INTENSIFICATION OF PROCESS OF FREEZING - OUT WATER FROM THE FOOD SOLUTIONS

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Abstract

In article efficiency of technologies of a freezing-out for concentrate and fraction of food solutions is shown. Perspectives of block freezer – out is shown, and also necessity of intensification is heat and mass transfer in a boundary layer of system «block of ice - solution». The physical model of block freezer – out with a horizontal lamellar crystallizer and features of formation boundary thermal and diffusion a layer is considered. The static model of process of a block freezing-out of a solution in conditions of the combined influence on process is submitted. As a result of modeling necessity of experimental researches of temperature fields and fields of concentration for researched system is established. Results of experimental researches of acoustic fluctuations on process of a block freezing-out of water of food solutions are resulted.

KEYWORDS

Process of freezing - out water, food solution, block freezer – out, boundary layer, intensification, mathematical and experimental modeling

INTRODUCTION

Refrigerating systems are widely applied in various branches of the food-processing industry to processing raw material and storage of food stuffs. Perspective is directions of use of refrigerating systems for low temperature division of food solutions, namely for dehydration of solutions with the purpose of them concentrating or allocation of the certain fractions of components. As against evaporation, cry-concentrating allows to keep in the best way quality of initial raw material and to carry out process at lower power expenses. In comparison with membrane technologies, to cry-dehydration rigid requirements concerning the contents of dry substances in an initial solution [7, 8] are not showed.

To the devices realizing process of low temperature division of food solutions, concerns block freezer – out [10]. Transition to technology of cultivation of crystals as the block of ice has allowed to reduce power expenses for process cry-dehydration a solution up to (0,55 - 0,6) MJ / kg of ice. Use in work of the refrigerating machine of the energy which has been saved up in the block of ice for partial condensation and overcooling of the refrigerating agent before trotting, has allowed to lower a level power expenses of installations on 30 % in comparison with base installation. Realization of a gravitational separation of the block of ice has allowed to reduce losses of dry substances of a solution at its branch from crystals of ice up to (0,1 - 0,5) % from weight of ice [1, 2, 9]. The further perfection block freezer – out is possible due to an intensification of processes heat and a mass-transfer in a boundary layer.

In modern food technologies for the decision of such problem the increasing application is found with the combined processes. Intensifying action render electric and magnetic fields, mechanical hashing, acoustic fluctuations and other external influences. Thus the opportunity of use of this or that method is caused thermo-physical, electro-physical, acoustic, chemical properties of a solution [4 - 6].

For processes of low temperature division of food solutions including for a block freezing-out, effects of the combined processes are investigated a little. Known researches basically concern to turbulence of flow of a divided solution due to mixing or pumping over devices [7, 8].

PRECONDITIONS FOR AN INTENSIFICATION OF PROCESS

Let's consider thermo-physical model of block freezer – out with a horizontal lamellar crystallizer. Process is carried out at constant temperature refrigerant, in conditions of natural gravitation, at atmospheric pressure and in limited by impenetrable walls of the concentrator and a crystallizer volume of a solution (Fig. 1).

During cooling a solution on a surface of crystallizer water as the block of ice that is accompanied by increase in concentration of dry substances in a solution is frozen. Between an external surface of the growing block of ice and a solution contacting to it there is the boundary layer consisting from thermal and diffusivity layer.

