Oct. 29, 1946. H. G. HOUGHTON 2,410,215

SPRAY NOZZLE

Filed Oct. 24, 1944

FIG. 1

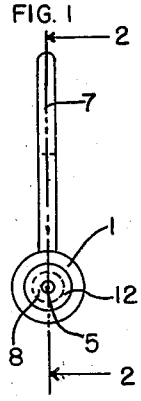


FIG. 2

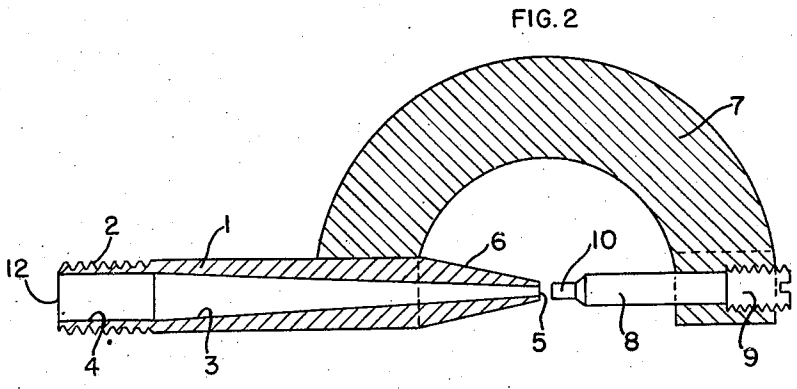
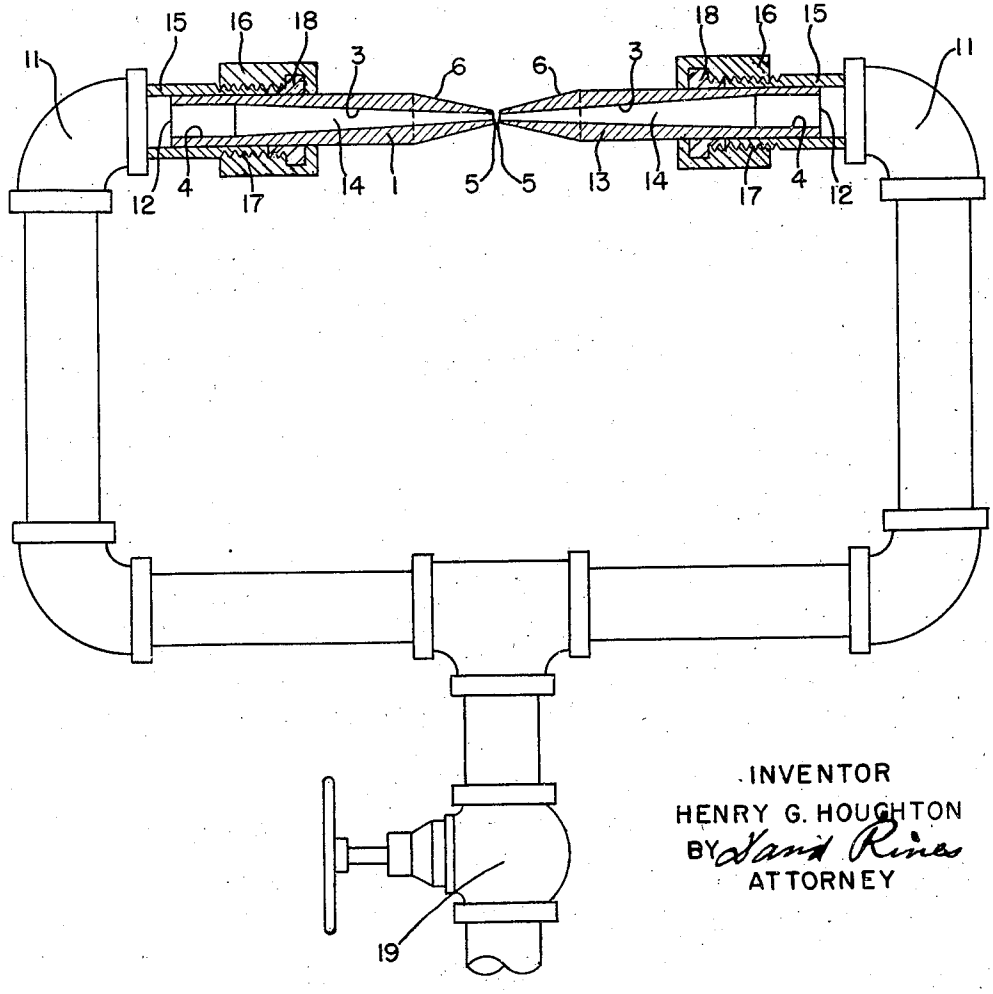


