UDK 664.1.05.004.15

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INTENSIFICATION OF THOROUGHLY BOILING OF MASSECUITE BY HYDRODYNAMIC METHOD

Підвищення ефективності цукрового виробництва пов'язане з інтенсифікацією процесів тепло- і масообміну під час уварювання утфеля. Результати теоретичного і експериментального дослідження робочих процесів покладені в основу гідродинамічного методу підсилення циркуляції у вакуум-апаратах періодичної дії. Розглянуті питання практичного використання цього методу інтенсифікації.

Повышение эффективности сахарного производства связано с интенсификацией процессов тепло- и массообмена во время уваривания утфеля. Результаты теоретического и опытного исследования положенные в основу гидродинамического метода усиления циркуляции в вакуум-аппаратах периодического действия. Рассмотрены вопросы практического использования этого метода интенсификации.

The effectiveness enhancing of sugar production due to the intensification of heat and mass transfer during boiling of massecuite. The results of theoretical and experimental research of workings processes are fixed in basis of hydrodynamic method of strengthening of circulation in vacuum pans of batch-type. The questions of the practical use of this method of intensification are considered.

G – the expense, kg/h; t/h;
K – coefficient heat transfer, W/(m^2·K);
α_2 – coefficient heat payment, W/(m^2·K);
ε – the expense vapor insufflations, %;
τ – the time, h; min.

Index:

ц – cycle to boil thoroughly;
вд – insufflations.

Devices are developed for hydrodynamic intensification of processes heat and mass-transfer in vacuum pans it is differentiated mass-transfer the methods of tricking into, distributing and mixing of the pumped solution or insufflations of pair in a vehicle. The simplest device is a circular tubular distributor with a radius, even the half of radius of vehicle. It is set between a bottom and warming chamber of vehicle and has openings for mixing of pair, insufflations, whether union couplings for the stream tricking into of pair in boil thoroughly product. On occasion distributive a collector took a place from outside a vehicle, and the union couplings for the stream tricking into of pair passed through the bottom of vehicle.

Such devices have the substantial failings, related to the uneven distributing of pair or gas, which is blown in boiling tubes, which are above the union couplings or openings of bubbler for tricking into of pair which is blown. Charges last will be considerably higher in certain tubes, than in nearby. To some tubes a pair which is blown will not get quite. It creates unevenness in maintenance of pair (gas) and speeds of circulation of product in a vehicle. In those tubes, where a pair will not get, speed of circulation of product can diminish comparably with those values which were got without insufflations of pair. Especially unfavorable will be terms heat- and to mass-transfer in those tubes, where speed of circulation of product will diminish to the zero or directed in an opposite side. For heat-sensible products such modes of operations of boiling pipes are impermissible, because they are accompanied the protracted stay of product in the conditions of considerable overheat and, as a result, his considerable disintegration.

New method of hydrodynamic intensification of thoroughly of boiling massecuite by insufflations of pair or gas inward every for boiling tube, the resulted in works [1–4] consists in the following: insufflations of gas or pair is carried out streams with such speed which allows to desperate pair (gas), good to mix up it with massecuite and, if not fully to eliminate, carry the area of existence of shell-piston form of flow nearer to the exit from a boiling tube; the expense of pair (to gas)

which is blown is supported in optimum values on every stage of to boil thoroughly; in a distributive chamber, considerably anymore pressure of pair (to gas) of, what is supported blown, than in vacuum pan, that pressure fluctuations in for boiling tubes substantially did not influence on an equitability pair (to gas) which is blown; a distributive device is executed so that not to create additional hydraulic supports massecuite which circulates, and stagnant areas; direction of streams of pair (to gas) is carried out so that an injection action created greater additional motive pressure as possible.

For realization of these method two constructions of device are developed with a distributive chamber and distributive collector. On fig. 1 a device is resulted for the hydrodynamic strengthening of circulation in vacuum pans with a distributive chamber, which has a transversal cut, identical to the cut of warming chambers. Lower ends of for boiling tubes are continuation of pipes of distributive chamber, in them openings are executed under the corner of 15…30° to the ax of for boiling tubes. Through these openings pair (gas) which is blown acts from a distributive chamber inward for boiling tubes.

