerodynamic device.

Deposition. The filament deposition follows the drawing. The filament deposition is also achieved using a specially designed aerodynamic device. They are usually referred as fanning or entangler units.

Over a period of past twenty-five years many filament spinning, drawing, and deposition systems have been patented and commercialized. Some of the basic principles involved in filament spinning, drawing, and deposition, have been proposed by Hartman [3]. A great number of spunbond processes can be fitted into one of these four routes proposed by Hartman [3] with appropriate modification. Many filament spinning, drawing, systems have been commercialized based on these concepts.

The conveyor belt carries the unbonded web to the bonding zone. There are three basic bonding techniques employed in a spunbond process: thermal, chemical/adhesive, and needling. The choice of a particular bonding technique is dictated mainly by the ultimate fabric applications. Occasionally, a combination of two or more techniques is employed to achieve bonding.

The spunbond web is usually wound on a cardboard core and processed further according to the end-use requirements. The combination of fiber entanglement and fiber-to-fiber bonding generally produces enough web strength so that the web can be readily used without further treatment.

Process Variables

The spunbonding process is quite complex and involves many operating variables. The processing variables can be divided into two categories: 1) operational variables, and 2) material variables. By manipulating the operational and the material variables one can produce a variety of spunbond fabrics with desired properties. Each of these variables plays a significant role in process economics and product reliability. Therefore, it is essential that each of these variables be precisely defined and understood in order to optimize the spunbond process. The following are the major process variables that affect the filament and web properties [2]:

- Polymer characteristics
- Melt viscosity and melt temperature
- Air temperature and air flow rate
- Filament draw speed
- Polymer throughput rate
- Collection speed
- Bonding conditions

Characteristics and Properties of Spunbond Webs

The spunbonded webs represent a new class of man-made product, with a property combinations falling between paper and woven fabric. Spunbonded webs offer a wide range of product characteristics -- ranging from very light and flexible structure to heavy and stiff structure. The following are some of the main characteristics and properties of a spunbonded web [2]:

- random fibrous structure;
- generally, the web is white with high opacity per unit area;
- most spunbond webs are layered or shingled structure, the number of layers increase with increasing basis weight;
- basis weight range between 5 and 800 g/m^2, typically 10 - 200 g/m^2;
- fiber diameter range between 1 and 50 μm, but the preferred range is between 15 and 35 μm;
- web thickness range between 0.1 and 4.0 mm, typically 0.2 - 1.5 mm;
- high strength-to-weight ratios compared to other nonwoven, woven, and knitted structures;
- high tear strength (for area bonded webs only);
- planar isotropic properties due to random laydown of the fibers;
- good fray and crease resistance;
- high liquid retention capacity due to high void content;
- high in-plane shear resistance; and
- low drapeability.

Applications of Spunbond Webs

Spunbonded webs are finding applications in a variety of end uses. In the early 1970's, spunbond webs were predominantly used for durable applications, such as carpet backing, furniture, bedding, and geotextiles. By 1980's and 90's, however, disposable applications accounted for an increasingly large percentage, primarily because of the acceptance of lighter spunbonded polypropylene webs as a coverstock for diapers and incontinence devices [4]. The uses of spunbond webs can be classified as follows: Automotive, Civil Engineering, Sanitary and Medical, and Packaging [2].

MELTBLOWING PROCESS

In the early 1950's, meltblown nonwoven fabric technology was developed to make microfiber filters to collect radioactive particles from the upper atmosphere. The microfibers (also referred as superfine or meltblown fibers) are fibrous materials generally less than 10 microns in diameter. Such fibers are found in nature in the form of spider silk and pineapple leaf fiber [5]. Man-made microfibers are produced using a variety of materials and production techniques. The submicron glass fibers in "glass wool" are a prime example.

In the late 1960's, the Esso Research and Engineering Company (now Exxon Chemical Company) recognized the strength and potential of microfiber technology for commercial applications. The Exxon Chemical Company started developing a low-cost method of producing blown microfibers from polypropylene. After the extensive research and development based on Wente's original work on microfiber technology [6,7], Exxon researchers patented the blown microfiber process (usually called as meltblown process). Later, Exxon decided to license the meltblown technology to others and concentrate primarily on producing resins to supply this novel process [8].

Besides Exxon's patented meltblowing process, there are other companies who have their own proprietary blown microfiber production processes. However, as a result of Exxon's dominant technology position coupled with tailored resin and competent authorized equipment suppliers, most of the meltblown production lines in operation today in the nonwoven industry are licensed through Exxon Chemical Company. A comprehensive list of companies involved in meltblown fiber production is given in [9].

