METHOD AND APPARATUS FOR SPINNING
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This invention relates to the production of
artificial fibers and more particularly it relates
to the dispersion or scattering of streams of spin-
ning solution into comparatively fine fibers by
means of a high potential electrical field of cer-
tain characteristics and collecting said fibers sub-
stantially parallel to each other in the form of a
continuous fiber band on a moving collecting
device. The dispersion of a stream of spinning
solution into fibers by a high electrical potential
shall heretofore, for convenience, be referred to
as the "electrical spinning" of fibers.
In accordance with previously known apparatus
and methods for the electrical spinning of fibers,
for example, the apparatus and methods disclosed
in U. S. Patent 1,973,594 to Formhals, U. S.
Patent 2,705,691 to Morton and U. S. Patent 2,446-
651 to Norton, a number of difficulties have been
experienced. Due to the comparatively short
distance intervening between the solution feeding
device and the fiber collecting devices it was
exceedingly difficult to sufficiently completely dry
out the formed fibers, and as a result the said
fibers would tend to stick not only to the collect-
ing devices but also to each other. Furthermore,
in the previous methods the formed fibers would
not tend to collect in a compact closely aggregated
form. While this was due partly to the fact that
the collecting electrodes presented continuous
plunge or curved surfaces for receiving the fibers
and to the use of serrated devices for feeding
discontinuous quantities of spinning solution into
the high potential electrical field, the apparatus
would still not collect the fibers in a compact
concentrated fashion even though continuous
streams of spinning solution were fed into the
electrical field. Particularly when a plurality of
spinning nozzles was used it was found that the
streams, and the fibers formed from said streams,
would take different courses and paths to the col-
collecting device. In other words, while the paths
which the streams and fibers might take between
the feeding and the collecting devices were deter-
mained to an approximate degree by the relative
position of these devices to each other, it was not
possible to predetermine this path precisely and
constantly, nor was it possible to predetermine the
paths of all of the streams and fibers thereof
from in a perfect manner from the different nozzles.
A further difficulty of previous apparatus and
methods was experienced by the bothersome tend-
ency of certain stray fibers to become electrically
charged in the proximity of the collecting de-
vice, thereby tending to fly back into the field
toward the solution feeding device. The occur-
rence of this phenomenon may be quite trouble-
some and will seriously interfere with the con-
tinuity of operation of the process. Stray fibers
which thus fail to attach themselves permanently
to the collecting device and tend to fly back into
the proximity of the feeding device tend to become
attracted and attach themselves to various parts
of the solution feeding mechanism, for instance,
the spinning nozzles. As the fibers accumulate
and around the spinning nozzle they may ama-
as to a sufficient extent so as to cause serious
interference to the free and uninterrupted del-
delivery of spinning solution. In extreme cases
they may amass themselves around a spinning
nozzle and completely interfere with its satisfac-
tory delivery, thereby necessitating stopping and
cleaning of the apparatus.
The above and other difficulties have con-
tributed to the failure to heretofore obtain a
smooth, continuous manufacturing basis a con-
tinuous, compact, coherent fiber band composed
of heterogeneous artificial filaments arranged
substantially parallel to each other and being
capable, without additional textile operation, of
being drawn and twisted into threads or yarns of
good quality and strength on standard textile
machinery.
In order to overcome the aforesaid difficulties,
a method is employed, in accordance with the
present invention, which is fundamentally new
and which permits the use of simple apparatus
similar to the type used in the early days of elec-
trical spinning, when skeins of fiber could not be
produced, but only balls of fiber.
In order that the process and apparatus of the
present invention be more readily understood,
reference is made to the drawing, in which:
Fig. 1 represents a diagrammatic showing of
the phenomenon underlying the theory of the In-
vention.
Fig. 2 denotes, in diagrammatic perspective, an
alternative system for carrying out the invention;
Fig. 3 shows a further alternative system and
Fig. 4 shows, in part section, a shielding hous-
ing which may be employed with either of the
systems shown in Figs. 2 and 3.
The physical phenomenon, on which the new
process is based is shown in Fig. 1. The nozzle
10, preferably negatively charged, delivers a
fiber-forming material which, as a result of the
force of gravity, tends to fall down vertically.
Between the nozzle 10 and the counter-electrode
preferably positively charged, there is a high difference of potential, i.e., a high tension field exists between them, which causes the formation of the fibers. Under the conditions previously employed in the prior art fibers formed from the fiber-forming liquid, after they had left the nozzle were attracted by the counter-electrodes opposite which they collected in the form of a tangled ball. This invention consists essentially in the discovery that by producing a suitably high field intensity on the counter-electrodes relative to the electrode fixed at the point where the liquid is discharged it is possible, shortly before the fibers reach the counter-electrode, to reverse the attracting power of this counter-electrode into a repelling power, so that the fibers do not collect on the counter-electrodes. In order to produce this reverse effect it is only necessary to produce on the counter-electrode a field intensity of such magnitude as will cause the desired reverse effect. This is accomplished by producing high differences of potential and using a counter-electrode which presents a particularly sharp surface. The reversal effect, upon which the present invention is based cannot yet be explained entirely satisfactorily from a scientific point of view. Very probably, however, it is brought about as follows:

