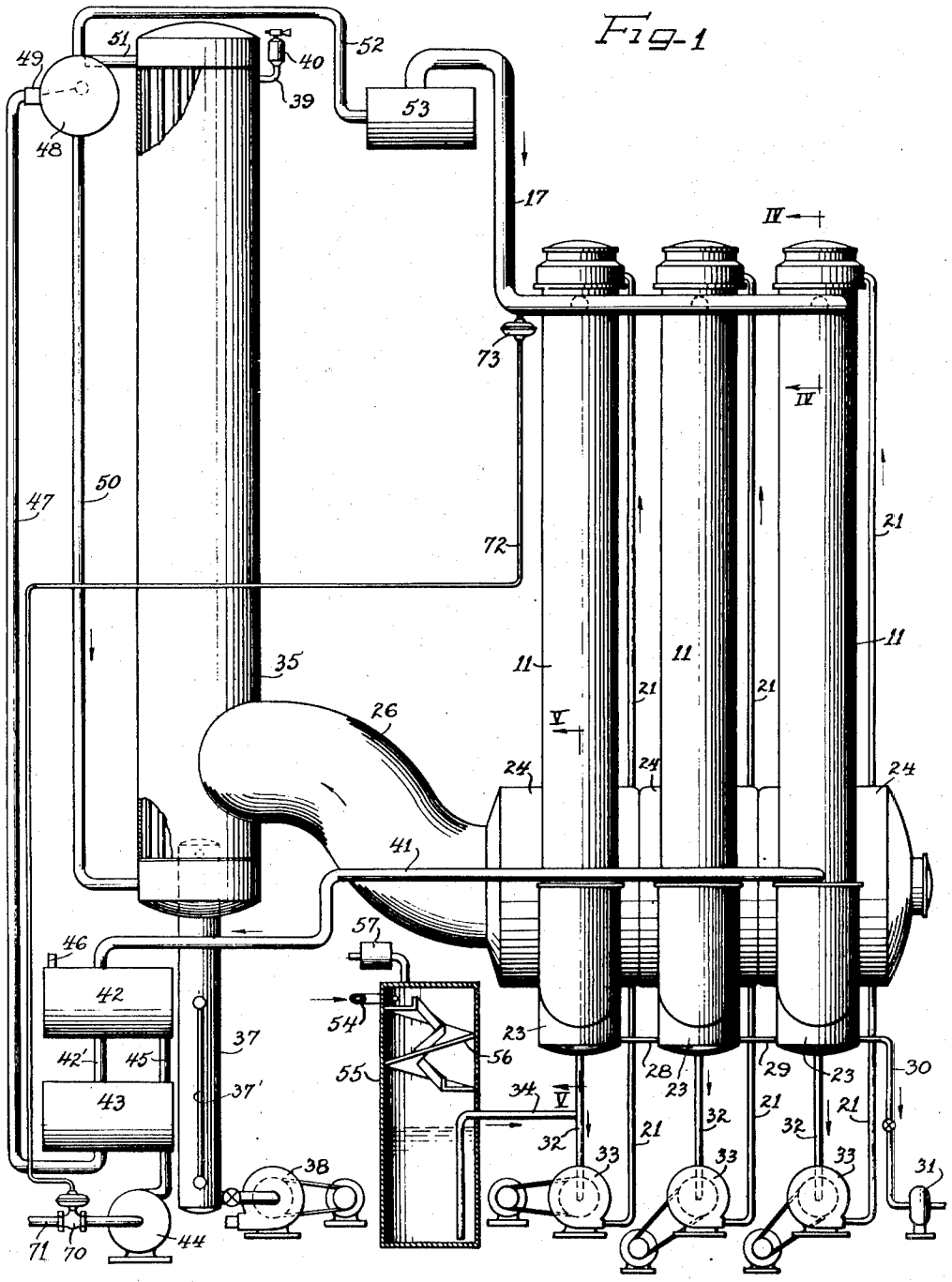
Oct. 9, 1951 J. A. CROSS 2,570,210

EVAPORATION METHOD AND APPARATUS

Filed Nov. 30, 1945 4 Sheets-Sheet 1

Fig-1



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Oct. 9, 1951 J. A. CROSS 2,570,210

