A patent for a spray drying apparatus is described. The apparatus consists of a spray nozzle, a formative element such as a screen positioned to receive the spray while the droplets are in a tacky condition to form a mat on the screen and a blower for drawing air from the enclosure through the mat and thence through the screen to dry the mat.

The patent includes claims and references to prior art, as well as a diagram illustrating the apparatus.
A LIQUID CONTAINING SOLIDS

FOR EXAMPLE - MILK, FRUIT & VEGETABLE JUICES, CHEMICAL SOLUTIONS, ETC.

SUSPEND DROPLETS IN DRYING ATMOSPHERE

ALLOW DROPLETS TO PARTIALLY DRY WHILE ENTRAINED IN DRYING ATMOSPHERE

CAUSE DRYING ATMOSPHERE TO PASS THROUGH A FORAMINOUS MEMBER

COLLECT THE PARTICLES ON THE FORAMINOUS MEMBER WHILE STILL TACKY BUT WITHOUT SUFFICIENT LIQUID TO COALESCE

CONTINUE TO FORCE THE DRYING ATMOSPHERE THROUGH THE PARTICLES COLLECTED UNTIL SUBSTANTIALLY DRY AGGLOMERATE FORMED IN SITU

REMOVING THE PARTICLES FROM THE FORAMINOUS MEMBER

**FIG 1**

**FIG 2**

**FIG 3**

**FIG 4**

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SPRAY DRYING APPARATUS

This application is a continuation-in-part of a prior application having the same title, Ser. No. 13,501 filed Feb. 24, 1970 and now abandoned, which is in turn a continuation-in-part of application Ser. No. 553,101, filed May 26, 1966, now U.S. Pat. 3,520,066, for “Spray Drying Method”.

The present invention relates to an apparatus for drying liquids containing dissolved and suspended material and more particularly to an apparatus for drying liquids in the form of a spray entrained in a gas stream.

In the past several decades the drying of materials has been carried out on an ever-increasing scale by spray drying materials that are to be dried into a hot dry stream of gas passing through a drying chamber and collecting the dried solids. This process, frequently referred to as “spray drying,” has become particularly widely used in the food industry for drying such products as milk, cream, instant coffee, cocoa, fruit and vegetable juices, extracts and flavorings. A variety of other products such as drugs, detergents, soaps, cosmetics, etc., have also been subjected to the process in other industries. The equipment now used in this process has several important disadvantages.

Product accumulation on the walls of the drying chamber is a major disadvantage. In spite of efforts to prevent this accumulation, the unintentional deposition of materials on the walls of the chambers has remained a problem, particularly with products having low melting points and sensitivity to heat.

Resulting from the accumulation of material is the necessity for interrupting the drying operation so that a workman can enter the drying tank and manually scrape the walls. This operation is not only a time-consuming and unpleasant task but is an expensive procedure and one which increases the opportunity for contaminating a product. Moreover, even after the tank has been scraped, the residual material remaining on the walls of the tank can produce a sanitation problem and produce off flavors in food products. The tendency of materials to accumulate has also limited the application of spray drying in general to those materials which either have high melting points or in which heat damage can be tolerated.

Prior spray drying equipment also releases a substantial amount of dust into the atmosphere or in the alternative requires an elaborate dust collecting apparatus such as a cyclone or textile bag filter frequency larger than the drying apparatus itself.

Moreover, the texture of the product produced in conventional spray drying varies to some extent; that is to say, the product lacks uniform consistency, some parts being hard, dense and brittle while others may be fine loose dust. In some areas of the drying chamber where the product accumulates in corners, very hard or even crystalline masses can be formed whereas in other areas relatively loosely packed powdered materials will accumulate.

Still another shortcoming of a conventional spray dryer is the loss of heat which is experienced. While a portion of the lost heat is carried away in the particles of solid material escaping from the dryer, an additional amount is also lost because there is insufficient contact time to bring about saturation of the drying atmosphere.

It has been previously proposed in spray drying equipment of the kind in which more than half of the material collects on the floor of a drying chamber to employ hanging screens as a lighting place for spray dried particles. A slowly rotating cam subjects the screens to periodic shocks which cause the powder to fall from the screens. These screens are not sealed at either their upper and lower ends. Consequently air is not forced to pass through the screens. Equipment of this kind is not suitable for the purposes of the present invention for several reasons. First, relatively little drying takes place once the material falls to the floor and becomes covered by a layer of falling particles. This is particularly important where the removal of the last bit of removable moisture may make the difference between commercial success and failure due to product deterioration. Furthermore, continuous removal of product from the screens prevents the development of a mat structure which applicant has found important in achieving high product dryness and improved drying efficiency. Moreover, there is no way to force the air through the screen when one or both of its ends swing up and down along an arc that is at times spaced from the top or floor of the drying chamber. Consequently, if a relatively thick bed or mat of particles were to accumulate on one of hanging screens, most of the air would go around the top or bottom of the screen due to the air space present, thereby defeating the objective of maintaining a steady current of air through the collected mat.

A variety of other drying systems previously proposed have been either costly or largely ineffective in eliminating the aforesaid problems and accordingly have not been widely used.

In view of the deficiencies of the prior art, it is the general object of the invention to provide an improved spray dryer having the following advantages and characteristics: (a) a reduction in the loss of material in the form of dust escaping through exhaust vents; (b) the reduction of hard, difficult-to-remove and heterogeneous cakes of dried material upon the walls of the drying chamber; (c) suitability for the production of a porous dried mat that can be subdivided into pieces of a predetermined size which if water dispersible will become moistened quickly when added to a liquid; (d) has increased drying capacity and better thermal efficiency; (e) is able to produce a dried product of a uniform consistency; and (f) makes provision for removing the collected mat from contact with the heated drying gas and exposing it to a cooling gas until the dried product reaches a chemically or thermally stable condition.

These and other more detailed and specific objects will be apparent in view of the following specification and attached drawings wherein:

FIG. 1 is a flow chart showing the steps performed in a preferred embodiment of the invention.

FIG. 2 is a diagram illustrating the method employed in accordance with one embodiment of the invention.

FIG. 3 is a drawing illustrating the appearance of a piece of spray dried material after being removed from the screen of FIG. 2.

FIG. 4 is a perspective view showing the appearance of another type of spray dried material after being removed from the screen of FIG. 2.

FIG. 5 is a side elevational view partially broken away of an apparatus employed for carrying out the present invention.
FIG. 6 is a transverse sectional view taken on line 6—6 of FIG. 5.