Process Description

The schematic of the meltblowing process is shown in Figure 2. A typical meltblowing process consists of the following elements: extruder, metering pump, die assembly, web formation, and winding.

The extruder and metering pump provide uniform polymer melt delivery to the die assembly. The die assembly is the most important element of the meltblown process. The die assembly has three distinct components: polymer feed distribution, die nosepiece, and air manifolds. The polymer feed distribution system delivers uniform polymer melt to the die nosepiece.

The air manifolds supply the high velocity hot air (also called primary air) through the slots to the top and bottom sides of the die nosepiece. The high velocity air is generated using an air compressor. As soon as the molten polymer is extruded from the die holes, high velocity hot air streams attenuate the polymer streams to form microfibers. As the hot air stream containing the microfibers progresses toward the collector screen, it draws a large amount of surrounding air (also called secondary air) that cools and solidifies the fibers. The solidified fibers subsequently get laid randomly onto the collecting screen, forming a self-bonded nonwoven web. The fibers in the meltblown web are held together by a combination of entanglement and cohesive sticking. The fibers are generally laid randomly (and also highly entangled) because of the turbulence in the air stream, but there is a small bias in the machine direction due to some directionality imparted by the moving collector. The collector speed and the collector distance from the die nosepiece can be varied to produce a variety of meltblown webs. Usually, a vacuum is applied to the inside of the collector screen to suck the hot air and to enhance the fiber laying process [10].

The meltblown web is usually wound on a cardboard core and processed further according to the end-use requirements. The combination of fiber entanglement and fiber-to-fiber bonding generally produces enough web cohesion so that the web can be readily used without further bonding [8]. However, the webs subsequently may be thermally calendered with a smooth or patterned finish, or webs may be thermally laminated with other substrates.

Process Variables

The meltblowing process is also quite complex and involves many operating variables. The processing variables can also be divided into two categories as explained in the spunbonding section of this paper. The following are the major process variables that affect the filament and web properties [11]:

- Polymer characteristics
- Melt viscosity and melt temperature
- Air temperature and air flow rate
- Die nosepiece, air angle, and air gap
- Polymer throughput rate
- Collection speed and distance

Characteristics and Properties of Meltblown Webs

Meltblown webs offer a wide range of product characteristics. The following are some of the main characteristics and properties of a meltblown web [11]:

- random fiber orientation;
- low to moderate web strength;
- generally, the web is highly opaque (high cover factor);
- meltblown webs derive their strength from mechanical entanglement and frictional forces;
- most meltblown webs are layered or shingled structure, the number of layers increase with increasing basis weight;
- fiber diameter range between 0.5 to 30 μm, but the typical range is 2 to 7 μm;
- basis weight range between 8 and 350 g/m^2, typically 20 - 200 g/m^2;
- micro fibers provide high surface area for good insulator and filter characteristics;
- the fibers have smooth surface texture and appeared to be circular in cross section [28];
- the fibers vary in diameter along a single fiber;
- the close examination of approximately 800 photomicrographs showed no "fiber ends" (except a few near "shot" area), therefore, the fibers are believed to be continuous in length;
- the fibers show thermal branching. The exact cause of thermal branching is not known, but according to Malkan [10] the branching of the fibers occur when propagating fibers collide with another propagating fibers, which in turn, stripe off portions of polymer streams as fine branches (filaments). Richardson [12] pointed out that when the velocity of the liquid jet relative to air jet increases, portions of the liquid are stripped off as filaments. Bresee and Wadsworth [13] stated that

fiber splitting (branching) occurs when extrudate is stressed in complex ways in flight towards the collector.

Applications of Meltblown Webs

The meltblown webs, due to their inherent property such as large fiber surface area, are suitable in filtration, insulation, and liquid absorption applications. The fine fiber network (large surface area) results in [15-18]:

- enhanced filtration efficiency
- good barrier properties
- good wicking action

PROCESS EQUIPMENT AND LAYOUT

As discussed in the process description sections of this paper, even though the two processes are conceptually simple, the production of high quality webs at commercial scale requires precisely designed and fabricated equipment. Although several nonwoven companies have the in-house capabilities to design and fabricate their own equipment, many others look to competent equipment vendors to build and supply key components or a complete turnkey line.

