# NONWOVEN PROCESSES AND PRODUCTS APPLICABLE TO COTTON AND OTHER CELLULOSIC FIBERS

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## Abstract

Nonwoven fabrics have quietly revolutionized consumer, medical, and industrial marketplaces throughout the world. They have been the ingredient through which many traditional products have been made better and the means by which many new products have been made possible. The intent of the following presentation is to provide a general overview of the basic technologies used to manufacture nonwoven fabrics and the product characteristics resulting from these technologies so that the cotton fiber producer can gain broad perspective of this viable industry in a short time and identify opportunities where the advantages of cotton and other cellulosic fiber characteristics can be applied.

## Introduction

The properties and performance characteristics of textile fabrics and paper sheets are primarily dependent on the chemical and physical properties of their constitute fibers. Likewise, the properties and performance characteristics of fibers and films are primarily dependent on the chemical and physical properties of their constitute polymers. The shortest path in the transformation of fiber to fabric involves placing a predetermined number of fibers into a two-dimensional array and locking them together. Likewise, the shortest path in the transformation of a polymeric material to fabric involves forming the fibers concurrent with placing a predetermined number of them into a two-dimensional array and locking them together. The processes involved in making these transformations are the essence of nonwoven manufacturing technology. The fabrics that result are technically sophisticated, engineered structures that can be made to resemble in appearance and exceed in properties many textile fabric, paper sheet, or plastic film products. The basic concept used in making a nonwoven fabric, therefore, can be regarded as transforming fiber-based materials into flat, flexible, porous, sheet structures with fabric characteristics. In practice, this concept is carried out in a number of different manners depending on the fiber material used and/or the fabric characteristics desired. Technologies used in three primary manufacturing industries - textiles, paper, and extrusion - and various combinations of established processes from one or more of these industries form the basis of the processes for manufacturing nonwovens. Accordingly, processes for manufacturing nonwoven fabric can be grouped into one of four general technology bases: textile, paper, extrusion, or hybrid (combination).

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### Textile-Based Processes

Traditional textile fabrics are made by weaving, which is the interlacing two or more yarn sets at right angles on a loom, or by knitting, which is the interlooping one or more yarns upon itself or themselves. Yarns are intermediate products to these fabric making processes and are composed of fiber or filament bundles held together by twist or entanglement. Nonwoven fabrics are similar to woven and knitted fabrics in that both are planar, inherently flexible, porous structures composed of relatively long fibers. The main difference between a nonwoven fabric and a woven or knitted fabric is the manner in which fibers or fiber-based materials are transformed into a planar configuration and interlocked to form a porous sheet with some degree of flexibility.

The use of textile technology to produce nonwovens involves adapting garnetting, carding, and aerodynamic forming methods to place textile fibers into preferentially-oriented webs. Fabrics produced by these systems are referred to as dry laid nonwovens and carry terms such as *"garnetted"*, *"carded"*, and *"air laid"*. These fabrics or fiber-network structures are manufactured with machinery associated with staple fiber processing designed to manipulate preformed fibers in the dry state. Also included in this category are structures formed from tow and fabrics composed of staple fibers bonded by stitching filaments or yarns.

A fabric made by placing a predetermined number of textile fibers, filaments, or yarns in a planar array through the use of textile technology and subsequently interlocking or bonding them by mechanical, chemical. or thermal means is designated a *dry laid nonwoven*.

### Paper-Based Processes

The classic papermaking process consists of suspending relatively short fibers in water and pumping the mixture onto a fine mesh screen through which the water flows and upon which the fibers are deposited in the form of a wet continuous mat. The mat is then pressed between rolls to mechanically remove the water held on and between the fibers, heated to dry out the water within the fibers and provide for hydrogen bonding, and wound into rolls. The chemical composition of papermaking fibers is cellulose in the form of wood pulp or chopped plant fibers such as hemp, cotton, sisal, abaca, or flax. When wetted and mechanically treated, cellulosic fibers split into a network of fine fibrils, which are drawn into intimate contact with other fibers by surface tension forces during drying, and interlock by the mechanism of hydrogen bonding. A nonwoven fabric can also be made by suspending fibers in water or some other fluid (including air); controlling the way by which the fibers and suspending media are separated; and then mechanically, chemically, or thermally interlocking the fibers together.

