METHOD AND APPARATUS FOR DEHYDRATING LIQUID MATERIALS

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This invention relates, generally, to the art of dehydrating materials and more particularly to an improved method of and improved continuously operating apparatus for the dehydrating of such liquid materials as heat sensitive juices and like compatible liquids.

In the dehydrating of wet materials, moisture is evaporated at a high rate during the initial part of the drying process. However, the rate of drying falls off rapidly as the action progresses with only a small amount of moisture being given off during the latter part of the operation. As a consequence of this rapid initial drying, some materials have a tendency to boil and spatter in giving off the easily evaporated moisture at the beginning of the drying operation if heated too rapidly. Furthermore, during the final stages of drying, the material, when nearly dry is liable to suffer deleterious overheating if the drying temperature is too high. Accordingly, it is desirable that the material be dried slowly at a high rate during the initial stage of drying; then more rapidly during the principal drying operation to effect dehydration as quickly as possible; and finally at a reduced rate to prevent damage to the nearly dry material during the final stages of drying.

With a view to effecting the dehydration of the wet material in the most economical manner, with least deleterious effect upon the product, the material should be dried from a thin film and the major portion of the drying action should be accomplished at relatively high temperatures obtained from an economical source applied for the shortest period of time that is feasible in effecting adequate drying. In order that the economical uniform drying heat may be utilized to the best advantage, the wet material to be dried should be preconditioned by preheating it at a reduced temperature to remove the moisture from the material gradually without boiling or spattering, while at the same time maintaining the material in an expanded or pulped condition adapted to withstand the predetermined higher uniform drying temperature. Likewise, after the principal drying action has been accomplished, it is desirable to continue heating the nearly dry material at a temperature adapted to complete the dehydration operation without detrimental overheating of the dried product.

A general object of the present invention is to improve the art of dehydrating heat sensitive materials such as juices and like difficult-to-dry materials. Another object of the invention is to provide an improved dehydrating apparatus of the heated drum and belt type.

Another object is to provide an improved method of dehydrating heat sensitive materials on a continuous basis. Another object is to provide an improved method of dehydrating material wherein the wet material to be dried is moved continuously in sequence through a preheating zone to effect progressive initial conditioning, then through a drying zone to effect the major drying action expeditiously and then through a finishing zone to effect progressive final drying.

Another object is to provide an improved dehydrator of the drum and belt type wherein the drum is operated at an optimum drying temperature too high to take the wet material without spattering and too high for finishing drying the material without overheating, operation of the drum at this high temperature being made possible by controlled preheating of the wet material before it reaches the drum and by controlled afterheating of the nearly dry material after it leaves the drum.

Another object is to provide an improved vacuum dehydration of the belt and drum type wherein auxiliary heat is applied to the run of the belt approaching the heating drum to prevent and precondition the material on the belt to adapt it for rapid drying under the influence of heat from the drum.

A further object of the invention is to provide an improved vacuum dehydration of the belt and drum type wherein auxiliary heat is applied to the nearly dried material on the run of the belt receding from the heating drum to complete the drying action at reduced temperature.

A still further object is to provide an improved vacuum dehydrator of the drum and belt type wherein the nearly dry material removed from the belt is retained and agitated for some time in an auxiliary drying compartment for further drying under the influence of the vacuum in the system.

Apparatus for practicing the present invention may be in the form of a vacuum dehydrator of the belt and drum type, in the major drying action wherein the film of liquid material carried by the belt is accomplished expeditiously and economically by heat from a heated drum as the belt runs over it. According to the present invention, the heated drum is operated at the highest temperature that is feasible in effecting the major drying action whereby most of the moisture is removed in the shortest time with best efficiency and least detrimental effect upon the product. To make possible such high temperature operation of the heated drying drum, the drying action of the drum is supplemented by controlled auxiliary heaters some of which are arranged to preheat the material carried on the belt toward the drum to precondition it for drying on the drum and others of which are arranged to provide further heating of the material on the run of the belt receding from the drum for completing the drying action without overheating the material. The drum is heated to the predetermined uniform high temperature preferably by steam in order to effect the greatest part of the drying action most economically. To provide for close control of the preheating and afterheating operations, the auxiliary heaters are controlled by independently controlled individual heating units that may be heated by steam or by electrically although other sources of heat may be utilized both for the major heating effect and for operating the auxiliary heaters. For preheating the material, one group of auxiliary heaters is arranged to supply heat to the inner surface of the belt between the point of application of wet material to the belt and the point at which the belt runs onto the heating drum, the arrangement being such that the material is subjected to progressive controlled partial drying and preconditioning to facilitate the subsequent rapid drying by heat from the drum. This auxiliary preheater is preferably in the form of a plurality of electrically operated radiant heaters controlled to provide regulated progressive heating of the wet material on the belt as it advances toward the zone of major drying on the drum. By this arrangement, the wet material may be warmed just sufficiently to maintain bubbles entrapped as foam within the film of material to expand and puff it, the heat being applied gradually and not rapidly enough to cause violent boiling, the bubbles otherwise result in dislodging the material from the belt. By this initial drying and expanding of the film of material, it is preconditioned to absorb heat more rapidly and to dry more expeditiously without boiling when subjected to the major drying action as the belt passes around the heating drum. With this preconditioning of the material, the drying temperature of the heating drum may be higher.
and the major drying action much more rapid and effective than could otherwise be the case without heat injury to the product. By the time the material on the belt passes around the heating drum it has been dried to such an extent that any further exposure to the relatively high temperature of the drum might result in overheating and damaging the nearly dry portions of the material that are not protected by the cooling effect of evaporating moisture. Whatever further drying of the material may be desirable is accomplished in accordance with the invention by the other group of auxiliary dryers that may also be electrically operated radiant heaters arranged to apply controlled heat to the outer surface of the nearly dry material on the run of the belt receding from the heating drum. If desired, additional auxiliary heaters may be disposed around the heating drum to apply heat to the outer surface of the material film on the belt as it passes around the drum and other additional heating units may be arranged below the belt to apply heat to the inner surface of the run of the belt leaving the drum. By suitably controlling elements of the auxiliary afterheaters the nearly dry material on the belt may be subjected to a further progressive drying action at moderate temperature to reduce its moisture content to a desired minimum and to condition it for removal from the belt while avoiding detrimental overheating of the dried product. After the progressive drying action is completed, the belt passes around a cooling drum where the dried material is cooled and is then removed from the belt in the form of readily reconstituted discrete particles. The cooling drum also serves to cool the belt to prepare it for receiving the film of wet material that is continuously applied to it as it moves toward the heating drum. The dried material from the belt may be discharged from the apparatus directly into product receiving containers or, in accordance with a variation of the invention, the particles may be retained for some time in an auxiliary drying compartment where they are agitated while subjected to further drying action of the vacuum in the system together with moderate heat to reduce the residual moisture still further before being discharged into the containers. By this improved arrangement for drying sensitive materials and the like on a continuous basis, the invention makes possible more economical drying of some materials than by methods heretofore known while at the same time effecting improvement in the quality of the dried products.