When the single fiber leaves the nozzle 10, as shown in Fig. 1, it is under the influence of gravity and also under the influence of the attraction of the electrode 11, since this electrode is of opposite polarity. The fiber therefore moves toward the sharp tip of the electrode 11, where there is the greatest field intensity. From the tip of the electrode 11 ions move toward the fibers 12. This phenomenon is well known in physics as "electric wind" or "ion wind" (cf. for example R. W. Pohl, "Elektrizitätstelehre," Berlin 1931, p. 175). The so-called "ion wind" is characterized by the fact that on the one hand charge-carriers move in a given direction, and on the other hand molecules of gas are carried along with these charge-carriers, so that a directed stream of gas is produced. This stream of gas endeavors to repel the fibers 12 from the electrode 11. At the same time, the charge-carriers emanating from the electrode 11 neutralize the charge on the fibers 12, and then charge the fibers with the same polarity as that of the electrode 11. The mechanical repulsion effect of the "ion wind" is thus strengthened by the electrical repulsion of the fibers 12 from the electrode 11. Under the influence of the purely mechanical action of the "ion wind," and as a result of the alteration in the charge of the fibers 12, the latter cannot collect upon the electrode 11; they approach to within a certain distance and are then repulsed.

If only one nozzle is used, far too little fiber is produced, and therefore would be expedient from an economic standpoint, to use a series of nozzles 10 in a row. It would also be necessary to provide a corresponding row of counter-electrodes 11. With this arrangement, the drum 13 would be very wide, and it would be covered with only a few fibers, which would lead to difficulties could be overcome if the fibers 12 were drawn out of the range of the electric field on a flat surface. A moving band of fibers could thus be formed, opposite to the row of electrodes 10, and as the fibers forming this band have received an opposite charge from the electrodes 11, this band of fibers would be of opposite polarity to those fibers whose charge had not yet been reversed. The band of fibers whose charge had been reversed would attract fibers whose charge had not yet been reversed, and would form a support for them.

From the foregoing it will be seen that it is of advantage to remove continuously the fibers which are first attracted and then repelled by the counter-electrode from the range of the electric field, and in such a way that they form a moving support for other fibers reaching them from the point where the liquid is discharged before their charge has been reversed by the counter-electrode.

In the apparatus for the practical operation of this, which is shown in Figs. 2 and 3, a large number of nozzles is provided and on different sides of each nozzle there are two counter-electrodes each of the same polarity, arranged in such a way as to attract to opposite sides the fibers which are formed from the liquid leaving the nozzles. There is such a high field intensity on the counter-electrodes that the fibers do not collect on them. Instead of consisting of separate tips, both the counter-electrodes of all the nozzles are formed of conductors so fine that there is a point repulsion effect along them, this effect being sufficiently great to prevent the fibers from collecting on them.