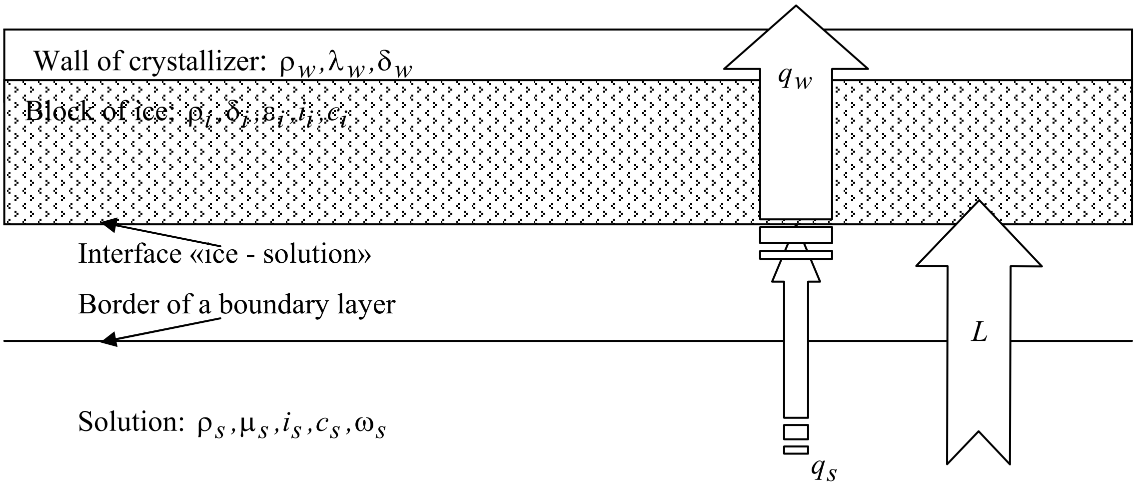


Fig.1. Thermophysical model of process of a block freezing-out

Field of temperatures in system «refrigerating agent - wall of a crystallizer - block of ice - boundary layer - solution», and also a field of concentration in system «block of ice - aboundary layer - a solution » are submitted in fig. 2.

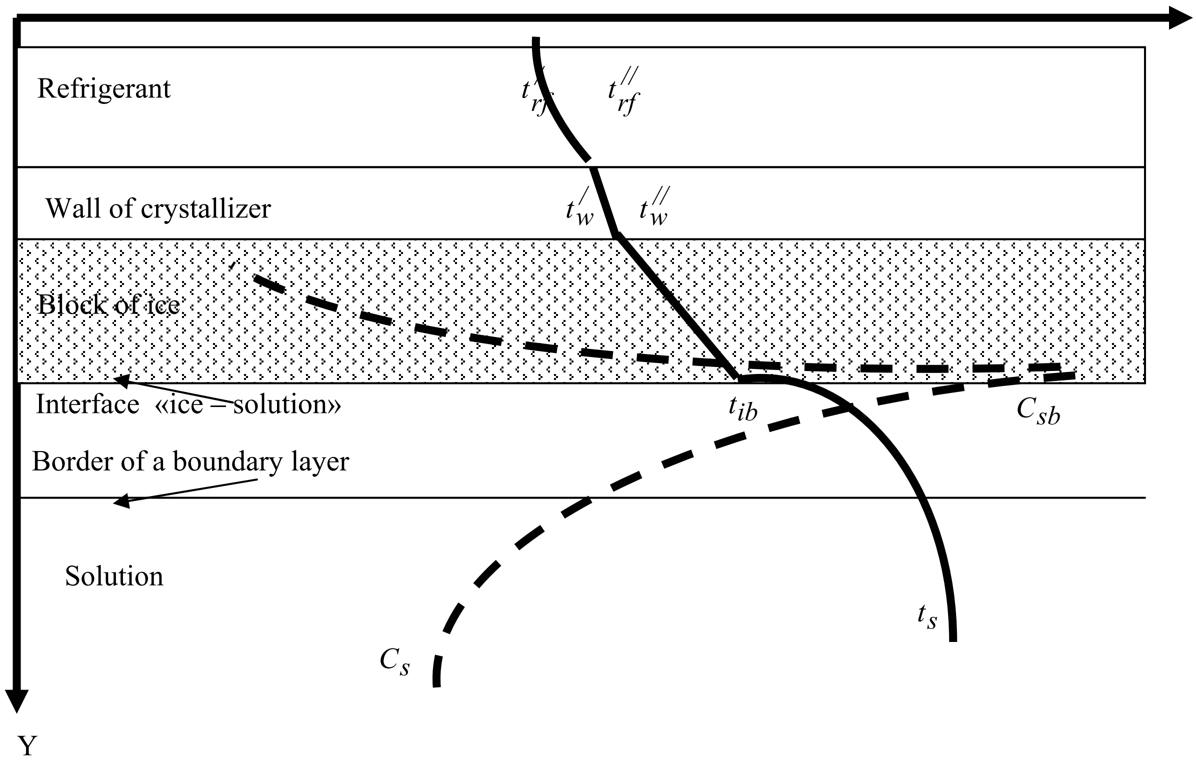


Fig. 2. Fields of temperatures and concentration

Temperature fields in elements of system are determined by sizes of corresponding thermal resistance, parameters of the refrigerating agent and kinetic characteristics of process of ice formation. In conditions of natural convection of a field of concentration have the expressed peak on border of the unit «solid phase - boundary layer».

On the basis of thermo-physical model it is possible to allocate the following phases of interaction of the refrigerating agent, a surface of a crystallizer, a solution and the block of ice. The first stage is thermal non-stationary processes of cooling of a solution. In result in volume of a product there is a downturn of temperature. The time interval of the first stage is determined by a condition of achievement in what or a point of a solution on border with a wall of temperature of the beginning of crystallization.

