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EVAPORATING APPARATUS AND METHOD

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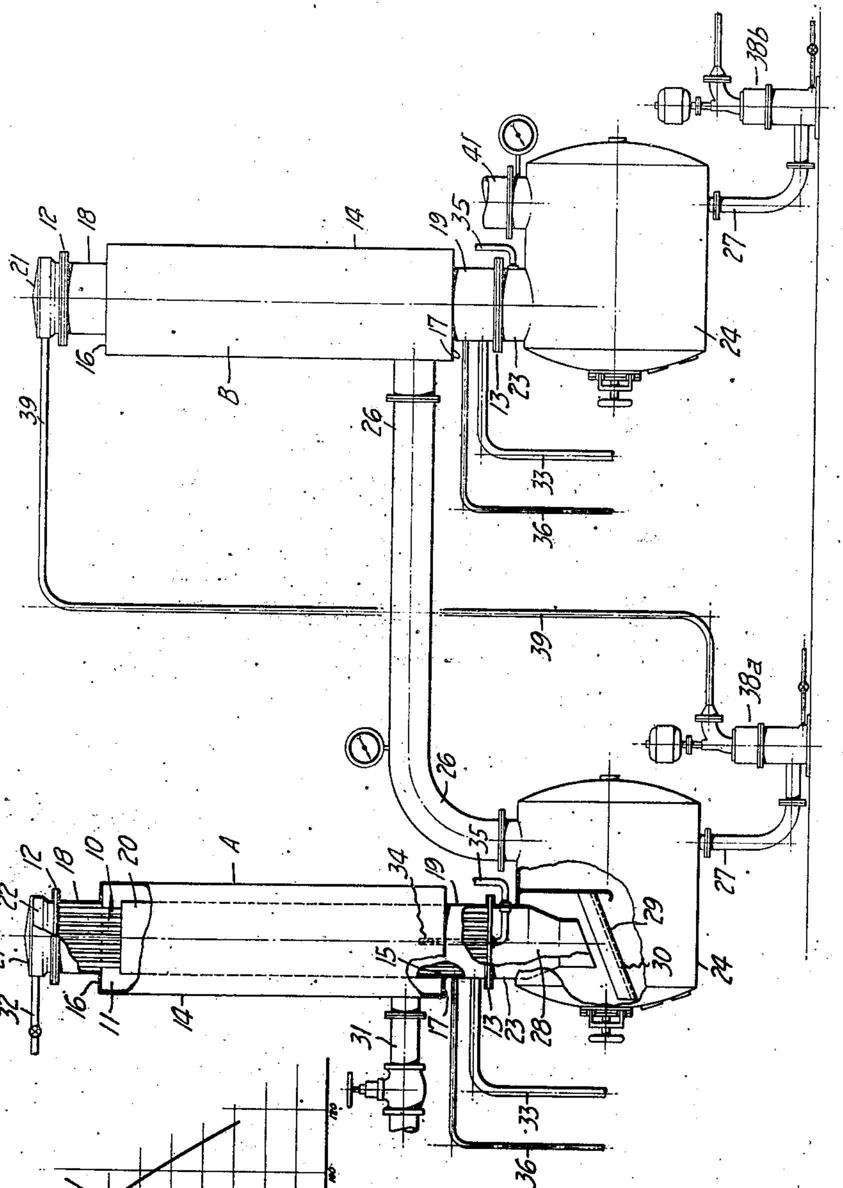

FIG. 1

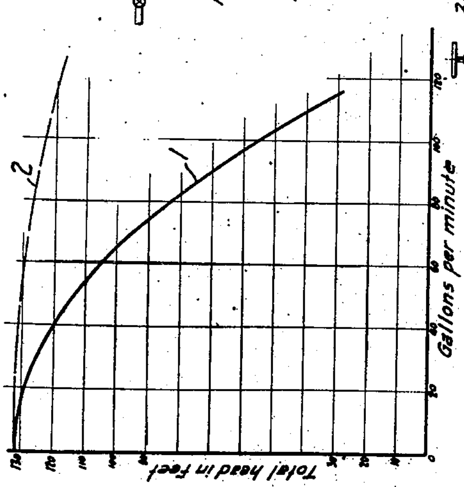

FIG. 2

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EVAPORATING APPARATUS AND METHOD

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This invention relates generally to apparatus and methods for the concentration of various liquid materials containing one or more vaporizable components. It has particular application where the liquid material to be evaporated contains organic ingredients, such as milk or milk products, fruit juices, and the like.