FIG. 7 is a greatly enlarged side elevational view of the collecting screen housing partly broken away.

FIG. 8 is a side elevational view of another embodiment of the invention partly broken away.

FIG. 9 is a side elevational view partly in section of still another embodiment of the invention.

FIG. 10 is a side elevational view of yet another embodiment of the invention.

FIG. 11 is a semi-diagrammatic side elevational view of a modified form of a dryer in accordance with the invention including a provision for precoating the collection screen.

FIG. 12 is a modified form of the apparatus in accordance with the invention including another provision for precoating the collection screen.

FIG. 13 is a partial side elevational view of the upper portion of the spray dryer of FIG. 8 showing the modified form of air flow control means.

FIG. 14 is a semidiagramatic vertical longitudinal sectional view of another form of apparatus embodying the invention.

FIG. 15 is a vertical sectional view of another embodiment of the invention.

FIG. 16 is a sectional view on a reduced scale taken on line 16—16 of FIG. 15.

FIG. 17 is a side elevational view partly broken away of another embodiment of the invention.

FIG. 18 is a side elevational view partly broken away of still another embodiment of the invention.

FIG. 19 is a sectional view taken on line 19—19 of FIG. 18.

FIG. 20 is a vertical sectional view of another embodiment of the invention.

Refer now to FIG. 1. The liquid to be dried contains a solid material either dissolved or suspended therein, e.g., milk, vegetable or fruit juices. This liquid is sprayed into a drying atmosphere composed, for example, of air heated to 200°—400°F. or of air having a relatively low humidity level or of heated dry air. The moisture present in the drying atmosphere is substantially below its saturation point. The term "drying atmosphere" used herein is intended to mean a gas at such conditions of temperature, pressure and vapor content as to be capable of absorbing a substantial quantity of liquid from the fluid to be dried.

In accordance with the invention, the liquid to be dried is sprayed into an enclosure containing a drying atmosphere and is collected upon a foraminous element such as a screen. A blower or other draft-producing device draws the drying atmosphere through the accumlated mat that forms on the screen and thence through the screen itself. The pressure differential produced across the screen in this way results in a steady flow of gas through the screen and the accumulating mat. This was found highly effective in assuring product uniformity, improving thermal efficiency and in achieving a low moisture level in the finished product.

It is important to have the screen placed with respect to the spray nozzle such that the surfaces of the particles are still in a tacky condition at the time they strike the mat on the screen but do not contain sufficient liquid to enable them to coalesce or run together to form a relatively impermeable continuous material. It was surprising to find that the tacky condition of the particles at the time they reached the screen was effective in preventing an excessive pressure drop across the screen (screen blinding). Thus, by properly positioning the screen with respect to the sprayer (under a given set of drying conditions and spray droplet size), the porosity of the mat is preserved.

By the term "coalesce" as used herein I mean a flowing or fusing together of the particles to form a relatively solid material in which the individual particles cannot be clearly recognized without magnification and wherein the spaces or interstices between them are relatively small (if present at all) compared with the size of the particles.

The particles are thus brought into contact with one another while the surfaces thereof are in a tacky condition to form bonds at the points of contact between the particles. This produces a relatively porous lacy reticulum in which a substantial portion of the agglomerate thus formed consists of communicating spaces or pores between the contacting and bonded particles.

Once the particles have been deposited on the collection screen, a sudden change will take place in the relation between the particles and the surrounding air; the air will begin to stream over and around the particles, and through the minute microporous interstices between the particles in the agglomerate. As this streaming takes place, moisture is removed from the particles at a much higher rate. Removal of the last traces of removable moisture from a material that is being dried is much slower than during the earlier drying period. It is commonly referred to as the falling rate drying period. In accordance with the present invention, after the movement of the particles has been arrested by deposition on the bed or screen, a substantial increase in the velocity of the drying gas relative to the particles is established. This provides a more effective means for removing moisture during the falling rate drying period.

In summary, the invention has the following advantages: First, filtration of air-entrained particles from the drying medium is accomplished by those particles already deposited in the mat, thus reducing and in some cases eliminating the need for auxiliary filters in the stream of exit drying gas. Since this phenomenon in the course of a drying operation has heretofore been unknown, it will be referred to as "autofiltration." Second, greater drying efficiency can be achieved than was heretofore possible. While the precise reason for this result is not known with certainty, it is believed to be, in part, due to the accelerated evaporation that results from the streaming of the drying gas around and through the particles that make up the mat and, in part, to the increased driving force across the solid and gaseous interface. Third, greater product dryness is accomplished with the invention because of the increased exposure of the material to the drying atmosphere. Fourth, the invention is capable of reducing the undesired accumulation of the product on the walls of the dryer. This allows the invention to be used with products which were heretofore difficult or impossible to dry by conventional spray drying techniques or, for that matter, by any previous drying process of which I am aware. The invention also increases the product quality because of the reduction of heat damage. Fifth, the product that is being dried is placed, while in a practically dried state, in a form which can be transferred from the drying zone to one or more additional zones in which further treatment may be performed. Sixth,
the invention places the product in a novel physical form (a porous, self-supporting mat which can be further processed if desired to provide products having advantageous properties).

Refer now to FIGS. 2, 3 and 4. In FIG. 2 is shown a stationary enclosure or vessel 20 which in this instance forms a portion of a horizontally disposed duct. A gaseous suspending medium such as heated air 22 is forced through the duct from left to right and through a screen 24 which is supported to extend over the entire cross section of vessel 20 so that all of the heated air 22 must pass through it. Upstream of the screen 24 is a nozzle 26 for producing a spray 28 of the fluid material that is to be dried. The material being dried collects as a highly porous mat or agglomerate 30.

The thickness of this deposit upon the screen will vary. I have found that when a vertical stationary screen is employed, the thickness of the material deposited on the lower end of the screen is sometimes much greater than at the top. For example, the thickness of the material deposited in one instance on a vertical screen was one-half inch thick at the top and 3 inches thick at the bottom.

The appearance of the agglomerate 30 formed on the screen 24 is shown in FIGS. 3 and 4. The surface 30a which is positioned adjacent to the screen 24 bears the configuration of the screen surface. If the material is relatively tacky at the time it was deposited, marked striations and channels 30b normal to the surface 30a as shown in FIG. 4 will be present. If the material contains less moisture or is only slightly tacky, it will have the irregular surface with no visible striations or markings as shown in FIG. 3.

