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BOILING APPARATUS FOR CONTINUOUS CRYSTALLIZATION AND METHOD OF OPERATING SAID APPARATUS

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8 Claims

ABSTRACT OF THE DISCLOSURE

An apparatus for continuous crystallization comprising an elongated, horizontal evaporating chamber having an increasing transverse section and an inclined bottom from one end to the other. A constant level bath of mother solution containing the growing crystals is heated by a longitudinal series of heating elements including heating surfaces which increase longitudinally and form, on one side of said chamber a series of vertical and transverse passages. The crystals in suspension in the bath advance longitudinally by gravity during their growth, while following a helical path with constant pitch.

DISCLOSURE

The process of crystallization by growth of seed crystals in a bath of solution has been the subject of numerous studies which have demonstrated that crystal growth is influenced by a great number of parameters which are difficult to control on an industrial scale so as to obtain a uniform rate of crystal growth for all crystals.

In the sugar industry, crystallization is generally carried out by boiling mother solution containing seed crystals in suspension, while continuously supplying feed solution so as to maintain a degree of supersaturation allowing progressive crystal growth. It is known that in order to obtain uniform crystals, the degree of supersaturation of the mother solution must be maintained while boiling, in the zone of supersaturation known as the metastable zone and in which existing crystals may grow rapidly but in which no new crystals can form. It is further not only necessary that crystal growth be effected with seed crystals having the same size but also that the duration and conditions of growth be as far as possible the same for all the crystals in order to obtain a uniform product. These conditions are however difficult to fulfill as the mother solution containing the crystals is generally agitated to a great extent while boiling thereby mixing crystals at different stages of growth with one another.

The boilers generally employed for crystallizing sugar generally operate discontinuously. As the syrup is supplied continuously in the sugar-refinery, discontinuous boiling requires the use of buffer tanks and waiting mixers before the separators. A further disadvantage of these discontinuous boilers is their relatively great bulk with respect to capacity. In addition, discontinuous operation requires regulating the different parameters which determine crystal growth while boiling. Thus for example, the heat supplied should be adapted at every instant to the increasing amount of mixture of crystals and mother solution present in the boiling apparatus. As the heating surface is constant, this regulation poses considerable problems.

Certain known boilers for crystallizing sugar comprise mechanical means for effecting forced circulation in the bath of mother solution to maintain uniform conditions therein as far as possible. It is well known that mechanical circulating devices pose considerable practical problems when used in a boiling apparatus, especially in a sugar-refinery boiler. It may be mentioned that, in this case, a motor with a speed-reducing gear, must be provided outside the boiler for driving a screw or propeller arranged in the bath of mother solution. Special packings are thus required for the driving shaft and these must be capable of functioning at the boiling temperature and of preventing the infiltration of any mother solution and hence the formation of crystals therein, in particular when cool, e.g., when boiling stops. In addition, especially when using a screw of great length, it is necessary to mount bearings within the boiler itself and this likewise creates problems. Besides the difficulties which are brought about by using packings and bearings operating at high temperature in the presence of viscous liquids, these mechanical means continuously conduct heat out of the boiler and considerable insulation problems must be solved in order to prevent formation of crystalline deposits on the agitating surfaces. Experience has shown in fact that mechanical circulating means are hardly suitable for use in boilers and in boilers used in sugar-refineries in particular.

A known apparatus for continuously crystallizing sugar comprises an elongated, substantially horizontal evaporating chamber subdivided into a longitudinal series of communicating compartments equipped with heating elements. This apparatus further comprises feed and discharge means for forming a bath of mother solution supplied with feed solution along its entire length, containing growing crystals in suspension and advancing horizontally from one end of this chamber to the other by gravity, while circulating transversely by convection. These successive evaporating compartments, each supplied with feed solution, thus correspond to several evaporators operating in series and serving, in particular, to reduce mixture of the massecuite or mass of syrup and crystals at different stages of growth of the crystals. The volumetric flow rate of the massecuite decreases, however, along the apparatus and, the cross-section of the latter being constant, the speed of advance of the bath increases likewise. In addition, the viscosity of this mass also increases considerably during growth of the crystals and thus affects heat exchange as well as the transverse circulation by natural convection. Circulation is effected, in this known apparatus, in several inner ascending branches connected to two lateral descending branches. This results in variations in the transverse circulating speed and the formation of undesirable stagnant zones, particularly where the mass coming from the outer descending branches passes to the inner ascending branches so that the crystals may decay prematurely or be mixed with crystals at other stages of growth in these zones. Such a circulation also produces considerable pressure loss.

