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THE INFLUENCE OF CAVITATION EFFECTS ON THE PURIFICATION PROCESSES OF BEET SUGAR PRODUCTION JUICES

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ABSTRACT

In the juices of sugar beet, the viscosity of the produced viscosity is determined. They contain sugars and non-sugary compounds. If they are in the form of associated or complex compounds, then when their state changes. Well under the action of external factors or at their removal from a solution it is obligatory. Its rheological properties will also change. Therefore, with the help of determining the viscosity, it is possible to conclude the complex processes that take place in juices under the action of the effects of vapor condensation cavitation, namely: the force between Leculiary bonds, the size of molecules, and the length of chemical bonds, etc. The paper presents studies of the influence of vapor-condensation cavitation effects on the change of such rheological properties of cell and diffusion juice as viscosity and surface tension. The viscosity of the steam-treated juice is affected by complex transformational changes that occur with the associated compounds under the effects of vapor-condensation cavitation, which leads to their destruction and this leads to a decrease in their molecular weight and changes in concentration. Studies have shown that with increasing steam consumption for juice processing in the range of 0 – 1.5% by weight of juice the upper tension increases. Such legitimacy is also an indirect confirmation of the processes of destruction of the association. important compounds of diffusion juice under the influence of the effects of steam condensation cavitation.

Keywords: diffuse juice; associates; cavitation effects; hydrodynamic cavitation; surface tension

INTRODUCTION

Diffusion juice is a complex solution of sucrose and various organic and inorganic compounds. According to the hypothesis of L. D. Bobrovnik, most of them are contained in the form of associated and complex compounds of varying degrees of stability, and the processes occurring during the lime-carbon dioxide purification of diffusion juice are largely processes of transformation of complexes. Sucrose also takes part in it, which as a result passes to a free state **(Alves et al., 2017)**.

To destroy and remove some non-sugars from the solution by coagulation, precipitation, or adsorption, it is necessary to spend thermal energy or energy of chemical reaction, which occurs according to the typical technological scheme of juice purification in the conditions of preliminary and main defecation **(Sheiko et al., 2019)**.

Thermal energy at all stages of purification is supplied to the juice mainly through recuperative heat exchange equipment **(Sukhenko et al., 2019)**. However, as practice shows, heating the juice through the heat exchange surface is not able to cause radical changes in hydrated substances of the most common associates in the juice system, or in real complex compounds formed by metals and other, mostly organic compounds that are always present in the juice **(Zheplinska et al., 2019)**. This led to the fact that the radical destruction of natural associates in the known methods of purification is realized through the use of the energy of a chemical reaction, i.e. reagent treatment of the juice **(Zheplinska et al., 2020)**.

But this method is quite long and requires a large cost of chemical reagent. At the same time, as the experiment proves, it is possible to destroy the associated structures in another way, namely by introducing water vapor into the juice. This is especially evident in the method proposed by L. D. Bobrovnik in Cuba for the purification of raw cane juice "mesclado", i.e. in production, where the cost of purification is 0.03% by weight of raw materials (while in sugar production they are 3.0%). During the application of the method, there was an increase in the purity of the juice by more than 2 units and the sedimentation rate of the coagulated particles of colloidal dispersion substances **(Palamarchuk et al., 2019)**.

Positive results were obtained in the case of treatment of diffusion juice with water vapor with the simultaneous introduction of lime milk. The use of this method allowed not only to increase the purity of the juice and reduce its color but also to reduce the cost of lime milk for cleaning **(Bhatia et al., 2016)**.

Hydrodynamic cavitation is used in the technological processes of food production relatively recently. But the available experience of such use allows to state that from all known influences hydromechanical is the most effective **(Somaratne et al., 2019)**. Industrial studies of the use of hydrodynamic cavitation to intensify the process of pre-defecation have shown that these conditions also significantly reduces the duration of the process and improves the conditions for further processes of purification of diffusion juice **(Matyashchuk et al., 1988)**. However, the authors note that a positive effect is observed only during the formation of cavitation bubbles of size Ro = 200300 µM when there are soft cavitation regimes.