It is an object of the invention to provide an apparatus and method of the above character which will be characterized by relatively high thermodynamic efficiency and utmost simplicity.

Another object of the invention is to provide an evaporator of the "vapor-mist" type, which will have inherent stability and which will avoid tendency towards the formation of incrustations.

A further object of the invention is to provide an apparatus and method for the efficient evaporation of liquids which are apt to be detrimentally affected by prolonged heating. In this connection the invention is characterized by the fact that for a given instant of operation a comparatively small amount of liquid being concentrated is within the system. A further characteristic is that generally a single pass through the system is sufficient to provide the concentration desired.

Further objects of the invention will appear from the following description in which the preferred embodiment of the invention has been set forth in detail in conjunction with the accompanying drawing.

Referring to the drawing:

Fig. 1 is a side elevational view showing a double effect evaporating apparatus incorporating the present invention.

Fig. 2 is a curve showing characteristics of the type of pump which is employed to remove liquid from such effect.

While Fig. 1 shows a double effect evaporating apparatus, it is to be understood that certain features of the invention may be incorporated in a single effect, or in a greater number of effects or stages if desired. The two effects, as shown in the drawing, have been identified by letters A and B and are illustrated as being duplicates. Each effect consists of a plurality of evaporating tubes 10 which are suitably jacketed to form a space 11 for steam or vapor. Referring to the first effect, the upper and lower ends of tubes 10 are shown connected to the upper and lower tube sheets 12 and 13, thereby forming flow paths through the tubes for vapor and liquid material being evaporated. In order that the jacket forming space 11 may accommodate unequal expansion and contraction, it is shown formed of a shell 14 secured to the end walls 16 and 17. The inner peripheral margins of end walls 16 and 17 are in turn secured to the extensions 18 and 19, which carry the tube sheets 12 and 13. Within the jacket 14 the tubes 10 are shrouded by a casing 20, the upper end of which terminates short of the end wall 16, and the lower end of which forms the extension 19. Immediately above end wall 17, casing 20 is provided, with openings 15 for drainage of condensate.

Enclosing the upper side of tube sheet 12 there is a head 21, serving to form an inflow chamber 22. Enclosing the space below the lower tube sheet 13 there is a conduit 23, which serves to deliver vapor and liquid material into the collector 24. This collector is shown in the form of a drum of adequate size, having a vapor outflow conduit 26 and a lower liquid outflow conduit 27.

Although it is possible to deliver flow from conduit 26 into an external apparatus for separating liquid from vapor, having a pipe connection for draining liquid back into the collector 24, it is usually more expedient to provide adequate separating means in the collector itself. In the construction illustrated, an inner straight or tapered boot 28 forms the discharge for conduit 23, and the discharge opening thus afforded is arranged above an inclined separating shelf or entrainment tray 29. Tray 29 is provided with spaced ribs or vanes 30, to promote efficient separation of entrained liquid from vapor, whereby liquid so separated out is caused to drain down the tray 29 into the lower portion of the collector 24.

The space 11 surrounding the tubes 10 is connected to a source of steam or like fluid source of heat by conduit 31, while the chamber 22 above tube sheets 12 is supplied with liquid material being concentrated through pipe 32. Because of the provision of casing 20, vapor flow occurs upwardly between shell 14 and casing 20, inwardly over the upper end of casing 20, and then downwardly through the space occupied by the tubes 10. Thus vapor is effectively distributed into contact with the tubes, and dead pockets or areas are avoided. Condensate formed from the steam introduced into space 11 may drain into the lower extension 19, and can be removed at a point adjacent the lower tube sheet 13 through pipe 33. In order to effect removal of non-condensable constituents, such as air, which may find their way into space 11, an upstanding pipe 34 is shown. This pipe extends upwardly through the center of tube sheet 13, with its inner portion perforated for communication with the steam space. Externally, pipe 34 connects to a pipe 35 which leads to suitable evacuating means. The steam space also connects with a pipe 36, serving as a vent for the condensate pump.

