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[11] 3,578,739

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[54] **APPARATUS FOR APPLYING ELECTROSTATIC CHARGE TO FIBROUS STRUCTURE**
8 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **18/8**
[51] **Int. Cl.** **D01d 9/00**
[50] **Field of Search** 18/8; 317/4

[56] **References Cited**
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3,277,526	10/1966	Hollberg	18/8
3,387,326	6/1968	Hollberg et al.	18/8
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ABSTRACT: An apparatus for electrostatically charging fibrous material being forwarded in a linear path that includes an ion gun and an opposed grounded target electrode positioned on opposite sides of the path. The electrode has a surface facing the ion gun that is covered by a dielectric material having a resistance measured at about 65° C. of between about 1×10^6 and 10^{10} ohms. Covering materials with resistances in this range minimize the disruptive effect on continuity of operation of polymer buildup on the target electrode.

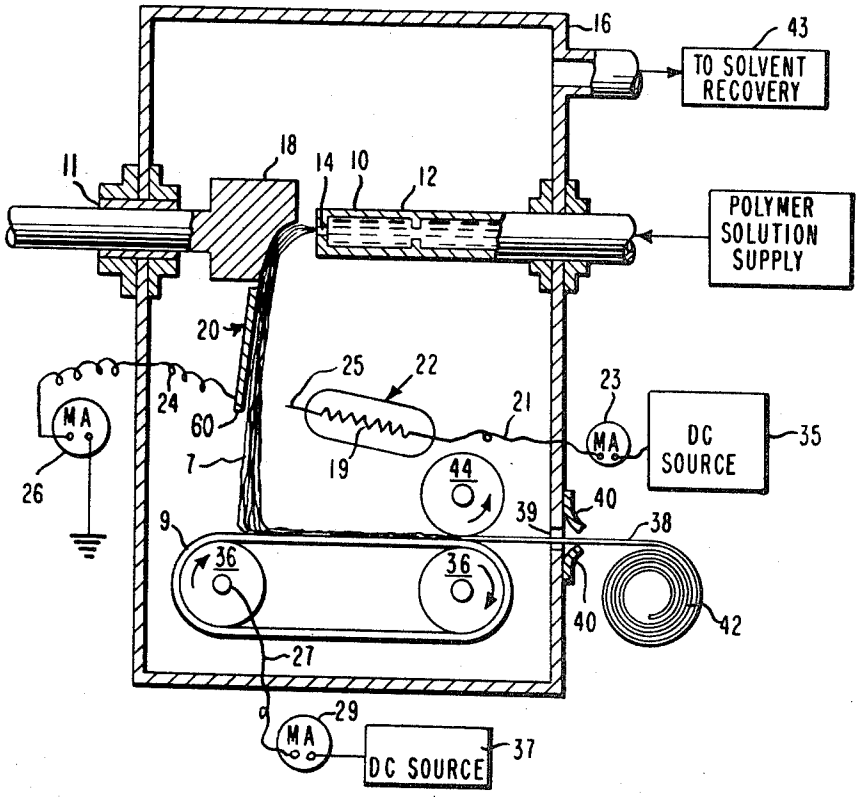


FIG. 1

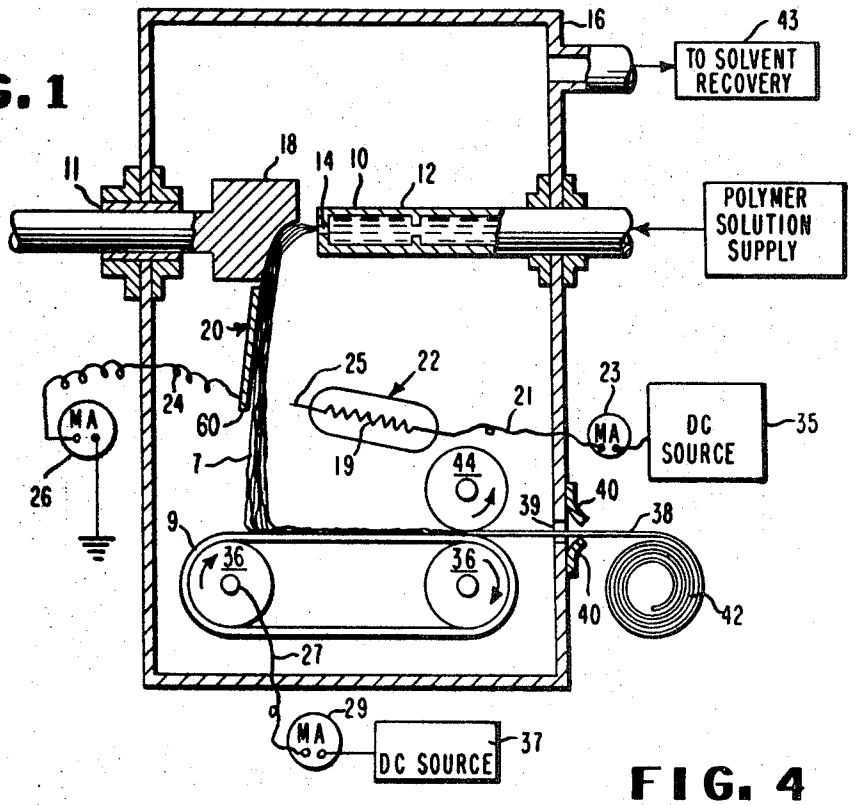


FIG. 2

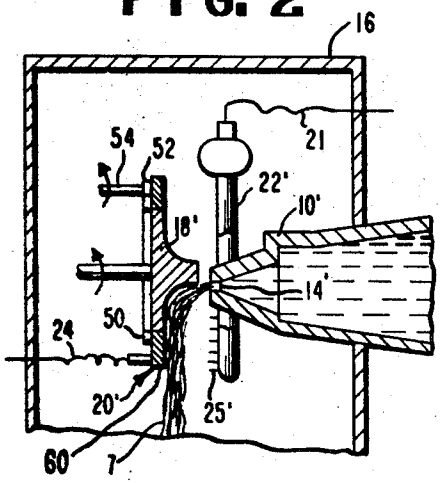


FIG. 3

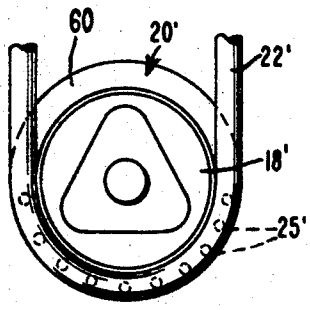
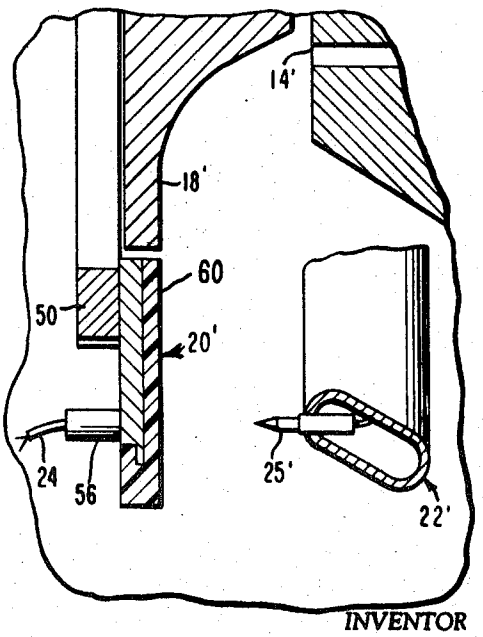


FIG. 4



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APPARATUS FOR APPLYING ELECTROSTATIC CHARGE TO FIBROUS STRUCTURE

BACKGROUND OF THE INVENTION

This invention relates to an improved apparatus for applying electrostatic charge to fibrous structures and depositing them on a moving receiver to form a nonwoven sheet. More particularly, it relates to an improvement in the target plate of a corona charging device which applies the electrostatic charge to the fibrous structures.

