PROCESS FOR FORMING A WEB

Filed Nov. 2, 1972 3 Sheets-Sheet 1

FIG. 1

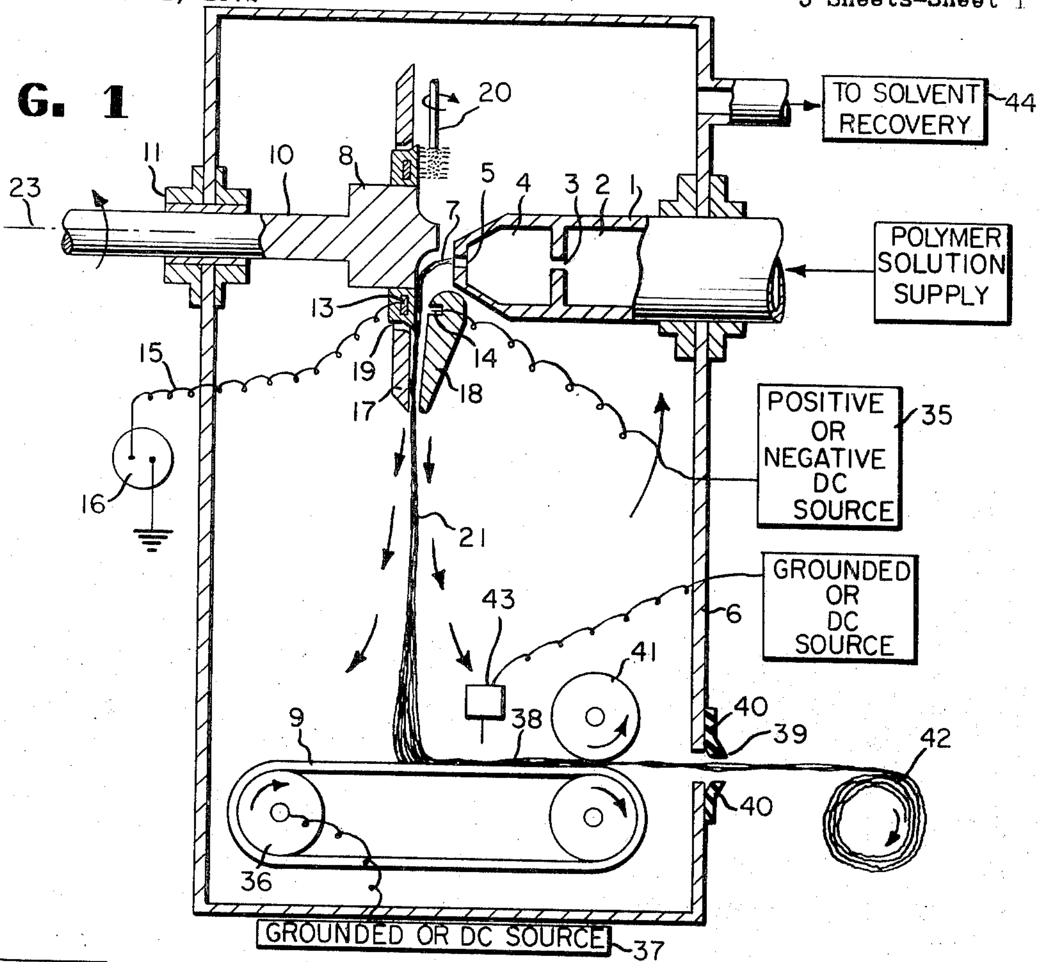
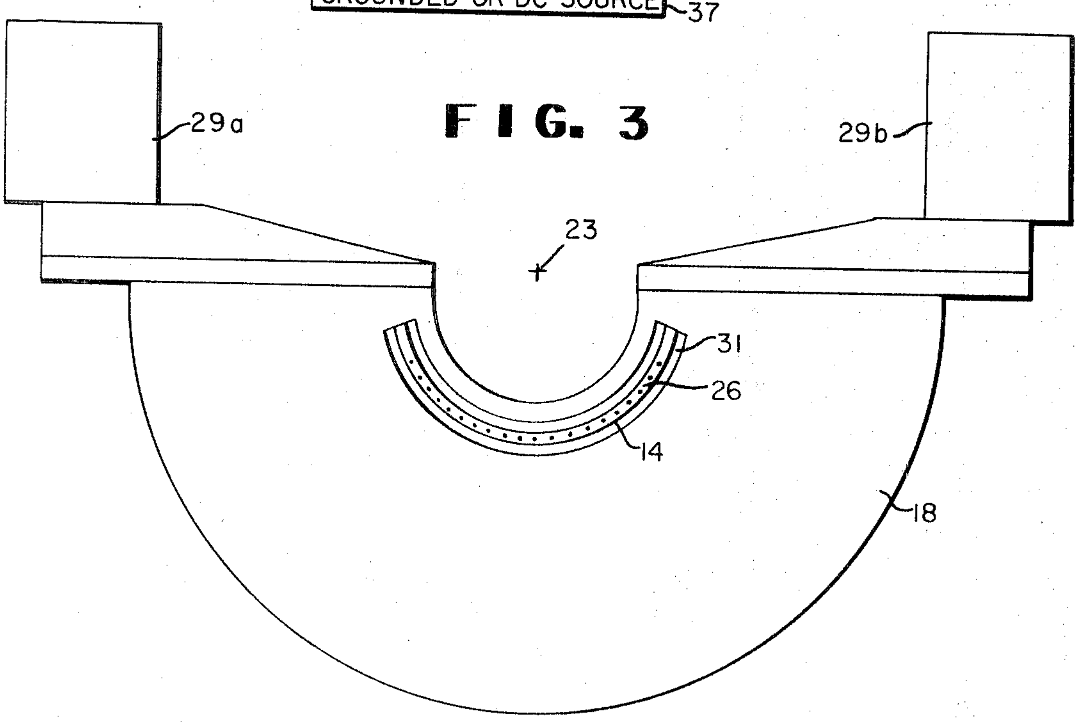


