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The acoustical flows of the hydrophobic and anticeptic liquids in porous media

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The paper presents the results of the experimental studies of the acoustical flows in the porous or microcrumbling media. Concrete and brick walls being porous media absorb water due to capillary effect. The damp penetrates into the foundation if the waterproofing layer between the foundation and the wall is damaged, the damp comes up the wall due to the natural capillary effect. Just the same, if the protective covering of the concrete or brick wall is damaged, they begin to absorb the damp from the air, growing damp by and by and worsening their protective properties. There exist some ways to restore damaged waterproofing layers. One possible way is to impregnate walls or/and foundations by some special hydrophobic liquid using the ultrasound. Being then dried out, the elements of constructions become water-repellent, do not absorb damp more and remain dry. The usage of the ultrasound makes the impregnation much more effective and fast, being at the same time the nondestructive method. The speed of the penetration depends on the porosity or microcrack factor.
The paper presents the results of the study of the dependence of the velocity of the hydrophobic liquid movement from the average diameter of the capillaries and from the acoustical intensity.

1 Introduction

It is possible to accelerate the impregnation and to increase its efficiency using ultrasound. The effect of saturation of porous media by the liquid in the ultrasonic field is based on the fact, That the acoustic pressure causes acoustic flow in the liquid. That is why the ultrasonic odcillations essentially help the liquid to move into the pores or capillaries of the material. The effect is strong within the wide range of frequencies and intensities of sound. The effect is well known. It is so called “ultrasonic capillary effect”. This effect was first opened in the USSR and described by Konovalov and Germanovitch [1]. It was also studied by Prokhorenko and Dezhkunov [2,3], ets.

The effect essentially increases after the arrival of cavitation. The essence of this effect is that the depth and the velocity of movement of the liquid into the capillaries increase significantly under the influence of cavitation in comparison with the influence of the acoustic radiation field.

2 Flows in walls and bricks

The impregnation in the presence of ultrasonic oscillations is widely used in electronic and chemical-engineering industry. As a rule, it is used in plants, where it is possible to submerge the detail fully into the impregnating bath filled with the liquid and having the high power ultrasonic transducer inside the bath.

The main goal of our investigation was to study the process of liquid penetration in real, not in laboratory conditions. It is quite clear, that the concrete foundation or the brick wall cannot be submerged into the bath. Obviously, we had to look for some other engineering solution.

Figure 1 shows our design [4]. The ultrasonic vibrator 1 is mounted upright near the wall 2, subject to impregnation. The liquid 3 (special silicone hydrophobic liquid) forms an intermediate layer between the emitting surface of the vibrator and the wall. A special elastic rubber U-tank 4 prevents liquid leakage from the layer. This U-tank forms a kind of a small caisson. The tank is feeded by the liquid from a special feeding service tank (not shown in the figure). The vibrator is firmly attached to the wall (the attaching construction is not shown in the figure), but it is necessary to control the layer thickness. This thickness must be quite definite – it is very important. The vibrator is excited by means of the power ultrasonic generator 5, that has the self-tuning circuit.

The depth L of liquid penetration into the porous material (brick) was measured by pulse ultrasonic method.

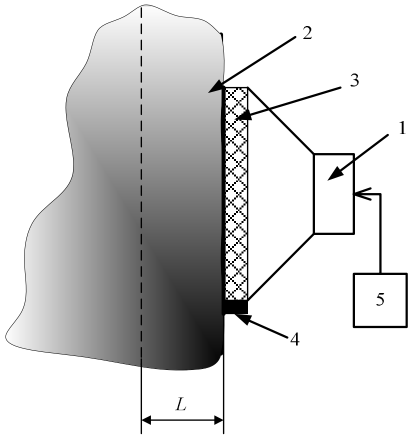


Figure 1. Experimental setup

The main goal of this work is to compare this depth of the liquid penetration into different types of bricks under the influence of ultrasound of different power and different frequency.

3 Experimental results

Three types of porous material were used for the experiment. These were bricks, and their properties one can see in the following table.

