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(54) Title: INDIVIDUALIZED CELLULOSIC FIBERS CROSSLINKED WITH POLYACRYLIC ACID POLYMERS (57) Abstract Disclosed are individualized, crosslinked fibers, and processes for making such fibers, and absorbent structures containing the fibers. The individualized, crosslinked fibers have a polymeric polyacrylic acid crosslinking agent reacted with the fibers in the form of intrafiber crosslink bonds. Preferably, the crosslinking agent is a copolymer of acrylic acid and maleic acid and preferably, between about 1.0 weight % and about 10.0 weight % of the crosslinking agent reacts with the individualized fibers to form the intrafiber crosslink bonds. The individualized, crosslinked fibers are useful in a variety of absorbent structure applications. The absorbent structures may also contain hydrogel-forming material. <i>Handwritten: 9/10/95 copy</i>		

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INDIVIDUALIZED CELLULOSIC FIBERS CROSSLINKED WITH POLYACRYLIC ACID POLYMERS

FIELD OF INVENTION

5 This invention relates to cellulosic fibers having high fluid absorption properties, absorbent structures made from such cellulosic fibers, and processes for making such fibers and structures. More specifically, this invention relates to individualized, crosslinked cellulosic fibers, processes for making such fibers, and absorbent structures
10 containing cellulosic fibers which are in an individualized, crosslinked form.

BACKGROUND OF THE INVENTION

 Fibers crosslinked in substantially individualized form and various
15 methods for making such fibers have been described in the art. The term "individualized, crosslinked fibers", refers to cellulosic fibers that have primarily intrafiber chemical crosslink bonds. That is, the crosslink bonds are primarily between cellulose molecules of a single fiber, rather than between cellulose molecules of separate fibers. Individualized,
20 crosslinked fibers are generally regarded as being useful in absorbent product applications. The fibers themselves and absorbent structures containing individualized, crosslinked fibers generally exhibit an improvement in at least one significant absorbency property relative to conventional, uncrosslinked fibers. Often, the improvement in
25 absorbency is reported in terms of absorbent capacity. Additionally, absorbent structures made from individualized crosslinked fibers generally exhibit increased wet resilience and increased dry resilience relative to absorbent structures made from uncrosslinked fibers. The term "resilience" shall hereinafter refer to the ability of pads made from
30 cellulosic fibers to return toward an expanded original state upon release of a compressional force. Dry resilience specifically refers to the ability of an absorbent structure to expand upon release of compressional force applied while the fibers are in a substantially dry condition. Wet resilience specifically refers to the ability of an
35 absorbent structure to expand upon release of compressional force

applied while the fibers are in a moistened condition. For the purposes of this invention and consistency of disclosure, wet resilience shall be observed and reported for an absorbent structure moistened to saturation.

5 In general, three categories of processes have been reported for making individualized, crosslinked fibers. These processes, described below, are herein referred to as dry crosslinking processes, aqueous solution crosslinking processes, and substantially non-aqueous solution crosslinking processes.

10 Processes for making individualized, crosslinked fibers with dry crosslinking technology are described in U.S. Patent No. 3,224,926, L. J. Bernardin, issued December 21, 1965. Individualized, crosslinked fibers are produced by impregnating swollen fibers in an aqueous solution with crosslinking agent, dewatering and defiberizing the fibers
15 by mechanical action, and drying the fibers at elevated temperature to effect crosslinking while the fibers are in a substantially individual state. The fibers are inherently crosslinked in an unswollen, collapsed state as a result of being dehydrated prior to crosslinking. Processes as exemplified in U.S. Patent No. 3,224,926, wherein crosslinking is
20 caused to occur while the fibers are in an unswollen, collapsed state, are referred to as processes for making "dry crosslinked" fibers. Dry crosslinked fibers are generally highly stiffened by crosslink bonds, and absorbent structures made therefrom exhibit relatively high wet and dry resilience. Dry crosslinked fibers are further characterized by low fluid
25 retention values (FRV).

Processes for producing aqueous solution crosslinked fibers are disclosed, for example, in U.S. Patent No. 3,241,553, F. H. Steiger, issued March 22, 1966. Individualized, crosslinked fibers are produced by crosslinking the fibers in an aqueous solution containing a
30 crosslinking agent and a catalyst. Fibers produced in this manner are hereinafter referred to as "aqueous solution crosslinked" fibers. Due to the swelling effect of water on cellulosic fibers, aqueous solution crosslinked fibers are crosslinked while in an uncollapsed, swollen state. Relative to dry crosslinked fibers, aqueous solution crosslinked fibers as
35 disclosed in U.S. Patent No. 3,241,553 have greater flexibility and less stiffness, and are characterized by higher fluid retention value (FRV).

Absorbent structures made from aqueous solution crosslinked fibers exhibit lower wet and dry resilience than structures made from dry crosslinked fibers.

In U.S. Patent No, 4,035,147, Sangenis et al., issued July 12, 1977, a method is disclosed for producing individualized, crosslinked fibers by contacting dehydrated, nonswollen fibers with crosslinking agent and catalyst in a substantially nonaqueous solution which contains an insufficient amount of water to cause the fibers to swell. Crosslinking occurs while the fibers are in this substantially nonaqueous solution. This type of process shall hereinafter be referred to as a nonaqueous solution crosslinked process; and the fibers thereby produced shall be referred to as nonaqueous solution crosslinked fibers. The nonaqueous solution crosslinked fibers disclosed in U.S. Patent No. 4,035,147 do not swell even upon extended contact with solutions known to those skilled in the art as swelling reagents. Like dry crosslinked fibers, they are highly stiffened by crosslink bonds, and absorbent structures made therefrom exhibit relatively high wet and dry resilience.

Crosslinked fibers as described above are believed to be useful for absorbent product applications such as diapers and catamenials. However, such fibers have not provided sufficient absorbency benefits, in view of their detriments and costs, over conventional fibers to result in significant commercial success. Commercial appeal of crosslinked fibers has also suffered due to safety concerns. The crosslinking agents most widely referred to in the literature are formaldehyde and formaldehyde addition products known as N-methylol agents or N-methylolamides, which, unfortunately, cause irritation to human skin and have been associated with other human safety concerns. Removal of free formaldehyde to sufficiently low levels in the crosslinked product such that irritation to skin and other human safety concerns are avoided has been hindered by both technical and economic barriers.

As mentioned above, the use of formaldehyde and various formaldehyde addition products to crosslink cellulosic fibers is known in the art. See, for example, U.S. Patent No. 3,224,926, Bernardin, issued on December 21, 1965; U.S. Patent No. 3,241,553, Steiger, issued on March 22, 1966; U.S. Patent No. 3,932,209, Chatterjee,

issued on January 13, 1976; U.S. Patent No. 4,035,147, Sangenis et al, issued on July 12, 1977; and U.S. Patent No. 3,756,913, Wodka, issued on September 4, 1973. Unfortunately, the irritating effect of formaldehyde vapor on the eyes and skin is a marked disadvantage of such references. A need is evident for cellulosic fiber crosslinking agents that do not require formaldehyde or its unstable derivatives.

Other references disclose the use of dialdehyde crosslinking agents. See, for example, U.S. Patent No. 4,689,118, Makoui et al, issued on August 25, 1987; and U.S. Patent No. 4,822,453, Dean et al, issued on April 18, 1989. The Dean et al reference discloses absorbent structures containing individualized, crosslinked fibers, wherein the crosslinking agent is selected from the group consisting of C₂ - C₈ dialdehydes, with glutaraldehyde being preferred. These references appear to overcome many of the disadvantages associated with formaldehyde and/or formaldehyde addition products. However, the cost associated with producing fibers crosslinked with dialdehyde crosslinking agents such as glutaraldehyde may be too high to result in significant commercial success. Therefore, there is a need to find cellulosic fiber crosslinking agents which are both safe for use on the human skin and also commercially feasible.

The use of polycarboxylic acids to impart wrinkle resistance to cotton fabrics is known in the art. See, for example, U.S. Patent No. 3,526,048, Roland et al, issued September 1, 1970; U.S. Patent No. 2,971,815, Bullock et al, issued February 14, 1961 and U.S. Patent No. 4,820,307, Welch et al, issued April 11, 1989. These references all pertain to treating cotton textile fabrics with polycarboxylic acids and specific curing catalysts to improve the wrinkle resistance and durability properties of the treated fabrics.

The use of specific monomeric polycarboxylic acids to crosslink cellulosic fibers is known in the art. For example, U.S. Patent No. 5,137,537, Herron et al., issued August 11, 1992, discloses absorbent structures containing individualized cellulosic fibers crosslinked with a C₂ - C₉ polycarboxylic acid. The ester crosslink bonds formed by the polycarboxylic acid crosslinking agents are different from the crosslink bonds that result from the mono- and di-aldehyde crosslinking agents, which form acetal crosslinked bonds.

Importantly, the C₂ - C₉ polycarboxylic acids disclosed for use in the U.S. Patent No. 5,137,537, are non toxic, unlike formaldehyde and formaldehyde addition products commonly used in the art. Unfortunately, the preferred C₂ - C₉ crosslinking agent, citric acid, can
5 cause discoloring (i.e., yellowing) of the white cellulosic fibers. In addition, unpleasant odors can also be associated with the use of alpha-hydroxy carboxylic acids such as citric acid. In addition, relatively low pH's are required to promote the most efficient crosslinking. These low pH's increase process capital cost by increasing the cost of equipment
10 which can withstand acid corrosion at low pH's. Also, citric acid is known not to be stable at temperatures that promote the most efficient crosslinking. It is believed that the acid derivatives of citric acid decomposition do not form intrafiber crosslinks as efficiently as polymeric polyacrylic crosslinking agents.