Fig. 2 shows an apparatus in which a number of nozzles 14 are arranged along a straight line. The nozzles 14 which are preferably negatively charged, are fixed on a distributing tube 15, and the fiber-forming liquid, which may be cellulose acetate, flows towards this tube from the storage tank 16 under the influence of the pressure which is produced by compressed gas in vessel 17. The pressure is preferably about 2 atm. Insulated conductors 18 and 19 are arranged below the rows of nozzles and parallel to it, on either side of it. The revolving device 20, which guides the fibers and which may, for instance, be in the form of a drum, is arranged in such a way that its direction of revolution is in accordance with the direction of the flow of the nozzles and of that of the conductors 18 and 19.

A high difference of potential is produced between the nozzles 14 and the conductors 18 and 19. An example of a successful difference of potential is about 50 kv. The potential of the nozzles 14 to earth is preferably about 55 kv, and that of the conductors 18 and 19 to earth is about 5 kv. Conductors 18 and 19 are of extremely thin wires of metal preferably of the piano wire type.

At first the liquid flows from the nozzles 14 in fine streams, falling vertically towards the earth. At the moment when the difference of potential is produced between the nozzles 14 and the wires 18 and 19, fibers begin to be formed, and streams of fiber are produced, flowing in principle in the direction shown in Fig. 2. Since two wires 18 and 19 are present, two streams of fiber are formed, flowing first towards the wire 18 or 19 respectively, then flowing away from these wires and finally falling towards the ground. The ends of the fiber which reach the ground are raised, for instance by means of a rod made of some insulating material, and placed on the revolving drum 26, which then draws them continuously out of the electric field. This forms a belt which moving fibers have the same polarity as the counter-electrodes 18 and 19. This belt of fibers forms a moving support for other fibers which have just been formed.
but which have not yet been repelled and had their charge reversed by the wires.

With the processes of the prior art, the distance between the point where the liquid leaves the nozzle and the fiber support always had to be comparatively small. There was therefore always the danger that when the fibers reached the drum, they would not be dry enough, and that they would stick. This danger does not exist in the process of the present invention. The device 28 which guides the fibers can be placed far enough from the row of nozzles for the fibers to be completely dry when they reach it.

In order to facilitate the conveyance of the fibers to the drum 29, a blast apparatus 21 may be provided to blow them towards this drum. The blast apparatus also helps to prevent the undesirable accumulation of fibers on the electrodes 18 and 19.

The apparatus shown in Fig. 3 is the same in principle as that shown in Fig. 2, except that the apparatus is curved in shape instead of being modelled on straight lines.

As shown in Fig. 3, a series of nozzles 22 is arranged in a closed curve, for instance in a circular form. The nozzles are fixed on to a ring-shaped liquid distributing tube 23, which is connected to the container 24 in which is a forming liquid, for example acetyl cellulose. The nozzles 22 are under a high potential, so that they form electric arcs at the same time. To each nozzle correspond two electrodes, also arranged in closed curves, which are on opposite sides of the curve on which the nozzles are arranged, but approximately concentric with this curve. Both the electrodes corresponding to each nozzle could be in the form of separate points.

Actually, in the apparatus illustrated in Fig. 3 all the counter-electrodes corresponding to the nozzles are in the form of conductors 25 and 26, curved in the same shape as the tube bearing the nozzles—i.e., in this example circular in form. The connection to the annular electrode 25 is surrounded by an insulator 27, to prevent sparking between it and the tube 23 or the nozzles 22.

After the fibers have passed between the two annular electrodes 25 and 26 which are below the nozzles 22, they are drawn through the device 28, stretched in another apparatus and then spun.

The device 29 for guiding or drawing off the fibers is formed a tube-shaped fibrous structure, which is very easy to spin.