Process variables are described in detail in the above-noted patent.

Refer now to FIGS. 5, 6 and 7 which illustrate one form of drying apparatus in accordance with the invention. As shown in the figures, there is provided a drying chamber or enclosure 40 including front and rear walls 42 and 44 and side walls 46 which are generally cylindrical but include a downwardly and centrally inclined wall portions 46a and 46b connected by a hemispherical trough 48 within which is mounted an auger 50 driven by means of a suitable motor 52. The auger 50 when rotated in the proper direction will convey dried material that falls to the bottom of the apparatus toward the right as seen in FIG. 5 to a collecting hopper 54 which is connected by means of a duct 56 to a storage container 58. The auger 50 is provided for collecting any of material which is deposited upon the walls of the vessel 40 and which thereafter becomes loosened from the walls and falls down the inclined surfaces 46a and 46b. A portion of the material will be collected on the foraminous collecting means described below. The enclosure 40 can be supported in any suitable manner as by means of tubular supporting frame members 60 connected in any suitable manner such as by welding to the enclosure 40.

In the wall 44 is provided a drying gas inlet duct 62 which communicates with a duct 64 that extends vertically and communicates with the outlet of an air heater 66 of any suitable known construction such as a gas burner. Air is supplied to the burner 66 from the atmosphere by means of a blower 68. Positioned concentrically within the air supply duct 62 is a spray nozzle 70 that communicates through a line 72 with a pump 74 which supplies the fluid to be dried from a supply tank 76. The fluid material being dried emerges from the nozzle 70 in the form of a fine spray 78. The sprayed particles are carried in the heated drying gas from left to right as seen in FIG. 5 toward a collecting device indicated generally at 80 which will not be described.

The collecting device 80, as shown in FIG. 7, comprises a tapered duct or funnel 82 and a pair of wire collecting screens 84 and 86 extending across funnel 82 in parallel spaced relationship. The screens 84 and 86 can be supported in any convenient manner but I have found that they will be suitably held in position by mounting screen 86 between the outward end of the funnel 88 and a square spacer 90 and the screen 84 between the spacer 90 and a short duct section 92. Bolts or other suitable fasteners can be used to secure the duct section 92 to the spacer 90 and the spacer in turn to the outward end of the funnel 82. The entire collecting apparatus is mounted upon a baffle 94 which is supported from the upper end of the vessel 40 upon brackets 96 and 98.

As shown in FIG. 7, a mat 100 of the type described hereinafore will form on the outward or central surface of the primary collecting screen 84. Screen 86 is not essential for proper operation but is included as a back-up screen for starting. The mat 100 will be highly porous and will contain channels that extend from the interior of the vessel 40 to the interior of the funnel 82 thereby allowing a substantial portion of the heated drying gas passing through the inlet 92 to pass through the mat 100 thereby further drying it after it has been deposited. The portion of the drying gas which does not pass through the screen will be exhausted through an outlet 102 (FIG. 5). Generally the exhausted gas passing through the outlet 102 will have a small amount of particulate material entrained in it and will consequently be passed through a suitable filtering mechanism such as a combination of cyclone collector and textile bag filter. Connected to the outlet end of the funnel 82 is a duct 104 to which is secured a flow control valve 106 and an exhaust blower 108 to reduce the pressure within the duct 104 and funnel 82. The exhaust blower 108 can be driven in any suitable manner by means of a motor 110.

The operation of the apparatus of FIGS. 5, 6 and 7 will now be described. To begin the operation, the heater 66 and blower 68 are started causing heated air to be introduced into the enclosure 40 through the inlet duct 62. The liquid to be dried is then admitted through nozzle 70. Simultaneously, the motor 110 is started with the valve 106 in the "open" position thereby causing a reduced pressure condition within the line 104 and funnel 82. This, in turn, causes a current of heated gas to pass through the screens 84 and 86 as clearly shown in FIG. 7. As the operation of the device continues, a deposit 100 of a porous product will begin to be produced upon the outward or central surface of the screen 84. After the deposit 100 is formed, little if any material will be added to the deposit 100 deposited on the screen 86 since the mat already formed upon the screen 84 acts as its own filter and thereby effectively removes all entrained particulate material from the stream of air passing through screen 84. However, because the openings in the screen 84 are much larger than the openings between the finely divided air entrained particles striking screen 84, a small amount of material will strike the screen 86 when the operation is started. Thus, as soon as the openings in the screen 84
become covered by the particles of the mat 100, the accretion of material on the screen 86 will be interrupted. In an apparatus of the type described in FIGS. 5, 6 and 7 used for drying a cake mix composition consisting primarily of shortening, flour and sugar, a screen having 16 openings to the square inch and having more than 70 percent open area was employed as a primary screen and another as a secondary or backup screen having 10 openings per square inch was employed. While the primary screen had an accumulation of about 1½ inches of material, the backup screen had less than one-eighth inch of material deposited upon it and this material was deposited during the first 5 seconds of running. When sugar is being dried with an air flow of 100–400 feet per minute through the dryer and an air temperature of 320°F entering the dryer, good results were obtained by placing the nozzle from about 9 to 10 feet from the screen. At shorter distances, 5–6 feet, the particles were wet and tended to coalesce. At greater distances, the particles were insufficiently tacky and tended to pack or pass through the screen.

Refer now to FIG. 8 which illustrates another embodiment of the invention. The apparatus of FIG. 8 comprises an enclosure such as a ventilation chamber 120 communicating through an inlet port with a supply duct 122 and a heater 124 which in turn communicates through a duct 126 with a damper 128 to which air is supplied by blower 130. Mounted concentrically within the upper and of chamber 120 is a nozzle 132 that communicates through a supply duct 134 with a fluid product which is to be dried. If desired, the fluid traveling through duct 134 may be aerated or any suitable air entrained therein to facilitate the drying operation and reducing the density of the material. The fluid is supplied from a storage tank 136 under pressure by a pump 138. The liquid sprayed from the nozzle 132 is initially present in the form of wet droplets 140. These droplets are entrained in the heated air passing downwardly from the duct 122. As the particles pass downwardly, they strike a moving foraminous element or belt 144 entrained over a pair of horizontally disposed spaced rollers 146 and 148, the former being driven by means of a belt 150 connected to a speed reducer 152 which is, in turn, operated by means of a belt driven by a motor 154. The foraminous belt 144 can comprise a variety of materials such as a woven wire screen or perforated metal sheet. The foraminous member or screen 144 is depicted diagrammatically. It can comprise a plurality of perforate plates positioned adjacent and coplanar to one another. A variety of other collecting elements will be apparent to those skilled in the art.