15 Applicants have found that the polymeric polyacrylic crosslinking agents described hereinafter are particularly suitable for forming ester crosslink bonds with cellulosic fibers. Importantly, the ester-crosslinked fibers tend to be brighter than those crosslinked with alpha-hydroxy acids such as citric acid. Furthermore, the polymeric polyacrylic
20 crosslinking agents are stable at higher temperatures, thus promoting more efficient crosslinking. In addition, absorbent structures made from these individualized, cellulosic fibers crosslinked with a polymeric polyacrylic acid exhibit increased wet resilience and dry resilience and improved responsiveness to wetting relative to structures containing
25 uncrosslinked fibers.

It is an object of this invention to provide individualized fibers crosslinked with a polyacrylic acid crosslinking agent and absorbent structures made from such fibers wherein the absorbent structures made from the crosslinked fibers have higher levels of absorbent
30 capacity relative to absorbent structures made from uncrosslinked fibers, and exhibit higher wet resilience and higher dry resilience than structures made from uncrosslinked fibers.

It is also an object of this invention to provide individualized fibers crosslinked with a polyacrylic acid crosslinking agent and absorbent
35 structures made from such fibers, as described above, which have a superior balance of absorbency properties.

It is further an object of this invention to provide commercially viable individualized, crosslinked fibers and absorbent structures made from such fibers, as described above, which can be safely utilized in the vicinity of human skin.

5 It is additionally an object of this invention to provide individualized, crosslinked fibers that exhibit a higher level of brightness relative to prior known crosslinked fibers.

It is another object of this invention to provide absorbent structures having improved absorbent capacity and wicking which, in
10 actual use, provide high levels of wearer skin dryness.

SUMMARY OF THE INVENTION

It has been found that the objects identified above may be met by individualized, crosslinked fibers and incorporation of these fibers into
15 absorbent structures, as disclosed herein. In general, these objects and other benefits are attained by individualized, crosslinked fibers having an effective amount of a polyacrylic acid crosslinking agent, preferably between about 1.0 wt. % and about 10.0 wt. %, more preferably between about 3.0 wt. % and about 7.0 wt. % crosslinking agent,
20 calculated on a dry fiber weight basis, reacted with the fibers in the form of intrafiber crosslink bonds. The polyacrylic acid crosslinking agent is preferably selected from the group consisting of polyacrylic acid polymers, copolymers of acrylic acid and mixtures thereof. Particularly preferred crosslinking agents include copolymers of acrylic
25 acid and maleic acid. Other preferred polyacrylic acid crosslinking agents include the low molecular weight monoalkyl substituted phosphinate and phosphonate copolymers described in U.S. Patent No. 5,256,746, Blankenship et al., issued October 26, 1993, and incorporated herein by reference. The polyacrylic acid polymers and
30 copolymers used herein can also be blended with monomeric carboxylic acids, such as citric acid. The crosslinking agent is reacted with the fibers in an intrafiber crosslinking bond form. Such fibers, which are characterized by having water retention values (WRV's) of from about 25 to about 60, have been found to fulfill the identified objects relating
35 to individualized, crosslinked fibers and provide unexpectedly good

absorbent performance in absorbent structure applications.

The individualized, crosslinked fibers are, without limiting the scope of the invention, preferably formed into compressed absorbent structures that expand upon wetting.

- 5 The absorbent structures may additionally contain hydrogel-forming material. Significantly improved skin dryness and absorbent capacity and skin dryness of the wearer may be obtained with the utilization of hydrogel-forming material with individualized, crosslinked fibers. Significantly improved wicking and absorbent capacity are
10 obtained by utilizing individualized, crosslinked fibers with hydrogel-forming material relative to utilizing conventional, uncrosslinked cellulose fibers with hydrogel-forming material. Surprisingly, such improved results may be obtained pursuant to the utilization of lower levels of hydrogel-forming material, calculated weight basis, for
15 individualized, crosslinked fiber-containing pads compared to conventional cellulosic fiber pads.

DETAILED DESCRIPTION OF THE INVENTION

- 20 The cellulosic fibers utilized for the present invention will normally be derived from wood pulp sources. Wood pulps useful include chemical pulps such as Kraft, sulfite and sulfate pulps as well as mechanical pulps including, for example, ground wood, thermomechanical pulps and chemically modified thermomechanical pulp (CTMP). Digested fibers from softwood or hardwood are
25 preferably utilized. Other cellulosic fibrous pulp fibers, such as fibers from Esparto grass, bagasse, kemp, flax, cotton linters, and other lignaceous and cellulosic fiber sources may also be utilized as raw material in the invention. The fibers may be supplied in slurry, unsheeted form or sheeted form. Fibers supplied as wet lap, dry lap or
30 other sheeted form are preferably rendered into unsettled form by mechanically disintegrating the sheet, typically after contacting the fibers with the crosslinking agent. Most preferably, the fibers are supplied as dry lap. In the case of dry lap, it is advantageous to apply the appropriate amount of crosslinking agent prior to mechanical
35 disintegration in order to minimize damage to the fibers.

The optimum fiber source utilized in conjunction with this invention will depend upon the particular end use contemplated. Generally, wood pulp fibers made by chemical pulping processes (e.g., Kraft, sulfite, or sulfate) are preferred. The fibers may be completely bleached, partially bleached, or unbleached. It may be desired to utilize bleached pulp for its superior brightness and consumer appeal. Chlorine-based bleaching processes as well as chlorine-free (e.g., oxygen-based) bleaching processes may be used. For products such as paper towels and absorbent cores for diapers, sanitary napkins, catamenials, and other similar absorbent paper products, it is especially preferred to utilize fibers from southern softwood pulp due to their premium absorbency characteristics.

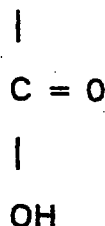
As used herein, the terms "polyacrylic acid polymers" and "polymeric polyacrylic acid" refer to polymerized acrylic acid (i.e., polyacrylic acid) as well as copolymers of acrylic acid, including, but not limited to, copolymers of polyacrylic acid and maleic acid and the low molecular weight monoalkyl substituted phosphinate and phosphonate copolymers described below, and mixtures thereof.

Applicants have found that crosslinking agents applicable to the present invention include polyacrylic acid polymers, copolymers of acrylic acid, and mixtures thereof. Particularly preferred polyacrylic acid crosslinking agents include copolymers of polyacrylic acid and maleic acid and the low molecular weight monoalkyl substituted phosphinate and phosphonate copolymers described in U.S. Patent No. 5,256,746, Blankenship et al., issued October 26, 1993, and incorporated herein by reference. These polymers are preferred for their ability to crosslink individualized cellulose fibers as described in this invention and their non-negative effect on cellulose brightness when used in the hereinafter described crosslinking process.

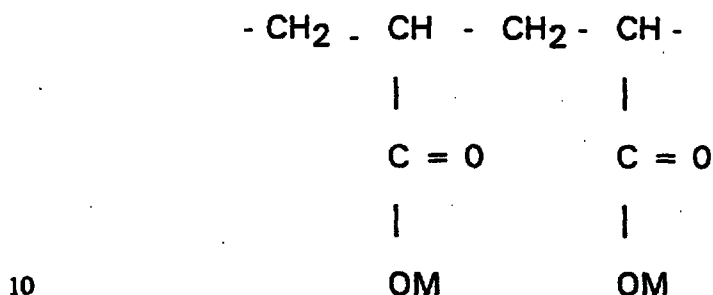
In particular, polyacrylic acid polymers suitable for use in the present invention have molecular weights in the range of from about 500 to 40,000, preferably, molecular weights of from about 1,000 to 20,000. Polyacrylic acid polymers are made by polymerizing acrylic acid.

CH₂ = CH

9



5 to form the repeating chain



wherein M is an alkali metal ammonium or hydrogen ion. Polymers of this type useful in the present invention are available from the Rohm and Haas Company.

Other polymers that are applicable to this invention are copolymers
 15 of polyacrylic acid and maleic acid. Preferably, the molecular weights of these copolymers range from 500 - 40,000, more preferably from about 1,000 to about 20,000. The weight ratio of acrylic acid to maleic acid can range from about 10:1 to about 1:1, more preferably from about 5:1 to 1.5:1. A particularly preferred copolymer contains
 20 about 65% by weight acrylic acid and 35% by weight maleic acid.

Another group of acrylic acid copolymers that are applicable to this invention are the low molecular weight monoalkyl substituted phosphinate and phosphonate copolymers described in U.S. Patent No. 5,256,746, Blankenship et al., issued October 26, 1993, and
 25 incorporated by reference herein. The copolymers described in U.S. Patent No. 5,256,746 are especially preferred, since they provide fibers with high levels of absorbency, resiliency and brightness, and are safe and non-irritating to human skin. These copolymers are prepared with hypophosphorus acid and its salts (commonly sodium hypophosphite)
 30 and/or phosphorus acid as chain transfer agents. Molecular weights of these types of copolymers are preferably below 20,000, and more preferably, below 3,000, and most preferably between about 1,000 and 2,000.

The polyacrylic acid polymers and copolymers described above can be used alone or in combination with other polycarboxylic acids such as citric acid.

Those knowledgeable in the area of polyacrylic acid polymers will
5 recognize that the polyacrylic acid polymeric crosslinking agents described above may be present in a variety of forms, such as the free acid form, and salts thereof. Although the free acid form is preferred, all such forms are meant to be included within the scope of the invention.

10 The individualized, crosslinked fibers of the present invention have an effective amount of the polymeric polyacrylic acid crosslinking agent reacted with the fibers in the form of intrafiber crosslink bonds. As used herein, "effective amount of crosslinking agent" refers to an amount of crosslinking agent sufficient to provide an improvement in at
15 least one significant absorbency property of the fibers themselves and/or absorbent structures containing the individualized, crosslinked fibers, relative to conventional, uncrosslinked fibers. One example of a significant absorbency property is drip capacity, which is a combined measurement of an absorbent structure's fluid absorbent capacity and
20 fluid absorbency rate. A detailed description of the procedure for determining drip capacity is provided hereinafter.

