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Zafiroglu

[11] **3,797,074**

[45] **Mar. 19, 1974**

[54] **AIR-LAYING PROCESS FOR FORMING A WEB OF TEXTILE FIBERS**

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[22] Filed: **Jan. 11, 1973**

[21] Appl. No.: **322,757**

Related U.S. Application Data

[63] Continuation-in-part of Ser. Nos. 241,924, April 7, 1972, and Ser. No. 135,735, April 20, 1971, said Ser. No. 241,924, is a continuation-in-part of Ser. No. 135,734, April 20, 1971, abandoned.

[52] **U.S. Cl.** **19/156.3**
[51] **Int. Cl.** **D01g 25/00**
[58] **Field of Search** 19/155–156.4

[56] **References Cited**

UNITED STATES PATENTS

2,676,363	4/1954	Plummer et al.	19/156.4
3,037,248	6/1962	Callaghan	19/156.4

Primary Examiner—Dorsey Newton

[57] **ABSTRACT**

A process is disclosed for high speed production of uniform webs by air-laydown of textile fibers. A feed batt of staple fibers is fed to a toothed disperser roll that projects the fibers at high velocity and low angle into an airstream of high uniform velocity and low turbulence to form a thin fiber stream from which the fibers are subsequently separated in the form of a web. The webs are suitable for producing high quality nonwoven fabrics by known fiber-interlocking or bonding treatments.