In the types of apparatus illustrated in Figs. 2 and 3 it is desirable to use as many nozzles as possible and to have them as close together as possible. There is a critical distance, however, determined by experimentation for different sized systems, and the nozzles should not be closer together than this. If they are closer together, the repulsion effect exercised on each other by the fibers formed by various nozzles will become so pronounced that the fibers will not be distributed uniformly over the two counter-electrodes 25 and 26, and part of the nozzles 22 will be supplying only one counter-electrode 28, while another part of the nozzles is supplying only the other counter-electrode 26. Fig. 4 shows a further modification of the invention employing, in this instance, but a single wire rather than the two wires shown in Figs. 2 and 3. The fiber forming material enters the apparatus through a conduit 29 and is fed to a series of nozzles 30. These nozzles, as in the systems shown in Figs. 2 and 3, constitute the jet electrodes and are preferably negatively charged. A thin wire or knife edge 31 appropriately supported by insulators 32 constitutes the counter-electrode which is preferably positively charged. The formation of fibers 33 is the same as in the systems previously described. An air jet 34 may be employed to facilitate the continuous movement of the fibers from the point of formation to the collecting device 35. The whole system, including jet electrodes, counter-electrodes, and air blast are preferably enclosed within a housing 36 in order to facilitate recovery of the solvent. Part of the solvent may be condensed and recovered at the bottom of the apparatus while some may be swept by the air current through the air outlet 37, the solvent from this source being condensed in suitable apparatus and used again in the process.

What I claim as my invention is:

1. Apparatus for preparing fiber from a fiber forming liquid which comprises a plurality of nozzles disposed along a straight line and forming one pole of a high potential field, two very thin wires fixed and disposed below and extending substantially parallel to said nozzles, said wires being of polarity opposite to said nozzles, and means for continuously removing fibers formed between the wires and below the nozzles.

2. In a process for preparing fibers from fiber forming liquid wherein a current of said liquid is subjected to a high potential electric field causing fiber formation between an electrode disposed at the point at which the liquid is given off and a fixed counter-electrode remote therefrom and of opposite polarity, the improvement which comprises generating at the counter-electrode a field intensity of such magnitude that the fiber attracting effect of said counter-electrode, attained by the fibers immediately in front of the counter-electrode, is reversed into a repellant effect, so that the fibers are prevented from depositing on said counter-electrode and continuously removing said repelled fibers from said high potential electric field.

3. The process of claim 2 wherein the repelled fiber formed between the electrodes are utilized as auxiliary electrodes for the deposition of subsequently formed fibers.

4. The process as in claim 2 wherein charged fibers repelled by said counter-electrode are positioned on a collector surface, and function as auxiliary electrodes to attract additionally repelled fibers from the field of high potential, and wherein an inert gas is blown through said high potential field to facilitate the removal and collection of repelled fibers.

5. A process for preparing fibers from a fiber forming liquid which comprises ejecting a stream of said liquid into a field of high potential from a zone of one polarity toward a zone of opposing polarity to form fibers having a given electric charge, establishing an ionic draft in said latter zone adapted to repel said formed fibers and a reversal of their electric charge, and continuously removing the said formed and repelled fibers from the field of high potential.

6. A process for preparing fibers from a fiber forming liquid which comprises ejecting a plurality of streams of said liquid into a field of high potential from a zone of one polarity toward a zone of opposing polarity to form fibers having a given electric charge, establishing an ionic draft in said latter zone adapted to repel said
formed fibers and by a reversal of their electric charge, and continuously removing the said formed and repelled fibers from the field of high potential.

7. A process for preparing fibers from a fiber forming liquid which comprises ejecting a plurality of streams of said liquid into a field of high potential from a zone of one polarity toward an extended zone of continuity and opposing polarity to form fibers having a given electric charge, establishing an ionic draft in the said latter zone adapted to repel said formed fibers and by a reversal of their electric charge, and continuously removing the said formed and repelled fibers from the field of high potential.

8. The method of producing artificial fibers from fiber forming liquid of the character of acetylcellulose which comprises passing a stream of said liquid, from a source positioned at one electrode, into an electric high potential field between said electrode and a fixed counter-electrode of opposing polarity spaced apart from said first electrode, the current strength at said counter-electrode being sufficient to exert a repelling effect on the formed fibers before they contact and deposit on said counter-electrode, thereby attaining a floating equilibrium of the repelled fibers between the two electrodes, and continuously withdrawing said repelled fibers from the electric high potential field.

9. The method as in claim 8 wherein the fibers, attaining a floating equilibrium between the electrodes and withdrawn from the high potential field, are positioned as a support for later formed fibers, thereby functioning as an auxiliary electrode to continuously withdraw newly formed repelled fibers from the electric high potential field.

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