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Vortex electromagnetic field system (AVS unit)

Introduction.

Electromagnetic systems with ferromagnetic elements are designed to intensify various physical and chemical processes.

The systems are air tight, do not require dynamic seals and consists of an electromagnetic dives with cooling system, operating chamber and a control panel.

AVS-100. General view

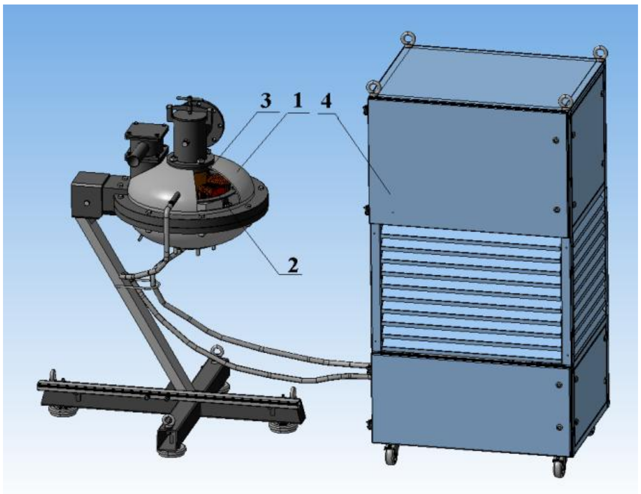


Fig. 2 AVS -150. Internal inductor diameter 150 mm, operating chamber diameter 136 mm.
1 – inductor body; 2 – EMF inductor; 3 – operating chamber; 4-controls.

AVS-150. General view

The control and cooling systems of AVS-150 are separate from the unit.

The systems are reliable, simple to install without special foundations. It is possible to arrange multiple units for increased processing capacity of a production line.

Processes in AVS are intensified by mixing and dispersion of components, acoustic and electromagnetic influence, high local pressures and electrolysis.

The units can be efficiently used in many industries: construction, machine building, chemical, agricultural, food production, mining and pharmaceutical. It is used for production of multicomponent emulsions and suspensions, acceleration of production of finely dispersed mixtures, activation of materials both in dry form and dispersed in water, leading to improve properties of resin and decreased vulcanizing time; for complete purification of industrial waste water from phenol, formaldehyde, heavy metals, arsenic, cyanides, acceleration of heat treatment, production of protein material from yeast cells; improvement of microbiological stability of food products and activation of yeast in bread baking; improvement of crude products and finished *products from meat and fish; intensification of extraction processes, including production of broth, juice, pectin etc; production of suspensions and emulsion of increased microbiological safety in food production without the used of staibilizers and increase of product output.*

Electromagnetic vortex generator specifications

Parameter	Type	
	AVS-100	**AVS-150**
Max processing rate, m^3/hour – water water treatment	12	30
– suspension production	5	15
Operating pressure, MPa (kg/cm^2), max:	0,25 (2,5)	
Work zone diameter, mm	90	136
Magnetic induction in work zone, T	0,15	0,15
Electric supply	From AC network	
Frequency, Hz	50	50
Voltage, B	380	380
Rotation of magnetic field in work area, RPM	3 000	3 000
Power consumption, kW	4,5	9,5
Dimensions, mm – unit	1200×900×1610	1300×1100×1 690
– controls	–	1 060×1030×1 900
Weight, kg – unit – controls	520	500 450

1.1 AVS principle of operation and design

The unit operates on the principle of transforming the energy of electromagnetic field into other forms of energy. The unit is a chamber (pipeline) of 90-136 mm diameter, located inside rotating electromagnetic field inductor. There are ferromagnetic cylindrical elements of 0.5 – 5 mm diameter and 5 – 60 mm length in the operating area, from several dozen to several hundred (0.05 – 5 kg), depending on the volume of the work zone (Fig. 3).

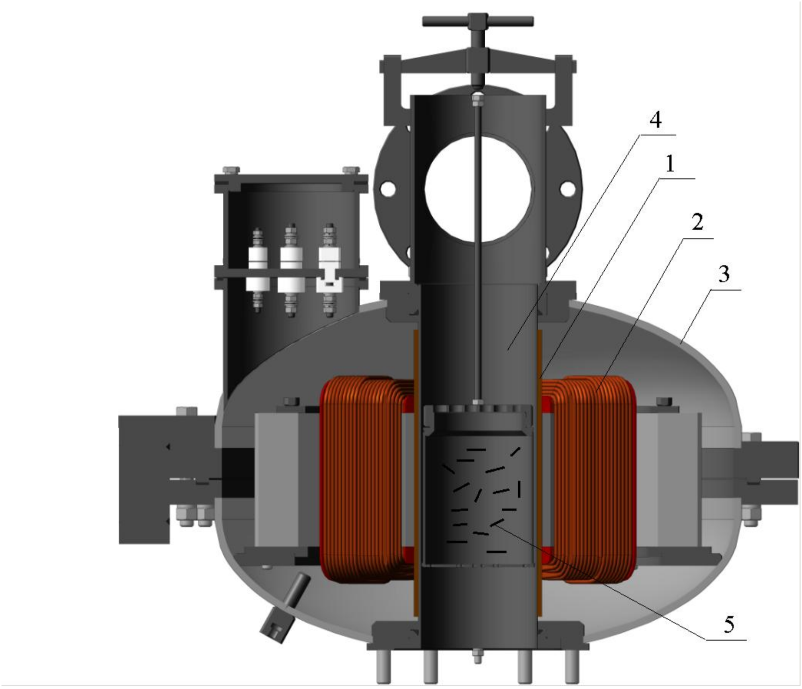


Fig. 3. Electromagnetic vortex system:
1 – protective bushing; 2 – inductor of rotating electromagnetic field;
3 – inductor body; 4 – non-magnetic material work operating chamber;
5 – ferromagnetic elements

The main components of electromagnetic units with vortex layer are: the inductor of rotating electromagnetic field with cooling system, connected to three phase 380/220V, 50Hz power supply, and operating chamber with ferromagnetic elements (Fig. 3).

The rotating electromagnetic field causes the ferromagnetic elements in the work zone to move and create the so called “vortex layer” (Fig. 4).