9 Claims, 7 Drawing Figures

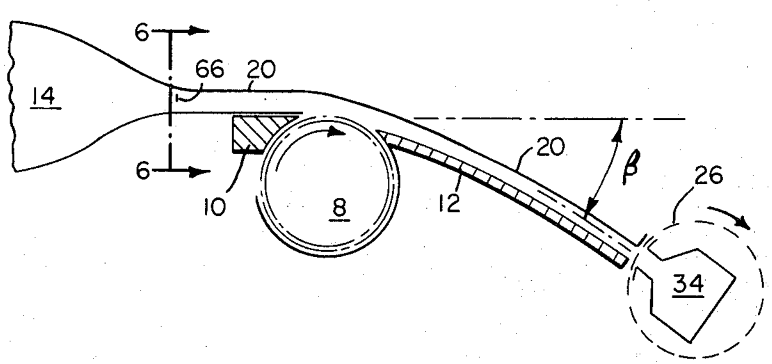

FIG. 6

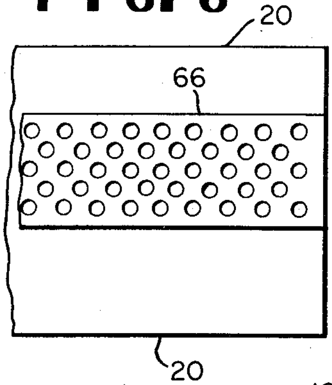

FIG. 1

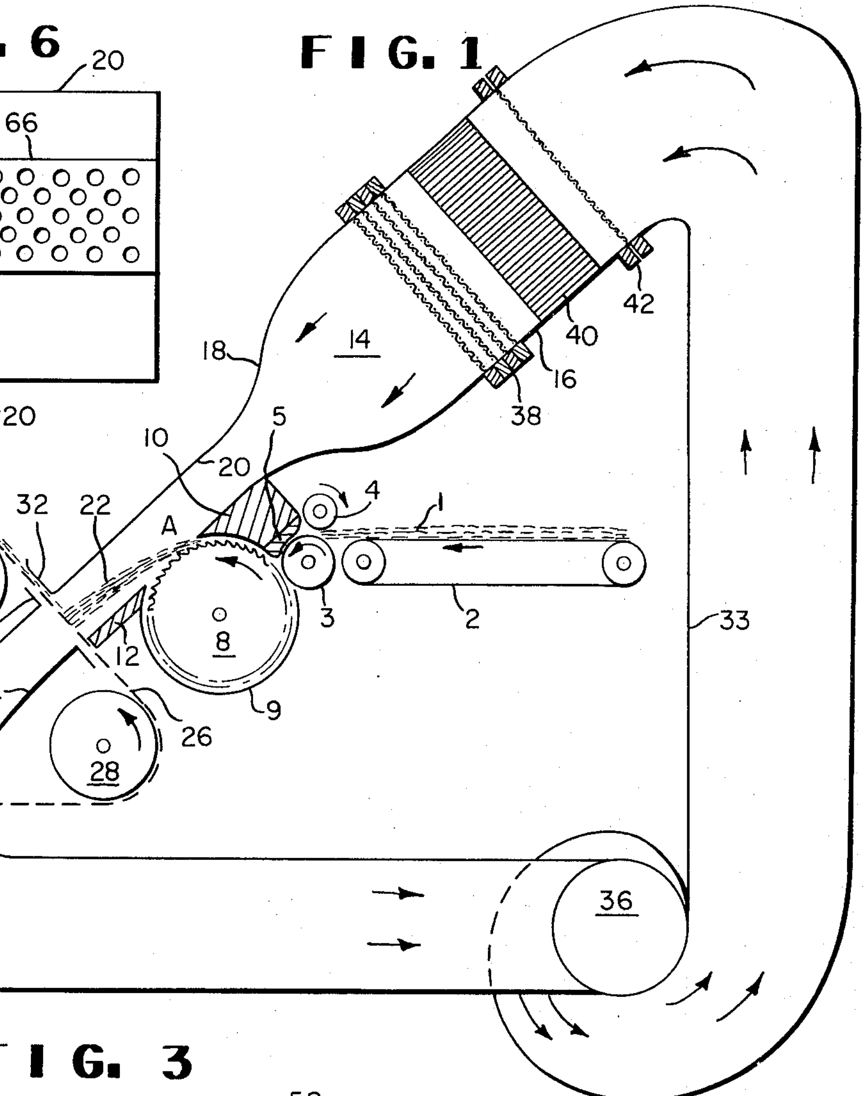

FIG. 3

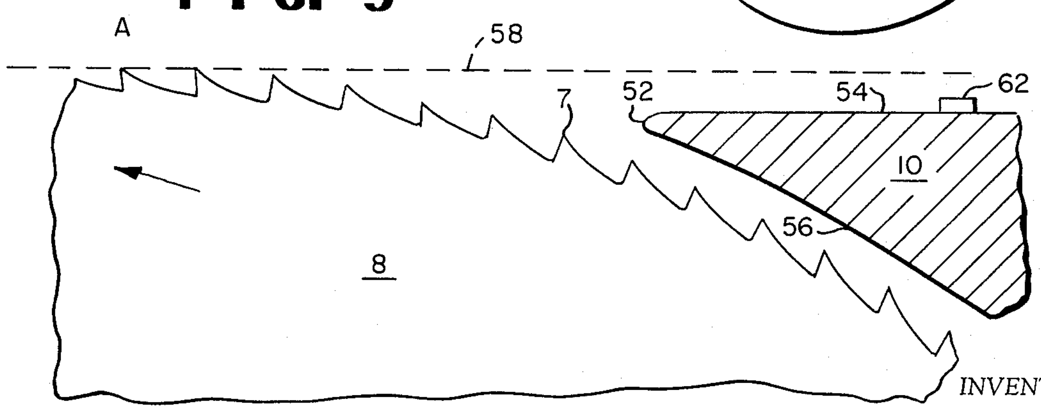

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FIG. 2

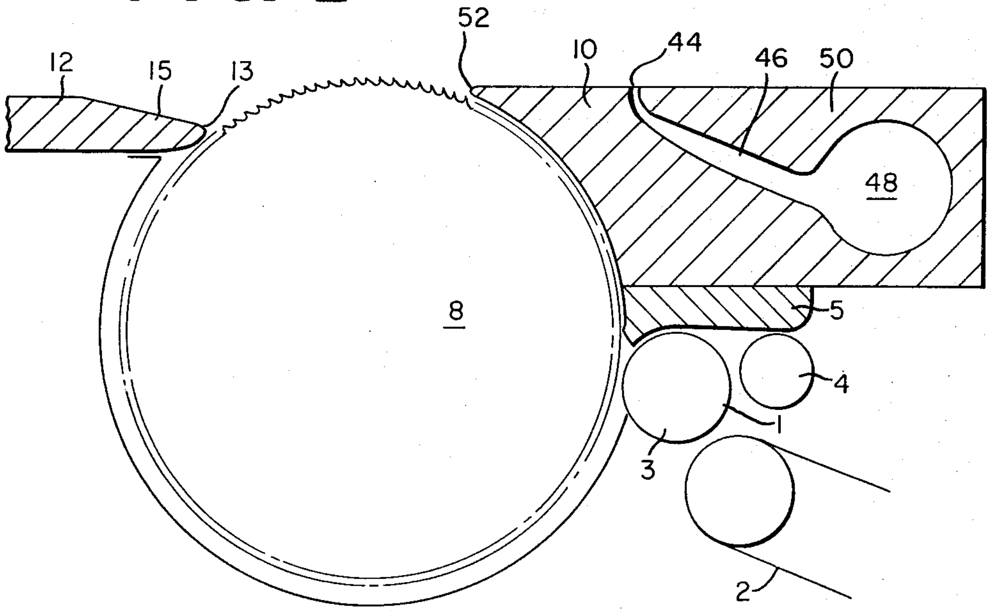

FIG. 4

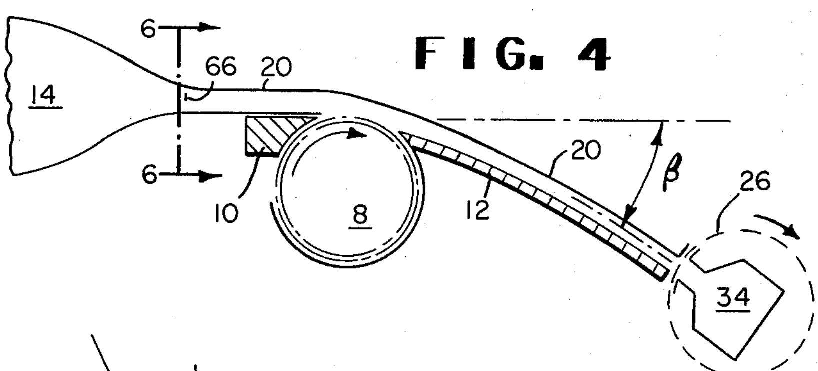

FIG. 5

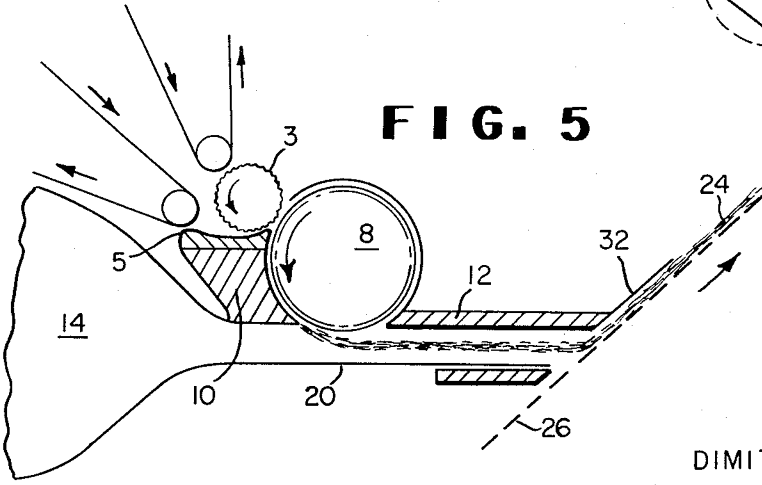

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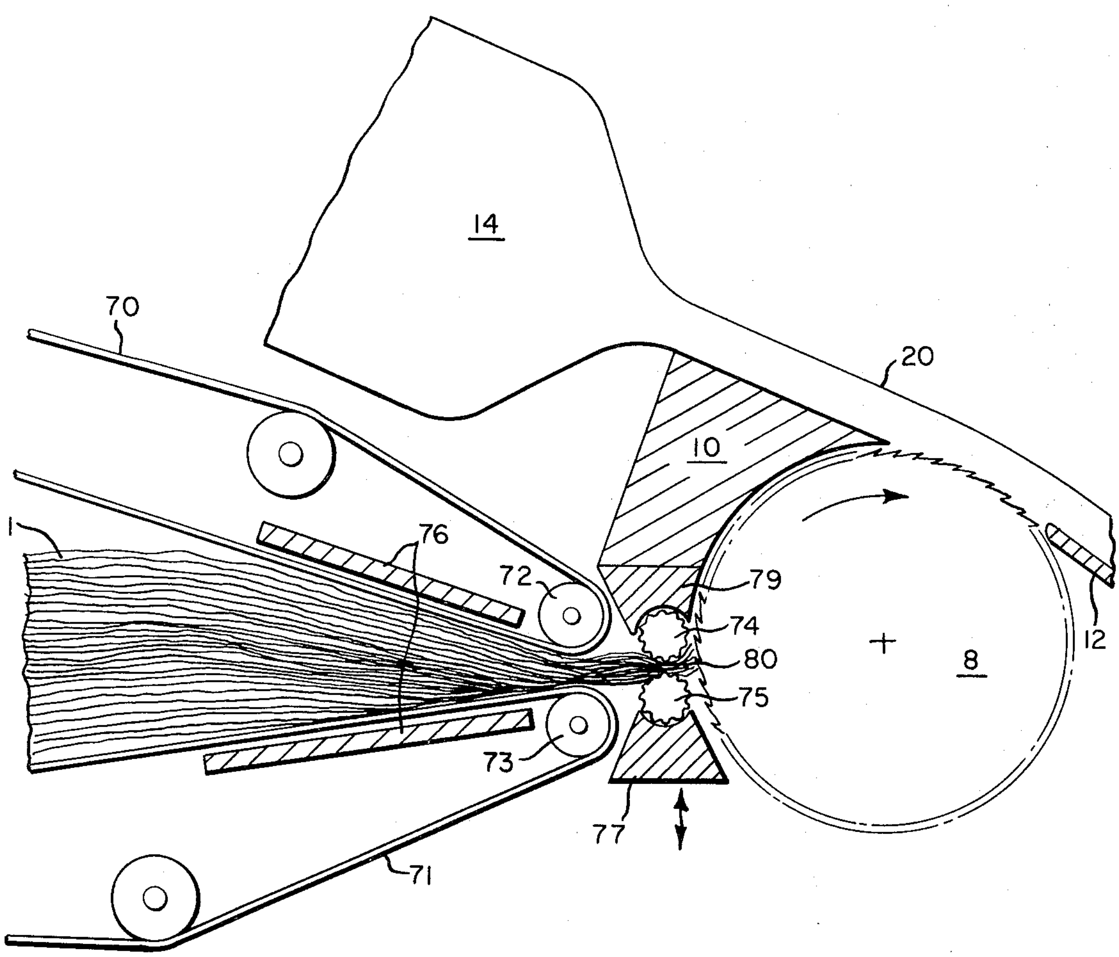
FIG. 7



AIR-LAYING PROCESS FOR FORMING A WEB OF TEXTILE FIBERS

REFERENCE TO RELATED APPLICATIONS

This is a continuation-in-part of my copending applications Ser. No. 241,924, filed Apr. 7, 1972, and Ser. No. 135,735, filed Apr. 20, 1971. Ser. No. 241,924 is a continuation-in-part of application Ser. No. 135,734, filed Apr. 20, 1971. Ser. No. 135,734 was abandoned after filing Ser. No. 241,924.