FIG. 3



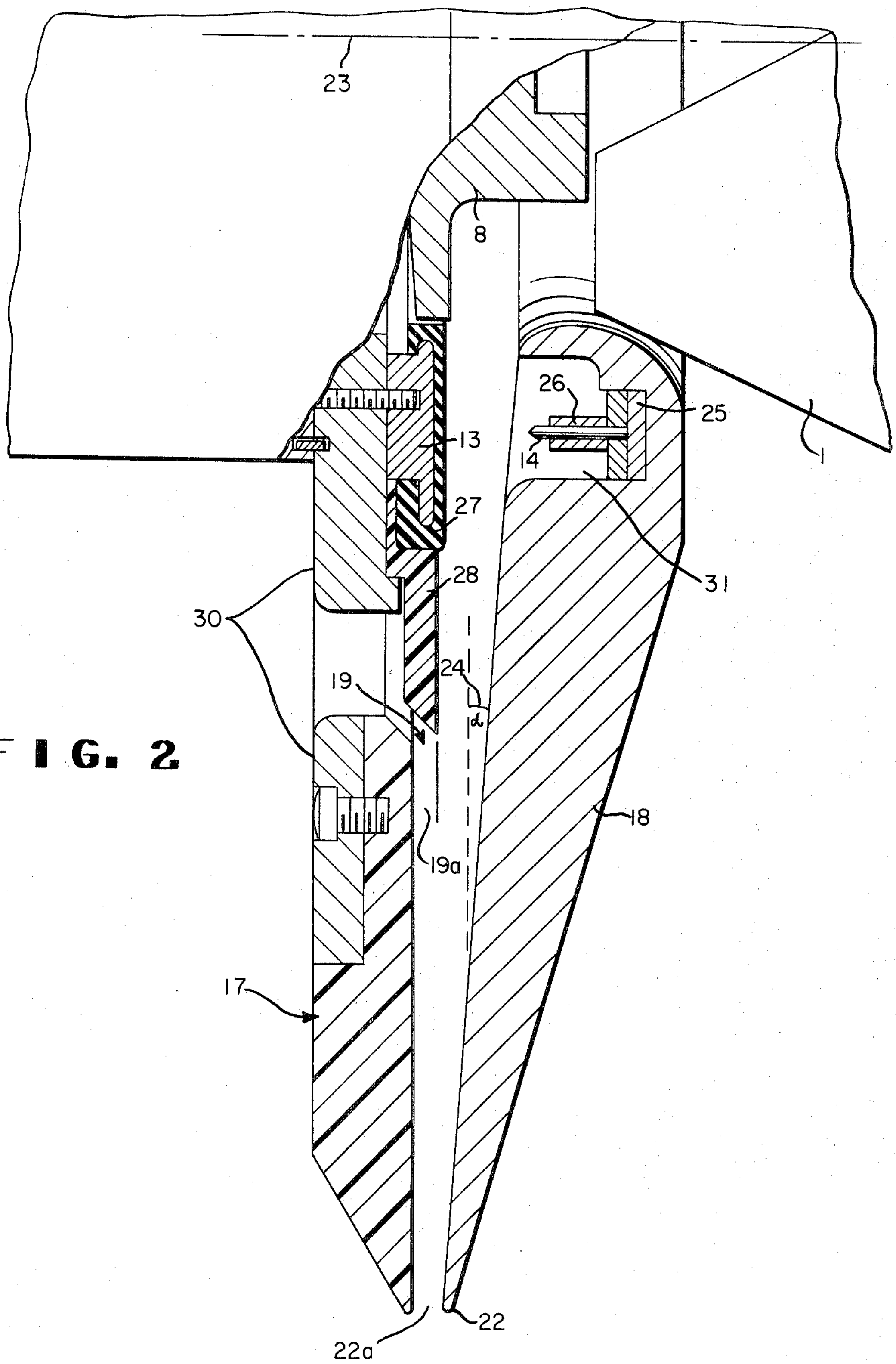
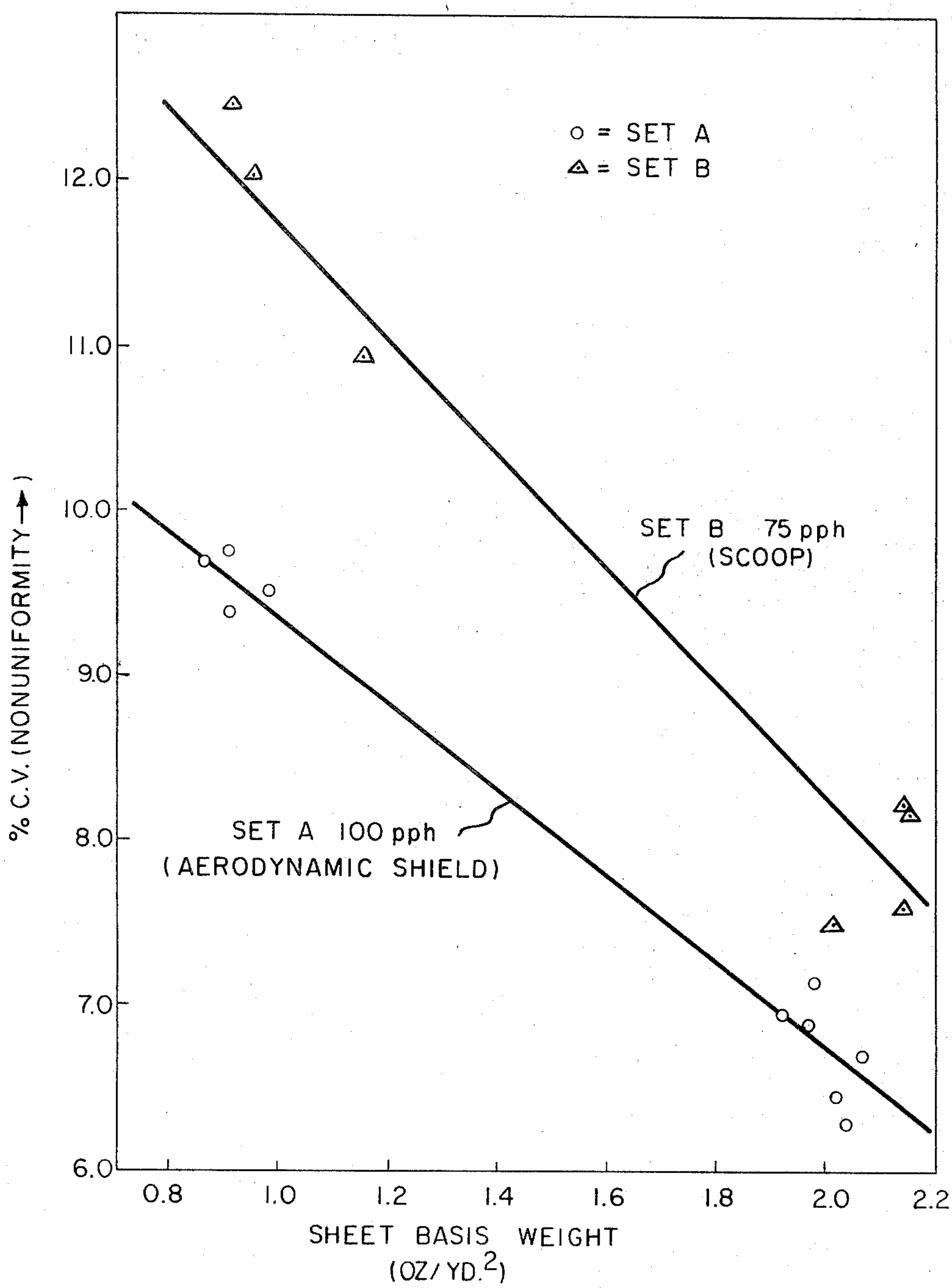


FIG. 2

FIG. 4


○ = SET A
△ = SET B
SET B 75 pph
(SCOOP)
SET A 100 pph
(AERODYNAMIC SHIELD)
% C.V. (NONUNIFORMITY →)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
SHEET BASIS WEIGHT
(OZ/YD.2)

3,851,023
PROCESS FOR FORMING A WEB

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U.S. Cl. 264—24 3 Claims

ABSTRACT OF THE DISCLOSURE

An improved apparatus for use in making nonwoven fibrous sheets of organic synthetic polymers includes a spinneret orifice through which a polymer solution is flash spun to form a plexifilamentary strand directed in a generally horizontal direction toward a rotating baffle whose axis of rotation is generally parallel to but spaced from the axis of the extrusion orifice and whose surface is contoured so as to simultaneously spread said strand into a planar web, direct the web into a generally vertical plane downward toward a collecting surface, and cause said web to oscillate in the plane as the baffle rotates. The improvement consists of an aerodynamic shield of specified configuration.

