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INVESTIGATION OF THE PROCESS OF VIBRO-IMPACT INTERACTION OF VIBRATION ACTIVATOR BLADES WITH TWO-PHASE ENVIRONMENT “HYDRATE LIME – WATER”

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Abstract. The process of mechanical activation of hydrated lime in the vibratory activator of the bunker type is investigated in the work. Economic and environmental effect in the production of reinforced concrete structures is achieved through the use of highly active hydrated lime as a modifying reinforcing additive to concrete based on Portland cement. Theoretical and experimental studies of the influence of vibration displacement parameters of the mixture on the rate and degree of dispersion of hydrated lime and the efficiency of vibroactivation are determined.

Keywords: highly active hydrated lime, vibroactivated lime, lime-colloidal system, lime dispersion, dynamic viscosity, vibration activator, vibration displacement, vibration activation efficiency**.**

Introduction and Problem Statement

Hydrated lime has wide applications in construction technologies. Calcium hydroxide is used as a stand-alone binder in lime-sand or other mixtures of air and autoclave curing, as a component of pozzolanic bonding systems, and as a component of composite materials (for example, powdery mildew in modified dry mixes). The effect of the growth of mechanical indicators is especially relevant in one of the modern directions of development of the construction industry, namely the design of warehouses of so-called “green concrete”.

One of the most important criteria for evaluating concrete according to this concept is the specific consumption of cement. In this regard, scientists and technologists have an important task to simultaneously increase the mechanical properties of concrete and reduce the specific cost of Portland cement for its preparation. Since most of the structural concrete is prepared based on Portland cement, the production of which requires significant fuel consumption, the use of modifying additives and, in particular, highly active hydrated lime, in addition to environmental will have a positive economic effect. Therefore, research in the field of highly active hydrated lime is of both scientific and practical interest.

Hydrated lime powder from Lhoist (Republic of Poland) was used for the research. The content of basic oxides in hydrated lime, % (wt.): CaO – 97.2; MgO – 0.7; CO_2 – 1.4; SO_3 – 0.4. Free water content – 1.3 %.

In the first phase of mechanical activation of hydrated lime, the viscosity of the colloidal system can be measured with high accuracy using a rotary viscometer “RION” type VT-04 (Fig. 1). This method is based on measuring the torque that occurs on the axis of the rotor in the form of a cylinder immersed in lime dough during its rotation. This device allows you to measure the numerical values of the viscosity of the system in the range from 0.01 to 40 Pa/s. However, this range of measurements is not sufficient, because in the process of further thickening of the system, the device becomes insensitive to increasing the viscosity of the system. Due to this, it is impossible to evaluate and control the processes of lime dispersion during further vibrational activation with the help of a rotary viscometer.

Therefore, for further measurements of the dynamic viscosity of the mixture, the vibration method of viscosity determination was used [8], which is based on determining the change in the amplitude of oscillations of the body during its immersion in a viscous medium.

The amplitude of oscillations in time is measured by a special sensor – accelerometer ANS 014-03. The range of measuring accelerations is from 0.5 to 300 m/s^2. The operating frequency range is from 1 to 125 Hz.

The time sweeps of the attenuating oscillations are measured and stored in the computer's memory using a two-channel OWON digital oscilloscope VDS1022 series with a bandwidth of 25 MHz.

The logarithmic decrement of vibration damping is determined by their time scans, and the dynamic viscosity of the mixture is determined by known formulas [8].