BACKGROUND OF THE INVENTION

This invention relates to an air-laydown process and for assembling textile fibers into webs, and is more particularly concerned with improvements in dispersing and transporting textile fibers in an air stream for collection on a moving screen to form webs which are suitable for use in producing high quality nonwoven fabric.

Nonwoven fabrics are produced from fibrous webs by bonding or interlocking the fibers to provide durability and strength. The fibers of the web may be hydraulically entangled by treatment with high energy liquid streams as disclosed in Evans U.S. Pat. No. 3,485,706, issued Dec. 23, 1969. When producing relatively heavy weight textile fabric Lauterbach U.S. Pat. No. 2,910,763, issued Nov. 3, 1959, discloses that fiber interlocking may be initiated by treatment with a needle loom and completed by crimping or shrinking the fibers. Production of bonded nonwoven fabrics may be accomplished as disclosed in Graham U.S. Pat. No. 2,765,247, issued Oct. 2, 1956. The quality of fabric produced by these methods depends upon the quality and uniformity of the web which is treated.

Webs suitable for producing high quality nonwoven fabrics, by treatments of the above type, can be prepared by air laydown of textile fibers. Prior art air-laydown processes and apparatus are illustrated by Buresh U.S. Pat. No. 2,451,915 issued Oct. 19, 1948, Plummer et al. U.S. Pat. No. 2,676,363 issued Apr. 27, 1954, and Simison U.S. Pat. No. 3,381,069 issued Apr. 30, 1968. Staple fibers are shipped as a compacted mass. Conventional picking and carding operations are used to separate the fibers. The resulting loosely opened fiber lap is fed to a toothed disperser roll and a stream of air is sucked or blown over the roll. The roll is rotated at high speed to feed the fibers into the air stream, the objective being to feed individual fibers rather than clumps or groups of fibers. The fibers are carried by the air stream as a spreading cloud through a conduit to the screen surface of a condenser roll or conveyor, where the fibers are deposited over a relatively large surface area to form a layer on the moving screen. The Plummer et al. patent discusses the importance of air turbulence for providing a generally uniform distribution of fibers over relatively large areas throughout the conduit. Turbulence is introduced in the air supply by changing the direction of air flow adjacent to the disperser roll, by providing a restricted air passage past the roll into an expanded duct, and by irregularities in the duct leading to the condenser roll.

A commercial embodiment of such prior art layer-forming apparatus is shown in FIGS. 38 and 40 of Evans U.S. Pat. No. 3,485,706. As stated at column 20, line 65, "The layer-forming apparatus processes a given weight of material at a relatively slow rate, whereas the jet-treating apparatus is capable of high speed operation." Non-blotchy, uniform webs weighing about 1 ounce per square yard (oz./yd.^{2}) have been produced at a maximum rate of about 18 feet per minute (ft./min.), or about 0.63 pounds per inch of disperser-roll width per hour (lb/in. hr.), when using such layer-forming apparatus. Production of high quality webs at significantly higher speed does not appear to be possible unless basic modifications are made in this layer-forming apparatus.

SUMMARY OF THE INVENTION

The present invention provides an air-laydown process and suitable for high speed production of uniform webs of excellent quality from feed batts of staple fibers. The new air-laydown process makes possible the production of such webs at rates in excess of 3 pounds per inch of web width during each hour of operation, even when lightweight webs of 0.5 to 2 oz/yd.^{2} are produced from fine, long staple fibers (e.g., 1.25 denier, 1½-inch long fibers). Highly uniform webs weighing 4 to 10 oz./yd.^{2} or more can be produced at rates of over 10 lbs./in. hr. and, in some cases, at rates above 15 to 20 lbs./in.hr. The invention provides webs of high quality when evaluated for blotchiness (i.e., small nonuniformities which may be formed, for example, by depositing clumps of fibers), streakiness (i.e., lines of different fiber density which may be caused, for example, by local variations in air stream velocity), and other visible defects. The invention also provides efficient air-laydown apparatus for producing the high quality webs. Other advantages will become apparent from the disclosure and claims.

The present invention is an improvement in processes for forming webs of textile fibers by dispersing staple fibers in a flow of air and then collecting the fibers on a moving screen to form a random fiber web. In accordance with this improvement staple fibers are projected at a uniform initial velocity of at least 3,000 ft./minute (preferably 10,000 to 20,000 ft./min.) at an angle of less than 25° (preferably less than 12°) into a controlled flow of air to form a thin stream of fibers. The flow of air is controlled so that the fibers are projected into a region of stable flow characterized, immediately upstream of the fiber stream by (a) an average velocity (V) between 0.5 and 3.5 times (preferably 0.5 to 1.2 times) the initial fiber velocity, (b) an average velocity in each 0.1-inch thick layer across the thickness of the region that varies by less than about ±15 percent from the overall average velocity (V), excluding the first 0.1-inch layer next to any wall, (c) a velocity variation across the width of the region of less than about ±10 percent in any one foot increment, and (d) an average turbulence intensity of no more than 15 percent (preferably less than 7 percent). The flow of air is also controlled to transport the fibers to collecting screen as a thin fiber stream in a region of stable flow characterized by (e) an average air velocity between 0.25 and 3 times (preferably 0.4 to 1.2 times) said average air velocity (V), and (f) an average turbulence intensity of no more than 15 percent (preferably less than 7 percent). The fibers are then separated from the flow of air to form a uniform web on the moving screen.

The fibers are preferably projected at a rate of 3 to 20 pounds per inch of stream width during each hour of operation, although the process is also suitable for slow speed operation. The weight rate of air flow is usually at least 25 times the weight rate at which the fibers are projected into the flow of air. The conditions are controlled to provide a thin fiber stream which is less than ¼-inch thick, as initially formed, and is preferably less than ⅛-inch thick. The thickness of the fiber stream increases somewhat thereafter, and high quality webs are obtained when the fiber stream is about ½ to 1 inch thick as it nears the web-forming screen.

GENERAL DESCRIPTION

The fibers are preferably centrifugally doffed from a toothed disperser roll rotating at a surface speed of at least 3,000 ft./min. Supply means feeds a substantially uniform layer of fibers onto the rotating disperser roll and a closely spaced, curved disperser plate holds the fibers close to the roll until a fiber-doffing position is reached at the tip of the disperser plate. At this location the stream of fibers is projected by tangential ejection from the disperser roll through an opening into duct means for supporting the fibers in air. The roll is mounted outside of and adjacent to the wall of the duct means so that a small surface arc of the roll is exposed within the duct and fills the opening without appreciably reducing the cross-sectional area defined by the duct walls.

Air supply means directs a uniform velocity, stable, low turbulence, low vorticity flow of air through the duct in the direction of movement of the roll surface so that the fibers are projected into the stream at an angle of less than about 25° and preferably less than 12° This projection angle is measured between the line tangent to the disperser roll at the point adjacent to the tip of the disperser plate and a line which coincides with the general direction of air flow through the duct. Boundary layer control means may be incorporated in the duct upstream of the exposed roll surface to provide a controlled, low level of turbulence in the air layer through which the fibers must uniformly project to reach the region of the air stream which has uniform flow of low turbulence and low vorticity. The duct configuration downstream of the disperser roll is contoured to prevent boundary layer separation and its attendant formation of vortices and eddies; generally sudden changes in duct cross-section or direction are avoided. Condenser means separates the fibers from the air to form webs weighing from about 0.1 to 10 oz./yd.^{2}.

