



US 20040097158A1

(19) **United States**

(12) **Patent Application Publication**

Rudisill et al.

(10) **Pub. No.: US 2004/0097158 A1**

(43) **Pub. Date: May 20, 2004**

(54) **NONWOVEN FIBROUS SHEET STRUCTURES**

(76) Inventors: **Edgar N. Rudisill**, Nashville, TN (US); **Michael C. Davis**, Midlothian, VA (US); **Hans Rudolf Edward Frankfort**, Kinston, NC (US); **Rudolph F. Janis**, Hopewell, VA (US); **Stephen Buckner Johnson**, Wilmington, NC (US); **David Jackson McGinty**, Midlothian, VA (US); **H. Vaughn Samuelson**, Chadds Ford, PA (US); **Hyunkook Shin**, Wilmington, DE (US); **George Vassilatos**, Wilmington, DE (US)

Correspondence Address:
E I DU PONT DE NEMOURS AND COMPANY
LEGAL PATENT RECORDS CENTER
BARLEY MILL PLAZA 25/1128
4417 LANCASTER PIKE
WILMINGTON, DE 19805 (US)

(21) Appl. No.: **10/703,795**

(22) Filed: **Nov. 7, 2003**

Related U.S. Application Data

- (63) Continuation of application No. 09/467,268, filed on Dec. 20, 1999, now abandoned, which is a continuation-in-part of application No. 09/273,578, filed on Mar. 22, 1999, now abandoned, which is a continuation-in-part of application No. 08/868,529, filed on Jun. 4, 1997, now Pat. No. 5,885,909.
- (60) Provisional application No. 60/019,277, filed on Jun. 7, 1996.

Publication Classification

- (51) **Int. Cl.⁷** **D04H 1/00**; D04H 3/00; D04H 5/00; D04H 13/00; D04H 3/16
- (52) **U.S. Cl.** **442/401**; 442/361; 442/364

(57) **ABSTRACT**

This invention relates to a nonwoven sheet material with high air permeability and substantial hydrostatic head liquid barrier properties. The sheet material is comprised of at least 90%, by weight, melt spun substantially continuous filament polymer fibers having an average cross sectional area of less than about 90 square microns. The sheet material has a basis weight of less than 125 g/m² and a grab tensile strength of at least 0.7 N/(g/m²). The invention is also directed to a process for melt spinning polymer fibers that can be used to make the nonwoven sheet material of the invention.