In making connections between two effects, a pump 38*a* has its inlet connected to the liquid pipe 27 of the first effect, and its discharge line 39 connected to the head 21 of the second effect. Pump 38*b* in turn receives liquid from the second effect for final discharge or for delivery to a further stage. As will be presently explained, these pumps preferably have particular characteristics, to effect inherent control. The vapor removal conduit 26 from the first effect connects to the steam space for effect B, and the corresponding conduit 41 for the second effect leads to a suitable vacuum condenser, such as one of the water jet type. Condensate pipes 33 for both effects may lead to suitable condensate pumps, which are vented through pipes 36, while pipes 35 may connect to the jet condenser or to an air pump, to exhaust non-condensables.

In operating a type of evaporating apparatus as described above, with pumps 38*a* and 38*b* having conventional characteristics, difficulty is encountered in securing a degree of automatic regulation to avoid constant and careful manual attention. Manual control of the various flow rates is difficult in that variations from optimum conditions are difficult to detect, and therefore variations of such a degree may be permitted as to cause injury to the material being evaporated, inefficient operation, or incrustation of the evaporating tubes. In this connection we have found that when operating under optimum conditions the tendency towards formation of incrustations on the inner walls of the evaporating tubes is reduced to a minimum, thus avoiding frequent shut-downs for cleaning out the apparatus. Such difficulties are accentuated when operating at high vacuums with liquids near boiling point.

In the present apparatus, inherent control is obtained by the use of pumps 38*a* and 38*b*, having characteristics differing from conventional construction. In general, each of these pumps has a head capacity curve which falls off rapidly with an increase in the pumping rate. Thus, referring to Fig. 3, a head capacity curve 1 for a centrifugal pump such as will give good results has been plotted between total head and pumping capacity in gallons per minute. This curve, which is for a given speed of operation, shows that the pumping rate is quite sensitive to changes in head. The characteristics of such a pump will be more fully appreciated by comparing curve 1 with curve 2, which is relatively flat-topped and which is typical of the usual pump of the centrifugal type.

The significance to be attached to the use of centrifugal pumps 38*a* and 38*b* having decidedly drooping head capacity curves, can be briefly explained as follows. These pumps are mounted below the respective collectors 24, so that they are primed by gravity liquid flow through the pipe lines 27. Under normal operating conditions, the level of liquid in a line 27 is below the corresponding collector 24, but flows by gravity to the inlet of pump 38*a*. Assuming that the rate with which liquid material is received by collector 24 decreases, there will be a corresponding fall in the level of liquid in line 27, with a corresponding decrease in the gravity head feeding pump 38*a*. Since this pump, because of its drooping head capacity curve, is sensitive to a change in inflow head, its pumping rate will be immediately reduced, thus preventing a further drop of liquid level in line 27. Correspondingly, if the liquid level in line 27 rises, due to an increase in the amount of liquid material received by collector 24, pump 38*a* increases its pumping rate, so that at all times collector 24 is substantially entirely drained of liquid and the separated liquid is thus completely removed from the evaporator system as fast as it is separated from the vapor. Pump 38*b*, having similar characteristics, operates in substantially the same manner, to automatically compensate for varying amounts of liquid material received by collector 24, while at the same time maintaining the liquid level feeding pump 38*b* between such limits of variation as to avoid undue accumulation of liquid in the collector. Pumps of the type described are particularly sensitive in securing the automatic compensation desired when the collectors are maintained under conditions of vacuum, as is normally the case.