A conventional type of toothed disperser roll is suitable for projecting the fibers into the uniform flow of air. The curved surface of a disperser plate is arranged at a small distance from the revolving surface of the roll to provide a narrow passage where the fibers are carried to the point of projection into the duct. The spacing between the stationary disperser plate and the tips of the disperser roll teeth, from the point where the fibers are picked up by the teeth to the point where they are projected into the air stream, should be less than ⅛ inch. The disperser roll teeth are usually shorter than ¼ inch, preferably about ⅛ inch. To the extent that the fibers penetrate between the teeth, the fiber stream projected into the air stream will be thicker than the clearance between the ends of the teeth and the disperser plate. Preferably that clearance will be 0.010 to 0.030 inch. The disperser roll has a surface speed of from 3,000 ft./min. to a maximum limited by speeds which damage the fibers or cause excessive vibration; preferably the surface speed is about 10,000 to 20,000 ft./min. The roll diameter should not be excessive, since the fibers are projected tangentially only a short distance before losing momentum, but a diameter of at least 16 inches may be required to reduce vibration on a wide machine. Preferably the portion of the disperser plate facing the roll has a low-friction surface to facilitate projection of the fibers.

The duct means for conveying fibers provides a conduit through which a uniform velocity, low turbulence stream of air is passed adjacent to the exposed surface of the disperser roll and on to the fiber condenser means. The duct configuration is such that substantially all of the fibers projected from the disperser roll are supported in the flow as a thin fiber stream (e.g., of less than ¼-inch initial thickness, and preferably less than ⅛-inch initial thickness) which is essentially kept away from layers of high turbulence, non-uniform flow, or separated flow. For economical operation the cross-section of the duct should be the minimum necessary for carrying out the process.

Preferably, the duct has a substantially rectangular cross section. The cross-sectional area may increase or decrease as the duct approaches the condenser means, provided that the changes in cross-section do not disturb the fiber stream. The adverse effects of boundary layer separation in a too-rapidly-diverging duct (e.g., a diffuser in which the walls diverge at more than a 30° angle) are avoided. Channel curvature through the duct should be kept to a minimum, but a slight curvature can help maintain the fiber stream centered in the duct. The length of the duct means should be sufficient to provide room for the various apparatus components.

The upstream side of the duct means is connected to conventional air supply means, such as is used in wind tunnels, for providing an air flow of low turbulence intensity and minimized eddy size. The required air supply can be furnished by fans blowing air into a highly uniform passage provided with flow distribution devices, such as vanes, perforated plates, honeycomb sections, and turbulence reduction screens, which also act as eddy eliminators. Typically, the air is forced through a multicell structure having uniform cells of regular cross-section. Each cell has diagonals of about ½-inch maximum length (preferably ⅛-inch, a maximum wall thickness of 1/16-inch (preferably 0.010 inch) and a cell length of at least 25 cell widths. Other equivalent vortex elimination systems are known in the art. The air passage will normally be the same width as the duct into which the fibers are projected and several times greater in the other cross-sectional dimension. Thus, the air velocity in the larger air passage in which the screens, honeycombs and perforated plates are located is much less than the air velocity in the relatively small duct means. The transition between the large air passage and the small duct means is gradually curved in accordance with good flow nozzle design to accelerate the air flow of low turbulence and substantially uniform velocity is supplied from the nozzle to the duct means.

Of key importance to this invention is the condition of the flow immediately upstream of the opening in the duct means through which the fibers are projected. The portion of the air stream which advances into the fiber path is carefully controlled. The air velocity in this region is uniform across the thickness of the region as well as across increments of width of the region. Across the thickness of the region, the velocity in each 0.1-inch-thick layer (excluding the first 0.1-inch thickness next to the wall) is within ±15 percent, and preferably within ±10 percent, of the average velocity in the region, and is designated hereinafter as ΔV/V. Values of ΔV/V in excess of ±15 percent result in excessive mixing among the layers which leads to eddies which disturb and expand the fiber stream. This causes the loss of fiber stream thickness and trajectory control leading to blotchiness in the web product. The velocity variation within any one foot increment across the width of the region of the air flow that advances into the fiber stream is less than ±10 percent, and preferably less than ±5 percent, and is designated hereinafter as ΔV/W. Values of ΔV/W in excess of ±10 percent result in eddies which deleteriously affect the fiber stream thickness and trajectory, thus leading to blotchiness in the web product. The average turbulence intensity (i.e., the standard deviation of velocity variation with time) in the region is less than 15 percent, preferably less than 7 percent. These numerical values refer only to the portion of the air stream which advances into the fiber path, and exclude the boundary layer portion within 0.1 inch of the wall. Average turbulence intensities of greater than 15 percent in this region (as well as in the subsequent path of fiber flow) or large eddies, as indicated by large velocity variations and unstable local turbulence intensities, prevent formation of a thin fiber stream, cause the fibers to disperse as an expanding cloud, and result in excessive blotchiness in the web product. The air passing through the duct means outside the region which advances into the path of fiber flow need not be limited in turbulence intensity or velocity distribution, so long as its influence on the air stream conveying the fibers to the condenser is such that the average turbulence intensity at any cross-section of the fiber path from the disperser to the condenser is less than 15 percent and preferably less than 7 percent. Turbulence intensities in excess of 15 percent in this portion of the fiber path also result in excessive blotchiness in the web product.

It is recognized that turbulence is produced by fluid friction with the walls of the duct. This can be confined by a boundary layer next to the walls by use of smooth, streamlined duct walls and by supplying the air flow to the duct in a proper condition, as described in the preceding paragraphs. The duct is also arranged to keep the fiber stream essentially centered in the low turbulence, uniform flow region, so that boundary layer turbulence will not disturb the fibers after the thin stream of fibers is formed. However, the fibers must be projected through the boundary layer turbulence on the disperser roll side of the duct. Thus, gross nonuniformities in that boundary layer should be avoided. A serious nonuniformity problem may be caused by a phenomenon of streamwise vorticity (i.e., small corkscrew-type vortices with high energy). These vortices can be detected by scanning the flow with a hot wire anemometer across a line perpendicular to the side walls of the duct in the plane of the flow cross section. A vortex shows as a local increase in turbulence intensity and a corresponding decrease in local air velocity. Fibers projected through such vortices are deflected from their intended paths. This results in nonuniform distribution of fiber in the airstream, which in turn produces streaks in the web product. A suction slot can be used to remove the turbulent boundary layer upstream of the disperser roll. To be effective, the slot is located in the wall close to the disperser roll. Vortices may also develop in a laminar-to-turbulent flow transition zone in the boundary layer that develops in the duct means shortly downstream of the location where the air enters the duct from the curved flow nozzle or in the newly developing boundary layer downstream of a suction slot. It has been found that web streaks due to these vortices can be eliminated when a very thin obstruction (frequently called a "boundary layer trip"), such as a strip of sandpaper or a smooth round wire of about 18 gauge (about 0.04 inch in diameter), is extended across the duct wall, in the boundary layer, just upstream of the laminar-to-turbulent transition zone. The transition to turbulence is then uniformly accelerated to form a uniform, stable, turbulent boundary layer which is penetrated uniformly by the fibers. The turbulence added by these obstructions is usually small and in general does not add significantly to stream mixing over the disperser roll or to the blotchiness of the final web. A combination of a suction slot to remove the boundary layer followed by a very fine wire boundary layer trip to prevent nonuniform redevelopment of the boundary layer, is preferred in cases where the slot cannot be placed sufficiently close to the disperser roll, because of space limitations.