The second stage is a complex connected hydro-mechanical, heat and mass transfer processes. Result of a mass-transfer is formation and growth of the block of ice. At the same time, fluctuations of temperatures and the concentration caused by convection flows at an interface of phases can create conditions at which the direction of a thermal flow in separate points of a surface of the block of ice changes. Such circumstances can arise if thermal resistance of ice appears in what - that the moment of time and in what or a point is higher, than thermal resistance of a convection heat-transfer. Then, at corresponding values of driving forces there can and be a short-term change of a direction of a thermal flow. Result of such action will be partial melting of ice.

In the important parameter determining value of the factor of division, the density of packing of crystals in the block of ice is. The above the density of packing, the is better divided a solution. However, ideal division demands infinitesimal values of driving forces. Hence, it is required to search for compromise modes, and necessary values of the factor of division to achieve by separate operation - a separation.

Independent problem is the ratio thermal and diffusivity resistance in volume of a boundary layer. The prevalence of the mechanism of heat conductivity will be characterized by growth of porous structure of ice. In a limit it is possible to leave on modes when divisions will not take place at all, and concentration will be equal the block of ice to concentration of an initial solution. Other limiting mode can be a situation when intensive convective currents are able to interfere with formation of the block of ice. Result of such mode volumetric crystallization.

Intensity of a mass-transfer is defined by a hydro-dynamical situation first of all in a boundary layer. Naturally, intensity of influence on a boundary layer defines efficiency heat and mass-transfer.

Thus, a problem connected heat and mass transfer models is definition of fields of temperatures in the block of ice and in a wall, enthalpy, fields of temperatures and concentration in the block of ice, a boundary layer and in volume of a solution.

STATIC MODEL OF PROCESS

Process of a block freezing-out of water from food solutions is represented as material balances on the general flows of substances (1) and on dry substances (2):

$$G_{in} = G_f + L\,, \tag{1}$$

$$G_{in}C_{in} = G_f C_f + LC_i\,, \tag{2}$$

where G_{in} and G_f - initial and final weight of a solution, kg; L - weight of the formed ice, kg; C_{in} and C_f - initial and final concentration of dry substances in a solution, kg/kg; C_i - concentration of dry substances in the block of ice, kg / kg.

The quantity of the formed solid phase is by the joint decision of the equations (1) and (2):

$$L = \frac{G_{in}(C_{in} - C_f)}{C_i - C_f}\,. \tag{3}$$

If thermal radiation in system to neglect, the equation of thermal balance can be expressed through density of a thermal flow through a wall of a crystallizer (q_w, W / m^2) and to present in the following kind:

$$q_w = q_s + (\rho\omega_y)_s i_{sb} - (\rho\omega_y)_i i_{ib}\,, \tag{4}$$

where q_s - a thermal flow for the account convective heat exchange (in view of heat conductivity, a convection and molecular diffusion) from a boundary layer, W/m^2 ; $(\rho\omega_y)_s i_{sb}$ - density of a flow of weight from a solution to border of the unit of phases, W/m^2 ; i_{sb} - enthalpy of a solution on border of the unit of phases, J/kg ; $(\rho\omega_y)_i i_{ib}$ - density of a flow of weight inside of a boundary layer from a surface of the block of ice, W/m^2 ; i_{ib} - enthalpy of ice on border of the unit of phases, J/kg ; ρ - densities of flow, kg/m^3 ; ω_y - speed of movement of flow, m/s .

In a mode of growth of the block of ice:

$$(\rho\omega_Y)_s = (\rho\omega_y)i = (\rho\omega_y) \tag{5}$$

According to the equation of Newton – Rihman cooling of a solution can be submitted as:

$$q_s = \frac{\alpha}{c_{ps}}(i_s - i_{sb}), \tag{6}$$

where α - coefficient of a heat-transfer from a solution, $W/(m^2 \cdot K)$; c_{ps} - isobaric specific thermal capacity of a solution, $J/(kg \cdot K)$.