The foregoing and other objects of this invention will become more fully apparent as the following detailed description of exemplary embodying apparatus constituting an improved vacuum dehydrating system is read in conjunction with the accompanying illustrative drawings, wherein:

FIG. 1 is a schematic diagram of an improved vacuum dehydrator embodying the present invention the representation of its housing being shown largely in vertical longitudinal section and its associated auxiliary control apparatus being indicated diagrammatically;

FIG. 2 is an enlarged detailed view showing one of the auxiliary heating units in elevation, the view being taken through a fragment of the upper part of the dehydrator housing in vertical transverse section;

FIG. 3 is another sectional view of the auxiliary heating unit taken along a vertical plane longitudinally on the housing;

FIG. 4 is a diagrammatic representation of another dehydrator apparatus embodying a modified form of the invention;

FIG. 5 is an enlarged view mostly in longitudinal section taken through an attached auxiliary drying compartment and tumbling drum that extends transversely from the dehydrator housing and constitutes another modification of the invention; and

FIG. 6 is an enlarged fragmentary view in perspective of a part of the auxiliary drying drum shown in FIG. 5 illustrating its material tumbling conveyer flights.

Referring more particularly to the drawing and especially to the schematic diagram in FIG. 1, the improved dehydrator there illustrated is of the type employing a material carrying belt operating over a pair of spaced drums in a vacuum chamber. The apparatus comprises in general a large cylindrical housing 11 that is closed at its ends and formed air-tight to constitute a vacuum chamber 12 for the material treating operating mechanism. As shown, the closure at the end of the chamber on the right in the drawing is in the form of a separate end-bell or dome 12 that is removable to provide access for moving the operating mechanism into or removing it from the chamber. Furthermore, both ends of the housing are provided with manholes for affording entrance to adjust the mechanism. The double drum and belt type material handling conveyer mechanism in the chamber constitutes a unitary apparatus having an independent frame that carries a large heating drum 13 shown rotatably mounted in the left end of the chamber and a cooling drum 14 in this instance mounted in the right end of the chamber, together with a cooperating thin endless material-supporting belt 15 that is alternately heated and cooled as it operates over the two drums.

The belt 15 is preferably a continuous band of relatively thin metal such as stainless steel that is maintained under suitable tension and is caused to track properly on the drums 13 and 14 by appropriate tensioning and tracking apparatus carried by the interconnected frame. The supporting and guiding apparatus and other operating mechanisms may be of the type shown in detail and described in copending application Serial No. 364,456 filed June 26, 1935, now Patent No. 2,924,271, directed to a continuous vacuum dehydrator of a kind similar in general nature to the apparatus illustrated diagrammatically in FIG. 1. This copending patent sets forth and explains in detail various mechanical features including apparatus whereby the belt 15 is driven at a selected speed by means of a suitable variable speed power source that is connected to operate a pair of pinions 16 that mesh with ring gears 17 on the respective ends of the cooling drum 14.

The material to be dried is applied in liquid form on the lower run of the belt 15 as a thin film rolled on to the outer or lower surface thereof by means of a feeding roller 18. As shown in the drawing, the roller 18 applies the material to the belt shortly after it leaves the cooling drum 14 and at a considerable distance from the heating drum 13. In order to maintain the belt 15 accurately in position to receive from the feeding roller 18 a film of material of predetermined thickness, there is provided a back up roller 19 that engages the inner or upper surface of the belt 15 at a point opposite from the feeding roller 18 in a manner to hold the belt flat and in an exact position relative to the feeding roller. Beneath the feeding roller 18 there is provided a feed pan 20 that is arranged to contain a supply of the wet material in contact with the feeding roller and to collect any material that may drip from the roller or from the belt 15 during the feeding operation.

In the drying operation, the film of material is carried by the belt around the heating drum 13, whereupon most of the liquid in it is removed by vaporization through the combined action of heat from the drum and the vacuum in the chamber, most of the required heat of vaporization being supplied by the heating drum. After the material has been dried the belt carries it around the cooling drum 14 where the dried material is chilled to prepare it for removal from the belt by a doctor blade 21 that engages the outer surface of the belt in the region of the bottom of the cooling drum 14 in a manner to scrape off the dried material. The particles of dried product thus removed by the doctor blade drop into a collecting trough 22 in
which a screw conveyor 33 operates to convey the material into a suitable product receiving container 24. The required reduced pressure atmosphere is maintained within the chamber 11 by means of a vacuum system comprising a multiple stage steam jet ejector or vacuum pump 26 that is shown connected to the left end of the housing 11. The vacuum system is provided with an adjustable automatic regulator 27 that responds to the pressure within the chamber and operates to establish theoretically any desired degree of vacuum within the limits of the capacity of the vacuum pump 26.

The liquid material to be dried may be in the form of an extract or juice concentrate that is drawn from a storage reservoir such as a tank 31 by means of a metering pump 32 that forces it at a predetermined rate through a perforated feed pipe or feeder 33 on to the periphery of the feeding roller 18. As fully explained in the previously mentioned copending Patent No. 2,924,271, the feeding roller 18 is accurately positioned and is rotated by power at a predetermined speed in a manner to apply a film of material of the required thickness to the surface of the belt 15.