Device for the hydrodynamic strengthening of circulation in vacuum pans with a distributive collector which is executed from pipes, for boiling tubes laid between rows very close to the lower pipe grate, it is resulted on fig. 2. In a collector there are sprayers with openings for insufflations of pair (to gas) inward every for boiling tube. An angle of slope of ax of openings is 15…30° to the ax of for boiling tubes. The diameters of openings in both devices execute small (0,8…1,0 mm). At the thickness of wall of for boiling tube or sprayer 2…3 mm such openings is short union couplings or snuffled, that form narrow the stream of steam (to gas) which is blown is directed.

For support in a distributive chamber or collector of considerably anymore pressure, than in vacuum pan, not enough to utilize the pair (gas) of the proper pressure only. It is also necessary for this purpose, that total area for insufflations was the cut of all of openings far fewer area to the cut of ducting's for which a pair (gas) is tricked into to them, that hydraulic resistance of openings for

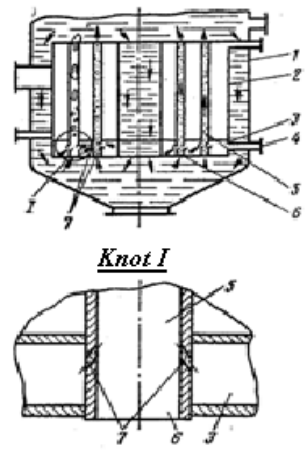

Fig. 1. A device is for the hydrodynamic strengthening of circulation: 1– corps; 2 – is a warming chamber; 3 – is a chamber distributor; 4 – is entrance of pair which is blown; 5 – are for boiling of tubes; 6 are lower ends for boiling tubes; 7 – are openings for insufflation of pair.

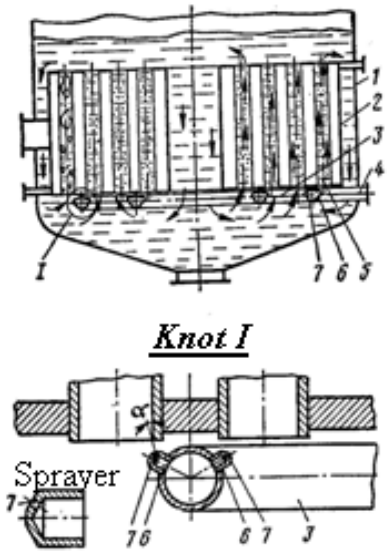

Fig. 2. A device is for the hydrodynamic strengthening of circulation: 1 – corps; 2 – is a warming chamber; 3 – chambers-distributor; 4 – is entrance of the blown pair; 5 – are for boiling tubes; 6 – is a sprayer; 7 – are openings for insufflation of pair.

insufflations was more high of resistance of pair (to gas) of highway of tricking into.

Such implementation of devices for the hydrodynamic strengthening of circulation allows

to utilize potential energy of pressure of pair (to gas) which is blown, for creation of additional motive pressure. The useful overfill of pressure of pair (to gas) is not outlaid on overcoming of resistances after length of highway of serve, but grows into kinetic energy of streams and at mixing passed to circulatory massecuite. Thus arrived at more even distributing of pair (to gas) between for boiling tubes, and also even circulation of massecuite in a warming chamber. At insufflations of pair (to gas) thin streams with high speed is his more complete dispergating and mixing with massecuite which reduces relative speed of pair (to gas) and promotes actual vapor keeping (gas keeping of contents) in for boiling tubes, and also diminishes possibility of formation of shell-piston form of flow of mixture. All of these features of the examined method and will build on for the hydrodynamic strengthening circulations in vacuum pans of extension his efficiency.

The hydrodynamic method of strengthening of circulation does not impose the special limits on the construction of vacuum pans, unlike mechanical method. Yes, mechanical circulators can be set in vehicles only with a central circulation pipe, while devices for insufflations of pair (to gas) it is possible to set also in vehicles with an external circular circulation channel or with two – central and external the circulation ducting's which are executed in modern vacuum pans in connection with a considerable increase them single power. In addition, mechanical circulators create the considerable unevenness of circulation of massecuite in vacuum pans with circular warming elements, while devices with the hydrodynamic strengthening of circulation can successfully work in such vacuum pans. Although vacuum pans with circular warming elements for today is used extremely rarely, their use is not eliminated in the future, as their surfaces of heating have low hydraulic resistance comparatively.