In order that the characteristics of pumps 38*a* and 38*b* may be utilized to best advantage, their inlet openings and the passages afforded by pipes 27 should be relatively large to offer a minimum of flow resistance and low liquid velocities, because the liquid is at or close to boiling point. It is also desirable to employ pumps having water-sealed glands or packing glands under pressure, in order to avoid drawing in of air.

Operation of the apparatus as a whole can now be outlined as follows:—Assuming that the liquid being evaporated is milk or a milk product, the milk is supplied to the first effect A at a substantially constant head and after being heated to a predetermined and controlled temperature. In the chamber 22 of effect A the pressure is somewhat less than the pressure corresponding to the boiling point of the liquid. Therefore a certain amount of vaporization of water immediately occurs, to form a mixed phase material of greatly increased volume. The release of vapor should not be pictured as forming separate layers of liquid and vapor in chamber 22, because the vapor formations occur spontaneously throughout the mass of liquid in the form of minute vapor bubbles, without an opportunity for stratification into separate layers or zones. The intermixed liquid and vapor from chamber 22 flows downwardly through tubes 10, where it receives further heat from the steam introduced into space 11. Further vaporization of water increases the ratio between liquid material and vapor, with an accompanying accelerated rate of flow down through the tubes, and with a discharge from the lower end of the tubes at a relatively high velocity. In terms of volume, the discharge from the lower end of the tubes is largely vapor, with the liquid material entrained in the vapor in the form of a mist. In the collector 24 the concentrated liquid material is separated from the vapor, with the vapor being delivered through conduit 26 to the second effect B, and with the concentrated material being drained through line 27 to the pump 38*a* for delivery to the head 21 of the second effect.

In the second effect B the process is repeated, there being, however, a lower pressure in chamber 22. Condensation of vapor from the receiver 24 of the first effect, in the second effect, serves to maintain a proper operating vacuum for the first effect, while a lower vacuum is maintained in the receiver **24** of the second effect by virtue of condensation of vapor removed through conduit **41** to the condenser.

The method utilized in the present invention should be distinguished from so-called "film evaporation" methods in which the inner surface of a heated tube is blanketed with a film of liquid. Under such conditions, vapor existing within the tube must be substantially saturated for practically the entire tube length. In accordance with our method, vapor at the inlet end of the tube is given a substantial amount of superheat, and this superheat is supported for the entire length of the tube. Likewise, for substantially the entire length of the tube the liquid is in the form of a mist, the individual particles of which travel at high velocity towards the discharge end through a region of continuously decreasing static pressure. Thus each increment of advancing movement of a liquid particle brings it into a region in which the pressure is reduced below the pressure corresponding to the boiling point of the particle, thereby causing the particle to evolve further vapor in attempting to establish a saturation equilibrium. Thus, the vapor at every point in the tube is in a condition of superheat with a continuous tendency toward establishment of equilibrium with respect to adjacent mist particles of liquid. In other words, because of the velocity of mist and vapor through the tube, accompanied by continuous transfer of heat through the walls of the tube and by the pressure gradient from one end of the tube to the other, unbalanced conditions are maintained to afford forced evaporation at a rapid rate.

The desired conditions cannot be maintained throughout the length of tubes **10** except with a passage which affords a substantial flow resistance at the velocities attained. Thus, in practice good results have been obtained by the use of tubes about 1¼" inside diameter, having a length of about 12 feet. In one installation having tubes of this character, the vapor velocity at the discharge ends of the tubes was about 120 feet per second for the first effect. The ratio of vapor to liquid (at the discharge ends) was such that the volume of vapor was about 930 times the volume of the liquid, and the liquid entering the head chamber **22** was at a temperature of about 16° F. higher than the boiling point corresponding to the pressure in the head chamber **22**. In the same installation and for the first effect, the pressure in the head chamber **22** was about 15 inches of mercury with a pressure of about 11.5 inches of mercury in the collector **24**. 150 tubes were employed in the first effect, with a rate of introduction of liquid into the head chamber **22** of about 0.177 cubic feet per second. The tubes represented a total volume of 15.3 cubic feet, or about 86.5 times the amount of liquid present. In the second effect, vapor velocity through the tubes is increased enormously, and in the example cited the rate of vapor discharge from the ends of the tubes was more than six times the comparable velocity for the first effect.