Scientific hypothesis

There are no data on the effect of steam condensation cavitation on the treated medium in the literature. It is possible that by analogy with hydrodynamic cavitation, the energy released due to the collapse of steam bubbles is sufficient to destroy some of the complex and associated compounds. If so, the constituent elements released under these conditions will be ion carriers and will be able to participate in reactions with the calcium ion. Indirect evidence of such destruction may be a change in the viscosity and surface tension of the juice.

If under the action of cavitation, the coagulation spatial structure of non-sugars is formed, which dramatically increases the strength of the system, the viscosity of the juice will increase and, conversely, in the case of destruction of associates and chains of macromolecular compounds, the mobility of the system will increase. The latter also occurs with partial complete coagulation of some compounds, such as proteins, the excretion of which should also reduce the viscosity.

MATERIAL AND METHODOLOGY

These works mainly cover the final technological result but do not consider the physical nature of the effects that occur during hydrodynamic or vapor-condensation cavitation treatment, and the mechanisms of their manifestation on the physico-chemical transformations of diffusion juice compounds, which necessarily occur. This is the subject of our research.

The direct objects of research were cellular and diffusion juices of beet sugar production. Cell juice was obtained by pressing beetroot chips on the mechanical press (Figure 1).

Diffusion juice was obtained by performing the process of extraction from beetroot chips using water, that is, extraction in the system of solid body-fluid was carried out. The study was performed on a laboratory installation of Figure 2.

Hydrodynamic cavitation is the local discontinuities of flow continuity caused by a decrease in pressure with the formation of cavities (bubbles, caverns) filled with steam, gas, or a mixture thereof, which subsequently slam (collapse) in a pulsed mode, creating a hydro in slam. The main active factor of hydrodynamic cavitation is the intense impulses created during the slam of a large number of small bubbles. Powerful micro-pulses of liquid compression with gas evolution, ionization, and rearrangement of the liquid structure, create favorable conditions for the intensification of hydromechanical, thermal, mass transfer, and chemical processes. Similar to such cavitation, phenomena occur when a jet of water vapor is injected through a nozzle into a turbulent liquid stream with less than steam pressure and a lower temperature. The bubbles of superheated vapor relative to the liquid are crushed, and then quickly condense and slam, creating microhydroshocks with similar to hydrodynamic cavitation effects – this is steam condensation cavitation. The scheme of the laboratory installation is presented in Figure 3.

Cell juice was obtained in the laboratory using a mechanical press by squeezing. Diffusion juice was also obtained in the laboratory by extraction in a screw diffusion apparatus. The extraction temperature was 75 ºC during the whole process until the dry matter content in the diffusion juice reached 14.2%. This equipment for the production of cell and diffusion juices are presented in Figure 2 and Figure 3, respectively. After squeezing the cell juice, the dry matter content of 22.8 units was also determined. The dry matter content was determined using a precision refractometer with an error of 0.01%. After obtaining the juices, they were immediately filtered through a filter with a pressure of 0.2 MPa. The filtration time was not determined because this was not the purpose of the study. It was necessary to obtain pure solutions without suspended particles so that they do not interfere with the determination of viscosity and surface tension at the temperature of the juices. Steam condensation kiting was performed on the apparatus (Figure 3) with the following parameters: vapor pressure of 0.2 MPa and an increase in juice temperature within 4 – 8 ºC. All studies were performed with beets of the same quality for 5 days, i.e. five repetitions, which showed a deviation of less than 1.5% in statistical processing.

Physical phenomena that cause a strong destructive or intensifying action are united by a general pattern: they occur in liquid media during a sharp change in external pressure and are accompanied by intense growth or flattening of the formed bubbles, if any, contained in the liquid. A distinctive feature of these phenomena is the Spatio-temporal localization of energy, which allows at a relatively low level of energy to form directed pulses of high power **(Mushtruk et al., 2020)**.

The dynamic viscosity was determined using a Hepler 9 viscometer and a rotary viscometer REOTEST.

Surface tension was measured using the Rebinder method, as well as a stalagmometer. Rebinder's method is to measure the pressure required to form and separate the gas bubble in the liquid from the surface of the capillary. The scheme of the device and the analysis was performed with the difference that the differential pressure gauge was not placed vertically but at an angle of 45, which reduced the effect of hydrostatic pressure on the accuracy of measurements.