Experimental information about influence of structural features of vacuum pans on efficiency of hydrodynamic method of strengthening of circulation of massecuite not enough. More perfect mechanism of operating on circulation of massecuite and imperfection of devices for insufflations of pair (to gas) not instrumental in wide distribution of this method. The production tests of hydrodynamic method of strengthening of circulation were conducted with the use of existent vacuum pans of batch-type [1 – 3]. Found out more considerable intensity of circulation of massecuite in vacuum pan i with the suspended warming chamber. One of such vehicles by the capacity of 6 t massecuite and with the area of surface of heating of 31 m^2 was equipped a device for the injection of pair under warming a chamber through eight openings, placed above the bottom of vehicle in the distance, to the even half of radius of vehicle from his ax.

Vakuum-pan of G4-PVA-40 (fig. 3) for strengthening of circulation has a chamber device (fig. 4). A vehicle had a diameter 3774 mm, height 7440 mm, warming a chamber with the area of surface of heating of 200 m^2, diameter 3350 mm, by the number of for boiling tubes 513 diameter 102 mm and long 1100 mm.

Additional insufflations of pair (to gas) violates balance of motive powers and forces of resistance of, which was folded during natural circulation, and results in the increase of both forces, only in a different degree. Obviously, effective a hydrodynamic method will be in case that at insufflations of pair (to gas) motive pressure will grow in a greater degree, than losses of pressure, related to supports. The first researches of this method rotined already, that the increase of expense of pair (to gas) of,що was blown, results in strengthening circulation and increase of efficiency heat- and to mass-transfer only to the defined optimum values. So at insufflations intensification of heat exchange is arrived at only at low thermal streams in a warming chamber. At higher pressure of warming pair and, consequently, enhance able thermal streams of insufflations practically did not influence on intensity of heat exchange, opposite, even worsened it.

Systematic researches of influence of insufflations of air on intensity of heat exchange at boiling of water and saccharine solutions rotined that mechanism of intensification of heat exchange into a for boiling tube at evaporation of water and saccharine solutions identical. At the increase

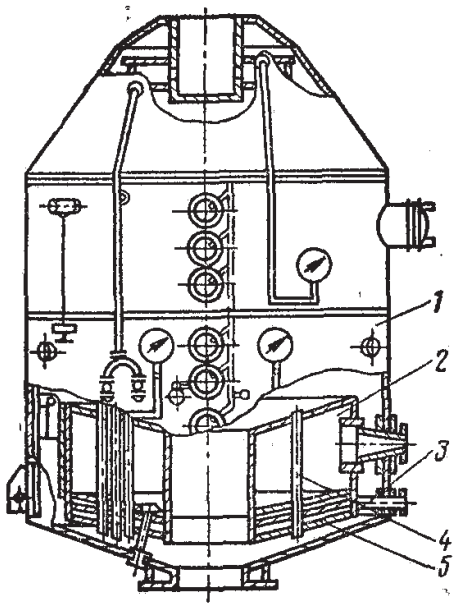

Fig. 3. Vacuum pan G4-PVA-40 the reinforcement of circulation: 1– corpus; 2 – superficies of that enhancer; 3 – insufflations of vapor; 4 – for boiling tubes; 5 – distributive object.

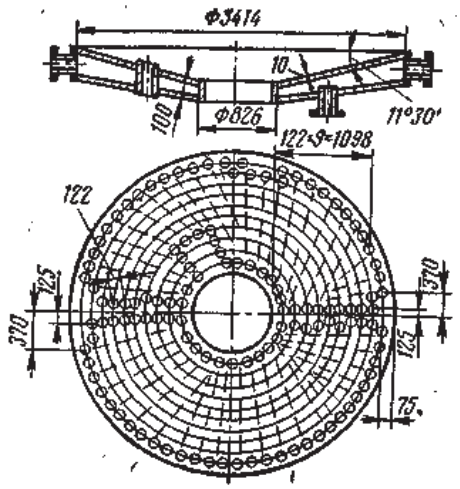

Fig. 4. Device for strengthening of circulation in chamber implementation for the vehicle of G4-PVA-40.

of expense of air which is blown, the coefficient of heat emission grows, but only to the certain optimum expense which is 4…6 % from an expense warming of pair. Increase of expense of air which is blown, over optimum values result in diminishing of coefficient of heat emission and pulsating mode in a boiling tube. The coefficient of heat emission at insufflations of air for water rises to 10 %, for saccharine solutions – to 15…20 %. With the increase of concentration of saccharine solution efficiency of insufflations grows.