The heating drum 13 which supplies the heat of vaporization to the film of material is preferably heated by steam drawn from a boiler or like source 35 and that flows through a pipe 36 and a rotary coupling 37 into one end of the drum 13. An adjustable automatically operating pressure regulating valve 38 connected in the pipe 36 operates to maintain the pressure of the steam constant and therefore controls heating of the drum 13 to a predetermined temperature. Water accumulating within the drum 13 as the steam condensates is discharged through a condensate pipe 39 that is in like manner connected by a rotary coupling to the other end of the drum and extends downward out of the chamber 11 to a water removing steam trap 40.

In a similar manner, the cooling drum 14 is provided with cooling liquid that is circulated from a receiver or storage tank 41 by means of a pump 42 through piping 43 connected by a rotary coupling 44 to one end of the drum 14. Another rotary coupling connects a discharge pipe 45 to the other end of the drum 14, the pipe 45 being arranged to return the cooling liquid to the receiver 41 for recirculation. Suitable cooling apparatus indicated by a coil 46 substantially in the circulating liquid in the receiver 41 may be arranged to maintain the cooling liquid at a predetermined temperature under the control of an adjustable automatically operating temperature regulator 47.

In a particular dehydrating apparatus constructed in accordance with the arrangement indicated diagrammatically in FIG. 1, both of the drums 13 and 14 are of equal size, being nearly eight feet in diameter and they carry a belt 15 that is four feet in width, although the drums may differ in size under other circumstances. The two drums are in this instance spaced apart a distance of about thirty-five feet center to center and the total length of the continuous belt 15 is about ninety-four feet. The action of the previously mentioned framework and tensioning mechanism serves to draw the belt tightly around the drums to establish a good contact between them for facilitating the transfer of heat to or from the belt. To further improve the heat transferring conditions, the inner side of the belt may be provided with a special heat absorbing surface that may be established by coloring that side of the belt black. The belt operates around the drums in the direction indicated by the arrows 51 at a speed that may range from about fifteen feet a minute to one hundred feet a minute ordinarily, although under special circumstances the belt speed may be increased to several hundred feet a minute. The vacuum within the chamber 11 may be such that the absolute pressure is in the order of from 5 to 7 mm. Hg or thereabouts and may range from about twenty mm. Hg or less depending upon the material being processed and other circumstances.

As previously mentioned, the heating drum 13 is heated by steam supplied at a predetermined uniform temperature in order that the major drying operation may be effected at best economy with heat supplied at a controlled optimum temperature. With this arrangement, the temperature of the drum may range from about 140° to about 295° F. with the ordinary operating range generally lying between 210° and 240° F. In order that the drying action of the drum may be most effective and operate with the least detrimental effect on the material being dried, the temperature of the drum should be maintained as high as it possibly can be without melting and overheating or scouring the material being dried. This results in increasing the overall efficiency of the drying operation and reduces the time during which the material is subjected to the principal drying action thereby reducing the likelihood of injuriously affecting the material through excessive heating. However, with the drum 13 heated to the optimum high temperature for best drying efficiency, the drum surface is so hot that if the belt were to carry freshly applied wet material onto it, the material would be caused to boil and spatter from the belt because of the rapid initial evaporation of the moisture.

In accordance with this invention, the difficulty with boiling of the material on the belt is overcome and the advantages of effecting rapid drying on the drum heated to a high temperature are realized by preconditioning the wet material on the belt to adapt it to withstand the high drum temperature without excessive boiling or spattering from the belt. This is accomplished by effecting a preliminary partial drying or pre-drying through gently preheating the wet material on the belt to effect gradual removal of the easily evaporated initially released moisture and to maintain the film of material in an expanded condition through the evaporation of small bubbles of water vapor and other gases which cause foaming or puffing, thereby increasing the porosity and surface area to facilitate the escape of moisture vapors from the material. By this arrangement the characteristics of the film of material being dried on the belt are modified to precondition it for drying at the relatively high temperature of the steam heated drum without spattering from the belt. With the film of material thus predried and preconditioned, it is capable of absorbing the heat of vaporization from the drum rapidly without excessive boiling and without increasing its temperature substantially or subjecting it to the risk of overheating or of heat damage from long exposure to high temperature.

In considering heat sensitive materials that may be dried in this manner, malted milk may be taken as a specific example. Although malted milk is subject to changes in flavor upon overheating, it expands well when drying and is a relatively easy material to dry in apparatus of the type indicated in FIG. 1. The malted milk concentrate for drying may for example be prepared with a moisture content of about 57% although the degree of moisture may range from 60% to 35% or thereabouts, being ordinarily in the neighborhood of 50%. It has been found that the temperature of the belt at the point of application of the material to it is important in determining the thickness and other characteristics of the film of material applied by the feeding roller 18. The temperature of the belt as it approaches the feeding roller is largely determined by the temperature of the cooling drum 14 and it is maintained at the predetermined relatively low level by regulating the temperature of the cooling drum through adjusting the temperature regulator 47. For malted milk, the feed roller is spaced about two hundredths of an inch from the lower surface of the belt 15 although the thickness of the film as applied to the belt may vary and may be as thin as five thousandths of an inch. As has been mentioned, the concentrate is pumped from the storage tank 21 through the perforated feeder pipe 33 which ap-
plies it to the surface of the feeding roller which operates to roll the material on to the outer or lower surface of the lower belt run in the form of a film of the predetermined thickness.

