May 14, 1968 J. H. BLAKE ETAL 3,382,585

INTERNAL SUBLIMATION CONDENSER APPARATUS

Filed Dec. 28, 1965 3 Sheets-Sheet 1

FIG_1

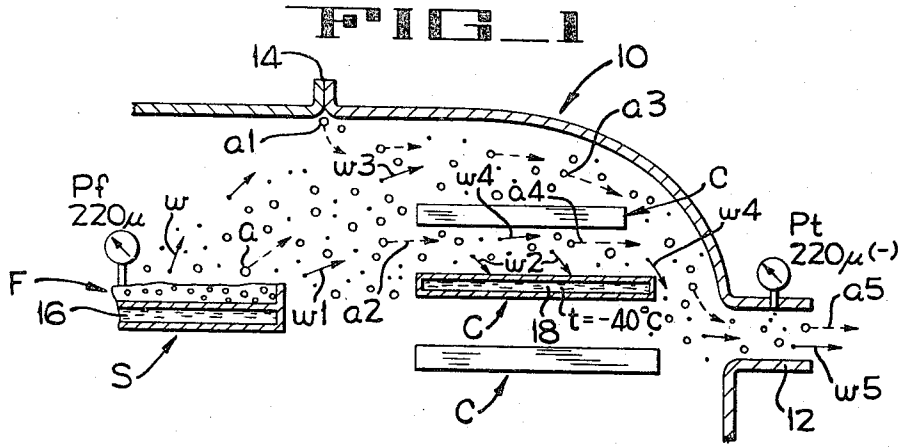


FIG_2

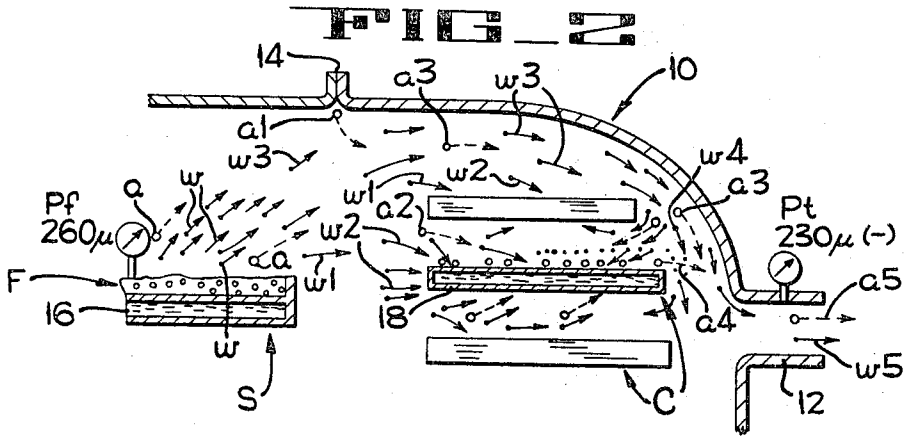
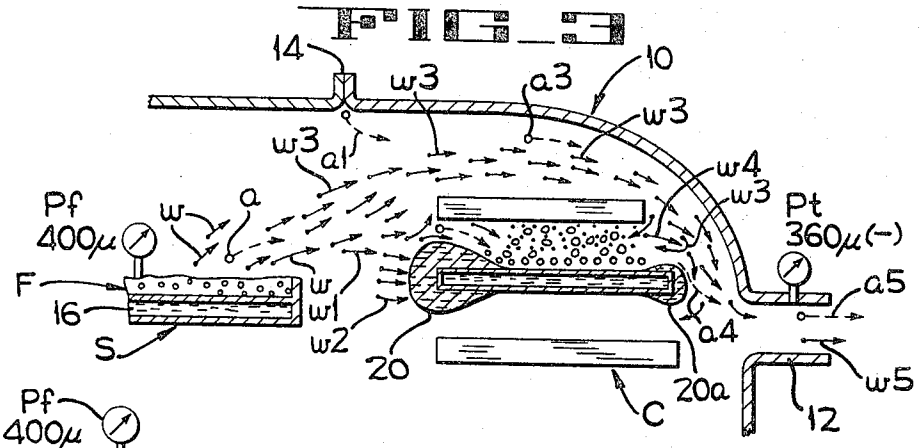


FIG_3



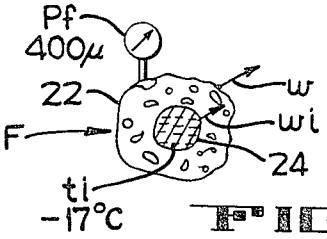


FIG_4

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INTERNAL SUBLIMATION CONDENSER APPARATUS

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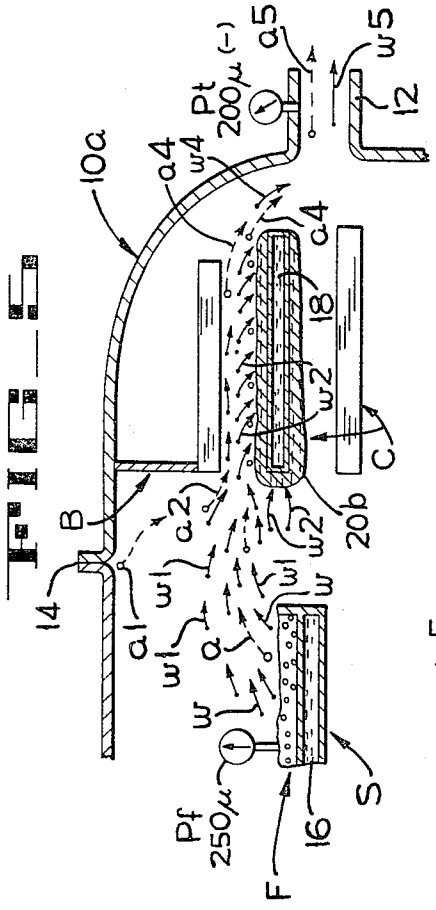