EVAPORATION METHOD AND APPARATUS

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Fig-2

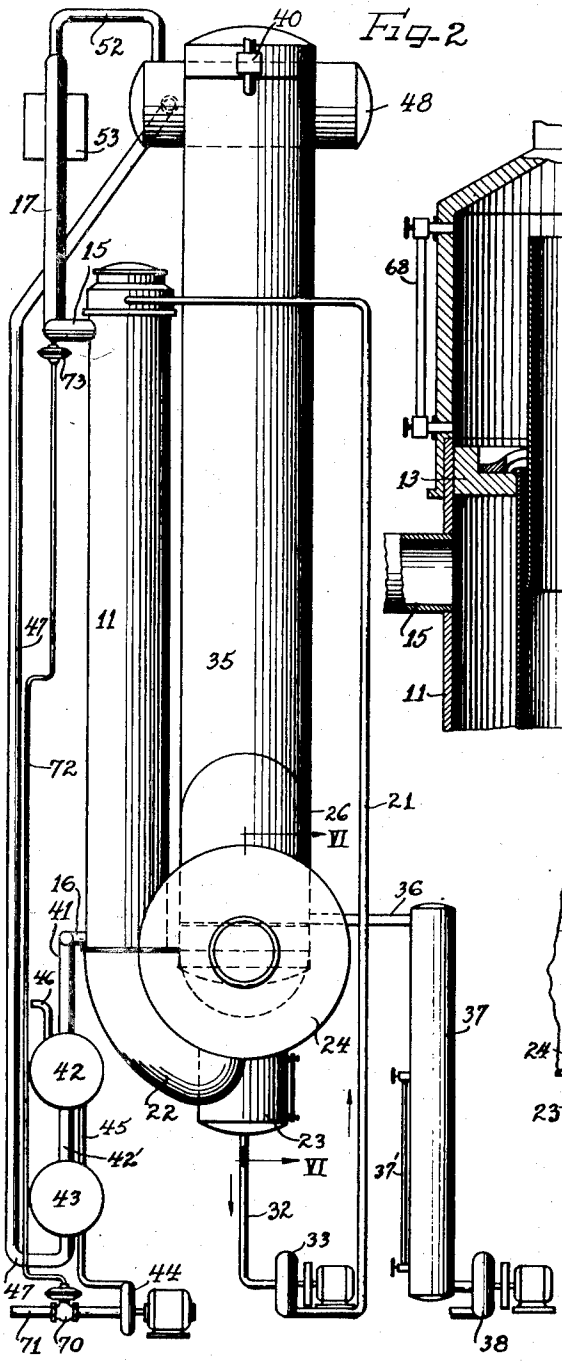


Fig-4

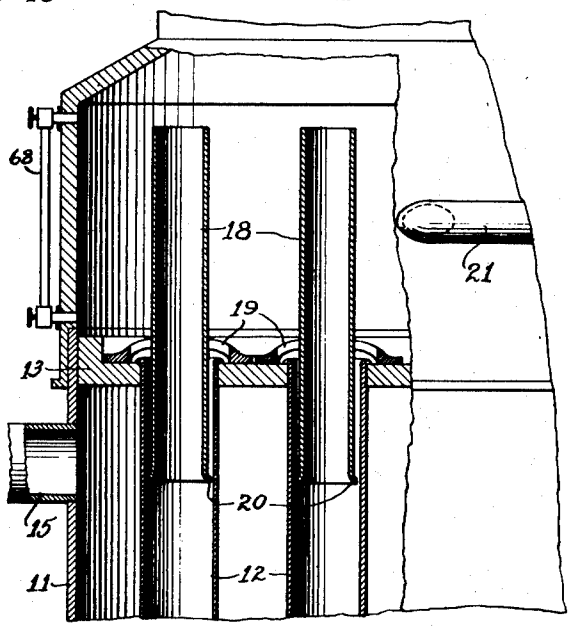
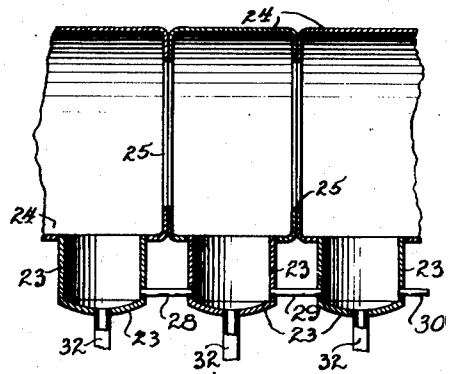


Fig-6



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EVAPORATION METHOD AND APPARATUS

Filed Nov. 30, 1945 4 Sheets-Sheet 3

Fig-3

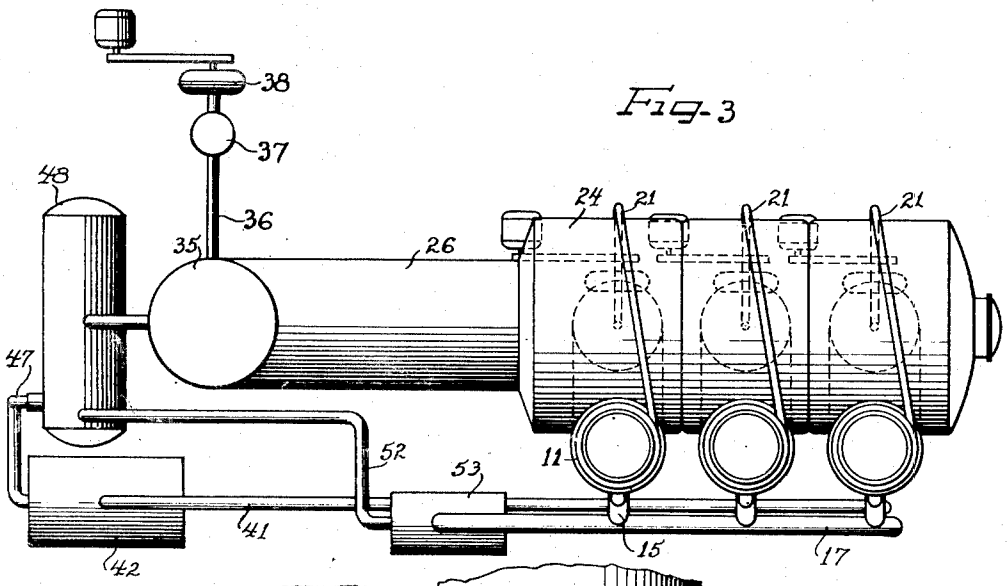


Fig-5

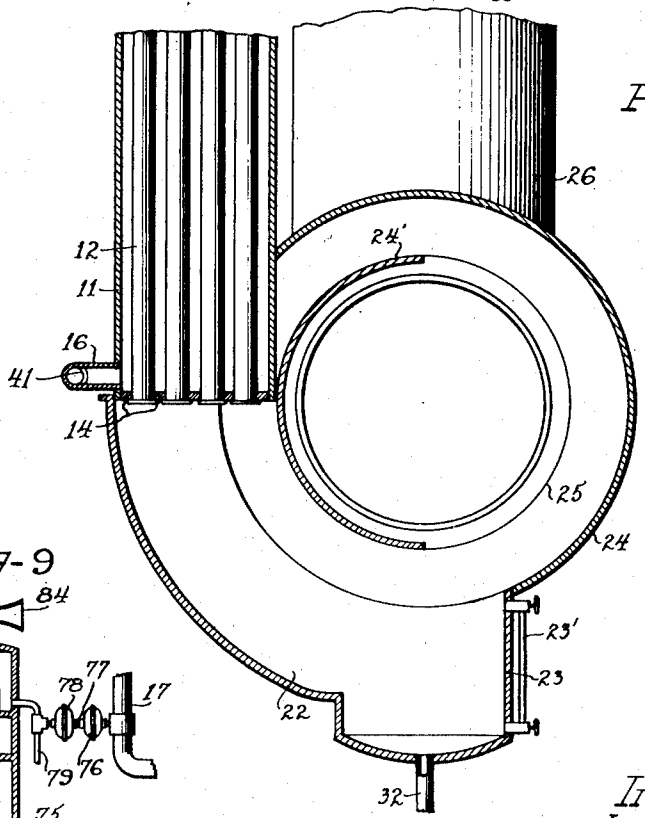
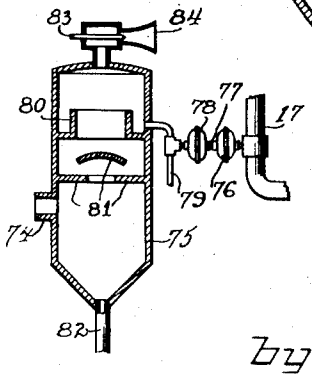


Fig-9



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Oct. 9, 1951 J. A. CROSS 2,570,210