FIG. 3



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SPRAY NOZZLE

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Application October 24, 1944, Serial No. 560,110

22 Claims. (Cl. 299—130)

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The present invention relates to spray nozzles for producing a spray from a liquid that is forced therethrough under pressure. This application is a continuation-in-part of application, Serial No. 357,868, filed September 23, 1940.

According to present-day practice, the liquid is discharged from the nozzle, usually in the form of a thin conical expanding liquid sheet or film. Due to the inherent instability of this expanding sheet or film, and its impact on the air, it breaks up into liquid drops of various sizes. For some of the purposes for which spray nozzles have heretofore been employed, such as for extinguishing fires, this variation in drop size is generally unobjectionable. Cases arise, however, as in fog dissipation, the washing and cooling of gases, and other uses, where it is desirable to obtain as many liquid drops as possible within a specified-size range. Even in humidifiers, a greater proportion of the water would be evaporated if the drops were of more uniform and small size.

An object of the present invention, therefore, is to increase the degree of uniformity of drop size produced by spray nozzles.

The reason for the large variation in size of the drops produced by the sprays of present-day nozzles is that a large proportion of the liquid sprayed is in the form of drops that are of much larger diameter than desired according to the present invention. Only a fraction of the liquid is discharged in the form of drops within the desired-size range.

Another object of the present invention accordingly, is to reduce the number of drops of maximum size produced in the spray, or even to eliminate such large-size drops altogether.

In researches leading to the present invention, it has been discovered that the uniformity of drop size may be increased and the number of very large drops decreased if laminar flow is maintained in the fluid streams and the fluid sheet of the spray nozzle. In laminar flow, sometimes called viscous flow, all the fluid particles move in substantially straight lines parallel to the axis of the stream or along the radii of a circular or conical fluid sheet. Laminar streams and sheets are easily recognized by the characteristic that they are perfectly smooth and transparent (if the fluid is transparent).

In turbulent flow, on the other hand, the fluid particles pursue very irregular and erratic paths. Turbulent streams and sheets appear rough and are usually semi-opaque.

It has been found that if the Reynolds' number, which is equal to

$$\frac{\text{The diameter of the stream times the velocity of the stream}}{\text{The kinematic viscosity of the fluid}}$$

is less than the critical value, usually taken as about 2,300, the flow will be laminar or will be-

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come laminar even though initially turbulent, if sufficient length of flow is permitted. On the other hand, if the fluid is initially non-turbulent and care is exercised, laminar flow may be maintained at Reynolds' numbers somewhat in excess of the critical value.

In present-day nozzles of ordinary capacity, operating at the usual fluid pressures, the Reynolds' number is well above the critical value. The flow through the nozzle, therefore, is ordinarily rough or turbulent, producing turbulent liquid sheets when discharged from the nozzle. For example, in a nozzle with an orifice diameter of 0.10 inch, spraying water at a pressure of 100 pounds per square inch, the Reynolds' number at the orifice is about 94,000. It is the turbulence of the fluid sheet, as has been demonstrated by researches leading to the present invention, that is responsible for the wide variation in drop size.

If the Reynolds' number is less than the critical value, the flow will be laminar, or non-turbulent, regardless of the construction of the nozzle. If, on the other hand, the Reynolds' number is in excess of the critical value, the flow may or may not be laminar, depending upon the nozzle construction. It is under these circumstances that the construction of the nozzle becomes important. And as the Reynolds' number increases more and more above the critical value, it becomes more and more difficult to produce a construction of nozzle that shall maintain the laminar flow.