FIG. 5

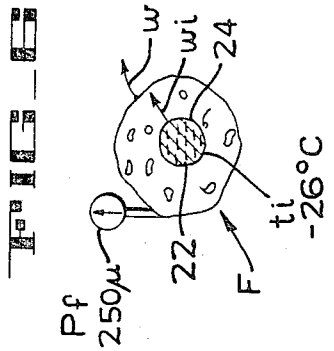


FIG. 6

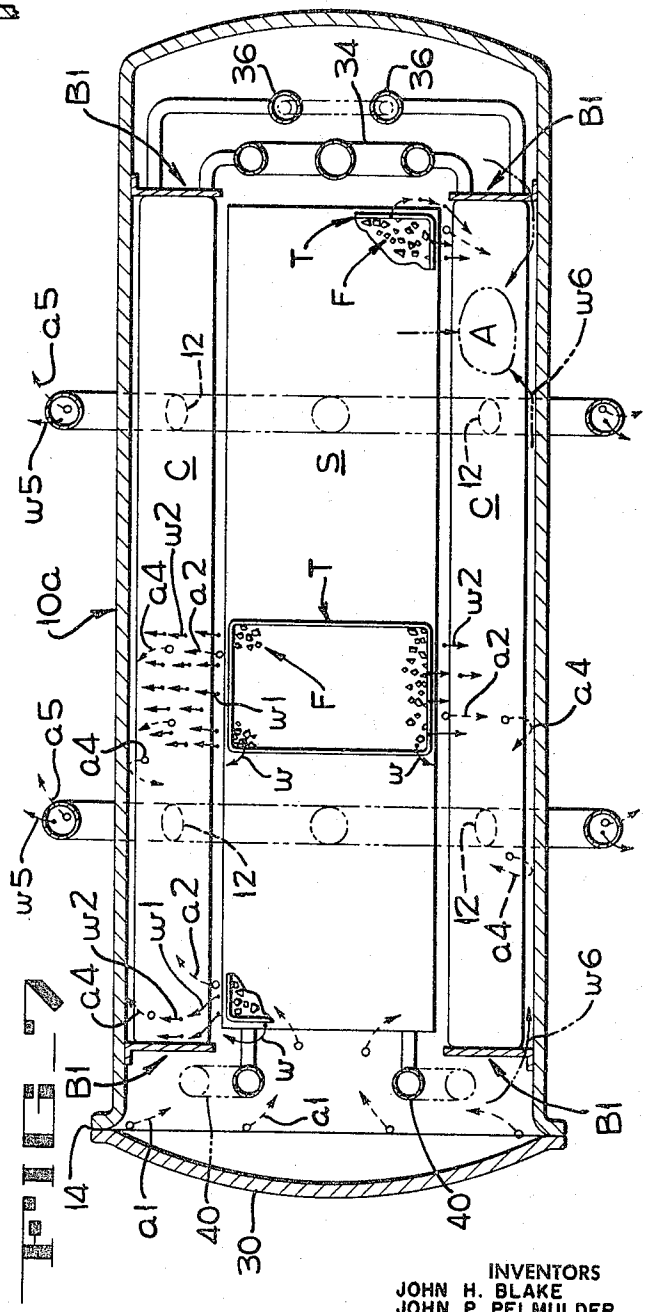


FIG. 7

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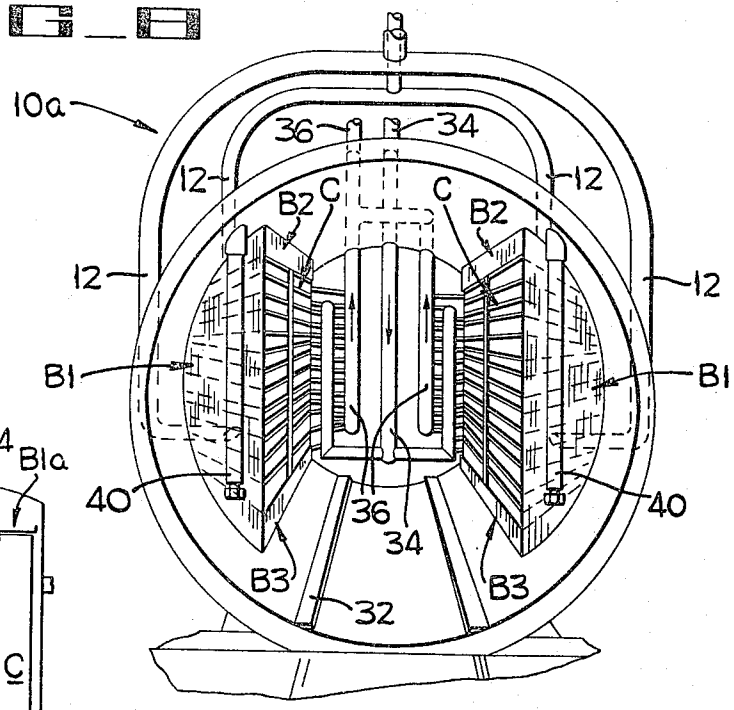
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INTERNAL SUBLIMATION CONDENSER APPARATUS