Spunbonding. Many spunbond web manufacturing companies have developed their own proprietary technology, such as DuPont, Freudenberg, Amoco, and Kimberly-Clark. These companies use their technology for in-house use and do not license the technology, equipment, or know-how to others. There are many nonwoven equipment manufacturing companies that have developed spunbond technology for licensing and purchase (company addresses are given in Appendix I). They are as follows:

- Docan System by Lugri
- Reicofil System by Reifenhäuser
- Impianti System by S.T.P. Impianti
- Meccaniche Moderne System by Meccaniche Moderne

The spunbond equipment layout is vertical only. The equipment is laid out in sections as follows:

- the top section consist of extruder, gear pump, and die block assembly;
- the middle section consist of fiber formation and air supply assembly; and,
- the bottom section consist of fiber laydown, spin belt, and bonding assembly.

The vertical space requirement depend on the type of fiber formation assembly. Usually, 50 feet is the minimum requirement. The horizontal space requirements depend on the total width of the die and the type of bonding unit. Usually, three times the vertical space is the minimum requirement for the horizontal space.

Meltblowing. Similar to spunbonding technology, many meltblown web manufacturing companies have developed their own proprietary technology, such as 3M and Freudenberg. Unlike the spunbond process where there are many key players and many variety of processes, the most of the meltblowing processes in the market are based on Exxon's Meltblowing Process.

Exxon has developed agreements with several competent equipment builders to supply complete lines or turnkey lines to Exxon licensees. The complete turnkey lines are offered by:

- Accuweb System by Accurate Products
- Meltblown System by Reifenhäuser
- J & M System by J & M Laboratories

The above mentioned systems can be licensed and purchased from the respective companies. If for some reasons, companies elect not to purchase a complete line but opt for purchase of key components, they can do so from the above mentioned companies and also from various key component vendors assigned by Exxon Chemical Company. A complete list of turn-key line and key component dealers for Exxon's meltblowing process is given in Appendix I.

The melt blowing process equipment layout is simpler and compact than spunbonding process. The meltblowing equipment layout can be vertical or horizontal depending on the requirements. A vertical layout is preferred when multiple dies are used. A horizontal layout is preferred when single die is used. The vertical space requirement depend on the die-to-collector distance. Usually, 20 feet is the minimum requirement. The horizontal space requirements depend on the total width of the die and end product requirements. Usually, three times the vertical space is the minimum requirement for the horizontal space.

The main advantages of purchasing the ready-made turnkey-line (spunbonding or meltblowing) are:

- less expensive than developing the technology from scratch on your own;
- success rate is high;
- system can be tailor made upto certain extent; and,
- modifications are easier later on.

PROCESS ECONOMICS

In nonwovens industry, the process economics can be influenced by many factors, such as -- energy requirement, capital investment, production speed, ease of raw material conversion, and so on. For the purpose of our discussion here, we will focus on the following:

Energy. Spunbonding process is less energy intensive than meltblowing process. The spunbonding process consume about 2 to 3 kwh per kg of polymer processed, while the meltblowing process consume about 6 to 8 kwh per kg of polymer processed. Meltblowing process is more energy intensive because of the use of compressed hot air for fiber attenuation. About, 70% of the total energy is used for compressed hot air. This higher energy consumption results in higher product cost. On the average, the spunbond web cost less than meltblown web. Typically, the price per square yard of 2.0 oz polypropylene spunbond web is 22-24 cents, while for meltblown it is 32-37 cents.

Capital Investment. The initial investment for spunbonding process is higher than the meltblowing process. On the average, the difference in initial investment is 3 to 4 times.

Production Speed. The spunbonding process is inherently faster than the meltblowing process. This is mainly because of the number of holes in the spinneret or die block and process complexities. The difference in number of holes is about 3 to 4 times. As an example, the spunbonding spinneret block usually has 100 holes per inch, while meltblown nose tip has 25-30 holes per inch.

PROCESS MECHANICS

The spunbonding and meltblowing processes incorporate many engineering concepts. Some of the key concepts are listed below:

- dynamics of Melt Spinning Process, which includes: mass balance, force balance, and energy balance;
- deposition Ratio;
- polymer residence time in an extruder; and,
- residence time in nip during calendering.

The above concepts are very useful in understanding the processes from the scientific stand point. A complete description of these concepts is given by Malkan and Wadsworth [19].

PROCESS LITERATURE

Despite the extensive research and development in the area of spunbonding and meltblowing, there is a paucity of published research studies mainly due to the secretive and competitive nature of the research and developmental work. However, there is a large body of patented literature available based on process enhancement and product development studies. An in-depth review of patents on the meltblowing process is given by Moore [20]. There are about fifty published research studies on the spunbonding and meltblowing process based on processing science and theoretical concepts. A complete review of literature on spunbonding and meltblowing is given by Malkan et al. [2,11].

MARKETS

The spunbond and meltblown production constitute one third of the total production of nonwovens in North America [1]. The polypropylene resin is by far the most widely used resin in both of these processes. In spunbonding, polypropylene constitutes 60 to 70 % of the total spunbond production in North America. In meltblowing, polypropylene constitutes, 70 to 85% of the total meltblown production in North America.