EVAPORATION METHOD AND APPARATUS

Filed Nov. 30, 1945 4 Sheets-Sheet 4

Fig. 7

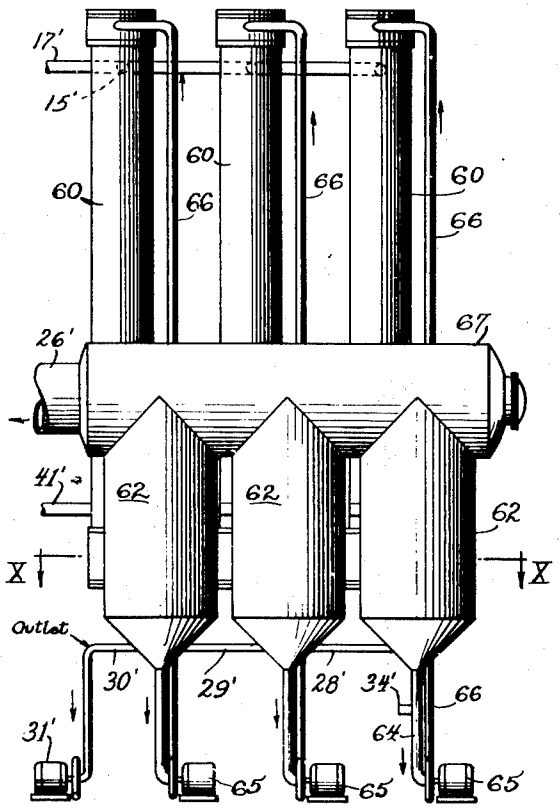


Fig. 8

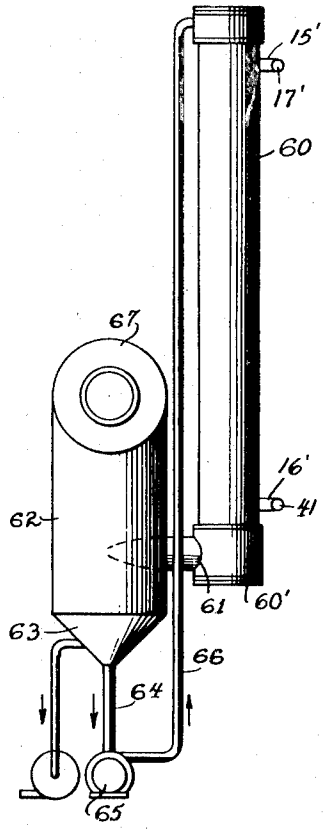
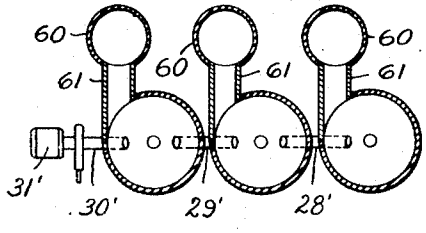


Fig. 10



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Patented Oct. 9, 1951

2,570,210

UNITED STATES PATENT OFFICE

2,570,210

EVAPORATION METHOD AND APPARATUS

Joseph A. Cross, Chicago, Ill., assignor to Mojonnier Bros. Co., Inc., Chicago, Ill., a corporation of Illinois

Application November 30, 1945, Serial No. 631,922

23 Claims. (Cl. 159—17)

1

This invention relates to methods and apparatus for evaporating liquids at lower than atmospheric boiling points and relates particularly to methods and apparatus that are suitable and especially adapted for the concentration of solutions containing heat-sensitive materials whereby evaporation at low temperature ranges is desirable.

The invention in its preferred form employs a refrigerating cycle wherein a compressed refrigerant gas having a relatively high temperature is employed to supply the heat to be imparted to the liquid undergoing evaporation, during which operation the refrigerant is largely liquified and after which the refrigerant gas is completely liquified, condensed and later cooled to a temperature below the temperature of the vapor escaping from the evaporating liquid and is thereby employed to effect condensation of the vapor, usually water vapor. This latter heat exchange evaporates the refrigerant, and the gas is then re-compressed. The condensation of the water vapor within the system induces a high vacuum upon the evaporating space in which the liquid is being evaporated, thus inducing evaporation at a lower temperature.

The system is designed and constructed for continuous operation. As contrasted to most evaporation processes, the present invention requires little fuel. A moderate amount of power is required for operating the refrigerant compressor, and only a relatively small amount of water or other coolant is required for accomplishing a desired cooling of the refrigerant.

One of the objects of the invention is to provide a method and apparatus for accomplishing the foregoing objectives and which employs a refrigerating cycle.

Another object of the invention is to provide a method and apparatus for accomplishing the foregoing objectives and which employs refrigeration apparatus adaptable for readily varying the operating conditions.

Another object of the invention is to provide a low temperature evaporation system and method requiring a minimum amount of heating or cooling means from outside sources.

Other objects and advantages of the invention will be specifically alluded to hereinafter, or will become apparent from the reading of the specification.

In the drawings I have shown, for illustrative purposes, a preferred embodiment of the invention and have described it as applied to the evaporation of heat sensitive materials, for example, citrus fruit juices and among them orange juice. I mention the latter because of the great utility of the invention as applied to the concentration of this particular product.

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While various refrigerants may be used, I have used ammonia and shall herein refer to temperatures and pressures at which I have employed ammonia.

In the drawings:

Figure 1 is an elevation partly in section of a diagrammatic lay-out of an apparatus by means of which the invention may be practiced;

Figure 2 is an end view of the apparatus shown in Figure 1;

Figure 3 is a top plan view of the apparatus shown in Figure 1;

Figure 4 is an enlarged partial sectional view of the upper end of one of the evaporators;

Figure 5 is a vertical sectional view of the lower end of one of the evaporators, on line V—V of Figure 1;

Figure 6 is a sectional view on the line VI—VI of Figure 2;

Figure 7 is a side elevation of a modified form of the juice evaporator units;

Figure 8 is an end elevation of the same units; and

Figure 9 is a vertical section of a condenser.

Figure 10 is a horizontal sectional view taken on the line X—X of Figure 7.

The apparatus includes an evaporator into which a hot compressed refrigerant gas is introduced to supply heat for boiling the liquid to be concentrated, and a condenser in which the low temperature water vapors from the evaporator are condensed during heat exchange with the liquefied refrigerant which at that time expands into a gas.

While various forms of heat exchangers may be employed, I have selected for disclosure herein the following: For the fruit juice evaporator I employ a series of connected falling film type evaporator units, each unit including a vertical tubular evaporator having a shell 11 and a nest of tubes such as 12 which are retained in the upper and lower tube sheets 13 and 14.

The compressed hot refrigerant gas is introduced into each evaporator through a pipe 15, and for circulation around the outsides of the tubes 12, being withdrawn, principally as a condensate through a bottom outlet pipe 16. The inlet pipes 15 for the refrigerant gas are connected to a common supply pipe 17.

As indicated in Figure 4, the upper ends of the tubes 12 are fixed in the upper tube sheet

13. It is intended that the space above the upper tube sheet will be kept flooded with the orange juice and in order to regulate the flow of juice into these tubes and downwardly, I insert in each tube 12 a removable tube 18 which is supported centrally in the top of the tube by a bracket in the form of a spider 19 having three or more legs which rest upon the top of the tube sheet, the legs being secured by welding or in any other suitable manner to the tubes 18 to support them in an upright position.

It will be noted that the lower end of each tube 18 is flared outwardly as shown at 20 to retard the flow of the orange juice past that area and to cause it to positively come into contact with the inner walls of the tubes 12. The supply of orange juice which is caused to flow downwardly through these tubes is brought to the top of each evaporator 11 by means of a pipe 21. It is apparent that the layer of juice above the tube sheet may be varied in depth, the greater the depth, the greater the rate of flow past the flared lower end of the regulating tubes 18. Since these tubes 18 are readily removable along with their supporting spiders, cleaning of the upper end of the evaporator and the vertical tubes 12 is facilitated.

As indicated in Figure 5, the lower ends of the tubes 12 open directly into a curved hood 22 which will serve to conduct the vapors and the unvaporized juice from the lower ends of the tubes. The liquid will flow into a sump 23 while the vapor will be drawn into a cylindrical chamber 24 and evacuated therefrom through a central aperture 25 and an outlet pipe 26 into the condensing unit.

The evaporator unit shown in Figures 1 and 3 consists of three vertical tubular evaporators 11 of substantially identical construction, all supplied with the hot refrigerant gas by the common supply pipe 17 and interconnected at their lower ends through the communicating drums 24, shown in section in Figure 6.

The sumps 23 are interconnected as shown by the pipes 28 and 29, to permit flow of a juice from the first sump to the next one to the right thereof, and from the second to the third sump, after which the concentrated juice is withdrawn through an outlet pipe 30 by a pump 31, from the system.