The method of measuring surface tension using a stalagmometer is described in the following scientific papers **(Mysels, 1990)**.

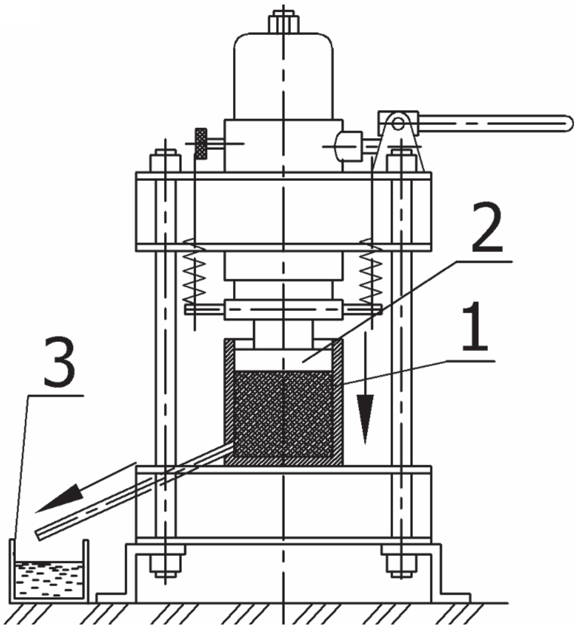

Figure 1 Mechanical press for obtaining cell juice from sugar beet. Note: 1 – cylindrical sleeve; 2 – the piston; 3 – capacity for collecting the juice.

Figure 2 Diffusion apparatus MT-131 for obtaining diffusion juice.

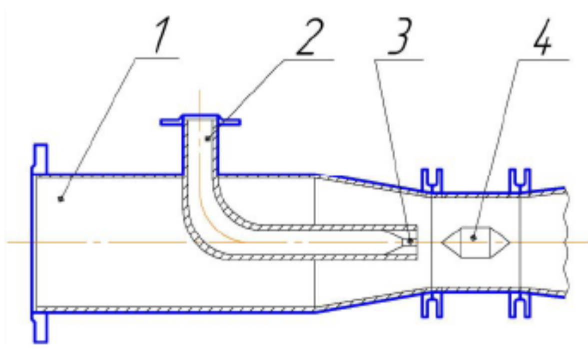

Figure 3 Steam condensation cavitation device. Note: 1 – l ime milk pipeline; 2 – a branch pipe for steam supply; 3 – nozzle; 4 – distribution insert.

Statistical Analysis

Mathematical and statistical processing of experimental data was carried out in determining the criteria of Cochran's C test, Fisher, and Student's *t*-test. The accuracy of the data was determined using the Cochrane criterion, and the adequacy of the mathematical model was checked using the Fisher and Student criteria. Statistical processing was performed in Microsoft Excel 2013 values were estimated using mean and standard deviations.

RESULTS AND DISCUSSION

Diffusion and cell juices of sugar beets were filtered, treated with steam at a constant potential of 0.2 MPa, and a temperature difference of 4 – 8 ºC. The authors of scientific works **(Buniowska et al., 2017; Verma et al., 2018; Shmyrin, Kanyugina and Kuznetsov, 2017)**, process the diffusion juice at a constant potential in the range from 0.4 to 0.7 MPa. The authors of scientific works **(Nadeem et al., 2018; Avalos-Llano, Molina and Sgroppo, 2020; Rahimi et al., 2020)**, process the diffusion juice at a constant potential in the range from 0.4 to 1.7 MPa.Using a Hepler viscometer, the determination was performed at a constant temperature of 20 ºC for the duration of the fall of the ball, the constant k of which was 0.01035 PA·cm^3.g^{-1}, the density of the ball material – 2.399 g.cm^{-3}. The value of the dynamic viscosity was determined by the formula (1):

$$\eta = \tau \times (d_1 - d_2) \times k, \qquad (1)$$

where:
η – dynamic viscosity, Pa · s;
τ – duration of falling of the ball, s;
d_1, d_2 – respectively, the density of the material of the ball and the liquid, $\frac{kg}{m^3}$;
k is the constant of the ball, $\frac{Pa \cdot m}{g}$

The results obtained are given in Table 1.