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ACKNOWLEDGMENTS

The research described in this paper was carried out by the author at the Textiles and Nonwovens Development Center (TANDEC), The University of Tennessee, Knoxville. The author gratefully acknowledges the support of Dr. Larry C. Wadsworth to this paper.

APPENDIX I

Addresses for Spunbonding Equipment Suppliers

Lurgi GmbH, Fiber Technology Section
Lurgi-Allee 5, P. O. Box 111231
Frankfurt D-6000, Germany

S. T. P. Impianti s.p.a.
20027 Rescaldina (MI) Italy
Via Resegone, 16/18

Reifenhäuser GmbH & Co.
Postfach 1664 Spicher Strable
D 5210 Troisdorf 15 Sieglar
Germany

Meccaniche Moderne S. R. L.
Extrusion Division
Corso Sempione 32, P. O. Box 388
Busto Arsizio-Varese 21052
Italy

Addresses for Meltblowing Equipment Suppliers

Complete Turnkey Lines

Reifenhäuser GmbH & Co.
Postfach 1664 Spicher Strable
D 5210 Troisdorf 15 Sieglar
Germany

Accurate Products
400 Hillside Avenue
Hillside, NJ 07205
USA

J & M Laboratories
12 J & M Drive
Dawsonville, GA 30534
USA

Component for Meltblown Systems

Kasen Nozzel Co., Inc.
5-11-9, Nishitenma Kita-Ku
Osaka 530, Japan

Nippon Nozzel co., Inc.
San Nomiya Int'l. Bldg.
1-30 2-Chom Hamebedori

F. Lli Ceccato
Via Trentacoste 14
21034 Milano
Italy

Enka Tecnica
Enka Ag
Werk Oberbrunch
D-5138 Heinsberg (Rhein)
Germany

The author certifies that all known suppliers of this equipment have been included in this listing.

