

Sept. 15, 1936.

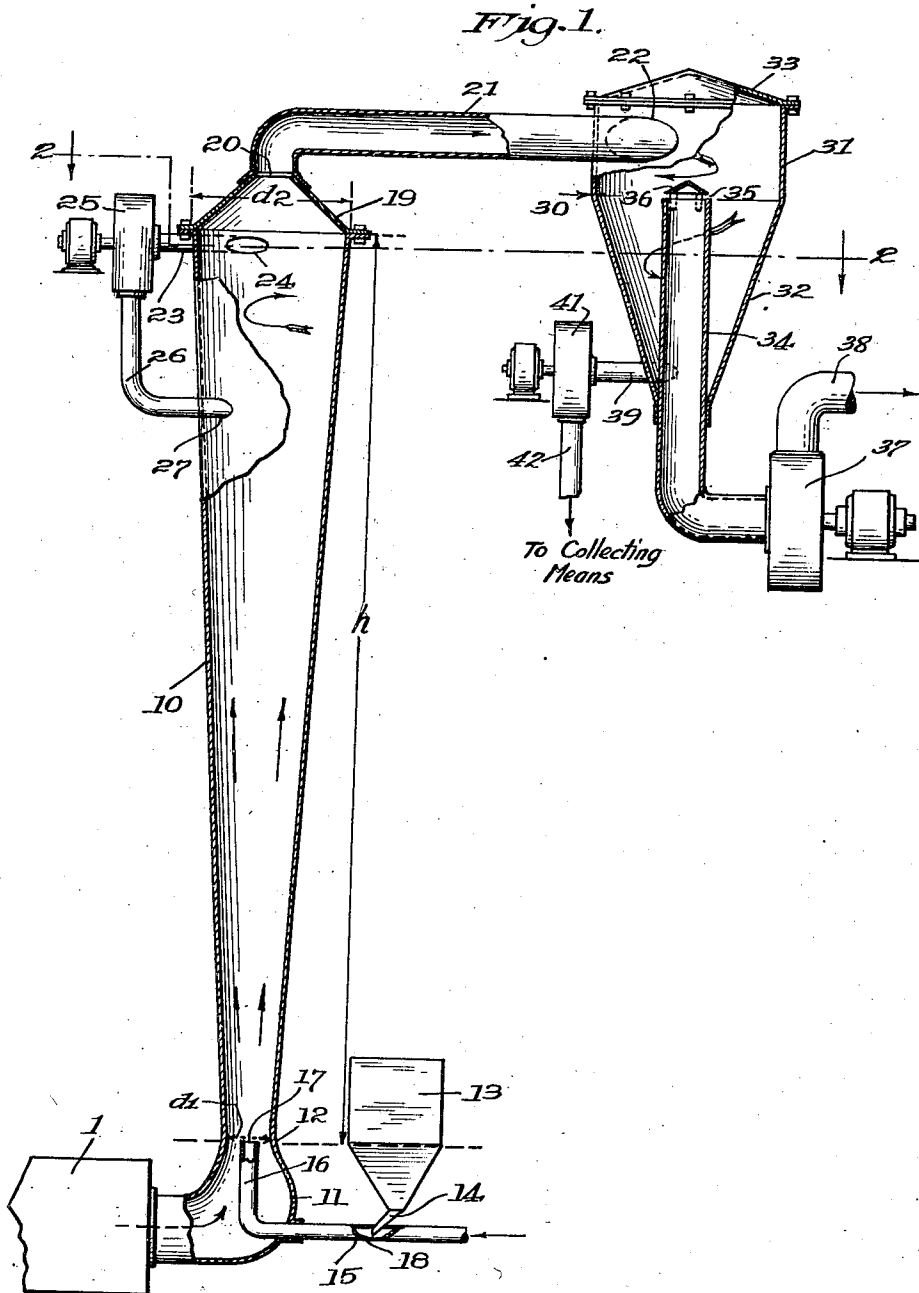
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2,054,441

METHOD AND APPARATUS FOR DRYING LIQUID CONTAINING MATERIALS

Filed Jan. 29, 1932

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

Fig. 2.

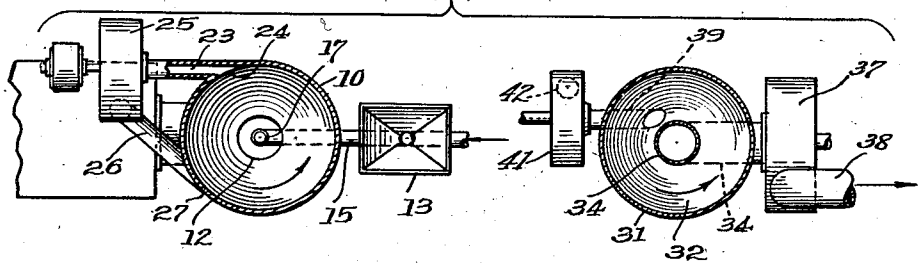


Fig. 3.

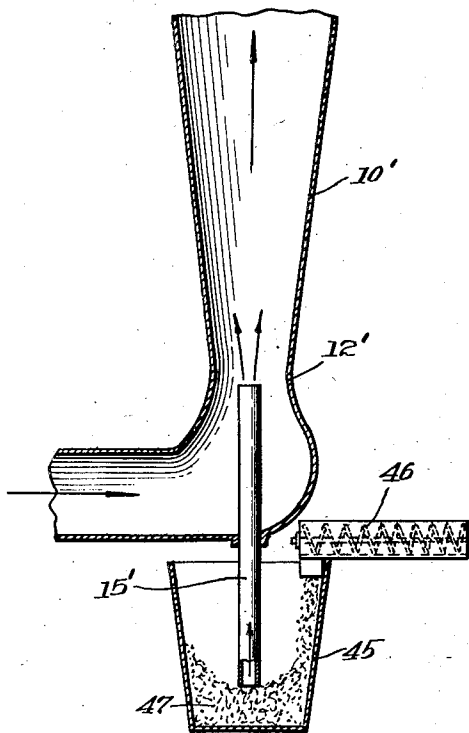
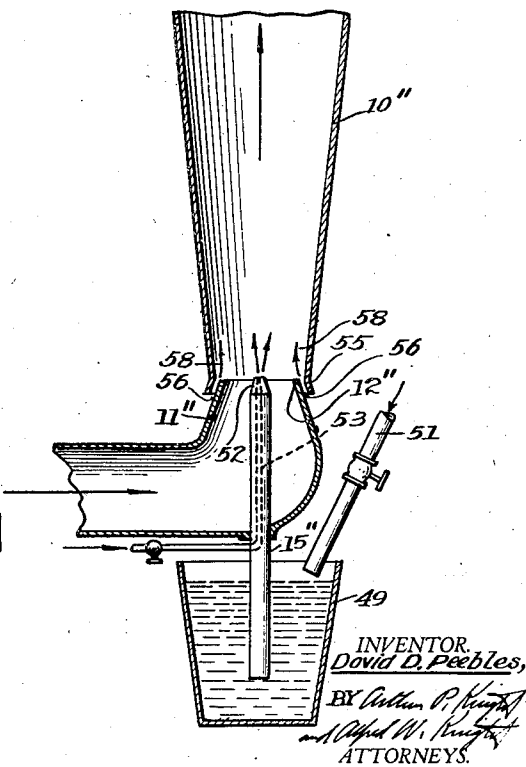