An object of the present invention is to overcome the above mentioned disadvantages by providing a boiling apparatus for continuous crystallization wherein the circulation of the mother solution containing the seed crystals takes place in a uniform manner and according to a well determined path.

The invention relates to an improvement of a boiling apparatus for continuously crystallizing a substance, in particular sugar, which comprises an elongated, generally horizontal evaporating chamber including heating elements and feed and discharge means for forming a bath of mother solution supplied with feed solution along its entire length, containing growing crystals in suspension and advancing horizontally by gravity from one end of
said chamber to the other while circulating transversely by convection. The improvement which constitutes the present invention lies in that the apparatus further comprises a feeding seed path, arranged at the up-stream end of said chamber, said heating elements being arranged so as to form, on one side of said bath, at least one row of vertical passages which extend transversely with respect to said advancing movement and are open at both ends for producing, by natural convection in said bath, an ascending movement in said passages on one side of said chamber and a descending movement on the other, the heating surface of said elements per unit length of said chamber increasing along the latter, said discharge means being arranged at the down-stream end of said chamber so as to form an overflow for maintaining the level of said bath above said elements, the bottom of said chamber being inclined and the width thereof increasing, in the direction of the advance of said bath, in such manner that the cross-section of the latter varies proportionally with the volumetric flow-rate passing through each cross-section so as to advance said bath at substantially constant speed whereby said bath, together with the growing crystals contained therein, is made to move along a helicoidal path with substantially constant pitch providing uniform growth of the crystals up to the desired size.

The variation of the cross-section of the apparatus according to the invention thus permits to form helicoidal movement throughout the apparatus, with minimum pressure loss. It thus becomes possible to select a relatively small cross-section at the entrance of the apparatus so as to obtain a sufficient speed of advance to prevent mixing of crystals at different stages of growth. At the same time it also becomes possible to adapt the heating surface to the variable characteristics of the bath and, in particular, to vary the height of these elements which depends on the increasing viscosity of the bath so as to obtain satisfactory transverse circulation up to the exit end of the apparatus. It is thereby possible to ensure effective heat and mass transfer by uniform rapid circulation of the bath while avoiding the formation of undesirable zones in which either the degree of supersaturation is too high thus favoring the formation of false grains or the concentration is too low thus leading to diminishing yields. Experience has shown that movement of the bath along a helicoidal path having substantially constant pitch is obtained even if the flow rate of the bath is varied substantially. Thus, owing to its particular construction, the apparatus according to the invention allows several parameters influencing the process of crystallization to be taken into account and even eliminates the need for controlling them. It is, in fact, sufficient to maintain the bath at a constant degree of supersaturation by adjusting the quantity of heat delivered which depends on the seed crystal feed rate on one hand and the feed solution supplied on the other in order to obtain uniform crystal growth up to the desired size.

The invention also relates to a method of operating the apparatus according to the invention, said method comprising the steps of introducing into said evaporating chamber an amount of feed solution to form said constant level bath, heating this bath by means of said heating elements to cause it to boil so that the concentration thereof attains a value corresponding to a predetermined degree of supersaturation allowing said crystal growth, while maintaining in said chamber, above said bath, a constant predetermined pressure, introducing continuously along said bath a predetermined amount of feed solution, introducing continuously into said bath a predetermined number of crystals, in suspension in a liquid, and adjusting the amount of heat delivered by said heating elements which depends on the feed solution flow-rate, whereby the solution forming said bath is kept boiling so as to maintain it at the desired concentration while this bath advances longitudinally at a constant predetermined speed.

The annexed drawing shows schematically an embodiment of the apparatus according to the invention as well as a variant thereof which is intended in particular for crystallizing sugar.

FIG. 1 is a longitudinal section of this embodiment. FIG. 2 is a cross-section along line II—II of FIG. 1. FIG. 3 is a horizontal section along line III—III of FIG. 1.

FIG. 4 is a longitudinal section of a variant of the apparatus according to FIG. 1.