A mat 160 forms on the upward surface of the foraminous belt 144. The air flowing into the chamber 120 from the duct 122 passes through this mat 160 as indicated by arrows into a compartment 162 below the screen and is exhausted through a duct 164. The foraminous screen 144 is moved so that the upper reach thereof travels toward the right as seen in FIG. 8 carrying the accumulated mat on its upward surface into a second chamber 166 through an opening 168 for purposes hereinafter described. The duct 164 is connected to an exhaust blower 170 driven by a speed reducer 172 and motor 174. From the blower 170 the air passes through a suitable damper 176 which like damper 128 can be opened or closed as conditions of operation require. The chamber 166 communicates with an inlet duct 180 which is connected to an air cooler 182 of any suitable known construction. Prior to entering the air cooler 182 the air is passed through a suitable filter 184. On the opposite side of the screen 144 from the chamber 166 is a chamber 186 which communicates with an outlet duct 190 to a blower 192 driven by means of motor 194 and speed reducer 196. Air passing through the blower 192 is exhausted through a damper 198. The foraminous member 144 and the rollers are mounted within a chamber 210. At the lower end of the chamber 210 is provided a rotating brush 212 for removing any remaining material from the foraminous belt 144 before the belt returns to the inlet end of the chamber 120. The mat may be removed by any other suitable technique such as a blast of air. Air can be forced through the apparatus by any suitable draft producing device connected to the upstream or downstream end of the drier.

During operation, as the foraminous member 144 travels over the roller 148, the pieces of the mat fall and pass between a pair of parallel driven sizing rolls 200 and 201 spaced appropriately to break the mat into smaller pieces of the desired size. The resulting pieces pass downwardly into a collecting trough 204. If desired, a conveyor can be provided below rolls 200, 201 to convey the broken material laterally. A doctor blade similar to 242 (FIG. 9) can be used ahead of the brush and the screen 144 can then be passed through a washer of suitable known construction. A suitable sifter can be provided for separating and grading various desired particle sizes and exhausting them through a pair of ducts 206 and 208 according to size.

As mentioned above, it is necessary to construct the apparatus with a predetermined spacing between the nozzle and the mat assuming a particular set of conditions of temperature and drying capacity of the gas introduced to the drying chamber. Under a given set of conditions, if the nozzle 132 is too close to the mat 160, the droplets will be of such high moisture content that they will coalesce or flow together to form large drops or pools of moisture. On the other hand, if the distance between the nozzle and the mat is too great for a given set of operating circumstances, the particles, due to their condition of dryness will be insufficiently tacky to become bonded to one another when they reach the mat 160. This will cause them to pass through the screen or to pack tightly together and blind the screen. Accordingly, it should be understood that the distance of the nozzle from the screen 144 (or mat 160) is established with respect to the temperature and drying capacity of the drying gas, so that the particles are sticky upon reaching the screen.

The upper section of the screen 144 between rolls 146 and 148 defines a collecting surface upon which the mat 160 accumulates and it should be understood that except for relatively minor amounts of material which collect upon the inside walls of the apparatus or manage to pass through the screen and are collected in bag filters, substantially all of the sprayed solids accumulate as a mat upon the screen 144. Even when conditions of operation are relatively unfavorable, with present apparatus at least 92–95 percent of the spaced solids are deposited in the mat 160. The expression "substantially all of the solids" are used herein shall mean that 90 percent or above of the total sprayed solids expelled through the spray nozzle are deposited in the mat.
It is important to note that the foraminous collecting screen 144, as in the embodiment of FIGS. 2, 5, 6 and 7, extends entirely across the outlet of the spray drier which communicates with the exhaust duct 164 and is sealed at all times along its edges to the outlet so that a pressure differential of at least a half inch of water can be developed across the screen by the blower 170. To this end, the upward edges of the front and rear vertical walls of the chamber below the top run of the screen and the corresponding vertical side walls (only one of which is shown in FIG. 8) either abut against the lower surface of the screen 144 or are positioned so closely adjacent to it that only insignificant amounts of air can pass through the gap. By thus sealing the collecting screen across the outlet 164, air exhausted by the blower 170 is forced to pass through the mat as the mat begins to build in thickness and regardless of the build-up, the air will be drawn steadily through the mat in spite of the increasing pressure drop across it. Depending upon the conditions of operation, the pressure differential may be as high as 10 to 15 inches of water but more typically is from about ½ to 5 inches of water but should not be so high as to crush or collapse the collected mat. In any event, it has been found that by sealing the edges of the screen at all times to the housing, it is possible to provide for a steady flow of drying gas through the collected mat in spite of increases in the thickness of the mat. The importance of sealing the screen along all of its edges can be understood better when it is realized that in the case of a typical mat, if an opening were made between the upstream and downstream sides of the mat which had an area of about 10 percent of the area of the mat, the air flow through the mat would drop to about one-fiftieth or so of its previous level.

It should be noted that the mat 160 just as described earlier in connection with FIGS. 3 and 4 is homogeneous and has no holes in it other than the pores between the individual dried droplets. In this way the air is forced to pass through the minute interstices between the particles which is important in obtaining the improvements in drying efficiency and product moisture uniformity that are achieved in the present invention. While the mat can be as little as about one-quarter of an inch in thickness, in most commercial applications, it is usually from about 1 inch to about 6 inches in thickness.

The speed of the drive motor 154 is determined with respect to the amount of material being sprayed and the cross-sectional area of the collecting surface so that the particles are able to accumulate without being subjected to jarring or vibration to a minimum thickness for practical purposes of at least about a quarter of an inch. By allowing the particles to accumulate as a mat in an essentially quiescent condition to a substantial thickness, e.g., at least about a quarter of an inch, it is possible for the particles present in the mat to serve as a collecting medium for additional particles and at the same time for the mat to take on a friable self-supporting integral structure. In this way if the spray rate is increased, other things being equal, the speed of drive motor 154 should be increased. Similarly, if the area of the screen within the dryer enclosure 120 is increased, the speed of the motor 154 should be reduced to assure development of the mat structure as described herein above to at least about a quarter of an inch thickness.