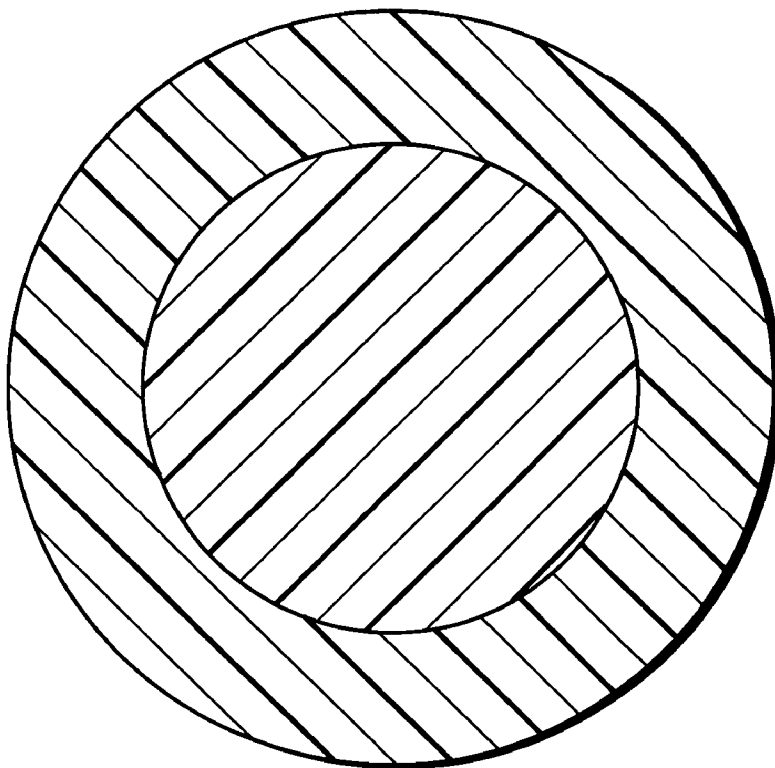


FIG. 1

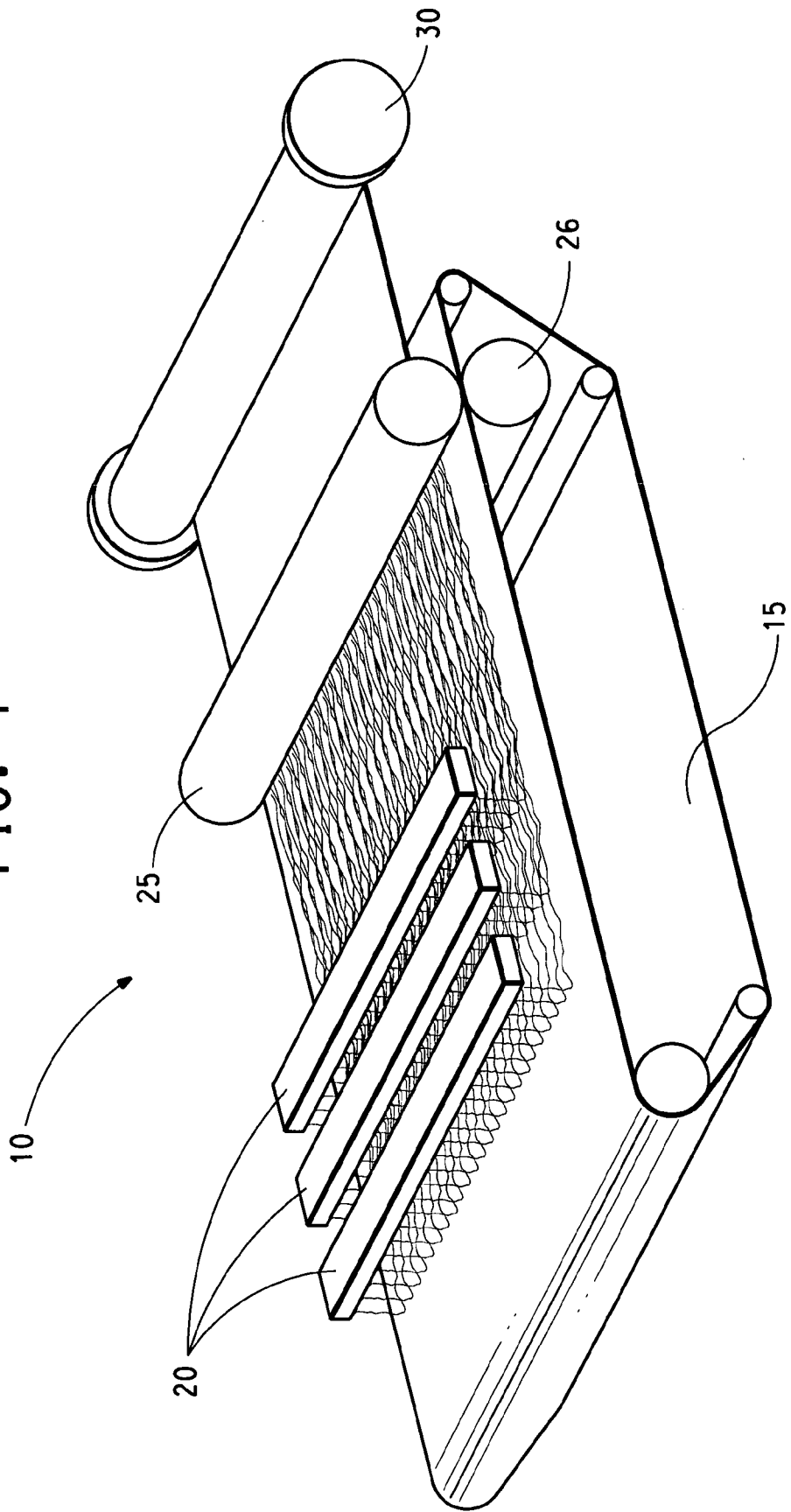


FIG. 2

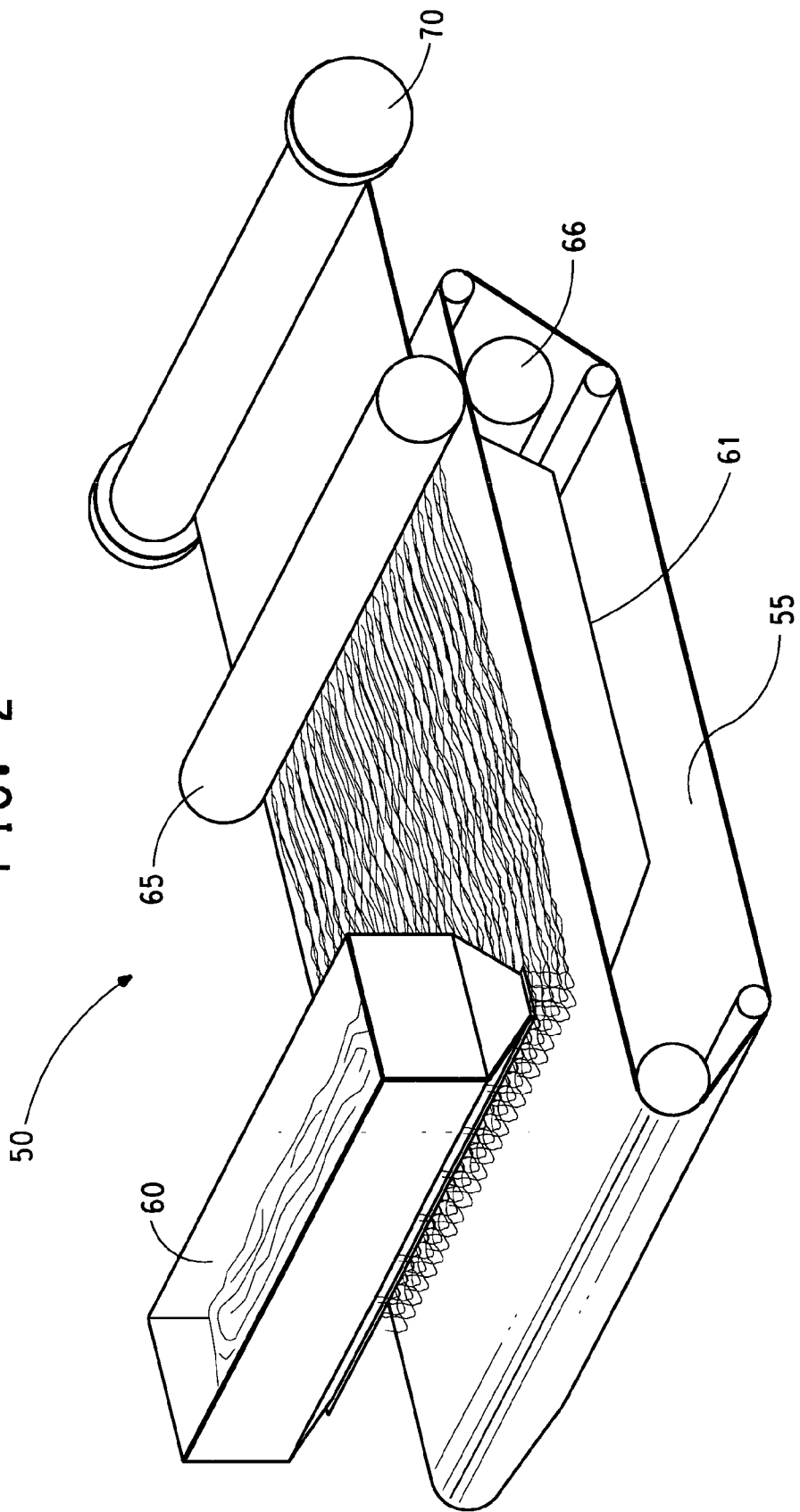


FIG. 3

2GT MICROFIBERS AT HIGH SPEED

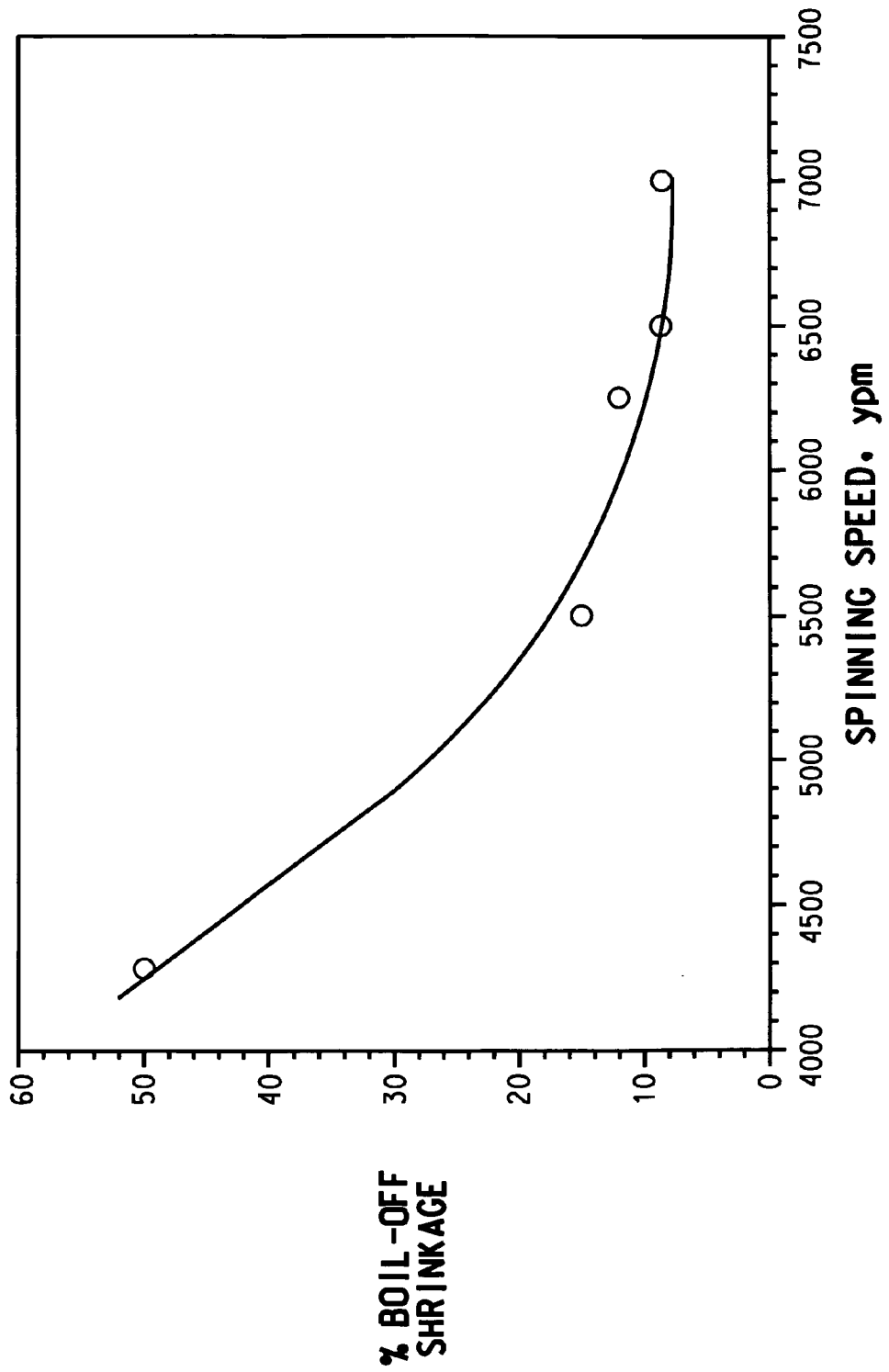


FIG. 4

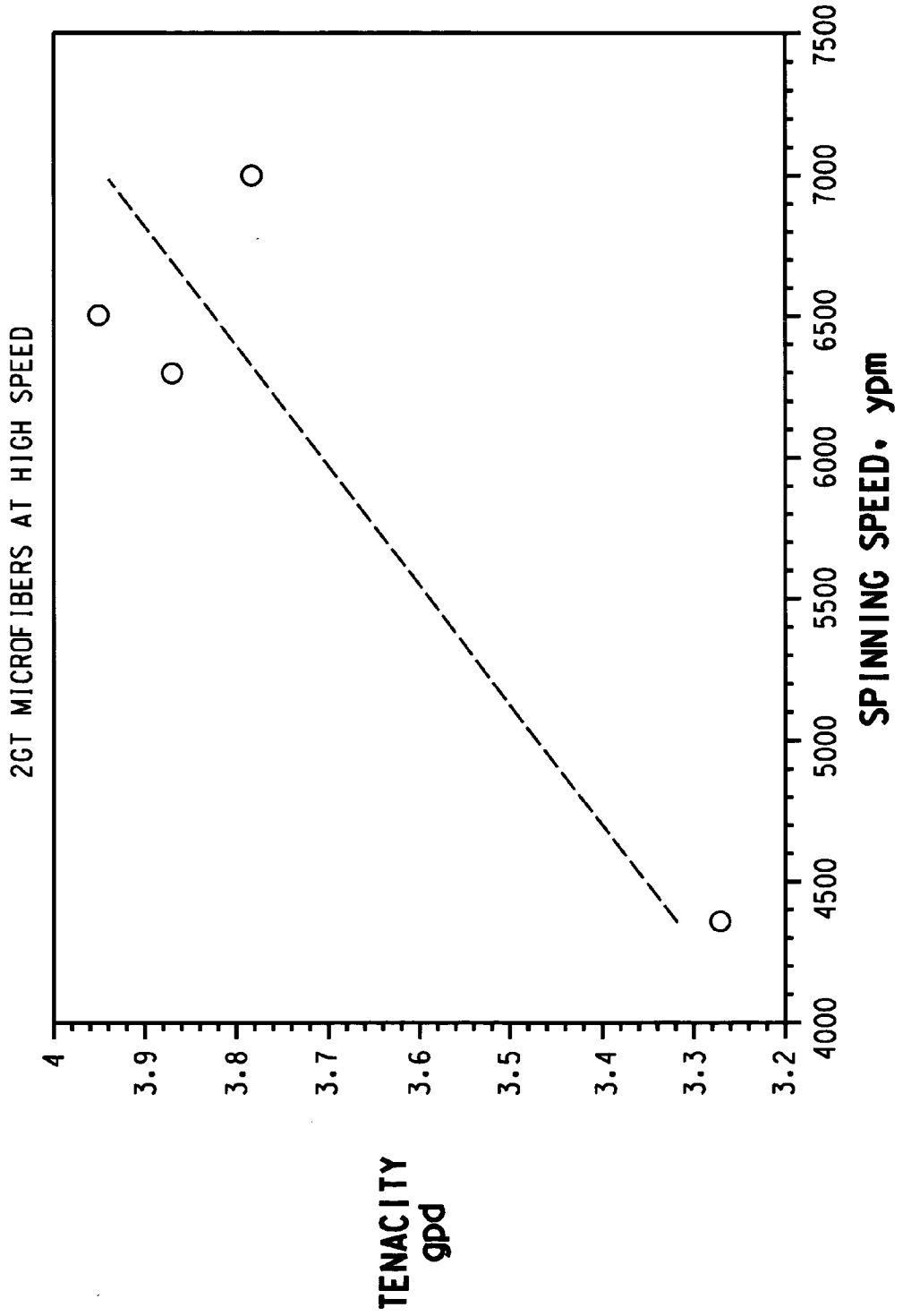


FIG. 5

2GT MICROFIBERS AT HIGH SPEED

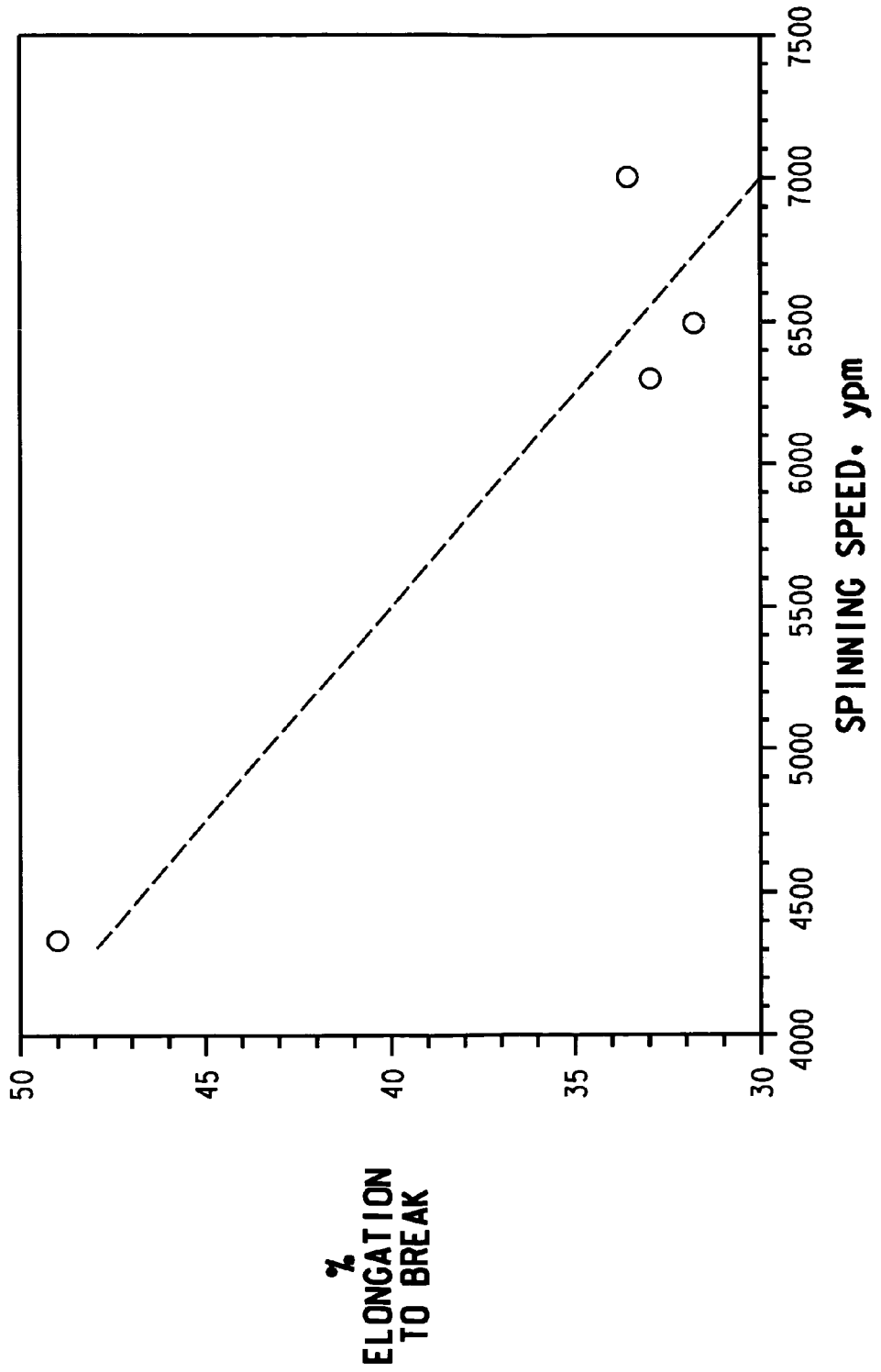
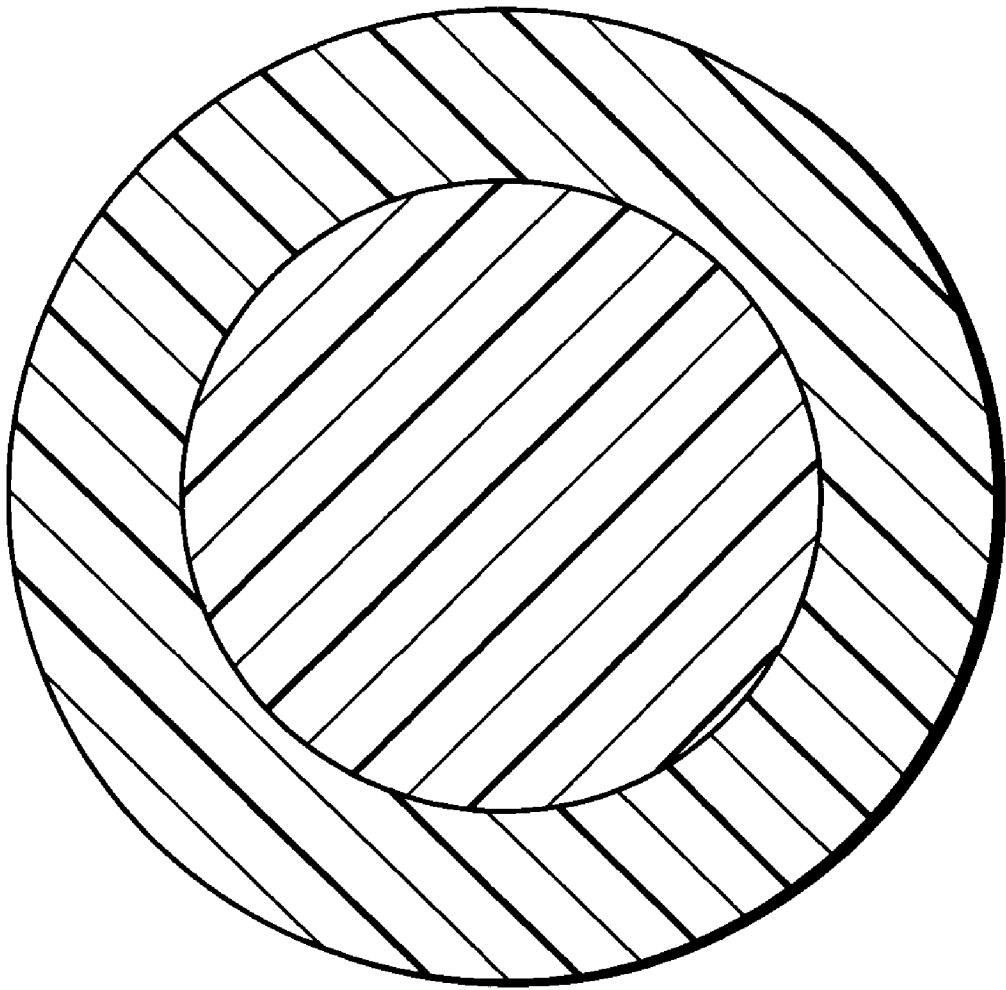