As the film of wet material is carried away from the feeding roller on the lower run of the belt 15 that is moving toward the heating drum 13, the material on the belt is subjected to the previously mentioned preconditioning effect through action of a preliminary auxiliary heater or preheater 53. The preheater 53 may be of any suitable type but is here shown in the form of a series of radiant heating units 54. As shown, the several heating units 54 are arranged to apply radiant heat to the heat absorbing inner or upper surface of the lower belt run by successive increments as the belt advances. The heat furnished by the auxiliary units 54 first serves to warm the belt that had been previously cooled for receiving the wet material and the belt, in turn, then warms the film of material gradually at a rate not high enough to cause boiling and spattering of the wet material but sufficiently high to effect vaporization of the easily removed initial moisture. Since during the preheating operation the film of material is clinging to the lower surface of the belt 15 the expansion and puffing of the film due to foaming is arrested by the action of the force of gravity. Through this arrangement, the film of wet material may be expanded into a porous layer or foam-like mass about twenty times its original thickness with the result that the area presented for the escape of vaporized moisture is correspondingly increased to facilitate rapid vaporization and quick drying of the material with minimum heat damage.

As the wet material on the belt 15 first comes under the influence of the radiant heating units 54 in the initial drying or pre-drying zone, the drying occurs at best efficiency in that the largest amount of moisture is removed for a given amount of heat applied. As the drying proceeds and the amount of moisture in the material decreases, more and more heat is required to effect the vaporization of the remaining moisture. Some of the required heat is provided by radiation from the heating drum 13 but the amount from this source is not adequate. To provide for the optimum level of heat being applied at successive positions along the lower run of the belt 15 approaching the heating drum 13, the several independent radiant heating units 54 are connected electrically in parallel; each pair being provided with a controlling voltage regulator unit 55. As shown, the several control units 55 are connected to receive electrical energy from a power supply line 56 and each unit 55 is arranged for independent adjustment by means of a suitable control knob 57. By adjusting the several control knobs 57, the amount of heating energy furnished to each pair of the radiant heating units 54 may be regulated conveniently to provide the desired heating effect. By this arrangement, each pair of heating units 54 may be adjusted to radiate to the material as much heat as can be absorbed by the wet material on the belt without causing the material to boil excessively and be dislodged from the belt. The preheating and predrying of the material on the belt may thus be accomplished according to a heat gradient or heat profile whereby the heating effect upon the wet material may be increased progressively in a manner best suited to the material as it approaches the heating drum 15 and the belt for preconditioning by increments to receive more and more drying heat without excessive boiling.

In the apparatus shown, the preheater 53 serves to remove some five to ten percent or thereabouts of the moisture originally in the wet material depending upon the characteristics of the material and other factors. In the case of drying the malted milk previously mentioned, the preheater removes something in the order of seven percent of the total moisture thereby reducing the moisture content of the wet material from the original 57% to about 53%. With the moisture content of the wet material reduced to this extent by the preheating units 54 in the initial drying zone, the belt may run on to the drum 13 at the preferred speed of operation without danger that the wet material will be dislodged from the belt by excessive boiling since the predried and expanded film of material has been preconditioned to withstand the high optimum temperature of the heating drum. Under this predrying arrangement, the temperature of the heating drum may be established at as high a level as necessary to effect the optimum drying action without danger that the preconditioned material will boil and spatter from the belt. In the case of drying malted milk, the drum temperature may be preferably in the range from 280° to 295° for rapid drying, although the temperature may be as low as 240° if different flavor characteristics are desired.

As the belt 15 passes around the drum 13, the heat released by steam condensing within the drum furnishes the heat of vaporization for evaporating the moisture in the material on the belt. However, since the moisture is evaporated rapidly under the low pressure vacuum condition obtaining within the chamber 11, the heat from the drum does not appear as sensible heat in the material and the temperature of the material decreases appreciably during the drying but remains at substantially the same temperature of vaporization of moisture at the reduced pressure at which the drying occurs.

This rapid vaporization of moisture and correspondingly large cooling effect is facilitated by the large surface area exposed by reason of the foaming or puffing action that occurred in the material during the predrying operation and continues until a considerable proportion of the liquid has been evaporated. Because of the rapidity of the drying action and the fact that the temperature of the material does not rise appreciably, the major portion of the dehydration is effected quickly with the least detrimental effect upon the heat sensitive material being dried.

During the drying operation, the degree of vacuum, the steam temperature, the speed of the belt and other factors are carefully controlled to maintain the expanded or puffed condition of the material on the belt as it travels around the heating drum 13. Preferably the drum is maintained as hot as possible without melting the puffed material and since the material closest to the belt is heated first, it tends to dry quickest. To compensate for this effect, the drum may be provided with the desired degree of puffing of the outer surface of the drum or there may be provided another auxiliary heater 58 constituting by heating units 59 that are shown fitted about the upper left quadrant of the heating drum 13 in FIG. 1 but may if desired extend further around the drum.

The radiant heating units 59 of the auxiliary heater 58 are likewise provided with a voltage regulating control unit 55 that is in this instance connected to a power supply line 61. By properly adjusting the heating effect of the auxiliary heater 58 through manipulating the control knob 57 of its control unit 55, the outer surface of the partially dried material on the belt may be arranged to dry at substantially the same rate that obtains for the inner surface closest to the heated drum and at the same time the expanded condition of the film may be regulated to provide the desired degree of puffing.

By the time the material carrying belt has travelled nearly around the heating drum and the material thereon approaches the dry condition and progressively less evaporation occurs. With less moisture in the material and less evaporation occurring, there is less cooling effect of evaporation and the temperature of the material tends to increase. Since the material is no longer protected by the cooling effect of evaporation, its temperature may increase, there is danger that it may be overheated with resultant damage to quality should it remain under the
influence of the high temperature drum for too long a time. Accordingly, the speed of movement of the belt and other factors are so adjusted that the belt carries the material away from the drum before it has been dried to such an extent that it is liable to be damaged by the high temperature heat from the drum. As previously mentioned, this withdrawal of material from the influence of the drum is required because the drum is operated at the optimum high temperature that is adapted for effecting the greater part of the drying operation most expeditiously at best efficiency with least detrimental effect on the material and the drum is therefore too hot to accomplish the removal of the final moisture content from the nearly dry material without danger of smoking or overheating it. Through operating at high temperature in this manner, the heating drum 13 is enabled to remove in the neighborhood of about ninety percent of the total moisture content of the material being dried with minimum harmful effect upon the product. In the case of the malted milk, previously mentioned as a specific example, the drum removes approximately eighty-eight percent of the moisture thereby reducing the moisture content of the material from about fifty-three percent to about three percent.