As can be seen, with increasing steam consumption, which corresponds to the more intense effect of vapor condensation cavitation on the juice, the viscosity of the latter decreases for both diffusion and cell juices. The viscosity of cell juice is always higher than that of diffusion juice, which is explained not only by the higher dry matter content but also by the preservation of the structure of associates and macromolecular compounds, which is partially destroyed in diffusion juice by thermal disaggregation. The authors of the following scientific papers **(Dalfré Filho, Assis and Genovez, 2015; Luo et al., 2019; Dhar et al., 2015)** claim that with increasing steam consumption, the viscosity of diffusion juices increases.

Similar dependencies were obtained in the case of using a viscometer REOTEST. The authors of scientific works **(Guo et al., 2018; Ozerov and Sapronov, 1985; Jiang, 2015; Almohammed et al., 2015)** used the viscosimeter of other brands and performed a chromatographic analysis of the obtained samples.

It is possible to deny the results of research, citing the fact that during the treatment of juices steamed their dilution with steam condensation. That's the way it is, but to prove that when steam is treated with steam, the decrease in viscosity occurs not only due to the dilution of the juice with condensate, we conducted studies on the effect of dilution on the viscosity of diffusion juice. The data are presented in Figure 4, which shows that when diluting the juice with distilled water to dry matter content, which is similar when treating the same juice with steam, the viscosity of the juice is greater than 6% of the viscosity of the diffusion juice treated with steam. The authors of the following scientific works **(Johnson, Zhou, and Wangersky, 1986; Lee et al., 2012; Lebovka et al., 2007)** conducted similar studies and found that the viscosity of the juice ranged from 10 – 15%.

That is, the viscosity of the steam-treated juice is affected not only by dilution but also by the complex transformational changes that occur with the associated compounds under the effects of vapor-condensation cavitation. In subsequent scientific works **(Katariya, Arya and Pandit, 2020; Kim et al., 2016; Kozelová et al., 2011; Krasulya et al., 2016)** such studies were not conducted.

Namely, they break down, which causes a decrease in their molecular weight and a change in concentration, because it is known that the greater the mass of macromolecular compounds, the greater the viscosity of their solution, as long chains of molecules interfere with fluid flow. The authors of scientific works **(Dehghannya et al., 2018; Moser et al., 2017; Zhu et al., 2016; Zdziennicka et al., 2017)** claim that the decrease in molecular weight and change in concentration change depending on the change in low molecular weight compounds.

This follows from the Staudengir equation, which relates viscosity to molecular weight by the formula (2):

$$\eta - \eta_0 / \eta_0 = kMC, \qquad (2)$$

where:
M – average molecular weight of macromolecular compounds;
C – concentration of the solution.

Also, spatial transformations of associates are possible.

Under the action of the effects of steam condensation cavitation, energy is released, which, in our opinion, causes the destruction of natural associates and increases the number of polar molecules of non-sugars of diffusion juice in the solution and thus increases the surface tension.
Therefore, the following studies were determined by us to determine the amount of surface tension of diffusion juice depending on the amount of steam entered into the juice, using the Rebinder method and using a squagometer.

The results of experiments to determine the dependence of the surface tension of the diffusion juice by the Rebinder method from the amount of steam in % to the mass of the juice that went to its treatment, are presented in Table 2.

To verify the results, we used the method of determining the surface tension using a stalagmometer. The results obtained are also presented in Table 2. As can be seen, under the influence of the effects of steam condensation cavitation, the surface tension of diffusion juice, determined by two methods, gives close in absolute value results, which show that with increasing steam consumption for juice

Table 1 Correlation of juice viscosity on steam consumption for their processing.

Type of juice	Viscosity, Pa s at steam consumption, % by weight of juice. Diffusion juice (dry matter content 14.2 %)				
	0	0.5	1.0	1.4	2.0
Diffusion juice (dry matter content 14.2 %)	1.92	1,86	1.80	1.77	1.74
Cell juice (dry matter content 22.8%)	3.04	2.87	2.78	2.70	2.66

Table 2 Influence of PC cavitation effects on the value of surface tension of diffusion juice.