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FIG_8



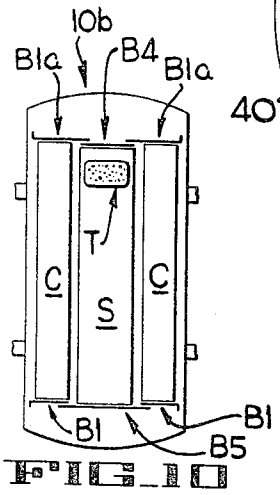


FIG_10

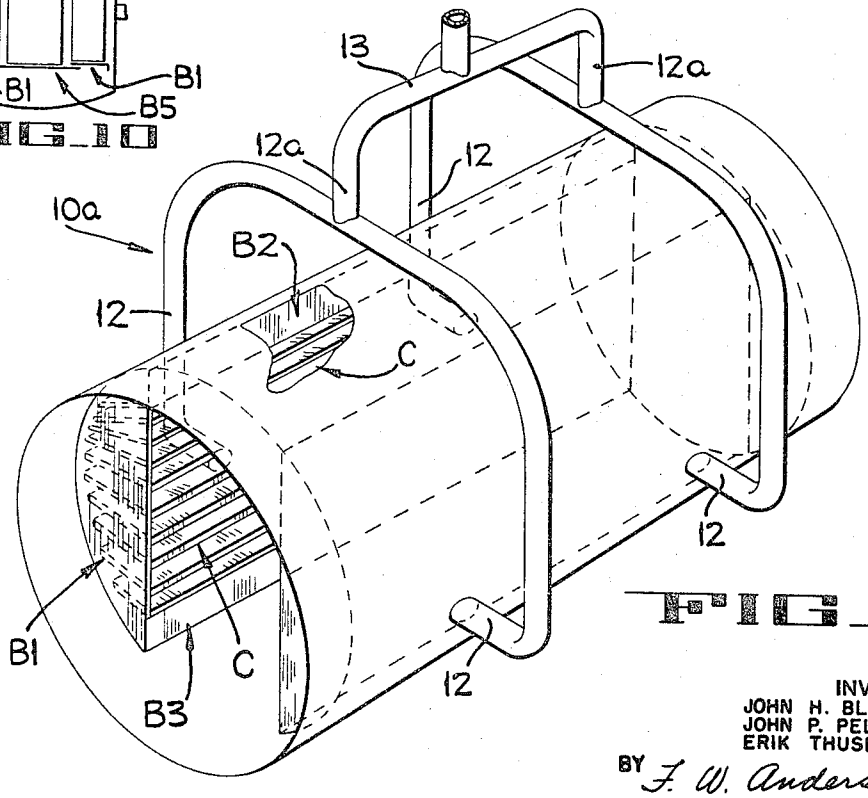


FIG_9

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3,382,585

INTERNAL SUBLIMATION CONDENSER APPARATUS

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Filed Dec. 28, 1965, Ser. No. 517,055
8 Claims. (Cl. 34—92)

ABSTRACT OF THE DISCLOSURE

Stagnation of air within the vapor condenser of an internal condenser freeze drying unit is prevented by providing baffles at the ends as well as above and below the condenser, thereby directing all gases through the condenser. A vacuum port for exhausting air is behind the baffled condenser unit.

This invention relates to apparatus for the drying or dehydration of a frozen product by sublimation of the water vapor from the product ice cores, without permitting melting and hence wetting of the dried product layer during the drying process. The most widespread use of this process is the preservation process known as freeze drying, wherein food, biologicals and the like, are brought to a very low percentage of moisture, and the example to be given will be such a process, wherein the drying chamber is what will be termed the internal condenser type.

Freeze drying systems of the type to which this invention relate commonly include a drying chamber for the frozen product; shelves for supporting the product in the chamber; a holding pump for evacuating non-condensable gases from the chamber during drying; means for supplying the heat of sublimation to the product; and means for condensing the water vapor evolving from the ice cores in the product. In the system of the present invention the condenser provides a large refrigerated surface area to water vapor subliming from the product, with the condensing surfaces or plates being disposed directly in the drying chamber. A system of this type is shown in the patent to Abbott et al. 3,132,930 issued May 12, 1964, and assigned to the assignee of the present invention.

The heart of the process carried out in freeze drying units of this type is in the condensation of the water vapor directly in the chamber. When it is considered that a freeze drying chamber which evaporates only 300 pounds of water per hour (for example) will cause the sublimation of 550,000 cubic feet of water vapor per *minute*, the significance of effective removal of this water vapor from the zone around the product will be apparent. The reliance on pumps, or the like for removing even a small fraction of this huge flow of vapor is not economical. Nevertheless, the water vapor pressure over the product must be a fraction of a millimeter of Hg in order to hold the actual ice core temperature well below its initial freezing point. The water in many products (e.g., fruit) contains various solutes such as sugars, which lower the freezing temperature below that of water. This may require maintaining a water vapor pressure over the product of less than 200 microns (0.2 mm. Hg) where the dried product layer resists outward diffusion of water vapor from the ice core, because the actual vapor pressure at the core will be considerably higher than that in the chamber. The total gas pressure in the chamber is the sum of the partial pressure of noncondensable gases (air) and the partial pressure of water vapor. This total pressure is substantially the same everywhere (except at the ice core of a partially dried product), but the composition of the gas mixture

is not the same. As will be seen, applicants have found that although the gas at the product is almost entirely water vapor (to be termed vapor), that behind the condenser zone may be predominantly air.