Review of Modern Information Sources on the Subject of the Paper

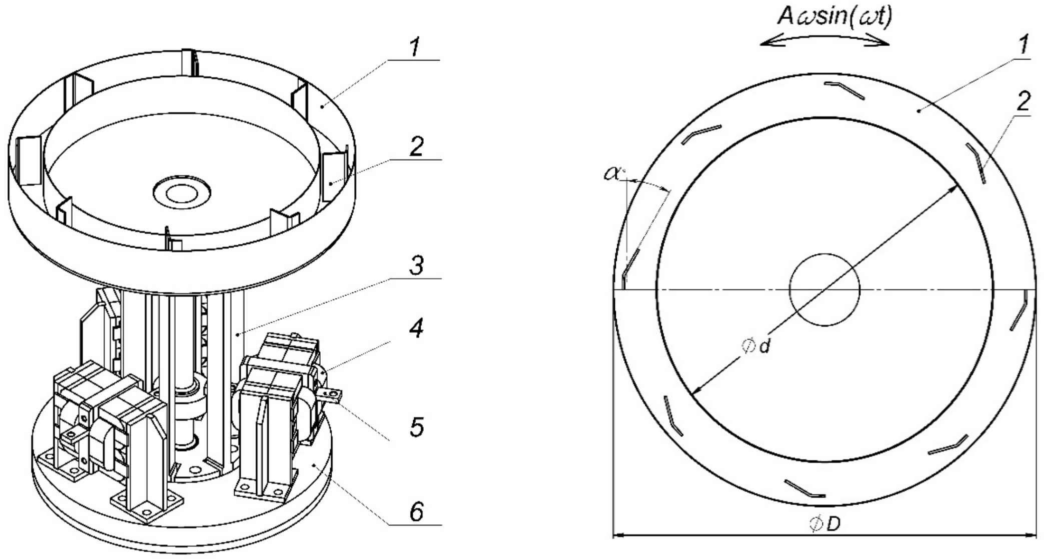
In recent years, research has been conducted on the use of hydrated lime as a modifying additive in mixtures based on Portland cement. The introduction of small amounts of calcium hydroxide in the composition of cement compositions allows for increasing the strength of the hardened product, without destroying reinforcement, cracking cement stone, or the formation of efflorescence on its surface [1]. The use of lime has a positive effect on improving the performance of products, which leads to its widespread use in construction technologies [1, 4]. In particular, for a different range of products, lime allows to increase strength [9], increase crack resistance, vapor and air permeability [10, 11], and so on. The positive effect of hydrated lime is determined by the particle size of $Ca(OH)_2$. After quenching, hydrated lime is a coarsely coagulated system [3], which significantly restrains its positive effect on the formation of the structure of hardened products and improves their performance [12–14]. Therefore, one of the effective ways to increase the activity of hydrated lime is its dispersion, ie reducing the particle size of $Ca(OH)_2$ to highly dispersed [15, 16]. There are various technologies for obtaining highly dispersed and, accordingly, highly active hydrated lime by grinding it. In [9], a method of mechanical dispersion of $Ca(OH)_2$ in a pasty state in a specially designed vibrating hopper was proposed. Studies have shown that a two-phase mixture of $Ca(OH)_2$ + water at high concentrations of the solid phase (> 50 %) behaves like Bingham plastic fluid [2], which retains a fairly rigid spatial structure at low shear rates between its particles. If the shear rate is reduced, the structure collapses and the mixture behaves like a normal Newtonian fluid.

Main Material Presentation

Vibroactivator is a near-resonant vibrating machine (Fig. 1, *a*) with an electromagnetic drive, which performs harmonic oscillations relative to the central vertical axis. The structure consists of a working body – a torus-shaped hopper (1), inside which are blades (2), a reactive mass (6) with electromagnets (4), and a spring system – torsion 3, which fastens the reactive mass and the working body together. The anchor of the electromagnetic drive (5) is fixed in the nodal point of torsion vibrations 3, to which the frame of the structure is attached through the rubber shock absorbers (not shown in the diagram). The use of the nodal (fixed) torsion point for mounting the electromagnetic drive anchors and shock absorbers of the frame provides high efficiency of the vibroactivator drive and vibration isolation of the frame structure.

The oscillation frequency of the vibroactivator is equal to the oscillation frequency of the industrial single-phase network (50 Hz), and the amplitude of oscillations is regulated by a laboratory autotransformer. The maximum value of the amplitude of oscillations of the unloaded working body of the activator is 8 mm. The amount of substance in the hopper and its viscosity reduce the amplitude of the hopper.

The blades (2, Fig. 1, *b*) are rigidly fixed to the outer wall of the hopper with some gap, which ensures the absence of dead zones in the mixture, which is subjected to vibration treatment. The outer and inner walls of the hopper form a hydraulic channel 50 mm wide and 100 mm deep (D = 500 mm; d = 400 mm) through which the mixture moves freely under the action of inertial forces.



a *b*

Fig. 1. Structural diagram of vibration activator

As previous studies [7] have shown, the optimal value of the angle of inclination of the blade α is close to 90 °, but cannot be equal to it due to the need to ensure orderly one-way movement of the mixture during its processing. Unilateral movement of the mixture (vibration) is due to different hydraulic resistance when the mixture interacts with the blades and hopper walls, which contributes to both the values of gaps between the blades and hopper walls and the optimal angle of attack of the blade (α = 86 °). Then the relative movement of the mixture through the channel for one complete cycle of its oscillations will be somewhat different. These differences in displacements provide insignificant (5–7 mm/s) one-sided vibratory movement of mix on the channel of the bunker that leads to transportation of the activated mix from shovels and not activated to them with their subsequent hashing.