In particular, unexpectedly good results are obtained for absorbent pads made from individualized, crosslinked fibers having between about 1.0 wt. % and about 10.0 wt. %, more preferably between about 3.0
25 wt. % and about 7.0 wt. %, most preferably between 4.0 wt. % and 6.0 wt. % crosslinking agent, calculated on a dry fiber basis, reacted with the fibers.

Preferably, the crosslinking agent is contacted with the fibers in a liquid medium, under such conditions that the crosslinking agent
30 penetrates into the interior of the individual fiber structures. However, other methods of crosslinking agent treatment, including spraying or spray and press, dip and press, etc., of the fibers while in individualized, fluffed form, or sheeted form are also within the scope of the invention.

35 Applicants have discovered that the crosslinking reaction can be

accomplished at practical rates without a catalyst, provided the pH is kept within a particular range (to be discussed in more detail below). This is contrary to the prior art which teaches that specific catalysts are needed to provide sufficiently rapid esterification and crosslinking of
5 fibrous cellulose by polycarboxylic acid crosslinking agents to be commercially feasible. See, for example, U.S. Patent No. 4,820,307, Welch et al., issued April 11, 1989.

However, if desired, the fibers can also be contacted with an appropriate catalyst prior to crosslinking. Applicants have found that
10 the type, amount, and method of contact of catalyst to the fibers will be dependent upon the particular crosslinking process practiced. These variables will be discussed in more detail below. One skilled in the art would realize that residual catalysts may be present from polymerization processes such as those disclosed in U.S. Patent No. 5,256,746.

15 Once the fibers are treated with crosslinking agent (and catalyst if one is used), the crosslinking agent is caused to react with the fibers in the substantial absence of interfiber bonds, i.e., while interfiber contact is maintained at a low degree of occurrence relative to unfluffed pulp fibers, or the fibers are submerged in a solution that does not facilitate
20 the formation of interfiber bonding, especially hydrogen bonding. This results in the formation of crosslink bonds which are intrafiber in nature. Under these conditions, the crosslinking agent reacts to form crosslink bonds between hydroxyl groups of a single cellulose chain or between hydroxyl groups of proximately located cellulose chains of a single
25 cellulosic fiber.

Although not presented or intended to limit the scope of the invention, it is believed that the carboxyl groups on the polymeric polyacrylic acid crosslinking agent react with the hydroxyl groups of the cellulose to form ester bonds. The formation of ester bonds, believed
30 to be the desirable bond type providing stable crosslink bonds, is favored under acidic reaction conditions. Therefore, acidic crosslinking conditions, i.e., pH ranges of from about 1.5 to about 5, are preferred for the purposes of this invention.

The fibers are preferably mechanically defibrated into a low
35 density, individualized, fibrous form known as "fluff" prior to reaction of the crosslinking agent with the fibers. Mechanical defibration may be

performed by a variety of methods which are presently known in the art or which may hereafter become known. Mechanical defibration is preferably performed by a method wherein knot formation and fiber damage are minimized. One type of device which has been found to be particularly useful for defibrating the cellulosic fibers is the three stage fluffing device described in U.S. Patent No. 3,987,968, issued to D. R. Moore and O. A. Shields on October 26, 1976, said patent being hereby expressly incorporated by reference into this disclosure. The fluffing device described in U.S. Patent No. 3,987,968 subjects moist cellulosic pulp fibers to a combination of mechanical impact, mechanical agitation, air agitation and a limited amount of air drying to create a substantially knot-free fluff. The individualized fibers have imparted thereto an enhanced degree of curl and twist relative to the amount of curl and twist naturally present in such fibers. It is believed that this additional curl and twist enhances the resilient character of absorbent structures made from the finished, crosslinked fibers.

Other applicable methods for defibrating the cellulosic fibers include, but are not limited to, treatment with a Waring blender and tangentially contacting the fibers with a rotating disk refiner, hammer mill or wire brush. Preferably, an air stream is directed toward the fibers during such defibration to aid in separating the fibers into substantially individual form.

Regardless of the particular mechanical device used to form the fluff, the fibers are preferably mechanically treated while initially containing at least about 20% moisture, more preferably containing between about 20% and about 60% moisture.

Mechanical refining of fibers at high consistency or of partially dried fibers may also be utilized to provide curl or twist to the fibers in addition to curl or twist imparted as a result of mechanical defibration.

The fibers made according to the present invention have unique combinations of stiffness and resiliency, which allow absorbent structures made from the fibers to maintain high levels of absorptivity, and exhibit high levels of resiliency and an expansionary responsiveness to wetting of a dry, compressed absorbent structure. In addition to having the levels of crosslinking within the stated ranges, the crosslinked fibers are characterized by having water retention values

(WRV's) of less than about 60, more preferably between about 25 to about 50, and most preferably between about 30 and about 45, for conventional, chemically pulped, papermaking fibers. The WRV of a particular fiber is indicative of the level of crosslinking for a particular crosslinking chemistry and method. Very highly crosslinked fibers, such as those produced by many of the prior art known crosslinking processes previously discussed, have been found to have WRV's of less than about 25, and generally less than about 20. The particular crosslinking process utilized will, of course, affect the WRV of the crosslinked fiber. However, any process which will result in crosslinking levels and WRV's within the stated limits is believed to be, and is intended to be, within the scope of this invention. Applicable methods of crosslinking include dry crosslinking processes and nonaqueous solution crosslinking processes as generally discussed in the Background Of The Invention. Certain preferred dry crosslinking and nonaqueous solution crosslinking processes for preparing the individualized, crosslinked fibers of the present invention, will be discussed in more detail below. Aqueous solution crosslinking processes wherein the solution causes the fibers to become highly swollen will result in fibers having WRV's which are in excess of about 60. These fibers will provide insufficient stiffness and resiliency for the purposes of the present invention.

Specifically referring to dry crosslinking processes, individualized, crosslinked fibers may be produced from such a process by providing a quantity of cellulosic fibers, contacting the fibers with a type and amount of crosslinking agent as described above, mechanically separating, e.g., defibrating, the fibers into substantially individual form, and drying the fibers and causing the crosslinking agent to react with the fibers in the presence of a catalyst, if desired, to form crosslink bonds while the fibers are maintained in substantially individual form. The defibration step, apart from the drying step, is believed to impart additional curl. Subsequent drying is accompanied by twisting of the fibers, with the degree of twist being enhanced by the curled geometry of the fiber. As used herein, fiber "curl" refers to a geometric curvature of the fiber about the longitudinal axis of the fiber. "Twist" refers to a rotation of the fiber about the perpendicular cross-section of the longitudinal axis of the fiber. The fibers of the preferred embodiment of

the present invention are individualized, crosslinked in intrafiber bond form, and are highly twisted and curled.

As used herein, the term "twist count" refers to the number of twist nodes present in a certain length of fiber. Twist count is utilized as a means of measuring the degree to which a fiber is rotated about its longitudinal axis. The term "twist node" refers to a substantially axial rotation of 180° about the longitudinal axis of the fiber, wherein a portion of the fiber (i.e., the "node") appears dark relative to the rest of the fiber when viewed under a microscope with transmitted light. The distance between nodes corresponds to an axial rotation of 180°. Those skilled in the art will recognize that the occurrence of a twist node as described above, is primarily a visual rather than a physical phenomena. However, the number of twist nodes in a certain length of fibers (i.e., the twist count) is directly indicative of the degree of fiber twist, which is a physical parameter of the fiber. The appearance and quantity of twist nodes will vary depending upon whether the fiber is a summerwood fiber or a springwood fiber. The twist nodes and total twist count are determined by a Twist Count Image Analysis Method which is described in the Experimental Method section of the disclosure. The average twist count referred to in describing the fibers of the present invention is properly determined by the aforementioned twist count method. When counting twist nodes, portions of fiber darkened due to fiber damage or fiber compression should be distinguished from portions of fiber appearing darkened due to fiber twisting.

The actual twist count of any given sample of fibers will vary depending upon the ratio of springwood fibers to summerwood fibers. The twist count of any particular springwood or summerwood fibers will also vary from fiber to fiber. Notwithstanding the above, the average twist count limitations are useful in defining the present invention, and these limitations apply regardless of the particular combination of springwood fibers and summerwood fibers. That is, any mass of fibers having twist count encompassed by the stated twist count limitations are meant to be encompassed within the scope of the present invention, so long as the other claimed limitations are met.

In the measurement of twist count for a sample of fibers, it is

important that a sufficient amount of fibers be examined in order to accurately represent the average level of twist of the variable individual fiber twist levels. It is suggested that at least five (5) inches of cumulative fiber length of a representative sample of a mass of fibers be
5 tested in order to provide a representative fiber twist count.

The wet fiber twist count is described and measured analogously to the dry fiber twist count, said method varying only in that the fiber is wetted with water prior to being treated and the twist nodes are then counted while wet in accordance with the Twist Count Image Analysis
10 Method.

In addition to being twisted, the fibers of the present invention are curled. Fiber curl may be described as a fractional shortening of the fiber due to kinks, twists, and/or bends in the fiber. For the purposes of this disclosure, fiber curl shall be measured in terms of a two
15 dimensional field. The level of fiber curl shall be referred to in terms of a fiber curl factor. The fiber curl factor, a two dimensional measurement of curl, is determined by viewing the fiber in a two dimensional plane, measuring the projected length of the fiber as the longest dimension of a rectangle encompassing the fiber, L_R , and the
20 actual length of the fiber L_A , and then calculating the fiber curl factor from the following equation:

$$(1) \text{ Curl Factor} = (L_A/L_R) - 1$$

A Fiber Curl Index Image Analysis Method is utilized to measure L_R and L_A . This method is described in the Experimental Methods section
25 of this disclosure. The background information for this method is described in the 1979 International Paper Physics Conference Symposium, The Harrison Hotel, Harrison Hot Springs, British Columbia, September 17-19, 1979, in a paper titled "Application Of Image Analysis To Pulp Fibre Characterization: Part 1," by B. D. Jordan and D.
30 H. Page, pp. 104-114, Canadian Pulp and Paper Association (Montreal, Quebec, Canada), said reference being incorporated by reference into this disclosure.

