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Influence of the parameters of the impact of electrical impulses on the yield of juice from the pulp

N Eshpulatov[1*], T Khalmuradov[2], F Rakhimov[3], S Abdurayimov[4], A Khurramov[4], U Ruziyeva[4], T Normetov[4], and I Maftuna[4]

[1]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, Kory Niyoziy str., 39, 100000, Tashkent, Uzbekistan
[2]Tashkent State Agrarian University, University str., 2, Tashkent region, Uzbekistan
[3]Navoi State Mining and Technological University, 27 Galaba Str., Navoiy region, Uzbekistan
[4]Chirchik higher tank command engineering school, Amir Temur str., 15, 111718, Tashkent region, Uzbekistan

[*]Email: nodir_1885@mail.ru

Abstract. This article presents the results of experimental studies to determine the effect of electrical impulse processing parameters on the output of juice from the pulp. It is based on the effect of pulse energy and voltage on apple juice. The influence of an electrical impulse on the production of juice before pressing fruit pulps has been studied. It is based on the optimal parameters of the grinding rate of the raw material, which affects the efficiency of processing with electric pulses. An additional large amount of juice was detected after the pulp was treated with electrical impulses. Based on the voltage dependence of the juice obtained from the raw material and the direct interaction of the field with the electrically charged system of the cell protoplasm.

1. Introduction
Our studies of the effect of electric current on plant tissue, the results of which are presented in [19, 22, 23], showed that under the influence of electric impulses, the protoplasm of cells is destroyed, and this leads to an increase in the yield of juice during the pressing of pulp subjected to such an effect. It was shown that the rate of juice output to some extent depends, among other things, on the magnitude of the specific pressure on the pulp. A certain influence on the juice yield is exerted by the choice of the stage of the pressing process, at which the pulp is processed with electric pulses. Therefore, it was necessary to link all these dependencies with each other and choose the optimal modes of processing raw materials with electric pulses [3-12].

It is quite clear that the parameters of the pulses themselves will have a noticeable effect on the juice yield. In the literature [1, 2] there are indications of a significant effect of the potential gradient on the efficiency of processing pulp with an alternating electric current of industrial frequency. We had to find out how the total energy of impulses and voltage affects the juice output. By reducing the capacitance of the capacitors and, accordingly, increasing the voltage, it is possible to reduce the cost of electrical energy for processing the pulp. All these considerations dictate the need to determine the optimal parameters of pulses and modes of pulp processing with such electrical pulses [13, 14, 15, 16, 17, 18].

2. Materials and methods

We carried out experiments in which the total pulse energy for different voltage values remained constant. These experiments were supposed to show how the potential gradient affects the efficiency of pulp processing. The experiments were carried out according to the scheme presented in Table 1.

Table 1. Scheme of conducting experiments to determine the effect of voltage and total pulse energy on the yield of juice from apples (Capacitance - 0.125 microfarads; Specific pressure - 8 kgf/cm2; The degree of grinding - 0.183; The duration of the pressing process is 50 minutes; Processing with electrical impulses - 30 minutes after the start of pressing)

Total pulse energy, J	Number of pulses at voltage U (kV)			
	10	20	30	40
250	40	10	4	3
500	80	20	9	5
750	160	40	18	10
1000	320	80	36	20

The experiments were carried out in the following sequence. A weighed amount of apple pulp was placed in a press chamber with electrodes lined with a linen cloth. The pulp was evenly distributed over the volume of the chamber, a pressing plate was installed, and pressure was applied to the pulp with a hydraulic press. The outgoing juice flowed down the tray into a measuring cup. The time of the start of pressing and recording of instrument readings was noted with a stopwatch. At certain time intervals, the amount of juice released from the pulp was measured. After 30 minutes of pressing, when practically no juice came out of the pulp, a series of electrical impulses were applied to the chamber and, while continuing pressing, an additional output of juice was recorded. The pressure was kept constant throughout the experiment [20, 21, 22, 23].

These and all subsequent experiments on the processing of the pulp with electric pulses were carried out on an experimental setup created on the basis of the B-140-5-2 device.

3. Results and Discussion

The experiments were carried out in triplicate. After each experiment, the pomace briquette was weighed to determine the unaccounted for juice losses. These losses did not exceed 0.5%. Table 2 shows the results of one of the experiments in this series.