FIG. 5 is a cross-section along line V—V of FIG. 4. FIG. 6 is a cross-section along line VI—VI of FIG. 4.

As may be seen from FIG. 1, the apparatus comprises an elongated evaporating chamber 1 arranged horizontally. This chamber comprises a bottom 2 which is inclined downwards from one end (A—A), towards the other end (B—B), which will be respectively called the entrance and the exit of the apparatus below. A plurality of inclined inlet tubes, in the present case six tubes 3, to 3, which are connected to a supply source 5 of solution for continuously introducing into said chamber 1 an adjustable quantity of feed solution, are fixed to the inclined bottom 2 in a longitudinal row. These inlet tubes 3, to 3, are provided with valves 4, to 4, for respectively regulating the feed flow rates Q1 to Q6 so as to maintain the bath of mother solution during crystallization.

Introduction of seed crystals from a supply source 5 is effected in a liquid or gaseous state and is continuously charged by means of an inlet tube 5 provided with a valve 6 and arranged at the entrance A—A of the chamber 1. The seed crystals must obviously be of substantially equal size in order to obtain uniform crystallization in the apparatus.

A discharge conduit comprising a horizontal branch 7, a vertical branch 8 and a horizontal branch 9 is arranged at the exit B—B for evacuating the crystals having the desired size in suspension in solution, either to an apparatus, not shown, for subsequent treatment, or to a reservoir. A transverse partition wall 10 is arranged a short distance before the exit B—B and extends vertically in the chamber 1 from a point situated above the level of the horizontal branch 7 down to a point situated at a distance above the bottom 2 so as to form an ascending passage 11 communications at its lower end with the bath of mother solution and at its upper end with the discharge conduit 7, 8, 9. This discharge conduit thus forms an overflow allowing said bath of solution to be kept at a constant level (shown by dashed lines in FIGS. 1 and 2) on one hand and to cause the bath to advance by gravity towards the exit B—B on the other hand. The mixture of solution and crystals having the desired size which is evacuated at the exit B—B is continuously replaced by supplying fresh seed crystals at the entrance A—A and mother solution along the bottom 2 of the chamber.

As shown in FIGS. 1 to 3, the cross-section of the chamber 1, and hence of said bath, increases progressively between the entrance A—A and the exit B—B. This increase is due on one hand to the slope of the bottom 2 and on the other to the increase in the width of the evaporating chamber 1 and in such that the ratio between each cross-section and the volumetric flow rate passing horizontally through this section be maintained constant whereby the bath advances longitudinally at constant speed towards the exit B—B.

A heat exchanger 12 supplied with steam from a source V extends longitudinally from the entrance A—A up to the partition wall 10 situated before the exit B—B, this exchanger being immersed in the bath of mother solution. As shown in FIGS. 1 to 3, the exchanger 12 comprises a steam coil 13 supplied with steam by means of an inlet tube 14 connected to the source V and equipped with a regulating valve 15, this steam chamber being arranged longitudinally in the evaporating chamber 1, in the vicinity of the side wall 16 thereof. The heating surfaces of the exchanger 12 consist essentially of a series of vertical transverse walls 17 connected in pairs by vertical, longitudinal walls of slight width,
5 thereby forming a longitudinal series of transverse passages 18 each communicating at both ends with the bath of solution.

The heat exchanger 12 serves to maintain the mother solution boiling whereby vapor bubbles of solvent are formed in the vicinity of the heating walls 17 forming the passages 18. These bubbles rise thereby producing an ascending movement of the solution in these passages 18 and are released at the surface of the bath. The bubbles are then evacuated through a discharge orifice 19 which, in the present case, is connected to atmosphere. As may be seen from FIGS. 1 to 3, the heating surface of the heat exchanger 12 per unit volume of the chamber 17 being progressively along the latter, so as to accommodate the increased volume of the bath towards the exit B—B as well as the decrease in the heat-transfer coefficient, due to the increase in viscosity of the mixture of solution and crystals towards the exit, so that the bath ascends at a constant speed along the entire apparatus.

The heating passages 18 thus serve to produce a transverse circulation constituted substantially by said ascending movement on one side of the chamber 1 and said descending movement on the other side, this circulation being represented by arrows in FIG. 2.