It will be observed, from the above formula, that the Reynolds' number is directly proportional to the diameter of the stream and to its velocity. The velocity, in turn, increases with the square root of the pressure. It therefore follows that there is no difficulty whatever involved in producing a laminar stream, with almost any apparatus, provided only that the diameter of the stream be kept low enough, and the pressure of the stream be kept also low, say, from 5 to 15 pounds per square inch. But a laminar stream of this character would find little or no practical application. Simple computation will demonstrate that the nozzle orifice would have to be so extremely small that it could produce only a very small discharge, and would become continually obstructed, in use. The degree of fineness of the drops, moreover, produced by any spray nozzle is dependent upon the fluid pressure. At low pressures, only a minimum number of drops of liquid would be produced, and of relatively very large size. To obtain the necessary fineness of drop size, the pressure must be substantially higher than the 15 pounds per square inch before mentioned; for a commercial nozzle, capable of discharging, say, from ½ to 100 or more

gallons per minute, the pressure would have to be at least 50 to 200 pounds per square inch.

A further object of the invention, therefore, is to discharge the fluid, under high pressure, through a large-size orifice, in the form of a smooth laminar or non-turbulent stream, at Reynolds' numbers up to 600,000.

It has further been demonstrated in researches leading to the present invention that laminar fluid sheets can be formed only when the streams forming the sheet are laminar. A further object of the invention is to provide novel apparatus for producing a laminar fluid sheet from a laminar fluid stream or streams.

The attainment of the results obtained by the present invention has not been possible heretofore. It has not been appreciated that, using large-enough nozzle apertures, and high-enough pressures, uniform-size drops could be attained at all, whether or not with the aid of laminar streams. No one has heretofore known that a laminar fluid stream, sheet or cone could produce drops of more uniform size than a turbulent fluid stream, sheet or cone. There is no a priori reasoning upon which it could have been predicted that a laminar sheet would break up into drops of uniform size.

Another object of the invention is to produce a maximum number of drops of a specified size range.

A further object of the invention is to provide novel apparatus for producing a novel disc-shaped sheet.

The usual cause of failure of present-day nozzles in their erosion by the liquid flowing therethrough. In the case of laminar flow, on the other hand, the velocity of flow, at the boundaries, is substantially zero and erosion is thereby reduced to a minimum.

Still another object of the invention, accordingly, is to reduce this erosion to a minimum.

Other and further objects will be explained hereinafter, and will be particularly pointed out in the appended claims.

The invention will now be more fully explained in connection with the accompanying drawing, in which Fig. 1 is an end view of one form of spray nozzle adapted to the formation of a laminar liquid sheet in accordance with the present invention; Fig. 2 is a longitudinal section of the same, taken upon the line 2—2 of Fig. 1, looking in the direction of the arrows; and Fig. 3 is a similar section of a modification, parts of the fluid system being shown in elevation. The fluid system is omitted from Figs. 1 and 2, for clearness.

The improved nozzle 1 of the present invention may be held by a packing nut 16 in a bushing 15, which is coupled to a liquid-supply pipe 11. The nozzle 1 may, however, be coupled to the pipe 11, directly by means of screw threads 2. Liquid is forced under pressure from the supply pipe 11, through an entrance aperture 12 of the nozzle, into a longitudinally disposed interior passage 14 of the nozzle, toward a discharge aperture or orifice 5. The stream of liquid in the passage is discharged through the orifice 5, either against an enlarged extension end 10 of a pin 8, screwed or otherwise held at 9 in a terminal boss or yoke 7, as illustrated in Figs. 1 and 2, or against a similar stream issuing from a similar orifice 5 of a similar nozzle 13, as illustrated in Fig. 3. The pin 8 and the said similar nozzle 13 are each oppositely disposed to the first-named nozzle 1, along the same longitudinal center line or axis as

the longitudinal center line or axis of the nozzle 1. In the latter case, the orifices 5 will be of substantially the same diameter. In the former case, the stream will be discharged against the extension 10 of the pin 8. The sheet or film produced with the apparatus of Fig. 3 will be substantially in a plane at right angles to the line joining the longitudinal axes or center lines of the passages 14 of the nozzles 1. The liquid streams, if they are suitably spaced apart, will then become transformed into a continuous disc-shaped laminar sheet. Using the apparatus of Figs. 1 and 2, however, the sheet or film will be in the form of substantially a right-circular cone, inclining away from the nozzle 1, and with the axis of the cone coinciding substantially with the longitudinal center line or axis of the passage 14 of the nozzle 1.