Table 2. The output of juice from the pulp, with its processing by electrical impulses (Pulp treatment with electrical impulses - 30 minutes after the start of pressing; Voltage - 20 kV; Capacitance - 0.125 microfarads; Total pulse energy - 500 J; The degree of grinding - 0.183)

Time min.	Specific pressure kgf/cm^2	Juice output	
		ml	AT %
1	2	71	21.5
2	4	116	35.4
3	6	140	42.5
4	8	158	47.8
5	8	170	48.5
10	8	194	59.0
15	8	199	60.1
20	8	204	61.8
30	8	209	63.4
35	8	222	67.1
40	8	230	69.9
50	8	238	72.1

It can be seen from the table that after processing the pulp with electrical impulses, almost an additional % of juice comes out of it. It should be noted that in calculating the percentage of juice yield, we took its specific gravity equal to one, that is, the true percentage of juice yield was slightly higher, since the specific gravity of the juice is slightly more than one. This greatly simplified the calculations, and the error was only a fraction of a percent.

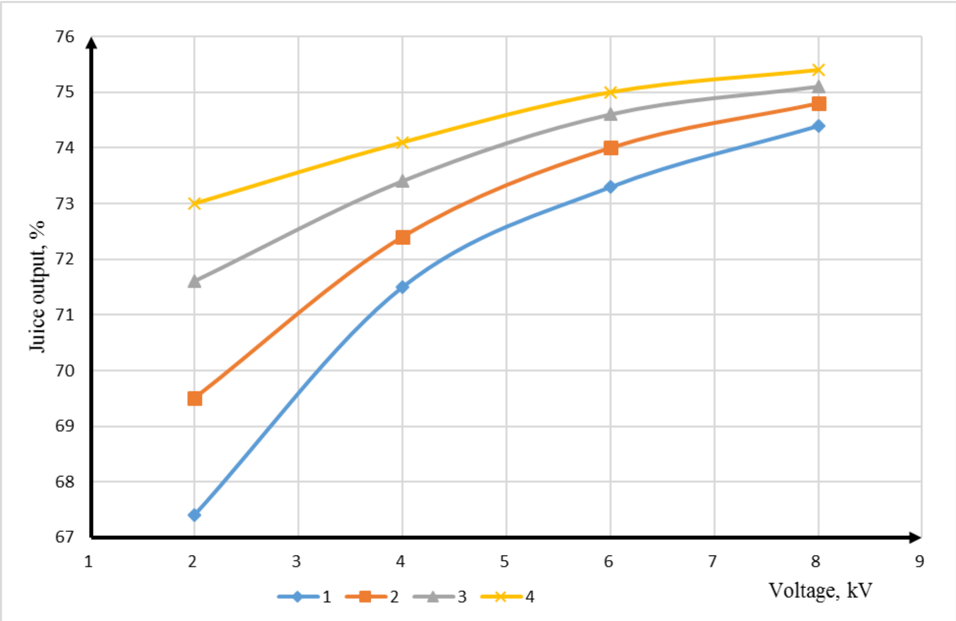

Figure 1. Dependence of apple pulp processing efficiency on voltage and total pulse energy (1 - 250 J, 2 - 500 J, 3 - 750 J, 4 - 1000 J)