Connected with the bottoms of the sumps are the pipes 32, each of which leads to a pump 33 for recirculating juice back again to the top of the same evaporator from which it is withdrawn, that is through the pipes 21. It is intended that, in the use of these falling film evaporators, rapid recirculation pumps will be provided which will keep a constant supply of liquid above the top tube sheet in each evaporator and return to the top of each evaporator whatever liquid passes downwardly through the tubes 12 without having become evaporated. In the meantime any vapor escaping from the juice within the tubes is drawn downwardly and passes into the drums 24 with a whirling motion which serves to throw entrained particles, if any, centrifugally against the outer walls of the drums, to thus free the vapor of droplets before it is evacuated through the central opening 25 and the vapor outlet pipe 26. It will be noted that the central openings 25 are formed by means of the inturned end flanges of the individual drums 24, these flanges being readily riveted or welded together, but having the large central openings indicated.

Each chamber 24 preferably will have an arcuate baffle 24' secured to the margin of opening 25 which will assist in imparting centrifugal motion about a horizontal axis to the vapors and prevent their more direct flow through ports 25.

The fresh dilute juice is supplied to the system of evaporators from a de-aerator (to be described later) through a pipe 34 connected to the downflow pipe 32 in the first evaporator. Each evaporator unit therefore performs a substantial portion of the total evaporation job, and because of the action of the outflow pump 31, there will be a continuous flow of juice from the first evaporator successively through the others to the last. The first evaporator, because it contains the most dilute juice, will evaporate the largest number of pounds of water per hour. Evaporation from the succeeding evaporators will be at a lower rate per hour and in the final evaporator the evaporation will continue at the lowest rate of evaporation until the desired density has been attained. A sight glass 23' on each sump, as in Figure 5, will facilitate maintaining adequate levels in the units.

The water vapor evacuated from the evaporators through the pipe 26 is conducted to a large tubular condenser 35, the vapor surrounding the tubes while evaporation of the liquid refrigerant within the tubes will cause condensation of the water vapor. The water vapor condensate will be withdrawn by a pipe 36 into a tank 37 and pumped therefrom by a condensate pump 38. The sight glass 37' will enable the operator to make certain that the pump is always primed.

As there may be some uncondensable gases such as air in the water vapor, these gases will be withdrawn from the evaporator 35 through a pipe 39 by an ejector 40, of any suitable design.

Under the pressure maintained on the refrigerant gas during this operation, most of this gas will become condensed in the evaporators 11 to a liquid state, the latent heat of liquefaction of the refrigerant being transferred to the boiling juices. The refrigerant whether partially or wholly condensed will be withdrawn from each tube chest through a pipe 16 into a common header 41, thence through a water cooled condenser 42, pipe 42' and a liquid refrigerant cooler 43. Cooling water for the cooler and condenser are supplied by a pump 44 to the cooler 43 and through the interconnecting pipe 45 to the condenser 42, and is discharged through an outlet pipe 46.

The liquid refrigerant then flows through pipe 47 to a receiver 48. If desired the admission of the liquid refrigerant into the receiver 48 may be controlled by a float valve 49, although it may be controlled by some other valve which will serve to maintain pressure on the high pressure side of the system.

Liquid refrigerant from the receiver 48 is conducted through a pipe 50 to the bottom of the tubular evaporator 35, which is preferably of a common tubular chest construction, and allowed to flow upwardly through the vertical tubes therein which are sufficiently indicated by a partial sectional view of the tube chest. The evaporator 35 is referred to hereinafter in the claims as a condenser, in view of its important function of condensing the water vapor received from the product evaporators 11.

In the operation of this system for condensing citrus fruit juices such as orange juice, it is con-

templated that ammonia, if used as the refrigerant, will be compressed to about 205 lbs. gauge pressure with a superheat which may attain 180° F. The sensible heat in the gas will be utilized but most of the evaporation is performed by the latent heat of liquefaction of the gas. The refrigerant will condense at about 102° F. and emerge from the evaporators at about 102° F. Even though the cooling water available near an orange juice extraction plant may be as high as 80° F., it will be entirely practical to cool the refrigerant from 102° F. down to about 85° F. in the condenser and cooler.

The degree of cooling of the refrigerant and the total heat removed therefrom at this point is a matter for regulation in order to maintain uniform operating pressures and temperatures in the system. This control and an alternative control for the same general purpose will be described hereinafter.

Before bringing the liquid refrigerant into heat exchange relationship with the water vapors which are to be condensed, it is desirable to chill the refrigerant below the temperature of the vapor. In the process contemplated the juices will be evaporated at about 60° F., and in order to attain an adequate temperature differential in the condenser **35** between the water vapor and the liquid refrigerant the latter preferably may be cooled to about 50° F., by flashing off some of the refrigerant into the suction side of the refrigerant cycle, for example, in the receiver **48**. By maintaining the compressor suction pressure at about 75 pounds' gauge pressure the refrigerant will vaporize in the condenser at about 50° F.

Vaporized refrigerant will then be withdrawn from the space in the condenser above the upper end of the tubes through a pipe **51** into the receiver **48** and thence through a pipe **52** into a compressor **53** of any suitable construction from which it is then delivered to the pipe **17** for recirculation again through the evaporators.

Thus, briefly, the latent heat of vaporization of the refrigerant is supplied by the water vapor, thus condensing the latter, while the sensible heat and latent heat of liquefaction of the refrigerant vapor is transferred to the juices in the evaporator to boil the water therefrom. Through the use of a suitable ejector and a condensate pump and an evacuator pump for the concentrated juice, the high vacuum produced principally by the condensation of the water vapor, can be maintained in the evaporator and the condenser. It is found that a vacuum of about ½ to 1½ inches of mercury absolute may be maintained easily.

In a system such as is here described orange juice may be evaporated from an initial average density of about 11 Brix to about 44 Brix. It is contemplated that the concentrated juice may immediately thereafter be frozen or kept at a very low temperature and reconstituted later into a solution of normal density at which time it will be found to retain substantially all of its initial qualities both as to food value and flavor.

As an aid to the maintenance of natural flavor, I have found it desirable to concentrate the fruit juice, or particularly orange juice, to about 55 Brix, discharge it from the evaporator to a tank under atmospheric pressure, and before freezing it, dilute it with sufficient fresh orange juice to lower the density to about 44 Brix. The introduction of this proportion of fresh juice is found to impart a sufficient natural flavor to the entire body of concentrate. Subsequent freezing of the concentrated product, thus produced, does not at all impair the flavor.

It is obvious that the preservation of citrus fruit juices in this condensed form offers many advantages from the standpoint of storage and shipping costs.

The invention is not limited to the concentration of citrus fruit juices, but embraces the evaporation of other aqueous solutions, which may be advantageously concentrated in this manner.

Orange juice, as it comes from the presses, is preferably heated to kill ensymes or other constituents that might interfere with its preservation. As it also contains considerable air I prefer to introduce it through pipe **54** into a de-aerator **55**, and allow it to flow downwardly in a thin film over a spiral channel **56** and then fall into the bottom of tank **55** from which it will be withdrawn by pipe **34**. A vacuum pump **57** of any suitable construction will evacuate the air from the film of juice flowing over channel **56**. Thus foaming of the juice in the evaporators will be prevented and counterpressures due to excess air in the water vapor space in condenser **35** will be avoided.