A suitable adjustment of the feed flow rates $Q_{11}$ to $Q_{14}$ and of the steam delivered to the heat exchanger 12 enables the bath to advance at constant horizontal speed towards the exit B—B, as well as said transverse circulation of this bath by natural convection, whereby the bath and the seed crystals contained therein move at constant speed along a helicoidal path with a well determined substantially constant pitch. The stable flow thus obtained allows mixing of crystals of different ages to be largely prevented. Consequently, seed crystals having the same initial size all follow the same path and hence are maintained for the same period in the bath so that they grow uniformly and will attain substantially the same size at the exit B—B of the apparatus. It is, however, obvious that in spite of these substantially uniform flow conditions, certain seed crystals, and especially the largest ones, may grow more rapidly than the others. Any crystals which attain prematurely a size and thus a mass which is too great to allow them to be carried upwards by the mother solutions will decant onto the inclined bottom 2 and will advance by gravity along the latter towards the exit B—B. Thus the uniform circulation on one hand and the relatively rapid evacuation of the large crystals along the inclined bottom 2 on the other, provide crystals of substantially uniform size at the exit of the apparatus.

It should be noted that, in this embodiment, a suitable adjustment of the heat supplied, i.e. of the steam rate $Q_s$ on one hand and of the feed flow rates $Q_{11}$ to $Q_{14}$ on the other allows a constant degree of supersaturation to be maintained in the bath of mother solution. To this effect, the supply of feed solution must obviously compensate the effect of evaporation as well as crystallization so as to maintain a constant degree of supersaturation of the mother solution throughout the bath.

The modified boiling apparatus shown in FIGS. 4 to 6, comprises an evaporation chamber similar to that described above and shown in FIGS. 1 to 3. In addition to the heat exchanger 12, it comprises a plurality of transverse partition walls 20 for subdividing the bath of solution into a longitudinal series of compartments 21. In the present embodiment shown, six partitions walls 20 and seven compartments 21 are provided. The successive compartments 21 communicate with each other by means of openings 22 arranged in the partition walls 21, just above the bottom 2.

Thus the mother solution containing the growing crystals follows the same helicoidal path with constant pitch as described above while passing from one compartment 21 to the next through the openings 22 near the bottom 2.

It is thus obvious that the partition walls serve solely to render movement of the solution forming the bath more uniform for preventing any possible backward movement and consequently mixing of crystals of different ages.

As further shown in FIG. 4, the vapor discharge orifice 19 is connected to a discharge conduit 23 provided with a valve 24 and leading to a condenser 25. The latter is connected in known manner to a vacuum pump 26 and supplied with water by means of a conduit 27 provided with a valve 28, whereby a desired sub-atmospheric pressure may be maintained in the evaporating chamber 1. Thus, in this modified embodiment, the pressure prevailing above the surface of the bath, in the evaporating chamber 1 may be controlled, so that the boiling temperature of the bath may be adjusted to a desired value substantially lower than the boiling point at atmospheric pressure.

As shown in FIG. 6, the heat exchanger 12 of the modified boiling apparatus comprises a vapor chamber 13 divided by a partition wall 29 into two sections 13a and 13b. The latter are respectively fed with steam from source V by means of lines 14a, 14b provided with regulating valves 15a, 15b. This division into two sections allows the amount of steam delivered to these two sections to be varied individually so as to take into account the need for evaporating a relatively large amount of water in the last section 13b with respect to the first section 13a.

As may further be seen in FIGS. 4 to 6, a heating jacket 30 surrounds the inclined bottom 2 of the evaporating chamber 1 as well as the side wall 16 in the vicinity of which the exchanger 12 is arranged. The jacket 30 is supplied with a suitable heating medium such as, for example, the condensate leaving the exchanger 12 and allows the transverse circulation to be improved and the formation of crystalline deposits on the bottom 2 to be prevented.

It may be mentioned that reducing the boiling temperature provides certain advantages with respect to boiling at atmospheric pressure. Thus, for example, such temperature reduction allows an increase of the temperature difference between the heating elements and the solution thus improving heat transfer. In addition, such temperature reduction is desirable or may even be necessary when the product to be boiled is sensitive to heat. As is known, when crystallizing sugar the conditions for circulating the solution forming the bath may be improved by choosing a boiling temperature of about 70°C and a constant degree of supersaturation lying between 1.1 and 1.3, the viscosity of the sugar syrup then being at its minimum value.