A means for charging a plexifilament is disclosed by Owens in U.S. Pat. No. 3,319,309, wherein horizontally flash-spun plexifilament immediately contacts an arcuate surface which spreads the plexifilament and directs it downward toward a moving collection belt. The arcuate surface may be oscillated to provide a traversing movement to the plexifilament. As the plexifilament continues downward, it crosses over an electrically conductive grounded target plate. Spaced oppositely from the target plate, and aimed at it, is an ion gun which provides a source of ionizing current. The ionizing current passes from the ion gun to the target plate through the gas-filled gap therebetween. Passage through the narrow gap between ion gun and target plate produces an electrostatic charge on the plexifilament. The charged plexifilament is then deposited on a moving receiver which is oppositely charged.

Associated with the flash spinning of fibrous structures is the generation of a small amount of tiny separated particles of solidified polymer. While this is particularly true of the production of plexifilaments, it is true to varying degrees for all flash spinning. These tiny particles become electrostatically charged like the endless fibrous structure, but, owing to their small mass and momentum, become attracted to the target electrode, rather than to the collection belt, and gradually form an electrically insulating film on the electrode. As the thickness of the film increases, the potential drop across it eventually exceeds its dielectric strength. Tiny craters then form through the film, which craters become sources of "back corona," i.e., large current density plasma jets of both polarities. This situation develops rapidly, when it occurs, and can be detected as a precipitous increase in current from the ion gun, i.e., corona discharge electrode. It causes neutralization of the charge on the plexifilament. Thereafter, the plexifilament does not spread out due to electrostatic repulsion of its elements, is not attracted to and held upon the collection belt, and tends to float above and to collect nonuniformly on the collection belt. The target electrode at this point is said to be "fouled," and the condition is described as "loss of electrostatic charging."

In order to postpone fouling, the target electrode has been constructed as an annulus and rotated so that the active area of its face continuously changes. An insulating film eventually forms over its whole face, nonetheless. Further postponement of fouling has resulted when a scraper blade has been mounted near the top, inactive portion of the rotating target plate to scrape off the deposited film. Still further postponement of fouling is provided by maintaining a conductive substance on the target plate surface facing the ion gun. For example, a conductive liquid is applied continuously to the surface by wiping the liquid onto the surface as the plate rotates.

Each of the above-described methods for delaying target plate fouling and prolonging continuity of operation has operated satisfactorily in the past and involves maintaining the target electrode at a low resistance level. However, efforts to increase throughput of flash-spun fibrous structures have been accompanied by increased generation of the tiny separated particles of solidified polymer that foul the target plates. In addition, higher throughputs have required higher current densities for efficient electrostatic charging of the plexifilaments. As a result, target plates become fouled more rapidly than in the past.

SUMMARY OF THE INVENTION

The purpose of the present invention is to provide an improved apparatus for electrostatically charging a continuous fibrous structure, which apparatus can operate efficiently even at high current densities and high throughput of the fibrous material.

In accordance with this invention, there is provided an apparatus for preparing nonwoven sheets from a continuous fibrous structure, including means for flash spinning the fibrous structure, means for applying an electrostatic charge to the fibrous structure by passage of the structure through a charging zone between a corona discharge electrode and a grounded target electrode and means for collecting the charged fibrous structure on an oppositely charged or grounded moving receiver. The target electrode has a conductive base that has a surface facing the corona discharge electrode which is covered by dielectric material having a high electrical resistance measured at about 65° C.

There are several desired characteristics for the high resistance facing. The facing must itself have a high dielectric strength in order to prevent electric breakdown and back corona through the facing layer. The breakdown potential of the facing in volts is simply the dielectric strength of the facing in volts per unit thickness multiplied by the facing thickness. This potential should be several fold higher than the operating voltage drop across the facing, which is given by the product of the current density j in 2, 2the volume resistivity of the facing e in ohm-cm and the facing thickness d in cm. The facing should be substantially solid, uniform, homogeneous and reasonably resistant to chemical or physical degradation due to the environment or to the adverse effects of the corona discharge. The use of a rotating annular electrode having a high resistivity facing is preferred because the facing need not be exposed continuously to ion bombardment; only about one-third of the surface is in the field. In addition, the inactive surface may be scraped continuously further minimizing buildup of the fouling layer. Equipment embodying the high resistance target plate should operate with the target plate taking about 25 percent or more of the total applied voltage drop (e.g., between corona discharge electrode and ground). The facing should have a resistance of between about 1×10^6 and 10^{10} ohms. The preferred range is between about 2×10^7 and about 4×10^8 ohms. Below resistances of about 10^6 ohms, the effect of the facing in postponing loss of electrostatic charging is lost. The upper values on resistance are determined from practical requirements such as the rating on the available power supply and the insulation of surrounding substances. If the resistance is too high, too high a voltage will be required to drive the current through the plate; hence current densities would have to be lowered and less efficient charging would occur. Since high resistance facings on the target plate require higher voltages, care must be exercised to avoid arcing from the corona discharge needles to an object other than the target plate.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional schematic elevation of an apparatus embodiment useful in the practice of the invention.