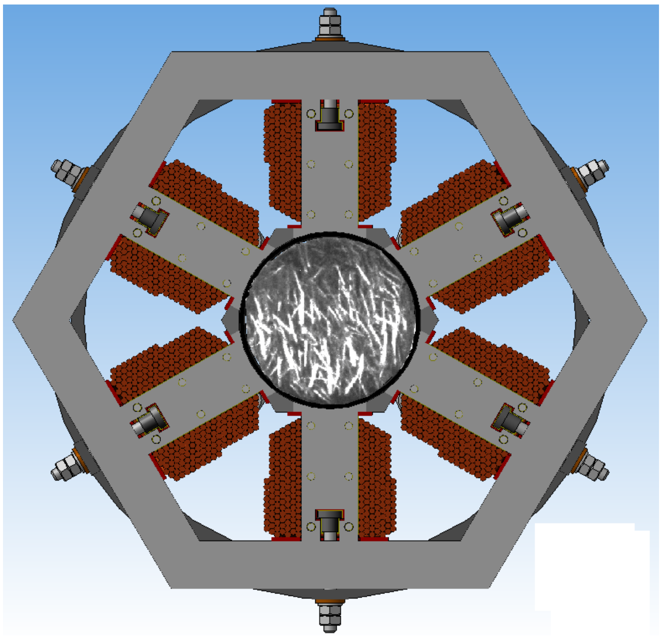


Figure 4. A photo of vortex layer (1000 frame per second camera)

In production of these electromagnetic devices the important parameters are magnetic field parameters and the dimensions of the chamber. The magnetic field of the inductor is characterized by strength, which does not depend on the medium, but only on the geometry of the contour and electric current, measured in A/m. The main characteristic of power interaction between the magnetic field and the electric current is magnetic induction, measured in tesla or in gauss.

The strength of electromagnetic field in the operating area of the AVS depends on the purpose of the unit and varies between 6.4×10^4 and 20.0×10^4 A/m.

The important parameter in the inductor is the length and bore diameter. Calculations show that with the ratio of inductor's length (l_{in}) to bore diameter D_{in} up to 0.3, the current of salient pole inductor is less than that of non-salient pole. With larger $\frac{L_{ін}}{D_{ін}} \succ 0{,}3$ a non-salient pole inductor consumes less current.

To optimize energy consumption and for better manufacturing technology, the AVS-100 and AVS-150 use salient pole inductors, which draw less current (Fig. 5).

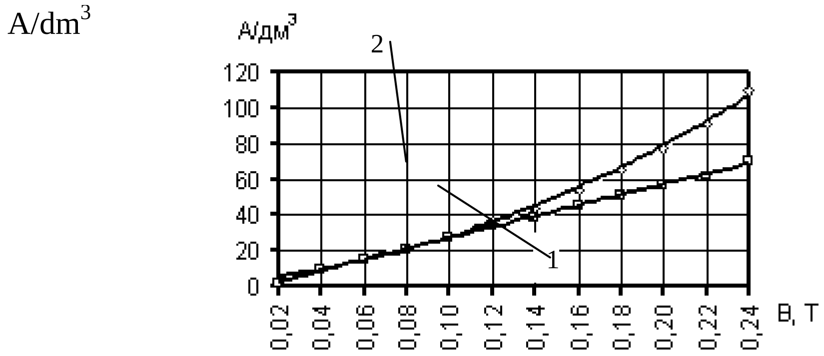


Figure 5. The current consumed by inductor windings to obtain required induction in the center of the inductor bore

1 – non-salient pole inductor $\frac{L_{ін}}{D_{ін}} = 0{,}86$;

2 – salient pole inductor $\frac{L_{ін}}{D_{ін}} = 1{,}0$.

It is important that the magnetic field is even in radia and longtitudinal section of the unit's chamber.

Figure 6 shows the main characteristics and values of magnetic induction along the inductor's bore with bore diameter 100 mm and $l_{in}/D_{in} = 1$.

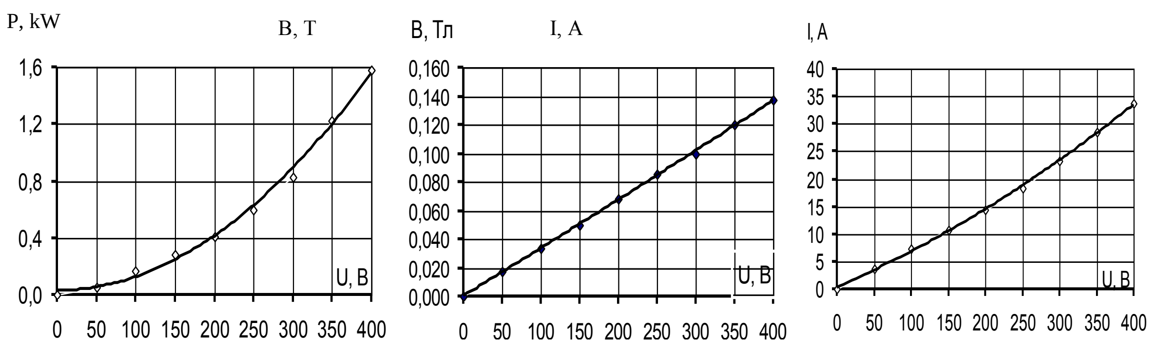


Fig. 6. Dependency of main characteristics of a salient pole rotating electromagnetic field inductor on voltage in windings (bore diameter – 100 mm, core length – 100 mm)

Energy consumption in the inductor depends on its internal geometry and field strength.

Consumption of energy in the chamber is defined only by its design, material and the thickness of the walls and does not depend on magnetic field strength. To reduce energy consumption, we manufacture the chamber from a non-magnetic material (stainless steel). The chamber can be designed in several ways depending on the requirements of the processes in the chamber.

For liquid phase processes, strainers are installed on the sides of the bush, or at outlet end only (Fig.7). If fibrous materials are processed, labyrinth type strailers are installed. These devices hold the ferromagnetic particles in the work zone.