Fig. 4.



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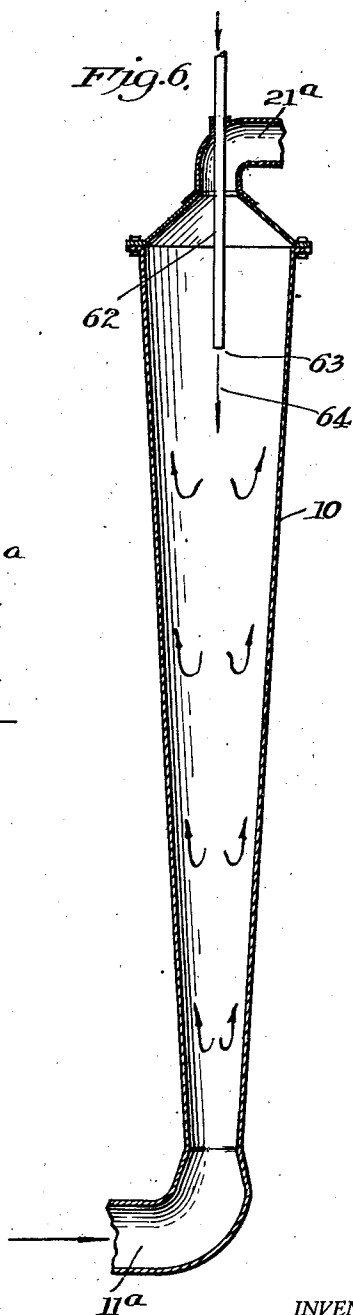
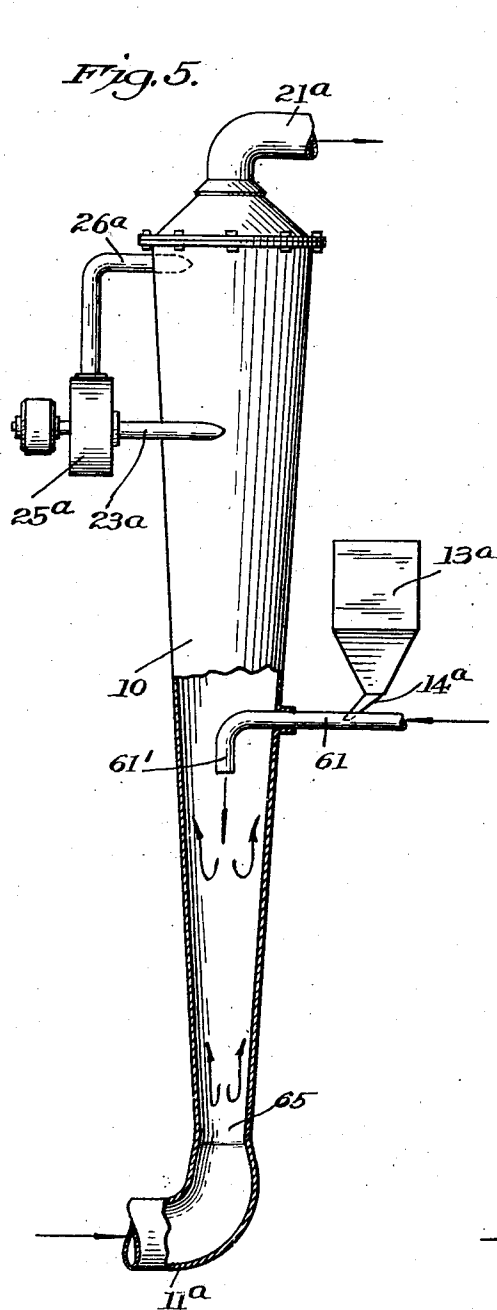
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METHOD AND APPARATUS FOR DRYING LIQUID CONTAINING MATERIALS

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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,054,441

METHOD AND APPARATUS FOR DRYING
LIQUID CONTAINING MATERIALSDavid D. Peebles, Eureka, Calif., assignor to
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Application January 29, 1932, Serial No. 589,645

11 Claims. (Cl. 159—4)

This invention relates to the drying of liquid-containing materials, by evaporation of liquid therefrom, and particularly to the dehydration of solid or liquid materials containing water, by contact with a heated gaseous drying medium.

In the methods heretofore used for this purpose, it has been customary to bring the material, in a state of suitable sub-division, into contact with a gaseous drying medium at a temperature sufficient to effect removal of liquid from such material, but in many cases difficulty has been experienced in obtaining a uniform degree of liquid removal from all the particles of material. This difficulty may be due in part to differences in initial liquid content of different particles of the material, in part to differences in size or physical structure of the particles, by reason of which the smaller particles, or those particles which are of less dense structure, tend to undergo a more complete liquid removal than the larger or more dense particles, and in part to a failure to obtain uniformly effective contact and uniform time of contact of all the particles of material with the gaseous drying medium. These factors have frequently resulted in insufficient drying of some of the particles of material, and excessive drying of other particles, and in some cases have caused burning, hardening or other injury to some of the particles. Under such non-uniform conditions, if it is attempted to insure drying of all the particles to less than a certain liquid content, by using a drying medium at sufficiently high temperature and providing a sufficiently long time of contact to cause drying to the desired extent of even the largest and densest of the particles and the particles having the highest original liquid content, as well as those particles which are subjected to the least effective contact with the drying medium, the result is not only an increase in cost of operation due to the greater amount of heat consumed in unnecessary and expensive heating of some of the more easily dried particles, but also, in many cases, serious injury to the material, due to heating of some of these particles to excessive temperatures, and to excessively prolonged treatment of such particles at these temperatures.