The use of paper technology base to produce nonwovens includes dry laid pulp and modified wet laid paper systems designed to accommodate fibers longer than wood pulps and different from cellulose. Fabric produced by these systems are referred to as *"dry laid pulp"* and *"wet laid"* nonwovens. These fabrics are manufactured with machinery associated with pulp fiberizing (i.e. hammer mills) and paper forming (i.e. slurry pumping onto continuous screens) designed to manipulate short fibers suspended in a fluid.

A fabric made by suspending short fibers in a fluid, depositing the fibers on a porous surface to separate the fibers from the fluid, and interlocking or bonding them by mechanical, chemical, or thermal means is designated a *wet laid nonwoven*.

**Extrusion-Based Processes**

The film extrusion process consists of passing molten polymer molten polymer through a narrow slit, solidifying the polymer in flat form, stretching the solid sheet to align the polymer molecules, and winding the into rolls. Synthetic fiber manufacturing is also a form of polymer extrusion. In this instance, materials such as polyethylene, polypropylene, polyester, and nylon are heated, forced through small holes, solidified by cooling, stretched to align polymer molecules, and appropriately packaged for further processing. Nonwoven fabrics can also be made by extending the fiber extrusion process to include interlocking the fibrous material concurrent with its extrusion, modifying the porosity of a formed film by perforating it, or modifying the film manufacturing process to incorporate the forming of a porous films concurrent with its extrusion.

The extrusion technology base includes spunbond, meltblown, and porous film systems. Fabrics produced by these systems are referred to individually as *"spunbond"*, *"meltblown"*, and *"textured"* or *"apertured film"* nonwovens; or, generically, as *"polymer laid"* nonwovens. These fabrics are produced with machinery associated with polymer extrusion (i.e. manufactured fiber spinning, film casting, extrusion coating). In polymer laid systems fiber structures are simultaneously formed and manipulated.

A fabric made by any of these variations of the extrusion process is designated a *polymer laid nonwoven*.

**Finishing**

Nonwoven web forming and bonding processes produce fabric in continuous lengths at widths greater than most product applications require. In tandem with these primary processes or “off-line” as separate “finishing” treatments, the fabric may be subjected to other operations to bring about or improve inherent properties. For logistics reasons, most nonwoven fabrics are handled in roll form. Roll dimensions are specified to accommodate end-use application or subsequent conversion processes.. Roll width is determined at the slitting operation, and roll length is determined at the winding operation. Slitting and winding are packaging processes common to all nonwoven manufacturing methods

Surface treatments adapted or borrowed directly from traditional textile, paper, or plastic finishing technologies are used to enhance fabric performance or aesthetic properties. Performance properties include functional characteristics such as moisture transport, absorbency, or repellency; flame retardancy; electrical conductivity or static propensity; abrasion resistance; and frictional behavior. Aesthetic properties include coloration, surface texture, and fragrance.

Generically, fabric finishing processes can be categorized as being either chemical, mechanical, or thermo-mechanical. Chemical finishing involves the application of dyestuffs, pigments, or chemical coatings to fibers as well as the impregnation of fabrics with chemical additives or fillers. Mechanical finishing processes alter fabric surface texture by physically repositioning and/or trimming fibers on or near the fabric surface. Thermo-mechanical finishing involves altering fabric dimensions or physical properties through the use of heat and/or pressure.

Finishing may also be viewed as an efficient means for providing nonwovens with additional application-dependent chemical and/or physical properties. Finishing processes bring about value-added fabrics with technically sophisticated properties for specific end-use applications.

**Nonwoven Converting and Product Fabrication Processes**

Nonwovens can be transformed into end-use products much more quickly and with a greater degree of flexibility than other sheet materials. This characteristic is due to the facts that nonwovens can be cut in virtually all directions without fraying or curling and can be joined by methods other than traditional sewing, namely, by adhesives or thermal bonding. The processes used to transform nonwoven roll goods into forms or shapes for use as a nonwoven product or for further processing as a sub-component of a nonwoven-based product has been generically termed converting. Converted nonwoven configurations include premeasured rolls with perforations for dispensing fabric in specific sheet dimensions, continuous rolls for wrapping, individual or interfolded sheets, and various die-cut or molded geometries. Converting processes also include arrangements of machine elements to achieve continuous fabrication or assembly of multicomponent products such as diapers and garments.