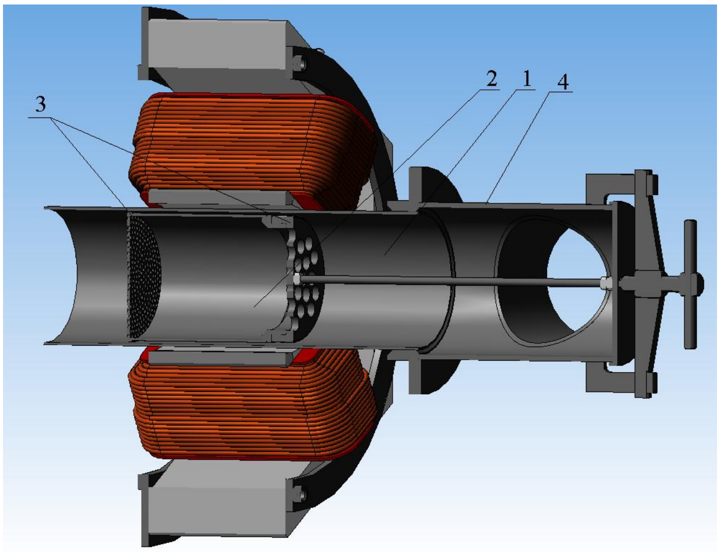


Fig. 7. The chamber of AVS for liquid phase processes:
1 – chamber; 2 – bush; 3– strainer;

Granulation and mixing may be performed not only by ferromagnetic pellets, but also by knoves (fig. 8), tubes (fig.9) or rotor (fig.10). In these cases the strainers function as filters (separators).

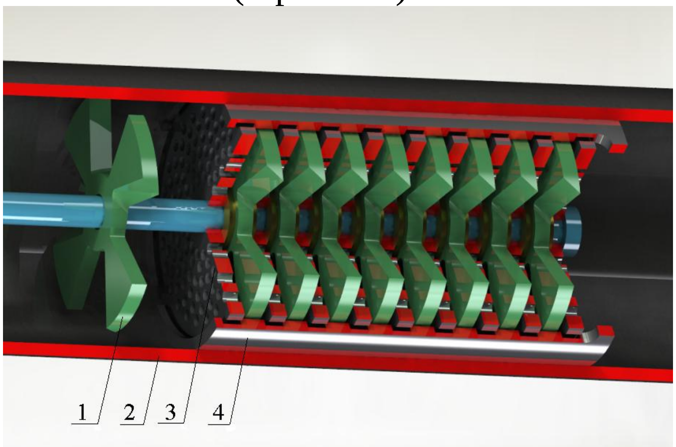


Fig. 8. AVS chamber with knives:
1 – knoves; 2 – chamber; 3– mesh filter; 4 – bush.

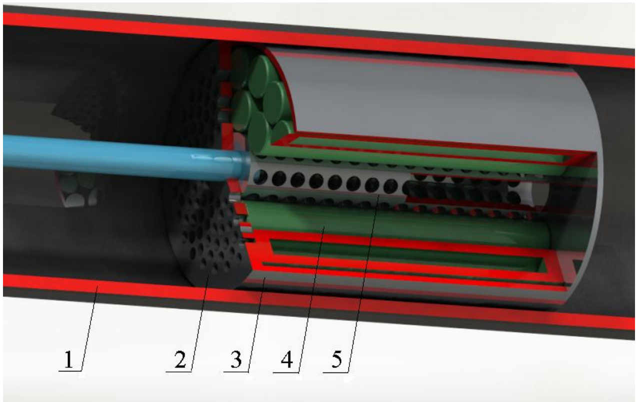


Fig. 9. AVS chamber with tubes:
1 – chamber; 2 – mesh; 3 – bush; 4 – tubes; 5 – filter tube.

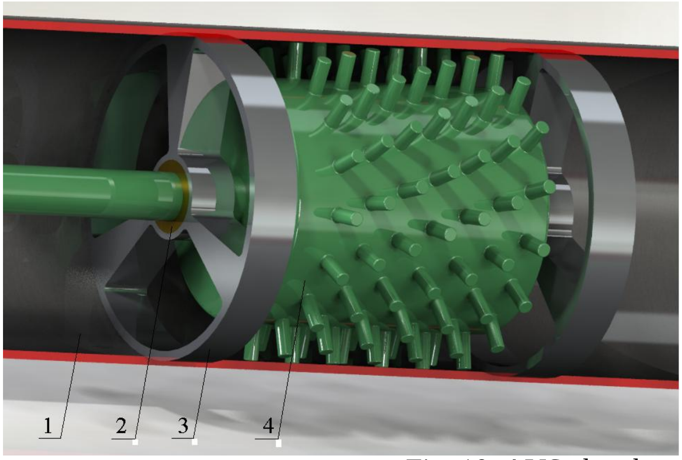


Fig. 10. AVS chamber with rotor:
1 – chamber; 2– bronze bushings (lubricated and cooled by the processed liquid); 3 – lid; 4 – rotor.

Ferromagnetic cylindrical elements, knives or tubes may be made of carbon steel, nickel etc (any ferromagnetic metal). For example, cylindrical ferromagnetic elements may be manufacture with wires or use rollers of needle bearings.

If necessary to prevent contact of the ferromagnetic material with the processes materials, the former can be covered with a polymer (polyethylene, polyvynilchloride, fluoroplast etc).

Ferromagnetic elements are added into the active zone by electromagnetic portioner (Fig. 11):

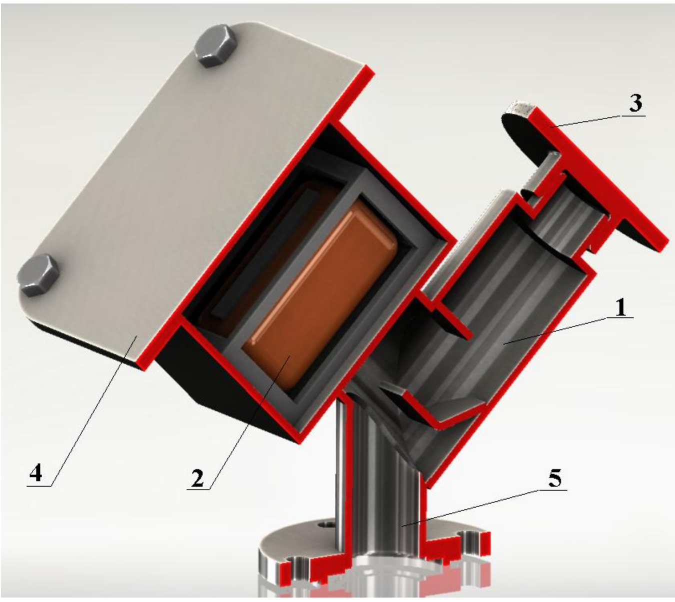


Fig. 11. Ferromagnetic element portioner:

1 – loading hopper; 2– electromagnet; 3 – lid; 4 – electromagnet body; 5 – supply chamber.

