April 30, 1974 J. T. McKNIGHT 3,808,094

WET-FORMED NONWOVEN TEXTILE FABRICS AND METHODS AND APPARATUS FOR MAKING THE SAME

Filed May 13, 1971 2 Sheets-Sheet 1

Fig. 1.

(PRIOR ART)

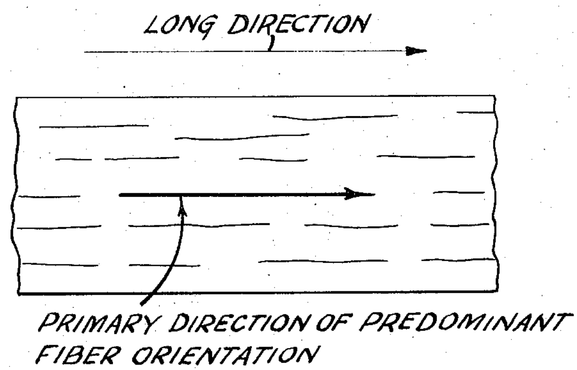

Fig. 2.

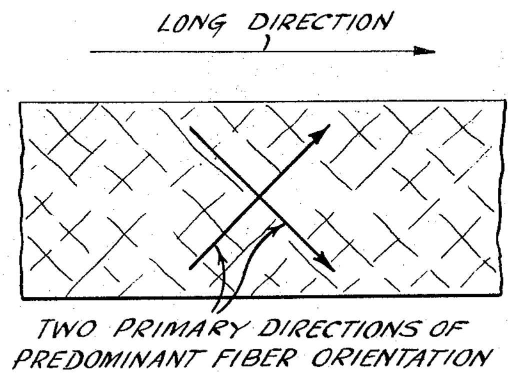

Fig. 3.

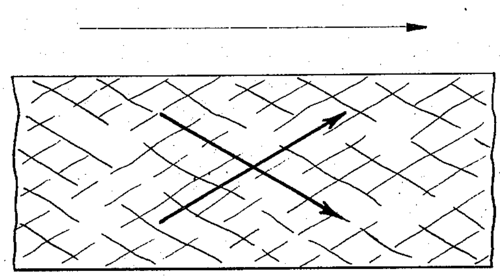

Fig. 4.

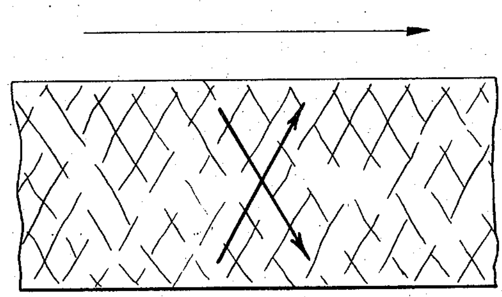

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FIG. 5.

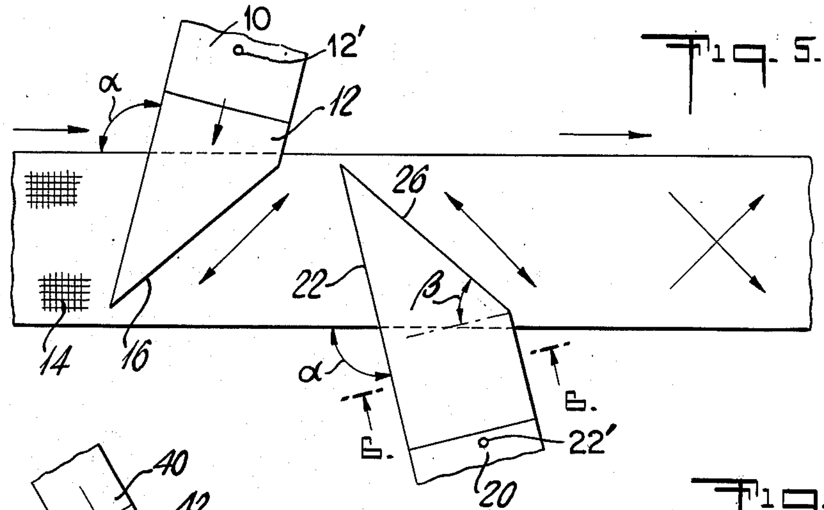


FIG. 7.

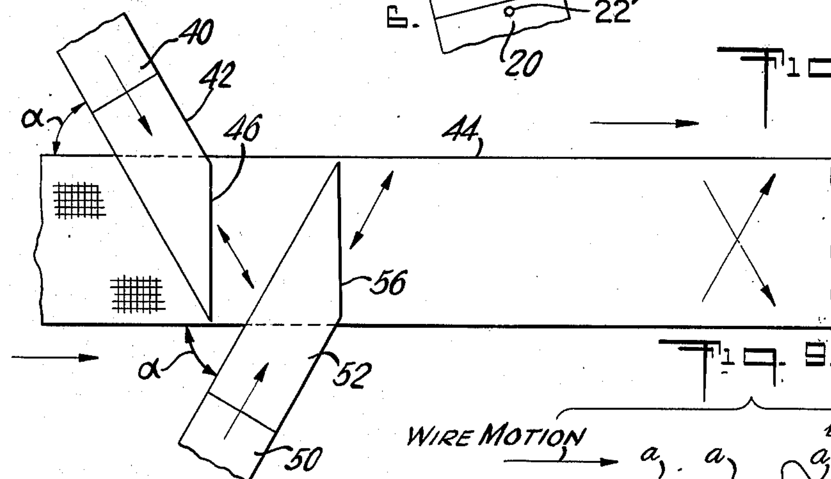


FIG. 9.

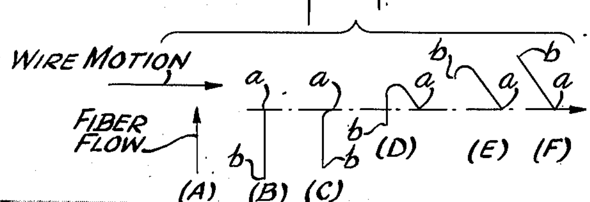


FIG. 8.

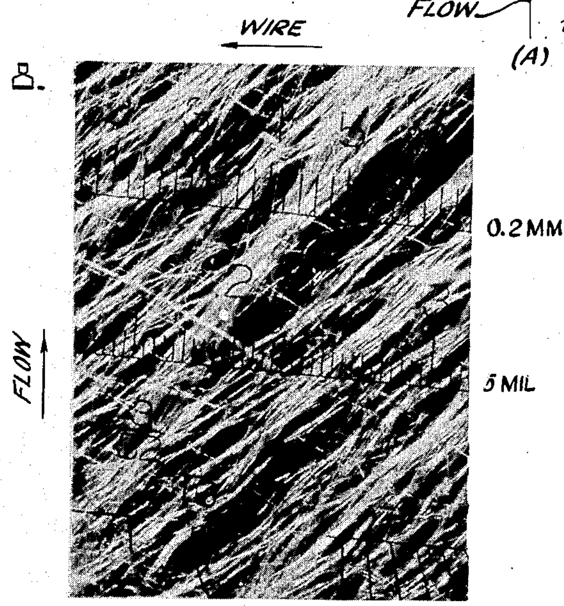
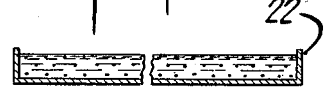


FIG. 6.



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WET-FORMED NONWOVEN TEXTILE FABRICS AND METHODS AND APPARATUS FOR MAKING THE SAME

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Int. Cl. D21f *1/06, 11/04*
U.S. Cl. 162—215 27 Claims

ABSTRACT OF THE DISCLOSURE

A foraminous, wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity, and good opacity and covering power comprising uncarded, relatively straight, smooth-surfaced, synthetic textile fibers having an average length of from about ⅜ inch to about 1½ inches or more, the nonwoven textile fabric having two major axes of predominant fiber orientation directed at angles to each other and mirror-imaged with respect to the long direction of the nonwoven textile fabric, a preponderance of the fibers being arranged in generally parallel arrays of bundles which are generally oriented in the direction of one of the two major axes of predominant fiber orientation, with the bundles having diameters of from about 0.04 mm. to about 0.6 to 1 mm. and extending angularly generally from one side of the nonwoven textile fabric to the other side thereof and containing from about 3 to about 200 or more fibers in each bundle and being spaced apart a distance of from about 0.2 mm. to about 1.5 mm., on an approximate center-to-center basis. Another feature is the presence in the fibrous structure of a very large number of randomly-arranged pores or openings which, however, are so extremely small in diameter that there is very little open surface area, that is, fabric areas of zero or very low fiber density. As a result, the fibrous structure has excellent opacity and covering power. Also included are methods and apparatus for making such wet-formed nonwoven fabrics comprising: forming an aqueous slurry which comprises synthetic fibers having an average length of from about ⅜ inch to about 1½ inches or more; causing the aqueous slurry of fibers to flow at a predetermined velocity in a thin, flat, sheet-like, planar configuration; angularly discharging the aqueous slurry of fibers upon a moving forming surface having a predetermined velocity, and forming a loosely-assembled fibrous structure thereon wherein the individual fibers have a predominant orientation directed angularly with respect to the direction of movement of the forming surface, the angular direction of predominant fiber orientation being affected by the velocity of the aqueous slurry, the angle of discharge of the aqueous slurry on the moving forming surface, and the velocity of the moving forming surface; and then subsequently angularly discharging a second aqueous slurry of fibers also having a thin, flat, sheetlike, planar configuration and a predetermined velocity upon the loosely-assembled fibrous structure, the second angle of discharge being equal to but oppositely directed in mirror-image fashion to the first angle of discharge with respect to the long direction of the forming surface, with the second slurry velocity and second forming surface velocity being substantially equal to the first slurry velocity and the first forming surface velocity, respectively, whereby the second aqueous fiber slurry forms a second loosely-assembled fibrous structure wherein the fibers have a predominant orientation which is oppositely-directed and in mirror-image relationship to the first predominant fiber orientation with respect to the long direction of the forming surface, the fibers of the second loosely-assembled fibrous structure intermingling and interentangling with the fibers of the first loosely-assembled fibrous structure whereby there is made a wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity, and good opacity and covering power.