FIG. 6



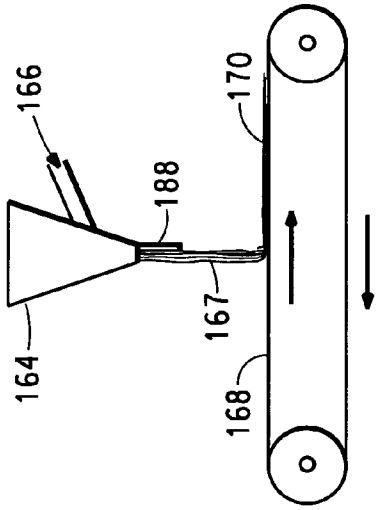


FIG. 8

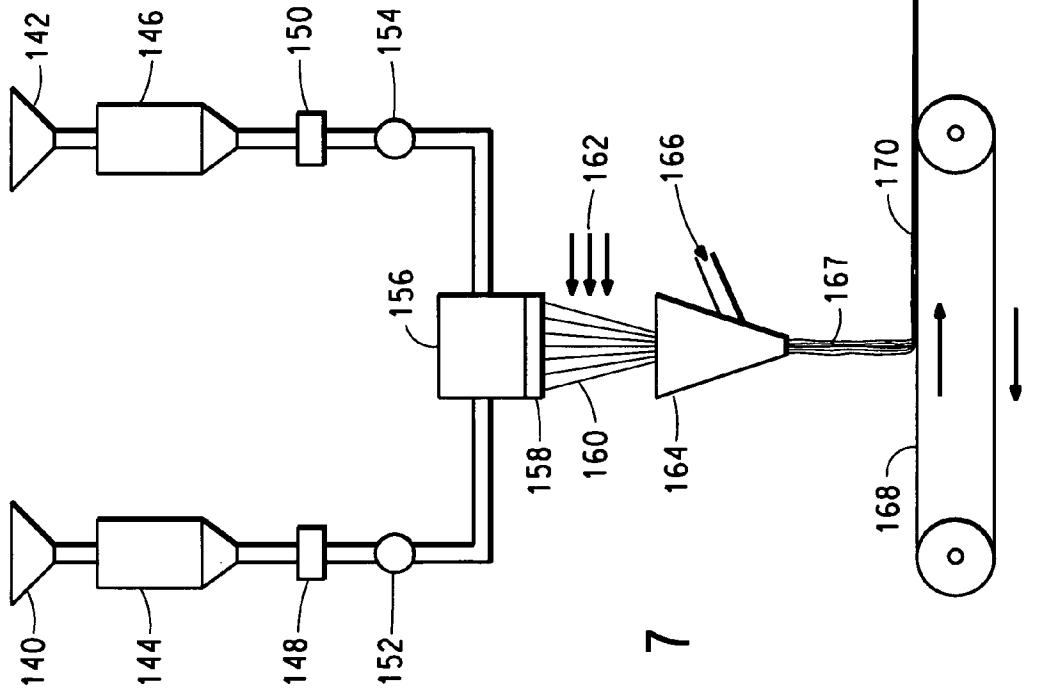


FIG. 7

NONWOVEN FIBROUS SHEET STRUCTURES

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] This invention relates to nonwoven fibrous structures and more particularly to breathable fabrics and sheet structures formed from fibers which are held together without weaving or knitting.