The entrance aperture 12 of each longitudinally disposed nozzle is shown relatively large compared to the discharge orifice 5. These relative dimensions result from the fact that, though the diameter of the entrance aperture 12 is nearly the same as that of the cylindrical exterior of the major portion of the nozzle 1, the orifice 5 is disposed at the reduced small tip of an externally conical extension 6 of the nozzle 1. It has been found that if the interior surface 3 of the longitudinally disposed passage 14 of the nozzles 1 and 13 be made conical and of small apex angle for a relatively large distance, and that if these nozzle passages extend uninterruptedly and unobstructed between the entrance aperture 12 and the orifice 5, then the stream of fluid in these passages will be laminar for a short distance from the orifice 5. After leaving the orifice 5, of course, the stream is cylindrical.

It is not essential that the entire passage 14 be conical; a very small portion 4 thereof, near the entrance aperture 12, indeed, is shown cylindrical. The cylindrical portion 4, however, and the conical portion 3 form a continuous uninterrupted surface between the entrance aperture 12 and the discharge orifice 5.

The dimensions of the nozzle may, however, vary over wide limits. Nozzles embodying the invention have been used with 0.030 inch-diameter orifices, with a maximum cone diameter of 0.25 inch; or the nozzles may have 0.63 inch-diameter orifices or more, with a maximum cone diameter of 3 inches or more. As the size of the nozzle increases, it becomes more and more difficult to produce a laminar stream, but this result may be attained with orifices between 0.030 inch and 0.63 inch diameter or more, and maximum cone diameters of between 0.25 inch and 3 inches or more. In general, it is desirable to use as long a conical section, or as small an included angle, as possible, but the larger the nozzle orifice, the smaller should be the cone angle. As no exact law can be given, it is necessary to experiment to determine the best dimensions in a given case. It appears to be necessary that the length of the conical surface 3 be large compared to its maximum diameter, say, four to twenty or more times as large, and that the maximum diameter of the conical surface be, say, four to twenty or more times as large as the diameter of the orifice 5.

The uninterrupted long narrow-angle conical approach to the orifice 5 is an important feature of the present invention, as it provides a very efficient medium for producing a laminar liquid sheet. If the cone angle is too large, or if it is not conical, but rounded, or if the conical angle

is separated from the orifice 5 by a cylinder, it becomes impossible to produce a laminar stream issuing through the orifice 5, or a laminar sheet after it leaves this orifice.

The yoke 7 is relatively thin, as shown in Figs. 1 and 2, so as to offer a minimum of interference to the liquid sheet issuing from the orifice 5. The free end of the extension 10 of the pin 8, opposite the orifice 5, is carefully squared off and smoothly finished, and may be constituted of any suitable material that will resist the erosive action of the liquid issuing thereon from the orifice 5.

The separation of this pin extension 10 from the orifice 5 should be adjusted so that the laminar stream formed in the passage 5 shall remain laminar at the time that it meets this pin extension. It is not possible to calculate exactly the position that the pin extension 10 should occupy, but it may readily be determined by adjusting the pin 8 back and forth in the yoke 7, as by means of the thread 9, until the resulting sheet or film of liquid issuing from the free end of the pin 10 is seen to be in true laminar form, as may be evidenced by its smoothness and its transparency.

It has been found that true axially alined conical passages of the above-described character, each 2½ inches long, with the larger diameter ⅜ of an inch, and the smaller diameter 0.07 inch, will operate efficiently if separated about 0.05 inch. The ratio of the spacing between the opposed orifices to the orifice diameter should decrease as the orifice diameter is increased. For orifices about 0.030 inch in diameter, the spacing may be from about 0.03 inch to 0.06 inch; for orifices 0.63 inch in diameter, the spacing may be about 0.32 inch or somewhat less.