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BACKGROUND

Many people have been engaged for many years in the manufacture of nonwoven textile fabrics which can be made without resorting to the spinning, twisting, and twining of individual fibers into yarns and strands, and the subsequent weaving, knitting, or other fabricating of these yarns and strands into fabrics.

Such nonwoven textile fabrics have usually been manufactured by laying down one or more fibrous layers or webs of textile length fibers by dry textile carding techniques which normally align the majority of the individual fibers more or less generally lengthwise of the fibrous layer or web being prepared.

The individual textile length fibers of these carded fibrous webs are then bonded by conventional bonding techniques, such as, for example, by intermittent print pattern bonding, whereby a unitary, self-sustaining nonwoven textile fabric is obtained.

Such manufacturing techniques, however, are relatively slow and it has always been desired that manufacturing processes having greater production rates be devised. Additionally, it is to be noted that such dry textile carding and bonding techniques are normally applicable only to fibers having a textile cardable length of at least about ½ inch, and preferably longer, and are not applicable to short fibers such as wood pulp fibers which have very short lengths of from about ⅙ inch down to about ¹⁄₂₅ inch or less.

More recently, people have been engaged in the manufacture or nonwoven textile fabrics by wet-forming techniques on conventional or modified papermaking or similar machines. Such manufacturing techniques advantageously have much higher production rates and are also applicable to very short fibers such as wood pulp fibers. Unfortunately, however, difficulties are often encountered in the use of the longer textile length fibers in such wet-forming manufacturing techniques.

One of the most intransigent problems of nonwoven textile fabric manufacture is the inherent tendency of all fibrous web forming processes using textile length fibers to produce a fabric having a majority of the fibers oriented in the machine or long direction. This is particularly true for light weight fibrous webs produced at relatively higher speeds. This unidirectional character is a familiar feature of carded fibrous webs and of wet-formed fibrous webs using the classic papermaking machine arrangement.

Attempts have been made previously to produce cross-oriented fibrous webs of textile length fibers by laminating, needling, or otherwise bonding cross lapped card webs but such procedures have failed to achieve a unitary structure, or good opacity and covering power, or sufficiently high production speeds. Specifically, in many of these attempts, it has been particularly noted that the cross-lapped fibrous webs do not satisfactorily form an integral or unitary structure, and considerable delamination problems have resulted in which the cross-lapped fibrous webs have undesirably separated from one another. Also, in many cases it has been noted that the cross-lapped fibrous webs do not possess sufficient opacity and covering power. This is particularly true if the webs are hydraulically rearranged into predetermined patterned apertured nonwoven textile fabrics containing apertures by processes and apparatus more particularly described in U.S. Pat. 2,862,251 which issued Dec. 2, 1958 to F. Kalwaites.

Although the nonwoven textile fabrics of the present inventive concept contain pores or openings, they are extremely small in diameter and are also located at random, whereby the opacity or covering power of the resulting nonwoven textile fabric is not substantially diminished.

THE INVENTIVE CONCEPT

It has been found that a foraminous, wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity, and good opacity and covering power comprising uncarded, relatively straight, smooth-surfaced, synthetic textile fibers having an average length of from about ⅜ inch to about 1½ inches or more, the nonwoven textile fabric having two major axes of predominant fiber orientation directed at angles to each other and mirror-imaged with respect to the long direction of the nonwoven textile fabric, a preponderance of the fibers being arranged in generally parallel arrays of bundles which are generally oriented in the direction of one of the two major axes of predominant fiber orientation, with the bundles having diameters of from about 0.04 mm. to about 0.6 to 1 mm. and extending angularly generally from one side of the nonwoven textile fabric to the other side thereof and containing from about 3 to about 200 or more fibers in each bundle and being spaced apart a distance of from about 0.2 mm. to about 1.5 mm., on an approximate center-to-center basis may be made by forming an aqueous slurry comprising synthetic fibers having an average length of from about ⅜ inch to about 1½ inches or more; causing the aqueous slurry of fibers to flow at a predetermined velocity in a thin, flat, sheet-like planar configuration; angularly discharging the aqueous slurry of fibers upon a moving forming surface having a predetermined velocity, and forming a loosely-assembled fibrous structure thereon wherein the individual fibers have a predominant orientation directed angularly with respect to the direction of movement of the forming surface, the angular direction of predominant fiber orientation being affected by the velocity of the aqueous slurry, the angle of discharge of the aqueous slurry on the moving forming surface, and the velocity of the moving forming surface; and then subsequently angularly discharging a second slurry of fibers also having a thin, flat, sheet-like planar configuration and a predetermined velocity upon the loosely-assembled fibrous structure, the second angle of discharge being equal to but oppositely directed in mirror-image fashion to the first angle of discharge with respect to the long direction of the forming surface, and the second slurry velocity and second forming surface velocity being substantially equal to the first slurry velocity and first forming surface velocity respectively, whereby the second aqueous fiber slurry forms a second loosely-assembled fibrous structure wherein the fibers have a predominant orientation which is oppositely-directed and in mirror-image relationship to the first predominant fiber orientation with respect to the long direction of the forming surface, the fibers of the second loosely-assembled fibrous structure intermingling and interentagling with the fibers of the first loosely-assembled fibrous structure whereby there is made a wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity, and good opacity and covering power.

In the following specification and accompanying drawings, there is described and illustrated preferred embodiments of the invention but it is to be understood that the inventive concept is not to be considered limited to the embodiments disclosed, except as determined by the scope of the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring to the accompanying drawings:

FIG. 1 is a schematic drawing showing a typical prior art nonwoven textile fabric wherein there is basically only one primary direction of predominant fiber orientation which is directed substantially in the long direction of the nonwoven textile fabric;

FIG. 2 is a schematic drawing showing a typical nonwoven textile fabric of the present invention wherein there are basically two primary directions of predominant fiber orientation which are directed at angles to each other and mirror-imaged with respect to the long direction of the nonwoven textile fabric;

FIG. 3 is a schematic drawing showing a modification of the invention nonwoven textile fabric of FIG. 2, wherein the two primary directions of predominant fiber orientation are directed at a different and lesser angle with respect to the long axis of the nonwoven textile fabric.

FIG. 4 is a schematic drawing showing another modification of the invention nonwoven textile fabric of FIG. 2, wherein the two primary directions of predominant fiber orientation are directed at a different and greater angle with respect to the long axis of the nonwoven textile fabric;

FIG. 5 is a schematic drawing showing a typical flow chart of a portion of a wet-forming manufacturing apparatus and process, representing a preferred high velocity embodiment of the present inventive concept;

FIG. 6 is an enlarged drawing of a cross-sectional view of a delivery tray which is part of the apparatus shown in FIG. 5, taken on the line **6—6** thereof, looking in the direction indicated by the arrows;

FIG. 7 is a schematic drawing showing a typical flow chart of a portion of another web-forming manufacturing apparatus and process, representing a preferred low velocity embodiment of the present inventive concept;

FIG. 8 is a photomicrograph of a typical single layer of a typical nonwoven textile fabric of the present inventive concept, according to one embodiment of the invention, at an original enlargement of approximately 15 to 1. This figure illustrates the fiber orientation and bundle formation described herein; and

FIGS. 9A through 9F are simplified schematic drawings showing a reasonable explanation of the theory involved in the various changes in the fiber configuration and orientation at several stages during the process, as applied to the concept illustrated in FIG. 5.

BRIEF DESCRIPTION OF THE PRODUCT OF THE INVENTION

With particular reference to FIG. 1, there is schematically shown a typical nonwoven textile fabric of the prior art wherein there is basically only one primary direction of predominant fiber orientation which is directed substantially in the long direction of the nonwoven textile fabric. Such a nonwoven textile fabric possesses very high strength, but very low elongation properties in the long direction, whereas it has very low strength but very high elongation properties in the cross direction. Additionally, the nonwoven textile fabric is very prone to splitting along a long axis but is very resistant to splitting in the cross direction. This naturally creates an unbalanced and undesirable fabric construction with an unbalanced and undesirable ratio of properties and characteristics in the long and cross directions of the nonwoven textile fabric.