Previous experimental studies indicate [5, 7] that the efficiency of vibroactivator increases if you increase the amplitude of oscillations and processing time of the mixture, and decreases if you reduce the solids concentration and increase the viscosity and amount of mixture.

To be able to assess the effectiveness of the vibroactivator, consider the movement of a pasty two-phase mixture of $Ca(OH)_2$ + water in an open channel that performs harmonic oscillations with known amplitude and frequency. For simplicity, we assume that the channel performs rectilinear rather than circular oscillations with an average value of amplitude corresponding to the average radius of the channel of the torus-like vibrating hopper. Assume that the value of the vibration velocity of the working body of the activator is sufficient for the mixture to behave like a Newtonian fluid. We also neglect the difference in hydraulic resistance as a minor factor influencing the process of interaction between the blades and the mixture. It is also assumed that the possible impact of the mixture and the blade is plastic, i.e. the mixture in an open pressure channel is devoid of elastic properties.

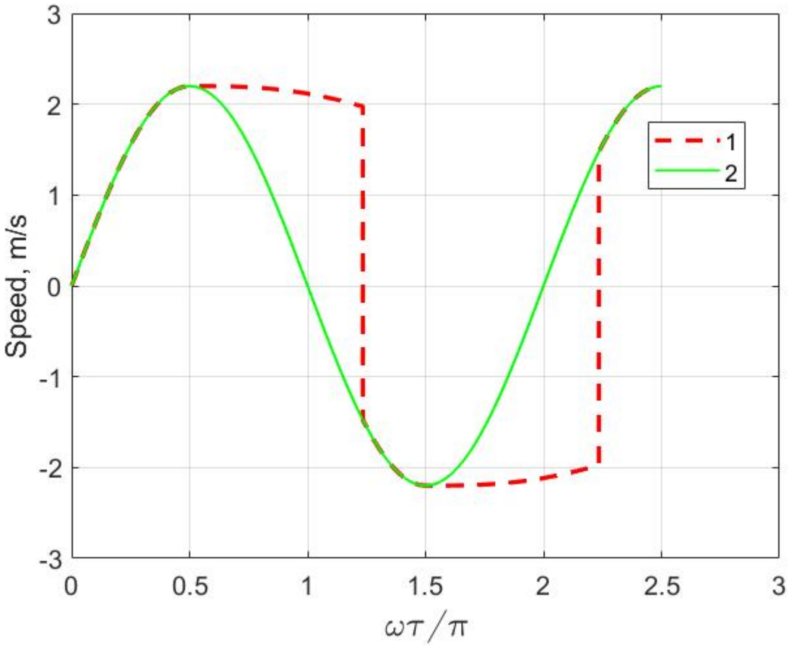


Fig. 2. Stages of possible relative movement of the channel and the mixture
(1 – the speed of the mixture; 2 – the speed of the activator channel)

Consider the interaction of the mixture and the hydraulic channel of the working body of the vibroactivator as the interaction of the material point associated with the working body by the force of viscous friction. Then, at the first possible stage – the stage of compatible motion (Fig. 2, from ωt = 0 to ωt = π / 2), when the mixture rests on a perpendicular blade and moves with the channel, the equation of motion is written as

$$\frac{d^2x_c}{dt^2} = \frac{d^2x_k}{dt^2} = A\omega^2\cos(\omega t)\ , \tag{1}$$

where: x_c; x_k are coordinates of the mixture and the channel; AND; ω is the amplitude and angular frequency of oscillations of the working body of the activator.