Large random eddies, arising from lack of proper preparation of the air flow to the duct means, can also cause the fibers to disperse uncontrollably as a cloud rather than as a thin stream, as soon as the fibers leave the disperser roll. In these cases, the air turbulence at a given point in the duct means is unstable. This instability is characterized by random, large, sudden increases in turbulence intensity to values of 1.5 to 2 times the average turbulence intensity at that point, even though the average turbulence intensity may be well below the desired 15 percent level. These large sudden increases in turbulence cause loss of control of fiber-stream thickness and trajectory. These unstable flows are usually also accompanied by large scale, relatively low frequency air velocity non-uniformities. In the operation of this invention, a stable, substantially uniform velocity across the width of the duct means is maintained at lines parallel to the slot where fibers are projected into the air stream. The velocity variation within any one foot distance along these lines (excluding end or wall effects), referred to herein as ΔV/W, as indicated above, is smaller than ±10 percent of the average within that same one-foot distance and preferably within ±5 percent.

The fibers are conveyed to condenser means of a type conventionally used to separate fibers from an air stream in the form of random fiber webs. The fibers are uniformly deposited in a succession of overlapping areas, somewhat analogous to the way shingles are laid. The shingle length is directly proportional to the width of the fiber laydown area and to the apparent thickness of the fiber stream. A low-turbulence thin stream having a fixed (non-oscillating) trajectory gives a shingle length of about ½ inch. An increased area of fiber-laydown can be provided by placing the condenser screen at a more oblique angle to the fiber path. Alternatively, a modification of the invention accomplishes an equivalent effect with means for controlling the flow of air to increase the effective fiber laydown area. Mixing stream generator means for controllably developing gradually enlarging eddies of low turbulence intensities can be located in the duct means between the duct entrance and the disperser roll position. For example, a ¾-inch metal strip perforated with ⅛-inch holes to give 42 percent open area, and fastened to the end walls of the duct to extend across the central portion of the duct, was found to increase the width of the effective fiber-laydown area from ½ inch to about 1¼ inches, thus giving a "spread stream effect". Alternatively, circular or square rods of various diameters or sizes (e.g., rods of 1/16 to ¼-inch diameter), depending upon the flow-mixing and shingle length desired, can be used to provide this effect. By blocking the upper half of the flow at the nozzle delivery with a solid or perforated plate, the area of laydown can be increased even more. These mixing stream generators initiate stable eddies of large dimensions while leaving the region of the air stream entering the fiber flow path essentially unaffected. The mixing stream generators of this invention produce stable average turbulence intensity values of less than 15 percent, preferably less than 7 percent in the fiber flow path. By use of mixing stream generators and long ducts (e.g., about 6 feet long) the effective fiber laydown area can be extended to as much as about 12 inches. All these mixing stream generators cause some lateral mixing within the fiber stream, which may be desirable for eliminating any fine streaks in the web produced by small nonuniformities in the fiber delivery point. These positive effects, however, must be balanced against the increase in blotchiness resulting from an accompanying increase in turbulence caused by the mixing stream generator.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a longitudinal vertical section of a form of the apparatus showing one embodiment of this invention.

FIG. **2** is a fragmentary enlarged diagrammatic longitudinal vertical section of the fiber dispersing section of the machine showing another embodiment of this invention.

FIG. **3** is a fragmentary enlarged diagrammatic longitudinal vertical section of the top portion of the fiber dispersing section showing another embodiment of the invention.

FIGS. **4** and **5** are longitudinal vertical sections of a part of the apparatus showing other embodiments of the invention.

FIG. **6** is a fragmentary section taken on line **6—6** of FIG. **4** showing another embodiment of the invention.

FIG. **7** is a longitudinal vertical section of a part of the apparatus, showing another embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to FIG. **1**, there is shown a fiber feeding means consisting, in this embodiment, of a conveyor belt **2**, feed roll **3**, compressing roll **4** and shoe **5** for supplying fiber **1** to the disperser roll **8**. The fiber feeding means is designed to feed a batt of staple fibers having a weight, in ounces per square yard, which is about 3 to 150 times the weight of the web to be produced. The disperser roll separates the fibers and carries them mixed with the air adjacent to the roll surface through the space between the roll and disperser plate **10**, and discharges this mixture centrifugally into duct **20** at Zone A. A shroud or casing **9** extends around the disperser roll from the lower edge of doff-bar **12** to feed-roll **3**. The fibers projected from the disperser roll form a thin fiber stream **22** in air flowing through the duct and are then separated from the air as web **24** on condenser screen **26**.

Air is supplied from air passage **14**, which has larger cross-sectional dimensions than the duct **20**. The parallel walls **16** of the air passage are connected to the duct walls **20** by converging section **18** of the flow nozzle configuration. Screens **38** and **42**, and honeycomb structure **40**, provide a uniform flow substantially free of turbulence and vorticity. Air is blown into the air passage by one or more fans **36**, through a duct system **33**, shown diagrammatically.

The fibers are deposited to form a web on continuous, moving screen **26** which is driven and supported by rolls **28** and **30**. The air flows through the screen and is withdrawn through vacuum duct **34**. The air may be filtered to remove any particles passing screen **26** and then be recirculated to fan **36**. Several fans in series or an open air system with one or more fans supplying the air and one or more fans exhausting the air can also be used. The screen **26** is sealed against the fiber duct **20** and the vacuum duct **34** by sealing means **32** such as a plate of polyethylene.

FIG. **2** shows another embodiment of the doff-bar **12** having a rounded edge **13** and an upper surface **15** which slopes. The tip of the doffing bar **13** should be less than 0.125 inch from the teeth of the disperser roll and preferably about 0.010 to 0.015 inch away from the teeth.

FIG. **2** also shows a further embodiment of the invention wherein the disperser plate **10** is provided with a slot **44** connected by conduit **46** to vacuum manifold **48** and a vacuum pump (not shown). In the arrangement shown, the walls **50** of the vacuum manifold **48** serve to support the disperser plate **10**. The slot may have a width of from 0.02 to 0.12 inch. The suction slot **44** serves to reduce or remove completely any turbulent boundary layer in the air stream that may develop on the lower side of the air duct. A vacuum of from 1 to 20 inches of water is suitable.

In FIG. **3**, dotted line **58** is the tangent to the outer edge of the disperser roll teeth **7**. The upper edge **54** of disperser plate **10** can be placed on the tangent line **58** or can be somewhat below the tangent line, e.g., ½ inch below. Preferably the disperser plate tip **52** is rounded with a radius of at least 0.015 inch but less than about 0.06 inch. The face **56** of the disperser plate is essentially concentric with the disperser roll. The clearance between the face **56** and the teeth **7** should be less than 0.125 inch in order to avoid premature turbulent mixing of air and fiber under the plate which would result in fiber clumps. Preferably a clearance of between about 0.01 and 0.03 inch is used.

An additional embodiment of the invention is shown by boundary layer tripping means **62** in FIG. **3**. The tripping means consists of a very thin obstruction, such as a round wire of about 18 gauge or a 0.50-inch wide strip of 60 grit sandpaper, located on disperser plate top surface **54** about 1 to 10 inches downstream from the start of the duct means, as determined for the particular process conditions. The resulting turbulent boundary layer (of the order of ¼-inch thick) is relatively uniform across the width of the duct.

The centerline of the fiber duct 22 may extend in a straight line parallel to the top of the disperser plate as shown in FIG. 1 or it can be bent as shown in FIG. 4. The angle between the top of the disperser plate and the centerline of the fiber duct at the condenser section is termed the bending angle. The bending angle should be less than 30° and is preferably from 0° to 10°. FIG. 4 also illustrates reduction of the cross-sectional area of the duct over the doff-bar 12 to cause the air to accelerate and provide a flatter velocity distribution after the fiber stream is formed.

FIGS. 4 and 6 show a further modification with the provision of eddy generator means 66 located in the air stream prior to the fiber doffing point. Generator 66 consists of a perforated plate or screen covering about the middle third of the air duct 20. The plate shown in FIG. 6 with a staggered array of holes (e.g., 0.125-inch diameter) and an open area of about 42 percent will provide a spread stream effect as fibers are deposited on rotary condenser screen 26. A solid plate in the upper portion of the air duct, and small diameter solid rods located in the middle of the air stream upstream of the fiber doffing point are also useful as eddy generator means.