With reference to FIG. 2, there is schematically shown a typical nonwoven textile fabric of the present invention wherein there are basically two primary directions of predominant fiber orientation which are directed at angles to each other and which are equally and oppositely mirror imaged with respect to the long direction of the nonwoven textile fabric. As indicated by the arrows, one primary direction of predominant fiber orientation is 45° (as measured clockwise) to the long direction of the nonwoven textile fabric whereas the other primary direction of predominant fiber orientation is 45° (as measured counter clockwise) to the long direction of the nonwoven textile fabric.

Each of these primary fiber orientations may be considered to be a property and characteristic vector which can be resolved into two component vectors, one in the long direction and the other in the cross direction of the nonwoven textile fabric. It is to be noted at once that all of these component vectors are equal, because the tangent and co-tangent of 45° are both equal to 1. As a result, the sum of the component vectors in the long direction equals the sum of the component vectors in the cross direction. Consequently, the properties and characteristics of the nonwoven textile fabric in the long direction are substantially equal to the properties and characteristics of the nonwoven textile fabric in the cross direction.

The result is a balanced and desirable fabric construction wherein the strength, elongation, resistance to splitting, and other properties and characteristics are generally balanced and equal in the long and cross direction.

In FIG. 3, there is schematically shown a modification of the nonwoven textile fabric of FIG. 2, wherein a different ratio of properties and characteristics in the long to the cross direction may be obtained, if so desired or required.

In FIG. 3, one primary direction of predominant fiber orientation is 30° (as measured clockwise) to the long direction of the nonwoven textile fabric whereas the other primary direction of predominant fiber orientation is 30° (as measured counter clockwise) to the long direction of the nonwoven textile fabric. Resolution of the two primary vectors into their component vectors will establish a ratio of properties of 1.732 to 1, since the co-tangent of 30° is 1.732. In such a case, for example, the strength in the long direction will be approximately 1.732 times the strength in the cross direction. Such a ratio may be desirable, depending upon the circumstances of the particular situation.

In FIG. 4, there is schematically shown still another modification of the present inventive concept wherein a still different ratio of long to cross properties and characteristics may be obtained, if so desired or required.

In FIG. 4, one primary direction of predominant fiber orientation is 60° (as measured clockwise) to the long direction of the nonwoven textile fabric whereas the other primary direction of predominant fiber orientation is 60° (as measured counter clockwise) to the long direction of the nonwoven textile fabric. Resolution of the two primary vectors into their component vectors will establish a ratio of properties of 1 to 0.577, since the co-tangent of 60° is 0.577. In such a case, the strength in the long direction will be approximately 0.577 times the strength in the cross direction. Such a ratio indicates that the nonwoven textile fabric has actually been "turned around" and that the cross tensile strength is now greater than the long tensile strength.

It can therefore be seen that a nonwoven textile fabric can be made to have predetermined desired properties and characteristics in the long and cross directions, as required or desired. FIGS. 5 and 6 illustrate a particular embodiment of preferred apparatus and process capable of carrying out the principles of the present invention.

BRIEF DESCRIPTION OF THE PROCESS OF THE INVENTION

With particular reference to FIG. 5, there is shown the discharge portion of a dispersion tank **10** which is suitable for forming a substantially uniform aqueous dispersion of the fibers to be used in the formation of the nonwoven textile fabric of the present invention.

FIBERS USED

The fibers which are dispersed in the dispersion tank **10** may comprise 100% uncarded, relatively straight, smooth-surfaced synthetic textile length fibers having an average length of from about ⅜ inch to about 1½ inches or more, or, if so desired or required, the dispersion may comprise a mixture of at least about 50% by weight of such textile length synthetic fibers and less than about 50% by weight of relatively unbeaten and unrefined short fibers having an average length of from about ⅙ inch (0.167 inch) to about 1/25 inch (0.040 inch) or less.

TEXTILE LENGTH SYNTHETIC FIBERS

The textile length fibers may be selected from a large group of synthetic or man-made fibers such as: the cellulosic fibers, notably regenerated cellulose (both viscose and cuprammonium processes), cellulose acetate, and cellulose triacetate; the non-cellulosic fibers such as: the polyamide fibers, notably nylon 6,6 and 6; the polyesters, notably "Dacron," "Fortrel" and "Kodel"; the acrylics, notably "Creslan," "Acrilan' and "Orlon; the modacrylics, notably 'Dynel' and "Verel"; the polyolefins, especially polypropylene and polyethylene, notably "Vectra" and "Herculon"; the spandexes, notably "Lycra" and "Unel"; the fluorocarbons, notably "Teflon" TFE and FEP; etc. These fibers may be used by themselves, or in various combinations and blends of two or more species in varying percentages, as desired or required.

The denier of the synthetic or man-made textile length fibers may be varied relatively widely, depending on the circumstances, and vary from about 1½ denier to about 6 denier, with lower deniers to about 1 or less, and higher deniers to about 9, 15, or more, being of use in special circumstances.

SHORT FIBERS

The remaining fibers of the aqueous dispersion, if other fibers are used, are wood pulp fibers or other short fibers.

Unbeaten or unrefined wood pulp fibers, or at least relatively unbeaten or unrefined wood pulp fibers, are preferably used inasmuch as beating and refining are rather severe mechanical treatments, and beat and macerate the fibers whereby enhanced hydration bonding is obtained in the final product which is not desired in the present inventive concept and which leads to a product which undesirably has increased stiffness, harshness and a papery hand.

However, in some circumstances, it may be desired to include a small amount, say, up to about 10% by weight of thoroughly beaten, thoroughly hydrated fibrillated wood pulp fibers which will act as a bonding agent, in order to unify the nonwoven textile fabric and to increase its cohesive properties.

Although softwood sulfate pulp will be disclosed as the preferred type of wood pulp fiber used in the application of the present invention, substantially any type of wood pulp, either hardwood or softwood, is of use. Examples of other types of wood pulp are: sulfite pulps in which the cooking liquor, calcium or magnesium bisulfite, is acid, or sodium sulfite which is neutral or slightly alkaline; soda pulps in which the cooking liquor, caustic soda, is alkaline; kraft or sulfate pulps in which the cooking liquor, sodium hydroxide and sodium sulfide, is alkaline, etc.

Although wood pulp fibers are preferred in the application of the present inventive concept, other short fibers or fibrous materials are of use. Examples of such short fibers or fibrous maetrials having lengths of from about ⅙ inch to about 1/25 inch or less are: cotton linters, bagasse, flax, jute, straw, bamboo, esparto grass, rayon, and the like.

It is essential that all the fibers used in the application of the principles of the present invention be capable of being dispersed substantially uniformly in the aqueous slurry. The concentration of the fibers in the fiber dispersion varies widely and normally is in the range of from about 0.02% by weight to about 0.2% by weight, based on the dry weight of the fibers. Greater or lesser fiber concentrations may be used for special circumstances.

DISPERSION AIDS

Dispersion aids are used in the aqueous slurry in order to assist or promote the desired uniformity of fiber dispersion. Examples of such dispersion aids are: collagen; "Cytame 5" and "Cytame 6," which are water-soluble synthetic anionic polyacrylamide linear polymers having extremely high average molecular weights of about 15 million; "Polyox" FRA and "Polyox" Coagulant, which are water-soluble ethylene oxide polymers having an average molecular weight of about 7 million and 5 million, respectively; "Reten" 210, which is a synthetic, strongly cationic polyamine having an average molecular weight of at least about 1 million; etc.

The concentration of the dispersion aid in the aqueous slurry varies widely depending on the type and concentration of the fibers used, the effectiveness of the dispersion aid itself, the dispersing effect desired or required, etc. Normally, from about 5 parts per million to about 500 parts per million of dispersion aid, based on the weight of the aqueous dispersion, is satisfactory with lesser or greater concentrations being of use in special circumstances..

THE DELIVERY TRAY

Having formed the substantially uniform, aqueous dispersion or slurry of fibers in the dispersion tank **10**, the aqueous slurry is then delivered through the discharge portion of the dispersion tank to a relatively flat, shallow delivery tray **12**. The delivery tray **12** is best shown in FIG. 5 (or perhaps in FIG. 6 showing a similar delivery tray) and it is to be noted that its width is many times its depth whereby the aqueous slurry of fibers which flows therein possesses a laminar flow substantially in a flat, sheet-like plane. Turbulence, eddy currents, and other disruptive effects are reduced to a minimum.

The ratio of the width of the delivery tray to its depth, or more importantly the ratio of the width of the aqueous slurry therein to its depth is normally on the order of at least about 20 to 1 and preferably 100 to 1, or even higher. For example, delivery trays having a width of about 36 inches normally carry an aqueous slurry having an average depth of from about ¼ inch to about ¾ inch which are equivalent to width:depth ratios of 144:1 and 48:1, respectively.

For very large commercial installations employing very wide Fourdrinier wires, it is advisable to use very wide delivery trays which may be as wide as about 40 feet and wherein the fiber slurry may have a depth of as little as ¼ inch to ½ inch. Such an arrangement would create a width to depth ratio as high as 1920:1 or 960:1, respectively. Such an arrangement would provide for the discharge of very large volumes of fiber slurry at relatively low slurry velocities and thus create smooth, even, nonturbulent flow.