**Manufacturing Systems Summary**

Nonwoven manufacturing methods derived from primary textile, paper, and extrusion technologies are collectively termed *Basic Nonwoven Fabric Manufacturing Systems*. These systems are or can be made to be continuous processes. Common to each of these systems are four principal elements or phases of manufacturing: fiber selection and preparation, web formation, web consolidation (bonding), and finishing. Fiber selection and preparation involves choosing the fiber or fiber material for a specific application and treating it so that the process will yield a fabric with properties sufficient to perform its intended function. Web formation is the process by which individual fibers or fibrous materials are arranged in order to bring about the physical properties desired in the fabric structure. Web consolidation or bonding is the process by which the fibers or fibrous materials are interlocked in order to provide the integrity or strength desired in the fabric structure. Finishing includes slitting the fabric to the width desired, winding the fabric in roll form or cutting it to the length desired, and treating the fabric surface chemically or mechanically to bring about enhanced functional or aesthetic properties. An outline of the three basic nonwoven manufacturing systems according to parent technology and the principal elements or manufacturing phases common to each is given in Table I.

**Nonwoven Hybrids**

The hybrid technology base includes (1) fabric/sheet combining systems, (2) combination systems, and (3) composite systems. Combining systems employ lamination technology or at least one basic nonwoven web formation or consolidation technology to join two or more fabric substrates. Combination systems utilize at least one basic nonwoven web formation element to enhance at least one fabric substrate. Composite systems integrate two or more basic nonwoven web formation technologies to produce web structures.

From the manufacturing flow matrix given in Table I, the routes for producing most nonwovens can be traced and additional fundamental points regarding the general nature of nonwovens can be inferred, namely: (1) nonwovens are fiber-material dependent; (2) individual fibers or fibrous materials are arranged in two or three dimensional networks; (3) fiber networks are interlocked to yield flat, flexible, porous sheet structures in the form of rolls; and (4) rolls can be provided engineered properties and are prepared for conversion to end-use items.

**Interrelationships**

These elements are interrelated further in that optimum product performance and maximum processing efficiency are a function of their mutual compatibility. A key factor in the evolution of the various nonwoven manufacturing technologies has been the development of means to utilize a wide variety of fibers and polymers and control individual fiber placement, fiber-to-fiber bonding, and fabric surface energy while employing basic principles known to textile, paper, and extrusion scientists, technologists, and practitioners. From a practical standpoint, the fiber or polymer must interact or "process" freely with the dynamics of web formation, and the resulting fiber network must be compatible with the bonding mechanism or media in order for the fabric structure to transmit the maximum potential inherent in the properties of the fiber. Ultimately, in order for a nonwoven to be totally effective and fully efficient, the fabric roll must be transformed to an end-use shape whose performance reflects the position characteristics of the fiber.

**Summary**

Manufacturers of nonwovens use technically sophisticated machinery to produce fabric directly from polymeric fiber or directly from the polymer from which the fibers themselves are made. Processes for producing nonwovens are, for the most part, continuous operations, and fabric is most frequently provided in the form of rolls, varying in length and width according to specific end-use product requirements. Consequently, discussions about nonwovens often focus on developments relevant to the technology associated with various roll goods manufacturing processes or the usage of nonwoven roll goods in various end-use products. According to roll goods manufacturing technology, nonwoven processes can be grouped into two categories: fiber based and polymer based. The fiber based category consists of wet laid and dry laid processes. The dry laid processes are further sub-grouped to include thermal bonded, chemically bonded, needled, hydroentangled, stitch bonded, and air laid nonwovens. The polymer based category encompasses spunbond, meltblown, and modified film nonwovens.

Currently about one and a half billion pounds of nonwoven fabric are produced in North America each year. This poundage translates into nearly 19 billion square yards of roll goods and is anticipated to expand by at least five percent per year. Nonwoven fabric applications are generically categorized as being the basis for either disposable or durable products, with disposables accounting for about 65 percent and durables about 35 percent. Figures 1 and 2 provide a glance at the distribution of current nonwoven fabric applications and production by manufacturing technology.