Maintaining the fibers in substantially individual form during drying and crosslinking allows the fibers to twist during drying and thereby be
35 crosslinked in such twisted, curled state. Drying fibers under such

conditions that the fibers may twist and curl is referred to as drying the fibers under substantially unrestrained conditions. On the other hand, drying fibers in sheeted form results in dried fibers which are not as highly twisted and curled as fibers dried in substantially individualized form. It is believed that interfiber hydrogen bonding "restrains" the relative occurrence of twisting and curling of the fiber.

There are various methods by which the fibers may be contacted with the crosslinking agent and catalyst (if a catalyst is used). In one embodiment, the fibers are contacted with a solution which initially contains both the crosslinking agent and the catalyst. In another embodiment, the fibers are contacted with an aqueous solution of crosslinking agent and allowed to soak prior to addition of the catalyst. The catalyst is subsequently added. In a third embodiment, the crosslinking agent and catalyst are added to an aqueous slurry of the cellulosic fibers. Other methods in addition to those described herein will be apparent to those skilled in the art, and are intended to be included within the scope of this invention. Regardless of the particular method by which the fibers are contacted with crosslinking agent and catalyst (if a catalyst is used), the cellulosic fibers, crosslinking agent and catalyst are preferably mixed and/or allowed to soak sufficiently with the fibers to assure thorough contact with and impregnation of the individual fibers.

Applicants have discovered that the crosslinking reaction can be accomplished without the use of a catalyst if the pH of the solution containing the crosslinking agent is kept within the ranges specified hereinafter. In particular, the aqueous portion of the cellulosic fiber slurry or crosslinking agent solution should be adjusted to a target pH of between about pH 1.5 and about pH 5, more preferably between about pH 2.0 and about pH 4.5, during the period of contact between the crosslinking agent and the fibers. The pH of the crosslinking agent solution can be adjusted with either the addition of an acid, e.g., hydrochloric acid or a base, e.g., sodium hydroxide as is appropriate.

Notwithstanding the above, in general, any substance which can catalyze the crosslinking mechanism may be utilized. Applicable catalysts include alkali metal hypophosphites, alkali metal phosphites, alkali metal polyphosphates, alkali metal phosphates, and alkali metal

sulfates. Especially preferred catalysts are the alkali metal hypophosphites, alkali metal phosphates, and alkali metal sulfates. A more complete list of catalysts useful herein can be found in U.S. Patent No. 4,820,307, Welch et al, issued April 11, 1989, incorporated herein by reference. The selected catalyst may be utilized as the sole catalyzing agent, or in combination with one or more other catalysts, or in combination with the polymer itself such as in U.S. Patent No. 5,256,746, Blankenship et al., issued October 26, 1993, incorporated herein by reference.

10 The amount of catalyst preferably utilized is, of course, dependent upon the particular type and amount of crosslinking agent and the reaction conditions, especially temperature and pH. In general, based upon technical and economic considerations, catalyst levels of between about 5 wt. % and about 80 wt. %, based on the weight of crosslinking agent added to the cellulosic fibers, are preferred. It is additionally desirable to adjust the aqueous portion of the cellulosic fiber slurry or crosslinking agent solution to a target pH of between about pH 1.5 and about pH 5, more preferably between about pH 2.0 and about pH 4.5, during the period of contact between the crosslinking agent and the fibers.

The cellulosic fibers should generally be dewatered and optionally dried. The workable and optimal consistencies will vary depending upon the type of fluffing equipment utilized. In the preferred embodiments, the cellulosic fibers are dewatered and optimally dried to a consistency of between about 20% and about 80%. More preferably, the fibers are dewatered and dried to a consistency level of between about 40% and about 80%. Drying the fibers to within these preferred ranges generally will facilitate defibration of the fibers into individualized form without excessive formation of knots associated with higher moisture levels and without high levels of fiber damage associated with lower moisture levels.

For exemplary purposes, dewatering may be accomplished by such methods as mechanically pressing, centrifuging, or air drying the pulp. Additional drying of the fibers within the 40% - 80% consistency range previously described is optional but is preferably performed by a method, known in the art as air drying, under conditions such that the

utilization of high temperature for an extended period of time is not required. Excessively high temperature and time in this stage may result in drying the fibers beyond 60% consistency, thereby possibly producing excessive fiber damage during the ensuing defibration stage.

5 After dewatering, the fibers are then mechanically defibrated as previously described.

The defibrated fibers are then dried to between about 60% and 100% consistency by a method known in the art as flash drying. This stage imparts additional twist and curl to the fibers as water is removed

10 from them. While the amount of water removed by this additional drying step may be varied, it is believed that flash drying to higher consistency provides a greater level of fiber twist and curl than does flash drying to a consistency in the lower part of the 60%-100% range. In the preferred embodiments, the fibers are dried to about 90%-95%

15 consistency. It is believed that this level of flash drying provides the desired level of fiber twist and curl without requiring the higher flash drying temperatures and retention times required to reach 100% consistency. Flash drying the fibers to a consistency, such as 90%-95%, in the higher portion of the 60%-100% range also reduces the

20 amount of drying which must be accomplished in the curing stage following flash drying.

The flash dried fibers are then heated to a suitable temperature for an effective period of time to cause the crosslinking agent to cure, i.e., to react with the cellulosic fibers. The rate and degree of crosslinking

25 depends upon dryness of the fiber, temperature, pH, time, amount and type of catalyst and crosslinking agent and the method utilized for heating and/or drying the fibers while crosslinking is performed. Crosslinking at a particular temperature will occur more quickly for fibers of a certain initial moisture content when accompanied by a

30 continuous, air-through drying than when subjected to drying/heating in a static oven. Those skilled in the art will recognize that a number of temperature-time relationships exist for the drying and curing of the crosslinking agent. Drying temperatures from about 145°C to about 165°C for periods of between about 30 minutes and 60 minutes, under

35 static, atmospheric conditions will generally provide acceptable curing efficiencies for fibers having moisture contents less than about 10%.

Those skilled in the art will also appreciate that higher temperatures and forced air convection decrease the time required for curing. Thus, drying temperatures from about 170°C to about 190°C for periods of between about 2 minutes and 20 minutes, in an air-through oven will
5 also generally provide acceptable curing efficiencies for fibers having moisture contents less than about 10%. Curing temperatures should be maintained at less than about 225°C, preferably less than about 200°C, since exposure of the fibers to such high temperatures may lead to darkening or other damaging of the fibers.

10 Following the crosslinking step, the fibers are washed, if desired. After washing, the fibers are defluidized and dried. The fibers while still in a moist condition may be subjected to a second mechanical defibration step which causes the crosslinked fibers to twist and curl between the defluidizing and drying steps. The same apparatuses and
15 methods previously described for defibrating the fibers are applicable to this second mechanical defibration step. As used in this paragraph, the term "defibration" refers to any of the procedures which may be used to mechanically separate the fibers into substantially individual form, even though the fibers may already be provided in such form.
20 "Defibration" therefore refers to the step of mechanically treating the fibers, in either individual form or in a more compacted form, wherein such mechanical treatment step a) separates the fibers into substantially individual form if they were not already in such form, and b) imparts curl and twist to the fibers upon drying.

25 This second defibration treatment, after the fibers have been crosslinked, is believed to increase the twisted, curled character of the pulp. This increase in the twisted, curled configuration of the fibers leads to enhanced absorbent structure resiliency and responsiveness to wetting.

30 The maximum level of crosslinking will be achieved when the fibers are essentially dry (having less than about 5% moisture). Due to this absence of water, the fibers are crosslinked while in a substantially unswollen, collapsed state. Consequently, they characteristically have low fluid retention values (FRV) relative to the range applicable to this
35 invention. The FRV refers to the amount of fluid calculated on a dry fiber basis, that remains absorbed by a sample of fibers that have been

soaked and then centrifuged to remove interfiber fluid. (The FRV is further defined and the Procedure For Determining FRV, is described below.) The amount of fluid that the crosslinked fibers can absorb is dependent upon their ability to swell upon saturation or, in other words, upon their interior diameter or volume upon swelling to a maximum level. This, in turn, is dependent upon the level of crosslinking. As the level of intrafiber crosslinking increases for a given fiber and process, the FRV of the fiber will decrease. Thus, the FRV value of a fiber is structurally descriptive of the physical condition of the fiber at saturation. Unless otherwise expressly indicated, FRV data described herein shall be reported in terms of the water retention value (WRV) of the fibers. Other fluids, such as salt water and synthetic urine, may also be advantageously utilized as a fluid medium for analysis. Generally, the FRV of a particular fiber crosslinked by procedures wherein curing is largely dependent upon drying, such as the present process, will be primarily dependent upon the crosslinking agent and the level of crosslinking. The WRV's of fibers crosslinked by this dry crosslinking process at crosslinking agent levels applicable to this invention are generally less than about 60, greater than about 25, preferably less than about 50, and more preferably between about 30 and about 45. Bleached SSK fibers having between about 4.0 wt. % and about 6.0 wt. % polyacrylic acid reacted thereon, calculated on a dry fiber weight basis, have been observed to have WRV's respectively ranging from about 25 to about 50. Post-crosslinking treatment of the fibers such as the degree of bleaching and the practice of post-crosslinking bleaching steps have been found to affect WRV. Southern softwood Kraft (SSK) fibers prepared by many of the prior art known crosslinking processes have levels of crosslinking higher than described herein, and have WRV's less than about 25. Such fibers, as previously discussed, have been observed to be exceedingly stiff and to exhibit lower absorbent capabilities than the fibers of the present invention.