The length of the delivery tray **12**, when combined with the length of the discharge portion of the dispersion tank **10**, should be long enough to provide a smooth, non-turbulent flow in the slurry as it moves to the end portion of the delivery tray **12**. Under normal circumstances, a length of at least about 1 or 2 feet is sufficient.

The velocity of the fibers of the aqueous slurry in the delivery tray **12** may also be varied relatively widely and normally is in the range of from about 20 feet per minute to about 260 feet per minute and preferably from about 100 to about 200 feet per minute. The velocity of the fibers as they move in the delivery tray is an important factor affecting the properties and characteristics of the resulting nonwoven textile fabric.

Inasmuch as the velocity range of from about 20 feet per minute to about 260 feet per minute represents a relatively wide velocity range for the fiber slurry, a more detailed breakdown of this velocity range is deemed advisable. Fiber slurries in the low range of from about 20 feet per minute to about 65 feet per minute are normally used with low angles of approach (to be defined in greater detail hereinafter) and with low Fourdrinier wire velocities (also to be defined in greater detail hereinafter). Fiber slurry velocities in the high range of from about 65 feet per minute to about 260 feet per minute are normally used with high angles of approach and with high Fourdrinier wire velocities.

The delivery tray **12** is positioned with its longitudinal axis directed angularly with respect to the direction of movement of a Fourdrinier wire **14** which is located immediately adjacent thereto, whereby the flat, sheet-like planar flow of the aqueous slurry and the fibers therein approach the Fourdrinier wire **14** at a predetermined angle α. The delivery tray **12** is adjustably or rotatably mounted by means of pivot **12'** so that it can be positioned at various angles to the Fourdrinier wire **14** so that the angle of approach α of the aqueous slurry can be selectively predetermined for reasons to become clear from the description which follows. As shown in FIG. 5, the angle of approach of the fiber slurry is 104 degrees but this angle is merely illustrative of one embodiment of the invention and is not to be construed as limitative thereof.

In general, angles of approach α fall within the range of from about 10 degrees to about 130 degrees, as measured clockwise with respect to the long axis of the Fourdrinier wire, and depend upon many factors, primarily the velocity of the aqueous slurry in the delivery tray, and particularly the velocity of the Fourdrinier wire.

The angle of approach α is an important factor affecting the properties and characteristics of the resulting nonwoven textile fabric.

Inasmuch as the range of the angles of approach of the fiber slurry of from about 10° to about 130° represents a relatively wide range, a more detailed breakdown is deemed advisable. Low angles of approach of from about 10° to about 80° are normally used with low fiber slurry velocities of from about 20 feet per minute to about 65 feet per minute and with low Fourdrinier wire velocities to be defined hereinafter. High angles of approach of from about 80° to about 130° are normally used with high fiber slurry velocities of from about 65 feet per minute to about 260 feet per minute and with high Fourdrinier wire velocities.

The front or discharge end of the delivery tray **12** preferably possesses an angular edge **16** whereby the aqueous slurry is capable of being delivered substantially uniformly across the full width of the Fourdrinier wire **14**. Such an angular cut to the front edge of the delivery tray **12** serves to deposit on the Fourdrinier wire a substantially uniform array of fibers across the width of the Fourdrinier which normally would not be possible if all the aqueous slurry were to be delivered at one edge of the Fourdrinier wire **14** and compelled to flow completely across the full width thereof.

The use of such an angular front edge **16** is of particular advantage when very wide Fourdrinier wires are used. The advantages are, of course, less when medium width Fourdrinier wires are used and may be dispensed with completely for narrow Fourdrinier wires. As shown, the front edge **16** is cut at an angle β of about 45° to the longitudinal axis of the delivery tray **12** but this angle β may be changed within a range of from about 0° to about 75°, as measured normal to the fiber flow, as desired or required, deepnding on the factors mentioned hereinbefore, and particularly the velocity of the Fourdrinier wire.

THE FOURDRINER WIRE

The Fourdrinier wire **14** passes directly immediately under the discharge end of the delivery tray **12** and is sufficiently close thereto, as measured in the vertical direction, as to substantially reduce the "fluid head" of the aqueous slurry to a matter of less than about ½ inch of "fluid head," or preferably even less, and to thereby minimize the "waterfall" effect of the slurry as it is delivered from the delivery tray **12** to the Fourdrinier wire **14**. This also serves to lessen the turbulence, swirling eddying in the aqueous slurry in the area of aqueous slurry transfer and to reduce the tendency of the fibers to move about into undesired orientations.

The Fourdrinier wire is a standard or conventional finely woven metal or synthetic fiber cloth which permits rapid drainage of water but retains fibers. The mesh size is preferably relatively coarse and is in the range of from about 15 mesh to about 120 mesh.

The velocity of the Fourdrinier wire **14** may be varied relatively widely but is normally in the range of from about 20 feet per minute to about 260 feet per minute. Higher or lower speeds may be used for special circumstances.

Inasmuch as the velocity range of the Fourdrinier wire of from about 20 feet per minute to about 260 feet per minute represents a relatively wide range, a more detailed breakdown of the range is deemed advisable. Low Fourdrinier wire velocities of from about 20 feet per minute to about 80 feet per minute are normally used with low fiber slurry velocities of from about 20 feet per minute to about 65 feet per minute and with low angles of approach of from about 10° to about 80°. High Fourdrinier wire velocities of from about 80 feet per minute to about 260 feet per minute are normally used with high fiber slurry velocities of from about 65 feet per minute to about 260 feet per minute and with high angles of approach of from about 80° to about 130°.

The following table shows the relationship between these factors and the drawings illustrating the particular processes involved.

Fourdrinier velocity	Slurry velocity (ft. per minute)	Angle of approach (degrees)	Fourdrinier velocity (ft. per minute)
Low range	20–65	10–80	20–80
Fig. 7	50	60	50
High range	65–260	80–130	80–260
Figs. 5–6	90	104	154

FIBER ORIENTATION

The fibers of the aqueous slurry deposited on the Fourdrinier wire assume an angular position thereon, as shown, with respect to the direction of movement of the Fourdrinier wire **14**. It is believed that this angular configuration is due primarily to the effect on the fibers of: (1) the velocity of the fibers in the planar flow in the delivery tray; (2) the angle of the delivery tray to the Fourdrinier wire; (3) the velocity of the Fourdrinier wire; (4) the mesh of the Fourdrinier wire; etc. The particular angular deposition illustrated in FIG. 5 is approximately 45° which represents a preferred embodiment of the present invention. Other angular depositions are possible, as will be described in greater detail hereinafter.

The aqueous slurry of fibers deposited on the Fourdrinier wire **14** by the delivery tray **12** is dewatered by drainage through the Fourdrinier wire and passes under the angularly positioned front or discharge end **26** of a second angularly positioned delivery tray **22** which is fed by a second dispersion tank **20** very similar to the first dispersion tank **10**. As a matter of fact, in the event that the aqueous slurries are alike, one dispersion tank may be used to feed both delivery trays, or a plurality of such trays, if more than two are used.

In the normal course of events, however, it has been desirable that two or more separate dispersion tanks be used and that the fiber consistency in the first dispersion tank be less than that in the second dispersion tank and that, if there are three dispersion tanks, that the fiber consistency in the second tank be less than that in the third tank, and so forth.

It is to be recalled that the first aqueous slurry is discharged directly onto the Fourdrinier wire which possesses certain drainage properties and characteristics. The second aqueous slurry, however, is discharged on top of the fibrous array or structure formed by the first aqueous slurry and hence its drainage is markedly different and considerably slower since the water must pass through the fibrous array or structure before draining through the Fourdrinier wire. Additionally, there may be more overflow over the sides of the Fourdrinier during the second drainage situation.

The overall range of fiber consistencies in the aqueous slurry is from about 0.02% by weight to about 0.2% by weight, on a dry fiber basis, with the fiber consistency in the first dispersion tank normally being in the range of from about 0.02% by weight to about 0.15% by weight and the fiber consistency in the second dispersion tank normally being in the range of from about 0.05% by weight to about 0.20% by weight. Normally, however, the second fiber consistency is from about 25% to about 200% greater than the first fiber consistency.

The aqueous slurry of fibers from the second delivery tray **22** also has a flat, substantially planar flow and its deposition on the Fourdrinier wire is similar to the deposition of fibers from the first delivery tray with one very notable exception. Specifically, the angular direction of the flow of the fibers in the second delivery tray is reversed in orientation and the angle of approach is now equal but opposite that of the first fiber deposition and is basically mirror-imaged with respect thereto. As a result, the fibers deposited from the second delivery tray are positioned at minus 45 degrees or approximately 90° out of phase with the fibers deposited from the first delivery tray. The fiber orientations are thus at right angles to each other, as shown in FIG. 2.

Additionally, during the deposition of the second fiber slurry, there is sufficient intergmingling and interentangling with the fibers of the first slurry that a significant number of the fibers intermix, particularly at the slurry interfaces, to form a unitary and integral structure which subsequently can be demonstrated as resisting separation of delamination. This significant intermingling of the fibers of each of the portions laid down by the delivery trays is an important and very desirable feature of the present invention.

The resulting nonwoven textile fabric is found to possess two major axes of predominant fiber orientation directed substantially at right angles to each other and with the fibers thereof substantially uniformly intermingled and interentangled with each other in a substantially planar configuration. The result is a foraminous, wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties and characteristics in the long and cross directions, uniformly, and good opacity and covering power.