Since freeze drying processes are ordinarily carried out to a point wherein the moisture content of the dried product is very low (in the nature of 2% of residual moisture), the drying times tend to be rather long because the quantity of heat applied to the product is limited by the maximum allowable product temperature and the heat transfer rate from the product surface to the ice core. In order to obtain a good quality product, it is necessary to hold the pressure of water vapor over the product to a minimum and this requires that the total pressure in the entire chamber be low. Since the volume of water vapor evolved is high, and since it is not practical to employ pumps or the like for removing it, reliance must be placed entirely on the effectiveness of the condensing system for holding down the vapor pressure over the product during the drying process.

In operating the apparatus of the type described, it has been found that despite the efficient mechanical arrangement of the product cart shelves, trays and condensing surfaces characteristic of that shown in the aforesaid Abbott et al. patent, performance is still not as good as would be ideally expected from optimum utilization of the equipment. The present invention represents a successful means for improving the performance of such a unit, which in turn can be translated into the provision of means for holding the pressure of water vapor over the product to a value lower than that obtainable in the same equipment before it was constructed to embody the present invention.

Examination of the condenser plates of the equipment described which did not embody the present invention, indicated that the ice formation on the condenser plates, which is an indication of the effectiveness of the condensers themselves, has been predominantly localized at the edges of the plates, and especially at the edges closest to the product being dried. Furthermore, measurements of total chamber pressure during a drying cycle has given evidence that optimum utilization of the condenser plates and hence minimum vapor pressure over the product has not been obtained. This condition is aggravated in drying cycles wherein there are temporary decreases in the effective tonnage of the refrigeration system for the condensers. Under such temporary decreases in the capacity of the refrigeration, the temperature of the condensers will rise somewhat and the total pressure in the drying chamber will rise also, under operation of the gas laws. It has been found that once an increase in condenser plate temperature occurs, the resultant pressure rise in the chamber is not readily removed by simply re-establishing the previous rate of refrigeration.

Analysis of the drying time and the chamber pressure record during the cycle indicated that the pressure is not as low as should be obtainable in an installation of this type. Consideration of this problem and investigation of these conditions reveal that the difficulties do not rise because of condenser deficiencies, excess heat, excess vapor, or an insufficient vacuum pump. They arise due to the fact that non-condensable gases are not adequately removed from the drying chamber during the drying cycle. It is true that a "holding" vacuum pump or the like is operating during the drying cycles for the very removal of these gases, and that such a pump is relatively ineffective for handling the water vapor. For example, in a system of the type described designed to evaporate 300 pounds per hour of water vapor, a holding pump capable of evacuating 300 cubic feet per minute would ordinarily be more than adequate. This pump would easily remove air that leaks in around any joints, doors, or the like, in

the drying chamber as well as air that is released from the product and air that has been trapped or pocketed in various portions of the apparatus. It is therefore postulated that the localized effectiveness of the condenser plates, the undesirably high total pressure over the product, and other factors tending to decrease the efficiency of the cycle are all caused by a body of substantially stagnant air blanketing an undesirably large area of the condenser plates, thereby reducing their efficiency and effectiveness. It was also postulated that a mere increase in the capacity of the holding vacuum pump would not solve this problem, because it would merely draw water vapor instead of air, the capacity of the pump already having been adequate to withdraw any air that can leak in during the cycle and that would be released from the product.

Based on these studies, conclusions, and postulations it was decided that the total vapor pressure over the food could be reduced with a corresponding decrease in ice core temperature and an improvement in product quality, if air were not permitted to accumulate or stagnate over the condenser plates, thereby partially blanketing the plates and forcing condensation of some substantial portion of the water vapor to be preceded by diffusion of the latter water vapor through the blanket of air. It was further postulated that the removal of the air between the condenser plates, coils or the like could be effected by insuring that substantially all gases, air or water vapor, that flow in steady state relation into the outlet leading to the vacuum pump be caused throughout the cycle to pass across, between, or in close proximity to the surfaces of the condenser within the drying chamber. In a system operating in accordance with these principles, providing sufficient refrigeration is provided, then substantially all of the water vapor should be condensed before it reaches the vacuum pump inlet and a flow pattern having thus been established for all gases through the system, there will result a steady state flow of air into, across and out of the condenser regions, and into the inlet to the vacuum pump. This condition would therefore insure that all air that enters by way of leakage, or is released from the food product or from pockets within the apparatus, will be in a steady state of flow into the condenser zone and out of it without permitting development of any stagnant blanket of air at that zone. The steady state of flow thus induced would insure that all the water vapor has a similar flow pattern, except that the latter would be condensed down to its equilibrium pressure at the condenser zone. The important result of this improvement stems from the fact that the partial pressure of air at the condenser is kept very low, and since the partial pressure of the vapor can be made as low as desired, the total chamber pressure will be low. The advantages of the latter have been mentioned.

The results of these hypotheses were carried into practice by constructing the drying chamber to produce exactly the effects just described.

In a freeze drying unit of the type described (with internal condensers) these desirable effects were provided by very simple means, namely, by providing impedances to flow of all gases through any path that does not cross, or pass in close proximity to, the condenser plates, coils or zones on their way to the vacuum pump ports. It will be seen in the detailed description of the invention that follows that these impedance units to be described were in the form of very simple and easily installed baffles. For example, these baffles could be applied to a unit such as that shown in the aforesaid Abbott et al. patent by several well known fabrication techniques. Of course the baffles can also be built into the equipment at the factory.

The manner whereby the aforesaid improved mode of operation of an internal condenser freeze drying apparatus can be attained, will be apparent to those skilled in the art from the following description of a preferred embodiment of the invention.