While the nature of the evaporating conditions should be clear from the foregoing, the effect obtained can also be likened to a flash evaporator in which the liquid, instead of flashing into an enlarged chamber, is flashed in an elongated restricted passage whereby the flashing into vapor occurs progressively throughout the length of the evaporating tube. Rapid passage of vapor through the evaporating tubes, at an ever-increasing rate, produces a condition of turbulence which promotes efficient heat transfer and vapor evolution from the liquid mist, and which is also conducive to a minimum amount of incrustation of the inner tube walls.

Superheat of vapor within the evaporating tubes is immediately dissipated as the vapor and entrained mist are discharged into the collectors **24**. However, such dissipation of superheat is accompanied by further evaporation of liquid.

Formation of mixed phase material, that is, a mixture of liquid and vapor, in the inflow chambers **22** of the effects, simplifies the problem of securing proper distribution of flow through the many parallel paths afforded by tubes **10**. If it were attempted to maintain chambers **22** filled with liquid without evaporation at this point, there would be a tendency for unequal flow through the tubes **10**. Therefore it would be necessary to provide flow regulating means to secure proper distribution, and the large volume of liquid present in the apparatus would be objectionable in that it would be difficult, if not impossible, to maintain a proper ratio between liquid and vapor in the evaporating tubes.

Aside from affording an inherent type of control such as has been previously described, pumps *38a* and *38b* make it possible to operate the apparatus with a minimum of liquid material being handled in the different effects at any one time. In handling organic liquid materials, such as milk or milk products, which are apt to be injured by heat treatment, this characteristic is an important advantage, since the time period during which the liquid material is subjected to evaporating action is minimized so that the rate of passage of each portion of the material through the evaporating system is substantially equal to the overall rate of passage of material through the system.

We claim:

1. In evaporating apparatus, a plurality of evaporating tubes, means for supplying heat to said tubes, means for introducing material to be evaporated into the inlet ends of said tubes, a collector serving to receive liquid material delivered from the discharge ends of said tubes, a liquid pump having a decidedly drooping head capacity curve, and an unobstructed gravity flow passage directly connecting the lowest portion of the collector to the inlet of the pump, whereby a variation in the liquid level on the inflow side of the pump serves to automatically vary the pumping rate.

2. In evaporating apparatus, a plurality of evaporating tubes, means for supplying heat to said tubes, means for introducing liquid material to be evaporated into the inlet ends of said tubes, a collector serving to receive vapor and liquid material delivered from the discharge ends of said tubes, a liquid pump having a decidedly drooping head capacity curve, and an unobstructed gravity flow passage directly connecting the lowest portion of said collector to the inlet of the pump, said pump being located at a level below the lower portion of said collector whereby a variation in liquid level on the inflow side of the pump serves to automatically vary the pumping rate.

3. In a multiple effect evaporating apparatus, at least two evaporating effects of the film type, each effect including a plurality of evaporating tubes, means for supplying heat to the tubes, and means for introducing liquid material to be evaporated into the inlet ends of the tubes, a

liquid collector associated with the first effect and adapted to receive liquid delivered from the discharge ends of the evaporating tubes, a liquid pump located at a level below the collector and having its inlet directly connected to the lowest portion of the collector, said pump having a decidedly drooping head capacity curve, and a pipe serving to connect the outlet side of the pump with the liquid introducing means of the second effect.

4. In a multiple effect evaporating apparatus, at least two evaporating effects, each effect including a plurality of evaporating tubes, means for supplying heat to said tubes, and a head forming an inflow chamber for feeding liquid material into the inlet ends of said tubes, a collector for each effect, each collector serving to receive liquid and vapor discharged from its associated evaporating tubes, a liquid pump associated with each of said collectors, each of said pumps being characterized by a drooping head capacity curve and having an unobstructed gravity flow passage directly connecting the lowest portion of the associated collector with its inlet, and a pipe serving to connect the discharge from the pump for the first effect to the head of the second effect.