Rotation of the delivery trays to different angular relationships other than the plus 104° and minus 104° illustrated in FIG. 5 will result in a change in the angular deposition of the fibers with respect to the direction of movement of the Fourdrinier wire. However, if the angular relationship of the delivery trays is numerically kept the same, although one is measured clockwise and other is measured counter clockwise, the result will still be the formation of the two major axes of predominant fiber orientations at angles to each other and mirror imaged with respect to the long axis of the Fourdrinier wire. Such angular relationships, however, will be no longer at plus 45 degrees and minus 45 degrees to the direction of movement of the Fourdrinier wire; other angles will be obtained depending upon the particular circumstances. As a result, the angular relationship of the individual fiber orientations can be changed, as desired or required, from the 45 degree-45 degree configuration shown in FIG. 2 to a range of other angular relationships.

Examples of nonwoven textile fabrics having different angular relationships of their predominant fiber orientations are illustrated in FIGS. 3 and 4.

In FIG. 3, there is illustrated a nonwoven textile fabric in which the long direction extends from left to right, as viewed in the figure. The two arrows on the nonwoven textile fabric represent the two primary directions of predominant fiber orientation. One of these directions is indicated as approximately 30° as measured clockwise with respect to the long direction of the nonwoven textile fabric and the other is represented as 30° measured counter clockwise to the long direction of the nonwoven textile fabric. A few individual fibers are included in FIG. 3 and schematically represent typical fiber orientation. Such a nonwoven textile fabric will possess properties and characteristics which are determined by the vector resolution of the two vectors illustrated.

In FIG. 4, there is illustrated another nonwoven textile fabric in which the long direction is indicated by the arrow adjacent the nonwoven textile fabric and the two primary directions of predominant fiber orientation are represented by the two arrows within the nonwoven textile fabric. It will be appreciated that the relationship of the properties and characteristics of the nonwoven textile fabric of FIG. 4 will be governed by the vector resolution of the two primary vectors illustrated in this drawing.

Many other primary directions of predominant fiber orientation are possible depending upon the various factors described herein.

LOW FOURDRINIER WIRE VELOCITY TECHNIQUES

Thus far, the emphasis has been placed primarily on process and apparatus suitable for application under "high velocity" conditions. In FIG. 7, there is illustrated process and apparatus suitable for application of the "low velocity" principles. In this figure, there is disclosed the discharge portion of a first dispersion tank **40** which leads to a first delivery tray **42** having an angular front or discharge edge **46** extending closely over a moving Fourdrinier wire **44**, as described previously. The first aqueous slurry prepared in the first dispersing tank is delivered in typical flat, sheet-like planar configuration to the Fourdrinier wire at an angle of discharge of about 60°, as measured clockwise to the direction of movement of the Fourdrinier wire. The directions of flow and the fiber orientation are as indicated.

A second dispersion tank **50** supplies a second aqueous slurry to a second delivery tray **52** having a front or discharge edge **56** which also extends closely over the moving Fourdrinier wire **44**. The second aqueous slurry prepared in the second dispersing tank is delivered in a flat, sheet-like planar configuration to the Fourdrinier wire at an angle of discharge of about 60°, as measured counter clockwise to the direction of movement of the Fourdrinier wire. And, it is delivered, as described previously, on top of the first fibrous array or structure formed from the first aqueous slurry. Again, the directions of flow and the fiber orientation are as indicated. The primary directions of predominant orientation are represented at the right hand end of the nonwoven textile fabric.

It is to be noted that, under the low Fourdrinier velocity techniques, the individual fibers are delivered at a specific angle to the Fourdrinier wire and that they are deposited and remain at that angle as the fibrous array or structure is drained and dewatered and moved forwardly.

FORMATION OF FIBER BUNDLES

An additional feature and result of the fluid and fiber interaction between (1) the substantially planar flow of the aqueous slurry and (2) the operating variables of slurry velocity, angle of approach, and Fourdrinier velocity and surface characteristics is the surprising and unexpected formation of the individual fibers into substantially parallel arrays of bundles or groups of fibers aligned generally in the primary directions of predominant fiber orientation.

These fiber bundles are of continuous length and extend angularly generally from one side of the textile fabric to the other side. Usually, there are up to about 20 fiber bundles per inch. Normally, they are approximately parallel and are spaced from one another by a distance of from about 0.2 to about 1.5 mm., center-to-center. Each bundle contains from about 3 to about 200 or more individual fibers with approximately 50% of the fibers in a bundle in multipoint, almost continuous contact for a distance of ¼ inch or more. The bundles have an approximate range of diameters of from about 0.04 millimeter to about 0.6 or 1 millimeter or more. Within a given fibrous structure, approximately 50% of the fibers in a given fiber bundle may participate in branching from one bundle to other adjacent bundles in a length of about ¼ inch. This branching is at an angle of about 35° or less to the primary direction of predominant fiber orientation. Other than that small portion of their length which is proceeding from one fiber bundle to other adjacent fiber bundles, the fibers in the primary fiber bundles are in multipoint, almost continuous contact with the same adjacent fiber or fibers for a distance of about ¼ inch or more. These continuous fiber bundles run the entire length and width of the nonwoven textile fabric. Within a given layer, the adjacent parallel fiber bundles are also linked by from about 20 to about 200 fibers in a distance of about ¼ inch at an angle of about 60° or more to the primary direction of predominant fiber orientation. These linkages are in addition to the branching described previously. Thse connecting fibers which intersect the primary fiber bundles at a large angle, approaching about 90°, extend in this general direction for a large fraction of their length, perhaps as much as about ⅜ inch.

A relatively large number of these fibers are actually interwoven and pass over and under other fibers in a random fashion with the primary fiber bundles, i.e., these connecting fibers which lie across the primary direction pass over, under and through the primary fiber bundles.

In adjacent fibrous layers, the fiber bundles are oriented angularly with respect to each other and are mirror-imaged to each other with respect to the long axis of the nonwoven textile fabric. Thus, they coincide angularly with the primary directions of predominant fiber orientation. This feature is illustrated in FIG. 8 which discloses the fiber structure of a single layer of a typical nonwoven textile fabric.

PORES OR OPENINGS OF THE FIBROUS STRUCTURE

Still another feature and result of the relationship between (1) the substantially planar flow of the aqueous slurry and (2) the operating variables of slurry viscosity, angle of approach, and velocity and surface characteristics of the Fourdrinier wire is the formation of a very large number of very small pores or openings randomly arranged or distributed in the fibrous structure. These pores or openings are so very small in diameter that, even though they are very many in number, they do not create very much open surface area, that is, fabric areas which have substantially zero or very low fiber density. As a result, the resulting fibrous structure possesses good opacity and covering power.

The determination of the number of pores or openings in the fibrous structure is a very difficult matter to determine inasmuch as the greater the magnification of the fibrous structure, then the greater is the number of pores or openings which can be detected. Basically, it resolves to a definition as to what is considered to be a "pore." Within the scope of the present invention, therefore, a pore or opening is herein defined as an area of substantially zero or very low fiber density and which possesses a diameter larger than 0.005 inch.

The fibrous structures of the present invention have substantially none, or at the very most, a very low number of pores or openings which have diameters equal to or greater than about 0.015 inch. This very low number is less than about 4% of the total number of pores or openings in the fibrous structure, and is normally on the order of about 1% or 2%.

More specifically, the vast preponderance of the randomly distributed pores or openings in the fibrous structure range in diameter from about 0.005 inch to about 0.015 inch and normally from about 0.005 inch to about 0.010 inch.

The total number of open surface areas created by the total number of pores or openings, that is, the total surface coverage of the areas which have substantially zero or very low fiber density in the fibrous structures of the present invention is less than about 10%, and more likely, on the order of less than about 5%.

The total number of pores or openings in the fibrous structure is on the order of from at least about 600 to about 1500 or more pores per square inch in the range of from about 0.005 inch to about 0.010 inch diameter, from about 100 to about 400 pores per square inch in the range of from about 0.010 inch to about 0.015 inch diameter, and from about 20 to 60 pores per square inch in the range of slightly greater than 0.015 inch diameter.

The following table set forth these values in percentage values:

Diameter of pores	Number of pores	Percentage
0.005—0.010	600–1,500	75–85
0.010–0.015	100–400	13–25
0.015	20–60	1–4

The exact mechanism whereby the novel and patentable results of the present inventive concept are obtained is not precisely known but it is believed that the following is a reasonable explanation thereof with particular reference to the concept illustrated in FIG. 5.

Consideration of the nature of viscous laminar flow of the aqueous slurry makes it clear that the bottom layers of fiber dispersion flowing down the flat, shallow delivery tray will be flowing much slower than the upper layers and therefore any fibers which extend from one layer to another will be straightened out in the machine or long direction. When this planar flow contacts the Fourdrinier wire, two new motions will be introduced into the fiber dispersion to varying extents in the various layers. These two new directions are: (1) down through the Fourdrinier wire at a very slow rate; and (2) in the direction of the Fourdrinier wire at a much faster rate. However, the very upper layers of the aqueous fiber dispersion remain essentially unaffected by the movement through or with the Fourdrinier wire.