This latter objection is particularly serious in the case of organic materials or other materials

susceptible to injury by heat. For example, in the dehydration of certain vegetables and fruits, which has long been practiced for the purpose of preserving the same and reducing the weight thereof, it has been found that the flavor, appearance, and other properties are injuriously affected if the material is subjected to excessively high temperature for an unduly long period. The same is also true in the treatment of heat sensitive liquid materials such as milk or milk products.

The principal object of the present invention is to provide for drying liquid-containing particles in such manner to produce material of a uniform degree of dryness, regardless of variations in the size of such particles, and at a minimum cost.

A further object of the invention is to minimize the heat required to remove a certain amount of liquid from liquid-containing materials, and particularly from liquid-containing materials in the form of particles differing from one another in size or physical structure, or in original liquid content.

A further object of the invention is to provide for the uniform drying, to any desired degree of dryness, of liquid-containing material susceptible to injury by heat, and to prevent any of such material from being subjected to high temperature for an excessive period of time. A particular object of the invention is to provide a method and apparatus for the above purpose, in which each particle of material is subjected to only such temperature and for only such length of time, as is required to effect the desired removal of liquid from that particular particle.

A particular object of the invention is to obtain an efficient and economical removal of liquid from materials containing the same, without causing burning, hardening or other injurious effects on such material, and also without causing excessive heating or hardening of the surface of the particles of such material.

A distinguishing feature of the present invention is that the movement of the particles of liquid-containing material through and out of the drying zone is controlled in accordance with the amount of liquid remaining in such particles, in such manner that, as the liquid content of each particle is reduced to a certain desired point,

such particle is removed from the high temperature zone and thus prevented from injury by continued subjection to high temperature and also prevented from taking up additional heat from the drying medium.

A further distinguishing feature is that the liquid-containing particles are subjected to heating and drying in an elongated drying chamber and that the temperature of the drying medium within said chamber is caused to be progressively reduced in the direction of travel of such particles therethrough, and the particles are introduced first into a zone of relatively high temperature and are progressively carried into zones of decreasing temperature in accordance with the degree of removal of liquid therefrom.

According to a preferred embodiment of the invention, the liquid-containing material is introduced in divided condition into an ascending column of heated gaseous drying medium of upwardly decreasing velocity and temperature. The upward velocity of the drying medium at the lower portion of said column should be sufficient to overcome the tendency of any of the particles to fall out of said column under the action of gravity, and thus keep all of the material in suspension. The lighter particles are carried upwardly by the gas stream until the upward velocity of the gas is sufficiently reduced to just balance the force of gravity on such particles, while the heavier particles, namely, particles of greater size or inherent density or having relatively high liquid content, remain in the lower portion of the gas stream and are subjected to the maximum temperature thereof. As the liquid content of each particle, and consequently the weight thereof, is reduced, the particle is carried upwardly by the gas stream to progressively higher levels where it is subjected to further drying action by gas of progressively lower temperature, until the liquid content is so reduced that the particle becomes sufficiently light to be carried to the top of the ascending column of gas. The spent gaseous drying medium together with dried particles carried away in suspension therein, is conducted from the top of the ascending column to suitable means for separation of the dried particles therefrom.

The liquid-containing material may be introduced at any suitable level in the ascending column, but is preferably introduced at or adjacent the lower end of said column.

I also prefer to provide means for producing vortical motion of the gaseous drying medium and suspended particles in the upper portion of the ascending column, such vortical motion being preferably effected by withdrawing a portion of the gaseous medium and suspended particles from one point in said upper portion and reintroducing the same at another point in said upper portion, such removal and reintroduction being carried out in a tangential direction with respect to the periphery of the ascending column, and in the same rotative direction so as to maintain whirling or vortical movement of the gaseous medium and suspended particles in the upper portion of the column and cause prolonged contact of the heavier particles of material with the drying medium, due to the greater tendency of such heavier particles to be thrown outwardly toward the periphery of the whirling gaseous medium by the action of centrifugal force. The gaseous drying medium is caused to leave the ascending column through a restricted central opening at the top of the column and of less diameter than

the column at the region of such vortical motion, so that no particles are permitted to be carried out through such openings until they are sufficiently light to be carried inwardly by the gas against the action of centrifugal force.

Means are also preferably provided for utilizing the velocity of the gaseous drying medium itself to create a reduced pressure at the point of introduction of the material to be dried, for the purpose of drawing such material into the drying column.

Other features and possible modifications of the invention will be described more fully hereinafter, and additional objects and advantages thereof will be either apparent from such description or specifically pointed out.

The accompanying drawings illustrate typical forms of apparatus according to the present invention, and in which the method of my invention may be advantageously carried out. Referring to these drawings:

Fig. 1 is a partly sectional side elevation of a preferred form of apparatus for removing liquid from divided solid materials.

Fig. 2 is a horizontal section on line 2-2 in Fig. 1.

Fig. 3 is a vertical section of the lower portion of the drying chamber showing a modified means for introducing divided solid material thereto.

Fig. 4 is a vertical section of the lower portion of the drying apparatus, showing a modification of such apparatus and of the material introducing means particularly adapted for the treatment of liquid materials.

Fig. 5 is a partly sectional side elevation of a modified form of drying apparatus, in which the liquid-containing material is introduced at a level somewhat above the bottom of the ascending gas column.

Fig. 6 is a vertical section of another modification, in which the liquid-containing material is introduced adjacent the upper end of the ascending gas column.

The apparatus shown in Figs. 1 and 2 comprises a source of heated gaseous drying medium, such as a furnace or heat exchanger indicated generally at 1, a vertically elongated drying chamber 10 and a partial separator or concentrator 30 for receiving the spent gaseous drying medium and suspended dried material and effecting a partial separation of such material from said drying medium and a concentration of such material in a relatively small proportion of such medium.