1.2. Energy performance of AVS

When the chamber with ferromagnetic elements is placed in the inductor of the rotating EM field, power consumption increases significantly; that energy is consumed by heating of the elements and by the processes occurring in the vortex layer during operation. Power consumption is influenced by the number of ferromagnetic elements in the chamber and their magnetic properties (fig. 12, table 1). The dimensions of the FE influence power consumption insignificantly, while the processed suspension in the chamber has no influence at all.

P, kW

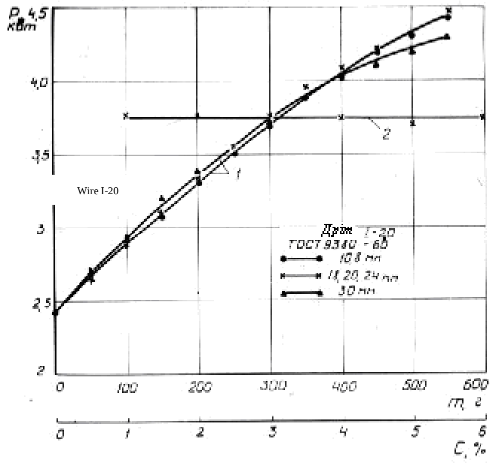


Fig. 12. Influence of weight and dimensions of FE on power consumption in AVS (inductor bore diameter 100 mm, ferromagnetic elements made of spring wire d = 2 mm):
1 – with varying length of FE;
2 – with varying concentration of cellulose suspension.

Table 1

Energy performance of AVS (inductor bore diameter 100 mm, EM field strength in the chamber H = 12.0 · 10^4A/m; ferromagnetic elements: d = 1.6 mm, $\frac{l}{d} = 10$; process: treatment of 3 % cellulose suspension)

FE weight in the chamber, g	Consumption of active power in the unit when using FE from various materials, kW			
	Steel 65 G	Steel 08G2S	Steel SH-15	Nickel NP-2
0	2,40	2,40	2,40	2,40
100	2,88	2,88	2,74	2,56
200	3,36	3,28	3,08	2,72
300	3,76	3,76	3,41	2,88
400	4,08	4,08	3,75	2,96

The above allows the conclusion that power is consumed by creation of the vortex layer, as well as the job it does, and is not a constant, depending mostly on the material of the FE and their number in the chamber. For ferromagnetic elements of carbon steel, it is in the range of 1.43–3.6 kW/kg and depends on the EM field inductor design (Table 1).

A significant portion (up to 48 %) of vortex layer power is spent on heating, stirring and pulverization (up to 35 %). The interaction between the FE and the bushing creates difference of potentials up to 17 mV, pulsing with the frequency 4–10 ms. This causes electrolysis in electrically conductive media, which consumes up to 15% of vortex layer energy, while only about 2% of energy is spent on creation of high frequency MF and acoustic waves in the media (Section 1.3).

1.3. Factors influencing efficiency of AVS processes

1.3.1. Movement of ferromagnetic elements in the vortex layer

Many factors influencing the process and its result depend on movement and collisions of ferromagnetic elements in the EMF of the unit. For each process we need to know the optimal velocity of the FE to create the required pressure and frequency of collisions. Data obtained shows that the frequency of element vibration f

and frequency of their collisions depends on the density of the vortex layer $\left(\frac{h}{l}\right)$, i.e. the coefficient of filling the chamber with FE. The coefficient equals to the ratio of the total volume of ferromagnetic particles in the vortex layer to the volume of the chamber's active zone.

Calculations show (Table 2) that the frequency of vibrations and the angular velocity of the elements may be changed by changing the strength of the external electromagnetic field. That is, the intensity of the process may very as required by the technology.

Table 2

Dependency of frequency and angular velocity of a ferromagnetic element on the strength of the external electromagnetic field $\left(\frac{h}{l} = 0,75; K_1 = 1,31\right)$

Parameters	**Electromagnetic field strength $H \cdot 10^{-3}$, A/m**					
	120	**135**	**150**	**165**	**180**	**200**
Collisions per second	362	410	476	538	564	646
Element vibration freuqncy *f*, Hz	332	350	380	412	448	490
Maximum angular velocity of the element at impact $\dot{\varphi}_{max}, c^{-1}$	1 992	2 080	2 124	2 228	2 246	2 359

K_1 – resistance of the media (found experimentally) (K_1 = 1.31 for water)

Considering the size of the ferromagnetic elements, the contact surface of two FE at impact is $(1...5)\cdot10^{-6}$m^2; the media between the two colliding elements is under pressure of up to 300 MPa. Such momentary pressure changes the tension in the processed media. Hence the significant effect of the vortex layer during production of fine emulsions and suspensions.

1.3.2. Critical coefficient of filling the chamber with ferromagnetic elements

The intensive motion of the ferromagnetic elements in the chamber is only possible to a certain amount of such elements. The increase of the amount in the chamber to the critical limits arrests their mostion and causes them to leave the EMF area. The criteria of the conditions when FE cease to intensively move in the active zone is the critical coefficient of filling the chamber with ferromagnetic elements.

This coefficient for cylindrical elements depends on many factors:

$$K_{кр} = f\left(x, d, l/d, I_z, V, H, \zeta, \rho, \ldots\right),$$

where x is the magnetic susceptibility of the FE material;

ℓ / d – parametric similarity criterion (where ℓ is the length and *d* is the diameter of the element);

I_z – element moment of inertia;

V – volume of one element;

H – strength of the magnetic field;

ζ – viscosity of the media;

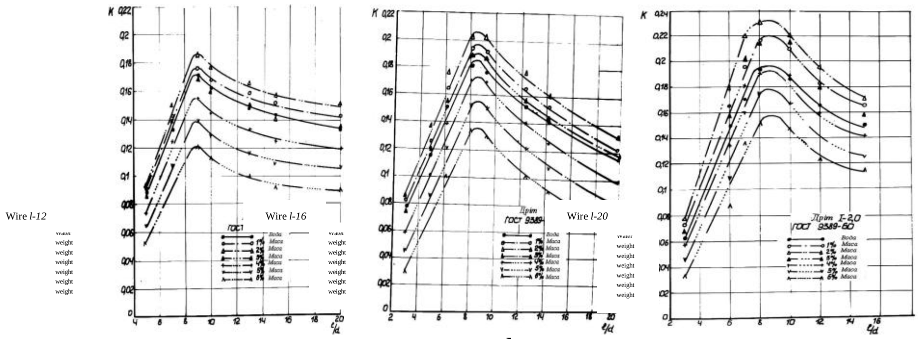
ρ – density of the media.