At the very bottom layers, the fiber orientation and the flow downwards means that leading end of the fiber will be caught by the lower layers of flow moving in the direction of the Fourdrinier wire before the trailing end of the fiber is affected. The intermediate portion of the fiber will be affected by the flow directions of the intermediate layers which will be in between the flow direction and the machine direction.

The results, as set forth in FIGS. 9A through 9F, of the movement of the segments of the fiber in several directions is a fiber orientation at about 45° if the Fourdrinier wire and the slurry flow spreads are in the proper ranges as described herein.

FIG. 9A discloses the directions of the Fourdrinier wire motion and the flow of the aqueous slurry of fibers. FIG. 9B discloses the fiber configuration and orientation as it is moving in the direction of movement of the aqueous fiber slurry. This is the fiber configuration before the fiber is deposited on the Fourdrinier wire. FIG. 9C illustrates the fiber configuration as it exists when the fiber tip *a* first contacts and is affected by the movement of the Fourdrinier wire. The curving of the leading end *a* and the direction of the trailing end *b* of the fiber is to be noted especially.

FIG. 9D represents the fiber configuration as the fiber is being laid down on the Fourdrinier wire. Notice the increase in curative. FIG. 9E represents the fiber configuration at a moment in time slightly after the time represented in FIG. 9D. Again, note the increase in the change in curvature. FIG. 9F represents the fiber configuration and orientation as the fiber finally comes to rest in its final position on the Fourdrinier wire.

These figures illustrate the mechanism for obtaining the primary directions of predominant fiber orientation using a smooth, flat, shallow delivery tray having a relatively high width to depth ratio for the aqueous slurry. This mechanism also accounts for the presence of a considerable amount of interweaving of the fibers which is noted in the final product. Such interweaving is brought about since some of the fibers may be deposited on the Fourdrinier wire before they have completed the reorientation process. As such, they thus partially lie across the primary orientation and are subsequently covered over by other oriented fibers.

The invention will be further illustrated in greater detail by the following specific examples. It should be understood, however, that although these examples may describe in particular detail some of the more specific features of the invention, they are given primarily for purposes of illustration and the invention in its broader aspects is not to be construed as limited thereto.

Example I

The apparatus illustrated in FIG. 5 of the drawings is used. Standard finished ¾ inch, 1.5 denier tow cut rayon fibers are dispersed in the first dispersing tank to a fiber consistency of 0.04% by weight on a dry fiber basis in the slurry by means of gentle, non-turbulent stirring of a large beater bar. Sixty parts per million of a dispersion aid "Cytame 6" is used to assist in the formation of a uniform dispersion of the fiber.

The fiber dispersion is delivered from the dispersion tank to a flat, shallow delivery tray having a front delivery edge cut at an angle of 45°. The flow rate of the fiber dispersion in the delivery tray is about 3 liters per second. The width of the delivery tray is 3 feet and the depth of the fiber dispersion in the delivery tray is between ¼ inch and ½ inch. The slurry width:depth ratio is from about 72:1 to about 144:1. The velocity of the fiber slurry is approximately 90 feet per minute. The delivery tray is positioned at an angle of about 104 degrees as measured clockwise to the direction of movement of the closely adjacent Fourdrinier wire which is travelling at a velocity of about 154 feet per minute.

The fiber slurry has a substantially flat, sheet-like planar flow and is discharged angularly by the delivery tray on the closely adjacent moving Fourdrinier wire to form a fibrous array or structure thereon wherein the fibers have a predominant orientation directed at an angle of 45° as measured counter clockwise to the direction of movement of the Fourdrinier wire.

The Fourdrinier wire carries the fibrous array or structure forwardly and is passed directly under the angular discharge portion of another delivery tray which is discharging a similar fiber slurry under similar conditions except that the fiber consistency of the second aqueous slurry is about 0.1% by weight.

In the case of the first delivery tray, the angle of approach of the aqueous slurry is 104° as measured clockwise to the direction of movement of the Fourdrinier wire. In the case of the second delivery tray, the aqueous slurry of fibers has an angle of approach of 76°, or actually an angle of approach of 104° as measured counter clockwise to the direction of movement of the Fourdrinier wire. As a result, the fiber slurry delivered from the second delivery tray forms a fibrous structure wherein the fibers have a predominant orientation directed at an angle of 45° as measured clockwise to the direction of movement of the Fourdrinier wire.

The direction of the predominant orientation given to both fibers is indicated at the right hand end of the Fourdrinier wire illustrated in FIG. 5.

Inasmuch as the fibrous structure deposited by the first delivery tray has just been formed and is not completely drained of water and has not "set" when the second fibrous slurry is deposited thereon, the fibers of both deposited slurries become substantially uniformly intermingled and interentangled with one another and form a substantially planar configuration. Some of the fibers of the first formed portion extend upwardly and into the second formed portion and similarly some of the fibers of the second formed portion extend downwardly into the first formed portion. A completely integral and unitary structure is thus obtained wherein the two portions are interentangled to such an extent that it is extremely difficult to delaminate the resulting product.

Analysis of the nonwoven textile fabric reveals that there are about 700 pores or openings per square inch and that the pores or openings have diameters in the range of from about 0.005 inch or less up to a maximum of about 0.015 inch with an average diameter of about 0.006 inch. These pores or openings are distributed at random. The amount of open space of such a fabric based on the number and size of these pores and openings is approximately 2%.

The fiber bundles are substantially of continuous length and extend angularly generally from one side of the nonwoven textile fabric to the other side. Normally, they are approximately parallel and are spaced from one another by a distance of from about 0.2 to about 1.5 mm., center-to-center. Each bundle contains from about 3 to about 200 or more individual fibers with approximately 50% of the fibers in a bundle in multipoint, almost continuous contact for a distance of about ¼ inch. The bundles have an approximate range of diameters of from about 0.04 mm. to about 0.6 mm. within a given fibrous structure and the adjacent parallel fiber bundles are linked and interconnected to each other by from about 5 to about 50 individual fibers branching from one fiber bundle to another along about ¼ of their length.

In adjacent fibrous layers, the fiber bundles are oriented angularly with respect to each other and are mirror-imaged to each other with respect to the long axis of the nonwoven textile fabric. Thus, they coincide angularly with the primary direction of predominant fiber orientation.

There are a very large number of very small pores or openings randomly arranged in the fibrous structure. Less than about 1% fall in the diameter size of 0.016 inch or greater. More than 99% are less than 0.015 inch. The vast preponderance is in the range of from about 0.005 inch to about 0.010 inch.

The resulting nonwoven textile fabric is found to be self-sustaining and basically of single-ply construction. It has balanced physical properties and characteristics in both the long and cross directions. It has excellent uniformity and has excellent opacity and covering power.

Example II

The procedures of Example I are followed substantially as set forth therein with the exception that the velocity of the Fourdrinier wire is decreased from 154 feet per minute to 110 feet per minute. As a result, the two primary directions of predominant fiber orientation have a different angular relationship and are positioned at approximately 140° to each other but are still mirror imaged with respect to the long axis of the Fourdrinier wire. The results are generally comparable to those obtained in Example I but it is to be noted that the product of this example has been "turned around" and the fibers extend more in the

cross direction than in the long direction. The tensile strength of the nonwoven textile fabric is greater in the cross direction than the long direction. Such a "turned around" nonwoven textile fabric is schematically shown in FIG. 4.

Example III

The procedures of Example I are followed substantially as set forth therein with the exception that the delivery tray is 64 centimeters wide. The volume flow rate is observed as approximately 50 liters in 14 seconds. The depth of the fiber slurry in the delivery tray is approximately 1 centimeter deep. The velocity of the fiber slurry is approximately 130 feet per minute.

The resulting nonwoven textile fabric is found to be generally comparable to the nonwoven textile fabric of Example I.

Example IV

The procedures of Example I are followed substantially as set forth therein with the exception that the fiber consistency in the first dispersion tank is increased from 0.04% to 0.06% by weight and the fiber consistency in the second dispersion tank is increased from 0.1% by weight to 0.12% by weight. These changes increase the basis weight of the resulting product. The results are generally comparable and the resulting nonwoven textile fabric possesses generally comparable physical properties and characteristics.

Example V

The procedures of Example I are followed substantially as set forth therein with the exception that the fiber consistency in the first dispersion tank is increased from 0.04% to 0.1% by weight and the fiber consistency in the second dispersion tank is increased from 0.1% by weight to 0.15% by weight. These changes increase the basis weight of the resulting product. The results are generally comparable and the resulting nonwoven textile fabric possesses generally comparable physical properties and characteristics.

Example VI

The procedures of Example I are followed substantially as set forth therein with the exception that the rayon fibers used in Example I are replaced by a mixture of fibers which comprises 60% by weight of polypropylene fibers and 40% by weight of rayon fibers. These fibers have a length of ¾" and have a denier of 1½. The fiber consistency in the aqueous slurry in the first dispersion tank is 0.1% by weight on a dry fiber basis and the fiber consistency in the second aqueous slurry is 0.15% by weight on a dry basis. The flow rate of the aqueous dispersion is 5 liters per second in the delivery tray and the tray width is 3 feet. The velocity of the fibers in the delivery tray is about 132 feet per minute.