In another process for making individualized, crosslinked fibers by a dry crosslinking process, cellulosic fibers are contacted with a solution containing a crosslinking agent as described above. Either before or after being contacted with the crosslinking agent, the fibers are provided in a sheet form. The fibers, while in sheeted form, are dried and caused to crosslink preferably by heating the fibers to a

temperature of between about 120°C and about 160°C. Subsequent to crosslinking, the fibers are mechanically separated into substantially individual form. This is preferably performed by treatment with a fiber fluffing apparatus such as the one described in U.S. Patent No. 3,987,968 or may be performed with other methods for defibrating fibers as may be known in the art. The individualized, crosslinked fibers made according to this sheet crosslinking process are treated with a sufficient amount of crosslinking agent such that an effective amount of crosslinking agent, preferably between about 4.0 wt. % and about 6.0 wt. % crosslinking agent, calculated on a dry fiber weight basis and measured subsequent to defibration, are reacted with the fibers in the form of intrafiber crosslink bonds. Another effect of drying and crosslinking the fibers while in sheet form is that fiber to fiber bonding restrains the fibers from twisting and curling with increased drying. Compared to individualized, crosslinked fibers made according to a process wherein the fibers are dried under substantially unrestrained conditions and subsequently crosslinked in a twisted, curled configuration, absorbent structures containing the relatively untwisted fibers made by the sheet curing process described above would be expected to exhibit lower wet resiliency and lower responsiveness to wetting.

It is also contemplated to mechanically separate the fibers into substantially individual form between the drying and the crosslinking step. That is, the fibers are contacted with the crosslinking agent and subsequently dried while in sheet form. Prior to crosslinking, the fibers are individualized to facilitate intrafiber crosslinking. This alternative crosslinking method, as well as other variations which will be apparent to those skilled in the art, are intended to be within the scope of this invention.

The crosslinked fibers of the present invention are preferably prepared in accordance with the previously described dry crosslinking process. The crosslinked fibers of the present invention may be utilized directly in the manufacture of air laid absorbent cores. Additionally, due to their stiffened and resilient character, the crosslinked fibers may be wet laid into an uncompacted, low density sheet which, when subsequently dried, is directly useful without further mechanical

processing as an absorbent core. The crosslinked fibers may also be wet laid as compacted pulp sheets for sale or transport to distant locations.

Relative to pulp sheets made from conventional, uncrosslinked
5 cellulosic fibers, the pulp sheets made from the crosslinked fibers of the present invention are more difficult to compress to conventional pulp sheet densities. Therefore, it may be desirable to combine crosslinked fibers with uncrosslinked fibers, such as those conventionally used in the manufacture of absorbent cores. Pulp sheets containing stiffened,
10 crosslinked fibers preferably contain between about 5% and about 90% uncrosslinked, cellulosic fibers, based upon the total dry weight of the sheet, mixed with the individualized, crosslinked fibers. It is especially preferred to include between about 5% and about 30% of highly refined, uncrosslinked cellulosic fibers or synthetic fibers, based upon
15 the total dry weight of the sheet. Such highly refined fibers are refined or beaten to a freeness level less than about 300 ml CSF, and preferably less than 100 ml CSF. The uncrosslinked fibers are preferably mixed with an aqueous slurry of the individualized, crosslinked fibers. This mixture may then be formed into a densified
20 pulp sheet for subsequent defibration and formation into absorbent pads. The incorporation of the uncrosslinked fibers eases compression of the pulp sheet into a densified form, while imparting a surprisingly small loss in absorbency to the subsequently formed absorbent pads. The uncrosslinked fibers additionally increase the tensile strength of the
25 pulp sheet and to absorbent pads made either from the pulp sheet or directly from the mixture of crosslinked and uncrosslinked fibers. Regardless of whether the blend of crosslinked and uncrosslinked fibers are first made into a pulp sheet and then formed into an absorbent pad or formed directly into an absorbent pad, the absorbent pad may be air-
30 laid or wet-laid.

Sheets or webs made from the individualized, crosslinked fibers, or from mixtures also containing uncrosslinked fibers, will preferably have basis weights of less than about 800 g/m^2 and densities of less than about 0.60 g/cm^3 . Although it is not intended to limit the scope of the
35 invention, wet-laid sheets having basis weights between 300 g/m^2 and about 600 g/m^2 and densities between 0.07 g/cm^3 and about 0.30

g/cm³ are especially contemplated for direct application as absorbent cores in disposable articles such as diapers, tampons, and other catamenial products. Structures having basis weights and densities higher than these levels are believed to be most useful for subsequent
5 comminution and air-laying or wet-laying to form a lower density and basis weight structure which is more useful for absorbent applications. Furthermore, such higher basis weight and density structures also exhibit surprisingly high absorptivity and responsiveness to wetting. Other applications contemplated for the fibers of the present invention
10 include low density tissue sheets having densities which may be less than about 0.03 g/cc.

If desired, the crosslinked fibers can be further processed to remove excess, unreacted crosslinking agent. One series of treatments found to successfully remove excess crosslinking agent comprise, in
15 sequence, washing the crosslinked fibers, allowing the fibers to soak in an aqueous solution for an appreciable time, screening the fibers, dewatering the fibers, e.g., by centrifuging, to a consistency of between about 40% and about 80%, mechanically defibrating the dewatered fibers as previously described and air drying the fibers. A
20 sufficient amount of an acidic substance may be added to the wash solution, if necessary, to keep the wash solution at a pH of less than about 7. Without being bound by theory, it is believed that the ester crosslinks are not stable under alkaline conditions and that keeping the wash treatment pH in the acidic range inhibits reversion of the ester
25 crosslinks which have formed. Acidity may be introduced by mineral acids such as sulfuric acid, or alternatively in the form of acidic bleach chemicals such as chlorine dioxide.

The crosslinked fibers described herein are useful for a variety of absorbent articles including, but not limited to, tissue sheets, disposable
30 diapers, catamenials, sanitary napkins, tampons, and bandages wherein each of said articles has an absorbent structure containing the individualized, crosslinked fibers described herein. For example, a disposable diaper or similar article having a liquid permeable topsheet, a liquid impermeable backsheet connected to the topsheet, and an
35 absorbent structure, disposed between the topsheet and backsheet, containing individualized, crosslinked fibers is particularly contemplated.

Such articles are described generally in U.S. Patent No. 3,860,003, issued to Kenneth B. Buell on January 14, 1975, hereby incorporated by reference into this disclosure. The crosslinked fibers described herein are also useful for making articles such as filter media.

5 Conventionally, absorbent cores for diapers and catamenials are made from unstiffened, uncrosslinked cellulosic fibers, wherein the absorbent cores have dry densities of about 0.06 g/cc and about 0.12 g/cc. Upon wetting, the absorbent core normally displays a reduction in volume.

10 It has been found that the crosslinked fibers of the present invention can be used to make absorbent cores having substantially higher fluid absorbing properties including, but not limited to, absorbent capacity and wicking rate relative to equivalent density absorbent cores made from conventional, uncrosslinked fibers. Furthermore, these
15 improved absorbency results may be obtained in conjunction with increased levels of wet resiliency. For absorbent cores having densities of between about 0.05 g/cc and about 0.15 g/cc which maintain substantially constant volume upon wetting, it is especially preferred to utilize crosslinked fibers having crosslinking levels of between about 4.0
20 wt. % and about 6.0 wt. % crosslinking agent, based upon a dry cellulose fiber weight basis. Absorbent cores made from such fibers have a desirable combination of structural integrity, i.e., resistance to compression, and wet resilience. The term wet resilience, in the present context, refers to the ability of a moistened pad to spring back
25 towards its original shape and volume upon exposure to and release from compressional forces. Compared to cores made from untreated fibers, the absorbent cores made from the fibers of the present invention will regain a substantially higher proportion of their original volumes upon release of wet compressional forces.

30 In another preferred embodiment, the individualized, crosslinked fibers are formed into either an air laid or wet laid (and subsequently dried) absorbent core which is compressed to a dry density less than the equilibrium wet density of the pad. The equilibrium wet density is the density of the pad, calculated on a dry fiber basis when the pad is
35 fully saturated with fluid. When fibers are formed into an absorbent core having a dry density less than the equilibrium wet density, upon

wetting to saturation, the core will collapse to the equilibrium wet density. Alternatively, when fibers are formed into an absorbent core having a dry density greater than the equilibrium wet density, upon wetting to saturation, the core will expand to the equilibrium wet density. Pads made from the fibers of the present invention have equilibrium wet densities which are substantially lower than pads made from conventional fluffed fibers. The fibers of the present invention can be compressed to a density higher than the equilibrium wet density, to form a thin pad which, upon wetting, will expand, thereby increasing absorbent capacity, to a degree significantly greater than obtained for uncrosslinked fibers.

In another preferred embodiment, high absorbency properties, wet resilience, and responsiveness to wetting may be obtained for crosslinking levels of between about 3.0 wt. % and about 6.0 wt. %, base calculated on a dry fiber weight basis. Preferably, such fibers are formed into absorbent cores having dry densities greater than their equilibrium wet densities. Preferably, the absorbent cores are compressed to densities of between about 0.12 g/cc and about 0.60 g/cc, wherein the corresponding equilibrium wet density is less than the density of the dry compressed pad. Also, preferably the absorbent cores are compressed to a density of between about 0.12 g/cc and about 0.40 g/cc, wherein the corresponding equilibrium wet densities are between about 0.08 g/cc and about 0.12 g/cc, and are less than the densities of the dry, compressed cores. It should be recognized, however, that absorbent structures within the higher density range can be made from crosslinked fibers having higher crosslinking levels, as can lower density absorbent structures be made from crosslinked fibers having lower levels of crosslinking.

While the foregoing discussion involves preferred embodiments for high and low density absorbent structures, it should be recognized that a variety of combinations of absorbent structure densities and crosslinking agent levels between the ranges disclosed herein will provide superior absorbency characteristics and absorbent structure integrity relative to conventional cellulosic fibers and prior known crosslinked fibers. Such embodiments are meant to be included within the scope of this invention.