The drying chamber is shown as comprising a vertically disposed casing of circular cross-section and having a height equal to several times its greatest diameter. Said casing is of upwardly increasing cross-sectional area throughout the greater portion of its height, increasing from a diameter d_1 near its lower end to a diameter d_2 near its upper end, which latter diameter may be for example from 2 to 6 or more times as great as the first-mentioned diameter. The height h of the casing, from the point of lesser diameter to the point of greater diameter is equal to several times the greater diameter, for example, said height may be from 3 to 6 or more times as great as said diameter. This major portion of the casing therefore has the form of a narrow, gradually tapering inverted frustum of a cone.

The lower end of the drying chamber is connected by a suitable entrance housing 11 to the source of gaseous drying medium. Such entrance chamber is shown as being of elbow shape and may advantageously be of somewhat greater diameter

than the minimum diameter d_1 of the main drying chamber, so as to provide a restricted throat 12 at the base of said drying chamber. Suitable means are provided for introducing the material to be dried into said drying chamber adjacent the lower end thereof and preferably at or near said restricted throat. For example, for the treatment of solid material in divided condition, such means may comprise a hopper-like receptacle 13 having a spout 14 leading from the lower end thereof into a conduit 15 which extends into the entrance chamber 11 and is provided with an upwardly extending portion 16 opening at its upper end 17 into the drying chamber at substantially the level of said throat. Said conduit preferably opens upwardly into the drying chamber and substantially centrally thereof. The conduit 15 may be connected at its other end to the atmosphere or to any suitable source of air or other gas at atmospheric temperature or at any other desired temperature, and at atmospheric or any other suitable pressure. According to a preferred embodiment of the invention, such conduit is open to the atmosphere, and the necessary velocity of air therethrough for conveying the divided solid material into the drying chamber is created by the reduction of pressure produced at the restricted throat 12 due to the high velocity of the gaseous drying medium at this point past the open end 17 of said conduit, the velocity of said gaseous medium at said point being sufficient to cause a reduction of pressure below atmospheric pressure. The delivery of divided solid material from the spout 14 into the gas stream in conduit 15 may be facilitated by inclining said spout downwardly and forwardly in the direction of gas flow through said conduit and by providing said spout with an opening 18 at its lower end which is disposed forwardly in the direction of such gas flow.

The casing 10 is shown as provided with an upper end portion 19 formed as a frustum of a cone, extending upwardly and inwardly from the point of maximum diameter of said casing to a restricted centrally disposed outlet opening 20. Said opening 20 is of considerably less diameter than the maximum diameter d_2 , and may, for example, be approximately equal to the minimum diameter d_1 . The converging upper portion 19 is of considerably greater inclination to the vertical than the main casing portion 10, and is consequently of relatively small height as compared to said main casing portion. The interior of the casing 10 is shown as being entirely unobstructed between the restricted throat 12 at the lower end thereof and the central outlet opening 20 at the upper end thereof. A conduit 21 leads from said outlet opening 20 to the partial separator or concentrator 30, and is shown as opening tangentially into said separator or concentrator, as indicated at 22.

Means are also preferably provided for producing vortical or whirling motion of the gas in the upper portion of the drying chamber, such means being shown as consisting of circulating means comprising a conduit 23 communicating substantially tangentially with the interior of the drying chamber adjacent the periphery thereof as shown at 24 and leading to a fan or blower 25 and a conduit 26 leading from the outlet of said fan or blower and opening substantially tangentially into said drying chamber adjacent the periphery thereof as shown at 27. The conduits 23 and 26 are so disposed as to respectively withdraw and reintroduce gas from and to said chamber in the

same rotative direction, so as to maintain an active whirling or vortical motion of the gas in the upper portion of said chamber. The conduit 23 is shown as disposed somewhat above the conduit 26, but this relationship is not essential to the invention. The vertical distance between these two conduits may be varied as desired, or the relative disposition thereof with respect to the height of the drying chamber may even be reversed if desired.

The separating apparatus 30 is shown as comprising a centrifugal separator adapted for downward flow of gas and suspended material, and comprises a housing of circular cross-section including an upper cylindrical portion 31 and a lower portion 32 of inverted frusto-conical shape. The upper end is closed by a top plate 33 of any suitable shape. A gas outlet conduit 34 extends centrally within the lower portion of the separator housing, from a level considerably above the lower end, thereof downwardly through said lower end, and opens at its upper end into the interior of the separator housing as shown at 35. The point of communication of said outlet conduit with the separator housing may, for example, be adjacent the level of the lower end of the cylindrical portion 31 and is, of course, substantially centrally disposed with respect to said housing. If desired, a suitably shaped hood or baffle 36 may be mounted over the upper end of said outlet conduit, but spaced somewhat above the same so as to permit outward flow of gas into said conduit. The other end of said outlet conduit may lead, as shown, to a suitable device such as a fan or blower 37 for creating the desired flow of gas through the apparatus. In case it is desired to remove any suspended particles which may remain in the gas discharged through outlet conduit 34, the discharge of said fan or blower may be connected by conduit 38 to any suitable means for collection of such material.

Another outlet pipe 39 opens substantially tangentially into the interior of the separator housing adjacent the periphery thereof and at or adjacent the lower end of the downwardly converging portion 32 thereof, and said conduit leads to a suitable device such as fan or blower 41 for withdrawing gas and suspended particles therefrom. The discharge of said fan or blower may be connected by conduit 42 to any suitable means, not shown, such as a centrifugal separator or filter, for separation and collection of the treated material from that portion of the gaseous medium which is removed from the separator 30 along with such material.