Table 1: Specimen properties

Specimen	Density ($\times 10^3$ kg/м^3)	Average grain diameter (мм)	Mean capillary diameter (mm)	Density (%)
1	3,4	0,35	0,02	8
2	2,9	0,5	0,05	17
3	1,8	1,0	0,17	38

The filling liquid was a special organic-silicon hydrophobic solution “Gifob” (density ρ=1,07·10^3 kg/m^3, viscosity η=0,19·10^{-3} Ps), the temperature t=+20±2 C°).

First it was necessary to compare the theoretical velocity of ultrasound in the porous partially filled material with experimental. Different authors proposed various theoretical models for the velocity of elastic wave. The best approaches were obtained by Sato [5] and Gilberstein [6].

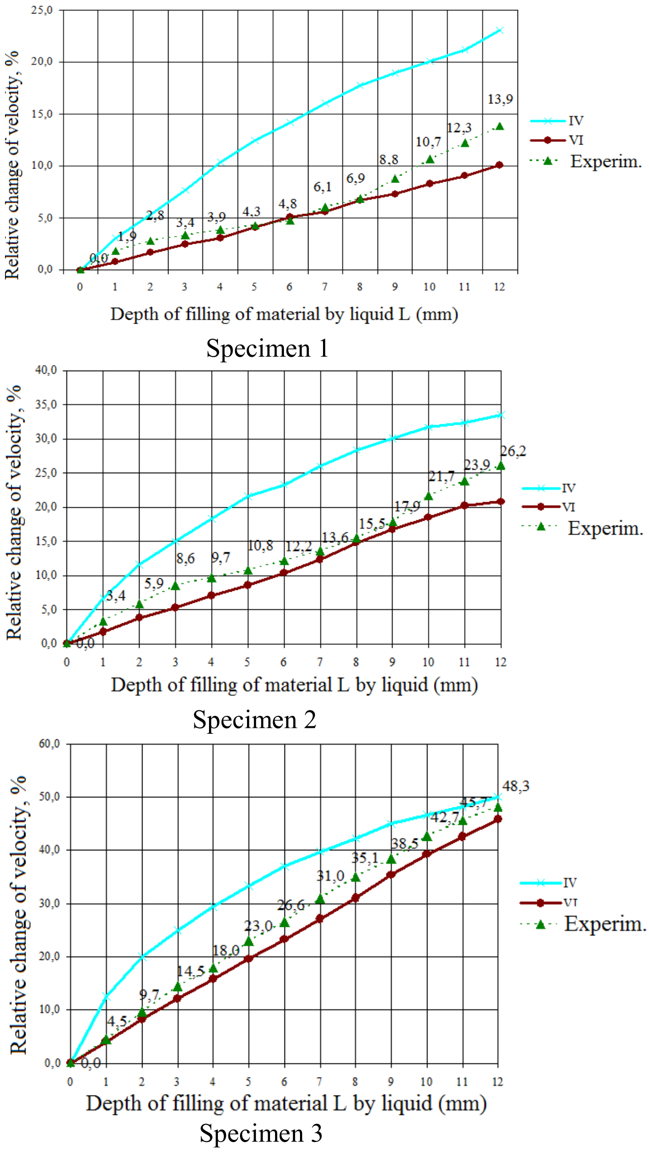


Figure 2. Calculated and experimental changes of ultrasound velocity from the depth of filling. IV and VI correspond to [5] and [6] respectively

Approximation of Sato [5] is the following:

$$C_x = C_0\{1 - z\cdot\frac{\phi}{2}[\frac{(1-k)(1+\sigma_1)}{2(1-2\sigma_1)+k(1+\sigma_1)} + , \qquad (1)$$

$$+10\frac{1-2\sigma_1}{7-5\sigma_1} - (1-D)]\}$$

where: $k = \frac{\rho_2 C_{2l}^2}{\rho_1 C_0^2}$;

C_0 – longitudinal velocity of elastic wave in porous media;
σ_1 — Poisson's ratio for $3D$ infinity media;
φ — porosity;
k — bulk elastic modulus of the liquid, filling capillaries, to that of continuous media;
D — density of the liquid to that of continuous media ratio;
z - depth of penetration factor.