FIG. 2 is a partial cross-sectional schematic elevation of another apparatus embodiment particularly useful in the practice of the invention.

FIG. 3 is an elevation showing the relative positions of the ion gun, rotary baffle and target plate of FIG. 2, the spinneret nozzle being removed for clarity.

FIG. 4 is a partially sectioned fragmentary view of FIG. 2, showing the relationship of the target electrode to the ion gun and the construction of the electrode.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

FIG. 1, shows a spinneret device 10, connected to a source of polymer dissolved in an organic solvent. Polymer solution 12 under pressure is fed through spinning orifice 14 into web forming chamber 16. The extrudate from spinning orifice 14 is a plexifilament 7. Due to the pressure drop at spinning orifice 14 vaporization of solvent creates a vapor blast which follows the contours of baffle 18 concomitantly with plexifilament 7 from spinning orifice 14 to collecting surface 9. Baffle 18 is oscillatably mounted and is powered through seal 11 to oscillate by means not shown. While oscillation of the baffle is not essential, it provides suitable means for the preparation of wide sheets.

As shown, the target plate consists of two parts, a metallic portion 20 and a high resistance surface portion 60. The target plate and ion gun 22 are disposed on opposite sides of the path of advance of the plexifilament web 7 and downstream from the web-forming device. The metallic portion 20 of the target plate is connected to ground by wire 24 and microammeter 26 which indicates target plate current. Ion gun 22 contains multiple needles 25, one of which is shown in FIG. 1. Each needle 25 of ion gun 22 is connected to a DC source 35 through resistor 19. Each of the resistors is connected to the source of power through conductor 21. Milliammeter 23 serves to measure ion gun current. A DC source in the range of from 45 to 100 kilovolts may be used. The target plate is so disposed that the vapor blast originating at spinning orifice 14 and the air flow pattern in chamber 16 carry plexifilament web 7 in close proximity to the high resistivity surface on the target. After passing through an ionized charging zone created by a corona discharge between ion gun 22 and the target plate, the charged plexifilament web 7 is deposited on collecting surface 9. The surface illustrated is a continuous belt forwarded by drive rolls 36. The belt is grounded or given an opposite charge to that imposed on web 7 by means of DC source 37 which is connected to the collecting apparatus through milliammeter 29 and lead 27. Due to the opposite polarity between web 7 and surface 9 the web in its arranged condition clings to the surface as sheets 38 with sufficient force to overcome the disruptive influences of whatever vapor blast may reach this area. Surface 9 carries sheet 38 past compacting roll 44 and feeds the sheet out of chamber 16 through port 39 where it is collected on windup roll 42. Flexible elements 40 across port 39 assist in the retention of vapor within chamber 16. Roller seals or labyrinth seals may also be used. A conventional solvent recovery unit 43 may be beneficially employed to improve economic operation.

An alternative apparatus embodiment useful in the practice of the invention is shown schematically in FIGS. 2, 3 and 4. In FIGS. 2 and 4, the extrudate from orifice 14′ of spinneret device 10′ is carried around the curved surface of a lobed baffle 18′ into close proximity with the high resistance surface 60 of an annular target electrode. Baffle 18′ is continuously rotated to impart oscillatory movement to the network of film fibril material as it is deflected from the lobed surface. Annular target electrode 20′ is coupled, for rotary movement about baffle 18′ by means of ring 50 and pinion gear 52 attached to driven shaft 54. The metallic portion 20′ of the annular target electrode is connected to lead 24 through a contacting carbon brush 56. Ion gun 22′ is U-shaped and is connected to a DC source through lead 21. FIG. 3 shows the arrangement of U-shaped ion gun 22′ opposite the annular target electrode with the baffle 18′ centered within the electrode. Needles 25′ are arranged in the lower tubular portion of the ion gun 22′ such that the axes of the needles are generally perpendicular to the high resistance surface 60 of the target electrode (FIG. 4).