In the drawings, FIGURE 1 is a simplified schematic

diagram showing the operation of a freeze drying unit of the internal condenser type as an aid to understanding the present invention. This diagram shows a loaded unit before the heat has been turned on for supplying the heat to sublimate.

FIGURE 2 is a diagram like that of FIGURE 1 showing the conditions in the unit soon after the heat has been turned on.

FIGURE 3 is a diagram showing the same unit during comparatively steady state operating conditions, at some stage after an hour or two of drying has taken place.

FIGURE 4 is an enlarged schematic diagram of the partially dried particle of the product.

FIGURE 5 is a diagram corresponding to that of FIGURE 3, showing the operation of the unit when it embodies the present invention.

FIGURE 6 is a diagram like that of FIGURE 4 showing the condition of a partially dried particle under the present invention.

FIGURE 7 is a horizontal section through a drying chamber embodying the invention.

FIGURE 8 is a perspective end view of the chamber with the shelf cart removed.

FIGURE 9 is a diagrammatic perspective of the chamber.

FIGURE 10 is a simplified diagrammatic plan of a modified form.

The principles of the present invention will be explained in connection with the schematic diagrams of FIGURES 1–6. These diagrams are highly simplified and only sufficient detail is shown to illustrate the principles involved in the mode of operation of the present invention.

The freeze drying system shown in the diagrams includes a vacuum chamber **10** having an outlet **12** for connection to a vacuum pump, which in the initial portion of the cycle may be a relatively large pump down unit that exhausts air and other gases from the chamber, but which during the drying portion of the cycle will be considered to represent a connection to a smaller holding vacuum pump. This is intended to hold the partial pressure of noncondensable gases (air) in the chamber at a very low value, thereby making it possible for the total chamber pressure to drop to a low figure, in fact well below a millimeter of mercury. In the discussion that follows, the term "air" will be assumed to include other noncondensable gases that enter into the system. The air being a principal component of this group of gases.

In this discussion, the product being dried will be considered to be of food F mounted on trays for receiving radiant heat as in the Abbott et al. patent, or directly on heating shelves S. The mode of heat transfer is not critical here. Only one of a number of shelves S appears in the diagram. During the drying cycle a heating medium **16** is circulated in the shelves S in order to supply the heat of sublimation. Also mounted within the drying chamber **10** is a condenser formed of a plurality of condenser elements C, only three of which are shown, one in section. These elements are also hollow and have a refrigerant **18** circulated therethrough in order to condense the water vapor evolved from the food and maintain its partial pressure in the chamber at a low figure.

The diagram of FIGURE 1 shown in the conditions within the chamber during the pump down portion of the cycle, before heating fluid **16** is circulated through the shelves S. In this and the other diagrams of FIGURES 2, 3 and 5, the following conventions will be adopted: Small, solid dots within the chamber will represent molecules of water vapor, and their motion is indicated by small solid arrows leading from the dots. The legend "*w*," with subscripts as required, indicates vapor. Air molecules free within the chamber are illustrated by small circles and their motion is illustrated by small arrows. Air is indicated by the letter "*a*" and numerical

subscripts, as required. When numerical data is given, it is by way of example only.

The vacuum chamber **10** cannot be considered to be air-tight and there will be one or more joints such as that indicated at **14**, which may be considered to represent a door. Air molecules *a*1 leak into the chamber whenever its pressure drops below that of the atmosphere. The arrows *a* indicate air molecules that were trapped in the food as well as air that was trapped in or clinging to the parts of the apparatus. During the pump down portion of the cycle and before the major phase of the drying cycle actually starts, conditions are as shown in FIGURE 1. The molecules of air leaking in and the trapped air *a* flow toward the vacuum pump outlet **12**. Some of the leakage air *a*1 and trapped air *a* flows toward the condenser plates. This air is indicated as *a*2. Other portions of the air *a* and *a*1 find a path between the walls of the chamber **10** and the condenser plates. This flow of air is indicated by the arrows *a*3 in the diagram. Other molecules of air may leave the condenser and flow toward the vacuum pump outlet **12**. These molecules of air are illustrated by arrows *a*4 in the diagram. All air leaving the chamber, from whatever source, and by whatever path, leaves the chamber through the vacuum port **12**, and this air being exhausted from the chamber is illustrated by the arrows *a*5 in the diagram.

Some water vapor *w* evaporates from the product before the heating liquid **16** is circulated through the shelves S. This evaporation increases as the pressure in the chamber drops, due to the removal of the air from the chamber as indicated at *a*5. As seen by the solid arrows, some of the water vapor *w* leaving the food flows toward the condenser. This vapor is indicated at *w*1. Since the refrigerant **18** is usually circulating through the condenser during the pump down period water vapor *w*1 that flows adjacent to the condenser plates will condense thereon, as shown at *w*2. The rest of the water vapor, *w*3, will flow between the condenser and the chamber walls. If the temperature "*t*" of the condenser plates of the refrigerator is −40° C., the equilibrium vapor pressure P*w* at the plates C will be 100 microns at the condensation zones around the condensers. The partial pressure P*w* of the water vapor at the food, and elsewhere in the chamber will be somewhat higher. The difference between these pressures (the equilibrium pressure and the pressure at the food), being the driving force that causes flow of the water vapor particles.