The shield terminates at an edge which lies substantially along an arc of a circle whose center lies on the axis of rotation of the baffle. Since the plexifilamentary strand impinges on the baffle at a point near its axis of rotation and is deflected as a web which therefore oscillates through various radial directions within the plane substantially perpendicular to the rotation axis, only the specified shield configuration will provide flow paths of approximately equal impedance, independent of the instantaneous radial direction at which the web leaves the baffle.

BACKGROUND OF THE INVENTION

This invention relates to a process and apparatus used in the preparation of nonwoven fibrous sheets of synthetic organic polymers. More particularly, it is directed to a process and apparatus for spreading a plexifilamentary strand into a planar web, directing the web toward a surface, charging the web and collecting the web in the form of a nonwoven fibrous swath.

Steuber, U.S. Pat. No. 3,169,899 describes a process for making a nonwoven sheet from flash-spun fibrous materials. In the flash spinning technique, a solution of an organic polymer which is under pressure and at a temperature far above the boiling point of the solvent is extruded into an area of substantially atmospheric pressure. As the material issues from the orifice, the solvent flash evaporates and a plexifilamentary strand is formed. The plexifilmentary strand is composed of very thin film fibril elements which are interconnected in a three-dimensional network as described in detail in Blades and White, U.S. Pat. No. 3,081,519. The three-dimensional network is spread into a wide web by causing it to be swept along a smooth path past a curved surface baffle whereupon the expanding solvent gas spreads the material. By oscillating the deflecting baffle, the web can be directed to various areas across the width of a moving collecting belt where it is deposited in the form of swaths. The web can be electrostatically charged to both further increase its width through mutual electrostatic repulsion between fibrils and also attract the swath to the belt and immobilize the deposit. A fibrous nonwoven sheet is thereby obtained.

In an alternative process described in Pollock and Smith, U.S. Pat. No. 3,497,918, the oscillating baffle can be replaced by a rotating baffle, having specially contoured surfaces, which simultaneously spreads and oscillates the web as it is directed through an electrostatic device to apply uniform electrostatic charge on the web and promote uniform deposition of the web on a moving collecting surface. A suitable charging apparatus is described in Kilby and Smith, U.S. Pat. No. 3,456,156. The apparatus consists of an annular disc target electrode which is concentric with the rotating baffle and rotates independently of said baffle. A multineedle ion gun is positioned opposite the target plate, the needles being aimed at a portion of the target electrode to provide a corona discharge zone. The fibrous material moving in a planar path between the target electrode and the ion gun needles is electrostatically charged before being deposited on the moving collecting surface.

A number of requirements must be satisfied in order to obtain wide, fibrous, nonwoven sheets having a uniform appearance and a uniform basis weight. In general, wide nonwovens are obtained by blending and overlapping the swaths from several spinning positions. Smith, U.S. Pat. No. 3,549,453, describes a mechanism for making fine adjustments and varying the weight distribution of the swaths deposited on the collection surface. Tests have shown that optimum basis weight uniformity in the cross machine direction (i.e., the direction at right angles to the direction of movement of the receiving surface) is obtained when the width of the swaths at this surface is within certain limits which depend on the shape of the cross machine direction basis weight profile of each swath. This width is a function of the amplitude of the oscillation imparted to the web by the baffle, the amount of electrostatic charge on the web and the distance between the baffle and the receiving surface.

Isakoff, U.S. Pat. No. 3,593,074, describes a short diffuser device, termed a "scoop," which "squeezes" the gaseous stream to increase its width, thereby also increasing the width of the entrained web. This scoop is situated between the baffle and the corona charging station, and leads to improvements in sheet uniformity by permitting shorter baffle-to-receiving surface distances for a given swath width. However, as spinning throughputs are increased, the larger volumes and velocities of gas produced in the flash spinning operation create an undesirable increase in turbulence. This increases the random oscillation of the web producing a nonwoven sheet having less than the desired uniformity.