Although dried material with a moisture content of three percent may be satisfactory for some purposes under certain conditions, it is ordinarily desirable to reduce the moisture content of the product somewhat further than can be accomplished on the drum when it is operating at the optimum high temperature. According to one phase of this invention, continuous operation of the heating drum at the optimum high temperature previously referred to is made possible even though a further reduction in moisture content is required, by reason of the fact that additional drying of the material is effected by means of another auxiliary heater 63 operating at a moderate drying temperature. This additional auxiliary heater or afterheater 63 is arranged to apply radiant heat to the upper surface of the material on the run of the belt receding from the heating drum in a manner to complete the drying operation at reduced temperature. As shown in FIG. 1, the auxiliary afterheater 63 is made up of a series of independent heating units 64 each pair of which is connected to a voltage regulator control unit 65 of the type previously mentioned, with all the units connected to receive electrical energy from the power supply line 61. As the belt 15 leaves the zone of action of the heating drum 13, the material carried on it is so nearly dry that very little effect of evaporation is to be expected as a result of subsequent drying. Accordingly, the afterheater 63 is regulated in such a manner that the first pair of heating units 64 provides just sufficient drying heat to effect as much further evaporation as is possible without increasing the temperature of the nearly dried material to an extent that might result in damage from overheating. Likewise, the second pair of afterheater units 64 may be adjusted to furnish somewhat less heat to the dried material since the possibility of overheating the material increases as the residual moisture in it decreases. In a like manner, the remaining heating units 64 are correspondingly adjusted to enable each unit to effect the maximum drying action that is possible without heat injury to the dry material. In this way, the nearly dry material on the belt is heated progressively as it moves away from the drum to effect the final drying action in accordance with a heating gradient or heat profile that provides the proper heating units of heat for gradually drying the material without heat injury in reducing the residual moisture content to a predetermined minimum value. Because of the fact that the afterheater 63 operates over a considerable length of the receding run of the belt 15, it is enabled to remove considerable additional moisture and in the case of malted milk, it removes about 3½% of the original moisture thereby reducing the moisture content from about three percent to about one percent or perhaps less.

Thus, of the total moisture contained in the malted milk being dried, the preheater 53 furnishes heat that vaporizes in the order of seven percent of the moisture, the drum removes about eighty-eight percent and the afterheater about 3½%. These figures are necessarily approximate since they will vary considerably under varying conditions of operation and may be quite different with different materials being dried, however, they are given as an example to provide an indication of the relative amounts of drying action occurring in the several drying zones of the dehydrator. In effecting the drying of malted milk, of the total heat utilized, about eighty-five percent is supplied through operation of the heating drum and the other fifteen percent by the auxiliary heaters. Of the auxiliary heat, about ten percent is furnished by the preheater and five percent by the afterheater.

In addition to effecting the final moisture removing operation, the upper auxiliary heater or afterheater 63 may also be operated to effect a slight melting action on the upper surface of the expanded film of material, in the case of certain substances being dried. This tends to control the amount of expansion of the film of material in the drying stage and thereby serves to assist in controlling the density of the final product as it is scraped from the belt by the doctor blade 21.

Since the upper run of the belt 15 is quite long it may be supported between the large drums 13 and 14 by one or more small supporting drums such as the drum 65 that is shown in engagement with the lower or inner surface of the belt midway between the drums 13 and 14 to hold it in predetermined spaced relationship with the heating units 64 of the afterheater 63.

In addition to the upper heating units 64 the afterheater 63 may be provided with lower heating units 66 arranged beneath the upper run of the belt for the purpose of applying radiant heat to the belt itself as a continuation of the heating action of the drum 13 but at a progressively reduced temperature to assist in the final drying operation. These additional units 66 are likewise provided with control units 55 which in this case are supplied by electricity from a power line 67. Obviously the number of auxiliary heating units utilized in completing the drying operation as the belt recedes from the drum 13 may be varied to meet varying conditions of operation depending upon the type of material being dried and under some circumstances it may be preferable to omit entirely the units 59 of the afterheater 58 arranged around the drum 13 or the unit 66 beneath the belt running the drum or both. It is ordinarily preferable to avoid placing auxiliary heating elements beneath the belt on the lower run since some of the wet material may drop from the belt onto the heating elements.

After the material on the belt has been dried to a predetermined moisture content by the cooperative action of the preheater 53, the heating drum 13 and the afterheater 63, the belt 15 carries the matrix of dried material around the cooling drum 14 where it is cooled or chilled to condition it for removal. The doctor blade 21 then scrapes the dried particles from the belt into the product receiving trough 22 from which the finished product is moved by the screw conveyer 23 to the material receiving container 24. As previously mentioned, the cooling drum 14 in addition serves to condition the moving belt 15 as it leaves the drum to adapt it to receive the film of wet material to be dried by cooling and the fact that it supplies a low temperature found best adapted to receive the wet material from the feeding roller 18 in a film of the required thickness and other characteristics best suited to the drying operation.

Because the drying action of the steam heated drum is accomplished most expeditiously and at least cost, it is preferable to effect as much as possible of the moisture removing operation by heat supplied from the steam heat-
ed drum. Since the heating action of the drum upon the material on the belt is direct, it is therefore perhaps somewhat more stable and uniform in its action regardless of changes in the condition of the material on the belt than is the more flexible indirect heating action of the auxiliary heaters. Furthermore, heat furnished to the material by the controlled auxiliary electrical heaters costs four or five times as much as heat furnished by the steam heated drum. Hence, it is apparent that ordinarily the heat furnished by the preheater and afterheater should be limited to an amount just sufficient to effect the necessary pre-conditioning and final drying operations at reduced temperature under closely regulated progressive control. However, in most instances, the use of auxiliary heaters tends to increase the rate of production of dried material in a given dehydrator and this tends to offset or compensate for the additional operating expense involved in using the auxiliary heat in spite of the fact that electrically energized radiant heaters cost so much more to operate than the steam-heated drum for the same amount of heat delivered to the material being dried. Furthermore, the cost of the auxiliary radiant heating apparatus itself is modest in comparison with the cost of the entire dehydration structure. Accordingly, if the rate of production is increased materially by the use of the radiant auxiliary heaters, more product results from the use of the apparatus and the overall cost of operation of the equipment per unit of material dried may be considerably less than the cost of operating without the auxiliary heaters.