In the operation of the above described apparatus the several fans 25, 37 and 41 are set in operation, and the furnace or other heating apparatus 1 is also operated, so as to cause gaseous drying medium at suitable temperature to be delivered from said heating apparatus through entrance chamber 11, through the restricted throat 12, and thence upwardly through the drying chamber. The liquid-containing material to be treated, consisting in this case of material of a solid nature, in suitably crushed, ground, shredded or otherwise divided condition, and containing water or other liquid, either chemically or physically associated therewith, is delivered to the feed receptacle 13 and thence through spout 14 into the current of air or other gas which is induced to flow through conduit 15 by the reduced pressure created at the restricted throat 12. Such material is mixed with and suspended in said current of air or other

gas and is carried thereby through said conduit and delivered upwardly through the opening 11 into the lower portion of the drying chamber. Such material is thus brought into contact with the ascending column of gaseous drying medium in said chamber and is simultaneously heated and carried upwardly thereby, the rate of such upward movement and consequently the duration of the drying operation being dependent upon the size and weight of the individual particles. The velocity of upward gas flow at the lower end of the drying chamber is sufficient to exert a great enough upward force to hold all the particles of material in suspension. Each particle is carried upwardly until a level is reached at which the upward velocity of gas is just sufficient to counter-balance the weight of such particle, and will thereafter gradually continue to rise as the weight is reduced due to evaporation of liquid therefrom. The cross-sectional area of the upper end of the drying chamber is so selected, in proportion to the amount of gas moving upwardly at this point, as to provide a certain upward velocity, which is insufficient to carry away any particle containing more than approximately desired amount of liquid, so that each particle is caused to remain in the drying chamber for whatever length of time may be necessary to reduce its liquid content to this desired point. Furthermore, particles of relatively high liquid content and consequently of relatively large weight are caused to remain at a lower level in the drying chamber than particles of relatively low liquid content, and are thus subjected to contact with the drying medium at relatively higher temperatures, since it will be observed that the temperature of the gaseous drying medium progressively decreases in its upward movement through the drying chamber due to transfer of heat to the solid particles and to utilization of such heat in evaporating liquid therefrom. Thus the temperature to which each particle is subjected, is progressively decreased as the liquid content thereof decreases, a feature which is of particular advantage in preventing burning or other injury to the material being treated. When the liquid content of such material is relatively high, burning or injury is prevented due to the rapid utilization of heat in evaporating such liquid, and probably also due in part to the presence of an envelope of liberated vapors around such particle; as the liquid content decreases the particle becomes more susceptible to injury by heat, but such injury is prevented according to this invention by a corresponding reduction in the temperature to which the particle is subjected. As the particles approach the desired state of dryness, and when their susceptibility to injury by heat is a maximum, they are subjected only to the relatively low temperature of the drying medium at or near the upper part of the drying chamber. The automatic removal of particles from the zone of highest temperature before the liquid content thereof is reduced below a certain point also prevents excessive heating and hardening of the surfaces of the particles, which would not only result in direct injury to the product, in certain cases, but would also tend to prevent the desired evaporation of liquid from the interior portions of the particles.

Furthermore, particles of relatively large size are moved upwardly within the drying chamber somewhat more slowly than particles of relatively small size, as the buoyant effect of the gas

on the suspended particles increases to a less extent with increased size of particle than does the downward pull exerted by the force of gravity. This is advantageous, since somewhat more prolonged heat treatment is required to remove a given proportion of liquid from a large particle than from a small particle, due to the longer time required for the entire particle to become heated and also to the greater difficulty of escape of vapors therefrom. The same is also true of particles of relatively high specific gravity, as these particles are carried upwardly more slowly than particles of relatively low specific gravity, and also require more prolonged heat treatment due to the fact that they are generally of a more dense structure and consequently give up their liquid by evaporation less readily.

In the upper portion of the drying chamber, a portion of the gaseous medium is continually withdrawn tangentially from the periphery of the chamber through conduit 23 and reintroduced tangentially adjacent the periphery of said chamber through conduit 26, and the gaseous medium in this portion of the chamber together with the suspended solid particles contained therein are thereby caused to whirl about the axis of said chamber at relatively high velocity. Any particles which might tend to pass through the drying chamber due to the initial upward momentum thereof, are caught in this whirling gas and, due to the relatively large weight thereof, are driven outwardly by centrifugal force and are either recirculated with the gas through said conduits 23 and 26 or are carried around with the whirling gas in the upper portion of the drying chamber until they are sufficiently dried so that their weight becomes sufficiently small to permit them to be carried upwardly and inwardly by the gas, against the action of centrifugal force, and to reach the restricted central outlet opening 20. I is, therefore, seen that the use of this restricted central outlet opening is of importance in connection with the whirling gas movement in the upper portion of the drying chamber, as no particle can move inwardly to said opening and against the action of centrifugal force until its weight is reduced to a certain predetermined point corresponding to a certain liquid content.

It is evident therefore that both the force of gravity and centrifugal force are utilized according to this invention for controlling the duration of the drying action and for causing all particles to remain in the drying chamber for just sufficient time to dry the same to the desired extent.

The gas discharged through opening 20, together with the suspended particles carried thereby, passes through conduit 21 and enters tangentially into the separator 30. Said gas passes downwardly with a whirling motion within the housing portions 31 and 32, and the major portion of the gas is drawn inwardly by the exhausting action of fan 37 and passes through opening 35 and conduit 34 to said fan. However, due to the centrifugal action on the suspended particles, such particles are prevented from being drawn inwardly with the gas and are concentrated principally or wholly in the outer layer of the whirling gas and against the walls of the separator housing, and are eventually carried downwardly to the lower end of said housing and are drawn off through the discharge conduit 39, together with a relatively small proportion of gas, by the action of fan 41. From said fan this concentrated suspension of solid particles in a relatively small volume of gas is delivered through

conduit 42 to the above-mentioned means for separating such suspended particles from this small volume of gas, and for collecting the dried material.

One advantage of the use of a centrifugal separator 30 of the down-draft type, such as above-described, is that it provides for removal of both gas and separated solids from the lower portion of the separator, instead of requiring that a gas outlet flue be carried up above the top of the separator housing, as is the case in separators of the ordinary cyclone type. Since the drying chamber itself is necessarily of considerable vertical height, and since it is advantageous to have the conduit 21 extend substantially horizontally from a position above the drying chamber outlet opening 20 to the tangential inlet of the separator 30 in order to minimize the draft loss in said conduit, it is evident that a considerable practical advantage in the way of minimizing the total height of the apparatus is realized by providing a separator of such type that no additional head room is required above the top of such separator.