SUMMARY OF THE INVENTION

An apparatus is provided for forming a fibrous web that includes means for flash spinning a polymer solution to form a plexifilamentary strand entrained in a gaseous stream, means at one location (e.g., a rotating baffle) for spreading the strand to form a web and oscillating the web in a generally vertical plane in a plurality of downward radial directions toward a collecting surface and means positioned below said spreading and oscillating means for charging said web. The improvement comprises an aerodynamic shield having front and rear members disposed on each side of said plane below said spreading and oscillating means. The members have surfaces facing said plane, said surfaces terminate in edges equispaced from each other that lie along arcs of equal radius extending from a horizontal axis proximate to said one location. The surface of the rear member facing said plane is substantialy parallel thereto and is a stepped surface, stepped away from said plane in the downward direction along one or more arcs concentric with the terminating edge of the rear member. The surface of the front member facing said plane is a section of a surface of revolution about said horizontal axis that converges downwardly toward said plane.

The surface of the front member facing the vertical plane preferably is a segment of a right circular cone converging downwardly toward said plane at an angle of about 5 degrees.

The front and rear members extend downward for a distance of from about 30 percent to about 60 percent of the distance from said one location to said collecting surface.

There are ports in said rear member at the location the surface of the rear member facing the vertical plane is stepped away from said plane.

The invention concerns an improved process that includes the steps of entraining a web in a gaseous stream flowing in a generally horizontal path toward one location, directing and oscillating said web and said stream from said one location in a plurality of downward radial directions in a substantially vertical plane through ambient gas toward a collecting means, and collecting said web on said collecting means as a fibrous sheet, the improvement comprising: converging said stream in said downward radial directions within a shield presenting substantially equal flow impedances in said radial directions. The process may include the step of aspirating said ambient gas into said shield generally in said downward radial directions.

Although some web deceleration can be tolerated within the aerodynamic shield of this invention, the primary function of the shield is not to diffuse the gas stream but rather to protect it and the entrained web as shaped by the rotating baffle and prevent premature mixing with the ambient gas. Accordingly, the exit gap width between front and rear shield members is selected such that there is neutral gas pressure on the members, i.e., the average internal and external gas pressures are equal. The actual gap width required is, of course, a function of the rate of gas generation by flash vaporization, the quantity of gas entrained and aspirated into the shield, the dimensions of the shield, etc. However, under any given set of spinning conditions the required gap width is readily determined by the neutral pressure condition.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional elevation indicating schematically the arrangement of various elements of an apparatus which can be used in the practice of the invention.

FIG. 2 is a more detailed cross-sectional view of a portion of a preferred embodiment of the aerodynamic shield of the present invention.

FIG. 3 is a view of the web facing surface of the front shield member of FIG. 2.

FIG. 4 is a graph presentation of data showing the improved machine direction sheet uniformity provided by the apparatus and process of the present invention.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

Referring to FIG. 1, a spinneret device **1** is shown connected to a polymer solution supply source. Polymer solution **2** under pressure is fed through an orifice **3** into intermediate pressure or letdown pressure zone **4** and then through spinning orifice **5** into web forming chamber **6**. The extrudate from spinning orifice **5** is a plexifilamentary strand **7**. Due to the pressure drop at spinning orifice **5** and the high temperature of the spinning solution, vaporization of solvent creates a vapor blast which, by passage along the surface of baffle **8** concomitantly with plexifilament **7**, generally follows the path of advance from spinning orifice **5** to collecting surface **9**, thereby creating a flow pattern within chamber **6** as indicated by the arrows in FIG. 1. Baffle **8** is mounted on shaft **10** which is mounted in bearing **11** and is rotated by means not shown. The surface of baffle **8** is so contoured that the plexifilamentary strand **7** issuing from orifice **5** is deflected into a generally vertical plane and simultaneously spread laterally to form a plexifilamentary web **21** which oscillates from side-to-side as baffle **8** is rotated.

The plexifilamentary web **21** passes from baffle **8** directly into the aerodynamic shield of this invention. The shield is comprised of front member **18** and a rear member comprising elements **13** and **17**. Multineedle ion gun **14** is mounted on the interior surface of front member **18**, and is connected to constant current power source **35** which supplies a potential of approximately 50–60 kilovolts. A corona discharge occurs between needles **14** and target plate **13** which is disposed so that the vapor blast originating at **5** and deflected by baffle **8** carries the plexifilament web along its charging surface. Target plate **13** is connected via commutating ring and brushes to ground by wire **15** and microammeter **16** which indicates target plate current.

Target plate **13** is an annular metal disc electrode, and is preferably covered with a dielectric insulating surface as disclosed in U.S. Pat. No. 3,578,739. Target plate **13** together with concentric annular segment **17** comprise the rear member of the aerodynamic shield, and are adapted to be rotated concentrically with, but independent of, baffle **8** by means not shown. During rotation of the rear member, its interior surface passes by rotating brush **20**, driven by means not shown, so that the surface of target plate **13** and adjacent parts may be cleared of any debris, thereby furnishing a continuously cleaned surface for optimum operation of the corona discharge. At intervals, in a circular pattern, the rear shield member is pierced by ports **19** through which ambient gas may be aspirated into the step region between concentric disc segments **13** and **17**.