In the drying of coffee concentrate as another example of a product adapted to be dried in the dehydrator, it has been found that the rate of production of the equipment can be more than doubled by the addition of auxiliary radiant heaters in accordance with this invention. Since this doubling of production is achieved by means of a capital investment equivalent to only a small fraction of the cost of the dehydrator proper, the savings effected in overhead costs are much greater than the additional cost of the heat furnished to the product by the radiant heaters. In drying coffee, this saving has been accomplished by utilizing a considerable amount of radiant heat in the afterheater zone thereby making it possible to increase the speed of the belt to double that previously used and thus double the rate of production.

Another material that is adapted to be dried in the dehydrator is orange juice concentrate. However, this material is much more difficult to dry successfully largely because of the high sugar content which makes the partially dried material sticky and difficult to handle and also because it is subject to scrunching if overheated. The orange juice to be dried is preferably concentrated to a moisture content of about thirty-five percent before drying although the degree of moisture in the concentrate may range from fifty-two percent to thirty percent or thereabouts.

With the liquid juice concentrated to a moisture content of thirty-five percent or thereabouts, its freezing point is reduced to well below zero degrees Fahrenheit. Accordingly, the material may be subjected to the drying action of a vacuum chamber in the order of from eight tenths of a mm. Hg to one and one half mm. Hg absolute pressure without causing the material to freeze. At this high vacuum, vaporization occurs at a rapid rate, the evaporation being much higher from the liquid state than it would be from the frozen state because the moisture escapes more readily from the liquid. Furthermore, the fact that the liquid material is in the form of a thin film facilitates the drying action since evaporation from a layer of material varies inversely with the square of the thickness of the layer. To this end the clearance between the feed roller 38 and the belt should be adjusted to about two hundredths of an inch. With a thin film of liquid material on the belt, the drying action occurs uniformly throughout the film. By applying the initial drying heat gradually to the thin film, localized areas of vaporization are avoided and the predrying progresses smoothly and as rapidly as possible. If the film is too thick and if the heat is applied too rapidly, pressure may build up at spots within the material thereby changing its drying characteristics and interfering with the uniformity of the entire drying cycle.

In applying the orange concentrate to the belt, it is preferable that the belt temperature at the point of application of the material should be cooled to about 40° to 80°F., although it may be somewhat higher. The belt may be operated at a speed in the neighborhood of fifty feet a minute or higher depending upon the circumstances of operation and the temperature of the belt in running over the heating drum 13 should be maintained at about 140° to 190°F. The cooling drum temperature should be quite low, in the order of zero degrees Fahrenheit, so that the dried product may be cooled below its plastic state temperature to facilitate removal from the belt by the doctor blade 21. Ordinarily the material is dried to the extent that the resulting orange crystals have a moisture content of two percent or less, it being preferable to dry them to less than one percent of moisture.

With orange concentrate the pre-conditioning of the wet material on the belt is beneficial since the material is particularly susceptible to excessive boiling and spattering from the belt when first applied in the wet condition. Accordingly, approximately nine percent of the total moisture is removed from the film of the orange concentrate by the gradual progressive action of the preheater 53 whereby reducing the moisture content of the wet material from about thirty-five percent to a little less than thirty-two percent. While the moisture content is being thus reduced during the preheating operation, the film of material is pre-conditioned and preconcentrated while maintained in an expanded condition through continual formation of small bubbles to form a mechanical structure of greatly increased volume and surface area. This puffed structure is sturdy enough to withstand the rapid evaporation occurring under the higher drying temperature of the heating drum 33 without danger that it will be dislodged from the belt by excessive boiling when it is carried by the belt onto the drum. As the belt passes around the drum, the wet material is dried at the proper rate to avoid excessive boiling or scrunching, the drum temperature and the chamber vacuum or drying pressure being regulated with other conditions to maintain the desired expanded condition of the film. While under the influence of the heat of the drum, about eighty percent of the total moisture content of the material is removed thereby reducing the moisture content from about thirty-two percent to about four percent. After the belt carries the material away from the drum, the afterheater 63 removes an additional six or seven percent of the moisture to reduce the final moisture content to approximately two percent or less. As mentioned before, these are approximate only and are subject to considerable variation depending upon the composition of the particular juice being dried and other varying conditions. During the after heating operation, the radiant heat from the heating unit 64 may be employed to effect limited melting of the outer surface of the plastic film of material in order to condition it for removal from the belt by the doctor blade as previously mentioned. This conditioning of the material film by the afterheater not only facilitates removal of the dried material from the belt but also influences the density of the material whereby regulation of the product density may be effected through control of the afterheater and other factors.

As previously mentioned, the various auxiliary heating units may be of any suitable type and may be heated by superheated steam, high temperature liquid or the like, but in the present instance they are represented by electrically energized radiant heaters and electrically energized radiant heaters may be in the form of infra-red lamps or the like but in this instance as shown are constituted by rod-like
heating elements. As indicated in FIG. 1 of the drawing, the several heating units 54, 59, 64 and 66 are essentially similar in construction and general characteristics. For illustrative purposes one of the afterheater heating units 66 has been selected as representative and is shown in detail in the enlarged view of FIG. 2 and 3. As there shown, each heating unit comprises essentially a reflector element 71 that may be formed from a plate or sheet of aluminum, stainless steel or like reflective material. As best shown in FIG. 2 the reflector plate is bent down at the ends to form flanges 72 that serve to prevent bending or warping of the plate and that are provided with a series of rounded edges or recesses 73. The recesses 73 are adapted to receive and support the respective ends of long heating elements 74 disposed transversely of the belt 15 as shown in FIG. 3. The elements 74 may be in the form of rods or strips enclosing electrical resistance elements, and are arranged beneath the reflective surface of the element 71 which serves to reflect heat downward onto the belt. Not all of the notches 73 in the flanges 72 are necessarily occupied by heating elements 74, the number and arrangement of elements being selected to adapt the unit to the heating requirements of the position occupied by it in the dehydrator. The adjacent ends of the several heating elements 74 are connected together by electrical conductors 75 and 76 respectively which lead through chamber terminal elements 77 and 78 to the respective terminals of the control unit 55 that controls the flow of electricity to the heating unit.