It will be assumed that the usual accessories such as valves, pressure gauges and thermometers will be supplied throughout the apparatus so that uniformity of desirable operating conditions may be observed and regulated.

In Figures 7 and 8 I have shown a modified form of juice evaporator units, the modification being a substitution of a different vapor separation device at the bottom of the evaporator tubes, to cause the vapors to rotate about a vertical axis instead of a horizontal axis, as in Figure 5.

The upper ends of the tube chests **60** will be constructed in the same manner as are the upper ends of tube chests **11**. The lower ends of the tubes, however, do not open directly into the vapor separators. Instead, the vapors and unvaporized juice will flow from the bottom vapor space **60'** below the tube ends through the horizontal ducts **61** tangentially into the cylindrical separator units **62**, the liquid falling into the conical sumps **63** for recirculation through pipes **64**, pumps **65** and pipes **66** back again to the liquid space in the top of each evaporator.

The pipe **34'** corresponds in function to the pipe **34** of Figure 1, that is, for the entry into the system of the solution to be evaporated, while the pipes **29'** and **28'** correspond in function to the pipes **29** and **28** of Figure 1 for the flow of partially concentrated solution from the first evaporator sump to the second and from the second evaporator sump to the third.

The upper end of each separator is united as by welding to open fully and directly into the horizontal vapor evacuator duct **67**, which delivers the low temperature water vapor from each of the units to the condenser **35** through a pipe such as **26'**.

In this type of separator the vapors will therefore rotate about a vertical axis, while entrained droplets, if any, will be thrown centrifugally against the separator walls and fall into the sumps **63**.

The connections to the tube chests for entry and exit of the refrigerant are the same as in the preferred form, hence need no detailed description here except to mention that heating medium, for example the refrigerant gas, supplied from the compressor through a common supply pipe **17'** and individual inlet pipes such as **15'** is introduced into the space surrounding

the tubes in the tube chests 60, and the condensate from the heating medium is withdrawn from the bottom of such space through individual outlet pipes such as 16' connected to a common outlet duct 41'.

The supplying of liquid to be evaporated, the evacuation of the concentrated liquid product, the recirculation of the liquid in the two forms of evaporators will be the same, hence no further description of these features in connection with Figures 7 and 8 will be required here. Sight glasses are not shown in these two figures, but as in the first described embodiment, a sight glass such as 23' (Figure 5) will be installed on the sump of each evaporator and a sight glass such as 68 (Figure 4) will be installed above the upper tube sheet in each evaporator. For highest efficiency the tubes of each evaporator unit should be covered with liquid film their entire lengths, and the recirculating pumps for each unit may be variable to assure this condition in each unit.

It is contemplated that the evaporation methods and apparatus herein described will be operated on a continuous basis, and to be used successfully the operation should proceed without substantial variation in the temperatures and pressures maintained in various parts of the system. Heat exchange with variable temperatures in the surrounding atmosphere, and variations in the constituents of the liquid, such as orange juice, undergoing concentration will tend to alter the operating temperatures and pressures.

The amount of refrigerant which must be evaporated per hour in the water vapor condenser, under constant load conditions, is such that this same quantity of refrigerant will contain more total heat when it passes through the juice evaporators than is required for production of the predetermined water vapor load. This excess heat will be due largely to the heat of compression of the refrigerant. Unless this excess heat is constantly eliminated from the system the high side gas pressure will continuously rise and disrupt the operation of the system.

Accordingly for controlling the system to make it operate uniformly I provide two methods of control, and will employ whichever heat elimination method suits local plant conditions.

For example, in the vicinity of orange groves, if the water available for cooling is warmer than the water vapor I may elect to eliminate excess heat by means of such cooling water flowing through the condenser 42 and liquid cooler 43. In this instance I install a pressure regulated valve 70, of any well known design, such as a diaphragm controlled valve, in the water intake pipe 71 leading to pump 44. A pipe 72, containing a fluid suitable for transmission of the regulating pressure, will connect this valve to the housing 73 which contains a diaphragm whose upper side is subject to pressure variations in the high pressure refrigerant gas line 15. Thus the rate of water flow, and hence heat discharge, will be controlled by the pressure of the compressed gas. If the heat load in the refrigerant should start to built up the pressure in the line 17, this increasing pressure, transmitted through the pipe 72 to the pressure regulated valve 70, would cause the valve to open a little wider and thus admit a higher rate of water flow into the condenser 42 and the liquid cooler 43. The increased volume of water flowing through the condenser and cooler would thus absorb more of the heat from the refrigerant, thus reducing the total heat carried by the refrigerant and reducing its pressure when it is delivered compressed into the refrigerant pipe 17, and as the refrigerant gas pressure in pipe 17 drops back again to the desired normal the valve 70 will gradually cut down the water flow, automatically maintaining the balance or normal pressure condition desired.

The details of construction of the valve 70 do not form a part of this invention, it being assumed that valves of this type are so well known in industry that they may readily be procured from a number of well known manufacturers, so that detailed description thereof is not needed here. No difficulty will exist in obtaining a valve which will be further opened by an increase in pressure on its associated diaphragm and will tend to close as pressure on the diaphragm decreases.

In the event that water available for cooling at the plant is colder than the water vapor temperature I may use the other method for eliminating excess heat from the system. In this latter instance I may install the condenser shown in Figure 9, connecting it to condenser 35 in place of the ejector 40 shown in Figure 1. The pipe 74 will be connected to the upper end of the water vapor space, in place of pipe 39 and will admit water vapor into the condensing chamber 75. A housing 76 containing a diaphragm will be connected to the compressed gas line 17 and its diaphragm, subject to the pressure in the gas line, will transmit pressure variations through pipe 77 to a diaphragm controlled valve 78 positioned in the water supply line 79 which delivers water to the condenser 75. Water spilling over the weir 80 and falling down over the splash plates 81 will condense the water vapor and be discharged through a barometric leg 82. A high pressure steam jet 83 will eject non-condensable gases through ejector 84.

Pressure in the compressed gas line will determine and regulate the amount of water vapor condensed in this manner. The liquid refrigerant evaporating in the condenser 35 will therefore have a constant condensing load, less than the total vapor received from the evaporators by the amount condensed in condenser 75. The amount of refrigerant evaporated, compressed and delivered into the pipe 17 is thus regulated to produce enough compressed gas at the predetermined desired pressure to accomplish a uniform amount of evaporation per hour. The water vapor and refrigerant temperatures and pressures may thus be kept uniform. This control method, of course, contemplates that pre-cooling of the refrigerant liquid before entry into condenser 35 will be accomplished, as heretofore explained by the flashing off to the suction side of the compressor of enough refrigerant to effect the desired pre-cooling.

The juice evaporator units disclosed herein are claimed in my co-pending application Serial No. 695,641 filed September 9, 1946, wherein substantially the same units are shown. Reference may also be made to my other co-pending applications Serial No. 554,015, filed September 14, 1944, now Patent No. 2,554,138; Serial No. 695,642, filed September 9, 1946, and Serial No. 716,581, filed December 16, 1946.

While I have herein described a preferred manner of practicing the invention and have described it in detail as applied to the concentrating of orange juice it should be understood that the invention is not limited to such details or such material, but is capable of considerable variation

and modification, within the scope of the appended claims.