The results are generally comparable to those set forth in Example I and the resulting product has generally similar properties and characteristics comparable to the product resulting from Example I.

Example VII

The procedures of Example I are carried out substantially as set forth therein with the exception that the rayon fibers used in Example I are replaced by a mixture of 50% by weight of ¾", 1.5 denier rayon and 50% by weight of a softwood sulfate wood pulp fiber. The fiber consistency in the first aqueous slurry is about 0.12% by weight and the fiber consistency in the second aqueous slurry is 0.18% by weight. The flow rate of the dispersion in the delivery tray is 5 liters per second. The width of the delivery tray is 3 feet.

The results are generally comparable to those set forth in Example I and the resulting product has generally similar properties and characteristics comparable to the product resulting from Example I.

Example VIII

The procedures of Example I are followed substantially as set forth therein with the exception that the concentration of the dispersing aid ("Cytame 6") is increased to 100 parts per million. The results are generally comparable to those obtained in Example I and the resulting nonwoven textile fabric is generally similar to the nonwoven textile fabric of Example I.

Example IX

The procedures of Example I are followed substantially as set forth therein with the exception that 60 parts per million of "Polyox" FRA is used as the dispersing agent. The results are generally comparable to those obtained in Example I and the resulting nonwoven textile fabric is generally similar to the nonwoven textile fabric in Example I.

Example X

The procedures of Example I are followed substantially as set forth therein with the exception that 25 parts per million of "Cytame 5" is used as the dispersing aid. The results are generally comparable to those obtained in Example I and the resulting nonwoven textile fabric is generally similar to the nonwoven textile fabric obtained in Example I.

Example XI

The procedures of Example I are followed substantially as set forth therein with the exception that 250 parts per million of acid swollen fibrillar collagen is used as the dispersion aid. The results are generally comparable to those obtained in Example I and the resulting nonwoven textile fabric is generally similar to the nonwoven textile fabric of Example I.

As used herein, the terms "two primary directions of predominant fiber orientation" or "two major axes" or like terms does not mean that every fiber in the fibrous structure is aligned in either of the two directions. There will be fibers which are basically aligned in other directions. However, the preponderance of the fibers is aligned in the two directions and other fibers are definitely of a secondary or minor nature.

Although several specific examples of the inventive concept have been described, the same should not be construed as limited thereby nor to the specific features mentioned therein but to include various other equivalent features as set forth in the claims appended hereto. It is understood that any suitable changes, modifications and variations may be made without departing from the spirit and scope of the invention.

What is claimed is:

1. A foraminous, wet-formed fibrous structure of use in the manufacture of a nonwoven textile fabric comprising relatively straight, synthetic fibers having an average length of from about ⅜ inch to about 1½ inches or more, said fibrous structure having a major axis of predominant fiber orientation directed at an angle to the long direction of said fibrous structure, said fibrous structure comprising bundles of fibers aligned generally in the direction of the major axis of predominant fiber orientation, said bundles including fibers disposed in a generally linear, substantially parallel relationship, said bundles being interconnected by branched portions of fibers common to a plurality of bundles, none of said branched portions forming an angle greater than 35° to the major axis of predominant fiber orientation, with said bundles having diameters of from about 0.04 mm. to about 1 mm. and extending angularly generally from one side of the fibrous structure to the other side thereof and containing from about 3 to about 200 or more fibers in each bundle and being spaced apart a distance of from about 0.2 mm. to about 1.5 mm., on an approximate center-to-center basis.

2. A foraminous, wet-formed fibrous structure as defined in claim **1** wherein the major axis of predominant fiber orientation is directed at an angle of 45° to the long direction of the fibrous structure.

3. A foraminous, wet-formed fibrous structure as defined in claim **1** wherein the major axis of predominant fiber orientation is directed at an angle of 60° to the long direction of the fibrous structure.

4. A foraminous, wet-formed fibrous structure according to claim **1** wherein said bundles of fibers are also linked by fibers disposed at an angle of about 60° or more to the major axis of predominant fiber orientation.

5. A foraminous, wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity and good opacity and covering power comprising relatively straight, synthetic textile fibers having an average length of from about ⅜ inch to about 1½ inches or more, said nonwoven textile fabric having two major axes of predominant fiber orientation directed at angles to each other and mirror-imaged with respect to the long direction of said nonwoven textile fabric, said fibrous structure comprising bundles of fibers, said bundles including fibers disposed in a generally linear, substantially parallel relationship, said bundles being interconnected by branched portions of fibers common to a plurality of bundles, none of said branched portions forming an angle greater than 35° to a major axis of predominant fiber orientation, some of said bundles being aligned generally in the direction of one of the major axes of predominant fiber orientation and other of said bundles being aligned generally in the direction of the other of the major axes of predominant fiber orientation, with said bundles having diameters of from about 0.04 mm. to about 1 mm. and extending angularly generally from one side of the nonwoven textile fabric to the other side thereof and containing from about 3 to about 200 or more fibers in each bundle and being spaced apart a distance of from about 0.2 mm. to about 1.5 mm., on an approximate center-to-center basis, said nonwoven textile fabric also possessing at least about 600 randomly distributed pores per square inch, the diameters of at least about 96% of said pores being less than 0.016 inch.

6. A foraminous, wet-formed nonwoven textile fabric as defined in claim **5** wherein the major axes of predominant fiber orientation are directed at an angle of plus 45° and minus 45° to the long direction of the nonwoven textile fabric.

7. A foraminous, wet-formed nonwoven textile fabric as defined in claim **5** wherein the major axes of predominant fiber orientation are directed at an angle of plus 60° and minus 60° to the long direction of the nonwoven textile fabric.

8. A method of making a foraminous, wet-formed fibrous structure of use in the manufacture of a nonwoven textile fabric comprising:

forming an aqueous slurry comprising relatively straight, synthetic fibers having an average length of from about ⅜ inch to about 1½ inches;

causing said aqueous slurry to flow at a predetermined velocity in a thin, flat, sheet-like planar configuration; and

angularly discharging said aqueous slurry of fibers having a thin, flat, sheet-like planar configuration upon a moving forming surface having a predetermined velocity and forming a fibrous structure thereon wherein the individual fibers have a predominant orientation directed angularly with respect to the direction of movement of said forming surface, said angular direction of predominant fiber orientation being affected by the velocity of said aqueous slurry, the angle of discharge of the aqueous slurry on the moving forming surface, and the velocity of the moving forming surface.

9. A method as defined in claim **8** wherein the predetermined velocity of the aqueous slurry is in the range of from about 20 feet per minute to about 260 feet per minute.

10. A method as defined in claim **8** wherein the angle of the angular discharge of the aqueous slurry is in the range of from about 10° to about 130°.

11. A method as defined in claim **8** wherein the velocity of the moving forming surface upon which the aqueous slurry is deposited is in the range of from about 20 feet per minute to about 260 feet per minute.

12. A method as defined in claim **8** wherein the predetermined velocity of the aqueous slurry is in the range of from about 20 feet per minute to about 65 feet per minute, the angle of the angular discharge of the aqueous slurry is in the range of from about 10° to about 80°, and the velocity of the moving forming surface upon which the aqueous slurry is deposited is in the range of from about 20 feet per minute to about 80 feet per minute.

13. A method as defined in claim **8** wherein the predetermined velocity of the aqueous slurry is in the range of from about 65 feet per minute to about 260 feet per minute, the angle of the angular discharge of the aqueous slurry is in the range of from about 80° to about 130°, and the velocity of the moving forming surface upon which the aqueous slurry is deposited is in the range of from about 80 feet per minute to about 260 feet per minute.

14. A method of making a wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity and good opacity and covering power comprising:

forming a first and second aqueous slurry comprising relatively straight, synthetic fibers having an average length of from about ⅜ inch to about 1½ inches;

causing each said aqueous slurry to flow at a predetermined velocity in a thin, flat, sheet-like planar configuration;

angularly discharging said first aqueous slurry of fibers having a thin, flat, sheet-like planar configuration upon a moving forming surface having a predetermined velocity and forming a loosely-assembled fibrous structure thereon wherein the individual fibers have a predominant orientation directed angularly with respect to the direction of movement of said forming surface, said angular direction of predominant fiber orientation being affected by the velocity of said first aqueous slurry, the angle of discharge of the aqueous slurry on the moving forming surface, and the velocity of the moving forming surface; and

angularly discharging, said second aqueous slurry of relatively straight fibers also having a thin, flat, sheet-like planar configuration and a predetermined velocity upon said loosely-assembled fibrous structure, said second angle of discharge being equal to but oppositely directed in mirror image fashion to the first angle of discharge with respect to the long direction of said forming surface, and said second slurry velocity and forming surface velocity being equal to said first slurry velocity and forming surface velocity respectively, whereby the second aqueous fiber slurry forms a second loosely-assembled fibrous structure wherein the fibers have a predominant orientation which is oppositely-directed and in mirror-image relationship to the first predominant fiber orientation with respect to the long direction of said forming surface, said second loosely-assembled fibrous structure intermingling and interentangling with said first loosely-assembled fibrous structure whereby there is made a wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity and good opacity and covering power.