The variables are so numerous that calculation of the coefficient is impractical; it is better to determine the coefficient experimentally, using the formula: $K_{кр} = \frac{V_{ф.ел}}{V_K}$,

where $V_{ф.ел}$ is the total volume of the FE in the chamber when the stop intensively moving in the chamber.

V_K – is the internal volume of the active zone, which, at up to 0.2 m/s stream velocity is defined as the volume in the area of the rotating EMF.

Fig. 13 shows $K_{кр}$ for FE made of spring wire, depending on their diameter, the ration of ℓ / d, as well as EMF strength in the active zone of the unit when processing cellulose suspension.



a b c

Fig. 13. Critical filling coefficient curves depending on dimensions and varying cellulose concentration at diamters:
a – 1.2 mm; б – 1.6 mm; в – 2 mm; (EMF strength 10.8 · 10^4 A/m)

The data shows that for FE with diameter 1.2 – 2 mm, K_{KP} is maximum at $\ell / d = 8 - 10$. Cellulose suspension (up to a certain concentration), positively influences the stability of vortex layer, confirming the correct experimental selection of $K_{кр}$. The dependency on EMF strength was also determined experimentally. The results show that $K_{кр}$ maximizes at EMF strength within $15.5 \cdot 10^4 \ldots 18.5 \cdot 10^4$ A/m and cellulose concentration 4 %.

It can be inferred that to ensure the required intensity of FE motion in vortex layer while increasing the concentration of cellulose, the strength of the EMF in the active zone of the unit must be increased; the simultaneous increase of field strength and the amount of FE in the chamber increases frequency of action of the ferromagnetic elements in the cellulose suspension by 3.5 times, thus was the optimal media processing mode selected experimentally.

1.3.3. Influence of media flow rate through the AVS on the efficiency of vortex layer operation

The degree of processing of multicomponent liquid systems in AVS, as was mentioned above, depends on the intensity of the motion of the FE in the chamber. When the unit is used in continuous processes, the flow rate of the media influences the nature of the vortex layer when mixing and dispersing the components. Moreover, the vortex layer of the ferromagnetic elements can exist up to a certain flow rate; when that flow rate is exceeded, the elements are expelled out of the active zone, and if devices preventing this exlution are installed, disks are formed (a critical case of vortex layer operation.

As mentioned above, calculation of the influence of liquid flow on the efficiency of the vortex layer is practically impossible. The results can be obtained by experiments. We will consider the tests performed on AVS-100 and AVS-150 units.

The critical velocity on critical vortex layer mode onset is determined as follows:

$$\upsilon_{kp} = \frac{Q_{max}}{S},$$

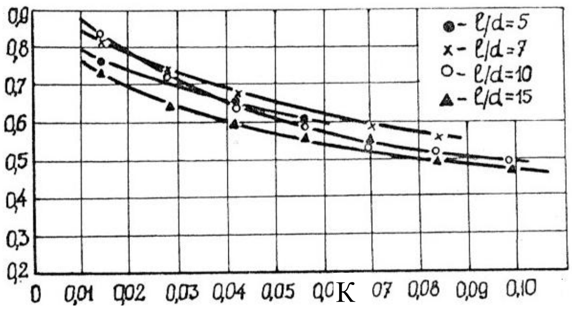
where Q_{max} – is the unit's processing rate, when ferromagnetic elements are expelled from the chamber, in m^3/second;

S – is the cross section area of the chamber, m^2.

However, even at speeds lower than υ_{kp}, the efficiency of the vortex layer also decreases, since it leads to compaction of and decrease of the effective chamber length.

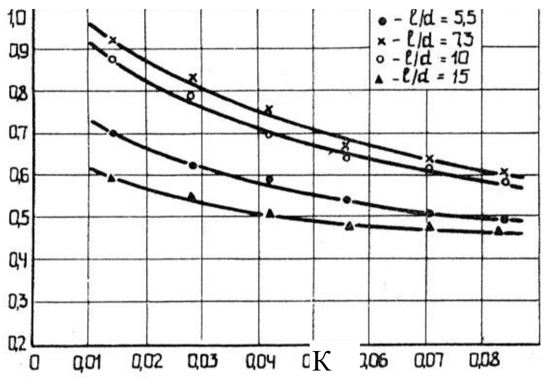
Trials were performed using ferromagnetic elements made of carbon steel, welding wire (1,2; 1,6; 1,8; 2,0; 3,0 mm diameter) at length to diameter ratio 5–15. Their weight in the chamber changed: for AVS-100 within the limits of 50–350 g, and for AVS-150 within 200–900 g, which corresponds to the chamber filling coefficient of 0,014–0,084 and viscosity of the product.

υ, м/с



a

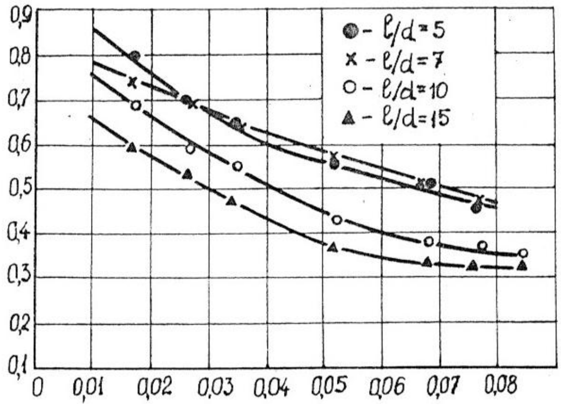
υ, м/с



б

Fig.14. Dependency of critical flow velocity on chamber filling coefficient ($D_{вн} = 76$ mm; $H = 11{,}8 \cdot 10^4$ A/m), ferromagnetic elements:
a – Steel 08G2S, $d = 1{,}6$ mm; б – Steel SH15, $d = 2{,}0$ mm

υ, м/с



K

Fig. 15. Dependency of the critical flow velocity on the coefficient of chamber filling with ferromagnetic elements
($D_{вн}$ = 121 mm, H = 12,3·10^4 A/m, ferromagnetic elements:
steel 08G2S, *d* = 1,6 mm)

Fig. 16 shows the dependency of critical flow velocity on the dimensions of the ferromagnetic elements: the critical velocity is almost independent of the ℓ/d ratio and increases with the increasing diameter of the FE.