[0003] 2. Description of the Related Art

[0004] Nonwoven fibrous structures have existed for many years and today there are a variety of different nonwoven technologies in commercial use. Nonwoven technologies continue to be developed by those seeking new applications and competitive advantages. One area where nonwoven fibrous structures are used is in protective products. Protective products include apparel and other products that provide protection from things like hazardous chemicals (as during chemical spill clean ups), blood and body fluids (as in the medical field), dry particulates, and other hazards such as paint or asbestos.

[0005] E. I. du Pont de Nemours and Company (DuPont) makes Sontara® spunlaced fabrics which are used extensively for medical gowns and drapes, and for certain applications within the medical field. Sontara® spunlaced fabrics have long been used in the medical field because of their exceptional performance and comfort. Sontara® spunlaced fabrics for medical protective apparel uses are typically comprised of staple length polyester fiber hydroentangled with woodpulp. The fabric is finished with a moisture repellent coating.

[0006] Composite nonwovens are also used in medical products such as gowns and drapes. Each layer in such composites provides certain properties desirable for a particular end use. One composite nonwoven is a spunbond/meltblown/spunbond laminate that is generally known as "SMS". The spunbond outer layers of an SMS material are comprised of spunbond nonwoven that contribute strength to the sheet. The inner layer of an SMS material is made of fine, low denier, meltblown fibers that contribute barrier properties to the sheet. Such SMS nonwoven materials are described in U.S. Pat. No. 4,041,203, with further improvements described in U.S. Pat. Nos. 4,374,888 and 4,041,203.

[0007] A single layer of bonded meltblown fibers can be used alone to provide a sheet with good barrier properties. However, such a meltblown fiber sheet does not exhibit sufficient strength to be used in many end use applications. U.S. Pat. Nos. 4,622,259 and 4,908,163 disclose meltblown fibers with somewhat improved tensile properties.

[0008] There is a need for fine fibers that exhibit good strength. There is also a need for a nonwoven structure made of such fine fibers, which structure exhibits high barrier to fluids, good air permeability and high strength.

BRIEF SUMMARY OF THE INVENTION

[0009] The invention is directed to a nonwoven sheet comprised of at least 90%, by weight, melt spun substantially continuous filament polymer fibers having an average cross sectional area of less than about 90 square microns. The sheet has a basis weight of less than 125 g/m², a grab tensile strength in both the machine and cross directions,

normalized for basis weight and measured according to ASTM D 5034, of at least 0.7 N/(g/m²), and a combination of a Frazier permeability and a hydrostatic head selected from the group of: a Frazier permeability of at least about 70 m³/min-m² and a hydrostatic head of at least about 20 cm; a Frazier permeability of at least about 28 m³/min-m² and a hydrostatic head of at least about 25 cm; a Frazier permeability of at least about 20 m³/min-m² and a hydrostatic head of at least about 35 cm; and a Frazier permeability of at least about 1 m³/min-m² and a hydrostatic head of at least about 80 cm. In a preferred embodiment of the invention, the sheet has a hydrostatic head of at least about 40 cm. Preferably, the fibers of the sheet have an average boil off shrinkage of less than ten percent. The invention is also directed to a garment made of the nonwoven sheet of the invention.

[0010] According to the preferred embodiment of the invention, the fibers of the sheet are comprised of at least 50% by weight of polyester polymer. More preferably, the fibers of the sheet are comprised of at least 80% by weight of polyester polymer selected from the group of polyethylene terephthalate, polypropylene terephthalate, polybutylene terephthalate polymer. Alternatively, the fibers of the sheet may be comprised of at least 50% by weight a nylon polymer, an elastomeric polymer, or a polyolefin polymer such as polyethylene or polypropylene. The fibers of the sheet may include additives blended into the polymer fibers such as fluorocarbons, ultraviolet energy stabilizers, process stabilizers, thermal stabilizers, antioxidants, wetting agents, pigments, antimicrobial agents, and antistatic electricity buildup agents.

[0011] According to an alternative embodiment of the invention, at least a portion of the fibers of the sheet of the invention may be formed of at least two separate component polymers. For example, one of such component polymers may overlay the other of the component polymers in a sheath-core arrangement. In one preferred embodiment of the invention, the sheath polymer has a lower melting temperature than the polymer comprising the core.

[0012] The fibers of the nonwoven sheet of the invention are bonded together by a method selected from the group of ultrasonic bonding, thermal bonding, adhesive bonding, and combinations thereof.

[0013] The present invention is also directed to a process for melt spinning substantially continuous filament polymer fibers having an average cross sectional area of less than about 90 square microns. The process includes the steps of extruding a melt spinnable polymer through a plurality of capillary openings to form fiber filaments; drawing said extruded fiber filaments by feeding the extruded filaments into a draw jet so as to apply a drawing tension to the fiber filaments, the draw jet including a fiber entrance, a fiber passage where an air jet impact the filaments in the direction that the filaments are traveling, and a fiber exit through which the drawn filaments are discharged from the draw jet; discharging the drawn fiber filaments through the fiber exit of the draw jet in a downwardly direction at a rate of at least 6000 m/min; guiding the fiber filaments being discharged from the fiber exit of the draw jet with an extension plate, the extension plate extending from the draw jet in a direction substantially parallel to the direction that the fibers are being discharged from the fiber exit of the draw jet, the fibers

passing within 1 cm of said extension plate over a distance of at least 5 cm; and laying the fibers discharged from the fiber exit of the draw jet on a collection surface.

BRIEF DESCRIPTION OF THE DRAWING

[0014] The invention will be more easily understood by a detailed explanation of the invention including drawings. It should be understood that the drawings are for explanation only and are not necessarily to scale. The drawings are briefly described as follows:

[0015] FIG. 1 is a perspective view of an apparatus for making the nonwoven sheet of the invention;

[0016] FIG. 2 is a perspective view of another apparatus for making the nonwoven sheet of the invention;

[0017] FIG. 3 is a chart illustrating one of the properties of the fibers of the nonwoven sheet of the invention;

[0018] FIG. 4 is second chart illustrating a second property of the fibers of the nonwoven sheet of the invention;

[0019] FIG. 5 is a third chart illustrating a third property of the fibers of the nonwoven sheet of the invention;

[0020] FIG. 6 is an enlarged cross sectional view of a sheath-core bicomponent fiber;

[0021] FIG. 7 is a schematic illustration of another apparatus for making the nonwoven sheet of the invention; and

[0022] FIG. 8 is a schematic illustration of a portion of an inventive apparatus for making the nonwoven sheet of the invention.

DEFINITIONS

[0023] The term “polymer” as used herein, generally includes but is not limited to, homopolymers, copolymers (such as for example, block, graft, random and alternating copolymers), terpolymers, etc. and blends and modifications thereof. Furthermore, unless otherwise specifically limited, the term “polymer” shall include all possible geometrical configurations of the material. These configurations include, but are not limited to isotactic, syndiotactic and random symmetries.

[0024] The term “polyolefin” as used herein, is intended to mean any of a series of largely saturated open chain polymeric hydrocarbons composed only of carbon and hydrogen. Typical polyolefins include, but are not limited to, polyethylene, polypropylene, polymethylpentene and various combinations of the ethylene, propylene, and methylpentene monomers.

[0025] The term “polyethylene” as used herein is intended to encompass not only homopolymers of ethylene, but also copolymers wherein at least 75% of the recurring units are ethylene units.

[0026] The term “polypropylene” as used herein is intended to embrace not only homopolymers of propylene but also copolymers where at least 85% of the recurring units are propylene units.

[0027] The term “polyester” as used herein is intended to embrace polymers wherein at least 85% of the recurring units are condensation products of carboxylic acids and dihydroxy alcohols with polymer linkages created by for-

mation of an ester unit. This includes, but is not limited to, aromatic, aliphatic, saturated, and unsaturated acids and di-alcohols. The term “polyester” as used herein also includes copolymers (such as block, graft, random and alternating copolymers), blends, and modifications thereof. A common example of a polyester is poly(ethylene terephthalate) which is a condensation product of ethylene glycol and terephthalic acid.

[0028] The term “melt spun fibers” as used herein means small diameter fibers which are formed by extruding molten thermoplastic polymer material as filaments from a plurality of fine, usually round, capillaries of a spinnerette with the diameter of the extruded filaments then being rapidly reduced. Melt spun fibers are generally continuous and have an average diameter of greater than about 5 microns.

[0029] The term “nonwoven fabric, sheet or web” as used herein means a structure of individual fibers or threads that are positioned in a random manner to form a planar material without an identifiable pattern, as in a knitted fabric.

[0030] As used herein, the “machine direction” is the long direction within the plane of a sheet, i.e., the direction in which the sheet is produced. The “cross direction” is the direction within the plane of the sheet that is substantially perpendicular to the machine direction.

[0031] The term “unitary fibrous sheet” as used herein, means woven or nonwoven fabrics or sheets made of the same types of fibers or fiber blends throughout the structure, wherein the fibers form a substantially homogeneous layer that is free of distinguishable laminations or other support structures.