The temperature of the gaseous drying medium used, as well as the nature and quantity of such medium, may be varied in accordance with the nature and quantity of material to be treated and the amount of liquid to be removed therefrom. For example, in one specific instance where it was desired to substantially dry alfalfa containing approximately 75% water, good results were obtained by using furnace gases at a temperature of approximately 625° F. at the point of entrance into the drying chamber. In any event the quantity of gas used and the initial temperature thereof should be sufficient so that the temperature of the gas at the outlet of the drying chamber and throughout the separating and collecting apparatus is above the dew-point of the gas containing the vapors evaporated from the material being treated, so as to prevent condensation of liquid in any part of the system. Preferably, the final temperature of the gases is above the boiling point of the liquid which is to be evaporated. For example, in the specific instance above-mentioned, the quantity of gases used was such that the temperature of the gas at the outlet of the drying chamber was approximately 220° F.

The relative quantity of gas circulated through the conduits 23 and 26, for maintaining whirling motion within the drying chamber, as compared to the total gas flow through the system may also be varied according to the requirements of any particular operation. For example, in the drying of alfalfa as above-mentioned, good results were obtained by circulation of from 600 to 800 cubic feet of gas per minute through said conduits, while the total gas volume discharged through fan 37 (not including the relatively small quantity of gas discharged through fan 41) was from 4500 to 4800 cubic feet per minute, both these volumes being calculated at approximately 220° F.

The upward velocity of the gaseous medium within the drying chamber, as well as the relation between the initial velocity at the diameter d_1 and the final velocity at the diameter d_2 , may also be varied according to the nature of the material to be treated and other conditions. For example, the initial upward velocity at the bottom of the drying chamber may be from 50 to 150 feet or more per second, and the minimum upward velocity at the top of the drying chamber may be from $\frac{1}{4}$ to $\frac{1}{20}$ of the initial velocity. It

will, of course, be understood that all of the above values are given only by way of example, and are not to be considered as limiting the invention to these particular values.

In the drying of alfalfa with the above-described apparatus, the alfalfa may be delivered to the receptacle 13 in shredded, chopped or otherwise divided condition, and of sufficiently small particle size to pass readily through the spout 14 and to be carried along by the gas passing through conduit 15. The same method may also be used for the drying of other liquid-containing materials of a solid nature, either organic or inorganic. However, the invention is particularly advantageous for the drying of organic materials which are more or less susceptible to injury by heat. Other examples of materials which may advantageously be dried by this method are vegetables, such as carrots or the like, and various kinds of fruits, which may also be reduced to shredded or chopped condition and introduced in the same manner as described above for alfalfa.

Other means may be used for introducing the liquid-containing material into the drying chamber. For example, in Fig. 3, the feed conduit 15' is shown as extending straight downwardly into a receptacle 45, to a position near the bottom of said receptacle, and divided solid material, such as one of the materials above-mentioned may be delivered to said receptacle as by means of screw conveyor 46, in such manner as to maintain a body of such material within said receptacle, as indicated at 47, up to or somewhat above the lower open end of conduit 15'. The conduit 15' opens, as before, into the restricted throat 12' of the drying chamber 10', in such manner that the reduced pressure created at said throat serves to draw the divided solid material from said receptacle upwardly through said conduit and into the drying chamber.

In Fig. 4 I have shown a form of feed means particularly adapted for use in the drying of liquid materials, such as milk or the like, which contain solids in solution or suspension therein. In this case the feed conduit 15'' extends downwardly into a receptacle 49, into which the liquid material is delivered as by means of pipe 51. The upper end of conduit 15'' opens into the drying chamber adjacent the restricted throat 12'', and is preferably tapered inwardly toward the discharge opening thereof, as shown at 52. Furthermore, in order to assist in atomization or subdivision of the liquid material into particles of relatively small size, I prefer to provide a pipe 53 which extends upwardly within the pipe 15', through which air, steam, or other gas, may be introduced. Said pipe 53 terminates in an opening adjacent the opening of pipe 15'', in the well known manner of spraying or atomizing devices of this type.

For use in the treatment of liquids, I also prefer to provide means for introducing air or other gas at relatively low temperature into the drying chamber and between the ascending column of high temperature gas and the walls of said chamber; such relatively cool gas being also preferably introduced in an upward direction so as to form a protecting layer which not only tends to prevent contact of the liquid material with the side walls but also to lower the temperature of the side walls sufficiently to prevent burning or injury to any particles of material which may come in contact therewith. For this purpose, the lower end of the drying chamber 10'' is shown as provided with a downwardly and outwardly extend-

ing flange 55, spaced somewhat from the correspondingly inclined upper edge portion of the entrance chamber 11'', so as to provide an annular opening or passage 56 therebetween, which opens upwardly and inwardly toward the interior of the drying chamber.

In the treatment of liquid materials in this form of apparatus, the liquid is drawn up through the conduit 15'' due to the reduced pressure at the throat 12''. As such liquid emerges from said conduit it is atomized or subdivided by the combined action of the gas admitted through pipe 53, preferably under suitable pressure, and the gas passing upwardly at high velocity around the tip portion 52 of said conduit. The material thus introduced is heated, and liquid is evaporated therefrom in substantially the same manner as described above in the treatment of solid materials, and the apparatus acts as before to insure the desired degree of removal of liquid from all of the particles, without injury or excessive heating of any of the particles, due to the fact that the size and weight of the particles decreases as liquid is evaporated therefrom. In this way, the solids contained in milk, or other liquid products, may be recovered in dry powdered condition, without danger of injury thereto by excessively prolonged contact with gas at high temperature.

The relatively cool air drawn in through the annular opening 56 passes upwardly along the walls of the drying chamber, as indicated by the arrows at 58, and assists in preventing the suspended liquid particles from contacting such side walls and also in maintaining such walls at a sufficiently low temperature so that any particles which may come in contact therewith are not injured or caused to stick to said walls.

The remainder of the operation, including the whirling of the gas and suspended particles in the upper portion of the drying chamber, the removal of the gas and dried particles from said chamber, and the subsequent separation of such particles from said gaseous medium, may be carried out in substantially the same manner as above described.

The form of apparatus shown in Fig. 5 comprises a vertically elongated drying chamber 10 of substantially the same type as shown in Fig. 1, means 11a for introducing heated drying medium from any suitable source upwardly into the lower end of said chamber, and a flue 21a for conducting the spent drying medium and dried particles from the upper end of said chamber.