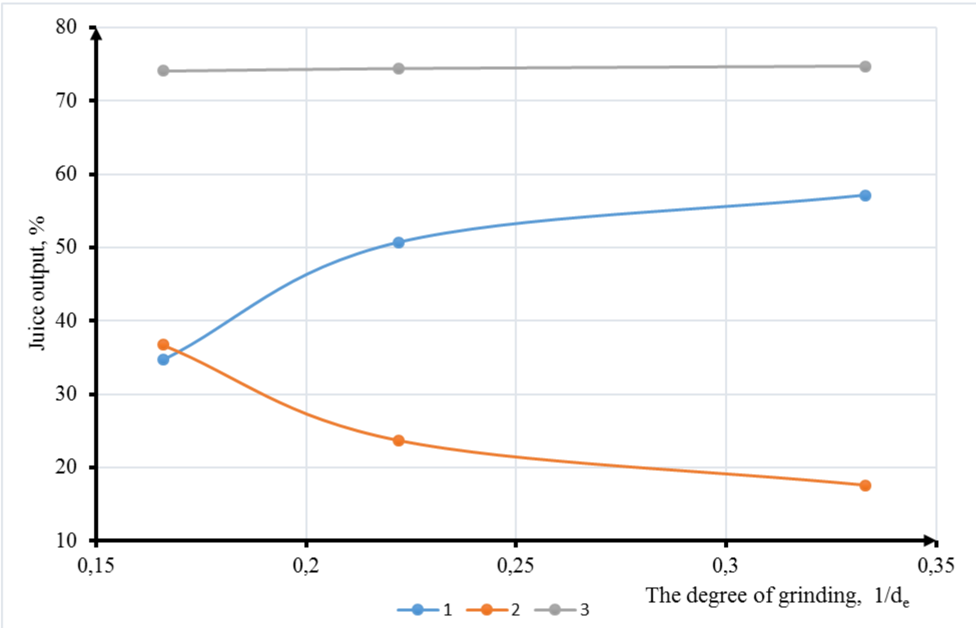

Figure 2. Influence of the degree of grinding of raw materials on the efficiency of processing with electrical impulses. Juice output: 1-before electrical treatment; 2-after electrical treatment; 3-total. Voltage 20 kV, Specific pressure 8 kgf/cm^2, total pulse energy 250 J, pulp treatment with electric pulses - 20 minutes after the start of pressing

The processed results of the experiments carried out to determine the dependence of the yield of juice from apples on the electrical processing parameters are summarized in Table 3.

Analysis of the results of the experiments, graphically presented in Figure 1 shows that with an increase in the total pulse energy, as well as with an increase in voltage, the juice yield increases. But the effect of voltage on the yield of juice from raw materials is much stronger than the energy of pulses.

So, at a constant pulse energy, a twofold increase in voltage has the same effect on the juice output as an increase in the total pulse energy by a factor of 4. This suggests that electrical impulses have a specific effect on tissue cells. If the influence of such an impact consisted only in the thermal effect of heating the protoplasmic membranes, which is usually used to explain the destructive effect of electric current on cells, then the same output of juice should have been obtained at constant values of the total pulse energy, regardless of the magnitude of the voltage. But this is not. There is a clear voltage dependence.

Table 3. Summary table for determining the yield of juice from apples depending on the voltage and total pulse energy (Specific pressure - 8 kgf/cm^2; Capacitor capacitance - 0.125 microfarads; Treatment with electrical impulses - 30 minutes after pressing; Juice yield in 30 minutes - 64%; Duration of pressing - 50 min.; The degree of grinding - 0.183)

Voltage, kV	Total energy, J	Juice yield in %	
		additional output	Total
10	250	3.2	67.2
	500	5.6	69.6
	1000	7.4	71.4
	2000	9.0	73.0
20	250	7.5	71.5
	500	8.5	72.5
	1000	9.3	73.3
	2000	10.0	74.0
30	250	9.4	73.4
	500	10.1	74.1
	1000	10.5	74.5
	2000	10.8	74.8
40	300	10.6	74.6
	500	10.9	74.9
	1000	11.1	75.1
	2000	11.3	75.3

The presence of a clear relationship between the efficiency of electrical action on the cells of plant tissue and the magnitude of the voltage used for this purpose, apparently, is associated with the direct interaction of the electric field with the electrically charged system of protoplasm. Perhaps, in this case, electrophoretic interaction and force deformation take place.

Of course, the thermal effect of electrical action cannot be completely excluded. But it prevails under relatively weak impacts on plant tissue, which is confirmed by experiments with low voltage, but high total pulse energy.

The experiments carried out showed that in order to obtain good results in the processing of pulp with electrical impulses and in order to reduce the specific consumption of electrical energy for such processing, it is advisable to follow the path of increasing the applied voltages and a corresponding decrease in the value of the storage capacity. The use of high voltages for the processing of plant materials has a number of other significant advantages over the use of alternating current with a frequency of 50 Hz and a voltage of 220/380 V, which will be shown below.

We have carried out comprehensive studies of the impact on the yield of juice from table beet pulse energy, the degree of grinding of raw materials, the stage of the juice extraction process, at which the pulp was processed with electric pulses. These experiments were carried out according to the same procedure as the experiments with apples. The degree of beet grinding was determined by the method described in [22, 23]. Different values of the total pulse energy were obtained by changing the number of pulses.

The results of two experiments of this series of experiments are shown in Table 4.

The results of the experiments, shown in table 4, show the dynamics of the output of juice from the pulp with large and small particles. From pulp with a high degree of grinding, more juice comes out in the first 20 minutes of pressing and the rate of its release is higher than from pulp with large particles. Processing the pulp with electrical impulses leads to an additional yield of juice. At this stage of the pressing process (after exposure to electrical impulses), the rate of juice output and its amount are greater for pulp with large particles and, thus, by the end of pressing, almost the same total juice output is obtained, regardless of the degree of grinding of the raw material. From this we can conclude that the total yield of juice depends on the degree of cell destruction (grinding and exposure to electrical impulses), and the rate of juice yield at the initial stage of the process depends on the degree of grinding of raw materials.