It has also been found that a preferred relationship exists between the exposed area of the screen 144 within the enclosure 120 and the air flow therethrough in a given period of time. Thus in a typical commercial sized unit, when the air flow is usually on the order of 20,000 to 30,000 cu. ft./min., the area of the screen exposed to the air flow should not be less than about 120 sq. ft.

The present invention in addition to achieving a higher drying efficiency makes possible lower operating temperatures which helps to preserve the quality of temperature sensitive materials as well as improving the production capacity of the apparatus for a given quantity of air. Both improvements appear to result from the improved contact of the particles with the drying medium which flows continuously through the minute interstices between them.

It can also be seen by reference again to FIG. 8 that the screen 144 and mat is completely removed from the drying chamber 120 before the mat 160 is itself removed from the screen. Thus the advance of the mat 160 around the roll 148 can be thought of as a means of removing the collector 120 for removing the mat from the screen after the screen has been withdrawn from communication with the upstream portion of the enclosure 120. If this were not the case, because of the substantial pressure drop across the mat, much of the air would pass through the part of the screen where the mat had been removed. This would defeat the objective of achieving a steady flow through the mat.

A slightly modified form of air flow control is shown in FIG. 13. This flow control consists of a grating 125 composed of a plurality of closely spaced parallel vertically disposed fins for establishing a laminar air flow which reduces the turbulence within the chamber 120 and the consequent nonuniform accumulation of dried product on the walls of the apparatus. The flow through the foraminous collecting member 144 is also laminar. It may be seen that my invention makes possible the provision of a spray drying apparatus without constrications in the air flow between the spray nozzle and the point at which the drying air is withdrawn from the drying chamber as in some prior devices.

In accordance with another modified form of the invention, an additional drying agency is employed consisting of a microwave heater of any well-known commercially available kind. The microwave heater is suitably mounted to heat that portion of the mat within either chamber 120 or the chamber 166 of FIG. 8 to assist in removing residual moisture from the mat. As electromagnetic wave energy from the microwave heater is transferred to the water molecules, their increased energy will accelerate evaporation and as soon as the water is converted to the vapor state it is removed by the current gas such as air passing through the mat from chamber 166 to chamber 186.

Refer now to FIG. 9 which illustrates another embodiment of the invention composed of an enclosure or chamber 220 having a top wall 222, side walls 224, 226, 227 and 229, inclined lower wall 228 and outlet duct 230 which communicates with a star valve 232. A drying gas inlet duct 234 is provided at the upward end of the chamber. Within the duct 234 is a spray nozzle 236 that communicates with a source of fluid to be dried (not shown). Mounted for rotation within the chamber 220 is a cylindrical collecting drum 236 sup-

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ported on a shaft 239 which is itself journaled in the walls 227 and 229 and driven by means of a motor (not shown) at a uniform speed in a clockwise direction as seen in FIG. 9. The cylindrical wall of the drum 236 comprises a foraminous member 240 which can consist, for example, of perforated sheet metal. The openings may suitably be one-fourth inch in diameter. A doctor blade 242 is mounted within the housing 220 in position to scrape deposited material 244 which has accumulated on the surface of the drum as shown. Material thus scraped from the drum falls downwardly in the form of porous chunks and pieces 246 along the inclined surface 228 into the star valve 232 and are exhausted through the duct 233. On the upper wall 222 is also provided an exhaust duct 248. Extending downwardly between the exhaust duct 248 and the inlet duct 234 is a baffle 250, the lower end of which contacts the upward surface of the drum 240. In this manner, the air passing through the duct 234 must pass through the accretion 244 to the interior of the drum before being exhausted thereby drying the material deposited upon the surface of the drum. The air passing through the drum section between the doctor blade 242 and the baffle 250 is exhausted through the duct 248.

In FIG. 10 is shown a drying chamber of vessel 260 including imperforate side, top and bottom walls. On each of the walls a foraminous collecting element each comprising an endless screen entrained over a pair of horizontally disposed vertically spaced rolls 262 and 264. On the bottom of the chamber is provided a similar collection surface comprising an endless screen 266 entrained over horizontally spaced rolls 268. A suitable driving means is provided for turning each pair of rolls in given feed directions. At the upper end of the apparatus is an inlet duct 270 for conveying heated air 272 to the upward end of the apparatus. A spray nozzle 274 is provided at the upward end of the chamber 260. The fluid to be dried is supplied to nozzle 274 from a storage container 276 through a duct 278. A metering pump 280 controls the flow of fluid from the storage container 276 to the nozzle 274.

During operation, the air 272 passing through into the chamber 260 flows downwardly and outwardly through each of the screens 262. Material expelled from the nozzle 272 accumulates on the inward surfaces of each of these foraminous collecting members 262. The solid material collecting on the surface of each of the screens either falls from the screens where the screens pass over the rolls or can be removed therefrom by means of a doctor blade (not shown). After being removed, the material falls downwardly and is discharged through a duct 282. The drying air is discharged through a duct 284. The apparatus of FIG. 10 has the advantage that all exposed walls are covered by one of the foraminous collecting surfaces. This effectively prevents the walls of the chamber 260 from being covered with cakes of dried material sprayed from the nozzle 274.

It was found that under some operating circumstances and in the case of certain materials, there is a tendency for the dried or semidried particulate material to pass through the portions of the screen at the point where they enter the apparatus prior to the formation of a coating on the screen. In accordance with the modified forms of my invention illustrated in FIGS. 11 and 12, a means is provided for reliably preventing the passage of dried particulate material through the screen and out of the apparatus through the outlet duct which, if allowed to take place, would be wasteful and would create a dust problem. To prevent this occurrence, I provide a preliminary coating layer on the upstream surface of the collection screen prior to passing a drying gas through the screen and expelling the gas into the atmosphere. This can be accomplished in various ways. For example, an external supply of particulate material can be applied to the outside surface of the screen prior to passage into the drying apparatus. Alternatively, a portion of the material collected on the screen can be allowed to remain at all times on the surface of the screen thereby providing a permanent preliminary coating layer. Two other alternative means for accomplishing this objective are described in connection with FIGS. 11 and 12 to which reference will now be made.

FIG. 11 shows a modified form of the invention including a provision for coating the collection screen with a predetermined thickness of the material that is to be dried prior to the passage of the drying gas through the screen and into the atmosphere. There is provided a drying enclosure or housing 300 including side, top and bottom walls, an inlet duct 302 through which a drying gas such as heated air is introduced and a duct 304 for supplying a moist material which is to be dried to a nozzle 306 positioned at the upper end of the housing 300 in the center of the duct 302.