Enthalpy of solution on border of the unit of phases it is possible to write down as the sum enthalpy of ice on border of phases and the latent heat of crystallization (Ω, J/kg):

$$i_{sb} = i_{ib} + \Omega. \tag{7}$$

Taking into account (5) and (6) ratio (4) it is possible to present as:

$$q_W = \frac{\alpha}{c_{ps}}(i_s - i_{sb}) + \rho w_Y (i_{ib} - \Omega) + \rho w_Y (i_{ib}) \tag{8}$$

Considering, that number Stenton enters the name as:

$$St = \frac{\alpha}{\rho\omega c_p}, \tag{9}$$

let's finally write down the equation of thermal balance:

$$q_W = \frac{\alpha}{c_{ps}}\left[(i_s - i_{sb}) + \Omega / St\right]. \tag{10}$$

The account from solutions of external influences results influence on process of a block freezing-out of water in new representation of thermal balance. So, at influence on process of electro- physical fields it is necessary to take into account the additional flow of energy caused by work of a radiator, which capacity N_e, W . In this case:

$$q_W = \frac{\alpha}{c_{ps}}\left[(i_s - i_{sb}) + \Omega / St\right] + \frac{Ne}{\pi d_i h_i}. \tag{11}$$

Here d_i and h_i - diameter and height of the block of ice, m .

In case of influence on process by mechanical means (vibration, fluctuations) it is necessary to take into account energy dissipation of mechanical work:

$$q_w = \frac{\alpha}{c_{ps}}\left[(i_s - i_{sb}) + \Omega / St\right] + \frac{N_m}{\pi d_i h_i}. \tag{12}$$

The analysis of balance ratio shows, that values of kinetic factors are necessary for calculation of process of a block freezing-out.

EXPERIMENTAL RESEARCHES

Experimental researches of an intensification of process of a block freezing-out with the help of acoustic fluctuations were carried out at the experimental stand which circuit is shown in fig. 3.

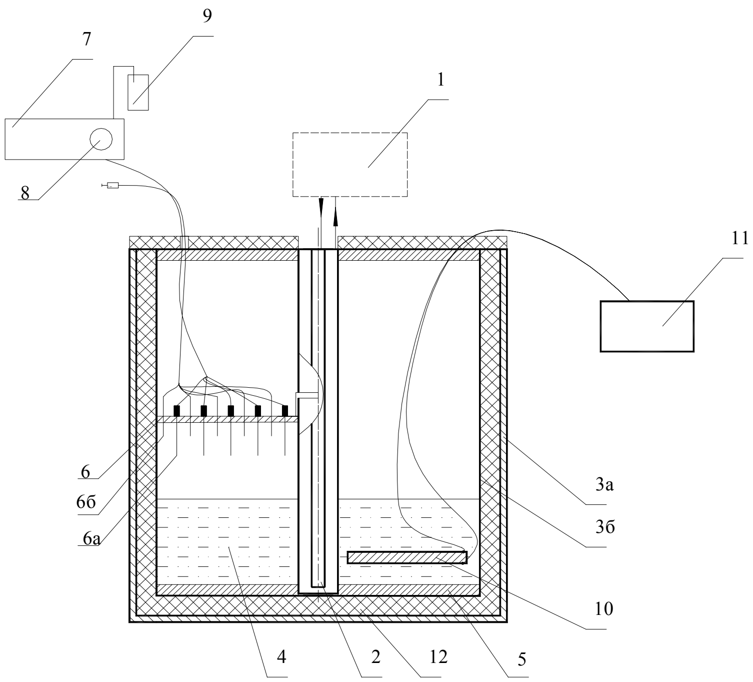


Fig. 3. Principle scheme of the experimental stand

The experimental stand will consist from: refrigerating system (1), crystallizer (2), concentrator (3) with internal (3a) and external (3б) in the capacities, a researched solution (4), concentric (top and bottom) washers (5), a comb (6) with five thermocouples (6a) and five tubes (6б) for sampling a solution, the micro-voltmeter (7), the switch of thermocouples (8), vessel of Duara (9), piezo-ceramic radiator (10), system of generation of acoustic fluctuations (11), isolation (12).

Piezo-ceramic radiator is represents a round plate such as "sandwich". External diameter and thickness of a radiator used in the stand makes $d_p = 20 \times 10^{-3}\,m$ and $\delta_p = 2 \times 10^{-4}\,m$ accordingly. The radiator moves freely and fixed in various points of the concentrator. The choice piezoelectric, namely piezo-ceramic radiator, with the mentioned above geometrical sizes, is caused by a number of the reasons:

- piezoelectric radiators allow to receive intensive acoustic fluctuations with frequency from 10 up to 100 кHz at which, according to references [4, 5] the greatest effect is reached at crystallization from solutions at the positive temperatures;

- piezo-ceramic radiators differ high efficiency, which makes η_p = (60 … 80) %;