Test Methods

[0032] In the description above and in the non-limiting examples that follow, the following test methods were employed to determine various reported characteristics and properties. ASTM refers to the American Society for Testing and Materials, and AATCC refers to the American Association of Textile Chemists and Colorists.

[0033] Fiber Diameter was measured via optical microscopy and is reported as an average value in microns.

[0034] Fiber Size is the weight in grams of 9000 meters of the fiber, and was calculated using the diameter of the fibers measured via optical microscopy and the polymer density, and is reported in deniers.

[0035] Fiber Cross Sectional Area was calculated using the diameter of the fibers via optical microscopy based on a round fiber cross section.

[0036] Spinning Speed is the maximum speed attained by the fiber filaments during the spinning process. Spinning speed is calculated from polymer throughput per capillary opening expressed in g/min, and the fiber size expressed in g/9000 m (1 denier=1 g/9000 m), according to the following equation:

$$\text{spinning speed (m/min)} = \frac{[\text{polymer throughput per opening (g/min)}] (9000)}{[\text{fiber size (g/9000 m)}]}$$

[0037] Thickness is the distance between one surface and its opposite and was measured according to ASTM D 5729-95.

[0038] Basis Weight is a measure of the mass per unit area of a fabric or sheet and was determined by ASTM D 3776, which is hereby incorporated by reference, and is reported in g/m².

[0039] Grab Tensile Strength is a measure of the breaking strength of a sheet and was conducted according to ASTM D 5034, which is hereby incorporated by reference, and is reported in Newtons.

[0040] Elongation of a sheet is a measure of the amount a sheet stretches prior to failure (breaking) in the grab tensile strength test and was conducted according to ASTM D 5034, which is hereby incorporated by reference, and is reported as a percent.

[0041] Hydrostatic Head is a measure of the resistance of the sheet to penetration by liquid water under a static pressure. The test was conducted according to MTCC-127, which is hereby incorporated by reference, and is reported in centimeters. In this application, unsupported hydrostatic head pressures are measured on the various sheet examples in a manner so that if the sheets do not comprise a sufficient number of strong fibers, the measurement is not attainable. Thus, the mere presence of an unsupported hydrostatic head pressure is also an indication that the sheet has the intrinsic strength to support the hydrostatic head pressure.

[0042] Frazier Permeability is a measure of air flow passing through a sheet under at a stated pressure differential between the surfaces of the sheet and was conducted according to ASTM D 737, which is hereby incorporated by reference, and is reported in m³/min/m².

[0043] Water Impact is a measure of the resistance of a sheet to the penetration of water by impact and was conducted according to AATCC 42-1989, which is hereby incorporated by reference, and is reported in grams.

[0044] Blood Strike Through is a measure of the resistance of fabrics to the penetration of synthetic blood under a continuously increasing mechanical pressure and was measured according to ASTM F 1819-98.

[0045] Alcohol Repellency is a measure of the resistance of fabrics to wetting and penetration by alcohol and alcohol/water solutions, expressed as the highest percentage of isopropyl alcohol solution that the fabric is capable of resisting (expressed on a 10 point scale -10 being pure isopropyl alcohol) and was conducted according to INDA IST 80.6-92.

[0046] Spray Rating is a measure of the resistance of fabrics to wetting by water and was conducted according to AATCC 22-1996, and is reported in percent.

[0047] Moisture Vapor Transmission Rate is a measure of the rate of diffusion of water vapor through a fabric and was conducted according to ASTM E 96-92, B upright cup, and is reported in g/m²/24 hr.

[0048] Trapezoid Tear is a measure of the tearing strength of a fabric in which a tear had previously been started and was conducted according to ASTM D 5733, and is reported in Newtons.

[0049] Intrinsic Viscosity (IV) is a measure of the inherent resistance to flow for a polymer solution. IV is determined by comparing the viscosity of a 1% solution of a polymer sample in orthochlorophenol with the viscosity of the pure solvent as measured at 25° C. in a capillary viscometer. IV is reported in dl/g, and is calculated using the formula:

$$IV = \eta_s / c$$

[0050] Where:

$$\eta_s = \text{specific viscosity} = \frac{\text{flow time of solution}}{\text{flow time of solvent}} - 1$$

[0051] and c is the concentration of the solution in g/100 ml.

DETAILED DESCRIPTION OF THE INVENTION

[0052] The present invention is a nonwoven sheet that exhibits high strength and an optimum combination of liquid barrier and air permeability properties. The invention also includes a process for making such sheets. The nonwoven sheet of the invention is comprised of at least 90%, by weight, melt spun substantially continuous filament polymer fibers having an average cross sectional area of less than about 90 square microns. The sheet has a basis weight of less than 125 g/m², a grab tensile strength in both the machine and cross directions, normalized for basis weight and measured according to ASTM D 5034, of at least 0.7 N/(g/m²), and a combination of a Frazier permeability and a hydrostatic head selected from the group of:

[0053] a Frazier permeability of at least about 70 m³/min-m² and a hydrostatic head of at least about 20 cm;

[0054] a Frazier permeability of at least about 28 m³/min-m² and a hydrostatic head of at least about 25 cm;

[0055] a Frazier permeability of at least about 15 m³/min-m² and a hydrostatic head of at least about 35 cm; and

[0056] a Frazier permeability of at least about 1 m³/min-m² and a hydrostatic head of at least about 80 cm.

[0057] The fibers in the nonwoven sheet of the invention are small denier polymeric fibers that, when made into a sheet structure, form numerous very small pores. It has been found that when such melt spun microfibers are used to create a nonwoven fibrous structure, the resulting fabric sheets have very high air permeability while also providing excellent liquid barrier and sheet strength. As the sheet material is comprised of generally continuous filaments, the sheet material exhibits low linting characteristics desirable for end use applications such as clean room apparel and wipes.

[0058] According to a more preferred embodiment of the invention, the nonwoven sheet is a unitary fibrous sheet comprised of melt spun substantially continuous filament polymer fibers wherein the sheet has a basis weight of from 13 g/m² to 125 g/m² and substantially all of the fibers are

melt spun fibers. More preferably, the nonwoven sheet of the invention has a basis weight within the range of 30 to 110 g/m², and most preferably within the range of 50 to 90 g/m².

[0059] The properties of the nonwoven sheet may be modified by varying the cross sections of the fibers. The preferred fibers in the nonwoven sheet of the invention have a cross sectional area of between about 20 and about 90 μm^2 . More preferably, the fibers have a cross sectional area of from about 25 to about 70 μm^2 , and most preferably from about 33 to about 60 μm^2 . It is believed that the properties of the sheet are determined in part by the physical size of the fibers. Fiber sizes are conventionally described in terms of denier or decitex. As denier and decitex relate to the weight of a long length of fiber, the density of the polymer influences the denier or decitex values. For example, if two fibers have the same cross section, but one is made of polyethylene while the other comprises polyester, the polyester fiber would have a greater denier because it tends to be more dense than polyethylene. However, it can generally be said that the preferred range of fiber denier is less than or nearly equal to about 1. The most compact fiber cross sections, when used in sheets, appear to yield sheets with pores that are small but not closed. Fibers with round cross sections and the above cross sectional areas have been used to make the nonwoven sheet of the invention. However, it is anticipated that the nonwoven sheets of the invention might be enhanced by changing the cross sectional shapes of the fibers.

[0060] It has been found that a sheet of melt spun microfibers can be made with sufficient strength to form a barrier fabric without the need for any type of supporting scrim, thus saving the additional materials and cost of such supporting materials. This can be achieved by using fibers with good tensile strength, as for example by using fibers having a minimum tensile strength of at least about 1.5 g/denier. This fiber strength would correspond to a fiber strength of about 182 MPa for a polyester fiber or about 118 MPa for a polypropylene fiber. Melt blown fibers would typically be expected to have tensile strengths from about 26 to about 42 MPa due to the lack of polymer orientation in the fiber. The grab tensile strength of the composite nonwoven sheet of the invention may vary depending on the bonding conditions employed. Preferably, the tensile strength of the sheet (in both the machine and cross directions), normalized for basis weight, is from 0.7 to 5 N/(g/m²), and more preferably from 0.8 to 4 N/(g/m²), and most preferably from 0.9 to 3 N/(g/m²). Fibers having a tensile strength of at least 1.5 g/denier should provide sheet grab strengths in excess of 0.7 N/(g/m²) normalized for basis weight. The strength of the sheets of the present invention will accommodate typical end use applications without reinforcement.

[0061] While fiber strength is an important property, fiber stability is also important. It has been found that microfibers melt spun at high speed can be made that exhibit low shrinkage even where the fibers are made of polyester. The preferred sheet of the invention is made with fibers that have an average boil off shrinkage of less than 10%. It has been found that when sheets are produced by the high speed melt spinning process described below with respect to FIG. 7, that sheets of strong fine denier poly(ethylene terephthalate) fibers can be made that have a boil off shrinkage of less than 5%.

[0062] According to one embodiment of the invention, the nonwoven sheet may be subjected to a heated nip to bond the fibers of the sheet. The fibers in the bonded sheet appear to be stacked on one another without having lost their basic cross sectional shape. It appears that this is a relevant aspect of the invention because each fiber appears to have not been distorted or substantially flattened which would close the pores. As a result, the sheet has good barrier properties as measured by hydrostatic head while still maintaining a high void ratio, a low density, and high Frazier permeability. Preferably, the nonwoven sheet of the invention has a Frazier permeability of at least 15 m³/min-m² and a hydrostatic head of at least 20 cm. More preferably, the sheet has a hydrostatic head of at least 25 cm, and even more preferably of at least 30 cm, and most preferably of at least 35 cm. It is further preferred that the sheet exhibit a water impact of less than 5 g, and more preferably less than 2 g, and most preferably less than 0.5 g. In the preferred embodiment of the invention, the sheet has a Frazier air permeability of at least 20 m³/min-m², and more preferably of at least 25 m³/min m². A fabric having high barrier properties with high breathability is believed to be desirable as a protective fabric in the medical field and possibly many other fields.