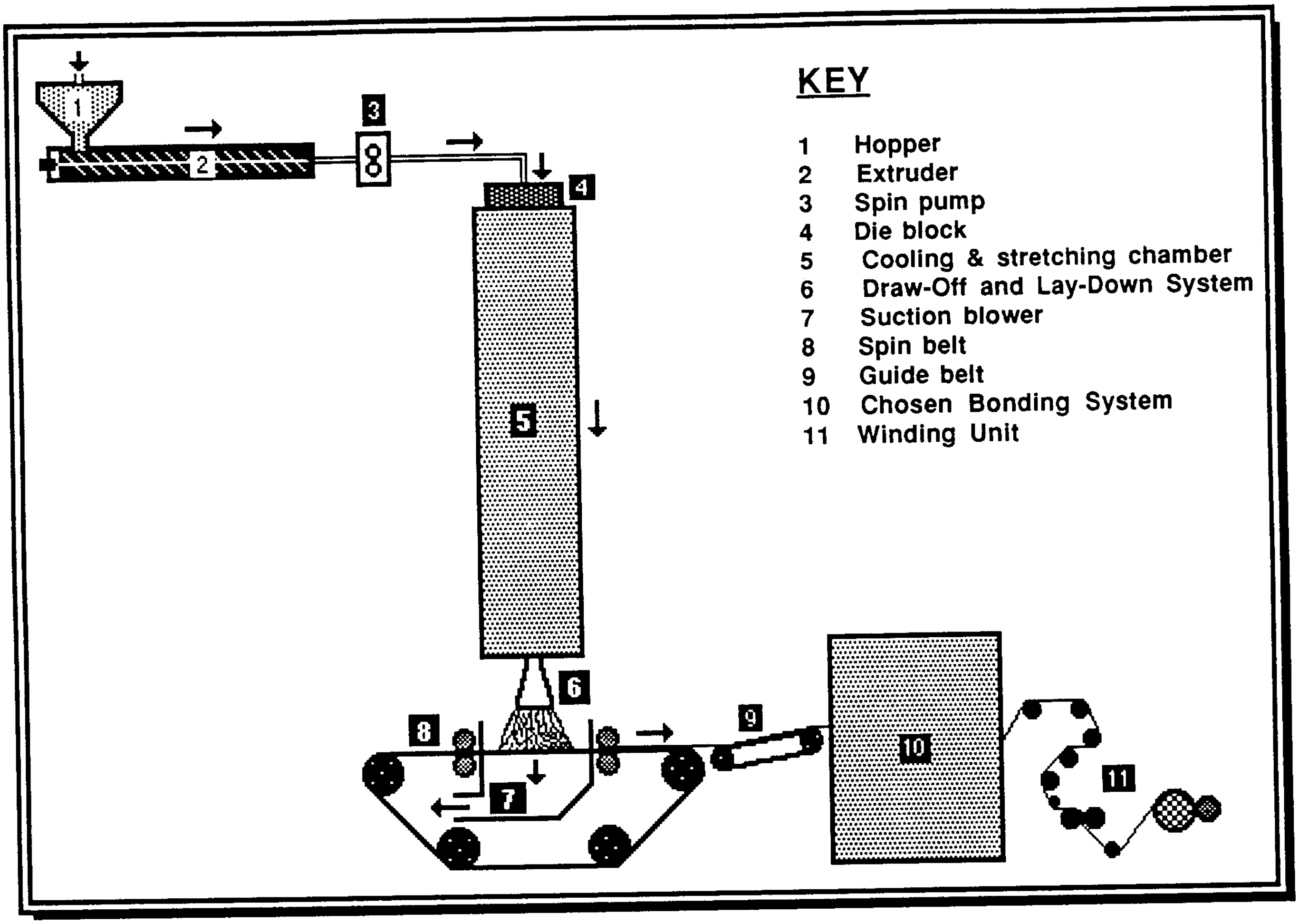

Figure 1. Schematic of a typical spunbonding process.

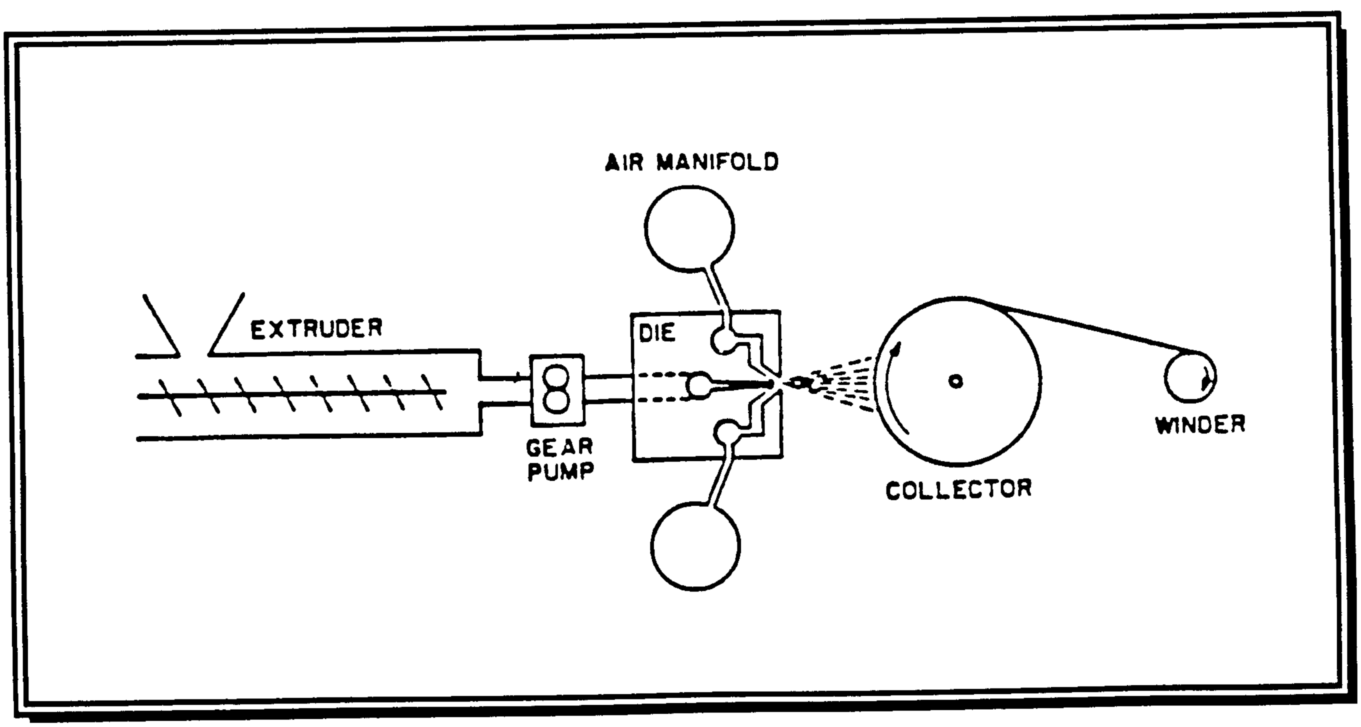

Figure 2. Schematic of Exxon's meltblowing process.