The principal distinction of this form of apparatus from that shown in Fig. 1 is that the liquid-containing material is introduced into the drying chamber at a level somewhat above the lower end thereof. In case the material to be treated consists of solid material in divided condition, the means for introducing such material may comprise a pipe 61 opening into the interior of said chamber at a level somewhat above the lower end thereof, but at a considerable distance below the upper end of said chamber, and preferably having its inner end portion 61' directed downwardly. A stream of air or other suitable conveying fluid may be introduced through said pipe, and the divided solid material, containing liquid which it is desired to remove therefrom, may be introduced into said fluid stream by means of hopper 13a and spout 14a. It will be understood that any other suitable means for introducing liquid-containing ma-

terial at an intermediate level in the drying chamber may be substituted for the means above described. In case such material is of a liquid nature, it may be either sprayed or atomized directly into the gaseous drying medium at the desired level or may be sprayed into a separate stream of conveying fluid, such as air, and carried thereby into the drying chamber.

The apparatus may in this case also be provided with means for maintaining whirling motion of the gaseous medium and suspended material in the upper portion of the drying chamber. Such means may comprise, as before, a fan or blower 25a and conduits 23a and 26a opening tangentially into said chamber adjacent the periphery thereof. In this case, however, the pipe 23a leading from the drying chamber to the inlet of said fan is shown as disposed at a somewhat lower level than the conduit 26a which leads from the fan back to the drying chamber, but this relative disposition is not essential.

In the operation of the form of apparatus last described the flow of drying medium into and through the drying chamber is substantially the same as before. The material to be dried, however, is delivered into the ascending column of drying medium at an intermediate level therein, and preferably in a downward direction. The lighter particles of such material are more quickly arrested in their downward movement and carried upwardly, while the heavier particles continue to fall to successively lower levels until their downward movement is finally arrested by the entraining effect of the upwardly moving gas, it being understood that the upward velocity of the gas at the bottom of the ascending column, that is, at the point indicated at 65, is preferably maintained sufficiently high to cause substantially all of the particles of material to be arrested in their downward movement and thus prevent the discharge of any appreciable quantity of such material through the lower end of the drying chamber. The particles of material are, as before, carried to progressively higher levels in the drying chamber as their liquid content and consequently their weight is progressively reduced, and are thus brought into contact with drying medium at progressively lower temperature. Furthermore, all the particles are caused to remain within the drying chamber until their liquid content, and consequently their weight, becomes sufficiently small to permit the same to be carried upwardly to the point of minimum gas velocity at the top of the drying chamber and thence out through conduit 21a. The whirling gas movement within the upper portion of the drying chamber also acts in substantially the same manner as before, to prevent particles of excessive weight and liquid content from being prematurely carried out of the drying chamber, and increases the period of subjection of such particles to contact with the drying medium.

The apparatus shown in Fig. 6 also comprises a drying chamber 10 of substantially the same type as above described, provided with inlet means 11a for delivering drying medium upwardly into the lower end thereof and outlet means 21a for conducting the spent drying medium and dried material from the upper end thereof. A pipe 62 extends downwardly into the drying chamber and is preferably disposed substantially axially thereof, and said pipe opens at its lower end 63 into the interior of the drying chamber at a level adjacent the upper end thereof. The material to be treated may be delivered through said pipe in any

suitable manner, for example in a manner similar to that in which it is delivered through the pipe 61 in Fig. 5. Any other means for introducing material of a solid or liquid nature, in divided condition, into the gaseous medium adjacent the upper end of the ascending column, may be substituted for the means above described.

In this case the apparatus is not shown as provided with means for maintaining whirling movement in the upper portion of the drying chamber.

In carrying out the drying operation in this form of apparatus the material is delivered downwardly from pipe 62 into the drying chamber, as indicated by the arrow at 64. The initial downward momentum of the particles of material so introduced, and also the force of gravity acting thereon, tend to cause such particles to fall toward the bottom of the drying chamber, but these forces are opposed by the entraining force of the upwardly moving gas column. The greater momentum and greater weight of the larger and heavier particles, including particles of relatively high liquid content, will cause such particles to descend to a relatively low level in said column before their downward motion is completely arrested, while the lighter particles will descend to a less distance and will remain at relatively high levels in the drying chamber. As before, the upward velocity of the drying medium at the lower end of the drying chamber is sufficient to substantially prevent outflow of any of the particles of liquid-containing material into the inlet means 11a, and such upward velocity progressively decreases throughout the height of the drying chamber, due to the increasing cross-section thereof. The removal of liquid from the suspended particles, the progressive movement of such particles to higher levels and consequently to points of progressively lower temperature, and the final removal from the drying chamber of particles whose liquid content is reduced to the desired point are carried out in this form of apparatus in substantially the same manner as above described, except for the effect of the whirling movement in the upper portion of the drying chamber, which in this case is omitted.

I claim:

1. The method of drying liquid-containing materials which comprises establishing an ascending column of gaseous drying medium of upwardly decreasing velocity and temperature, introducing liquid-containing material in divided condition into said column so as to cause removal of liquid from such material by evaporation and cause particles from which liquid is so removed to be carried upwardly in said column, the drying medium in the lower portion of said column being caused to move substantially vertically upward, maintaining whirling movement of gaseous medium and suspended particles in only the upper portion of said column about the axis thereof, and removing gaseous medium and suspended particles from said column above the region of such whirling movement.

2. The method of drying liquid-containing materials which comprises establishing an ascending column of gaseous drying medium of upwardly decreasing velocity and temperature, introducing liquid-containing material in divided condition into said column so as to cause removal of liquid from such material by evaporation and cause particles thereof from which liquid is so removed to be carried upwardly in said column, removing gaseous medium substantially tangentially from the upper portion of said column and reintroduc-

ing such gaseous medium substantially tangentially into the upper portion of said column so as to maintain whirling movement in said upper portion about the axis of said column, and removing gaseous medium and suspended particles from said column above the region of such whirling movement, and separating such gaseous medium and suspended particles from one another.