Intensification of heat exchange at insufflations of air takes a place mainly on the initial area of tube which is explained falling of piezometer level of liquid and, consequently, diminishing of hydrostatical pressure, and also increase of turbulence of stream. On the initial area of for boiling tube there was a decline of α_2 to the values more low, than without insufflations. It is explained high maintenance of pair in mixture, that drove to the separate moments to drying out of liquid tape on some areas of tube. Insufflations of pair or air carried out in a for boiling tube long 5 m codes pithily effervescence of solutions of glycerin which is on 3 m codes higher than surface of heating. Thus there was an increase of speed of circulation, and intensity of heat exchange grew on 200…300 %. Thus, the height of level of product influences on efficiency of hydrodynamic method of intensification of for boil thoroughly, at what with growth of level efficiency of method rises.

No less important is also a question about dispersion of pair (to gas) that is blown. Searches of ways of intensification heat- and turbulizations over of streams of massecuite are unavoidable brought to the necessity mass-transfer. Bubbles which are entered in a liquid create plenty of whirlwinds of, which is instrumental in the increase of intensity heat- and to mass-transfer. The use of barbotage allowed to create a new high-efficiency equipment – air-lift reactors, vehicles with a foamy contact, reactors with gas-liquid pseudo fluidizing of particulate matters and others like that.

The source of with-phase turbulence in the gas-liquid systems [5] is an origin of whirlwinds of, which is generated instability of free or with-phase interphase. With-phase turbulence arises up, if the rates of movement of phases differ on a size and direction. Viscosity of force of liquid cause breaking the action of opposite streamlines gas. Thus there is a rotation of layers of streams and interphase with the subsequent passing to the whirlwinds. Intensity of braking of stream is

proportional energy of basic indignations. Thus, a friction between the streams of gas and liquid results in a volume, that the boundary layers of gas and liquid are pierced whirlwinds which under the action of force Joukovsky get to the depth of gas and liquid streams and intensity of the vertical field is, strengthened those.

Due to formation xopok the surface of phase contact grows in unit of volume. The hydrodynamic system of gas-liquid emulsion which arises up here is the mobile system of gas-liquid whirlwinds. They arise up in the volume of liquid as a result of collision of bubbles and streamed gas that move with high speed. The collision of bubbles and filling gas of liquid is conditioned kinetic energy of gas, that is why at high-rate enough of gas all of liquid grows into gas-liquid emulsion in which on forward motion of gas whir is are imposed. These factors provide the considerable increase of intensity of processes heat- and to mass-transfer.

With the increase of viscidity of liquid considerable kinetic energy of gas is needed for the receipt of gas-liquid emulsion. In addition, at motion along for boiling tubes the structure of flow tests a change as a result of viscid dissipation of energy of whirlwinds. However impossible it is to ignore possibility of intensification of to boil thoroughly of massecuite due to rev-up insufflations of pair (to gas) and creation of vapor (gas) of - massecuite emulsion even on the initial areas of for boiling tubes. Greater efficiency of heat exchange is arrived at the low charges of air which is blown as thin streams with high speed.

Resistance of mass-transfer which tests molecule of saccharose in transition from surrounding solution in the grate of crystal is examined as a sum of resistance of tricking into of mass to the crystal (diffusive constituent) and resistance of reaction of transition (reactionary constituent). Diffusive resistance is proportional the thickness of diffusive layer of the impoverished solution which surrounds a crystal, and back proportional the coefficient of diffusion of saccharose in solution. Diffusive resistance depends on a temperature, viscidity of solution, and also from the relative rate of movement of crystals in interpure solution.

Interfusion substantially influences on diffusive resistance. The bubbles of air which is blown are saturated aquatic pair, except for an especially hydrodynamic effect which operates on massecuite as a result of change of closeness of mixture in the lifting's ducting's, take part in transference of impulses on separate crystals, which acquire thus relative motion in interpure solution [6].

At the permanent sizes of circulation contour intensity of crystallization of saccharose considerably grows with the increase of length of area, on which interfusion of massecuite was by air which is blown. At the same time the increase of height of circulation contour at other permanent parameters resulted in the decline of efficiency of action of insufflations of air. The increase of diameter of tube also resulted in the decline of intensification of mass-transfer at insufflations of air.