The next stage of the movement is the stage of relative slippage of the mixture relative to the channel is described by the equations:

$$\frac{d^2x_c}{dt^2} = -F\left(\frac{dx_c}{dx} - \frac{dx_k}{dx}\right), \tag{2}$$

$$\frac{d^2x_k}{dt^2} = A\omega^2\cos(\omega t)\ , \tag{3}$$

where: F is the force of hydraulic resistance of the channel [2].

$$F = \left(\left(F1\times F2\right)/\left(F1+F2\right)\right),$$
$$F1 = \left(\mu\ \ L1\ \ S^2\ \ z/\left(2\ \ \pi\ \ R1^4\right)\right),\ F2 = \left(\mu \mathrm{n} L2 \mathrm{n} S^2 \mathrm{nz}/\left(2\mathrm{n}\pi\mathrm{n}R2^4\right)\right), \tag{4}$$

where $F1$, $F2$ – the resistance of the outer and inner slits of the channel; z is the number of blades; μ – dynamic viscosity of the mixture; $L1$; $L2$ – the length of the outer and inner slits; S is the area of the normal projection of the blade; $R1$, $R2$ – hydraulic radius of the outer and inner slit.

The stage will begin when the inequality is true:

$$A\omega^2\cos(\omega t) > F\left(\frac{dx_c}{dx} - \frac{dx_k}{dx}\right). \tag{5}$$

That is when the force of inertia becomes greater than the force of resistance. This stage will end when the mixture and the shovel meet, ie there will be a blow. Since the impact is quite plastic, the speed of the mixture will instantly become equal to the speed of the blade, ie the channel. The duration of this stage is possible from 0.5π to 1.5π.

The impact will occur when the relative displacement of the material point becomes equal to the value of the gap that exists between it and the blade against which it hits. We cannot set this gap. It is installed automatically by a dynamic system, but we can fix it experimentally. Therefore, let's call it the established gap.

It is at this point, the moment of impact, that the mixture is activated. This process is carried out both directly on the surface of the blade and at some depth of the mixture – the distance from the surface of the blade. The value of this distance is also an important indicator of the effectiveness of vibration activation. It will be proportional to the square of the velocity (energy of surface destruction) and inversely proportional to the dissipation forces of this energy, namely the viscosity force.

By setting a certain value of the established gap and solving equations (3) (4) and inequality (5), we obtain the value of the main parameter of the efficiency of the vibration activation process – the speed of collision of the blade and the mixture.

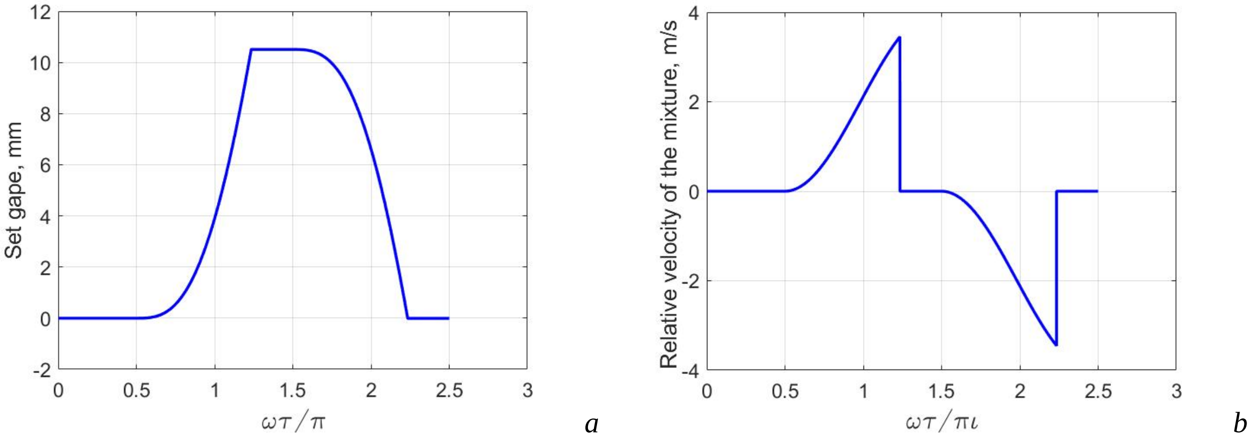


Fig. 3. The results of the study of the model (*a* – the relative movement of the mixture; *b* – the relative velocity of the mixture)

In Fig. 3, and shows the graphical dependence of the relative movement of the mixture from the phase angle of the process at a set gap of 10.5 mm, and in Fig. 3, *b* is a graph of the relative velocity of the mixture. The vertical line shows the speed of collision of the mixture and the blade.

Figs. 2 and 3 show two blows of the mixture and the blade during one period of oscillation, the steady motion of which exists in the phase angles from 0.5π to 2.5π. As can be seen from the figures, the impact stage ends with the joint movement stage, which indicates the process of steady vibration movement.