**EXAMPLE**

In order to obtain 1 t./h. of sugar crystals having an average size of 0.4 mm., a boiling apparatus as described above and shown in FIGS. 4 to 6 is used.

Seeding is effected in this case with sugar crystals having an average size of 0.03 mm. Assuming that the number of crystals remains constant in the apparatus, the number of crystals seeded per hour is $10^9$.

For feeding the bath, a sugar syrup is used which has 100% sucrose purity and a supersaturation of 1.25. The total feed syrup flow rate is about 3 t./h.

The evaporating chamber has a total length of 2.80 m. and six partition walls divide the bath into seven compartments of equal length (0.4 m.). The volume of the bath is 1 m$^3$.

The height and width of the bath of solution vary linearly between the entrance and the exit of the apparatus, the initial height and width being 0.275 and 0.185 m. and the final height and width being 1.20 and 0.74 m. respectively. Saturated heating steam is used at 1.46 kg./cm$^2$ (110°C) and the total heating surface is about 13 m$^2$.

The evaporating chamber 1 is maintained at an absolute
pressure of 0.2 kg./cm.$^2$ which corresponds to a boiling point of 70° C for a degree of supersaturation of 1.25 of the solution forming the bath.

The following table shows the values of the feed flow rate $Q_0$, the average cross-section $S$, the volume $V$ and the heating surface $F$ in the respective compartments ($21_1$ to $21_7$) of the apparatus.

<table>
<thead>
<tr>
<th>Compartment</th>
<th>$21_1$</th>
<th>$21_2$</th>
<th>$21_3$</th>
<th>$21_4$</th>
<th>$21_5$</th>
<th>$21_6$</th>
<th>$21_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_0$, l/hr</td>
<td>0.10</td>
<td>0.80</td>
<td>0.60</td>
<td>0.60</td>
<td>0.80</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>$S$, mm.$^2$</td>
<td>3.12</td>
<td>21.5</td>
<td>32.4</td>
<td>34.4</td>
<td>44.2</td>
<td>28.1</td>
<td>28.1</td>
</tr>
<tr>
<td>$V$, cm.$^2$</td>
<td>9</td>
<td>35</td>
<td>66</td>
<td>118</td>
<td>208</td>
<td>265</td>
<td>52</td>
</tr>
</tbody>
</table>

As is known, the purity of the feed syrup which is used plays an important role in crystallization. Thus, in the above example, if syrup having a purity of 90% instead of 100% were used, the duration of stay necessary for crystal growth is about three times as long. Consequently the flow rate of the crystals obtained with the same apparatus would be $\frac{1}{3}$ l/hr. For a flow rate of 1 l/hr, the linear dimensions of the apparatus must be increased by the factor $3^{\frac{1}{3}}$ while the heating surfaces may, however, remain the same.

Uniform crystal growth is obtained in the apparatus according to the invention due to the fact that the crystals follow a helicoidal path with constant pitch in the bath of solution having a constant degree of supersaturation. One thus obtains a substantially linear variation of the average size of the growing crystals along the bath. Thus, for other initial and/or final sizes than those given in the above example the length of the apparatus will be decreased or increased to scale. For final sizes greater than 0.4 mm., a corresponding section will be added so as to lengthen the apparatus at the exit end.

On the other hand, for final sizes less than 0.4 mm. a corresponding section will be removed so as to shorten the apparatus at this same end. In addition, if seeding is to be effected with crystals having a smaller size than 0.03 mm., the apparatus should be lengthened on the entrance side by means of a corresponding section.

We claim:

1. A apparatus for continuously crystallizing a substance from a solution by evaporation, said apparatus comprising means for feeding the evaporating chamber with feed solution, said solution being supplied to the evaporator with a regulating valve.

2. An apparatus according to claim 1 wherein the discharge means for the vapor released by evaporation comprise a condenser and a vacuum pump connected in series and a discharge orifice situated at the upper part of the evaporating chamber.

3. An apparatus according to claim 1 wherein said heating elements are supplied with steam by means of at least one inlet tube provided with a regulating valve.

4. A apparatus according to claim 1 wherein the side-walls of the chamber and the evaporating chamber, by means of openings arranged at the lower end of said partition walls.

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