After exiting the aerodynamic shield, plexifilament web **21** is deposited upon a collecting surface **9**. The surface illustrated is a continuous electrically conductive belt forwarded by drive roll **36**. The belt may either be grounded or charged to a positive or negative potential by power source **37**. Due to differences in their electrostatic charge, the plexifilament web **21** is attracted to surface **9** and clings to it in its arranged condition as a swath **38** with sufficient force to overcome the disruptive influences of whatever vapor blast may reach this area. Since high rates of production can generate high turbulence in chamber **6**, auxiliary corona devices **43** stationed just above the surface of belt **9** may be employed to place even higher electrostatic charge on swath **38**, thereby pinning it even more tightly to belt **9**. Wide sheets are produced by blending and overlapping the output from several spinning positions placed in an appropriate manner across the width of a receiving surface such as the belt **9**. The degree of uniformity of the web deposits tends to increase as the aerodynamic shield is extended to protect a greater fraction of the vertical distance from the baffle to the receiving surface. However, unless some free-fall is permitted, the web fibril orientation is biased too heavily in the cross machine direction. Furthermore, too extensive a shield can lead to nonuniform deposits and "hang-up" due to electrostatic attraction and erratic clinging of the charged web to the internal shield surfaces. Applicants have discovered that a preferred balance in sheet uniformity and fibril directionality is attained when the aerodynamic shield extends over about 30–60% of the vertical distance from the edge of the baffle to the collecting surface. The sheet is then lightly compacted by roll **41** and is collected on windup roll **42** after passing through port **39** and flexible elements (or rolls) **40** which assist in retention of vapor within chamber **6**. A conventional solvent recovery unit **44** may be beneficially employed to improve economic operation.

FIG. 2 is an enlarged cross-sectional view of a portion of the aerodynamic shield depicted in FIG. 1. Front member **18** is constructed of Lucite® (trademark for Du Pont acrylic resin), its exit lip **22** lies along a semicircle centered on rotating baffle axis **23** and the angle of convergence **24** is 5°. Multineedle corona charging electrode

14 consists of 17 needles smoothly graduated in length, spaced at intervals along conductor **25** to provide a varying needle-to-needle target spacing. The needle electrode is recessed in channel **31** cut into the web facing surface of front member **18**. The needles lie along an arc of a circle centered on axis **23**, and the angle subtended by the end needles as viewed from the center of the circle is 140°, which is sufficient to overlap the plexifilamentary web envelope throughout its period of oscillation. (The angle subtended by channel **31**, viewed from the center of the circle is 166°.) The 17 needles pass through a curved strip of "Lexan" **26** whose width is tapered to allow each needle point to protrude the same distance. This strip thus bridges the gap between adjacent needles and prevents plexifilamentary debris from building up from the base of the individual needles during spinning, which debris could alter the shape and intensity of the electrical field and thereby lead to nonuniform corona generation and consequent erratic web charging and sheet nonuniformities.

The rear shield member is comprised of metallic annular target plate **13**, covered by a dielectric surface **27** having a volume resistivity between 5×10^9 and 1×10^{10} ohm centimeters, and annular target plate extension **28** constructed of Lucite® plus concentric annular segment **17**, also constructed of Lucite®. These rear shield member's elements are assembled by means of annular "Lexan" (General Electric's polycarbonate resin) support member **30** and thereby adapted to be rotated as a unit about axis **23**, i.e., concentrically with baffle **8**. (Baffle **8** is rotated at much higher speeds than the rear shield unit.) The step height between elements **28** and **17** is designated **19***a*, and support member **30** is perforated at intervals by aspiration ports **19**. The provision of access ports in the rear member near the step permits a suitable quantity of ambient gas to be aspirated into the aerodynamic shield to form a protective cushion of gas which flows toward the exit lip along the internal surface of the rear member.