The nozzles 1 and 13 may be adjusted back and forth relatively to each other by loosening the packing nuts 16, which are fitted with threads 17, and sliding the nozzles within the sleeves 15 until the streams issuing from the orifices 5 are observed to be in laminar form, thereby producing a disc-shaped laminar sheet concentric with and perpendicular to the common axis of the passages 14. Leakage of fluid may be prevented by filling the space 18 with suitable packing material.

According to the modification of Figs. 1 and 2, the liquid stream will become transformed into a continuous conical laminar sheet. The included angle of this conical fluid sheet may be varied by varying the diameter of the free end of the pin extension 10; for this included angle increases with the diameter of the free end of this pin extension 10.

Exceedingly small erosion is produced with the apparatus of Fig. 3, because the streams issuing from the orifices 5 engage against each other, and not against any additional surface. The only engagement of the liquid is against the walls of the long conical passages 3, and since the flow is laminar, the velocity of the liquid against the walls of these passages, as before stated, is practically zero, reducing erosion of the nozzle by the liquid to a minimum.

The laminar sheet produced by impacting the laminar stream issuing from the long uninterrupted conical passage 3 of the nozzle 1 against the smooth coaxially disposed pin extension 10, positioned close to the orifice 5, as in Figs. 1 and 2, or against another similarly disposed similarly positioned coaxial stream, as in Fig. 3, breaks up in a much more uniform manner than turbulent sheets, resulting in the formation of a much

larger number of drops of a given size from a given total quantity of liquid. To obtain a maximum number of drops of predetermined size, it is sometimes necessary to adjust also the pressure, as by means of a valve 19, as higher pressures, though involving increased cost of operation, produce usually smaller drops. At the same pressure, however, the nozzles of the present invention will form more drops within a given-size range than present-day nozzles of the same capacity. As appears from the following table, from two to three times as many drops in a desired-size range may be produced by the nozzles of the present invention as are obtainable from conventional nozzles, using the same quantity of liquid, at the same liquid pressure. The table is copied from page 36 of a paper by H. G. Houghton and W. H. Radford, entitled, "On the Local Dissipation of Natural Fog," published as volume VI, No. 3, of "Papers of Physical Oceanography and Meteorology," by the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, October, 1938, and the results were obtained at a pressure of approximately 50 pounds per square inch.

TABLE II

Drop size distribution data for the spray nozzles used

Nominal diameter of drop group, microns	Number of drops in each size group formed when a total of 1 cc. of solution is sprayed	
	Original nozzle	Improved nozzle
50	43,000	107,000
100	22,200	84,000
150	16,800	43,500
200	10,300	28,600
250	6,500	18,900
300	4,500	9,900
350	2,300	4,250
400	2,000	2,700
450	1,900	1,400
500	1,600	1,100
550	900	550
600	800	370
650	600	180
700	400	90
800	300	
900	150	

It has been stated above that laminar streams may be produced with almost any construction, provided that the dimensions be small enough and the fluid pressure low enough. The present invention, on the other hand, is capable of operation, and has been operated, under conditions yielding very high Reynolds' numbers—as high as 600,000 has actually been attained. The Reynolds' number may, however, be as low as 20,000.

It has been stated above that the invention finds use in fog dissipation. It is by no means, however, limited thereto. It has been successfully applied also to the washing and cooling of blast-furnace gas, and in other similar operations. It has been proven that drops of uniform size are more effective for the washing and cooling of gases than drops of a wide range of sizes. Both of these operations depend on exposing the maximum amount of surface for a given amount of water, and as very small drops evaporate too rapidly to be of value, the drops should be of fairly uniform size. The formation of very large drops, as in present-day nozzles, is especially disadvantageous. The laminar fluid sheet produced with the aid of the nozzle of the present inven-

tion, on the other hand, does not form these large drops. Since continuous operation of the nozzles, over periods of several months, is required, moreover, it is essential that the erosion of the nozzles be a minimum. This result also follows from the laminar flow within the orifices of the nozzle of the present invention.

Further modifications will occur to persons skilled in the art and all such are considered to fall within the spirit and scope of the invention, as defined in the appended claims.