I claim as my invention:

1. A continuous process for evaporating a heat-sensitive water-containing solution under vacuum at relatively low temperatures comprising utilizing the latent heat contained in a compressed refrigerant gas for boiling the solution to extract water vapor therefrom, liquifying and cooling the refrigerant to a temperature substantially below the temperature of the water vapor, continuously discharging from the system sufficient of the heat extracted from the refrigerant during said cooling to maintain uniform temperatures and pressures in the system, condensing the water vapor to produce a vacuum on the boiling solution by vaporizing the cooled liquid refrigerant in heat exchange relationship with the water vapor, recompressing the vaporized refrigerant for recycling through the system, and continuously adding fresh solution and separately discharging from the system the condensed water vapor and concentrated solution in a controlled manner to maintain the vacuum on the evaporating solution.

2. A continuous process for concentrating citrus fruit juices within a low temperature range comprising compressing a refrigerant gas to its liquefaction pressure at a temperature substantially above the desired evaporating temperature for the juice, utilizing said compressed refrigerant gas in a first heat exchanger for evaporating the juice at a temperature substantially below the gas liquefaction temperature, liquifying and cooling the refrigerant to a temperature substantially below the temperature of the water vapor boiled out of the juice in said heat exchanger, introducing said cooled liquid refrigerant and said water vapor into a second heat exchanger in heat exchanging relationship to evaporate the liquid refrigerant and to condense the water vapor, recompressing the refrigerant gas and reusing it in the same cycle, maintaining the water vapor space in the second heat exchanger in communication with the water vapor space in the first heat exchanger to thereby impress a high vacuum upon the boiling juice in the first heat exchanger, continuously supplying fresh juice to the first heat exchanger, continuously discharging the condensed water vapor and any non-condensable gases associated therewith from the second heat exchanger, continuously evacuating the concentrated juice from the first heat exchanger.

3. A method of concentrating citrus fruit juices at relatively low temperatures comprising compressing a refrigerant gas to a high enough pressure to be condensable at a temperature substantially above the desired fruit juice evaporating temperature, condensing the major portion of the compressed gas by transferring its sensible and latent heat to the juice in a first heat exchanger while simultaneously boiling water vapor from the juice, conducting the water vapor to a second heat exchanger, cooling the liquified refrigerant to a temperature substantially below the temperature of the water vapor, re-evaporating the cooled refrigerant in the second heat exchanger in heat exchange relation with the water vapor thereby simultaneously condensing the water vapor, recompressing the refrigerant gas and recirculating it through the same cycle, continuously supplying fresh juice to the first heat exchanger and evacuating the condensed water vapor from the second exchanger and the concentrated juice from the first exchanger to maintain a high vacuum in both exchangers within the space occupied by the juice and water vapor.

4. A continuous process for evaporating a solution under vacuum at low temperature comprising continuously flowing the solution through a series of successively connected evaporators in which the dilute solution enters the first of the series and attains successively higher concentrations in the succeeding evaporators until withdrawn from the last evaporator, repeatedly recirculating the solution in each evaporator under flow conditions which provide a thin layer of the solution on the heat exchange surfaces, utilizing the latent heat in a compressed refrigerant gas to supply the heat to said evaporators for boiling the solution in said layers and thereby condensing substantially all of the refrigerant gas so employed, subsequently cooling the liquid refrigerant to a temperature below that of the vapor derived from said evaporators, employing the vapors to supply the latent heat in a condenser for evaporating the liquid refrigerant and thereby condensing the vapors, recompressing the refrigerant gas and recycling it back through the evaporators, discharging the vapor condensate from the system, and during said cooling of the refrigerant continuously extracting a portion of the heat carried by the refrigerant and discharging it from the system to maintain substantially an unvarying compression load and temperature and pressure conditions in the evaporators and vapor condenser.

5. A continuous low temperature evaporation process comprising recirculating a solution under vacuum in film formation over each of a plurality of separated heat exchange surfaces and progressively thereover while increasing the concentration of the films, evaporating the films principally by means of transfer thereto of the heat of liquefaction of a compressed refrigerant vapor supplied at the same pressure to all of said surfaces, condensing the vapor derived from the films and evaporating the liquefied refrigerant by heat transfer therebetween in a condenser, recompressing the refrigerant vapor for re-use in the aforesaid evaporation of said films on said heat exchange surfaces, evacuating from the process both the condensed vapor derived from the solution, and the concentrated solution, continuously adding fresh solution to the process, and continuously discharging regulatably from the process sufficient heat resulting from the compression of the refrigerant to maintain substantially unvarying operating refrigerant pressures in the process.

6. A continuous process for evaporating an aqueous solution under vacuum at low temperature comprising continuously adding fresh solution and flowing the solution during progressive concentration under vacuum through a heat exchange apparatus in which the solution is maintained on one side of the heat exchange surfaces in heat exchange relation at substantially no hydrostatic pressure with a condensable refrigerant gas on the opposite side of the heat exchange surfaces, the latter being maintained at a pressure which makes it condensable at a temperature substantially above the temperature at which water evaporates from the solution under the existing vacuum on the solution, thereby utilizing the latent heat of liquefaction of the refrigerant to supply the latent heat of vaporization of the water, continuously discharging solu-

tion having a desired concentration, cooling the condensed refrigerant to a temperature lower than that of the water vapor, and condensing the water vapor to provide a vacuum upon the evaporating solution by conducting the water vapor through a condenser in heat exchange relation with the cooled liquid refrigerant to thereby evaporate the refrigerant, recompressing the refrigerant gas and recycling it back to said heat exchange apparatus.

7. A continuous process for evaporating a solution under vacuum at low temperature comprising continuously introducing fresh solution into the process and repeatedly flowing the solution under vacuum in film formation at substantially no hydrostatic pressure into heat exchange relationship with a condensable refrigerant gas, the latter being maintained at a pressure which makes it condensable at a temperature substantially above the temperature at which vapor evaporates from the solution thereby utilizing the latent heat of liquefaction of the refrigerant as the refrigerant condenses to supply the latent heat for vaporization of the solution, progressively increasing the concentration of the solution as it moves to a discharge port, continuously discharging the concentrated solution, cooling the condensed refrigerant to a temperature lower than that of the vapor, condensing the vapor by heat exchange with the cooled refrigerant thereby imposing a vacuum upon the evaporating solution and evaporating the refrigerant, recompressing the refrigerant gas and recycling it back for further heat exchange with the solution, discharging the vapor condensate, and during said cooling of the refrigerant continuously extracting under control of the pressure of the compressed refrigerant gas regulatably from the refrigerant and discharging from the system sufficient heat to maintain in the system a substantially unvarying compression load and unvarying temperature and pressure conditions in the evaporation and condensing portions of the process.

8. A continuous low temperature evaporation process comprising continuously introducing an aqueous solution into the process and flowing it under vacuum from its dilute stage to its concentrated stage over a series of separated heat exchange surfaces whereon films of the solution at successively higher concentrations on successive heat exchange surfaces are maintained at a hydrostatic head not substantially greater than the vapor pressure thereon, evaporating water from the films by transfer to the films of the latent heat of liquefaction of a compressed refrigerant gas in heat exchange relationship therewith under such compression as to be condensable at a temperature above the vaporization temperature of the water, subsequently cooling the condensed refrigerant to lower than the water vapor temperature, employing the water vapor to evaporate in a condenser the cooled liquid refrigerant while simultaneously condensing the water vapor, recompressing the resultant refrigerant vapor for re-use in heat exchange with said films for further evaporation of the latter, evacuating the condensed water vapor and concentrated solution from the process, and regulatably discharging from the process sufficient of the heat added to the process by compression of the refrigerant to maintain substantially unvarying operating pressure in the process.