Table 4. Dynamics of juice yield during pressing beet pulp, with its processing by electric impulses (Pulp processing - 20 minutes after the start of pressing; Voltage - 20 kV; Capacitance - 0.125 microfarads; Total pulse energy - 500 J)

Time, min.	Juice output			
	The degree of grinding, $1/d_e$ = 0,166		The degree of grinding, $1/d_e$ = 0,333	
	ml	% by weight	ml	% by weight
1	50	20.0	56	22.3
2	66	26.4	88	35.2
3	71	28.6	103	41.2
5	79	31,8	113	45.4
10	87	34.8	126	50.4
15	91	36.6	135	54.2
20	93	37.4	143	57.2
30	149	59.6	164	65.8
50	189	75.6	194	77.6

The processed results of a series of experiments with table beets are summarized in Table 5.

An analysis of the data given in this table shows that after processing the pulp with electrical impulses, a significant amount of juice additionally comes out.

The efficiency of this treatment is greater for pulp with large particles. This can be seen from the graph shown in Figure 2. With an increase in the degree of grinding, the juice yield increases, without any additional processing of the pulp, but, accordingly, the proportion of juice that comes out after processing the pulp with electrical impulses decreases. This indicates that the parameters of such an electrical effect on the pulp provide a fairly complete destruction of all, or almost all, cells. In addition, the data obtained confirm that there is some upper limit to the possible yield of juice during the pressing of vegetable raw materials, no matter how the pulp is prepared.

Table 5. Summary table of the results of experiments to determine the effect of pulse energy, the start time of electrical treatment and the degree of grinding of table beets on the juice yield (Specific pressure - 8 kgf/cm^2; Voltage - 20 kV; Capacitance - 0.125 microfarads; Pressing time - 50 minutes)

Total pulse energy, J	The moment of the beginning of the electrical treatment, min	The degree of grinding, $1/d_e$								
		0.166			0.222			0.333		
		Juice yield in %								
		Before electrical processing	Additional output	Total	Before electrical processing	Additional output	Total	Before electrical processing	Additional output	Total
250	5	31.3	42.8	74.1	40.2	34.2	74.4	46.2	28.5	74.7
	10	35.1	39	74.1	45.4	29	74.4	50.8	23.9	74.7
	20	37.4	36.7	74.1	50.7	23.7	74.4	57.1	17.6	74.7
500	5	31.3	43.7	75	40.2	35.6	75.8	46.2	30.3	77.5
	10	35.1	39.9	75	45.4	30.4	75.8	50.8	25.7	77.5
	20	37.4	37.6	75	50.7	25.1	75.8	57.1	19.4	77.5
1000	5	31.3	45.2	76.5	40.2	37.3	77.5	46.2	32.6	78.8
	10	35.1	41.4	76.5	45.4	32.1	77.5	50.8	28	78.8
	20	37.4	39.1	76.5	50.7	26.2	77.5	57.1	21.7	78.8

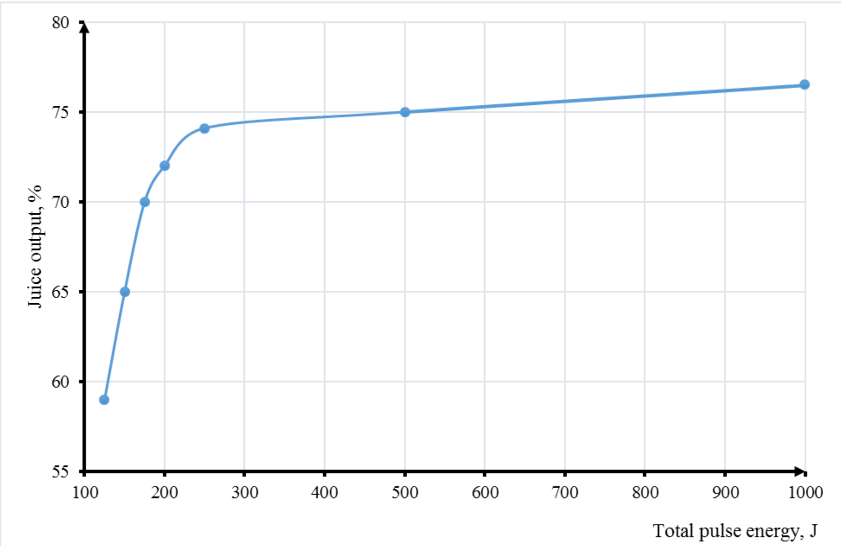

Figure 3. Juice yield from table beets depending on the total pulse energy: U=10 kV; $1/d_e$=0.166; t =20 min; T=50 min