FIG. 5 shows another arrangement of a suitable machine with the disperser roll 8 located above the fiber duct. FIG. 5 also illustrates the use of a condenser screen 26 moving at a 45° angle to the fiber stream.

FIG. 7 shows another embodiment which has a pair of conveyor belts 70 and 71, a pair of compression rolls 72 and 73 about which the belts run, and a pair of feed folls 74 and 75. The batt of fibers 1 is carried by the belts 70 and 71 between restraining means 76 and fed through the nip between positively-driven, fluted, feed rolls 74 and 75 to the transfer zone 80 defined by the space between the feed rolls and the teeth of disperser roll 8. Feed roll 74 is mounted in fixed shoe 79 and feed roll 75 is mounted in a spring-loaded shoe 77. The initial loose staple fiber batt, having a bulk density of no more than about 1 pound per cubic foot and preferably weighing from 40 to 150 ounces per square yard (or more), is first partially compressed between the belts, is further compressed to a maximum density of at least 4 pounds per cubic foot in the nip of the feed rolls, and then expands to a density of about 2 to 5 pounds per cubic foot in the transfer zone, where it is forwarded in a substantially radial direction to the toothed surface of the disperser roll.

The disperser roll 8 is of conventional design and is usually about 5 to 50 inches diameter. It is usually of hollow construction. The cylindrical outer surface of the roll is usually provided with low rake, fine metallic wire clothing 7 (FIG. 3) formed by spirally winding one or several saw-tooth strips about the roll and anchoring it. The sharp ends of the teeth are located so that the ends lie in a substantially true cylinder about the axis of rotation of roll 8. Typical arrangements include:

Tooth rake : Face angle within about 8° from radial direction.

Tooth length : Shorter than ¼ inch, preferably about ⅛ inch.

Tooth ends : Tip width less than 0.030 inch.

Tooth density : Between about 8 and 350 teeth per square inch of roll surface.

Roll Diameter (inches)	Peripheral Speed (feet/minute)	Acceleration (times gravity)
16	3000 to 20,000	117 to 5200
24	3600 to 24,000	112 to 5000
32	4200 to 30,000	115 to 5700

The disperser plate 10 and the doff bar 12 can be constructed of any suitable materials, such as plastic or metal, that will maintain the close clearance with the disperser roll 8 at the high speeds used. The disperser plate should have a length of at least ½ of the length of the staple fiber used but for mechanical convenience it may have a length corresponding to 45° to 90° or more of the arc of the disperser roll. Although unitary disperser plates and doff bars are shown in FIGS. 1 and 2, both parts can be fabricated of a number of sections with suitable attachments.

In all of the above-described embodiments of this invention, disperser roll 8 projects fibers into the air stream at an initial angle of less than 12° to the general direction of air flow. Although low angles of fiber projection are preferred, angles as high as about 25° are suitable in some cases. At angles greater than about 25°, the roll intrudes excessively into the duct means, so that unstable eddies form just upstream of the disperser roll. This causes an unstable and nonuniform region of air flow to be advanced into the fiber stream being projected by the disperser roll which results in a thick cloud of fibers, rather than a thin stream, being dispersed. This in turn results in a blotchy, streaky web product. Moreover, with angles greater than 25°, the fibers may be impinged against the opposite duct wall leading to agglomeration of the fiber dispersion and formation of a blotchy web.

An air supply means which provides a uniform, stable, low-turbulence, low-vorticity flow of air is used and is illustrated in FIG. 1. The inside surfaces of the ducts should be streamlined and smooth, particularly that section between the last screen 38 and disperser roll 8. The converging section 18 should be a smooth, gradual curve. The ASME Long Radius Flow Nozzle Design described in "Fan Engineering", 6th Edition, page 89, (Buffalo Forge Co., 1961) is satisfactory but a preferred design is that of Rouse and Hassan in "Mechanical Engineering", Volume 71, No. 3, March, 1949, which is approximated in FIG. 1. This air supply assembly provides a uniform flow of air at the exit of the nozzle. Exclusive of boundary layers (i.e., layers within about ½ inch of the duct walls), the flow has a total velocity variation across the cross-section, both vertically and laterally of less than ±10 percent, but usually and preferably less than ±5 percent, and a stable turbulence intensity of less than about 15 percent, but usually and preferably well below 7 percent. The peripheral velocity (V_o) of the disperser roll is at least 3,000 ft./min. A suitable range of air velocity (V) at the edge of the disperser plate in Zone A is between about 0.5 and 3.5 times V_o and preferably about 0.5 to 1.2 times V_o. A suitable range of maximum air velocity in Zone A (i.e., over the point of highest, intrusion of the disperser roll into the duct) is between about 0.5 and 3 times V_o, but preferably between 0.7 and 1.7 times V_o. Suitable ratios of weight rates of flow of air to fiber are at least 25 to 1.

MEASUREMENT OF AIR VELOCITY AND TURBULENCE INTENSITY

The velocity of the air flow at various points is determined with a conventional hot wire anemometer. A suitable instrument for this purpose, which was used for the measurements reported herein, is a Model 1050 B–4 hot-wire anemometer, manufactured by Thermal Systems Inc., of St. Paul, Minnesota. Others are well known in the art. When the output of the anemometer is also passed to an a-c coupled, root-meansquare (RMS) voltmeter, such as a Model 3400A, manufactured by Hewlett Packard, Inc., of Loveland, Colorado, the RMS value of the velocity fluctuation in the direction of air flow with time is measured. For the values reported herein, the RMS readings were averaged for about 5 to 10 seconds. The RMS value of the velocity fluctuation, multiplied by 100 and divided by the average velocity at that location is referred to herein as the local turbulence intensity. Further details on the use of hot wire anemometers for measuring velocity and turbulence intensity is given in numerous places in the art, such as Bulletin 53, "The Hot Wire Anemometer", of Flow Corporation of Cambridge, Massachusetts. Theoretical discussions of turbulence intensity are found in H. Schlichting, "Boundary Layer Theory", 6th Ed., McGraw Hill Book Company, New York, 1968, pages 455–457, 538–539, 558, etc.

The velocities and turbulence intensities which are of key importance to this invention are those associated with the air layers that advance along the fiber path and carry the fibers to the condenser. To determine the path of the fibers in the process of this invention is relatively simple, since the process provides a distinct stream of fibers. One way is to determine the fiber path optically through transparent sections of the duct means. For convenience, the fiber stream can be lighted from the top and the thickness clearly seen and measured from the edge of the transparent section of the duct means. Permanent records of the fiber path can be made with regular speed "Polaroid" photos or high speed (near 10^{-6} second exposure) "Polaroid" photos. The high speed photos show the instantaneous position of individual fibers in the duct. Once the fiber path has been determined, the velocity and turbulence intensity measurements are made with no fiber flowing. The resultant measurements without fiber flowing are considered typical of the case with fiber flowing (all other things being equal) because of the very high minimum weight ratio of air to fiber flow (i.e., at least 25 to 1).

The velocities and turbulence intensities are measured at at least three typical key locations: (1) in the flow layers advancing over the disperser plate tip into the fiber path just upstream of the disperser roll; (2) in the fiber path flow just downstream of the disperser roll over the doff bar tip; and (3) in the fiber path flow at the end of the doff bar just upstream of the condenser. The velocity and turbulence intensities are measured at each of these locations, in a typical stream position (i.e., removed from the side walls) at intervals of 0.1 inch, starting 0.1 inch away from the wall of the duct containing the disperser-roll opening and continuing through the thickness of the fiber path. The measurements at each location are averaged for the thickness of the path to give an average velocity and an average turbulence intensity. If the fiber path is very wide, scans of the path should be made at additional points in the width of the stream at the three above-mentioned locations. In all embodiments of this invention, the average turbulence intensity at each of these locations along the fiber path is no more than about 15 percent. Average turbulence intensities in excess of 15 percent result in blotchy webs.