15. A method as defined in claim **14** wherein said predetermined velocities of the first and second aqueous slurries is in the range of from about 20 feet per minute to about 260 feet per minute.

16. A method as defined in claim **14** wherein the angle of the angular discharge of the first aqueous slurry is in the range of from about 10° to about 130°.

17. A method as defined in claim **14** wherein the velocity of the moving forming surface upon which the aqueous slurries are deposited is in the range of from about 20 feet per minute to about 260 feet per minute.

18. A method as defined in claim **14** wherein the predetermined velocities of the first and second aqueous slurries are in the range of from about 20 feet per minute to about 65 feet per minute, the angle of the angular discharge of the first aqueous slurry is in the range of from about 10° to about 80°, and the velocity of the moving forming surface upon which the aqueous slurries are deposited is in the range of from about 20 feet per minute to about 80 feet per minute.

19. A method as defined in claim 14 wherein the predetermined velocities of the aqueous slurries are in the range of from about 65 feet per minute to about 260 feet per minute, the angle of the angular discharge of the first aqueous slurry is in the range of from about 80° to about 130°, and the velocity of the moving forming surface upon which the aqueous slurries are deposited is in the range of from about 80 feet per minute to about 260 feet per minute.

20. Apparatus for making a foraminous, wet-formed fibrous structure of use in the manufacture of a nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity and good opacity and covering power comprising:

means for forming an aqueous slurry comprising relatively straight, synthetic fibers having an average length of from about ⅜ inch to about 1½ inches;

means for causing said aqueous slurry to flow at a predetermined velocity in a thin, flat, sheet-like planar configuration and for angularly discharging said aqueous slurry of fibers having a thin, flat, sheet-like plan configuration upon a moving forming surface having a predetermined velocity and forming a fibrous structure thereon wherein the individual fibers have a predominant orientation directed angularly with respect to the direction of movement of said forming surface, said angular direction of predominant fiber orientation being affected by the velocity of said aqueous slurry, the angle of discharge of the aqueous slurry on the moving forming surface, and the velocity of the moving forming surface, and means for angularly adjusting said means for causing said aqueous slurry to flow and for angularly discharging said aqueous slurry.

21. Apparatus for making a foraminous, wet-formed fibrous structure as defined in claim **20** wherein the means for causing said aqueous slurry to flow and for angularly discharging said aqueous slurry is a relatively flat, shallow delivery tray.

22. Apparatus for making a foraminous, wet-formed fibrous structure as defined in claim **21** wherein the ratio of the width to the depth of the relatively flat, shallow delivery tray is in the range of from about 20 to 1 to about 1000 to 1.

23. Apparatus for making a wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predeterminded desired properties in the long and cross directions, uniformity and good opacity and covering power comprising:

means for forming a first and second aqueous slurry comprising relatively straight, synthetic fibers having an average length of from about ⅜ inch to about 1½ inches;

means for causing said first aqueous slurry to flow at a predetermined velocity in a thin, flat, sheet-like planar configuration and for angularly discharging said first aqueous slurry of fibers having a thin, flat, sheet-like planar configuration upon a moving forming surface having a predetermined velocity and forming a loosely-assembled fibrous structure thereon wherein the individual fibers have a predominant orientation directed angularly with respect to the direction of movement of said forming surface, said angular direction of predominant fiber orientation being affected by the velocity of said first aqueous slurry, the angle of discharge of the first aqueous slurry on the moving forming surface, and the velocity of the moving forming surface, means for angularly adjusting said means for causing said first aqueous slurry to flow and for angularly discharging said first aqueous slurry;

means for angularly discharging a second aqueous slurry of relatively straight fibers also having a thin, flat, sheet-like planar configuration and a predetermined velocity upon said loosely-assembled fibrous structure, said second angle of discharge being equal to but oppositely directed in mirror-image fashion to the first angle of discharge with respect to the long direction of said forming surface, means for angularly adjusting said means for angularly discharging a second aqueous slurry, and said second slurry velocity and forming surface velocity being equal to said first slurry velocity and forming surface velocity respectively, whereby the second aqueous fiber slurry forms a second loosely-assembled fibrous structure wherein the fibers have a predominant orientation which is oppositely-directed and in mirror-image relationship to the first predominant fiber orientation with respect to the long direction of said forming surface, said second loosely-assembled fibrous structure intermingling and interentangling with said first loosely-assembled fibrous structure whereby there is made a wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity and good opacity and covering power.

24. Apparatus for making a foraminous, wet-formed fibrous structure of use in the manufacture of a nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity and good opacity and covering power comprising:

means for forming an aqueous slurry comprising relatively straight, synthetic fibers having an average length of from about ⅜ inch to about 1½ inches;

means for causing said aqueous slurry to flow at a predetermined velocity in a thin, flat, sheet-like planar configuration and for angularly discharging said aqueous slurry of fibers having a thin, flat, sheet-like planar configuration upon a moving forming surface having a predetermined velocity and forming a fibrous structure thereon wherein the individual fibers have a predominant orientation directed angularly with respect to the direction of movement of said forming surface, said means for causing said aqueous slurry to flow and for angularly discharging said aqueous slurry being positioned at an angle with respect to the direction of movement of said forming surface, said angular direction of predominant fiber orientation being affected by the velocity of said aqueous slurry, the angle of discharge of the aqueous slurry on the moving forming surface, and the velocity of the moving forming surface, and means for angularly adjusting said means for causing said aqueous slurry to flow and for angularly discharging said aqueous slurry.

25. Apparatus for making a foraminous, wet-formed fibrous structure as defined in claim **24** wherein said angle is from about 10 degrees to about 130 degrees.

26. A method of making a foraminous, wet-formed fibrous structure of use in the manufacture of a nonwoven textile fabric comprising:

forming an aqueous slurry comprising relatively straight, synthetic fibers having an average length of from about ⅜ inch to about 1½ inches;

causing said aqueous slurry to flow at a predetermined velocity in a thin, flat, sheet-like planar configuration, the fibers comprising the slurry being aligned in the direction of flow; and

angularly discharging said aqueous slurry having a thin, flat, sheet-like planar configuration and having the fibers thereof aligned in the direction of discharge upon a moving forming surface having a predetermined velocity and forming a fibrous structure thereon wherein the individual fibers have a predominant orientation directed angularly with respect to the direction of movement of said forming surface, said angular direction of predominant fiber orientation being affected by the velocity of said aqueous slurry, the angle of discharge of the aqueous slurry on the moving forming surface, and the velocity of the moving forming surface.

27. A method of making a wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross directions, uniformity and good opacity and covering power comprising:

forming a first and second aqueous slurry comprising relatively straight, synthetic fibers having an average length of from about ⅜ inch to about 1½ inches;

causing said first and second aqueous slurries to flow at a predetermined velocity in a thin, flat, sheet-like planar configuration, the fibers comprising said slurries being aligned in the direction of flow; and

angularly discharging said first aqueous slurry having a thin, flat, sheet-like planar configuration and having the fibers thereof aligned in the direction of discharge upon a moving forming surface having a predetermined velocity and forming a loosely-assembled fibrous structure thereon wherein the individual fibers have a predominant orientation directed angularly with respect to the direction of movement of said forming surface, said angular direction of predominant fiber orientation being affected by the velocity of said aqueous slurry, the angle of discharge of the aqueous slurry on the moving forming surface, and the velocity of the moving forming surface; and

angularly discharging said second aqueous slurry of relatively stright fibers upon said loosely-assembled fibrous structure, said second slurry also having a thin, flat, sheet-like planar configuration and having the fibers thereof aligned in the direction of discharge, said second angle of discharge being equal to but oppositely directed in mirror image fashion to the first angle of discharge with respect to the long direction of said forming surface, and said second slurry velocity and forming surface velocity being equal to said first slurry velocity and forming surface velocity respectively, whereby the second aqueous fiber slurry forms a second loosely-assembled fibrous structure wherein the fibers have a predominant orientation which is oppositely-directed and in mirror-image relationship to the first predominant fiber orientation with respect to thte long direction of said forming surface, said second loosely-assembled fibrous structure intermingling and interentangling with said first loosely-assembled fibrous structure whereby there is made a wet-formed nonwoven textile fabric having a unitary structure, balanced construction, predetermined desired properties in the long and cross direction, uniformity and good opacity and covering power.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,808,094 Dated April 30, 1974

Inventor(s) James T. McKnight

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Column 2, line 38, "or" should read --"of" --.

In Column 3, line 48, "second slurry" should read -- "second aqueous slurry" --.

In Column 6, line 67, "maetrials" should read '' "materials --.

In Column 9, line 5, "swirling eddying" should read -- "swirling and eddying" --.

In Column 10, line 37, "intergmingling" should read -- "intermingling" --.

In Column 10, line 55, "uniformly" should read -- "uniformity"--.

In Column 12, line 33, "Thse" should read -- "These" --.

In Column 14, line 6, "curative" should read -- "curvature"--.

In Column 20, line 43, "plan" should read --"planar" --.

In Column 21, line 18, the last words in the line should be -- "slurry"; and --.

In Column 22, line 53, "stright" should read -- "straight" --.

In Column 22, line 69, "thte" should read --"the" --.

Signed and sealed this 29th day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
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Commissioner of Patents