[0063] It should be recognized that although the nonwoven sheet of the invention has been characterized by hydrostatic head, that the small pores will make a good barrier for dry particulate materials. Thus, with its high Frazier permeability, the sheet of the invention should make a suitable filtration media. It should be recognized that the basis weight of the sheet material will have some effect on the balance of hydrostatic head and permeability properties. In most cases, it will be desirable from both an economic and productivity standpoint, as well as from a property balance standpoint, to have the sheet basis weight be about or below 75 g/m². However, there are potential end uses where heavier and higher barrier sheet materials would be desirable such as certain protective apparel applications. In such cases, the sheet basis weight may be greater than about 75 g/m².

[0064] The fibers of the preferred nonwoven sheet of the invention are comprised of synthetic melt spinnable polymer. The preferred fiber is comprised of one or more of any of a variety of polymers or copolymers including polyethylene, polypropylene, polyester, nylon, elastomer, and other melt spinnable polymers that can be spun into fibers of less than approximately 1.2 decitex per filament. More preferably, the fibers are comprised of at least 50% by weight polyester polymer, such as poly(ethylene terephthalate), poly(propylene terephthalate), or poly(butylene terephthalate) polymer. According to other preferred embodiments of the invention, the fibers may be comprised of at least 50% by weight of a nylon polymer, a polyolefin polymer such as polyethylene or polypropylene, or an elastomeric polymer such as polyurethane or co-polyether ester.

[0065] One polyester that has been used to make very fine and strong fibers in the nonwoven sheet of the invention is poly(ethylene terephthalate) having an intrinsic viscosity of 0.5 to 0.6 dl/g. The intrinsic viscosity or "IV" of a polymer is an indicator of the polymer's molecular weight, with a higher IV being indicative of a higher molecular weight. The normal intrinsic viscosity for a poly(ethylene terephthalate) polyester is in the range of 0.65 to 0.70 dl/g. Poly(ethylene terephthalate) with an IV below about 0.6 dl/g is considered

to be a low IV polyester, and has not historically been used in melt spinning because the filaments break. Applicants have now found that low IV poly(ethylene terephthalate) can be spun and drawn into fine fibers with good strength when spun at high spinning speeds. The use of low IV poly(ethylene terephthalate) has made it possible to spin finer polyester fibers of less than 0.8 dpf and to spin the fibers at speeds in excess of 6000 m/min. Surprisingly, it has been found that such fibers made with low IV poly(ethylene terephthalate) have good strength equivalent to that of larger poly(ethylene terephthalate) fibers directly spun from regular IV polyester normalized for fiber size.

[0066] The fibers of the nonwoven sheet may be spun with one or more additives blended into the polymer of the fibers. Additives that may be advantageously spun into some or all of the fibers of the nonwoven sheet include fluorocarbons, ultraviolet energy stabilizers, process stabilizers, thermal stabilizers, antioxidants, wetting agents, pigments, antimicrobial agents, and antistatic electricity buildup agents. An antimicrobial additive may be suitable in some healthcare applications. Stabilizers and antioxidants may be provided for a number of end use applications where exposure to ultraviolet energy, such as sunlight, is likely. A static electricity discharge additive may be used for applications where a build up of electricity is possible and undesirable. Another additive that may be suitable is a wetting agent to make the sheet material suitable as a wipe or absorbent or to allow liquids to flow through the fabric while very fine solids are collected in the fine pores of the sheet material. Alternatively, the nonwoven sheet of the invention may be topically treated with a finish in order to alter the properties of the nonwoven sheet. For example, a fluorochemical coating can be applied to the nonwoven sheet to reduce the surface energy of the fiber surfaces and thus increase the fabric's resistance to liquid penetration, especially where the sheet must serve as a barrier to low surface tension liquids. Typical fluorochemical finishes include ZONYL® fluorochemical (available from DuPont, Wilmington, Del.) or REPEARL® fluorochemical (available from Mitsubishi Int. Corp, New York, N.Y.).

[0067] In the nonwoven sheet of the invention, a portion of the fibers may be comprised of at least two separate component polymers. These polymer components may be arranged in a sheath-core arrangement, a side-by-side arrangement, a segmented pie arrangement, an "islands in the sea" arrangement, or any other known configuration for multiple component fibers. Where the multiple component fibers have a sheath-core arrangement, the polymers may be selected such that the polymer comprising the sheath has a lower melting temperature than the polymer comprising the core. Such fibers can be more easily thermally bonded without sacrificing fiber tensile strength. In addition, small denier fibers spun as multiple component fibers may split into even finer fibers after the fibers are spun. One advantage of spinning multi-component fibers is that higher production rates can be attained depending on the mechanism for splitting the multi-component fibers. Each of the resulting split fibers may have a pie-shaped or other-shaped cross section.

[0068] A sheath-core bicomponent fiber is illustrated in FIG. 6 where a fiber 80 is shown in cross section. The sheath polymer 82 surrounds the core polymer 84 and the relative amounts of polymer may be adjusted so that the core

polymer 84 may comprise more or less than fifty percent of the cross sectional area. With this arrangement, a number of attractive alternatives can be produced. For example, the sheath polymer 82 can be blended with pigments which are not wasted in the core, thereby reducing the costs for pigments while obtaining a suitably colored material. A hydrophobic material such as a fluorocarbon may also be spun into the sheath polymer to obtain the desired liquid repellency at minimal cost. As mentioned above, a polymer having a lower melt point or melting temperature may be used as the sheath so as to be amenable to melting during bonding while the core polymer does not soften. One very interesting example is a sheath core arrangement using 2GT polyester as the core and 3GT polyester as the sheath. Such an arrangement would be suited for radiation sterilization such as e-beam and gamma ray sterilization without degradation. Other combinations of multi-component fibers and blends of fibers may be envisioned.

[0069] The fibers of the nonwoven sheet of the invention are preferably high strength fibers, which conventionally are made as fibers that have been fully drawn and annealed to provide good strength and low shrinkage. Fibers strengthened by high speed melt spinning are preferred for the present invention. The nonwoven sheet of the invention may be created without the steps of annealing and drawing. In particular, it has been found that spinning microfibers at high spinning speeds causes considerable changes in the properties of the fibers. Experiments were run with 2GT polyester at a range of spinning speeds to show the effect of the spinning speed differences on the fiber properties. As illustrated in the charts in FIGS. 3, 4, and 5, it can be seen that as the fiber spinning speeds were increased, the tenacity of the fibers dramatically increased, while the elongation to break and boil off shrinkage of the fibers dramatically decreased. The 2GT microfibers spun at high spinning speeds are strong and stable. Such high production speeds are also desirable for high production rates of nonwoven sheets. The data is also tabulated in the following Table A:

TABLE A

Spinning Speed (m/min)	3998	5029	5761	5943	6401
(yards/min)	4372	5500	6300	6500	7000
No. of Filaments	200	200	200	200	200
Fiber Size (denier)	0.5	0.5	0.5	0.5	0.5
Boil Off Shrinkage (%)	50.1	15.1	12.1	7.8	8.1
Tenacity (g/denier)	3.3	—	3.9	3.9	3.8
Elongation to Break (%)	49.0	—	33.0	31.8	33.2

[0070] The fibers of the nonwoven sheet of the invention may be bonded together by known methods such as thermal calendar bonding, through-air bonding, steam bonding, ultrasonic bonding, and adhesive bonding.

[0071] The nonwoven sheet of the invention can also be used as a spunbond layer in a spunbond-meltblown-spunbond ("SMS") composite sheet. In conventional SMS composites, the exterior layers are spunbond fiber layers that contribute strength to the overall composite, while the core layer is a meltblown fiber layer that provides barrier properties. When the nonwoven sheet of the invention is used for the spunbond layers, in addition to contributing strength, the spunbond fiber layers can provide additional barrier properties to the composite sheet.

[0072] The nonwoven sheet of the invention may be produced using a high speed melt spinning process, such as the high speed spinning processes disclosed in U.S. Pat. Nos. 3,802,817; 5,545,371; and 5,885,909; which are hereby incorporated by reference. According to the preferred high speed melt spinning process, one or more extruders supply melted polymer to a spin pack where the polymer is fiberized as it passes through openings to form a curtain of filaments. The filaments are partially cooled in an air quenching zone while being pneumatically drawn to reduce their size and impart increased strength. The filaments are deposited on a moving belt, scrim or other fibrous layer. Fibers produced by the preferred high speed melt spinning process are substantially continuous and have a diameter of from 5 to 11 microns. These fibers can be produced as single component fibers, as multiple component fibers, or as some combination thereof. Multiple component fibers can be made in various known cross-sectional configurations, including side-by-side, sheath-core, segmented pie, or islands-in-the-sea configurations.

[0073] An apparatus for producing high strength mono-component or bicomponent melt spun fibers at high speeds is schematically illustrated in FIG. 7. In this apparatus, two thermoplastic polymers are fed into the hoppers 140 and 142, respectively. The polymer in hopper 140 is fed into the extruder 144 and the polymer in the hopper 142 is fed into the extruder 146. The extruders 144 and 146 each melt and pressurize the polymer and push it through filters 148 and 150 and metering pumps 152 and 154, respectively. The polymer from hopper 140 is combined with polymer from hopper 142 in the spin pack 156 by known methods to produce the desired bicomponent filament cross sections mentioned above, as for example by using a multiple component spin pack like that disclosed in U.S. Pat. No. 5,162,074, which is hereby incorporated by reference. Where the filaments have a sheath-core cross section, a lower melting temperature polymer is typically used for the sheath layer so as to enhance thermal bonding. If desired, single component fibers can be spun from the multiple component apparatus shown in FIG. 7 by putting the same polymer in both of the hoppers 140 and 142.