It is believed that postponement of the loss of electrostatic charging by the improved apparatus of this invention can be explained as follows. The target plate, or passive electrode, has a facing of dielectric or high volume resistivity material. This facing in effect simulates an infinite network of series and parallel resistors over the surface of the passive electrode. The simulated network acts as limiting resistors and consequently any back corona breakdown which is initiated due to a fouling deposit on the surface is restricted because of the limited amount of current that can be drawn to that spot.

In preparing nonwoven sheets from continuous fibrous structures uniform charging is required to maintain webs spread and to efficiently pin them to the collection surface. An electrostatic charge is imparted to the webs by passing them through the unipolar region over the surface of the target plates. The unipolar region is established by the flow of ions from the corona discharge device to the target plate. The charge captured by the fibrous structure is the same polarity as that of the discharge electrodes and the coulomb repulsion forces to maintain the web spread. The regions close to the discharge needles and the target plate surfaces have the highest charge densities. The glow region near the discharge electrode, however, is bipolar (i.e., both negative and positive charges are present) and tends to neutralize charges picked up by the web. Therefore, the unipolar region near the target plate should be used although the web could be charged anywhere outside the corona glow region.

When the tiny solid polymer particles, which are generated by the flash-spinning process enter the electrostatic field region, they get sprayed with ions, charged and then attracted predominantly to the grounded target plate to form a nonconducting layer. The voltage drop across the fouling deposit is given by the equation

$$V_1 = j\rho_1 d_1$$

where V_1 is the voltage drop across the deposite, j is the current density in amperes/cm.^{2}, ρ_1 is the volume resistivity of the deposit in ohm-cm. and d_1 is the deposit thickness in cm.

When voltage drop V_1 exceeds the breakdown potential V_2 of the fouling deposite, breakdown of the deposit occurs in the form of craters and back corona takes place. Positive and negative ions are produced in the craters. These ions in turn decrease the unipolarity of the region near the target plate and this results in loss of web charge.

When the target electrode has a facing material of high resistance in accordance with the improved apparatus of this invention, back corona is drastically reduced. The facing material functions to spread out the charging field, thus reducing current density. When some breakdown occurs in the fouling deposit and some back corona ensues, the high resistivity facing restricts the amount of current that can be drawn to the point of breakdown. Substantial loss of web charge from neutralization of oppositely charged ions in a back corona region is prevented for extended periods of time. Thus, the improved apparatus of this invention reduces the effects of fouling deposits, rather than altering the amount or nature of the deposit, thereby prolonging the periods of efficient web charging. By comparison, at high throughput of flash-spun polyethylene plexifilaments, the best target plate of the prior art operated efficiently for between 4—8 hours, whereas the improved target plates of this invention have operated satisfactorily in excess of 4 days.

The series of tests and procedures that established the range of electrical resistances that are suitable for the target plates of the improved apparatus of this invention is as follows.

The spinneret device of FIG. 2 is located over a moving belt similar to the one shown in FIG. 1. Nonwoven sheets are prepared at high throughput (i.e., about 60—80 pounds/hour/spinneret) from plexifilaments that are flash-spun from solutions of linear polyethylene in trichlorofluoromethane (Freon®-11). Target plates of the types shown in FIGS. 2—4 are used. The target electrode is conveniently 7.5 inches in outer diameter, 4 inches in inner diameter, and the metal portion about five-sixteenth inch thick. The outer trailing edge of the target plate comprises an extension of the facing into which the rim of the metal portion sets. This edge extends one-half inch beyond the end of the

metal portion and is contoured on the back side to avoid aerodynamic interference with the descending plexifilament. A U-shaped corona discharge electrode of the type shown in FIG. 3 is used. The discharge electrode has 10 needles spaced three-fourths inch apart or 20 needles spaced three-eighths inch apart, located on the 3-inch-radius portion of the electrode. The needle points are located five-eights inch from the target plate surface and about nine-sixteenths inch above the trailing edge of the target. A positive DC voltage is provided to the corona discharge needles. A current density of at least 5 microamps/cm.^{2} and a charge on the plexifilaments in excess of 5 microcoulombs/gram and preferably in excess of 8 microcoulombs/gram, are established as conditions of satisfactory charging.