3. The method of drying liquid-containing materials which comprises establishing an ascending column of gaseous drying medium of upwardly decreasing velocity and temperature, introducing liquid-containing material in divided condition into said column so as to cause removal of liquid from such material by evaporation and cause particles thereof from which liquid is so removed to be carried upwardly by said ascending column, the drying medium in the lower portion of said column being caused to move substantially vertically upward, maintaining whirling movement of gas and suspended particles in only the upper portion of said column about the axis thereof, and removing gaseous medium and suspended material from said column above the region of such whirling movement and solely at a position disposed centrally of said column and wholly within an area of considerably less diameter than the maximum diameter of said column.

4. An apparatus for drying liquid-containing material comprising a vertical chamber of upwardly increasing cross-section and provided at its lower end with a restricted throat, means for delivering gaseous medium at relatively high temperature upwardly through said restricted throat into the lower portion of said chamber at high velocity so as to create reduced pressure at said throat, means for introducing liquid-containing material in divided condition into the gaseous medium in the lower portion of said chamber, said chamber having an upwardly and inwardly directed opening at said restricted throat for introducing relatively cool gas upwardly into said chamber adjacent the side walls thereof at a level adjacent the point of introduction of such liquid-containing material, and means for removing gaseous medium and suspended particles from the upper portion of said chamber.

5. An apparatus for drying liquid-containing material comprising a vertical chamber of circular cross-section and of upwardly increasing diameter, means for introducing gaseous medium at relatively high temperature upwardly into the lower portion of said chamber, means for delivering liquid-containing material in divided condition into the gaseous medium within said chamber, means connected to the upper portion of said chamber for withdrawing gaseous medium therefrom and re-introducing the same tangentially into the upper portion thereof, so as to create whirling movement of gaseous medium and suspended particles in only the upper portion of said chamber and about the axis thereof, and means for removing gas and suspended particles from the upper portion of said chamber.

6. An apparatus for drying liquid-containing material comprising a vertical chamber of circular cross-section and of upwardly increasing diameter, means for introducing gaseous medium at relatively high temperature upwardly into the lower portion of said chamber, means for delivering liquid-containing material in divided condition into the gaseous medium within said chamber, circulating conduit means communicating substantially tangentially with said chamber at

two separate positions, fan means connected in said conduit means for effecting withdrawal of gaseous medium from said chamber at one of said positions and reintroduction of said gaseous medium into said chamber at the other of said positions, said last-named position being located at the upper portion of said chamber, and means for removing gaseous medium and suspended particles from said chamber at a position above said circulating conduit means.

7. An apparatus for drying liquid-containing materials comprising a vertical chamber of circular cross-section and of upwardly increasing diameter, means for introducing gaseous medium at relatively high temperature upwardly into the lower portion of said chamber, means for delivering liquid-containing material in divided condition into the gaseous medium in said chamber, means at the upper portion of said chamber for maintaining whirling movement of gaseous medium and suspended particles in said upper portion of the chamber about the axis thereof, means closing the upper end of said chamber and providing a restricted centrally disposed outlet opening whose diameter is considerably less than the maximum diameter of said chamber, and means for removing gas and suspended particles through said outlet opening, said means for maintaining whirling movement in the upper portion of the chamber comprising conduit means opening at each end into said chamber tangentially and in opposite directions and at different levels, and fan means connected in said conduit means.

8. An apparatus for drying liquid-containing materials comprising a vertical chamber of circular cross-section and of upwardly increasing diameter, means for introducing gaseous medium at relatively high temperature upwardly into the lower portion of said chamber, means for delivering liquid-containing material in divided condition into the gaseous medium within said chamber, means at the upper portion of said chamber for maintaining whirling movement of gaseous medium and suspended particles in said upper portion and about the axis of the chamber, said chamber having an upwardly converging portion at its upper end above the region of such whirling movement and extending from the point of maximum diameter upwardly to a restricted central outlet opening, and means for removing gaseous medium and suspended particles through said outlet opening, said means for maintaining whirling movement in the upper portion of the chamber comprising conduit means opening at each end into said chamber tangentially and in opposite directions and at different levels, and fan means connected in said conduit means.

9. An apparatus for drying liquid-containing materials comprising a vertical chamber whose major portion is of upwardly increasing diameter and is of considerably greater height than diame-

ter and whose upper portion converges upwardly from the upper end of said major portion to a restricted central outlet opening, means for introducing gaseous medium at relatively high temperature upwardly into the lower end of said major portion of the chamber, the interior of said chamber being substantially unobstructed between said lower end and said restricted central outlet opening, means for delivering liquid-containing material in divided condition into the gaseous medium within said chamber, means connected to the upper portion of said chamber for withdrawing gaseous medium therefrom and reintroducing the same tangentially into the upper portion thereof, so as to create whirling movement of gaseous medium and suspended particles in only the upper portion of said chamber about the axis thereof, and means for removing gaseous material and suspended particles from said chamber through said restricted central outlet opening.

10. An apparatus for drying liquid-containing materials comprising a vertically extending chamber of circular cross-section and of upwardly increasing diameter, said chamber increasing uniformly in diameter from a point of minimum diameter near the lower end thereof to the upper end thereof, a frusto-conical member connected directly to the upper end of said chamber and provided at its upper end with a centrally disposed outlet opening, means for delivering heated gaseous medium substantially vertically upwardly into said chamber at said point of minimum diameter, means for introducing liquid-containing material in divided condition into the lower portion of said chamber, and means for maintaining whirling motion of the gaseous medium in the upper portion of said chamber, about the axis thereof.

11. The method of drying liquid-containing materials which comprises establishing an ascending column of gaseous drying medium of upwardly decreasing velocity and temperature in an inclosed chamber, continually introducing heated gaseous drying medium upwardly into said chamber through a restricted throat at the lower end thereof, the velocity of said gaseous medium at said restricted throat being sufficient to create a reduced pressure at this point, introducing liquid-containing material in divided condition into the ascending gaseous drying medium at the region of reduced pressure adjacent said restricted throat so as to effect removal of liquid from such material by evaporation and cause particles thereof from which liquid is so removed to be carried upwardly in said column, introducing a relatively cool gaseous medium upwardly into said chamber adjacent the side walls thereof at a point of reduced pressure adjacent said restricted throat, and removing gaseous medium and supported particles from the upper portion of said chamber.

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