The housing 300 includes horizontally disposed and laterally spaced openings 308 and 310 through which passes a suitable foraminous member such as an endless woven foraminous screen 312 entrained over a pair of horizontally spaced parallel and laterally extending drive rolls 314 and 316, each suitably journaled for rotation and driven in given feed directions for advancing the screen through the housing 300.

Below a portion of the screen 312 within the housing 300 is a chamber designated 300a that defines an outlet plenum which receives the drying gas after it is passed through the screen 312. The drying gas within the chamber 300a is exhausted through a duct 318 connected to the inlet of a suitable blower (not shown). Below the first portion of the screen 312 entering the slot 308 is a blocking plate 320 which will ordinarily rest in engagement with the lower surface of the screen 312 or closely adjacent thereto. A portion of the plate 320 can extend out of the apparatus through the slot 308. The plate 320 is preferably slidably mounted within the slot 308 for movement toward either the left or right as seen in FIG. 11 so that the area of the plate 320 underlying a portion of the screen 312 within the housing 300 can be controlled as desired. A handle 322 is provided for permitting manual adjustments to be easily made.

During operation of the apparatus illustrated in FIG. 11, the droplets sprayed from the nozzle 306 will be carried downwardly by the air passing through duct 302 toward the bottom of the housing. When the operation is started, the rolls 314 and 316 are turned in given feed directions thereby advancing the screen 312 toward the right through the housing. The particles will become tacky as moisture is removed from them as they travel toward the lower end of the housing and will form a deposit on the upper surface of the screen 312. The particles which are either extremely small or have been dried to the point where they are no longer tacky may initially pass through the screen 312 and will be
exhausted through duct 318. A deposit will, however, immediately begin to accumulate upon the upper surface of the screen 312 adjacent the plate 320 since substantially no air will be able to pass through that portion of the screen. This coating layer is designated 12a in FIG. 11. Because the layer 11a will be formed upon the screen prior to the time that the drying gas is allowed to flow through the screen, the loss of particulate material which would otherwise pass through the screen prior to the buildup of a coating layer is prevented.

Refer now to FIG. 12 which is similar to FIG. 11 and in which the same numbers have been used for corresponding parts except for the differences which will now be explained. As clearly seen in FIG. 12, no blocking plate has been employed. Instead, there is provided a collection chamber 324 defined by the side and bottom walls of the housing 300 and by a plate 326 which separates the chamber 324 from the chamber 300a. A duct 327 connects the chamber 324 to the inlet of a blower 328. The outlet of the blower 328 is, in turn, connected by means of duct 330. The chamber 300 will thereby recirculating gas from chamber 324 to the upper chamber of housing 300.

The operation of the apparatus illustrated in FIG. 12 will now be described. To begin the operation, the rolls 314 and 316 are driven in given feed directions to convey the upper reach of the screen 312 from left to right as seen in the figures so that it travels first over the chamber 324 and next over the chamber 300a. The sprayer 306 is then operated as described hereinabove such that the droplets are carried downward and partially dried in the stream of drying gas entering through the inlet 302. The screen 312 is first contacted by partially dried particles upon entering the chamber from the left. Any particles which happen to pass through the screen at this point are recirculated through the duct 326, blower 328 and duct 330. The particles which remain on the screen form an initial coating layer or deposit designated 12a, the thickness of which can be controlled by the speed of the screen 312 and the characteristics of the blower 328 and by other factors which will be apparent to those skilled in the art.

In this manner, a coating layer of semidried product designated 12a will be formed upon the upward surface of the collection screen 312 prior to the final deposit of the dried product thereon in the area designated 12b. In this manner, the product which initially passes through the screen will be recirculated to the drying chamber upstream of the collecting screen instead of being lost through the outlet duct 318.

The formation of the preliminary coating layer as described herein is highly effective in preventing the loss of dried products from the dryer. Moreover, the preliminary coating layers were found surprisingly porous and uniform in consistency.

Refer now to FIG. 14 which illustrates a modified form of the invention embodying an endless moving collecting element. The apparatus includes a nozzle 26 connected to a source of liquid to be dried by a duct 29. The liquid to be dried is expelled as a spray 31 into a drying chamber 33. At the lower end of the chamber 33 is a pair of laterally spaced horizontally disposed rolls 35 over which is entrained a porous collecting element such as a woven screen 37. During operation, the heated drying gas enters the apparatus in the area of the nozzle 26, passes through the screen 37 and is exhausted through a duct 39. The screen is thus exposed between the air inlet and air outlet of the enclosure. The screen 37 is preferably driven in a direction of travel opposite the flow of material through the nozzle, i.e., from right to left in FIG. 2. It will be seen that the particles containing the greatest amount of moisture travel the greatest distance in the air and are therefore deposited furthest from the nozzle 26. They consequently are subjected to drying for a greater period of time as they travel toward the outlet of the machine on the screen. A greater number of relatively small particles will be deposited near the outlet of the machine and consequently dried for a shorter period of time.

A variety of measures can be taken to prevent the undesired depositions of material upon the walls of the dryer. For example, the walls of the dryer can be coated with a poorly adherent material sometimes referred to as a release composition. This composition should, of course, be compatible with the product being processed and in the event that the product is food, it should have no toxic characteristics. One suitable material which may be mentioned by way of example is an acetylated monoglyceride such as the product sold under the tradename "Mycacet" by the Distillation Products Industries of New York. In the alternative, a foraminous or louvered liner can be provided within the drying chamber and a gas passed from the space between the liner and the outer portion of the chamber through the pores or louvers as the case may be into the interior of the dryer thereby preventing suspended particles from impinging against the walls. Other methods for preventing the deposition of particles on the walls of the dryer will be apparent to those skilled in the art.

I have found that in some instances the material formed in accordance with the invention contains relatively fine particles which are collected by autofiltration from the gaseous drying medium as the medium passes through the agglomerate. These fine particles may be adhesively bonded to the mat but in some cases owing to their relatively low moisture content are merely mechanically trapped in the agglomerate. Moreover, a dry pulverulent material can be introduced into the drying chamber and intermixed with the dispersed air trained liquid particles and collected by autofiltration on the mat of agglomerated material. The pulverulent material can have either the same or different compositions from the liquid particles.