The impact stage is instantaneous and can be described by setting a certain value of acceleration:

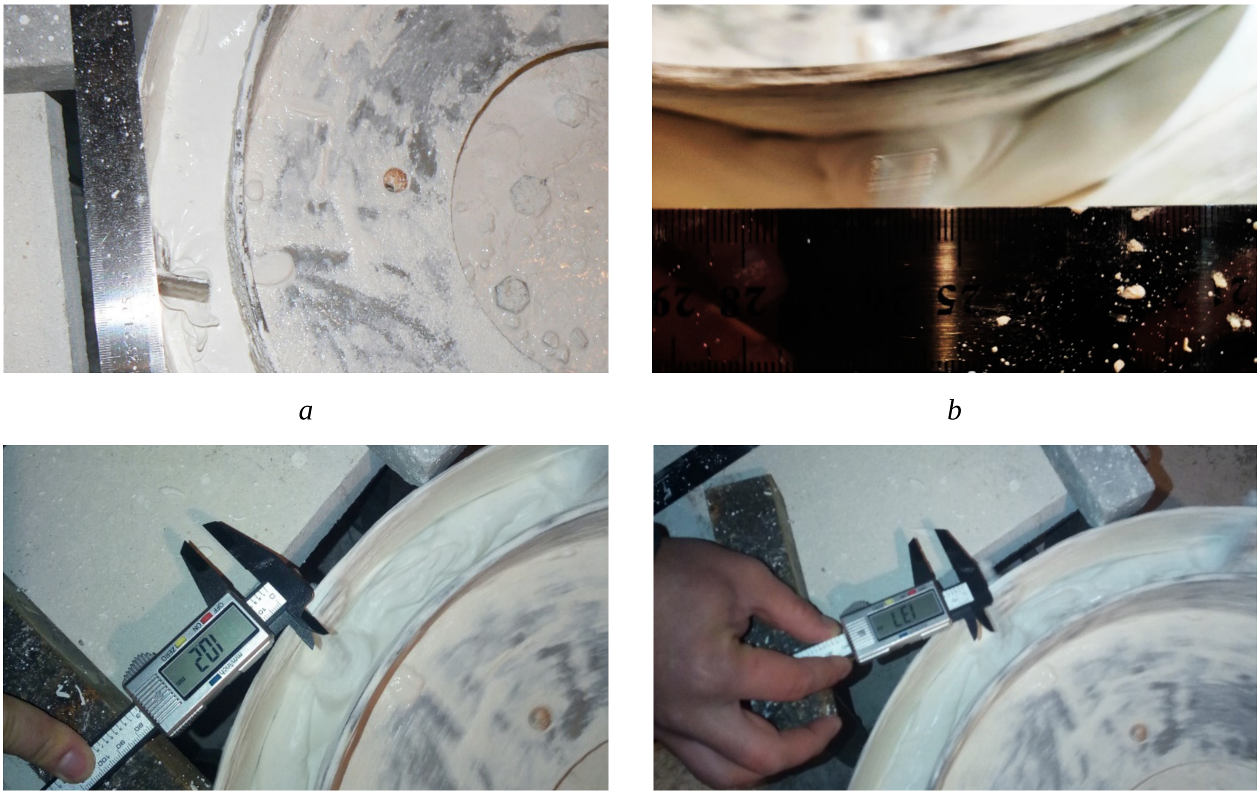
$$\frac{d^2x_c}{dt^2} = -1\times 10^6\, \text{м}/c^2. \tag{6}$$

The value of this acceleration is not sufficiently substantiated and requires a separate study, but this is the value of the solutions of equations (1)–(6), which are shown in Figs. 2 and 3.

For other parameters of the studied vibration activator: amplitude of oscillations 7 mm, frequency 50 Hz, the dynamic viscosity of the mixture 12.5 Pa × s.

Experimental studies

Experimental work was carried out on the vibroactivator, the design of which is presented in Fig. 1, and photos of the working body of the activator in the process of vibroactivation of the mixture, in Fig. 4.



a *b*

c *d*

Fig. 4. Photos of the working body of the activator in the process of activating the mixture:
a – static image; b – dynamic image; c – measuring the amplitude of oscillations; d – measuring the set gap

Fig. 4, a shows a static image of the vibration activation process – a photo taken with the shortest possible shutter speed. As a result, a clear (still) image is obtained, which shows wavy bumps of the mixture near the blades, the geometric parameters of which can be measured using a ruler or caliper. Increasing the shutter speed of the camera (Fig. 4, b) gives a more realistic picture of the process, familiar to the human eye. This photo shows the extreme values of the blade (oscillation range) and the established gap between the mixture and the blade. The values of the oscillation range (double amplitude) and the established gap were measured by a caliper (Fig. 4, c, d).