υ, m/s

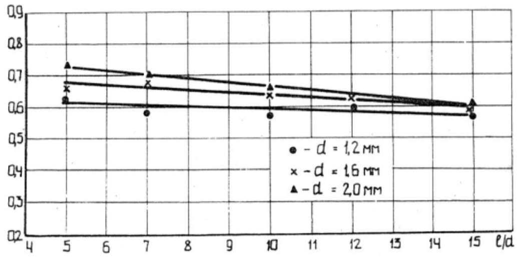


Fig. 16. Dependency of critical flow velocity on *l/d* ratio for various diameters of ferromagnetic elements
($D_{external}$ = 76 mm; H = 11,8·10^4 A/m); ferromagnetic elements: steel 08G2S, *m* = 150 g)

The data implies that decreasing of the chamber filling coefficient causes decrease of the hydraulic resistance of the vortex layer and increase of the critical flow velocity. This leads to the conclusion that independent of chamber diameter, parameters of the ferromagnetic elements (construction material, diameter and the ℓ/d ratio) and EMF strength, the critical velocity of flow through the AVS unit decreases with the increase of the chamber filling ratio.

Increase of product viscosity, the action of the flow on the vortex layer is proportional to product viscosity. With the increasing viscosity, the critical speed of the flow decreases (fig. 17).

υ, m/s

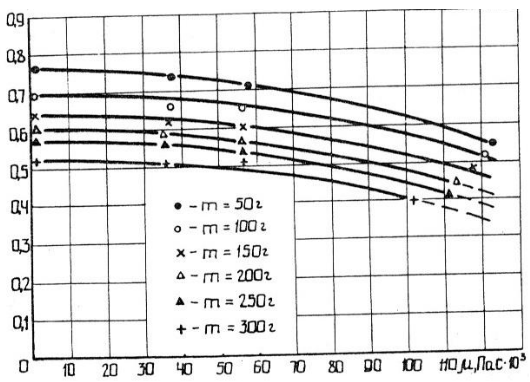
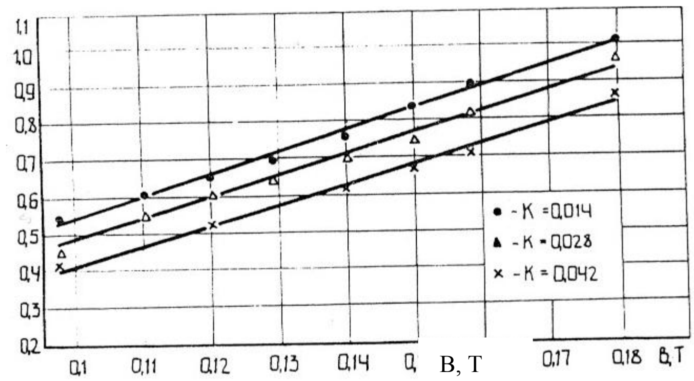


Fig. 17. Dependence of critical flow velocity on kinetic product viscosity coefficient
($D_{external}$ = 76 mm; H = 11,8 · 10^4 A/m; ferromagnetic elements:
steel 08G2S, *d* = 2 mm, *l/d* = 10)

Beside the influence of the flow on the vortex layer and the hydrodynamic resistance of the layer itself, the critical velocity also depends on the forces that hold the FE in the chamber of the AVS, which is determined by the magnetic induction of the EMF and the magnetic moment of an element. The critical flow velocity is proportional to magnetic induction in tested ranges.

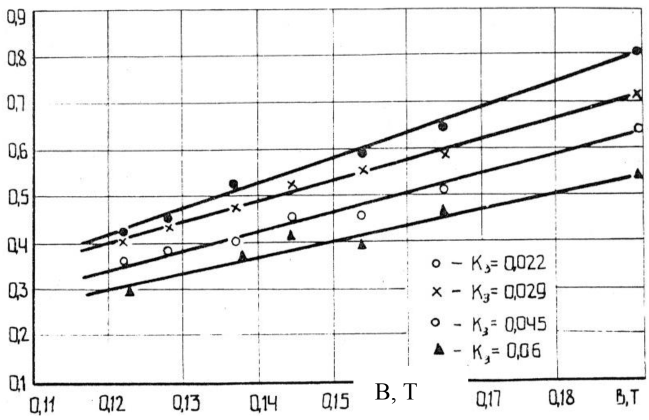
At the same time it should be noted that increasing magnetic induction, regardless of the force with which the flow acts on the vortex layer, the expultion of the ferromagnetic elements increases due to the increase of forces with which the ferromagnetic elements collide with each other and with the walls of the chamber. Besides, increasing the diameter of the chamber, the critical velocity of the flow through the AVS decreases with the same induction (fig. 18 - 19).

υ, m/s



a

υ, m/s



б

Fig. 18. Dependency of the critical flow velocity on the magnetic induction with varying chamber filling coefficients:
a – $D_{external}$ = 76 mm; ferromagnetic elements:
steel 08G2S, *d* = 1,6 mm, *l/d* = 10;
б – $D_{external}$ = 121 mm; ferromantic elements:
steel 08G2S, *d* = 2 mm, *l/d* = 10

υ, м/с

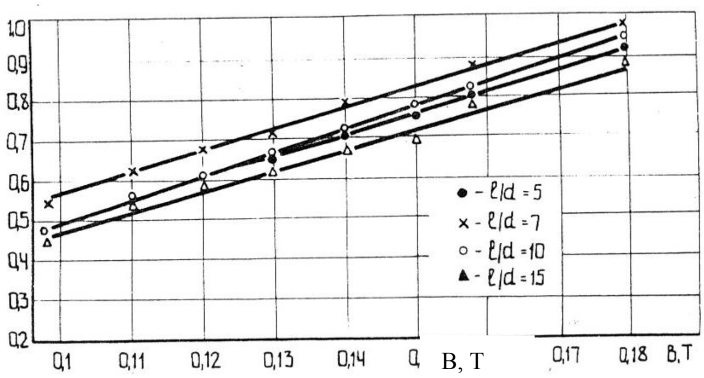


Fig. 19. Dependency of the critical flow velocity on the magnetic induction with various l/d ratios ($D_{вн}$ = 76 mm; ferromagnetic elements: steel 08G2S, d = 1,6 mm, m = 100 g)

The results of the research show that the critical velocity of the product flow through the AVS depends onteh magnetic properties of the ferromagnetic elements, on the hydraulic resistance of the vortex layer, on the force, with which the flow is acting on the layer and the force of retaining the ferromagnetic elements by the magnetic field. In turn, the hydrodynamic resistance of the vortex layer at constant flow velocity depends mostly on the chamber filling coefficient and the dimensions of the ferromagnetic elements.