Measurements of velocity across the width of the fiber path at the same three locations mentioned above (without fiber flowing), also provide a measure of large scale, low frequency, velocity nonuniformities. Immediately upstream of the disperser roll, the velocity variation in a foot width of stream advancing into the fiber path is less than ±10 percent for embodiments of this invention, and preferably less than ±5 percent. The velocity variation for 0.1 inch thick layers of this advancing stream (excluding the first 0.1 inch from the wall) is within 15 percent (preferably within 10 percent) of the average velocity in the region.

If the fiber path from the disperser roll to the condenser is long, more than the three turbulence-intensity measuring locations mentioned above should be used to characterize the turbulence to which the fiber stream is exposed in its advance to the condenser. It is recommended that the measuring locations be spaced essentially equidistant from each other.

The following examples, which illustrate specific embodiments of this invention, are not intended to limit the invention in any way.

EXAMPLE I

In this example, an apparatus, similar to that illustrated in FIG. 1, is used to form 36-inch wide, high quality webs at the following rates:

Production Rates		Product Weight
lbs/in. hr.	yards/min.	oz/yd²
6.5	55	1.1
9.1	78	1.1
12.1	68	1.6

In each of the above runs, the feed to the disperser roll consists of 1.25-denier-per-fiber, ¾-inch-long, polyethylene terephthalate staple fibers in the form of a loosely opened 100-oz./yd.²batt. This is fed to a 24-inch diameter disperser roll having 40 teeth/ square inch, each tooth being 0.09 inch high and 0.009 inch thick. The clearance between the ends of the teeth of roll **8** and the curved plate **10** is maintained at 0.025 inch. The roll rotates at 3,000 rpm and projects a uniform thin stream of fibers into the duct at an initial uniform velocity of 18,600 ft/min. The average air velocity at the exit of the contoured nozzle connecting to rectangular duct **20** is 9,000 ft/min. with a turbulence intensity of about 0.4 percent. The velocity gradient across the width of the duct at this location is less than 1 percent per foot. The approximate height dimensions of 36-inch wide rectangular duct **20** and the average air velocities at various locations in the duct are as follows:

Location	Thickness (inches)	Velocity (ft/min)
X. Immediately downstream of nozzle (i.e., at entry to rectangular duct)	2	9,000
1. Over plate **10** just upstream of disperser roll	1⅜	13,000
2. At point of maximum intrusion of roll into duct	⅞	20,600
3. Over plate **12**, just downstream of disperser roll	1⅛	16,000
4. Just upstream of collecting screen **26**	1⅞	9,600

The distance between locations X and **1** is about 9 inches; between 1 and 3, about 8½ inches; and between 3 and 4, about 19 inches. The fibers are projected into the duct at an initial angle to the air flow of about 9° and then conveyed in the air stream in a thin straight path to the collecting screen. At no location along the fiber path is the turbulence intensity greater than about 2 percent.

EXAMPLE II

This example illustrates the effect of turbulence intensity along the fiber path on the production rate of high quality, defect-free webs.

Apparatus similar to that illustrated in FIG. **1** is used to form a 70-inch wide web weighing 1 oz/yd^2 at a rate of 60 yards per minute. The feed batt consists of 1.5-denier-per-fiber, ¾-inch rayon staple which is carded into a loosely opened fiber lap. This is fed at a rate of 6.25 lbs./in. hr. to a 16-inch diameter disperser roll rotating at a surface speed of 12,500 feet per minute. Air is supplied through the duct at 5,000 feet per minute under conditions such that the turbulence intensity in the air stream leaving the nozzle is about 0.4 percent. A uniform web of high quality is produced. When the turbulence intensity leaving the nozzle is increased from 0.4 to 0.7 percent, equivalent blotch level in the web can be obtained at production speeds of only about 40 yards per minute or less.

EXAMPLE III

This example shows the beneficial effects that can be obtained through use of suction as a means of boundary layer control.

Apparatus similar to that illustrated in FIG. **1**, but provided with suction means for removing boundary layer turbulence as shown in FIG. **2**, is used to form a 36-inch wide web weighing 1 oz/yd^2 at a rate of 80 yards per minute. An air-formed batt of 1.5 denier per fiber, ¾-inch polyethylene terephthalate staple is fed at a rate of 8.3 lb/in. hr. to a 24-inch diameter disperser roll rotating at a surface speed of 15,000 feet per minute. Air is supplied through the duct at 8,000 feet per minute under conditions such that the maximum turbulence intensity in the fiber path is about 0.5 percent. A uniform web is produced which is of high quality and free from streaks. When the above-described conditions are repeated without suction to remove boundary layer turbulence, some streaks are formed due to nonuniformities in the boundary layer.

EXAMPLE IV

In this example a series of webs is produced under different conditions of turbulence intensity along the fiber path.

An apparatus similar to that illustrated in FIG. **1** is used to form a series of 11-inch wide webs of about 1 oz/yd^2 unit weight at a rate of 5 lbs/in. hr. The batts fed to disperser roll **8** are 70 oz/yd^2 batts of 1.25 denier per fiber, ¾-inch long polyethylene terephthalate stable fibers prepared from multiple 2 oz/yd^2 layers formed on a Rando-Webber. The disperser roll is **16** inches in diameter, has 80 teeth per square inch, each tooth being 0.090 inch high and having a 0.009 inch tip thickness. A 0.02 inch clearance is maintained between the tips of the teeth and plate **10**. The disperser roll projects a thin stream of fiber into the duct means at an initial angle of 11° with the general direction of air flow and at an initial velocity (V_o) of 11,600 ft/min. The dimensions of the rectangular duct means at specified locations downstream of the cubic nozzle are as follows:

Location No.	Location	Duct Dimension height inches	Duct Dimension width inches
X	Entrance to rectangular duct	1 11/16	11
1	Over plate **10**, just upstream of disperser roll	1⅜	11
2	At point of maximum intrusion of the roll into duct	⅞	11
3	Over plate **12**, just downstream of disperser roll	1¼	11
4	Just upstream of collecting screen **26**	1⅝	11

In this apparatus, the moving screen **26** interrupts the air-fiber stream at a 45° angle. The distance between the specified locations X and **1**, **1** and **3**, and **3** and **4** are respectively 8, 11 and 12 inches.

To control the turbulence intensity in the fiber path a series of mixing stream devices were positioned at location "X". The webs produced with these devices and under the conditions described above were then arranged in order of increasing blotchiness. The results are summarized in the table below. The designations V_1, V_2, V_3 and V_4 are used for average air velocities at the above locations **1**, **2**, **3** and **4**, respectively. Turbulence intensity measurements (I) were made as described hereinbefore at locations **1**, **3** and **4**. The velocity variations in the region of the air stream which advances into the fiber path was also measured at location **1** ($\Delta V/V$).

Without making any changes in the operation of the apparatus except to decrease the speed of the web-collecting screen, a series of webs with about 3 oz./yd.^{2} unit weight is also produced.

The blotchiness of the 1 oz./yd.^{2} and 3 oz./yd.^{2} webs is measured by means of a Paper Formation Tester (M. N. Davis et al., Technical Association of the Pulp and Paper Industry, Technical Papers, Series 18, 386–391 (1935). As a standard for determination of formation value (FV), a suitable number of sheets of 1 oz./yd.^{2} onion-skin paper are used to give a unit weight corresponding to the web samples to be examined. The data reported in the table are averages of three determinations on single samples of each web.