As we know from previous studies [5], the process of activation of the mixture is the continuous formation of new surfaces that absorb water, which leads to an increase in the dynamic viscosity of the mixture.

The graphical dependence of the process of increasing the viscosity of the mixture, which is subjected to vibration activation, is shown in Fig. 5.

As can be seen from the figure, the first 5 minutes of treatment (zone 1) do not affect the change in viscosity, which indicates the absence of the process of activation of the mixture. However, over time, the viscosity of the mixture begins to increase (zone 2) and after 80 minutes there is a slowdown in inactivation (zone 3). This can be caused both by the effect of a high value of dynamic viscosity (energy damping) and by the completion of the activation process by reaching a certain particle size characteristic of a certain energy value.

Therefore, in the process of vibration activation of hydrated lime, similar experimental works were performed to determine the dynamic viscosity by the vibration method [8]. Generalized research results are presented in table 1.

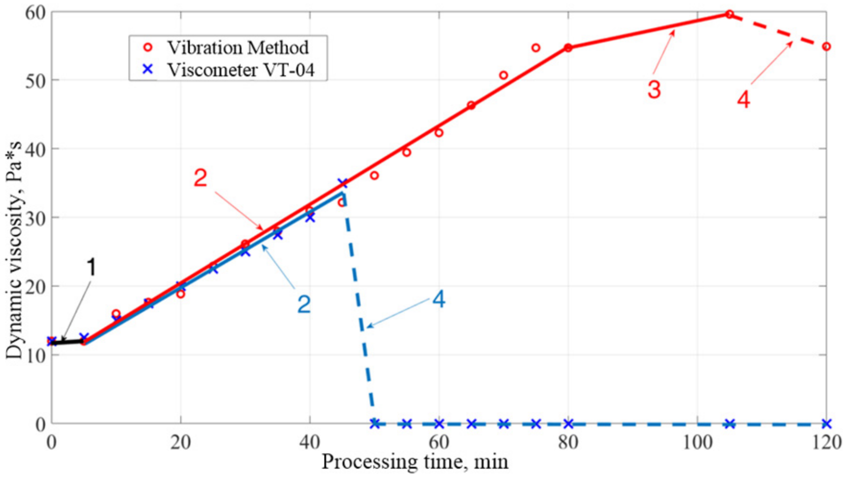


Fig. 5.The value of the viscosity of lime dough in the process of vibration activation:
1 – zone of constant viscosity; 2 – zone of proportional growth;
3 – the area of reduced growth; 4 – insensitivity zone of the device

Table 1

Generalized research results

Processing time, min	Amplitude of oscillations *a*, mm	The value of the set gap Δ, mm	Dynamic viscosity of the mixture μ, Pa × s
< 10	5,1	Not observed	12,2
10	5,1	7,5	15,5
20	5,1	10,0	19,1
30	5,0	12,5	25,5
40	4,9	10,1	32,0

According to the analysis of tabular data, the viscosity of the mixture increases over time, and the set gap passes the maximum, and during the first 10 minutes of vibration activation, the presence of the set gap between the mixture and blades is not observed, ie its value is equal to or close to zero.

To assess the effectiveness of the process of vibroactivation of the mixture, the experimental data (> 10 min.) Table 1 was entered into a mathematical model based on equations (1–6). The results of the calculations are presented in Figs. 6 and 7.