When determining the more rational orientation of the chamber (horizontal or vertical), the results above show that AVS units with vertically aligned chamber have higher critical flow velocities than ones with horizontally aligned chamber (fig. 20).

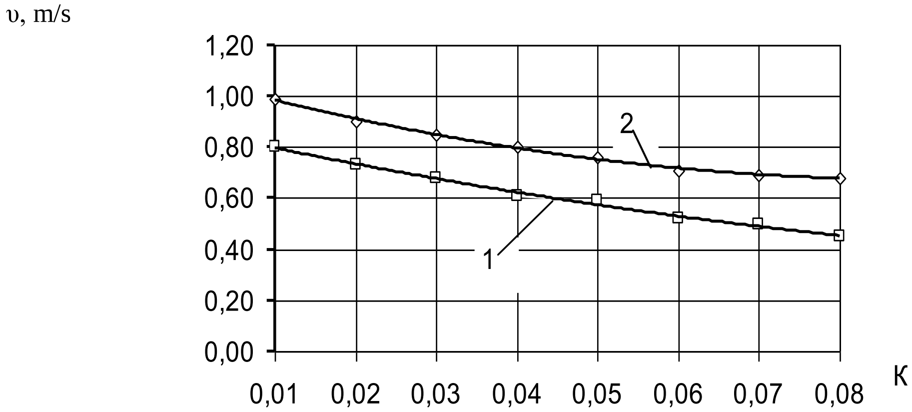


Fig. 20. Dependency of critical flow velocity on chamber filling coefficient (D_{int} = 121 mm; H = 12,3 · 10^4 A/m; ferromagnetic elements: steel 08GS, d = 2 mm, l/d = 10:
1 – horizontal chamber alignment;
2 – vertical chamber alignment

To increase the critical velocity of the liquid flow through the active zone and the processing rate of the units, grates with openings of varying diameter or labyrinth like devices are installed on the outlet side of the chamber (fig. 21). Using grates (table 3) allows to increase critical flow velocity by 20–40 % compared to operation without them, and labyrinths allow increase of critical velocity up to 15%.

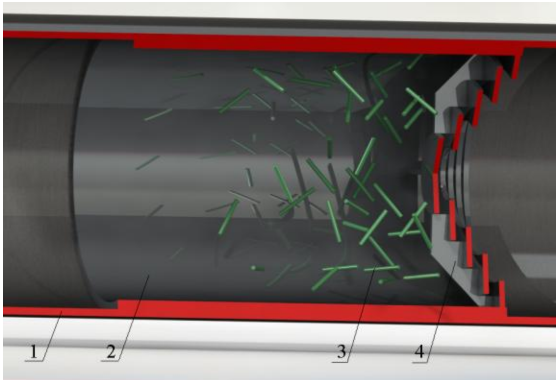


Fig. 21. Labyrinth

1 – chamber; 2– bushing; 3 – ferromagnetic element; 4 – labyrinth.

Table 3

Influence of the chamber design elements on the critical velocity of the liquid flow
(D_{int} = 121 mm, H = 12,3 · 10^4 A/m, ferromagnetic elements: steel 08G2S; d = 2,0 mm; l/d = 10)

Device limiting active zone of the vortex layer		Weight of FE, m, g	Chamber filling coefficient	Critical flow velocity V_{cr}, m/s
Type	Total are of openings for flow exit from the active zone F_{opn}, mm^2			
Grate (d_{opn} = 8 mm)	4 521,68	200	0,0147	1,02
		300	0,0220	0,87
		400	0,0294	0,78
		600	0,0441	0,61
		800	0,0588	0,56
		900	0,0660	0,52
Labyrinth (slit width– 8 mm)	4 527,88	200	0,0147	0,77
		300	0,0220	0,66
		400	0,0294	0,60
		600	0,0441	0,52
		800	0,0588	0,48
		900	0,0660	0,44

Increase of flow velocity through the unit is tightly connected to another important parameter – the actual density of the vortex layer (table 4), which defines the intensity of component processing in the unit. Increasing of the flow velocity facilitates increase of its action on the vortex layer in general, which compresses it along the length of the active zone.

Table 4

Influence of water flow velocity thorough AVS and design elements of the chamber on decrease of the effective active zone length (D_{int} = 121 mm, H = 12,3 · 10^4 A/m, ferromagnetic elements: steel 08G2S; d = 2,0 mm; l/d = 10)

Device limiting active zone of the vortex layer: Type	Device limiting active zone of the vortex layer: Total are of openings for flow exit from the active zone F_{opn}, mm^2	Chamber filling coefficient	Flow velocity V, m/s	Effective length of the active zone L_{eff}, mm
Grate (d_{opn} = 8 mm)	4 521,68	0,0441	0,04	150
			0,09	150
			0,20	148
			0,25	135
			0,38	102
			0,47	73
			0,61	62
Labyrinth (slit width– 8 mm)	4 527,88	0,0441	0,04	150
			0,09	150
			0,25	118
			0,38	100
			0,52	83
No limiting device	11 493,185	0,0441	0,09	150
			0,29	127
			0,38	109
			0,43	90

The result is that for units with D_{int} = 121 mm the compression of the vortex layer occurs at velocities exceeding 0.2 m/s. Further increase of the velocity by 0,1 m/s leads to length decreasing by 10–30 mm, and, as the result, to increased density and reduced efficiency of the ferromagnetic element action on the components processed in the vortex layer.