Table I. Basic Nonwoven Fabric Manufacturing Systems

| | Textile | | | Paper | | Extrusion | | |
|---|---|---|---|---|---|---|---|---|
| | Garnetting | Carding | Air Laid Fiber | Air Laid Pulp | Wet Laid | Spunbond | Meltblown | Film |
| **Fiber Selection and Preparation** | Natural and Manufactured Textile Fibers | | | Natural and Manufactured Fiber/Pulp | | Fiberforming Polymer Chips | | |
| | Mechanical Opening and Volumetric Blending | | | Mechanical Opening | | Mechanical, Electrostatic, Aerodynamic Filament Orientation | Aerodynamic Fiber Orientation and Shattering | Perforate, Cast; Cast and Aperture |
| | | | | Gravimetric Feeding | Wet Slurry | | | |
| **Web Formation** | Mechanical | | Fluid | | | | | |
| | Parallel Fiber Layers<br>Randomized Batts<br>Crosslapped Layers | | Isotropic Fiber Layers | | Random Fiber Matts<br>Controlled Fiber Layers | Pattern Layering on Conveyer Screen | Collection on Conveyer Screen or Shape | Heat, Heat Stretch, Perforate, Heat, Stretch |
| **Web Consolidation (Bonding)** | Mechanical | | | | Mechanical | Mechanical | Cooling | |
| | Stitchbonding, Needlepunching, Hydroentangling | | | | Hydroentangling | Needlepunching | | |
| | Chemical | | | | | | | |
| | Sprayed Latex or Powder; Saturated, Printed, or Frothed Latex; Solvent | | | | | | | |
| | Thermal | | | | | | | |
| | Thermal Calender, Radiant or Convection Oven, Vacuum Drum or Mold, Laminating, Sonic Welding | | | | | | | |
| **Finishing** | Slitting, Winding | | | | | | | |
| | Other Application-Dependant Physical or Chemical Surface Treatments | | | | | | | |

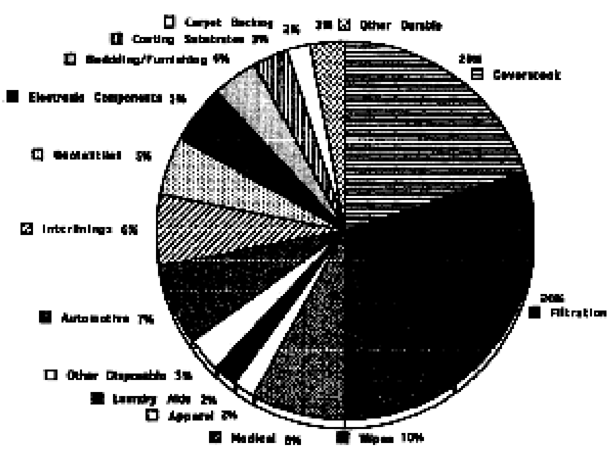


Figure 1. Nonwoven Fabric Applications

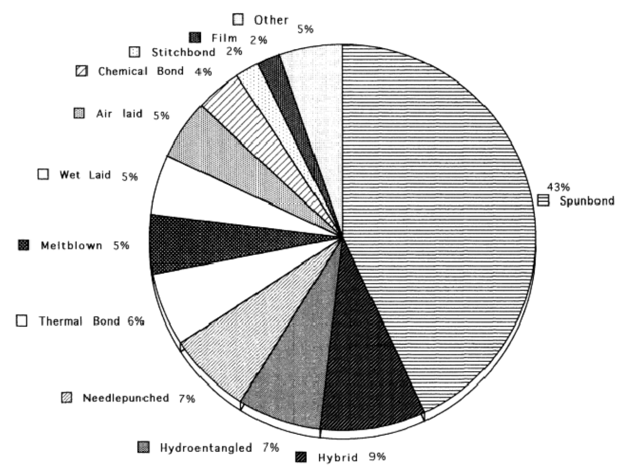


Figure 2. Nonwoven Fabric Production by Manufacturing Technology