The diagram of FIGURE 2 illustrates the condition within the chamber just after the circulation of heated fluid **16** in the shelves S has begun. The temperature of this fluid (which is usually a liquid such as propylene glycol, or the like) will be in the present example in the order of 150° C. When the heat is turned on, a flood of water vapor *w* is sublimed from the ice cores in the individual food particles, and the partial pressure P*w* of the water vapor rises at once. This flow of water vapor out of the food carries air with it, but there is very little free air present in this location at any one time, so that the pressure P*a* of the air at this location will be quite low. The total pressure P*f* over the food will be 260 microns, and the gas here is almost all water vapor. The mass flow of water vapor and the relatively few molecules of air interned therein proceeds as follows along paths of least resistance: some water vapor *w*1 flows toward the condenser plates. As indicated at *w*2, some of these molecules are condensed out on the plates to start a layer of ice particles. Other water molecules *w*3 have a readily available pathway for flow between the walls of the chamber **10** and the condenser plate. These molecules condense on the back edge of the condenser plate and also condense between the plates near the back edge. Some of the water vapor molecules *w*3, are carried on past the condenser to the region of the vacuum port **12** without coming into contact with the condenser plates. Also, a relatively few water vapor molecules, indicated at *w*4, may escape from the ice layer or from between the condenser plates and flow toward the vacuum port **12**.

The effects on the air particles in FIGURE 2 can be explained as follows: air molecules *a* are swept away from the food F by the water vapor *w* and away from other surfaces to which it is clinging. Likewise leakage air *a*1 continues to enter the system through the joint **14**. The air will be swept along with the water vapor as shown at *a*2 and *a*3. When the water vapor condenses on the refrigerated plate it leaves the air next to the plates. A very small amount of air *a*4 will leave the zone between the condenser plates and flow to the low pressure zone at the pump port **12**. This flow of air from between the condenser plates is inhibited by the flow of water vapor coming from near the chamber wall to condense on the back edge of the condenser plate and between the plates near the back edge. Therefore only a small quantity of air *a*4 can flow to the vacuum port **12**. The water vapor *w*3 which flows to the area of the vacuum port **12** will have some air *a*3 with it, but this will only be a small fraction of the total volume of gas and vapor flowing. Therefore, the vacuum pump port **12** will be exposed to vast quantities of water vapor *w*3 and small quantities of air *a*3 and *a*4. The pump will then remove mostly water vapor from the chamber and permit quantities of air to accumulate next to the condenser plates. When this condition is allowed to persist the situation shown in FIGURE 3 will develop. FIGURE 3 shows schematically the conditions that will exist after the drying cycle has been under way for an hour or two. The concentration of air between the condenser plates has increased so that it presents a great resistance to flow of water vapor. But water vapor *w*1 continues to flow toward the condenser plates, and water vapor *w*2 reaching those plates is condensed out at the edges of the plate in a thick layer of ice with a small area indicated in FIGURE 3 at **20**, **20***a*. Water vapor fails to condense on the flat sides of the plates because of the resistance of the blanket of air between the plates.

The heat of the condensing water vapor must be transferred through the thick layer of ice to the refrigerant **18**. Therefore, the surface of the ice will be warmer than the refrigerant **18**. The water vapor must all be condensed on a relatively small area of ice and therefore the water vapor pressure must exceed the saturation pressure of the ice by more than the normal amount. To continue to transfer the same mass of water vapor, the water vapor pressure at the product must therefore rise to provide the necessary driving force.

As seen in FIGURE 4, with the phenomena just explained, an undesirably high ice core temperature with incipient melting conditions and melting of the food particles results. The total pressure P*f* outside the dried layer **22** of the food is now 400 microns. It requires a pressure drop for water vapor *w*1 to diffuse through the layer **22**, thus the pressure P*i* at the ice core will be significantly higher than 400 microns corresponding to an ice core temperature *ti* which is above the melting point of many sugar solutions. Wetting of the layer **22** is possible, if uncontrolled conditions cause a further increase in total chamber pressure. The inefficient use of the condenser surfaces as indicated by the localized ice bulge **20**, FIGURE 3, at the leading ends of the condenser plates; and the undesirably high total pressure (P*f* 400 microns) in the chamber; which both can be corrected and improved in a simple manner in accordance with the present invention. An explanation of these improvements will be given in connection with the schematic diagram of FIGURE 5, which is like those previously discussed except that the principle of modifying the drying chamber **10** into a chamber **10***a* is incorporated in the diagram, and will be explained.

The diagram of FIGURE 5 illustrates a stage in the drying cycle, corresponding to that of FIGURE 3. Water vapor *w* is being sublimed from the ice cores of the

product and that shown at *w*1 is approaching the condenser plates C. However, in this drying chamber a baffle B has been installed between the wall of the drying chamber and the uppermost condenser plate C. This baffle prevents gas originating in the left zone of the chamber, as it is viewed in FIGURE 5, from blowing between the wall of the chamber and the upper condenser plate C. Thus, all gases flowing to the vacuum port **12** must flow between pairs of condenser plates C, or close to corresponding condensing surfaces in case condenser plates are not the type of condensing surfaces employed. In the system of the invention, and as shown diagrammatically in FIGURE 5, water vapor *w* is sublimed due to the application of heat from the shelves S, as before. Molecules *w*1 of water vapor flow away from the shelves as before, but now these all flow toward the condenser. The water vapor *w*2 reaching the condenser or the ice core surrounding it, condenses onto the plates.

Likewise as before, air *a* that was trapped in the food particles, and other air, is entrained in the waper vapor *w* as it leaves the food F and flows toward the condensers C with the water vapor. When the water vapor condenses the air is left next to the condensers C. However, in this case there is no flow of water vapor from near the chamber wall into the space between the back edges of the condenser plates and therefore nothing slows the flow of water vapor to the low pressure area near the vacuum pump port.