FIG. 3 is a view of the web facing surface of front shield member **18** showing the needle electrode unit **14**, channel **31**, "Lexan" strip **26**, and also indicating support members **29***a* and **29***b*. Front shield member **18** is suspended from pivot points (not shown) inside members **29***a* and **29***b*, both located on a common horizontal axis, which thus permits front shield member **18** to swing farther away from the rear shield member momentarily whenever a mass of plexifilamentary material may begin to plug the shield passageway. Also mounted within members **29***a* and **29***b* are metal spring elements (not shown) urging front member **18** back into normal operating position as soon as the plug mass is expelled. Adjustable stops (not shown) are provided such that the normal exit gap width **22***a* is set in the range of from ⅛ to ⅜ inch, or the value at which no net gas pressure difference exists on front element **18** in a direction parallel to axis **23**. The specific neutral pressure gap width may be established during spinning, for example, by temporarily releasing the front member from the spring biasing means and allowing it to swing free on its pivots and seek a position such that pressure on the web side (or "inside") is in balance with the ambient gas pressure on the opposite side ("outside"). Of course, appropriate allowance or correction may need to be made should the center of gravity of the front shield member not lie directly beneath the pivot points. As may be noted from FIGS. 2 and 3, the entrance edge of front member **18** has a configuration approximating a section of a toroid, thus "surrounding" a portion of baffle **8** and extending backward to a point close to the spinneret housing in order to restrict entrainment of ambient gas while still providing sufficient clearance for the occasional swinging motion required to relieve adventitious plugs.

The web facing surface of the front member of the aerodynamic shield must satisfy two requirements: (1) it should present approximately equal gas flow impedance at all radial directions at which the web may leave the rotary baffle in the vertical plane, and (2) the spacing between confronting surfaces of front and rear members should decrease on the average as the web moves radially through the shield from entrance to exit. This decreasing separation between shield members partially compensates for the increase in width of the gas stream as it flows along diverging radial directions within the vertical plane as directed by the contoured surface of the rotating baffle, and thereby keeps the cross-sectional area of the gas stream taken at right angles to its direction of flow from increasing so rapidly that excessive deceleration and sticking of the web to the shield can occur. The equal impedance criterion is met by a front shield member whose web facing surface is a section of a surface of revolution about the rotation axis of the baffle; and since the rear member's surface is approximately flat (apart from the annular steps), the convergence criterion can simultaneously be satisfied most simply by choosing the surface of the front member to be a segment of a right circular cone. The optimum angle of convergence (i.e., the angle between the vertical and a straight line tangent to the web-facing surface of the front member at two points proximate its entrance and exit edges, respectively, measured on a vertical cross section perpendicular to the web oscillation plane) is a function of the detailed contour of the baffle surface, the number and size of the steps in the rear shield member, etc. Fortunately, this convergence angle appears to be not too sensitive to variations in these parameters and a convergence angle of 5° has been found to be generally satisfactory. Various materials, e.g., Lucite®, nylon, Teflon® (trademark for Du Pont fluorocarbon resin), various filled nylons and Teflons®, Nema G (laminated glass/epoxy insulating materials), "Lexan," etc., can be used for members **17**, **18**, **26**, **28** and **30**, if desired.

In order to illustrate the improved uniformity of nonwoven sheets made possible by the present invention, particularly at higher productivities, a series of samples is prepared employing prior art apparatus and compared with a series of samples prepared with the present apparatus, using percent coefficient of variation of basis weight uniformity as the criterion.

PERCENT CV OF BASIS WEIGHT UNIFORMITY

A sheet of material about 500 inches long and at least 8 inches wide is used. Eighty 1-inch diameter circles are cut from the sheet along each of three rows, the center-center distances of these circles being about 3 inches in the width direction of the sheet and 6 inches in the length direction. The coefficient of variation (percent CV) of the weights of these 1 inch circles in each row is calculated and the average percent CV for the three rows is used as a measure of the sheet uniformity.

EXAMPLE

Linear polyethylene having a density of 0.95 g./cc. and a melt flow rate of 0.9 gram/10 minutes as determined by ASTM method D–1238–57T, condition E, is flash spun from a hot trichlorofluoromethane solution. The solution is continuously pumped to the spinneret assembly under high pressure. The solution then passes into a small chamber through a first orifice to reduce the pressure to the desired value for flash spinning, and is then immediately extruded into a region at substantially atmospheric pressure through a second (spin) orifice. Initial flash vaporization occurs inside a short cylindrical "tunnel" immediately downstream and coaxial with the spin orifice, which serves to shape the resulting high velocity gas and entrained strand. The resulting plexifilamentary strand passes along the surface of a rotating baffle which simultaneously spreads it, imparts lateral oscillation and directs it vertically downwards through a corona charging zone between a multineedle corona discharge electrode and a grounded target plate toward a moving belt, where it is collected in overlapping layers. The sheet is then lightly consolidated by passage between a pair of rolls under a pressure of about 45 lb./lineal inch. The speed of the laydown receiver is adjusted incrementally to obtain a set of nonwoven sheet samples of granduated basis weights.