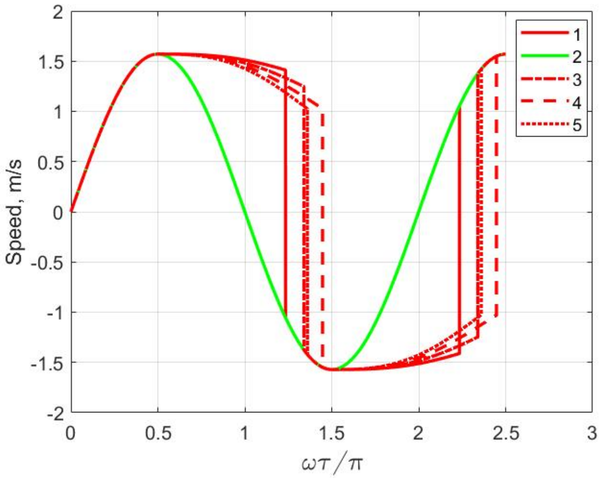
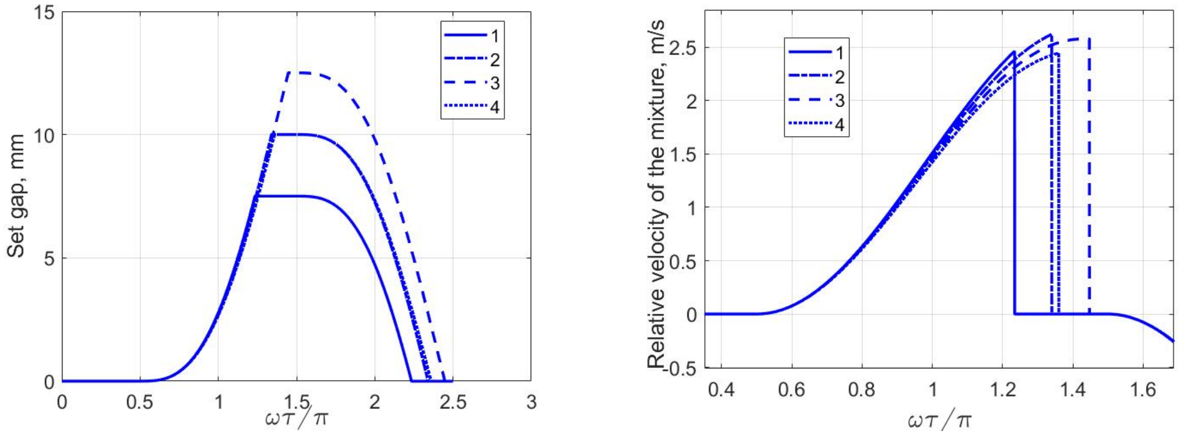


Fig. 6. The results of the study of the model – the graphical dependence of the speed of the mixture and the working body of the vibroactivator in the process of its oscillations: 1 – μ = 15.5 Pa × s, Δ = 7.5 mm; 3 – μ = 19.1 Pa × s, Δ = 10 mm; 4 – μ = 25.5 Pa × s, Δ = 12.5 mm; 5 – μ = 32 Pa × s, Δ = 10.1 mm

As can be seen from Fig. 6, the increase in the viscosity of the mixture leads to a greater slope of the velocity curve at the stage of relative slippage of the mixture due to its more intensive braking, but at the same time increases the phase angle of impact by increasing the steady-state. Therefore, it is difficult to give an unambiguous estimate of the intensity of this figure.

If we divide the relative displacements of the mixture with different viscosities (Fig. 7, *a*) and relative velocities (Fig. 7, *b*), then we see the following dependencies.



a *b*

Fig. 7. The results of the study model: a – relative movement of the mixture,
b – relative velocity of the mixture; 1 – μ = 15.5 PA × s, Δ = 7.5 mm; 2 – μ = 19.1 PA × s, Δ = 10 mm;
3 – μ = 25.5 Pa × s, Δ = 12.5 mm; 4 – μ = 32 Pa × s, Δ = 10.1 mm

Mixtures with the same set clearances (curves 2 and 4) have different collision velocities due to different viscosity values.

The speed of collisions of mixtures with the blades is disproportionate to the values of their established gaps.

Given the factor of the negative impact of the viscosity of the mixture on the process of its activation, preference should be given to modes 1 and 2 and not 3 and 4. That is, processing of the mixture should be carried out until its viscosity reaches 19 PA × s (curve 2) and then add the water sprayed by the nozzles until its viscosity drops to 15.5 Pa × s (curve 1) and so continue the process until the activation of the mixture, ie until its viscosity stops growing.

Conclusions

Effective vibration activation of the paste-like mixture of hydrated lime with water is possible only in the presence of the vibration-shock mode of the activator, ie the presence of a set gap between the mixture and blades, which self-generates only at certain physical and mechanical parameters of the mixture. the viscosity of the mixture.

The efficiency of vibration activation is directly proportional to the speed of impact of the mixture on the blade and inversely proportional to its viscosity.

Vibration activation of the mixture should be carried out in a certain optimal range of its viscosity.

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