What is claimed is:

1. A spray nozzle having a liquid discharge orifice of about 0.030 inch diameter, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle and having a maximum cone diameter of about 0.25 inch, and the distance of the conical passage in the region of the discharge orifice being large compared to the said maximum diameter of the conical passage, whereby the liquid will issue from the orifice in the form of a laminar stream.

2. A spray nozzle having a liquid discharge orifice of about 0.63 inch diameter, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle and having a maximum cone diameter of about 3 inches, and the distance of the conical passage in the region of the discharge orifice being large compared to the said maximum diameter of the conical passage, whereby the liquid will issue from the orifice in the form of a laminar stream.

3. A spray nozzle having a liquid discharge orifice, a liquid entrance aperture of diameter about four to twenty times as large as the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle for a length in the region of the orifice that is about four to twenty times as large as the maximum diameter of the conical passage, whereby the liquid will issue from the orifice in the form of a laminar liquid stream.

4. A spray nozzle having a liquid discharge orifice, a liquid entrance aperture of diameter about four to twenty times as large as the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle for a length in the region of the orifice that is about four to twenty times as large as the maximum diameter of the conical passage, whereby the liquid will issue from the orifice in the form of a laminar stream, and a pin disposed opposite to the orifice against which the liquid is adapted to impinge as it issues from the orifice, the axis of the pin being substantially along the axis of the passage, and the pin being positioned at a distance from the orifice such that the liquid shall impinge upon it in laminar form to produce a laminar liquid sheet.

5. A spray nozzle having a liquid entrance aperture of relatively large diameter, a liquid discharge orifice of relatively small diameter and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle for a length in the region of the discharge orifice that is large compared to the maximum diameter of the conical passage, and the dimensions of the nozzle being such that when liquid is supplied under pressure at the entrance aperture the liquid will issue from the orifice in the form of a laminar stream under conditions such that

$$\frac{\text{The diameter of the stream times the velocity of the stream}}{\text{The kinematic viscosity of the fluid}}$$

yields a value between about 20,000 and 600,000 at the orifice.

6. A spray nozzle having a liquid entrance aperture, a liquid discharge orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle for a length in the region of the discharge orifice that is about four to twenty times as large as the maximum diameter of the conical passage, the said maximum diameter of the conical passage being about four to twenty times as large as the diameter of the orifice, and the dimensions of the nozzle being such that when liquid is supplied under pressure at the entrance aperture the liquid will issue from the orifice in the form of a laminar stream under conditions such that

$$\frac{\text{The diameter of the stream times the velocity of the stream}}{\text{The kinematic viscosity of the stream}}$$

yields a value between about 20,000 and 600,000 at the orifice.

7. A spray nozzle having a liquid entrance aperture of relatively large diameter, a liquid discharge orifice of relatively small diameter and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle for a length in the region of the discharge orifice that is large compared to the maximum diameter of the conical passage, the dimensions of the nozzle being such that when liquid is supplied under pressure at the entrance aperture the liquid will issue from the orifice in the form of a laminar stream under conditions such that

$$\frac{\text{The diameter of the stream times the velocity of the stream}}{\text{The kinematic viscosity of the stream}}$$

yields a value between about 20,000 and 600,000 at the orifice, and means disposed opposite to the orifice against which the liquid is adapted to impinge as it issues from the orifice, the means being positioned at a distance from the orifice such that the liquid shall impinge upon it in laminar form to produce a laminar sheet.

8. A spray nozzle having a liquid discharge orifice of about 0.030 to 0.63 inch diameter, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle and having a maximum cone diameter of about 0.25 to 3 inches, and the length of the conical passage in the region of the discharge orifice being large compared to the said maximum diameter of the conical passage, whereby the liquid will issue from the orifice in the form of a laminar stream.

9. A spray nozzle having a liquid discharge orifice of about 0.030 to 0.63 inch diameter, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninter-

ruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle and having a maximum cone diameter of about 0.25 to 3 inches, the length of the conical passage in the region of the discharge orifice being large compared to the said maximum diameter of the conical passage, whereby the liquid will issue from the orifice in the form of a laminar stream, and a pin disposed opposite to the orifice against which the liquid is adapted to impinge as it issues from the orifice, the axis of the pin being substantially along the axis of the passage, and the pin being positioned at a distance from the orifice such that the liquid shall impinge upon it in laminar form to produce a laminar sheet.