As indicated in FIGS. 2 and 3, the sides of the plate forming each reflector 71 are turned upward to effect further stiffening of the plate and to form flanges 81 by means of which the unit is supported in the dehydrator. Each flange 81 is pierced by spaced holes 82 which receive suspending bolt hooks or hangers 83, the arrangement being such that a hanger is provided near each corner of each of the hooks 83 are threaded as shown and in the instance of the upper heating unit 64, they extend upward through openings in angle brackets 84 welded to and depending from the top of the housing 11. A pair of nuts 85 are threaded on each hanger bolt 83 to engage opposite sides of the corresponding brackets 84 for retaining the heating unit in predetermined adjusted position. By suitably adjusting the position of the nuts 85 on the hanger bolts 83, it is possible to raise or lower the heating unit 64 and level it in desired position with the heating elements 74 disposed at a predetermined distance from the material being dried on the belt 15.

Although the auxiliary heating units are preferably in the form of the radiant heaters shown in FIGS. 2 and 3, they may take other forms such as the heating platens shown in the modified version of the apparatus illustrated in FIG. 4. In the apparatus there represented diagrammatically a relatively large heating drum 91 at the left carries one loop of a material supporting belt 92 that runs over idler pulleys 93 in the direction of the arrow 93. The belt 92 is further supported at its other loop by an idler pulley 94 and a superimposed combined tensioning and tracking pulley 95 at the right end of the structure as illustrated in FIG. 4. In this instance the liquid material to be dried is applied to the top of the upper run of the belt as it leaves the pulley 95, by means of a spray type applicator 96. The preheating and preconditioning of the material on the belt 92 as it approaches the heating drum 91 is in this instance accomplished by means of arched heating platens 97 a plurality of which are arranged to form a smooth curved surface. The elements of which form up the upper run provide for frictional heat exchanging relationship with the inner surface thereof.

The heating platens 97 and the spray type applicator 96 may be of the type shown in the low temperature dehydrator covered by Patent No. 2,515,698 issued July 17, 1950 to H. L. Smith, Jr., and assigned to Chain Belt Company. Although apparatus of this type is adapted to dry certain materials from the frozen state under appropriate circum-
stances, the material to be dried is usually so highly concentrated that its freezing point is quite low and it ordi-

Each of the platens 97 is heated independently, in this instance preferably by circulating hot water or steam through it, with the temperature of the individual platens controlled as required to effect progressive heating of the belt 92 and the material carried by it in a manner to pre-

Instead of the platens 97 may be used heating elements 101 that may be formed from a substantially cylindrical housing 111 that extends at right angles from the lower part of the discharge end of the dehydrator housing 11 at a position substantially in alignment with the product conveyor screw 23. To avoid stresses that might result from temperature and pressure changes and permit limited relative movement between the main housing 11 and the auxiliary housing 111, the auxiliary housing 111 is connected to the main housing by an airtight flexible joint or expansion bellows 112. The housing 111 is likewise airtight and is in communication through the bellows 112 with the housing 11, it constitutes an extension of the vacuum chamber.

With this modified arrangement, instead of the dried product that is scraped from the belt by the doctor blade 21 being fed directly into the product container 24 as previously described, the screw conveyor 23 in this in-

The rotary tumbling drum 113 is mounted on a plu-

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rality of supporting rollers 114 one of which is provided with a drive shaft 115 that may be connected to the drive mechanism for the screw 53 or some other suitable driven apparatus within the housing 11 for operating the drum in synchronization with the belt 15 of the dehydrator. As best shown by the enlarged view FIG. 6, the interior of the rotating drum 113 is provided with a series of conveyor flights 116 that serve to lift and tumble the dried material in a manner to agitate it for exposing the individual particles of the material to the further drying influence of the vacuum. As shown, the flights 116 are pitched in a direction to cause the dried material to be advanced slowly along the drum 113 as it rotates thereby progressing it toward the discharge end thereof as shown in FIG. 5. The pitch of the flights 116 and the rate of rotation of the drum are such that the tumbling powdered material may be retained in the auxiliary chamber for a period of about five minutes or more.

To assist in the further drying operation, the compartment 111 may be provided with heating units 118 generally similar to the auxiliary radiant electrical heating units within the taing dehydrator housing 11 and arranged to heat the outer surface of the drum 113. As shown, each heating unit 118 is provided with a voltage regulator control unit 55 that functions to regulate the temperature of the heater, the units 55 being supplied in this instance from an electrical supply line 119. To further assist in the supplemental drying within the auxiliary chamber 111 a limited amount of dry warm air or other suitable dry gas may be admitted into the chamber 111 through an inlet opening 121 in the right end of the housing from a suitable supply tank 122 under the control of a regulating valve 123. The dry gas admitted through the inlet 121 flows slowly toward the left through the housing 111 and tends to displace and carry away the moisture evaporated from the material in the drum thereby reducing the moisture content of the atmosphere within the auxiliary housing 111 and improving the drying action.

When the dried material arrives at the right end of the drum 113 after undergoing the supplemental drying action therein it is discharged from the end of the drum and falls into a chute 126 which is arranged to feed the material into the product container 24. As explained in the previously mentioned copending application, two product containers 24 are arranged as a pair in order that a filled container may be replaced by an empty one while the other container of the pair is being filled. Although the rotating drum 113 need not be large in proportion to the dehydrator housing 111, it is to be understood that the auxiliary drying compartment and the drum may be made of any size that may be found practical for retaining the dried material as long as required to effect the desired degree of reduction in the residual moisture content.