Refer now to FIGS. 15 and 16 which illustrate how the invention can be applied to modify existing spray drying equipment such as spray dryers manufactured by the Rogers Company. The dryer of FIGS. 15 and 16 includes a housing 500 formed from sheet metal composed of a rectangular upper portion 500a and a hopper 500b defining the lower portion of the housing. The bottom wall of the Rogers dryer which normally is located at 502 is removed and replaced with the hopper section 500b. A vertically disposed plate 504 is also placed within the enclosure 500 between the spray nozzle 506 which is supplied with liquid to be dried by pump 508 through line 510, and an outlet plenum 512 which contains vertically disposed bag filters 514 of suitable known construction. The bag filters 514 are periodically subjected to agitation by vibrators 516 to shake loose dust that has collected within them. The separator plate 504 has provided in its center a collection screen 518 which is subjected to agitation periodically during operation by a vibrator 521 connected to
the screen by means of a rod 522. The rod is secured to the screen with retaining discs 523 and 524. A blower 520 forces air into the dryer through heater 522, duct work 524 and inlet tube 526. Air is exhausted from the plenum 512 through an exhaust fan 528. At the lower end of the separator 504 is a gate valve 530 that can be opened or closed during operation to permit material to fall downwardly through an outlet duct 532 from either side of the screen 518.

During operation, a mat 534 will accumulate on the screen 518. The vibrator 521 will periodically shake portions of this mat 534 to the bottom of the hopper section 500b. The vibration 516 will also shake material from the bag filters 514. In this way, relatively large droplets and those that contain a substantial percentage of moisture will accumulate within the mat 534 and will be dried by a continuous stream of hot air that passes through the mat and screen 518. Any relatively dry or small particles that are not collected upon screen 518 will be collected within the bags 514; and both the material from the bags and from the screen 518 will together pass through the outlet duct 532 and fall into a receptacle 533.

Refer now to FIG. 17 which shows a modified form of the apparatus shown in FIGS. 5, 6 and 7. In the embodiment of FIG. 17, the collection device 80 has been replaced by a vertically disposed screen 550 which extends across the entire height and width of dryer 40 to divide it into two chambers which communicate with each other only through the screen 550. During operation, the mat is allowed to accumulate on the screen 550 as described hereinabove in connection with the screen 84. Material which is collected upon the screen 550 is periodically removed by agitation imparted to the screen 550 by a vibrator 552 through a connecting rod 554 and anchoring plates 556 and 558. In a modified form of construction, vibration is imparted to the screen 550 by means of a vibrator 558a at the top of the screen. If this modification is made, the vibrator 552 can be eliminated.

Refer now to FIGS. 18 and 19 which illustrate a modified form of dryer in which a horizontally disposed circular collection screen 600 is mounted within a cylindrical drying chamber 602 for collecting material sprayed from a nozzle 604 into a stream of hot drying gas introduced through duct 606. The screen 600 is provided with a radially disposed opening 608 (FIG. 19) below which is mounted an auger 610 and trough 612. A radially disposed scraper blade 614 supported at its inward end upon a drive shaft 616 is rotated during operation by a motor 618 connected to the lower end of the shaft 616. As the blade 14 rotates, the accumulated material on the upper surface of the screen 600 is scraped off the screen and allowed to fall into the trough 612 (FIG. 19) where it is removed by the auger 610. The liquid to be dried is fed from the supply tank 620 through line 622 to the nozzle by means of a pump 624. The warm air that passes downwardly through the product which has accumulated upon the screen 600 and the screen itself is exhausted through an outlet duct 626.

Refer now to FIG. 20 which illustrates one way in which the invention can be used in a multiple bank dryer of the type manufactured, for example, by the Rogers Company. To modify an existing dryer, the bottom wall of the rectangular dryer enclosure 700 (normally located along the line designated 702) is removed and replaced by a housing 704 containing a parallel horizontally disposed transversely extending screen supporting rolls 706 and 708 over which is entrained a screen 710. Beneath the upper reach of screen 710 is a suction plenum 712 directed into compartments (which serve as a plurality of linearly distributed suction plenums) by vertical plates 712a that communicate through a manifold 712 with a suction blower 716. Dampers 717 make it possible to vary the suction applied to the mat above each compartment of the suction plenum 712. Hot air is fed into the dryer through a manifold 718 by a blower 720 which is connected to an air filter 722. The air passes from the manifold 718 to the enclosure 700 through inlet ports 724, each of which has located at its center a spray nozzle 726. The sprayed material collects as a mat (not shown) on the upper surface of the screen 710 and is conveyed from left to right in the figures as the rolls 706 and 708 are driven in the feed direction shown. The mat is removed by suitable doctor blade 730. Bag filters 732 contained within an exhaust plenum 733 are periodically vibrated by means of vibrator 734. Hot air is drawn from the enclosure 700 through the bag filters 732 by a blower 736. The general operation is the same as the embodiment of FIG. 8 except that no cooling gas is forced through the collected mat.

The invention will be better understood by reference to the following example which illustrates the preparation of a specific product in accordance with my invention.

**EXAMPLE I**

A yellow cake premix was prepared and dried in accordance with the invention using the apparatus generally similar to that illustrated in FIGS. 5, 6 and 7. The mix consisted of 54 parts flour, 29 parts sucrose, 14 parts fat including both shortening and emulsifiers and 3 percent moisture by weight. The dry mix was added to water to produce a suspension consisting of 44.2 percent solids. Mixing was carried out in a high-speed mixer of the type known as an Oakes mixer and air was entrained in the feed stream at a pressure of 3,800 psig. The resulting aerated mixture had a density of 0.85 gms/cc and when entrained air was removed from the mix, the density was 1.15 gms/cc. The viscosity of the aerated suspension at 125°F. was 1,200 Cp. The resulting suspension was heated and fed at a pressure of 3,500 psig, to the spray nozzle at which point the temperature was 124°F. The dry bulb temperature of the drying gas fed to the dryer was maintained between 315°F. and 325°F., and the wet bulb temperature was less than 110°F. The air exhausted through the duct 102 (FIG. 5) had a temperature between about 190°F. and 200°F. The air exhausted through the duct 102 had a dew point of about 94°F. The amount of entering air estimated at the inlet was about 2,500 C.F.M. The froth forming collecting screen 84 had an area of 2 square feet and consisted of a woven stainless steel screen formed from 0.150 inch round wire of 10 mesh/inch. The distance of the screen from the nozzle was 9 feet 3 inches.