9. An evaporation process comprising continuously introducing a dilute solution into the first of a series of progressively connected heat exchangers, continuing the flow of progressively concentrated solution through the series and withdrawing it at a desired concentration from the last exchanger in the series, supplying heat simultaneously to all said exchangers from a common supply of compressed refrigerant gas condensable under a regulated pressure at a temperature above the boiling temperature of the solution, evacuating the condensed refrigerant and cooling it to lower than the temperature of the vapor boiled from the solution, continuously evaporating the cooled refrigerant in a condenser by heat derived from said vapor while condensing said vapor, evacuating the vapor condensate from the process, re-compressing the vaporized refrigerant to said regulated pressure for recycling through the heat exchanger, and during said cooling of the refrigerant continuously discharging from the process a portion of the heat carried by the refrigerant to maintain substantially unvarying compression load and temperature and pressure conditions in the heat exchanger and condenser.

10. A continuous low temperature evaporation process comprising continuously adding and flowing a solution under vacuum in exposed films of successively higher concentrations over successive heat exchange surfaces, evaporating said films principally by the heat of liquefaction of a refrigerant vapor under such compression on the sides of the heat exchange surfaces opposite said films as to be condensable at a temperature above the desired vaporization temperature of the water in said solution, cooling the liquified refrigerant to lower than the water vapor temperature, eliminating from recirculation in the process sufficient of the heat of compression of the refrigerant to maintain uniform operating conditions in the process, employing the water vapor to evaporate the liquified refrigerant in a condenser while simultaneously condensing the water vapor, re-compressing the refrigerant for re-use in the process, and continuously evacuating the condensed water vapor and the solution at a desired concentration.

11. An evaporation process comprising maintaining a continuous flow of an aqueous solution at progressively higher concentrations to a point of discharge through a series of progressively connected evaporators, recirculating a body of the solution under vacuum repeatedly in each evaporator, maintaining the bulk of the solution in each evaporator when contacting a heat exchange surface at substantially the same hydrostatic head as the vapor pressure thereon, employing the latent heat of a compressed refrigerant gas condensable at a temperature above the boiling temperature of the solution in each evaporator for vaporizing water from said solutions while thereby condensing said refrigerant, withdrawing the condensed refrigerant and water vapor separately from said evaporators, cooling the liquid refrigerant to less than the water vapor temperature, employing the latent heat of the water vapor in a condenser to boil the refrigerant while thereby condensing the water vapor and maintaining a high vacuum on the solution in the evaporators, re-compressing the refrigerant gas and recirculating it back to said evaporators, removing the water vapor condensate under vacuum from the system, and continuously discharging from the system a portion of the heat carried by the refrigerant to maintain a substantially unvarying compression load and

temperature and pressure conditions in the condenser and evaporators.

12. A low temperature continuous evaporation process for evaporating water from an aqueous solution comprising continuously adding fresh solution and flowing the solution under vacuum through a series of successively connected evaporators, causing the solution to flow as films in the evaporators while heating the film principally by means of the heat of liquefaction of a refrigerant gas in heat exchange relationship with the films, supplying said refrigerant gas from a common source at a common pressure enabling the gas to condense at a temperature above the vaporizing temperature of the water in said solution films, cooling the refrigerant regulatably after condensation and continuously and regulatably discharging from the process sufficient of the heat extracted from the refrigerant during said cooling to maintain uniform operating pressures in the process, maintaining the vacuum on said solution by condensing the water vapor in heat exchange with the cooled refrigerant while thus causing the latter to be re-evaporated, re-compressing the refrigerant gas and re-using the compressed gas in further heat exchange with said films, and continuously discharging from the process the water vapor condensate and the concentrated solution.

13. Apparatus for dehydrating fruit juices at low temperatures comprising a refrigerant gas compressor, an evaporator, means for introducing the compressed refrigerant gas into said evaporator and means for withdrawing it therefrom in liquid state, means for continuously introducing dilute juice into said evaporator and means for withdrawing concentrated juice therefrom, a water vapor condenser having a condensing chamber communicating with the juice space in said evaporator, means for cooling the liquid refrigerant to a temperature below the temperature of the water vapor, means for regulatably introducing pre-cooled liquid refrigerant into said water vapor condenser in heat exchanging relationship with the water vapor therein, means connecting the compressor with the refrigerant vapor space in said condenser, said refrigerant cooling means including means controlled by the pressure of the compressed refrigerant for regulatably extracting from the refrigerant and discharging from the system sufficient heat to maintain substantially uniform operating conditions in the apparatus.

14. A low temperature evaporation apparatus comprising a series of successively connected falling film evaporators, means for causing a falling film flow of an aqueous solution on the insides of the evaporator tubes, means for supplying a condensable refrigerant gas to the tube chest of each evaporator at a pressure sufficient to enable the refrigerant gas to condense at temperatures above the vaporization temperature of the aqueous solution, means for conducting the unvaporized solution from the bottom of each evaporator to the next succeeding evaporator for circulation through the tubes thereof and from the last evaporator in the series to a point of discharge, a condenser, means for conducting the condensed refrigerant from the evaporators to said condenser, means controlled by the pressure of the compressed refrigerant for partially cooling the condensed refrigerant enroute to said condenser and for discharging from the system the heat added to the refrigerant during compression, means for further cooling the partially cooled liquid refrigerant to lower than the water vapor temperature, means for conducting the water vapor from the evaporators into heat exchange relation with the cooled liquid refrigerant in the condenser, means for recompressing the vaporized refrigerant for return to the evaporators, and means for discharging the condensed water vapor under vacuum from the system.

15. Apparatus for concentrating an aqueous solution under vacuum at low temperature comprising a compressor arranged to compress a refrigerant gas to a pressure whereby it is condensable at a temperature above the desired evaporating temperature of the solution, an evaporator having heat exchange surfaces, means for controllably flowing the solution in film formation at successively higher concentrations over said surfaces, means for evacuating solution of a desired concentration from the evaporator, means for introducing the compressed refrigerant gas into said evaporator, means for withdrawing condensed refrigerant from said evaporator, means for partially cooling the condensed refrigerant, means for further cooling the condensed refrigerant to lower than the water vapor temperature, a condenser, means connecting the condenser and evaporator to conduct water vapor from the evaporator to the condenser, means for introducing the cooled liquid refrigerant into said condenser for condensing said vapor and evaporating the refrigerant, and means for evacuating the condensed vapor, said partial cooling means including controllable means for extracting from the refrigerant and means controlled by the compressed refrigerant for discharging from the apparatus sufficient of the heat created by compression of the refrigerant to maintain uniform operating conditions in the apparatus.