The extent of fiber charging is indicated by the receiver or belt current measured by microammeter **29** (FIG. **1**). The belt mechanism is electrically insulated from ground except for the path through microammeter **29**. It has been found that substantially all of the current flowing from the corona discharge electrode is collected by either the target plate or by the collecting belt; thus

$$I_g - I_{tp} = I_b$$

where I_g equals the ion gun current, I_{tp} equals target plate current to ground, and I_b equals belt current to ground. The charge on the fibers is calculated from the belt current I_b and the polymer flow rate W by means of the equation:

$$\frac{I_b}{W} = Q$$

wherein I_b is the belt current in microamperes, W is the weight in grams of fiber passing between the discharge electrode and target plate per second, Q is the charge expressed in microcoulombs per gram.

The current density is determined from the target plate current to ground I_{tp}, measured by microammeter **26** (FIG. 1) and A, the area of the charging zone in cm.^{2} The area of the charging zone may be measured either in the spin enclosure or in the laboratory. In the spin enclosure, **16**, the procedure is to stop the target plate from rotating and allow the deposit from the spinning solution to build up on the plate. The deposits will outline the corona field. In the laboratory, polyethylene powder can be sprayed into the area between the discharge electrode and the target plate and it will take the outline of the field. Atmospheric conditions in the laboratory must be the same as spin conditions. The area outlined by the deposit is the charging area. For the series of tests described herein, the area of the charging zone measured about 40 cm.^{2}

The resistance of the target plate facing is determined as follows. First, without any flow of plexifilaments in the corona charging zone, the voltage required to maintain a given corona discharge current between the discharge electrode and a clean, bare metal target electrode is measured from the DC power supply meters. The corona current is measured by microammeter **23**. As noted above, the target electrode in this series of tests is located five-eighths inch away from the corona discharge needles. The total resistance of the ⅝-inch-thick gap and the resistance of a metal electrode are then calculated from the current and voltage by Ohm's law (i.e., the voltage drop equals the product of the current and resistance). The resistance of the gap alone is approximately equal to the total resistance, or may be obtained precisely by subtracting the resistance of the metal target electrode from the total resistance. The resistance of the gap depends on the gas composition, concentration, pressure and temperature as well as on the corona current density. For example, a ⅝-inch-thick gap between the corona-needle tips and the target plate surface, when filled with 92 to 99$^+$ percent Freon -11 (the remainder being air) at 65° C., shows the following relationship between current density and resistance:

Corona current density (μ amps/cm.^{2}):	Gap resistance (ohms)
3.75	1.78×10^8
5.00	1.50×10^8
7.50	1.21×10^8
10.00	1.05×10^8
12.50	0.92×10^8

The measurement of corona discharge current and voltage required to maintain this current is then repeated with a target electrode having a high resistance facing in place of the are metal target plate. The distance from the corona needles to the facing surface remains five-eighths inch and atmospheric conditions remain the same. From these measurements, the total resistance of the system is determined by Ohm's law as above. The resistance of the ⅝-inch-thick Freon ® gap, as determined from the above table and the resistance of the metal portion of the target electrode are then subtracted from the total resistance, to give the resistance of the target plate facing. The resistance of the metal portion of the target electrode is always negligible compared to the resistance of the gap or the resistance of the target plate facings of this invention.