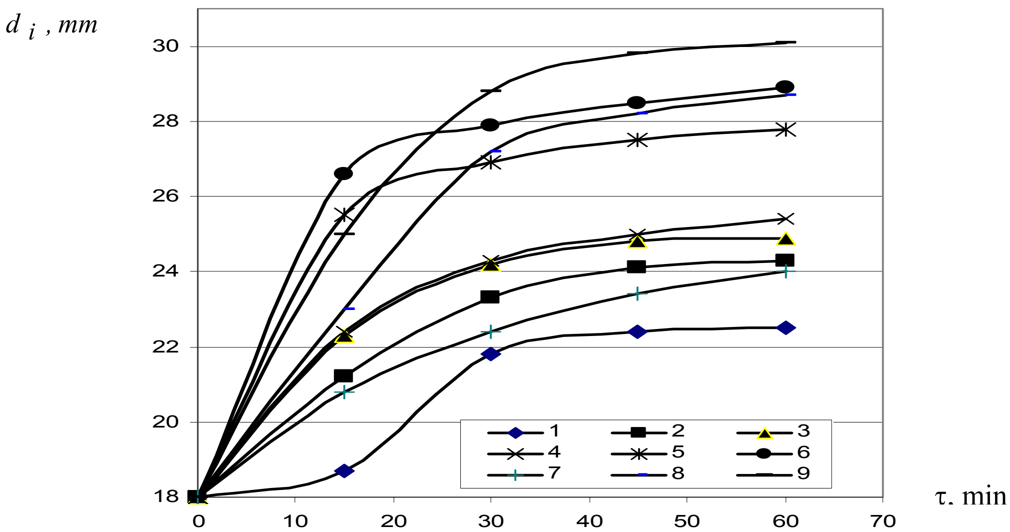
- use piezo-ceramic radiators it is not connected with intensive turbulence of flow of solution. It is very essential for technology of a block freezing-out as intensive hashing of layers of a solution promotes increase in a heat-transfer on the part of a solution and causes growth of small crystals of ice, that in turn worsens conditions for division of a solution and a separation of the block of ice;

- among piezoelectric radiators, piezo-ceramic are characterized in (10 … 100) time big piezo module, that allows to receive at much smaller pressure effect even at poorly conducting a current liquids which many food solutions are [4, 5].

In connection with that influence of acoustic fluctuations on process of a block freezing-out of water from a solution is not known, preliminary experimental researches kinetics of process are lead. Objects of researches had been chose grape juice and extract. Researches were carried out at an arrangement of radiators at the bottom and on the center of the concentrator.

The technique of researches included studying influence of frequency of acoustic fluctuations on kinetics of growth of the block of ice and change of concentration of dry substances in solutions. During experiment were measured frequency of acoustic fluctuations (f, kHz), initial temperature of a solution ($t_s, {}^oC$) and temperature of refrigerant ($t_{rf}, {}^oC$), initial (C_s^{in} , %) and final concentration (C_s^{f} , %) dry substances in a solution, initial volume of a solution (V_s , *ml*), diameter of the block of ice (d_i , *mm*) top (в), average (с) and bottom (н) parts, duration of process of crystallization (τ , *minute*). Researches were carried out at the following frequencies of acoustic fluctuations: 4,5 *kHz*, 15 *kHz*, 50 *kHz* and 100 *kHz*.

As a result of the lead researches the kinetic dependences submitted in fig. 4 and 5 are received.



№	f, kHz	C_s^{in}, %	t_s, ${}^0C$	V_s, ml	t_{rf}, ${}^0C$	d_i
1	0	13,4	10,6	150	-10,2	в
2	0	13,4	10,6	150	-10,2	с
3	0	13,4	10,6	150	-10,2	н
4	4,5	13,4	9,3	150	-10	в
5	4,5	13,4	9,3	150	-10	с
6	4,5	13,4	9,3	150	-10	н
7	50	13,4	10,8	150	-10,5	в
8	50	13,4	10,8	150	-10,5	с
9	50	13,4	10,8	150	-10,5	н

Fig. 4. Kinetics of growth the block of ice in conditions of a natural convection and with influence of acoustic fluctuations