TABLE I

Run No.	Mixing stream generator	Incoming air stream V_1	$\Delta V/W$	$\Delta V/V$	V_1/V_0	I_1	Over disperser V_2	V_2/V_0	Path to collector V_3	I_3	V_4	I_4
a	None	8,700	1	4	0.75	1.4	13,600	1.17	11,700	1.7	9,000	1.2
b	1/16-inch diameter wire*	8,700	1	4	0.75	2.6	13,600	1.17	11,700	2.0	9,000	1.8
c	3/32-inch diameter wire*	8,700	--------	3	0.75	2.9	13,600	1.17	11,700	2.8	9,000	2.0
d	⅛-inch diameter wire*	8,600	1	3	0.74	3.3	13,500	1.16	11,600	3.3	8,900	2.2
e	3/16-inch diameter rod*	8,600	--------	2	0.74	6.2	13,500	1.16	11,600	4.5	8,900	4.2
f	¼-inch diameter rod*	8,500	3	3	0.73	8.3	13,400	1.15	11,500	5.6	8,800	4.8
g	1-inch gate opening+	8,200	--------	7	0.71	3.3	12,800	1.10	11,100	13.5	8,500	7.2
h	¾-inch gate opening+	8,000	5	14	0.69	25.1	12,600	1.08	10,900	19.5	8,300	12.1

*The wire or rod mixing stream generator is located across the middle of the incoming air stream at location X.

+The gate is at location X on the side of the duct opposite the disperser roll (i.e., the gate opening is on the disperser-roll side of the duct).

V_0=Initial projection velocity of the fibers, ft./min.

V_1=Average velocity of incoming air stream, ft./min.

$\Delta V/W$=Velocity variation across the width of the region of the air stream advancing into the path of fiber flow, ± percent/foot of width.

$\Delta V/V$=Velocity variation in the region of the air stream advancing into the path of fiber flow, ± percent.

I=Turbulence intensity, ±percent.

Subscripts refer to the specified locations 1, 2, 3 and 4.

FORMATION VALUE

Run No.	1 oz./yd.² Web	3 oz./yd.² Web
a	98	129
b	94	128
c	89	127
d	91	111
e	89	100
f	74	94
g	72	73
h	65	66

The webs made under the conditions described in the table above for runs *a*, *b*, *c*, *d* and *e* were of excellent to good quality having very little blotchiness. The webs of run *f*, although still satisfactory, were more blotchy. Webs of run *g*, although made within the scope of the invention, were still more blotchy and somewhat marginal in quality. Run *h* produced the blotchiest and most streaky web in this series and is considered to be unsatisfactory for the purposes of this invention.

From this series of runs and others it is concluded that low, stable turbulence intensities of less than 15 percent and preferably less than 7 percent along the fiber stream path are required to produce high quality webs at high rates. Further, a velocity variation of less than ±15 percent in the region of air flow that advances into the fiber path is also required and a variation of less than ±10 percent is preferable.

In a second series of runs without mixing stream generators the velocities ratios V_1/V_o and V_2/V_o were varied between 0.4 and 2.0 and between 0.6 and 3.1, respectively. This series of tests and others showed that the suitable range for V_1/V_o is between about 0.5 and 3.5, with 0.5 to 1.2 being preferred, and the suitable range for V_2/V_o is between 0.5 and 3.0, with 0.7 to 1.7 being preferred in order to obtain the most uniform webs at the highest production rates. In addition, these tests showed that the suitable range for the average air velocity at any cross-section downstream of the location where the thin fiber stream forms is between 0.25 and 3 times and preferably between 0.4 and 1.2 times the initial average air velocity (V_1).

EXAMPLE V

Good quality dispersions (as judged by high-speed photographs of fiber flying over the disperser roll or by inspection of thin webs laid down from the dispersion) suitable for making a uniform 1 ounce per square yard web, with no fiber clumps or neps and substantially no breakage of fibers are obtained when using the conditions given in Table II.

The fiber for Run No. 1 consists of a mixture of 65 percent 1½inch long, 1.5 dpf acrylic fibers and 35 percent ¼ inch long, 1.5 dpf rayon fibers. The fiber for Runs 2 to 5 is 1.5 dpf rayon with a length of 1 inch for Run 2 and 0.75 inch for Runs 3 to 5.

Batts of well-opened fibers made by cross-lapping a card web in a direction transverse to the dispersion feeding direction are fed to an apparatus similar to FIG. 7 using a 16 inch diameter disperser roll operating at a peripheral speed of 12,500 feet per minute.

The throughput rate for Runs 3 to 5 is the maximum possible under the conditions used which will produce an acceptable degree of dispersion. However, the use of a 60 oz./yd.² feed batt under the conditions of Run 3 gives a better dispersion and an 80 oz./yd.² feed batt gives even a larger improvement.

When webs of from about 1 to 4 oz./yd.² weight are made from the above fiber dispersions, using the air stream conditions of Example I, uniform webs are made.

TABLE II

Run No.	1	2	3	4	5
Initial Batt Weight (oz./yd.²)	30	30	40	60	80
Density (lb./ft.³)	0.21	0.35	0.37	0.50	0.55
Compressed Batt Max. density (lb./ft.³)	13.2	13.2	17.6	19.9	18.5
Density at disperser roll face (lb./ft.³)	2.5	2.5	2.8	3.6	4.4
Throughput (lb./in./hr.)	6	7	10	15	20

I claim:

1. In a process for forming a web of textile fibers wherein staple fibers are dispersed in a flow of air and then collected on a moving screen to form a random fiber web; the improvement which comprises projecting staple fibers at a uniform initial velocity of at least 3,000 feet per minute into a controlled flow of air at an angle of less than 25° with the direction of said flow to form a thin stream of fibers; controlling the flow of air so that the fibers are projected into a region of stable air flow characterized by (a) an average air velocity (V) between 0.5 and 3.5 times said initial fiber velocity, (b) an average velocity variation in each 0.1-inch thick layer across the thickness of said region, excluding the first 0.1-inch layer next to any wall, which is less than ±15 percent of said velocity (V), (c) a velocity variation across the width of said region which is less than ±10 percent in any one foot increment, and (d) an average turbulence intensity of no more than 15 percent; controlling the flow of air to transport the fibers to the collecting screen as a thin fiber stream in a stable flow of air characterized by (e) an average air velocity between 0.25 and 3 times said velocity (V) and (f) an average turbulence intensity in the fiber path of no more than 15 percent; and then separating the fibers from the flow of air to form a uniform web on the moving screen.

2. The process defined in claim **1** wherein the fibers are projected at a uniform initial velocity of 10,000 to 20,000 feet per minute to form a fiber stream of less than ¼-inch initial thickness.

3. The process defined in claim **1** wherein the fibers are projected at a rate of 3 to 20 pounds per inch of stream width during each hour of operation.

4. The process defined in claim **1** wherein the fibers are projected at an angle of less than 12° with the direction of air flow.

5. The process defined in claim **1** wherein said flow of air is controlled to provide an average velocity (V) between 0.5 and 1.2 times said initial fiber velocity in said stable flow region immediately upstream of the fiber stream, and an average velocity between 0.4 and 1.2 times said velocity (V) after the fiber stream is formed.

6. The process defined in claim **5** wherein said average turbulence intensities are less than 7 percent.

7. The process defined in claim **5** wherein said average velocity variations across the thickness of said stable flow region are less than ±10 percent of siad velocity (V), and said velocity variation across the width of said region is less than ±5 percent.

8. The process defined in claim **1** wherein the weight rate of said flow of air is at least 25 times the weight rate at which the fibers are projected into the flow of air.

9. The process defined in claim **1** wherein said fiber stream is about ½ to 1 inch thick as it nears the web-forming screen.

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