[0074] The melted polymers exit the spin pack 156 through a plurality of capillary openings on the face of the spinneret 158. The capillary openings may be arranged on the spinneret face in a conventional pattern (rectangular, staggered, etc.) with the spacing of the openings set to optimize productivity and fiber quenching. The density of the openings is typically in the range of 500 to 8000 holes/meter width of the pack. Typical polymer throughputs per opening are in the range of 0.3 to 5.0 g/min. The capillary openings may have round cross sections where round fibers are desired.

[0075] The filaments 160 extruded from the spin pack 156 are initially cooled with quenching air 162 and then drawn by a pneumatic draw jet 164 before being laid down. The quenching air is provided by one or more conventional quench boxes that direct air against the filaments at a rate of about 0.3 to 2.5 m/sec and at a temperature in the range of 50 to 25° C. Typically, two quench boxes facing each other from opposite sides of the line of filaments are used in what is known as a co-current air configuration. The distance between the capillary openings and the draw jet may be anywhere from 30 to 130 cm, depending on the fiber

properties desired. The quenched filaments enter the pneumatic draw jet 164 where the filaments are drawn by air 166 to fiber speeds in the range of from 6000 to 12,000 m/min. This pulling of the filaments draws and elongates the filaments as the filaments pass through the quench zone.

[0076] Optionally, the end of the pneumatic draw jet 164 may include a draw jet extension 188, as illustrated in FIG. 8. The draw jet extension 188 is preferably a smooth rectangular plate that extends from the draw jet 164 in a direction substantially parallel to the curtain of filaments 167 exiting the draw jet. The draw jet extension 188 guides the filaments to the laydown surface so that the filaments more consistently impinge the laydown surface at the same location which improves sheet uniformity. In the preferred embodiment, the draw jet extension is on the side of the curtain of filaments toward which the filaments move once they are on the laydown belt 168. Preferably, the draw jet extension extends about 5 to 50 cm down from the end of the draw jet, and more preferably about 10 to 25 cm, and most preferably about 17 cm down from the end of the draw jet. The fiber filaments discharged from the exit of the draw jet pass within 1 cm of the surface of the draw jet extension over a distance of at least 5 cm. Alternatively, the draw jet extension can be placed on the other side of the filament curtain or draw jet extensions can be used on both sides of the curtain of filaments. According to another preferred embodiment of the invention, the draw jet surface facing the filaments could be textured with grooves or rounded protrusions so as to generate a fine scale turbulence that helps to disperse the filaments in a manner that reduces filament clustering and make a more uniform sheet.

[0077] The filaments 167 exiting the draw jet 164 are thinner and stronger than the filaments were when they were extruded from the spin pack 156. The substantially continuous fiber filaments 167 are strong fibers having a tensile strength of at least about 1.5 g/denier, and having an effective diameter of from 5 to 11 microns. The filaments 167 are deposited onto a laydown belt or forming screen 168 as substantially continuous fiber filaments. The distance between the exit of the draw jet 164 and the laydown belt is varied depending on the properties desired in the nonwoven web, and generally ranges between 13 and 76 cm. A vacuum suction is usually applied through the laydown belt 168 to help pin the fiber web. Where desired, the resulting web 170 can be passed between thermal bonding rolls 172 and 174 before being collected on the roll 178 as bonded web 176.

[0078] Preferably, the bonding rolls 172 and 174 are heated rolls maintained at a temperature within plus or minus 20° C. of the lowest melting temperature polymer in the web and the bonding line speed is in the range of 20 to 100 m/min. In general, a bonding temperature in the range of 105-260° C. and a bonding pressure in the range of 35-70 N/mm has been applied to obtain good thermal bonding of the nonwoven sheet. For a sheet containing polyethylene, a bonding temperature in the range of 105-135° C. and a bonding pressure in the range of 35-70 N/mm has been applied to obtain good thermal bonding. For a sheet containing a low melting temperature copolyester or a low melting temperature polyester such as poly(trimethylene terephthalate), a bonding temperature in the range of 140-220° C. and a bonding pressure in the range of 35-70 N/mm has been applied to obtain good thermal bonding. For a sheet containing a higher melting temperature polyester such as

poly(ethylene terephthalate), a bonding temperature in the range of 170-260° C. and a bonding pressure in the range of 35-70 N/mm has been applied to obtain good thermal bonding.

[0079] Where a topical treatment is applied to the web, such as a fluorochemical coating, known methods for applying the treatment can be used. Such application methods include spray application, roll coating, foam application, and dip-squeeze application methods. A topical finishing process can be carried out either in-line with the fabric production or in a separate process step.

[0080] Another process for making the nonwoven sheet of the invention is shown in FIG. 1. A low denier melt-spinning system for making a continuous roll of fabric is generally referred to by the number 10. The system 10 comprises a continuous belt 15 running over a series of rollers. The belt 15 includes a generally horizontal run under a series of one or more spinning beams 20. Each spinning beam 20 is provided with molten polymer and a large number of very small holes, for example, holes of 7 to 16 mils in diameter. The polymer exits through the holes forming a single fiber at each hole. The fibers are preferably strong and resist shrinkage. Typically, such fibers are made by quenching, drawing and annealing the fibers after they are spun so that the polymer chains are oriented within the fiber. It has now been found that such fibers may also be made by high speed spinning.

[0081] Once the strong fibers have been formed, the fast moving and very fine fibers are directed to the moving belt 15. This is no small task due to the number of fibers and their sensitivity to turbulent air forces. Suitable guides, preferably including air baffles, are provided to maintain some control as the fibers are randomly arranged on the belt 15. One additional alternative for controlling the fibers may be to electrostatically charge the fibers and perhaps oppositely charge the belt 15 so that the fibers will be pinned to the belt once they are laid down. The web of fibers are thereafter bonded together to form the fabric. The bonding may be accomplished by any suitable technique including thermal bonding or adhesive bonding. Hot air bonding and ultrasonic bonding may provide attractive alternatives, but thermal bonding with the illustrated pinch rolls 25 and 26 is preferred. It is also recognized that the sheet material may be point bonded for many applications to provide a fabric-like hand and feel, although there may be other end uses for which it is preferred that the sheet be area bonded with a smoother finish. With the point bonded finish, the bonding pattern and percentage of the sheet material bonded will be dictated so as to control fiber liberation and pilling as well as by other requirements such as sheet drape, softness and strength. The fabric is then rolled up on a roll 30 for storage and subsequent finishing as desired.

[0082] While the description of the invention has thus far been related to melt spun fibers, there may be other spinning technologies either now developed or yet to be invented that could provide suitable polymeric fibers. An alternative process for making the nonwoven sheet of the present invention is shown in FIG. 2. In FIG. 2, there is shown a wetlay nonwoven fabric forming system generally referred to by the number 50. The wet lay system 50 includes a foraminous or screen belt 55 running over a series of rollers. A trough 60 is arranged over the belt 55 to deposit a slurry of liquid and

discontinuous fiber thereon. As the slurry moves along with the belt 55, the liquid passes through the openings in the belt 55 and into a pan 61 (also called a pit). The fiber is randomly arranged and is bonded together at the pinch rollers 65 and 66. It should be recognized that there are a number of techniques for bonding the fibers together including through air bonding, resin bonding as well as other suitable bonding techniques. The nonwoven fabric is then rolled up on a roll 70 for storage or subsequent finishing.

[0083] This invention will now be illustrated by the following non-limiting examples which are intended to illustrate the invention and not to limit the invention in any manner.

EXAMPLES

[0084] In the following examples, nonwoven sheets were produced using a high speed melt spinning process described above with regard to the process shown in FIG. 7.

Example 1

[0085] A nonwoven sheet was made from melt spun fibers produced using the process and apparatus described above with regard to FIG. 7. The fibers were spun from poly(ethylene terephthalate) polyester resin with an intrinsic viscosity of 0.58 (as measured in U.S. Pat. No. 4,743,504) available from DuPont as Crystar® polyester (Merge 1988). The polyester resin was crystallized at a temperature of 180° C. and dried at a temperature of 120° C. to a moisture content of less than 50 ppm before use. This polyester was heated to 290° C. in two separate extruders. The polyester polymer was extruded, filtered and metered from each extruder to a bicomponent spin pack maintained at 295° C. and designed to produce a sheath-core filament cross section. However, because both polymer feeds comprised the same polymer, a monocomponent fiber was produced. The spin pack was 0.5 meters wide with a depth of 9 inches (22.9 cm) with 6720 capillaries/meter across the width of the spin pack. Each capillary was round with a diameter of 0.23 to 0.35 mm. The total polymer throughput per spin pack capillary was 0.5 g/min. The filaments were cooled in a 15 inch (38.1 cm) long quenching zone with quenching air provided from two opposing quench boxes at a temperature of 12° C. and a velocity of 1 m/sec. The filaments passed into a pneumatic draw jet spaced 20 inches (50.8 cm) below the capillary openings of the spin pack where the filaments were drawn at a rate of approximately 9000 m/min. The resulting smaller, stronger substantially continuous filaments were deposited onto a laydown belt located 36 cm below the draw jet exit. The laydown belt used vacuum suction to help pin the fibers on the belt. The fibers in the web had an effective diameter in the range of 6 to 9 microns.

[0086] The web was thermally bonded between an engraved oil-heated metal calender roll and a smooth oil heated metal calender roll. Both rolls had a diameter of 466 mm. The engraved roll had a chrome coated non-hardened steel surface with a diamond pattern having a point size of 0.466 mm², a point depth of 0.86 mm, a point spacing of 1.2 mm, and a bond area of 14.6%. The smooth roll had a hardened steel surface. The web was bonded at a temperature of 250° C., a nip pressure of 70 N/mm, and a line speed of 50 m/min. The bonded sheet was collected on a roll.