In the first run, a dry friable highly porous agglomerated mass was deposited on the collecting screen having a moisture content when removed of 2.3 percent moisture by weight. By comparison, the product collected from the interior wall of the dryer had a moisture
content of 2.6 percent by weight. All percentages given below will be represented in parts by weight.

A second run was conducted at a somewhat reduced exit temperature. In this run, a product was obtained on the collecting screen having a moisture content of 3.6 percent. The material collected on the wall of the dryer had a moisture content of 4.2 percent.

In the third run, a product was obtained on the screen having a moisture content of 1.4 percent. The corresponding product obtained on the interior wall of the dryer had a moisture content of 3.6 percent. In each of these three runs, the product obtained on the screen was highly porous, foraminous, and friable agglomerate or mat consisting of a multiplicity of microscopic spheroidal particles bonded together at their points of contact and having a multiplicity of interconnecting passages extending therethrough from the free surface thereof up to the screen and communicating through the screen with the portion of the dryer in the opposite side of the screen. The product was dry to the touch and could readily be either broken or otherwise subdivided into pieces of the required size or reduced to a fine powder as required.

What is claimed is:

1. A spray drying apparatus comprising in combination: a liquid supply, dispersing means connected to the liquid supply for reducing the liquid to a multiplicity of minute gas-suspended droplets, a spray enclosure surrounding the dispersing means to contain the drying gas and maintain the gas in contact with the droplets, a source of drying gas communicating with the enclosure, a draft producing means connected to communicate with the enclosure for forcing the drying gas from the gas source through the enclosure, an outlet communicating with the enclosure and with the draft producing means for exhausting the drying gas from the enclosure, an endless foraminous collecting screen located within the enclosure, rolls supporting the collecting screen so that the latter defines a collecting surface extending from one side of the enclosure to the other across the enclosure whereby substantially all of the solids expelled from the dispersing means are deposited as a mat upon the screen, drive means for advancing the collecting screen from one side of the enclosure to the other at a speed with the respect to the size of the collecting surface and the spray rate such that the mat accumulates in a quiescent condition to a thickness of at least about a quarter of an inch whereby the particles present in the mat itself serve as a collecting medium for additional particles, said collecting surface extending entirely across the outlet and being sealed at all times along its edges whereby a pressure differential of at least one-half inch of water is developed thereacross by means of the draft producing means and the gas that passes through the outlet flows steadily through the collecting screen and so as to deposit the droplets on the collecting surface as a homogeneous mat having no holes therein other than pores between the individual dried droplets and composed of the partially dried droplets of the liquid bonded together at their points of contact, the nozzle being spaced from the collecting surface for a particular temperature and drying capacity of the gas so that the particles are tacky but contain insufficient liquid to flow together when they impinge upon the collecting surface and means for removing the mat from the screen operative outside of the enclosure after the screen has been withdrawn from communication with the upstream portion of the enclosure.

2. The apparatus according to claim 1 wherein the foraminous screen comprises a plurality of perforated plates positioned adjacent and coplanar to one another.

3. The apparatus according to claim 1 wherein a chamber communicates with the downstream portion of the screen and a duct means communicates between said chamber and the upstream side of the screen for returning particulate material from the chamber to the upstream side of the screen.

4. The apparatus of claim 1 wherein a plurality of linearly distributed suction plenums are positioned on the opposite side of the foraminous collecting member from the dispersing means.

5. The apparatus according to claim 1 wherein a means is provided for precoating the screen on its upstream surface with a porous material adapted to serve as a collecting bed for the tacky droplets.

6. The apparatus according to claim 5 wherein said precoating means comprises an imperforate element positioned on the side of the screen closest to the said outlet, said imperforate element being positioned adjacent to a portion of the foraminous member to block the flow therethrough until a deposit of the sprayed material forms thereupon.

7. An apparatus according to claim 1 wherein there is provided a second enclosure, a means for forcing a second gas into said second enclosure and through the screen and the screen is driven so as to move the accumulated mat thereon from said enclosure into said second enclosure whereby the mat upon the screen is exposed first to the gas within the enclosure and thereafter to the gas within the second enclosure.

8. The apparatus of claim 7 wherein a duct means is provided for exposing the mat upon the screen in the second enclosure to a gas having a composition that is different from the gas in the enclosure.

9. The apparatus of claim 7 wherein a source of cooling gas is provided and a duct means is provided for circulating the cooling gas through the mat on the screen in the second enclosure after the gas within the first mentioned enclosure has passed through said mat.

10. The apparatus of claim 1 wherein a brush is provided to remove material from the screen.

11. The apparatus of claim 10 wherein a conveyor is provided for receiving pieces of the mat leaving the end of the screen after the pieces have been removed.

12. A spray drying apparatus comprising in combination: a liquid supply, dispersing means connected to the liquid supply for reducing the liquid to a multiplicity of minute gas-suspended droplets, a spray enclosure surrounding the dispersing means to contain the drying gas and maintain the gas in contact with the droplets, a source of drying gas communicating with the enclosure, a blower connected to communicate with the enclosure for forcing the drying gas from the gas source through the enclosure, an outlet communicating with the enclosure and with the blower for exhausting the drying gas from the enclosure, a relatively fixed foraminous collecting screen located within the enclosure whereby substantially all of the solids expelled from the dispersing means are deposited as a mat upon the screen, the lower portion of the enclosure comprising a hopper having side walls that converge toward the bottom thereof, said foraminous collecting screen being disposed vertically and sealed along all of its
edges across the enclosure between the source of drying gas and the blower, a gate valve within the hopper at the bottom of the screen for allowing material that is collected upon the screen to flow periodically when the gate valve is in an open position to the outlet at the bottom of the hopper whereby gas in the enclosure can be forced to pass exclusively through the foraminous collecting screen when the gate valve is in a closed position, whereby the mat accumulates in a quiescent condition to a thickness of at least about a quarter of an inch whereby particles present in the mat itself serve as a collecting medium for additional particles, said collecting surface extending entirely across the outlet and being sealed at all times along its edges whereby producing a pressure differential of at least one-half inch of water is developed thereacross by means of the blower and the gas that passes through the outlet flows steadily through the collecting screen and so as to deposit the droplets on the collecting surface as a homogeneous mat having no holes therein other than pores between the individual dried droplets and composed of the partially dried droplets of the liquid bonded together at their points of contact, the nozzle being spaced from the collecting surface for a particular temperature and drying capacity of the gas so that the particles are tacky but contain insufficient liquid to flow together when they impinge upon the collecting surface and means for removing the mat from the screen.