10. A spray nozzle having a liquid discharge orifice of about 0.030 to 0.63 inch diameter, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle and having a maximum cone diameter of about 0.25 to 3 inches, the length of the conical passage in the region of the discharge orifice being large compared to the said maximum diameter of the conical passage, and means disposed opposite to the orifice against which the liquid is adapted to impinge as it issues from the orifice, the means being positioned at a distance from the orifice such that the liquid shall impinge upon it in laminar form to produce a laminar sheet.

11. A spray nozzle having a liquid entrance aperture of relatively large diameter, a liquid discharge orifice of relatively small diameter and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle for a length in the region of the discharge orifice that is large compared to the maximum diameter of the conical passage, the dimensions of the nozzle being such that when liquid is supplied under pressure at the entrance aperture the liquid will issue from the orifice in the form of a laminar stream under conditions such that

$$\frac{\text{The diameter of the stream times the velocity of the stream}}{\text{The kinematic viscosity of the fluid}}$$

yields a value between about 20,000 and 600,000, at the orifice, and a pin disposed opposite to the orifice against which the liquid is adapted to impinge as it issues from the orifice, the axis of the pin being substantially along the axis of the passage, and the pin being positioned at a distance from the orifice such that the liquid shall impinge upon it in laminar form to produce a laminar sheet.

12. A spray nozzle having a liquid entrance aperture of relatively large diameter, a liquid discharge orifice of relatively small diameter, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle for a length in the region of the discharge orifice that is large compared to the maximum diameter of the conical passage, the dimensions of the nozzle and the length of the conical passage being such that the nozzle will produce a laminar stream under a pressure substantially higher than 15 pounds per square inch, and means disposed opposite to the orifice against which the liquid is adapted to impinge as it issues from the orifice, the means being positioned at a distance from the orifice such that the liquid shall impinge upon it in laminar form to produce a laminar sheet.

13. A spray nozzle having a liquid discharge orifice, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle for a length in the region of the discharge orifice large compared to the maximum diameter of the conical passage, the dimensions of the nozzle and the length of the conical passage being such that the nozzle shall produce a laminar stream under a pressure substantially higher than 15 pounds per square inch.

14. A spray nozzle having a liquid discharge orifice, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle for a length in the region of the discharge orifice large compared to the maximum diameter of the conical passage, the dimensions of the nozzle and the length of the conical passage being such that the nozzle shall produce a laminar stream under a pressure substantially higher than 15 pounds per square inch, and a pin disposed opposite to the orifice against which the liquid is adapted to impinge as it issues from the orifice, the axis of the pin being substantially along the axis of the passage, and the pin being positioned at a distance from the orifice such that the liquid shall impinge upon it in laminar form to produce a laminar liquid sheet.

15. A spray nozzle having a liquid discharge orifice of about 0.030 to 0.63 inch diameter, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle and having a maximum cone diameter of about 0.25 to 3 inches, and the length of the conical passage in the region of the discharge orifice being large compared to the said maximum diameter of the conical passage, the dimensions of the nozzle and the length of the conical passage being such that the nozzle shall produce a laminar stream under a pressure substantially higher than 15 pounds per square inch.

16. A spray nozzle having a liquid discharge orifice of about 0.030 to 0.63 inch diameter, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the passage being conical of relatively small apex angle and having a maximum cone diameter of about 0.25 to 3 inches, the length of the conical passage in the region of the discharge orifice being large compared to the said maximum diameter of the conical passage, the dimensions of the nozzle and the length of the conical passage being such that the nozzle shall produce a laminar stream under a pressure substantially higher than 15 pounds per square inch, and means disposed opposite to the orifice against which the liquid is adapted to impinge as it issues from the orifice, the means being positioned at a distance from the orifice such that the liquid shall impinge upon it in laminar form to produce a laminar sheet.

17. Apparatus of the character described comprising two nozzles each having a liquid discharge orifice, a liquid entrance aperture of di-

ameter about four to twenty times as large as the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the nozzles being disposed with their orifices adjacent to each other and with the axes of their passages substantially coincident, each passage being conical of relatively small apex angle for a length in the region of the orifice that is about four to twenty times as large as the maximum diameter of the conical passage, whereby the liquid will issue from the orifices in the form of laminar streams, the orifices being separated from each other by a distance such that the liquid streams will impinge upon each other in laminar form to produce a laminar liquid sheet.