In the series of high throughput flash-spinning tests to determine the suitable range of resistances for the target plates of this invention, several facing materials are tested. These tests include carbon-filled polymeric materials such as Hypalon® chlorosulphonated-polyethylene, Teflon ® poly (tetrafluroethylene), and neoprene, glass, sprayed Teflon®film, and bare metal. As an aid to maintaining good charging efficiency with the bare metal target electrode, deposits on the rotating electrode are removed by means of a scraper and a conductive fluid (i.e., Zelec®UN mixed monoand dialkyl esters of phosphoric acid) is wicked onto the metal surface. Still another type of target electrode with a high resistance surface is used. This plate comprises a perforated aluminum base having about 31.5 holes/in.^{2} each being 0.090-inch diameter, an outer ¼-inch-wide epoxy rim to prevent corona at a spray metal edge, and a sprayed 0.0022-inch-thick coat of paint on the surface. In these tests, efforts are made to maintain for long periods of efficient operation (i.e., corona current densities above 5μ amps/cm.^{2} and charge on the plexifilaments above 5 μ colombs/gram and preferably in excess of 7μ coul./gm.). Test results with Hypalon®faced target plates, the Hypalon being between one-sixth and one-eighth inch thick containing between 8.6 and 24 percent carbon, and having resistances between about 2 ×x **7 10**^{7} and 1.2×10^8 ohms, shows the plexifilament charge of above about 10 μ coul./gm. are maintained for up to 96 hours. Each of the tests is terminated without loss of efficient charging. A ⅛-inch-thick-glass faced target plate of 3.5×10^8 ohm resistance efficiently charges plexifilaments at 8.8 μ coul./gm. for more than 3 hours without loss of efficient charging. The paint-coated perforated target plate described above and having a resistance of about 3×10^6 ohms, also charges plexifilaments efficiently at 7.5 μ coul./gm. for more than 3 hours. Each of these tests was terminated for other reasons.

By contrast to the satisfactory results described above, a target plate with a facing resistance of 4×10^5 ohms operates efficiently for less than 10 minutes, at which time plexifilament charge reduces to about 2 ½μ coul./gm. which is insufficient to permit collection of satisfactory, uniform, nonropy sheet. In another test, the target plate facing resistance is too high, 1.2×10^{11} ohms, causing the corona field to spread out so for from the corona discharge needles that the current density in the charging zone on the target plate is so low that not enough charge can be placed on the plexifilament to make it pin to the belt. By further comparison with the satisfactory results described above, the bare metal electrode that is scraped and has a conductive fluid wicked onto its surface, charges the plexifilament satisfactorily for less than 80 minutes; within that time the charge on the plexifilament drops from 12.1 to less that 2 1/2 μ coul./gm., which is insufficient for satisfactory collection of sheet.

From above results, it is concluded that satisfactory produc-

tion of nonwoven sheets can be obtained at high electrostatic charging rates when a target electrode is used which has a facing of between about 10^6 and 10^{10} ohms and preferably between 2×10^7 and 4×10^8 ohms.

I claim:

1. In an apparatus for electrostatically charging a continuous fibrous material being forwarded in a path from a source to a collecting means including a charged ion gun and an opposed grounded target electrode positioned on opposite sides of said path between said source and said collecting means, the improvement comprising: said target electrode having a surface facing said ion gun, said surface being covered with a material having a resistance measured at 65° C. of between 1×10^6 and 10^{10} ohms.

2. The apparatus as defined in claim 1, said material having a resistance of from about 2×10^7 to about 4×10^8 ohms.

3. The apparatus as defined in claim 1, said collecting means being oppositely charged with respect to said fibrous material.

4. An apparatus for preparing nonwoven sheets from a continuous fibrous structure including means for flash spinning the structure, means for collecting the fibrous structure and means for charging said fibrous structure as it passes in a path from said spinning means to said collecting means, said charging means including a corona discharge electrode and an opposed grounded target electrode positioned on opposite sides of the path, and a direct current source connected to said discharge electrode, the improvement comprising: said target electrode having a conductive base, said base having a surface facing said discharge electrode, said surface being covered with a material having an electrical resistance measured at 65° C. of between 1×10^6 and 10^{10} ohms.

5. The apparatus as defined in claim 4, said material having an electrical resistance measured at 65° C. of between about 2×10^7 and 4×10^8 ohms.

6. The apparatus as defined in claim 4, said base being metal, said material being a carbon-filled polymeric material.

7. The apparatus as defined in claim 6, said polymeric material being chlorosulphonated-polyethylene.

8. The apparatus as defined in claim 6, said polymeric material being poly (tetrafluoroethylene).