16. A process for concentrating an aqueous solution under high vacuum at low temperature comprising employing the latent heat in a compressed refrigerant gas condensable above the desired evaporating temperature of the solution for evaporating water from the solution, partially cooling the refrigerant condensed during evaporation of the solution and discharging from the process the heat thus extracted to maintain uniform temperature and pressure conditions in the process, further cooling the liquid refrigerant to a temperature lower than the water vapor temperature by flashing off a portion of the refrigerant to the suction side of the refrigerant cycle, employing the water vapor for evaporating in a condenser the said further cooled refrigerant, and compressing all of the vaporized refrigerant for re-use in the process.

17. A process for concentrating orange juice comprising subjecting the juice to a vacuum to extract air therefrom and discharging the air, continuously introducing the de-aerated juice into the first of a series of vertical tubular evaporator units, recirculating a body of the juice repeatedly through the first unit in a manner to cause a downward film flow through each tube thereof, continuously diverting a stream of partially concentrated juice into the next unit and recirculating it therethrough in the same manner, repeating said diversion and recirculation in the remainder of said units until a desired concentration is attained in the last unit, continuously withdrawing concentrated juice from the last unit, supplying to the tube chest of each unit from a common supply source a compressed re-

frigerant gas maintained at such a uniform predetermined pressure as can be condensible at a temperature above the desired evaporating temperature for the juice, conducting the water vapor from the juice to a condenser therefor, withdrawing from all of the evaporator units the condensed refrigerant and cooling it to less than the water vapor temperature, vaporizing the cooled liquid refrigerant in said condenser in heat exchange relation with said vapor to condense the latter at a rate effective to impose a high vacuum on the vapor space in said evaporators, recompressing the vaporized refrigerant for return to said supply source, and continuously discharging from the system sufficient heat extracted from the refrigerant during said cooling of the refrigerant to facilitate uniform operation of the compressor and uniform flow of the juice.

18. A process for concentrating an aqueous solution under vacuum comprising employing the latent heat in a compressed refrigerant gas condensable above the desired evaporating temperature of the solution for evaporating water from the solution while simultaneously liquefying the refrigerant, conducting the water vapor to a condenser therefor, cooling the condensed refrigerant, segregating a body of the cooled liquefied refrigerant out of heat exchange relationship with the solution and further cooling the segregated refrigerant to less than the water vapor temperature by vaporizing a portion of said body to chill the remainder of said body, effecting heat exchange between the cooled refrigerant and the water vapor to vaporize the refrigerant, to condense the water vapor and to impose a vacuum upon the vaporizing solution, compressing the vaporized refrigerant for re-use in evaporation of the solution, continuously supplying fresh solution to the process, continuously discharging from the process condensed water vapor and concentrated solution, and continuously discharging from the process under control of the pressure of the compressed gas, of sufficient of the heat of compression of the gas to maintain a uniform pressure on the compressed gas to facilitate uniform compressor output.

19. A continuous process for concentrating an aqueous solution under vacuum comprising employing the latent heat in a compressed refrigerant gas condensable above the desired evaporating temperature of the solution for evaporating water from the solution while simultaneously liquefying the refrigerant, conducting the water vapor to a condenser therefor, sub-cooling the liquid refrigerant to less than the water vapor temperature by vaporizing a portion of a body of it to chill the remainder of said body, effecting heat exchange between the sub-cooled liquid refrigerant and the water vapor to vaporize the refrigerant, to condense the water vapor and to thus impose a vacuum upon the vaporizing solution, discharging from the process the water vapor thus condensed, compressing the vaporized refrigerant for re-use in evaporation of said solution, continuously and regulatably under control of the pressure of the compressed gas discharging from the process a quantity of heat, extracted from a portion of the water vapor by direct condensing in a stream of cooling water, which heat otherwise would be re-cycled in the refrigerant, to maintain a uniform pressure on the compressed gas to facilitate uniform compressor output, and continuously supplying fresh solution to the process and withdrawing concentrated solution therefrom.

20. A continuous process for evaporating a volatile liquid from a solution under vacuum comprising continuously adding fresh solution to the process and effecting heat exchange between a compressed refrigerant gas and the solution to vaporize said liquid and liquefy the gas, sub-cooling the liquefied refrigerant to lower than the vapor temperature, effecting heat exchange between the sub-cooled refrigerant and the vapor to vaporize the refrigerant and condense the vapor and to impose a vacuum on the boiling solution, recompressing the vaporized refrigerant for re-use in boiling further solution, continuously discharging separately the condensed vapor and the concentrated solution, and regulatably under control of the pressure of said compressed gas discharging continuously from the process sufficient of the heat, which otherwise would be re-cycled in the refrigerant, to maintain at substantially constant compressor output a uniform compressor output pressure.

21. A continuous process for evaporating an aqueous solution under vacuum comprising effecting heat exchange between the solution and refrigerant from a common supply of a compressed refrigerant gas to vaporize the solution and liquefy the gas, the solution undergoing evaporation being maintained in separate bodies of successively higher concentrations but interconnected to maintain them under a common vacuum, sub-cooling the liquefied refrigerant to lower than the water vapor temperature, effecting heat exchange between the sub-cooled refrigerant and the water vapor to vaporize the refrigerant and condense the water vapor to impose a vacuum on the boiling solution, recompressing the vaporized refrigerant for re-use in boiling further solution, continuously adding fresh solution to the process and continuously discharging the vapor condensate and concentrated solution, and regulatably under control of the pressure on said compressed gas discharging continuously from the process sufficient of the heat which otherwise would be re-cycled in the refrigerant to maintain at substantially constant compressor output a uniform compressor output pressure.

22. A continuous method of concentrating fruit juices at relatively low temperatures to avoid injury to heat sensitive materials therein, comprising compressing a refrigerant gas circulating in a closed cycle to such a pressure that its liquefaction temperature is substantially above the desired evaporation temperature for the fruit juices, continuously circulating the compressed gas in heat-exchanging relationship with the juice to effect the desired concentration of the juice, withdrawing the refrigerant from said heat-exchanging relationship largely in liquid condition and cooling and condensing the refrigerant to liquefy all of it, regulating said cooling of the refrigerant and discharging from the cycle sufficient of the heat carried by the refrigerant as to maintain continuously substantially uniform temperatures and pressures on the refrigerant in both the high and low pressure sides of the cycle, further cooling the liquid refrigerant to a temperature substantially below the temperature of the water vapor boiled from the juices, condensing said water vapor by heat exchange with said pre-cooled refrigerant and thus imposing a high vacuum on the boiling juice, while at the same time evaporating the pre-cooled liquid refrigerant, recompressing the vaporized re-

frigerant and returning it through the cycle, discharging the condensate, and continuously adding fresh juice to and withdrawing concentrated juice from the process.

23. A continuous process for evaporating a volatile liquid from a solution under vacuum comprising continuously adding fresh solution to the process and effecting heat exchange between a compressed refrigerant gas and the solution to vaporize said liquid and to liquify the gas, sub-cooling the liquid refrigerant to lower than the vapor temperature, effecting heat exchange between the sub-cooled refrigerant and the vapor to vaporize the refrigerant and to condense the vapor and to impose a vacuum on the boiling solution, recompressing the vaporized refrigerant for re-use in boiling further solution, continously discharging the vapor condensate and the solution concentrate separately from the process, and regulatably discharging from the process continuously sufficient of the heat added thereto by compression of the refrigerant, to maintain a uniform pressure on the compressed gas to facilitate uniform operation of the process.

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