18. Apparatus of the character described comprising two nozzles each having a liquid entrance aperture of relatively large diameter, a liquid discharge orifice of relatively small diameter and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the nozzles being disposed with their orifices adjacent to each other and with the axes of their passages substantially coincident, each passage being conical of relatively small apex angle for a length in the region of the corresponding discharge orifice that is large compared to the maximum diameter of the conical passage, the dimensions of each nozzle being such that when liquid is supplied under pressure at the corresponding entrance aperture the liquid will issue from the orifices in the form of laminar streams under conditions such that

$$\frac{\text{The diameter of the stream times the velocity of the stream}}{\text{The kinematic viscosity of the fluid}}$$

yields a value between about 20,000 and 600,000 at the orifice, and the orifices being separated from each other by a distance such that the liquid streams shall impinge upon each other in laminar form to produce a laminar sheet.

19. Apparatus of the character described comprising two nozzles each having a liquid entrance aperture of relatively large diameter, a liquid discharge orifice of relatively small diameter, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the nozzles being disposed with their orifices adjacent to each other and with the axes of their passages substantially coincident, each passage being conical of relatively small apex angle for a length in the region of the discharge orifice that is about four to twenty times as large as the maximum diameter of the conical passage, the said maximum diameter of the conical passage being about four to twenty times as large as the diameter of the corresponding orifice, and the dimensions of each nozzle being such that when liquid is supplied at the entrance aperture the liquid will issue from the orifices in the form of laminar streams under conditions such that

$$\frac{\text{The diameter of the stream times the velocity of the stream}}{\text{The kinematic viscosity of the fluid}}$$

yields a value between about 20,000 and 600,000 at the orifice, and the orifices being separated from each other by a distance such that the liquid streams shall impinge upon each other in laminar form to produce a laminar sheet.

20. Apparatus of the character described comprising two nozzles each having a liquid discharge orifice of about 0.030 to 0.63 inch diameter, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the nozzles being disposed with their orifices adjacent to each other and with the axes of their passages substantially coincident, each passage being conical of relatively small apex angle and having a maximum diameter of about 0.25 to 3 inches, the length of the conical passage in the region of the discharge orifices being large compared to the said maximum diameter of the conical passage, whereby the liquid will issue from the orifices in the form of laminar streams, and the orifices being separated from each other by a distance such that the liquid streams will impinge upon each other in laminar form to produce a laminar sheet.

21. Apparatus of the character described comprising two nozzles each having a liquid entrance aperture of relatively large diameter, a liquid discharge orifice of relatively small diameter, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the nozzles being disposed with their orifices adjacent to each other and with the axes of their passages substantially coincident, each passage being conical of relatively small apex angle for a length in the region of the corresponding discharge orifice that is large compared to the maximum diameter of the conical passage, the dimensions of the nozzles and the lengths of the conical passages being such that the nozzles shall produce laminar streams under a pressure substantially higher than 15 pounds per square inch, and the orifices being separated from each other by a distance such that the liquid streams shall impinge upon each other in laminar form to produce a laminar sheet.

22. Apparatus of the character described comprising two nozzles each having a liquid discharge orifice of about 0.030 to 0.63 inch diameter, a liquid entrance aperture of diameter relatively large compared to the diameter of the orifice, and a longitudinally disposed interior passage uninterruptedly connecting the aperture and the orifice, the nozzles being disposed with their orifices adjacent to each other and with the axes of their passages substantially coincident, each passage being conical of relatively small apex angle and having a maximum diameter of about 0.25 to 3 inches, the length of the conical passage in the region of the corresponding discharge orifice being large compared to the said maximum diameter of the conical passage, the dimensions of the nozzles and the lengths of the conical passages being such that nozzles shall produce laminar streams under a pressure substantially higher than 15 pounds per square inch, and the orifices being separated from each other by a distance such that the streams shall impinge upon each other in laminar form to produce a laminar sheet.

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