The tests of vacuum pans are conducted with increased a hydrodynamic method rotined [2, 3, 6] circulation of massecuite, that intensity of heat exchange at insufflations of pair grew on an end to boil thoroughly massecuite. On fig. 5 the typical graphic arts of change of coefficient of heat-transfer are presented K at all stages of cycle. The sizes of coefficient of heat-transfer test considerable changes both in experiments without insufflations and with insufflations of pair. Maximal values K at the beginning of to boil thoroughly and intermediate values of spades K answer the terms of to boil thoroughly of liquid products after the duty pumpings in vehicles. Minimum value K answers to boil thoroughly of products, to certain thickening, before the duty pumping. In an initial period of to boil thoroughly intensification of heat exchange due to insufflations of pair had irregular character. It can be explained that boiling of liquid products at high enough on the initial stage thermal streams and low levels in to boil thoroughly mass is carried out in the optimum mode of operations of for boiling tubes, when there is the developed boiling on all of their length. In these terms of insufflations of additional pair ineffective. mass-transfer with-phase to boil thoroughly massecuite boiling vacuum pans for boiling

Far higher efficiency of intensification of heat exchange is on the finishing's stages of boiling.

Attached to boil thoroughly of the finished goods of value *K* is on the last stages at insufflations of pair considerably higher than without insufflations. With the increase of expense of pair which is blown, value *K* grew, though not in an identical degree. Yes, over 120 kg/h did not bring an increase over of expense to the increase intensity of *K*. Attached to insufflations of pair there were higher amplitudes of vibrations of values *K*, than at to boil thoroughly without insufflations. Possibly, at insufflations of pumping of fresh treacle quick interfuse with massecuite in a vehicle, reducing his concentration and viscidity which brings intensities over of heat-transfer to greater growth, while without insufflations such interfusion is protracted or carries local character.

On fig. 6 the graphic arts of change of mass of crystals of *G* and mass speed of crystallization of d*G*/dτ are resulted on the different stages of to boil thoroughly. The crooked growths of mass maintenance of crystals have *S*-similar kind. Slow growth of mass of crystals in an initial period is explained small sizes and, consequently, by the small surface of crystallization. In this period often a heat exchange passes ahead mass-transfer which can result in second crystal-formation. Terms for a heat exchange on this stage more favorable, than terms are for crystallization. A level of product is in a vehicle, the amount of crystals and their sizes is small, mass is mobile enough, for boiling tubes work in optimum terms with the maximal coefficients of heat-transfer. It is thus possible to support maximal satieties and speeds of crystallization.

The small sizes of crystals and considerable distances do not allow between them to conduct intensive crystallization on the led crystals. At small sizes and relative speed of growth of crystals in interpure solution is insignificant. In such terms more frequent all there is second crystal-formation. That it did not take a place, recommended on 10...15 min. after introduction of crystals to halt the serve of warming pair.

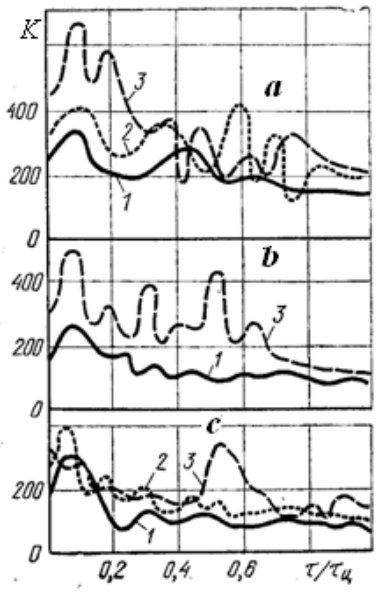

Fig. 5. A change of coefficients of heat-transfer is at to boil thoroughly of massecuite: a – are II crystallizations; b – are III crystallizations of sugar-beet production; c – IV crystallizations at processing of cane-sugar-raw; 1 – $G_{вд}$ = 0 kg/h; 2 – $G_{вд}$ = 80 kg/h; 3 – $G_{вд}$ = 120 kg/h.