In some instances it may be desirable to effect a greater proportion of the total drying action in the auxiliary chamber and somewhat less final drying on the belt, the proportions depending upon the characteristics of the particular material being dehydrated.

From the foregoing description and explanation of exemplary dehydrating apparatus and its mode of operation, it will be apparent that the improved arrangement provided by the present invention is adapted to effect economical and thorough dehydration of heat sensitive materials and the like without subjecting the material to the deleterious effects of overheating or prolonged high temperatures, whereby the moisture content may be reduced as much as necessary to provide for indefinite storage while retaining in the highly soluble dried products all of the characteristics of the original material that later may be caused to reappear upon reconstitution through dissolving the dried product particles in a liquid.

Although specific examples of dehydrating apparatus illustrative of the present invention have been set forth herein by way of a full disclosure of useful embodiments of the invention, it is to be understood that other arrangements of the apparatus and different types of heating units and like elements may be incorporated by those familiar with the art of dehydrating apparatus of the general type disclosed without departing from the spirit and scope of the invention as defined by the subjoined claims.

The various features of the invention having now been fully set forth and explained, we claim as our invention:

1. A method of drying a liquid material which comprises applying the liquid in a thin film to a moving surface in a vacuum chamber, progressively heating the liquid while on said surface at a temperature to cause it to puff and expand to form a porous, foam-like mass having a substantially increased volume, the heat being applied gradually and not rapidly enough to cause spattering and deterioration of the material due to overheating, and thereafter rapidly drying the foam-like mass by subjecting it to a temperature greater than the liquid film could have withstood, without substantial spattering and overheating, in the absence of said puffing.  

2. The method of drying a liquid material as set forth in claim 1 including finish-drying the material at a temperature substantially lower than said higher temperature after said material has been dried at said higher temperature.

3. The method of drying a liquid material as set forth in claim 2 in which the temperature to which the material is heated during the finish-drying is sufficiently high and the duration of the heat treatment at that temperature is sufficiently long to effect a limited melting of the outer surface of the film of material.

4. The method of drying a liquid material as set forth in claim 1 in which the surface to which the liquid material is applied is moved in said vacuum chamber through heating zones arranged in sequence along the path of travel of said surface to sequentially heat said liquid material at said low and high temperatures.

5. A method of drying a liquid material as set forth in claim 1 in which the liquid material to be dried contains milk concentrated to a moisture content of between about 35 and 60 percent, the initial low temperature heating removes between about 5 to 10 percent of said moisture content, and the high temperature heating removes about 88 percent of said moisture content.

6. The method of drying a liquid material as set forth in claim 1 in which the liquid material is orange juice concentrated to a moisture content of from about 30% to about 52%, a vacuum of from about 0.8 to about 1.5 mm. Hg absolute pressure is maintained in the vacuum chamber, said surface is an endless metallic belt, the juice is applied to said belt at a position thereon at which the temperature of the belt is between about 40°C and 80°C, the puffed material is subjected to said rapid drying until about 80% of the moisture thereof has been removed, and the material thus dried is subjected to further and final drying by heating it while on the belt at a lower temperature than that to which it was subjected during the rapid drying.

7. The method as set forth in claim 6 in which the material after final drying is cooled to condition it for removal from the belt, the cooled material is removed from the belt, and the belt, after removal of the material therefrom, is cooled to said temperature of from about 40°C to 80°C before additional material to be dried is applied thereto.

8. The method of claim 1 in which the liquid material is orange juice.

9. The method of claim 8 in which the orange juice is concentrated to a moisture content of from about 30% to 52%, solids before it is applied as a thin film to said moving surface, and the vacuum chamber is maintained at an absolute pressure of from about 0.8 mm. to 1.5 mm. Hg.

10. In a continuous method of drying a liquid material in a vacuum chamber which comprises the passing of said material through a preliminary heating zone, a high temperature zone and subsequently through a finish-drying
zone, the improvement comprising progressively heating the liquid material while in the form of a film in said preliminary zone at a temperature to cause it to puff and expand to form a porous foam-like mass having a substantially increased volume, the heat being applied gradually and not rapidly enough to cause spattering, and thereafter rapidly drying the foam-like mass in said high temperature zone by subjecting it to a temperature greater than the liquid film could have withstood, without spattering and overheating in the absence of said initial puffing.

11. The method of drying a liquid material as set forth in claim 10 in which the liquid material is sequentially heated in said preliminary zone while passing through a series of heating zones.

12. The method of drying a liquid material as set forth in claim 11 wherein the time the material is in said high temperature zone comprises a minor portion of the entire drying period.

13. In a vacuum dehydrator of the belt type, a housing constituting a vacuum chamber, spaced heat exchanging drums rotatably mounted within said vacuum chamber, means to drive one of said drums continuously, a drying belt trained over said spaced drums, regulatable heating means operatively arranged to heat one of said heat exchanging drums, regulatable cooling means operatively arranged to cool the other of said heat exchanging drums, an applicator disposed to apply liquid material to be dried to the exterior surface of the run of said belt moving from said cooled drum toward said heated drum, an auxiliary heater disposed to apply heat to the interior surface of said belt between said applicator and said heated drum for pre-heating the liquid material on said belt before it is acted upon by drying heat from said heated drum, another auxiliary heater disposed to apply heat to the material on the exterior surface of said belt after it has been acted upon by the drying heat from said heated drum to further dry the material, a doctor blade disposed to remove the substantially dried material from the surface of said belt in the form of discrete particles after it has been cooled by said cooled drum, an auxiliary compartment interconnected with said housing and constituting an extension of said vacuum chamber, means to convey the particles of substantially dried material removed from said belt into said auxiliary compartment, a tumbling drum disposed within said auxiliary compartment to receive the particles of substantially dried material, said tumbling drum being arranged for rotation to agitate the material and advance it gradually through said auxiliary compartment while subject to the drying effect of the vacuum in said chamber to reduce its residual moisture content, means to drive said tumbling drum, and discharge apparatus arranged to receive the dried material from said tumbling drum and to discharge it from said vacuum chamber.

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