Values/method	Surface tension, N/m at steam consumption, % by weight of juice			
	0	0.5	1.0	1.5
Rebinder	0.705	0.710	0.715	0.720
Stalagmometer	0.710	0.713	0.718	0.722

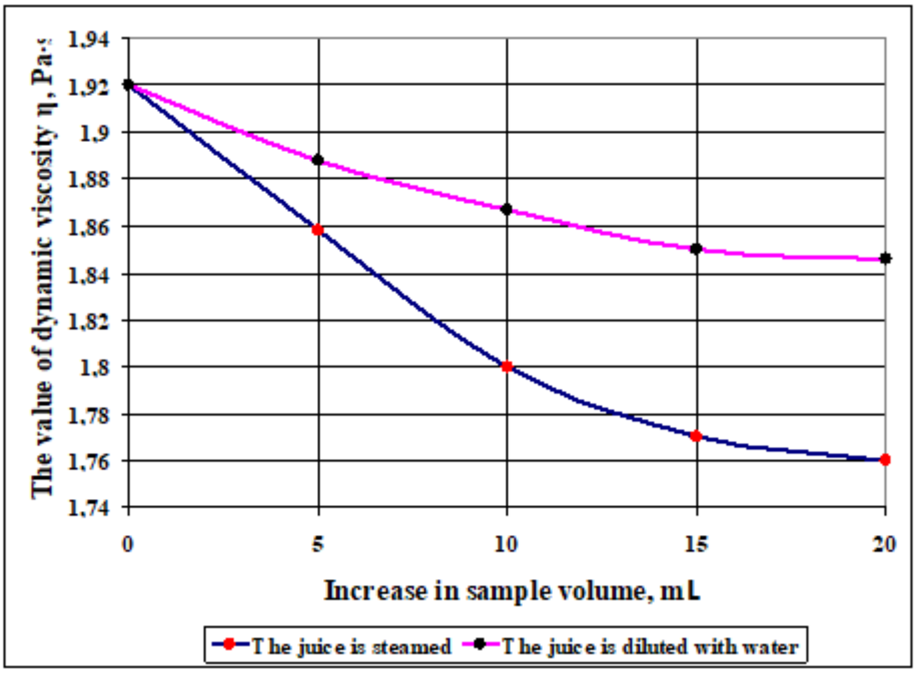

Figure 4 Change in viscosity of diffusion juice when treated with steam or diluted with water.

treatment within 0 – 1.5% by weight of juice surface tension increases.

The authors of **(Noguiera Felix et al., 2019; Sasikumar, Chutia and Deka, 2019; Cervantes-Elizarrarás et al., 2017)** conducted studies that show that with increasing steam consumption for juice treatment within 0 – 3.5% by weight of juice, the surface tension decreases. This pattern is also an indirect confirmation of the processes of destruction of the associated compounds of diffusion juice under the influence of the effects of steam condensation cavitation. However, because the difference between the final and initial values of the surface tension is within the error of the methods used, to explain the processes that occur by changing the surface tension is not entirely correct. Although in general, the constant increase in the value of surface tension confirms the hypothesis of partially destructive nature of cavitation of high molecular weight and associated compounds of diffusion juice.

Thus, it was found that the viscosity of cell and diffusion juices under the action of vapor-condensation cavitation decreases, and the surface tension increases, which indicates the destruction or change of spatial orientation of the associated and complex compounds of diffusion juice.

CONCLUSION

Thus, the application of the effects of steam condensation cavitation is a promising area of intensification of technological processes in sugar production. In many cases, cavitation processes are still insufficiently studied and quantitative relationships have not been established to calculate the effects obtained, but the implementation of proven solutions can help increase production efficiency. The paper presents studies of the influence of vapor-condensation cavitation effects on the change of rheological properties of cell and diffusion juice – viscosity and surface tension.

The viscosity of the steam-treated juices was affected by complex transformational changes that occur with the associated compounds under the effects of vapor-condensation cavitation, leading to their destruction and a decrease in their molecular weight and changes in concentration.

Studies have shown that with increasing steam consumption for juice treatment in the range of 0 – 1.5% by weight of the juice, the surface tension increases and the value of the dynamic viscosity coefficient decreases. This pattern is also an indirect confirmation of the processes of destruction of the associated compounds of diffusion juice under the influence of the effects of steam condensation cavitation.

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Conflict of Interest:

The authors declare no conflict of interest.

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