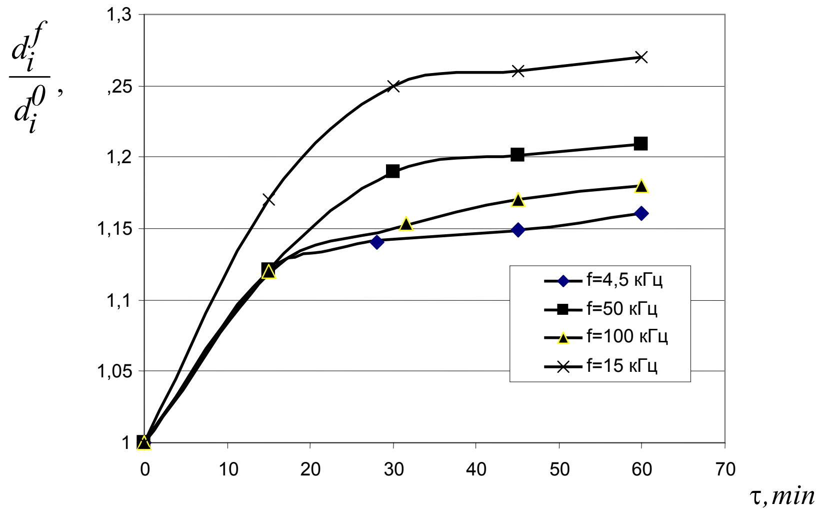


Fig. 5. Analysis of influence of frequency of acoustic fluctuations on kinetics of crystallization of ice from a solution

Analyzing the received kinetic dependences, it is possible to note the following laws:

- during a freezing-out of water from the sounded and not sounded solution growth of the block of ice is carried out non-uniform on height. More intensive growth characteristic for the bottom part of the block of ice also is caused by design features of a crystallizer and a close arrangement to radiators;
- with increase of frequency of acoustic fluctuations heat exchange in system is intensified unequally. The greatest influence is observed in a range from 15 up to 50 *κHz*. Intensity of growth of the block of ice in this range of frequencies increases on (20 … 30) % in comparison with base process;
- the greatest effect from acoustic fluctuations on process of growth of the block of ice is observed during the first 20 … 30 minutes;
- at increase in frequency of acoustic fluctuations friability of the block of ice is increase and carrying out of process of a block freezing-out of water from a solution becomes impossible.

From the resulted researches obviously, that the maximal effect in an intensification of process of a block freezing-out is reached in a range of frequencies from 15 up to 50 *κHz*. For specification of an optimum mode researches of change of power consumption (W_{el} , W) and capacities, radiation by the converter (W_{ac} ,W) are lead depending on frequency of acoustic fluctuations.

Influence of frequency on change of capacity piezo-ceramic radiators used in the experimental stand, is shown in fig. 6.

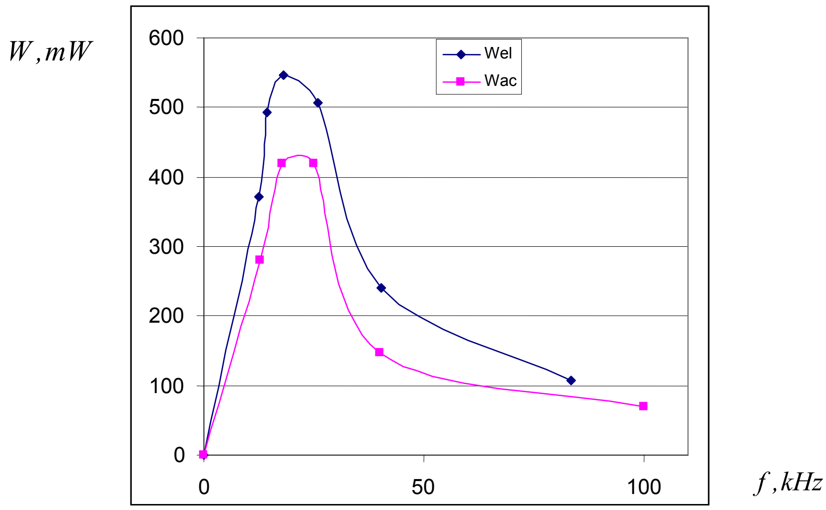


Fig. 6. Influence of frequency on change of capacity piezo-ceramic radiator

Analyzing the received results it is possible to note the following: piezo-ceramic radiator at frequency (18 … 22) *kHz* is characterized by the greatest capacity. Taking into account frequency of own fluctuations of molecules of water and also according to requirements to the technological devices using intensive low-frequency fluctuations, we shall stop on frequency equal 22 *kHz*.

At the frequency of acoustic fluctuations equal 22 *kHz* research of change of temperature fields and fields of concentration in a frozen water solutions and the growing block of ice will be lead.

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