Absorbent structures made from individualized, crosslinked fibers may additionally contain discrete particles of substantially water-insoluble, hydrogel-forming material. Hydrogel-forming materials are chemical compounds capable of absorbing fluids and retaining them under moderate pressures.

Suitable hydrogel-forming materials can be inorganic materials such as silica gels or organic compounds such as crosslinked polymers. It should be understood that crosslinking, when referred to in connection with hydrogel-forming materials, assumes a broader meaning than contemplated in connection with the reaction of crosslinking agents with cellulosic fibers to form individualized, crosslinked fibers. Crosslinked hydrogel-forming polymers may be crosslinked by covalent, ionic, Van der Waals, or hydrogen bonding. Examples of hydrogel-forming materials include polyacrylamides, polyvinyl alcohol, ethylene maleic anhydride copolymers, polyvinyl ethers, hydroxypropyl cellulose, carboxymethyl cellulose, polyvinyl morpholinone, polymers and copolymers of vinyl sulfonic acid, polyacrylates, polyacrylamides, polyvinyl pyridine and the like. Other suitable hydrogel-forming materials are those disclosed in Assarsson et al., U.S. Patent No. 3,901,236, issued August 26, 1975, the disclosure of which is incorporated herein by reference. Particularly preferred hydrogel-forming polymers for use in the absorbent core are hydrolyzed acrylonitrile grafted starch, acrylic acid grafted starch, polyacrylates, and isobutylene maleic anhydride copolymers, or mixtures thereof. Examples of hydrogel-forming materials which may be used are Aqualic L-73, a partially neutralized polyacrylic acid made by Nippon Shokubai Co., Japan, and Sanwet IM 1000, a partially neutralized acrylic acid grafted starch made by Sanyo Co., Ltd., Japan. Hydrogel forming materials having relatively high gel strengths, as described in U.S. Patent Application Serial No. 746,152, filed June 18, 1985, hereby incorporated herein by reference, are preferred for utilization with individualized, crosslinked fibers.

Process for preparing hydrogel-forming materials are disclosed in Masuda et al., U.S. Patent No. 4,076,663, issued February 28, 1978; in Tsubakimoto et al., U.S. Patent No. 4,286,082, issued August 25, 1981; and further in U.S. Patents 3,734,876, 3,661,815, 3,670,731,

3,664,343, 3,783,871, and Belgian Patent 785,850, the disclosures of which are all incorporated herein by reference.

The hydrogel-forming material may be distributed throughout an absorbent structure containing individualized, crosslinked fibers, or be
5 limited to distribution throughout a particular layer or section of the absorbent structure. In another embodiment, the hydrogel-forming material is adhered or laminated onto a sheet or film which is juxtaposed against a fibrous, absorbent structure, which may include individualized, crosslinked fibers. Such sheet or film may be
10 multilayered such that the hydrogel-forming material is contained between the layers. In another embodiment, the hydrogel-forming material may be adhered directly onto the surface fibers of the absorbent structure.

Surprisingly large increases in skin dryness have been observed for
15 absorbent structures combining the individualized, crosslinked fibers of the present invention and hydrogel-forming materials, according to the skin wetness level measured by an evaporimeter subsequent to contacting moistened absorbent structures to human skin. This improvement is believed due to the high wicking ability of individualized,
20 crosslinked fibers relative to conventional fibers and the increased absorptive capacity of the structure. Unique wicking ability of structures made from individualized, crosslinked fibers results from the stiff nature of the fibers and the relatively large void spaces resulting therefrom. However, excessively high levels of crosslinking agent, as
25 may be present in certain prior known individualized, crosslinked fibers, may reduce wicking due to the hydrophobic characteristics of the crosslinking agent.

Another important advantage has been observed with respect to absorbent structures made from individualized, crosslinked fibers having
30 dry densities which are higher than their corresponding equilibrium wet densities (calculated on a dry fiber basis). Specifically, this type of absorbent structure expands in volume upon wetting. As a result of this expansion, the interfiber capillary network of fibers also enlarges. In conventional absorbent structures having hydrogel-forming material
35 blended therein, the hydrogel-forming material expands in volume due to fluid absorption, and may block or reduce in size the capillary routes

for fluid absorption prior to utilization of the entire fluid absorbing potential of the structure. This phenomenon is known as gel blocking. Capillary enlargement due to expansion of fibrous network of the absorbent structure reduces the occurrence of gel blocking. This allows
5 larger proportions of the fluid absorbency potential of the structure to be utilized and allows higher levels of hydrogel-forming material (if desired) to be incorporated into the absorbent structure, without significant levels of gel-blocking.

Absorbent structures containing individualized, crosslinked fibers
10 and hydrogel-forming material for diaper core applications preferably have dry densities of between about 0.15 g/cc and about 0.40 g/cc and preferably contain from about 20% to about 50%, by weight of hydrogel-forming material, calculated on a dry fiber weight basis. Most preferably, the individualized, crosslinked fibers have between about
15 3.0 weight % and about 7.0 weight % crosslinking agent, calculated on a dry fiber weight basis, reacted therewith in the form of intrafiber crosslink bonds wherein the fibers are formed into a relatively thin absorbent structure in a sufficiently compressed dry state such that the structure may expand upon wetting.

20 The hydrogel-forming material may be homogeneously dispersed throughout all or part of the absorbent structure. For a diaper structure as disclosed in U.S. Patent No. 3,860,003, having an absorbent core which contains the preferred individualized, crosslinked fibers, has a dry density of about 0.20 g/cc, and also contains hydrogel-forming material
25 dispersed throughout the core. It is presently believed that an optimal balance of diaper wicking, total absorbent capacity, skin wetness, and economic viability is obtained for contents of between about 20 to about 50 wt. %, based on the total weight of the dry absorbent core, of a hydrogen forming material such as Aqualic L-73. The hydrogel-
30 forming material is preferably homogeneously blended with the individualized, crosslinked fibers-containing absorbent cores in products as disclosed in U.S. Patent No. 3,860,003.

The absorbent structures described above may also include
35 conventional, fluffed fibers, or highly refined fibers, wherein the amount of hydrogel-forming material is based upon the total weight of the fibers as previously discussed. The embodiments disclosed herein are

exemplary in nature and are not meant to limit the scope of application of hydrogel-forming material with individualized, crosslinked fibers.

PROCEDURE FOR DETERMINING FLUID RETENTION VALUE

5 The following procedure can be utilized to determine the water retention value of cellulosic fibers.

A sample of about 0.3 g to about 0.4 g of fibers is soaked in a covered container with about 100 ml distilled or deionized water at room temperature for between about 15 and about 20 hours. The soaked fibers are collected on a filter and transferred to an 80-mesh wire basket supported about 1 1/2 inches above a 60-mesh screened bottom of a centrifuge tube. The tube is covered with a plastic cover and the sample is centrifuged at a relative centrifuge force of 1500 to 1700 gravities for 19 to 21 minutes. The centrifuged fibers are then removed from the basket and weighed. The weighed fibers are dried to a constant weight at 105°C and reweighed. The water retention value is calculated as follows:

$$(1) \text{ WRV} = \frac{(W-D)}{D} \times 100$$

20 where,

W = wet weight of the centrifuged fibers;

D = dry weight of the fibers; and

W-D = weight of absorbed water.

PROCEDURE FOR DETERMINING DRIP CAPACITY

25 The following procedure can be utilized to determine drip capacity of absorbent cores. Drip capacity is utilized as a combined measure of absorbent capacity and absorbency rate of the cores.

A four inch by four inch absorbent pad weighing about 7.5 g is placed on a screen mesh. Synthetic urine is applied to the center of the pad at a rate of 8 ml/s. The flow of synthetic urine is halted when the first drop of synthetic urine escapes from the bottom or sides of the

pad. The drip capacity is calculated by the difference in mass of the pad prior to and subsequent to introduction of the synthetic urine divided by the mass of the fibers, bone dry basis.

5 PROCEDURE FOR DETERMINING WET COMPRESSIBILITY

The following procedure can be utilized to determine wet compressibility of absorbent structures. Wet compressibility is utilized as a measure of resistance to wet compression, wet structural integrity and wet resilience of the absorbent cores.

10 A four inch by four inch square pad weighing about 7.5 g is prepared, its thickness measured and density calculated. The pad is loaded with synthetic urine to ten times its dry weight or to its saturation point, whichever is less. A 0.1 PSI compressional load is applied to the pad. After about 60 seconds, during which time the pad
15 equilibrates, the thickness of the pad is measured. The compressional load is then increased to 1.1 PSI, the pad is allowed to equilibrate, and the thickness is measured. The compressional load is then reduced to 0.1 PSI, the pad allowed to equilibrate and the thickness is again measured. The densities are calculated for the pad at the original 0.1
20 PSI load, the 1.1 PSI load and the second 0.1 PSI load, referred to as 0.1 PSIR (PSI rebound) load. The void volume reported in cc/g, is then determined for each respective pressure load. The void volume is the reciprocal of the wet pad density minus the fiber volume (0.95 cc/g). The 0.1 PSI and 1.1 PSI void volumes are useful indicators of resistance
25 to wet compression and wet structural integrity. Higher void volumes for a common initial pad densities indicate greater resistance to wet compression and greater wet structural integrity. The difference between 0.1 PSI and 0.1 PSIR void volumes is useful for comparing wet resilience of absorbent pads. A smaller difference between 0.1 PSI void
30 volume and 0.1 PSIR void volume, indicates higher wet resilience.

Also, the difference in caliper between the dry pad and the saturated pad prior to compression is found to be a useful indicator of the responsiveness to wetting of the pads.

35 PROCEDURE FOR DETERMINING DRY COMPRESSIBILITY

The following procedure can be utilized to determine dry compressibility of absorbent cores. Dry compressibility is utilized as a measure of dry resilience of the cores.

A four inch by four inch square air laid pad having a mass of about 7.5 g is prepared and compressed, in a dry state, by a hydraulic press to a pressure of 5500 lbs/16 in². The pad is inverted and the pressing is repeated. The thickness of the pad is measured before and after pressing with a no-load caliper. Density before and after pressing is then calculated as mass/(area X thickness). Larger differences between density before and after pressing indicate lower dry resilience.