[0087] The nonwoven sheet was treated with a standard fluorochemical finish to reduce the surface energy of the

fiber surface, and thus increase the fabric's resistance to liquid penetration. The sheet was dipped into an aqueous bath of 2% (w/w) Zonyl 7040 (obtained from DuPont), 2% (w/w) Freepel 1225 (obtained from B. F. Goodrich), 0.25% (w/w) Zelec TY antistat (obtained from Stepan), 0.18% (w/w) Alkanol 6112 wetting agent (obtained from DuPont). The sheet was then squeezed to remove excess liquid and dried and cured in an oven at 168° C. for 2 minutes.

[0088] The physical properties of the sheet are reported in Table 1.

Example 2

[0089] A nonwoven sheet was formed according to the procedure of Examples 1 except that polymer resin used was film grade poly(ethylene terephthalate) polyester containing 0.6% by weight calcium carbonate with a typical particle size of less than 100 nanometers, having an intrinsic viscosity of 0.58 dl/g. The physical properties of the sheet are reported in Table 1.

Example 3

[0090] A nonwoven sheet was formed according to the procedure of Example 1 except that the polymer resin used was poly(ethylene terephthalate) polyester with an intrinsic viscosity of 0.67 dl/g available from DuPont as Crystar® polyester (Merge 3934). Also, the sheet bonding temperature was 180° C. instead of 250° C. The physical properties of the sheet are reported in Table 1.

[0091] The fibers of the nonwoven sheet made in Examples 1-3 were melt spun at high speed to provide very fine fiber size while maintaining overall spinning continuity. The low intrinsic viscosity polyester used in Examples 1 and 2 resulted in fibers with lower denier that were less sensitive to turbulence in the quench region and than the fibers made with the higher intrinsic viscosity polyester of Example 3. In addition, with the lower intrinsic viscosity polyester of Examples 1 and 2, spinning was more robust (i.e., broken filaments did not cause adjacent filaments to break) than with the higher intrinsic viscosity polymer of Example 2. The low intrinsic viscosity polyester melt spun at high speeds maintained filament strength better than has been the case with low intrinsic viscosity polyester that has been melt spun at conventional speeds. In Examples 1 and 2, the polyester polymer with a low intrinsic viscosity of 0.58 dl/g made smaller size fibers and generally stronger fibers than the polyester polymer of Example 3, which had a higher intrinsic viscosity of 0.67dl/g.

Example 4

[0092] A nonwoven sheet was formed according to the procedure of Example 1 except that 1.5% weight percent cobalt-aluminate based blue pigment was added to the polymer fed into the extruder that fed the sheath portion of the bicomponent spinning apparatus. The polymer from the two extruders fed polymer to the spin pack at relative feed rates so as to make bicomponent fibers that were 50 weight percent sheath and 50 weight percent core. The pigment added to the sheath polymer provided the resulting fabric with color and additional opacity. A bonding temperature of 250° C. was used. The physical properties of the sheet are reported in Table 1.

Example 5

[0093] A nonwoven sheet was formed according to the procedure of Examples 1 except different polymers were put

in the two extruders so as to produce bicomponent sheath-core fibers. Poly(trimethylene terephthalate) polyester with an intrinsic viscosity of 0.45 dl/g was extruded to produce the fiber sheaths and poly(ethylene terephthalate) polyester with an intrinsic viscosity of 0.53 dl/g (available from DuPont as Crystar® polyester (Merge 3949)) was extruded to produce the fiber cores. The sheath comprised about 30% of the fiber cross sections and the core comprised about 70% of the fiber cross sections. The sheets were bonded at 150° C. instead of 250° C. The physical properties of the sheet are reported in Table 1.

Example 6

[0094] A nonwoven sheet was formed according to the procedure of Example 5 except a bicomponent sheath-core fiber was made by using a low melt 17% modified di-methyl isophthalate co-polyester with an intrinsic viscosity of 0.61 dl/g produced by DuPont as Crystar® co-polyester (Merge 4442) in the sheath and poly(ethylene terephthalate) polyester with an intrinsic viscosity of 0.53 dl/g available from DuPont as Crystar® polyester (Merge 3949) in the core. The sheath comprised about 30% of the fiber cross sections and the core comprised about 70% of the fiber cross sections. The physical properties of the sheet are reported in Table 1.

Example 7

[0095] A nonwoven sheet was formed according to the procedure of Example 5 except a bicomponent sheath-core fiber was made by using linear low density polyethylene with a melt index of 27 g/10 minutes (measured according to ASTM D1238)(available from Dow as Aspun® 6811A) in the sheath and poly(ethylene terephthalate) polyester with an intrinsic viscosity of 0.53 dl/g available from DuPont as Crystar® polyester (Merge 3949) in the core. The sheath comprised about 30% of the fiber cross sections and the core comprised about 70% of the fiber cross sections. Also, the sheet bonding temperature was 120° C. instead of 250° C. The physical properties of the sheet are reported in Table 1.

Example 8

[0096] A nonwoven sheet was formed according to the procedure of Example 5 except a bicomponent sheath-core fiber was made by using a low melt 17% modified di-methyl isophthalate co-polyester with an intrinsic viscosity of 0.61 dl/g produced by DuPont as Crystar® co-polyester (Merge 4442) in the sheath and poly(ethylene terephthalate) polyester with an intrinsic viscosity of 0.53 dl/g (available from DuPont as Crystar® polyester (Merge 3949)) in the core. Also, the draw jet extension as described above with regard to FIG. 8 was added. The draw jet extension was a 17 cm long, smooth surface, rectangular plate that extended down from the exit of the draw jet on the side of the curtain of filaments facing toward which the filaments move once they are on the laydown belt. The sheet was bonded at a temperature was 210° C. instead of 250° C. The physical properties of the sheet are reported in Table 1.

Example 9

[0097] A nonwoven sheet was formed according to the procedure of Example 8 except the draw jet extension was removed. The physical properties of the sheet are reported in Table 1.

[0098] Comparing the data from Table 1 for Examples 8 and 9 shows that the presence of the draw jet extension leads to increased hydrostatic head and tensile properties.

TABLE 1

	Example								
	1	2	3	4	5	6	7	8	9
Spinning Speed (m/min)	6618	7714	4765	6818	4500	7258	3750	8333	7895
Fiber Diameter (μm)	8.6	8.6	9.4	8.3	10.2	8.1	10.0	7.5	7.6
Fiber Size (denier)	0.71	0.70	0.85	0.66	1.00	0.62	0.96	0.54	0.57
Cross Sectional Area (μm^2)	58	58	70	54	82	51	79	44	45
Thickness (mm)	0.36	0.30	0.30	0.36	0.36	0.34	0.31	0.33	0.31
Basis Weight (g/m^2)	71	58	62	71	81	73	60	78	78
Hydrostatic Head (cm)	39	40	20	40	29	38	25	48	42
Blood Strike Through (psig)	2.0	—	1.2	1.8	1.6	2.2	1.3	—	—
Water Impact (g)	0.00	—	1.50	0.06	0.48	0.05	—	0.08	0.09
Alcohol Repellency	10	—	10	10	10	10	—	—	—
Spray Rating (%)	100	—	100	100	100	100	—	—	—
Frazier Air Permeability ($\text{m}^3/\text{min}\cdot\text{m}^2$)	24	39	61	21	34	23	35	18	24
Moisture Vapor Transmission Rate ($\text{g}/\text{m}^2/24\text{ hr}$)	1338	—	1448	1204	1401	1425	1304	—	—
Mullen Burst (N/m^2)	0.22	—	0.24	0.28	0.25	0.59	0.42	—	—
Grab Tensile MD (N)	117	125	62	126	97	222	142	304	259
Grab Tensile/BW MD ($\text{N}/\text{g}/\text{m}^2$)	1.6	2.2	1.0	1.8	1.2	3.1	2.4	3.9	3.3
Elongation MD (%)	23	48	27	21	18	17	30	—	—
Grab Tensile XD (N)	82	82	62	69	76	129	73	228	175
Grab Tensile/BW XD ($\text{N}/\text{g}/\text{m}^2$)	1.2	1.4	1.0	1.0	0.9	1.8	1.2	2.9	2.2
Elongation XD (%)	29	72	56	31	22	17	70	—	—
Trapezoid Tear MD (N)	13	—	13	18	9	11	27	—	—
Trapezoid Tear XD (N)	8	—	12	7	9	8	11	—	—

[0099] The data from Table 1 clearly indicate that a unique combination of barrier and air permeability may be formed by the inventive fabric which is not found in other available nonwoven fabrics. The uses of such fabrics and structures may be exceptionally broad as the combination or balance of properties has not been found in a single fabric. Principally, the fabric may be used in special use apparel such as a medical gown for a surgeon. It would be for a single use to protect the surgeon or other medical personnel from hazardous liquids such as contaminated body fluids. However, during a long and intense operation, the medical personnel would not be overheating but rather would be quite comfortable in a garment that breathes. After use, the garment would preferably be fully recyclable where constituted of a single polymer which would be readily recycled back to constituent monomer as compared to other materials which are combinations of dissimilar polymers or wherein at least one constituent is not a recyclable polymer.

[0100] The foregoing description and drawings were intended to explain and describe the invention so as to

contribute to the public base of knowledge. In exchange for this contribution of knowledge and understanding, exclusive rights are sought and should be respected. The scope of such exclusive rights should not be limited or narrowed in any way by the particular details and preferred arrangements that may have been shown. Clearly, the scope of any patent rights granted on this application should be measured and determined by the claims that follow.

We claim:

1. A nonwoven fabric comprising at least one nonwoven layer of spunbond polypropylene fibers, said fabric having a basis weight between about 13-125 g/m^2 , a grab tensile strength in both the machine- and cross-directions between about 0.9 to 3 $\text{N}/(\text{g}/\text{m}^2)$, normalized for basis weight, and a combination of Frazier permeability between about 10 and 30 $\text{m}^3/\text{min}\cdot\text{m}^2$ and hydrostatic head between about 66 and 99 cm.

* * * * *