Gilberstein [6] proposed the following approximation:

$$C_x = \frac{C_0}{\sqrt{\frac{1-zQ}{1-1,08zQ}(1+1,08zQS)}} , \qquad (2)$$

$$S = \frac{1+2\sigma_1(1-\sigma_1)}{1-\sigma_1} ,$$

where C_0 – longitudinal velocity of elastic wave in porous media;
σ_1 — Poisson's ratio for $3D$ infinity media;
Q — total volumes of holes to that of material;
z - depth of penetration factor.

One can see from figure 2, that the model, proposed by Gilberstein fits very good with experiment.

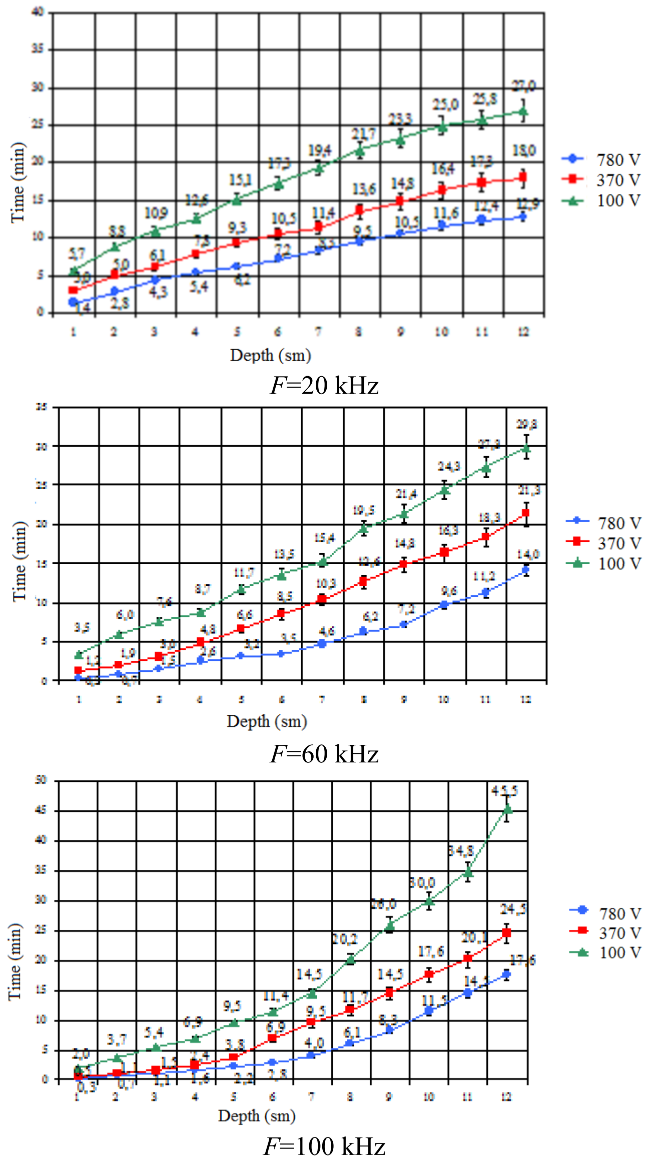
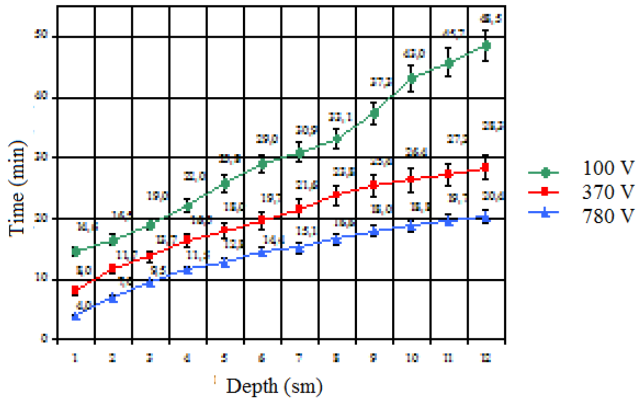
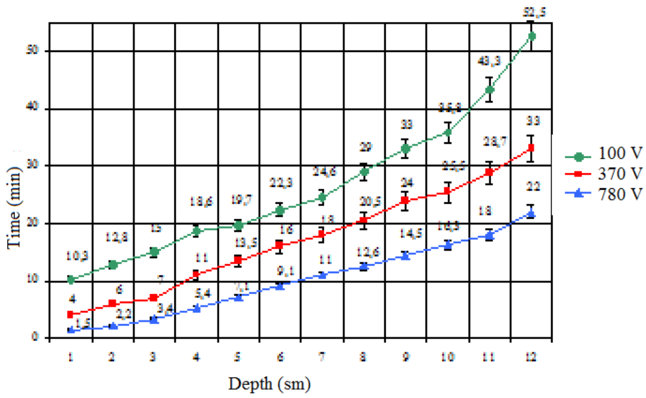