TABLE 1

Sample	Solution: Conc., percent	Solution: Temp., °C.	Solution: Pres., p.s.i.g.	Tunnel, L/D	Flow rate (p.p.h. polymer)	Swath width (inches)	Web charge (microcoulombs/gm.)	Basis wt. (oz./yd.²)	Percent CV
Set A.—Aerodynamic shield, baffle edge to belt=13¼ inches, spin orifice=52±½ mils									
1	12.6	184	980	0.300″/0.300″	100.7	23.5	10	2.02	6.45
2	12.6	184	980	0.300″/0.300″	100.7	23.5	11	2.04	6.29
3	12.6	184	980	0.300″/0.300″	100.7	23.5	12	1.97	6.91
4	12.6	184	980	0.300″/0.300″	100.7	24	13	1.92	6.95
5	12.6	185	1,000	0.300″/0.300″	105.0	23.5	11	1.98	7.15
6	12.6	185	1,000	0.300″/0.300″	104.6	23.5	11	0.98	9.52
7	12.6	186	1,000	0.300″/0.300″	102.6	26	11	0.91	9.77
8	12.6	186	1,000	0.300″/0.300″	102.6	26.5	11	2.07	6.71
9	12.6	186	1,000	0.300″/0.300″	102.6	---------	12	0.91	9.56
10	12.6	186	1,000	0.300″/0.300″	102.6	27	13	0.86	9.70
Set B.—Scoop, baffle edge to belt=11¼ inches, spin orifice=44±2 mils									
11	12.6	185	1,060	0.266″/0.266″	70.6	27.5	11.8	2.01	7.50
12	12.6	186	1,060	0.234″/0.234″	68.6	26	11.5	2.15	8.17
13	12.2	186	1,000	0.234″/0.234″	72.6	22.5	11.7	0.91	12.44
14	12.2	186	1,000	0.234″/0.234″	72.6	23.5	11.1	0.95	12.01
15	12.6	187	1,100	0.234″/0.266″	85.3	24.5	10.1	1.15	10.94
16	12.6	186	1,060	0.234″/0.266″	76.6	26	11.9	2.14	8.24
17	12.6	186	1,060	0.234″/0.266″	76.6	26	11.9	2.14	7.60

Two sets of plexifilamentary sheet samples are prepared. Set A is prepared employing the aerodynamic shield of the present invention, using the preferred embodiment detailed in FIGS. 2 and 3, and having exit and entrance radii of 9½ and 2¼ inches, respectively, with a step height of 5/32 inch. For comparison, set B is prepared employing the best available prior art apparatus, namely, the "scoop" diffuser disclosed in U.S. Pat. No. 3,593,074 and in particular the embodiment described in Example 4 of the patent. For each set of samples the optimum available baffle designs are employed, together with the appropriate baffle-to-belt distance required to obtain a 25±2½ inch swath width for the plexifilamentary deposits on the belt. In addition, maximum possible sheet uniformity is sought by applying the highest electrostatic charge level to the web which can be tolerated without causing web "hangups," disruptive lightening discharges, etc. The specific parameters employed for each sample are listed in Table 1. All samples in set A are prepared employing a spin orifice sized to yield a nominal polymer throughput of 100 lbs./hr., while all samples in set B are prepared with a smaller orifice providing a nominal 75 lbs./hr. of polymer.

The percent coefficient of variation of basis weight uniformity is determined for the sheet samples within each set, as listed in Table 1, and the data are presented graphically in FIG. 4. Low values of percent CV, corresponding to the greatest degree of uniformity are, of course, preferred. It is apparent on comparing the curves for sample sets A and B, that substantially superior sheet uniformity is provided by the apparatus and process of the present invention, than can be achieved by the best prior art technology. This has been accomplished even at higher rates of productivity (100 versus 75 lbs./hr.) which, except for the benefits provided by the present invention, otherwise inherently lead to degradation in sheet uniformity. It has also been observed that the apparatus of the present invention provides the further advantages of less variable swath width from run-to-run and day-to-day, and substantially decreases sensitivity to other process variables such as equipment alignment, web charge, etc.

What is claimed is:

1. In a process for forming fibrous sheets that includes the steps of entraining a web in a gaseous stream flowing in a generally horizontal path toward one location on a baffle, directing and oscillating said web and said stream from said one location in a plurality of downward radial directions in a substantially vertical plane through ambient gas toward a collecting means, electrostatically charging the web, and collecting said web on said collecting means as a fibrous sheet, the improvement comprising: converging said stream below said baffle in said downward radial directions within a shield presenting substantially equal flow impedances in said radial directions for a distance of from 30 to 60 percent of the distance from said one location to said collecting means thereby maintaining the stream entrained web substantially as formed by said baffle and preventing premature mixing with said ambient gas.

2. The process as defined in claim **1**, including the step of aspirating said ambient gas into said shield generally in said downward radial directions through holes in said shield.

3. The process as defined in claim **1**, the step of electrostatically charging the web being accomplished within said shield.

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JAY H. WOO, Primary Examiner

U.S. Cl. X.R.

264—20.5; 425—174.8 E