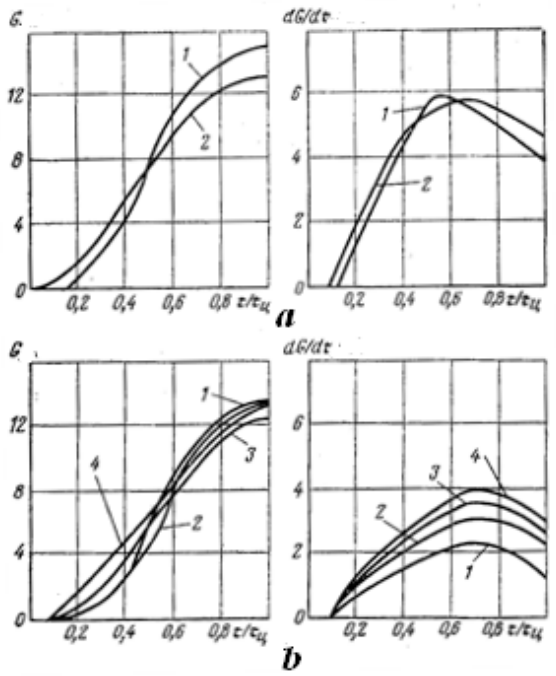

Fig. 6. Change of maintenance of crystals and speed crystallizations are at to boil thoroughly of massecuite: a – II crystallizations: 1 – $G_{вд}$ = 0 kg/h., $\tau_{ц}$ = 305 min; 2 – $G_{вд}$ = 180 kg/h., $\tau_{ц}$ =225 min; b – III crystallizations beet production: 1 – $G_{вд}$ = 0 kg/h., $\tau_{ц}$ = 735 min; 2 – $G_{вд}$ = 80 kg/h., $\tau_{ц}$ =448 min; 3 – $G_{вд}$ = 120 kg/h, $\tau_{ц}$ = 390 min; 4 – $G_{вд}$ = 180 kg/h., τц = 320 min.

Comparisons crooked (see fig. 6) of mass growth of crystals in massecuite, cooked with insufflations of pair and without it, shows that in first case intensity of crystallization is considerably more high in an initial period. As intensity of heat exchange in this period rose insignificantly, it is possible to assume that the increase of intensity of mass crystallization is conditioned direct influence of steam streams and bubbles on formation of crystals in massecuite.

The increase of intensity of mass growth of crystals is conditioned the increase of efficiency of recrystal at insufflations of pair in vacuum pans. At fluctuation in a temperature and satiety in the volume of massecuite with certain amplitude and frequency factious composition of crystals in it tests considerable changes. Thus large crystals grow quick than at permanent satiety as a result of partial or complete dissolution of shallow crystals. During mass crystallization molecular mass-transfer appears in less degree, and growth of large crystals is carried out by building in their crystalline grates to the embryonic clots of molecules of matter which is crystallizable. It is carried out in the places of sharp growth of satiety [6].

Speed of mass crystallization in the middle of boiling grows at τ/τ_{φ} = 0,5…0,8 has maximal values (see fig. 6). It is caused a jumbo zing crystals of their surface. Thus distance diminishes between crystals, less than is become by the thickness of diffusive layer of solution on-the-spot crystals. Process of mass-transfer on this stage of to boil thoroughly limited to nothing. At the same time as a result of growth of mass maintenance of crystals and accumulation of no sugar in interpure solution viscidity of massecuite grows sharply. It results in the substantial decline of intensity of heat exchange. High speed of mass crystallization is observed, when processes heat- and it is flowed mass-transfer with the proper intensity. The maximal values of speeds of mass crystallization at to boil thoroughly with insufflations of pair move nearer to the end of to boil thoroughly.

On the finishing stage of to boil thoroughly considerable intensification of process of crystallization is arrived at by insufflations of pair in for boiling tubes, that conditioned by considerable intensification of heat exchange. At natural circulation of massecuite intensity of heat exchange on this stage sharply goes down as a result of increase of level of massecuite in a vehicle, growth of concentration of crystals and increase of viscidity. Often boiling of massecuite in warming tubes is halted, massecuite here overheats only, and effervescence of it takes a place in a volume above the surface of heating. At insufflations of pair boiling is carried in warming tubes. Speed of circulation and mass crystallization of massecuite grows.

Conclusions

1. The expense of pair or gas for hydrodynamic intensification of to boil thoroughly of massecuite must not exceed ε = 10…15 % from an expense warming of pair. Values of ε, got at to boil thoroughly of saccharine solutions, are 4…6 %. Thus a for boiling tube worked in the optimum mode at the levels of boiling solution to 40 % from length of tube. In these terms of increase of ε to 15 % accompanied strengthening of pressure and rates of movement of mixture fluctuations in a for boiling tube with the extras of solution in a separator, and at ε = 25 % the coefficients of heat exchange went down so much. Therefore in vacuum pans with the hydrodynamic strengthening of circulation it is impossible to assume the charges of the blown pair (to gas) higher than optimum values.

2. The optimum charges of air or pair which is blown in a for boiling tube above the warming surface of evaporator with the taken away area of boiling made ~5 % from the amount of the evaporated water. Thus with the increase of useful difference of temperatures the optimum values of ε grow.

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Получено 14.06.2012 г.