Of great interest was the determination of the optimal energy of a series of electrical impulses, which ensures the destruction of most plant tissue cells. For this, additional experiments were carried out, in which, 20 minutes after the start of pressing, the compressed pulp was exposed to a series of pulses with a total energy of 125; 150; 200; 250 joules at 10 kV. The processing of the pulp with electrical impulses was carried out 20 minutes after the start of pressing. The entire juice pressing cycle lasted 50 minutes. The pressure during the experiment was maintained constant and was equal to 8 kgf/cm2. Based on the data of these experiments and the results of the experiments given in Table 5, the graph shown in Figure 3. The inflection point on this graph determines the optimal total energy of impulses that ensure the destruction of most cells. A small increase in the total juice yield with a further increase in the pulse energy shows that a certain number of cells still remain intact. Apparently, these are cells located in the very thickness of large particles, and the cells are somewhat more resistant to force impacts.

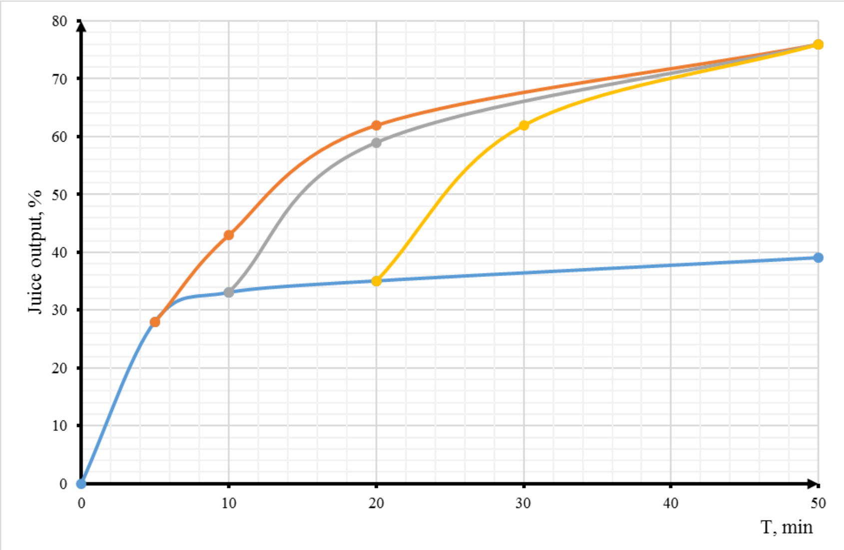

Figure 4. Influence of the start time of pulp processing by electric pulses on the juice output from it (W_c=1000 J, U=10 kV, 1/d_e=0.166)

When calculating the optimal value of the pulse energy for processing the pulp, one should take the values that ensure the destruction of most tissue cells. If such calculations are based on the maximum possible juice yield, then the costs of electrical energy for such processing may be unreasonably high and, in addition, the process time will increase significantly. Additional yield of juice due to this is only a fraction of a percent of its total yield from raw materials. Therefore, it is inappropriate to take into account the optimal energy of the pulses the upper limit of the possible output of juice, and apparently it can be limited to 97-98% of the maximum value.
Experiments to determine the effect on the juice yield of the moment when the impact of electrical impulses on the pulp during the pressing process (see Table 5 and Figure 4) showed that the total juice yield at the parameters of the electrical exposure, ensuring the destruction of most cells, practically does not depend on the choice of this moment . It follows that the choice of the moment of processing the pulp with electrical impulses should be made based on other considerations - technological and taking into account the structural and mechanical properties of the pulp, which are continuously changing during the pressing process.
To determine the effect on the juice yield of the value of the specific pressure of pulp pressing of various degrees of grinding, a series of experiments was carried out on table beets. The effect on the juice yield of the specific pressure of pulp pressing of various degrees of grinding was determined and the data obtained were compared with the juice yield from the pulp subjected to electrical impulses. The data of these experiments are shown in Table 6.