PROCEDURE FOR DETERMINING LEVEL OF POLYACRYLIC ACID REACTED WITH CELLULOSIC FIBERS

There exist a variety of analytical methods suitable for determining the level of polyacrylic acid crosslinked with cellulosic fibers. Any suitable method can be used. For the purposes of determining the level of preferred polymeric polyacrylic acid (such a polymeric monoalkyl phosphinates and polymeric monoalkyl phosphonates; i.e., polymers containing a known weight percent of a certain inorganic element chemically bound to the polymer) which reacts to form intrafiber crosslink bonds with the cellulosic component of the individualized, crosslinked fibers in the examples of the present invention, the following procedure is used. First, a sample of crosslinked fibers is washed with sufficient hot water to remove any unreacted crosslinking chemicals or catalysts. Next, the fibers are dried to equilibrium moisture content. The bone dry weight of the sample is then determined with a moisture balance or other suitable equipment. Then, the sample is burned, or "ashed", in a furnace at a temperature suitable to remove all organic material in the sample. The remaining inorganic material from the sample is dissolved in a strong acid, such as perchloric acid. This acid solution is then analyzed to determine the mass of the inorganic element which was present in the initial polymer (in a known mass ratio of (total polymer)/(inorganic element)) applied to the cellulosic fibers. Inductively coupled plasma atomic emission spectroscopy (ICP AES) is one method which may be used for analyzing

this solution. The amount of polymer which is crosslinked onto the cellulosic fibers may then be calculated by the following formula:

$$\text{Crosslinking level (weight \%)} = \frac{W_i R}{W_c} \times 100$$

Where

W_i = mass of the sample's inorganic element bound to the polymer, which is crosslinked to the cellulose fibers, measured as described above, (in grams)

R = ratio defined by: mass of the total polymer divided by the mass of the inorganic element bound to the polymer

W_c = bone dry mass of the cellulosic fiber sample being analyzed (in grams)

15

For the purposes of determining the level of preferred polymeric polyacrylic acid (e.g., polyacrylic acid with a molecular weight of about 1000, or an acrylic/maleic copolymer containing 65% by weight acrylic acid and 35% by weight maleic acid having a molecular weight of about 9000) which reacts to form intrafiber crosslink bonds with the cellulosic component of the individualized, crosslinked fibers in the examples of the present invention, the following procedure is used. The reaction efficiency (defined as the percent of polymer applied to the cellulosic fibers which reacts with the cellulose to form intrafiber crosslink bonds) of a similar polymer containing an inorganic element is determined by the ICP AES method described above. This reaction efficiency is then assumed to be applicable to the polymer in question. The applied amount of the polymer in question is then multiplied by the reaction efficiency to determine the amount of the polymer in question which is reacted with the cellulosic fibers to form intrafiber crosslink bonds. Typically the reaction efficiency is about 0.75.

PROCEDURE FOR DETERMINING TWIST COUNT

The following method can be used to determine the twist count of fibers analyzed in this disclosure.

Dry fibers are placed on a slide coated with a thin film of immersion oil, and then covered with a cover slip. The effect of the immersion oil was to render the fiber transparent without inducing swelling and thereby aid in identification of the twist nodes (described below). Wet fibers are placed on a slide by pouring a low consistency slurry of the fibers on the slide which is then covered with a cover slip. The water rendered the fibers transparent so that twist node identification is facilitated.

An image analyzer comprising a computer-controlled microscope, a video camera, a video screen, and a computer loaded with QUIPS software, available from Cambridge Instruments Limited (Cambridge, England; Buffalo, New York), is used to determine twist count.

The total length of fibers within a particular area of the microscope slide at 200X magnification is measured by the image analyzer. The twist nodes are identified and marked by an operator. This procedure is continued, measuring fiber length and marking twist nodes until 1270 mm inches of total fiber length are analyzed. The number of twist nodes per millimeter is calculated from this data by dividing the total fiber length into the total number of twist nodes marked.

PROCEDURE FOR DETERMINING CURL FACTOR

The following method can be utilized to measure fiber curl index.

Dry fibers are placed onto a microscope slide. A cover slip is placed over the fibers and glued in place at the edges. The actual length LA and the maximum projected length LR (equivalent to the length of the longest side of a rectangle encompassing the fiber) are measured utilizing an image analyzer comprising a software controlled microscope, video camera, video monitor, and computer. The software utilized is the same as that described in the Twist Count Image Analysis Method section above.

Once LA and LR are obtained, the curl factor is calculated according to Equation (1) shown above. The curl factor for each sample of fiber is calculated for at least 250 individual fibers and then

averaged to determine the mean curl factor for the sample. Fibers having LA less than 0.25 mm are excluded from the calculation.

The following examples illustrate the practice of the present invention but are not intended to be limiting thereof.

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EXAMPLE I

Individualized, crosslinked fibers of the present invention are made by a dry crosslinking process utilizing an acrylic/maleic copolymer (containing 65% by weight acrylic acid and 35% by weight maleic acid having a molecular weight of about 9000) as the crosslinking agent.

10 The procedure used to produce the acrylic/maleic copolymer acid crosslinked fibers is as follows:

1. For each sample, 1735 g of once dried, southern softwood kraft (SSK) pulp is provided. The fibers have a moisture content of about 7% (equivalent to 93% consistency).

2. A slurry is formed by adding the fibers to an aqueous solution containing about 2,942 g of the acrylic/maleic copolymer and 410 ml of 50% sodium hydroxide solution in 59,323 g of H₂O. The fibers are soaked in the slurry for about 60 minutes. This step is also referred to as "steeping". The steep pH is about 3.0.

3. The fibers are then dewatered by centrifuging to a consistency ranging from about 40% to about 50%. the centrifuged slurry consistency of this step combined with the carboxylic acid concentration in the slurry filtrate in step 2 set the amount of crosslinking agent present on the fibers after centrifuging. In this example, about 6 wt. % of the acrylic/maleic copolymer on a dry fiber cellulose anhydroglucose basis is present on the fibers after the initial centrifuging. In practice, the concentration of the crosslinking agent in the slurry filtrate is calculated by assuming a targeted dewatering consistency and a desired level of chemicals on the fibers.

4. Next, the dewatered fibers are defibrated using a Sprout-Waldron 12" disk refiner (model number 105-A) whose plates are set at a gap which yields fibers substantially individualized but with a minimum amount of fiber damage. As the individualized fibers exit the refiner, they are flash dried with hot air in two vertical tubes in order to provide fiber twist and curl. The fibers contain approximately 10% moisture upon exiting these tubes and are ready to be cured. If the moisture content of the fibers is greater than about 10% upon exiting the flash drying tubes, then the fibers are dried with ambient temperature air until the moisture content is about 10%.

5. The nearly dry fibers are then placed on trays and cured in an air-through drying oven for a length of time and at a temperature which in practice depends on the amount of copolymer added, dryness of the fibers, etc. In this example, the samples are cured at a temperature of about 188°C for a period of about 8 minutes. Crosslinking is completed during the period in the oven.

6. The crosslinked, individualized fibers are placed on a mesh screen and rinsed with about 20°C water, soaked at 1% consistency for one (1) hour in about 60°C water, screened, rinsed with about 20°C water for a second time, centrifuged to about 60% fiber consistency, and dried to an equilibrium moisture content of about 8% with ambient

temperature air.

The resulting individualized crosslinked cellulosic fibers have a WRV of 43 and contain 4.6% by weight of the acrylic acid/maleic acid copolymer, calculated on a dry fiber weight basis, reacted with the
5 fibers in the form of intrafiber crosslink bonds.

Importantly, the resulting individualized, crosslinked fibers have improved responsiveness to wetting relative to conventional, uncrosslinked fibers and prior known crosslinked fibers, and can be safely utilized in the vicinity of human skin.

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EXAMPLE II

Individualized crosslinked fibers of the present invention are made by a dry crosslinking process utilizing polyacrylic acid with a molecular weight of about 1000 as the crosslinking agent. The individualized crosslinked fibers are produced in accordance with the hereinbefore
15 described process of Example I with the following modifications: The slurry in step 2 of Example I contains 150 g of dry pulp, 1186 g of H₂O, 63.6 g of polyacrylic acid, and 4 g of sodium hydroxide. In step 5, the fibers are cured at a temperature of about 190°C for a period of about 30 minutes.

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The resulting individualized crosslinked cellulosic fibers have a WRV of 38 and contain 4.2% by weight polyacrylic acid calculated on a dry fiber weight basis, reacted with the fibers in the form of intrafiber crosslink bonds.

Importantly, the resulting individualized, crosslinked fibers have
25 improved responsiveness to wetting relative to conventional, uncrosslinked fibers and prior known crosslinked fibers, and can be safely utilized in the vicinity of human skin.

EXAMPLE III

Individualized crosslinked fibers of the present invention are made
30 by a dry crosslinking process utilizing an acrylic acid and maleic acid copolymer and citric acid. The total applied percent of the copolymer and citric acid is 4.53%. The citric acid concentration is 33% of the total. The ratio of acrylic acid to maleic acid is 65:35. The molecular weight of the copolymer is 9,000.

The individualized crosslinked fibers are produced in accordance with the hereinbefore described process of Example I with the following modifications: The slurry in step 2 of Example I contains 150 g of dry pulp, 1113 g of H₂O, 28 g of copolymer and citric acid mixture. In
5 step 5, the fibers are cured at a temperature of about 190°C for a period of about 30 minutes.

The resulting individualized crosslinked cellulosic fibers have a WRV of 38 and contain 3.4% by weight acrylic acid/maleic acid/citric acid crosslinking agent calculated on a dry fiber weight basis, reacted
10 with the fibers in the form of intrafiber crosslink bonds.