There is no significant static of stagnant body of air permitted to build up between the condenser plates under the present invention. Furthermore, the baffle B prevents water vapor at nearly the product vapor pressure from reaching the vacuum port **12** as occurred in FIGS. 2 and 3 since in FIG. 5 all of the water vapor must pass close to a condenser plate before reaching the vacuum port. Water vapor *w*4 will be at a low pressure corresponding to the temperature of the condenser plate C. The water vapor *w*5 going to the vacuum pump is now a smaller portion of the gas pumped than was the case in FIGS. 2 and 3 and the air *a*5 pumped is a much larger portion.

The pressure P*t* within the chamber will thus be 250 microns and the pressure at the vacuum port **12** will be about 200 microns because of the pressure drop due to the large volume flowing. The pressure P*f* at the food will be somewhat higher, as before, in this case in the order of 200 microns. This pressure will not be exceded during the drying cycle.

An important advantage of these chamber conditions shown in FIGURE 5, under the present invention, is shown in FIGURE 6. Herewith is the total pressure P*f* over the food of 250 microns. This represents the maximum partial pressure P*w* of the water vapor over the fruit and the corresponding temperature of the ice core will now be substantially below the freezing or eutectic temperature of sugar solutions, or the like, in many food products and fruit. These advantageous results are attained because no significant stangnant body of air lies between the condenser plates. The result is, then, that water vapor can reach and flow to and across substantially the entire refrigerated areas. This is evidenced by the appearance of the layer of ice **20***b* that coats the condenser plates at the end of the drying cycle. As illustrated in FIGURE 5, this layer of ice **20***b* will be found to be of substantially uniform thickness across the plates. This indicates that optimum utilization of the condenser surfaces is being made.

Another advantage of this is that the lack of response of the system operation to corrections in momentary rises in refrigeration temperature no longer exists. Should the refrigeration temperature temporarily rise and then be lowered again (due to control reasons or the like), the chamber pressure will follow the incidence curve of the temperature with only a slight lag. The reason for this is that since a relatively small quantity of air is trapped between the plates, the water vapor that is involved will substantially flow through them up to their very outside edges, leaving the air *a*4 at the outer plate edges for flow to the vacuum port **12**. Thus, even though the temperature of the refrigerant temporarily rises, the flow of water vapor continues, although the condensation rate may be temporarily reduced somewhat. Thus when the temperature of the refrigerant is restored, to the example given of —40° C., since no appreciable amount of air was ever between the plates, since little could accumulate there, there is virtually no diffusion barrier to the water vapor, in its attempt to reach the condenser plates. Rather, the water vapor continues to flow in substantially laminar fashion under mass flow phenomena across the plates, to be condensed thereout, under the conditions previously described in the diagram of FIGURE 5.

FIGURES 7, 8 and 9 show, in somewhat diagrammatic form, an internal condenser freeze drying unit embodying the present invention. This unit is of the type shown in the aforesaid Abbott et al. patent, and only those details of the unit will be described for those skilled in the art to practice the invention. Details as to the construction of the drying shelves, trays, condenser plates, etc. may, insofar as necessary, be obtained by reference to the aforesaid Abbott et al. patent.

Referring to FIGURE 7, the vacuum drying chamber **10***a* has a door **30** which can be considered to provide the leakage path **14** for the air *a*1 previously referred to as entering during the drying cycle. The door **30** does not appear in FIGURES 8 and 9 but FIGURE 8, shows tracks **32** for the entry of a shelf cart (not shown) which has heated shelves S that are arranged in vertical tiers and support trays T for the frozen food F, as seen in FIGURE 7. The outer edges of the heated shelves and the trays thereon are in close proximity to the inner edges of the condenser plates C of the condenser. Under the present invention, the close spacing here is not as important as before.

In the preferred construction, the chamber **10***a* is long, and there are actually four vacuum ports **12**. These are located in the lower half of the chamber, particularly where the chamber is cylindrical as shown. The ports are manifold to a common pipe **13** leading to the pump. This location of the vacuum ports **12** assists in removing pockets of air, such as that indicated generally at A in FIGURE 7. These pockets were previously found to have accumulated between the condensers plates C, particularly away from the vacuum ports between the lower plates. The relatively low mounting of the vacuum ports **12** alleviates this condition. As mentioned, where the drying chamber is relatively long compared to its diameter, as in the chamber **10***a* of the drawings, it has been found desirable to distribute two or more vacuum ports **12** along the length of the chamber. It has also been found that the efficiency of the operation will be improved if ports **12** are placed at each side of the chamber.

These considerations have heretofore been overlooked or best unemphasized, and has not been recognized that there can be an objectionable amount of stagnant air trapped or remaining between the condenser plates, and that the function of the holding pump, which should theoretically remove non-condensable gases, is not efficiently effected. The assumption being that non-condensable gases will adequately find their way to the pump, simply by connecting it at any convenient zone in the drying chamber is fallacious.

As seen in FIGURES 7 and 8, inlet lines 34 and outlet lines **36** are provided for circulating refrigerant to the condenser plates C. Also, flexible hoses **40** have connections (not shown) to a source of heating fluid for the shelves S, and quick attachable connections for connecting up to the shelves themselves, when the food cart (not shown in FIGURE 8) is rolled into place in the drying chamber. One of the connections **40** will be an inlet connection and the other an outlet connection, these details

appearing in the Abbott et al. patent and not being critical to the present invention.