Table 6. Dependence of the yield of juice from table beets on the degree of grinding and specific pressing pressure

The degree of grinding, 1/d_e	Juice yield in % at specific pressure on the pulp		
	4 kgf/cm^2	6 kgf/cm^2	8 kgf/cm^2
0.166	24.1	31.6	39.0
0.222	37.5	44.8	52.1
0.335	46.2	52.5	59.0

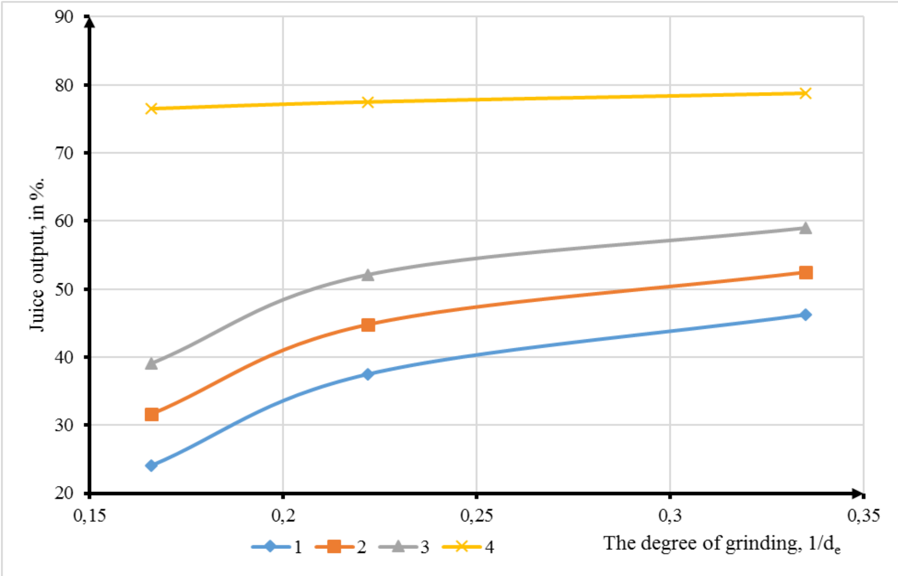

Figure 5. Influence of the specific pressure of pressing and pulp processing by electric impulses on the juice output. Specific pressure: 1-4 kgf/cm^2; 2-6 kgf/cm^2; 3-8 kgf/cm^2; 4-8 kgf/cm^2+el. impulses U=10 kV, W_c =1000 J.

Based on the results of these experiments and experiments, the results of which are summarized in Table 5, the graph shown in Figure 5. This graph characterizes the dependence of the yield of juice from crushed table beets on the specific pressure on it. The same graph shows curve 4, which characterizes the yield of juice from pulp processed with electrical impulses. As follows from the consideration of the given data, with an increase in the degree of grinding of raw materials, as well as with an increase in the specific pressure of pressing, the juice yield increases, but the influence of the first factor is noticeably greater at given values of the specific pressure. This shows the great influence of the operation of grinding raw materials on the quality of the preparation of the pulp and on the yield of juice during pressing without the use of electrical impulses for processing the pulp.

The yield of juice from pulp treated with electrical impulses is much higher than from pulp not subjected to such an effect of electricity. In this case, the influence of the degree of grinding of raw materials on the juice yield is insignificant. A decisive influence on the yield of juice is exerted by the action of electrical impulses on the cells of plant tissue. In this regard, it was necessary to find out what role the operation of grinding raw materials should play in the process of obtaining juice by pressing the pulp processed by high-voltage pulses. It was also necessary to determine the optimal values for the given case of the degree of grinding of raw materials.

4. Conclusions

It is shown that the efficiency of the action of electrical impulses on the crushed plant tissue depends both on the total energy of the impulses and on the voltage. The influence of the latter is stronger. An increase in voltage by a factor of two is equivalent in terms of the impact force to an increase in the total energy of pulses by a factor of 4.

Based on the dependence of the yield of juice from raw materials on voltage, one can speak of a direct interaction of the field with an electrically charged system of cell protoplasm. At high voltages, the influence of the thermal effect of the current is much overridden by this force interaction.

It has been established that the degree of grinding of raw materials in preparation for pressing using electrical impulses should be determined by the task of ensuring optimal hydrodynamic conditions for juice drainage. The high yield of juice is ensured by the selection of optimal parameters for the impact of electrical impulses.
The moment of processing the pulp with electrical impulses affects the rate of drainage of the juice and practically does not affect its overall yield from the raw material. This moment is determined taking into account the technological and structural-mechanical properties of the pressed pulp, which is a solid-liquid body.

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