Importantly, the resulting individualized, crosslinked fibers have improved responsiveness to wetting relative to conventional, uncrosslinked fibers and prior known crosslinked fibers, and can be safely utilized in the vicinity of human skin.

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EXAMPLE IV

Individualized crosslinked fibers of the present invention are made by a dry crosslinking process utilizing a acrylic acid/sodium hypophosphite copolymer having a molecular weight of about 1600 as the crosslinking agent. The total applied percent of the copolymer is
20 5.92%. The weight ratio of acrylic acid to maleic acid to sodium hypophosphite is 51/26/23. The individualized crosslinked fibers are produced in accordance with the hereinbefore described process of Example I with the following modifications: The slurry in step 2 of Example I contains 333 g of dry pulp, 230 g of H₂O, and 15 g of
25 polymer. The pH of the polymer solution is adjusted to 3 using hydrochloric acid. In step 5, the fibers are cured in an air through oven at 178°C for a period of about 6 minutes.

The resulting individualized crosslinked cellulosic fibers have a WRV of 42 and contain 4.4% by weight of the copolymer calculated on a dry fiber weight basis, reacted with the fibers in the form of intrafiber crosslink bonds.
30

Importantly, the resulting individualized, crosslinked fibers have improved responsiveness to wetting relative to conventional, uncrosslinked fibers and prior known crosslinked fibers, and can be
35 safely utilized in the vicinity of human skin.

EXAMPLE V

The individualized crosslinked fibers are produced in accordance with the hereinbefore described process of Example I with the following modifications: In step 2 of Example I, the solution containing the crosslinking agent is sprayed directly onto a sheet of fibers. The fiber consistency of the sprayed sheet ranges from about 50% to about 80%, by weight. The consistency of the sheet combined with the concentration of the crosslinking solution set the amount of crosslinking agent (and base, if needed) present on the fibers. The concentration of the crosslinking agent (and the base) are calculated by determining a target consistency and a desired level of chemicals on the fibers.

The resulting individualized crosslinked cellulosic fibers have a WRV of 43 and contain 4.2% by weight of the acrylic acid/maleic acid copolymer calculated on a dry fiber weight basis, reacted with the fibers in the form of intrafiber crosslink bonds.

Importantly, the resulting individualized, crosslinked fibers have improved responsiveness to wetting relative to conventional, uncrosslinked fibers and prior known crosslinked fibers, and can be safely utilized in the vicinity of human skin.

EXAMPLE VI

The individualized, crosslinked fibers of Example I are air laid to form absorbent pads, and compressed with a hydraulic press to a density of 0.10 g/cc and 0.20 g/cc. The pads are subsequently tested for absorbency, resiliency, and structural integrity according to the previously outlined procedures. The results are reported in Table 1 and compared to an absorbent pad made from conventional uncrosslinked cellulosic fibers.

TABLE 1

Sample #	Crosslinking Agent (weight %) <u>Reacted</u>	WRV (%)	Drip Cap. @ 8 ml/s (g/g)	Wet compressibility 0.1/0.2 g/cc <u>Test Pad Density</u>
1	0	79.2	4.56	6.04/5.38
2	4.6	43	11.58	7.75/6.24

As can be seen from Table 1, the absorbent pads containing individualized, acrylic/maleic acid crosslinked fibers (i.e., Sample 2) have significantly higher drip capacities and wet compressibilities at both 0.10 g/cc and 0.20 g/cc test pad densities relative to pads containing conventional, uncrosslinked fibers (i.e., Sample 1). In addition to having improved responsiveness to wetting relative to conventional uncrosslinked fibers, the absorbent pads containing the acrylic/maleic acid copolymer crosslinked fibers can be safely utilized in the vicinity of human skin.

EXAMPLE VII

The individualized, crosslinked fibers of Example II are air laid to form absorbent pads, and compressed with a hydraulic press to a density of 0.10 g/cc and 0.20 g/cc. The pads are subsequently tested for absorbency, resiliency, and structural integrity according to the previously outlined procedures. The results are reported in Table 1 and compared to an absorbent pad made from conventional uncrosslinked cellulosic fibers.

TABLE 2

Sample #	Crosslinking Agent (weight %) <u>Reacted</u>	WRV (%)	Drip Cap. @ 8 ml/s (g/g)	Wet compressibility 0.1/0.2 g/cc <u>Test Pad Density</u>
1	0	79.2	4.56	6.04/5.38
3	4.2	38	8.44	6.92/5.99

As can be seen from Table 2, the absorbent pads containing individualized, polyacrylic crosslinked fibers (i.e., Sample 2) have

significantly higher drip capacities and wet compressibilities at both 0.10 g/cc and 0.20 g/cc test pad densities relative to pads containing conventional, uncrosslinked fibers (i.e., Sample 1). In addition to having improved responsiveness to wetting relative to conventional uncrosslinked fibers, the absorbent pads containing polyacrylic acid crosslinked fibers can be safely utilized in the vicinity of human skin.

EXAMPLE VIII

The individualized, crosslinked fibers of Example III are air laid to form absorbent pads, and compressed with a hydraulic press to a density of 0.10 g/cc and 0.20 g/cc. The pads are subsequently tested for absorbency, resiliency, and structural integrity according to the previously outlined procedures. The results are reported in Table 1 and compared to an absorbent pad made from conventional uncrosslinked cellulosic fibers.

TABLE 3

Sample #	Crosslinking Agent (weight %) <u>Reacted</u>	WRV (%)	Drip Cap. @ 8 ml/s (g/g)	Wet compressibility 0.1/0.2 g/cc <u>Test Pad Density</u>
1	0	79.2	4.56	6.04/5.38
4	3.4	38	11.54	7.82/6.46

As can be seen from Table 3, the absorbent pads containing individualized, acrylic acid/maleic acid/citric acid crosslinked fibers (i.e., Sample 4) have significantly higher drip capacities and wet compressibilities at both 0.10 g/cc and 0.20 g/cc test pad densities relative to pads containing conventional, uncrosslinked fibers (i.e., Sample 1). In addition to having improved responsiveness to wetting relative to conventional uncrosslinked fibers, the absorbent pads containing the acrylic acid/maleic acid copolymer crosslinked fibers can be safely utilized in the vicinity of human skin.

EXAMPLE IX

The individualized, crosslinked fibers of Example IV are air laid to form absorbent pads, and compressed with a hydraulic press to a density of 0.10 g/cc and 0.20 g/cc. The pads are subsequently tested

for absorbency, resiliency, and structural integrity according to the previously outlined procedures. The results are reported in Table 1 and compared to an absorbent pad made from conventional uncrosslinked cellulosic fibers.

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TABLE 4

Sample #	Crosslinking Agent (weight %) <u>Reacted</u>	WRV (%)	Drip Cap. @ 8 ml/s (g/g)	Wet compressibility 0.1/0.2 g/cc <u>Test Pad Density</u>
1	0	79.2	4.56	6.04/5.38
5	4.4	42	13.56	8.06/6.80

As can be seen from Table 4, the absorbent pads containing individualized, acrylic acid/maleic acid/sodium hypophosphite crosslinked fibers (i.e., Sample 5) have significantly higher drip capacities and wet compressibilities at both 0.10 g/cc and 0.20 g/cc test pad densities relative to pads containing conventional, uncrosslinked fibers (i.e., Sample 1). In addition to having improved responsiveness to wetting relative to conventional uncrosslinked fibers, the absorbent pads containing the acrylic acid/maleic acid/sodium hypophosphite crosslinked fibers can be safely utilized in the vicinity of human skin.

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**What is Claimed is:**

1. Individualized, crosslinked cellulosic fibers, said fibers having an effective amount of a polymeric polyacrylic acid crosslinking agent reacted with said fibers in intrafiber crosslink bond form, wherein said polymeric polyacrylic acid crosslinking agent is selected from polyacrylic acid polymers, copolymers of acrylic acid, and mixtures thereof.
2. The individualized, crosslinked fibers of Claim 1 wherein said fibers have between 1.0 weight % and 10.0 weight %, preferably between 3 weight and 7 weight %, crosslinking agent, calculated on a dry fiber weight basis, reacted therewith in the form of intrafiber crosslink bonds, and wherein said crosslinked fibers have a water retention value of from 25 to 60, preferably from 30 to 45.
3. The individualized, crosslinked fibers of Claim 1 or 2 wherein said crosslinking agent is a polyacrylic acid polymer having a molecular weight of from 500 to 40,000, preferably from 1,000 to 20,000.
4. The individualized, crosslinked fibers of any of Claims 1 - 3 wherein said polymeric polyacrylic acid crosslinking agent is a copolymer of acrylic acid and maleic acid.
5. The individualized, crosslinked fibers of Claim 4 wherein the weight ratio of acrylic acid to maleic acid is from 10:1 to 1:1, preferably from 5:1 to 1.5:1.
6. The individualized, crosslinked fibers of any of Claims 1 - 5 wherein an effective amount of citric acid is mixed with said polymeric polyacrylic acid crosslinking agent.
7. Individualized, crosslinked cellulosic fibers, said fibers having an effective amount of a polymer mixture crosslinking agent reacted with said fibers in intrafiber crosslink bond form, wherein said polymer mixture crosslinking agent comprises polymeric monoalkyl phosphinates and polymeric monoalkyl phosphonates.
8. The individualized, crosslinked fibers of Claim 7 wherein said fibers have between 1.0 weight % and 10.0 weight %, preferably



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between 3 weight and 7 weight %, crosslinking agent, calculated on a dry fiber weight basis, reacted therewith in the form of intrafiber crosslink bonds and wherein said crosslinked fibers have a water retention value of from 25 to 60, preferably from 30 to 45.

9. The individualized, crosslinked fibers of Claim 7 or 8 wherein said polymer mixture crosslinking agent has a molecular weight of less than 5,000.
10. The individualized, crosslinked fibers of any of Claims 7 - 9 wherein an effective amount of citric acid is mixed with said polymer mixture crosslinking agent.