As previously described and explained, considerable improvement in the operation of the chamber just shown in FIGURES 7 to 9 is provided by insuring that the principal, and in fact, substantially the only flow path available for water vapor evolving from the food on the heated shelves S is between or over condenser plates. It may be true that water vapor flow substantially ends at the outer (far) edges of the condenser plates, but this is only because all the water vapor in excess of that corresponding to the equilibrium pressure of the condenser plates will have now been condensed up to these edges. However, air which evolves during the process, or leaks into the chamber, and which can only be withdrawn by the vacuum pump, must also take the same path, and it is induced to take this path by the aforesaid flow of water vapor, even though the latter terminates as described. In other words, there is an air flow in the chamber of this invention sufficient to hold the total pressure down in the chamber to a point that sublimation is rapid and that no melting of the ice cores in the product occurs.

The optimum baffling system for the chambers of FIGURES 7–9 includes principally baffles B1 closing off the fore and aft ends of the condenser plates C. These baffles seal off the ends of all condenser plates, not only those at the top or bottom designated B2 and B3 in FIG. 8 and also shown in the diagrams of FIGURES 1 to 5. As seen in the upper left of FIGURE 7, water vapor *w* evolving from the food, if it is to flow at all as directional flow (which is the type of flow that will normally occur under the low driving forces developed in the chamber) must flow between the condenser plates C. These are the very locations wherein pockets of air A, as shown at the upper right of FIGURE 7, have previously been permitted to accumulate. Any water vapor that finds its way into the end pockets of the chamber will merely stagnate there and will serve as a diffusion barrier to water vapor *w* leaving the food. The latter will therefore take the path of least resistance, which will flow into and across the condenser plates.

Since the mere presence of vacuum ports **12** has been found to not be effective to produce the advantages of the present invention, contrary to prior teachings, it has also been found that the pairing of vacuum ports **12** on opposite sides of the chamber significantly reduces the total pressure in the chamber. For example, in a given installation where the baffles are installed as in FIGURE 7, the chamber pressure dropped from 180 microns to 100 microns total by simply pairing the vacuum ports **12** as shown in the drawings. This difference apparently results because the present invention insures that the vacuum ports can serve their intended function and efficiently remove air, whereas previously they would not, and it made no difference where they were located, or even if more than one were provided.

FIGURE 10 illustrates schematically a modified form of the invention wherein the flow paths for gas out of the ends of the shelf cart is blocked. In this form, the drying chamber **10***b* has the baffles B1 on the front edges of the condenser plates C as before. The rear baffles B1*a* project inwardly past the plates C. The shelf cart and shelves S have a rear baffle B4 that extends vertically for closing off the spaces between the shelves at the rear. The front baffle B5 serves the same function but projects past the sides of the shelves to cooperate with baffles B7. Thus with the shelf cart and shelves S in place in the chamber, the water vapor evolving from the food at the ends of the shelves will be directed over the condenser plates by the baffle construction described.

Having explained the invention so that those skilled in the art may practice the same, we claim:

1. Freeze drying apparatus comprising a drying chamber, at least one vapor condenser comprising a plurality of refrigerated surface-condenser elements in said chamber, one side of said condenser being adjacent to but spaced from at least one side of the chamber, a vacuum port connection in said one side of the chamber, heated shelf means in said chamber having one side adjacent to but spaced from the opposite side of said condenser, and baffle means for directing vapor flowing from said shelf means across the condensing surfaces of said condenser element while blocking the flow of gas, not emanating directly from said shelf means, into the space between said one side of the condenser and said one side of the chamber, and hence toward said vacuum port connection.

2. Apparatus for freeze drying or the like comprising a drying chamber, vapor condensers extending along opposite sides of the chamber and having their outer sides spaced from the chamber walls, means for supporting the product to be dried between said condensers, means for supplying heat to the product, vacuum port connections in the walls of the chamber opposite the outer sides of said condensers, and baffle means at the ends of said condensers for blocking gas from flowing into the space between the outer sides of the condensers and the associated chamber walls, and hence toward the vacuum connections, unless the gas has also passed through said vapor condensers.

3. Apparatus for freeze drying or the like comprising a drying chamber, vapor condensers extending along opposite sides of the chamber and having their outer sides spaced from the chamber walls, said condensers each comprising a tier of generally longitudinally extending, plate like elements having vapor condensing surfaces, means for supporting the product to be dried between said condensers, means for supplying heat to the product, vacuum port connections in the walls of the chamber opposite the outer sides of said condensers, and baffle means extending along the ends of said condensers and to the adjacent chamber walls for blocking gas from flowing into the space between the outer sides of the condensers and the associated chamber walls, and hence toward the vacuum connections, unless the gas has also passed through said vapor condensers.

4. The apparatus of claim **3**, wherein said condenser elements are generally horizontal, and wherein baffle means are also provided for blocking the flow of gas between the upper condenser element and the associated chamber wall.

5. The apparatus of claim **3**, wherein said condenser elements are generally horizontal, and wherein baffle means are also provided for blocking the flow of gas between the lower condenser element and the associated chamber wall.

6. The apparatus of claim **3**, wherein said condenser elements are generally horizontal, and wherein baffle means are also provided for blocking the flow of gas between the upper and the lower condenser elements and the associated chamber walls.

7. The apparatus of claim **3**, wherein a plurality of vacuum port connections are provided at each side of the chamber.

8. The apparatus of claim **7**, wherein said product supporting and heating means comprises a tier of hollow shelves, with the edges of the shelves being adjacent to the inner edges of said condenser elements.

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