5. A method of concentrating heat-sensitive organic liquid material by evaporation which comprises continuously converting a stream of said material into a mixture of vapor and liquid by subjecting it to a pressure below its vapor pressure, passing the mixture of vapor and liquid at high velocity through a heating zone whereby a further portion of the liquid material is evaporated, separating the liquid and vapor and substantially immediately and completely removing the separated liquid from the evaporating system as fast as it is separated from the vapor.

6. A method of concentrating heat-sensitive organic liquid material by evaporation which comprises continuously converting a stream of said material into a mixture of vapor and liquid by subjecting it to a pressure below its vapor pressure, passing the mixture of vapor and liquid at high velocity through a heating zone whereby a further portion of the liquid material is evaporated, separating the liquid and vapor and substantially immediately and completely removing the separated liquid from the evaporating system as fast as it is separated from the vapor so that the rate of passage of every portion of the material through the evaporating system is substantially equal to the overall rate of passage of material through the system.

7. A method of concentrating heat-sensitive organic liquids in multiple effect evaporators which comprises passing a stream of liquid into the first effect at a temperature above the boiling point corresponding to the pressure in the effect whereby the stream of liquid is converted by pressure drop evaporation into a high velocity stream of vapor and liquid, passing said stream of vapor and liquid through a heating zone in said effect whereby a further portion of the liquid is evaporated, separating the liquid and vapor leaving said heating zone and substantially immediately and completely conveying the separated liquid from the first effect into a successive effect whereby the liquid is passed through the evaporating system in a continuously flowing stream without any pools.

8. A method of concentrating heat-sensitive organic liquids in multiple effect evaporators which comprises passing a stream of liquid into the first effect at a temperature above the boiling point corresponding to the pressure in the effect whereby the stream of liquid is converted by pressure drop evaporation into a high velocity stream of vapor and liquid, passing said stream of vapor and liquid through a heating zone in said effect whereby a further portion of the liquid is evaporated, separating the liquid and vapor leaving said heating zone and substantially immediately and completely conveying the separated liquid from the first effect into a successive effect whereby the liquid is passed through the evaporating system in a continuously flowing stream without any pools so that the rate of passage of every portion of the material through the evaporating system is substantially equal to the overall rate of passage of material through the system.

9. In a method for the concentration of heat-sensitive organic liquid material by evaporation, the improvement which comprises passing a stream of the liquid and evolved vapor at high velocity through a heating zone, separating the liquid and vapor leaving said heating zone and substantially immediately and completely removing the separated liquid so that the rate of passage of every portion of the material through the evaporating system is substantially equal to the overall rate of passage of material through the system.

10. In a method for the concentration of heat-sensitive organic liquid material by evaporation, the improvement which comprises passing a stream of the liquid and evolved vapor at high velocity successively through a plurality of heating zones, separating the liquid and vapor leaving each of said heating zones, and substantially immediately and completely removing the separated liquid so that the rate of passage of every portion of the material through the evaporating system is substantially equal to the overall rate of passage of material through the system.

11. In a method for the concentration of heat-sensitive organic liquid material by evaporation, the improvement which comprises passing a stream of the liquid and evolved vapor at high velocity successively through a plurality of heating zones, separating the liquid and vapor leaving each of said heating zones under successively lower pressures, and substantially immediately and completely removing the separated liquid so that the rate of passage of every portion of the material through the evaporating system is substantially equal to the overall rate of passage of material through the system.

12. A method of concentrating heat sensitive organic liquid material which comprises continuously converting a stream of said material into a mixture of vapor and liquid by subjecting it to a pressure below its vapor pressure, passing the mixture of vapor and liquid at high velocity through a heating zone whereby a further portion of the liquid is evaporated, separating the liquid and vapor leaving the heating zone and substantially immediately and completely conveying the separated liquid into a successive heating zone as fast as it is separated from the vapor.

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