As mentioned above, the critical velocity of the flow depends on many parameters.

$$\upsilon_{kp} = 4{,}5 \cdot 10^{-9} \frac{H^2 \cdot \mu' \cdot \ell}{\mu} \cdot \frac{\ell}{d} \cdot \left(\frac{m}{m_{\kappa p}} \right)^{-0{,}175}.$$

m – weight of the ferromagnetic elements, g;
d – diameter of the ferromagnetic elements, m;
l – length of the ferromagnetic elements, m;
H – strength of the electromagnetic field, A/m;
μ – dynamic viscosity of the medium, (N · s)/m^2;
μ' – magnetic permability of the FE material, Gn/m^2.

$m_{\kappa p}$ – maximum weight of the FE in the vortex layer (above which the elements are expelled from the active zone);

$\frac{l}{d}$ – parametric criterion of the ferromagnetic elements.

The experiments show that the recommended maximum range of flow velocities for continuous processing in AVS is:

$$\upsilon_p = (0{,}7 - 0{,}9)\upsilon_{\kappa p}.$$

1.3.4. Acoustic waves in AVS

The motion of the ferromagnetic elements present in sufficient quantities and with sufficient interaction in the active zone, as well as in the presence of forces resisting their movement, considered above, show that they oscillate mechanically along the vector of EMF strength, as well as magnetostrictive oscillations due to their rapid collisions with each other and the walls of the chamber, due to Villard’s effect during collisions.

Mechanical and magnetostrictive oscillations are transferred to the media, causing acoustic waves to occur. Since the active zone contains a large number of ferromagnetic elements, the resulting parameters of the acoustic waves in any point of the active zone equals to the sum of parameters of each separate wave.

It has been determined experimentally that the spectrum of acoustic waves in any point in the vortex layer is continuous and is within the range from several periods per second to several MHz. The results are presented in fig. 22, 23.

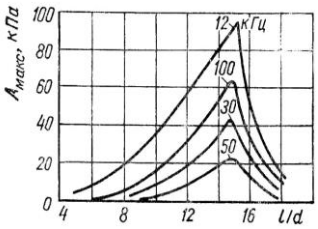


Fig. 22. Dependency of the maximum amplitude of accoustiv wave pressure on the ℓ / d ratio for nickel ferromagnetic elements d = 1 mm

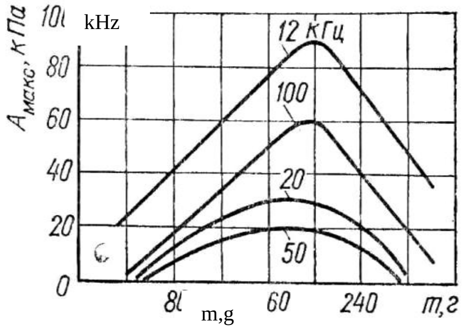


Fig. 23. Dependency of the maximum amplitude of acoustic wave pressure on the weight of nickel ferromagnetic elements with diameter of d = 1 mm and length of ℓ = 15 mm in the active zone with 76 mm diameter

Fig. 24 shows the dependency of the maximum acoustic wave pressure on oscillation frequency with various amount of ferromagnetic elements in the chamber. The analysis of the data shows that the vortex layer has an area of sharp pressure maximum from 10 to 15 kHz, and increase of amplitude at frequencies above 90kHz.

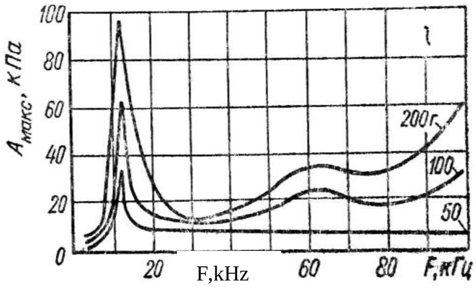


Fig. 24. Dependency of the maximum acoustic wave amplitude on the frequency of oscillations for ferromagnetic elements made of nickel wire with diameter d = 1 mm and length of ℓ = 15 mm

The acoustic waves cause cavitation on the surface of solid particles of processed media and on the walls of the chamber. Cavitation is closely connected to formation of shockwaves in the liquid, caused by implosion of cavitation bubbles in the compression phase of the acoustic wave. Local pressures near the bubble can reach tens of thousand atmospheres.

It has been determined that in the process of cavitation, the vapor-gas bubbles have their own frequency of pulsation, depending on their size; the bubbles pulse in the media with the frequency:

$$S = \frac{1}{2\pi r}\sqrt{\frac{3V}{\rho}\left(\frac{P_c}{\rho_0} + \frac{2\sigma}{r}\right)},$$

where $V = \frac{C_p}{C_v}$ – ratio of specific heat capacity of gas or vapor filling the bubble;

σ – interfacial tension;

ρ – liquid density;

r – bubble radius;

P_c – pressure in the media.

Every bubble has a resonant frequency depending on its diameter. In the vortex layer, the spectrum of acoustic wave frequencies is continuous. Cavitation bubbles, formed in the underpressure zone of the wave, collapse in overpressure zones. In the process of collapsing, their size decreases and the frequency of their oscillation increases. Since the acoustic spectrum caused by movement of the ferromagnetic elements is continuous, the collapsing bubble is always under the influence of the changing resonant frequency. The result is that the specific energy release into the media is increased, which can influence the rate of various physical and chemical processes occurring in the AVS unit.

It is known, for instance, that acoustic fields of ultrasonic range in water influence cellulose fibers. During processing, the fibers experience high dynamic loads due to acoustic pressure of the media, cavitation processes, resonant oscillations of the gas bubbles, as well as thermal influence due to increased media temperature caused by absorbed acoustic energy. Processing of cellulose with 23.6 kHz ultrasound leads to fibrillary dilamination of the fibers. Low ultrasonic frequencies cause fiber destruction, while medium or high frequencies cause soft external and internal fibrillation. Considering the positive influence of acoustic waves on fibrous materials, experiments were performed while processing in various units to test the influence of acoustic oscillations on the paper-forming properties of cellulose. It has been determined that the degree of cellulose atomization in acoustic process has not changed, but the paper-forming properties of the cellulose did change (table 5). For instance, the breaking length of paper increase by 10 %, bursting and tear strength increased by 25 % and 4,5 % .

Table 5

Effects of acoustic treatment of cellulose sulfate suspension in AVS-100 unit on paper strength (cellulose concentration – 1,1 %)

Degree of atomization, °	Processing time, s	Weight of 1 m^2 of paper, g	Breaking length, m	Strength	
				Bursth, MPa	Tear, N
16	0	100	6 750	0,35	1,72
16	30	100	7 400	0,44	1,64

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