Figure 3. Mean times (t) of filling specimen № 1, L=12 sm

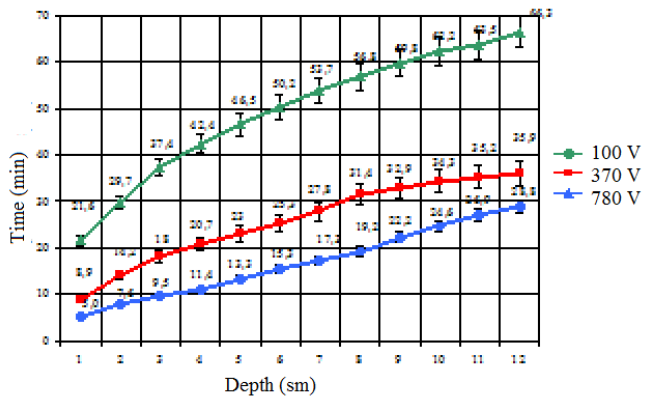
The experiment showed, that the intensity of filling the specimen by liquid increases with increasing of the ultrasonic field power. This effect can be seen from figures 3, 4 and 5. Figure 3 shows the dependences of time of filling from the depth of penetration for different frequencies – 20 kHz, 60 kHz and 100 kHz and different values of power for the specimen № 1. Different values of electric amplitude on transducer – 100 V, 370 V and 780 V correspond to different values of sound-energy-flux density. These values are $2\cdot10^4$ Wt/m^2, $4\cdot10^4$ Wt/m^2 and $8\cdot10^4$ Wt/m^2, correspondingly. All The measurements were carried out below the threshold of cavitation. This level for this type of the hydrophobic liquid was about $8{,}4\cdot10^4$ Wt/m^2. The increase of the sound intensity causes the increase of the impregnation velocity, but it is quite necessary to avoid cavitation, because cavitation demolishes the water-repellent properties of liquid.



F=20 kHz



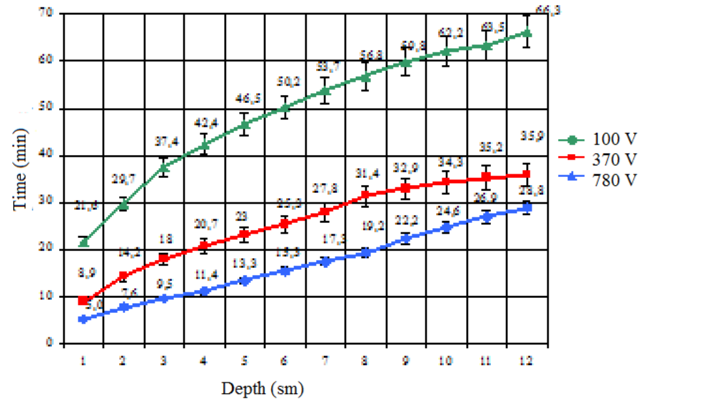
F=60 kHz



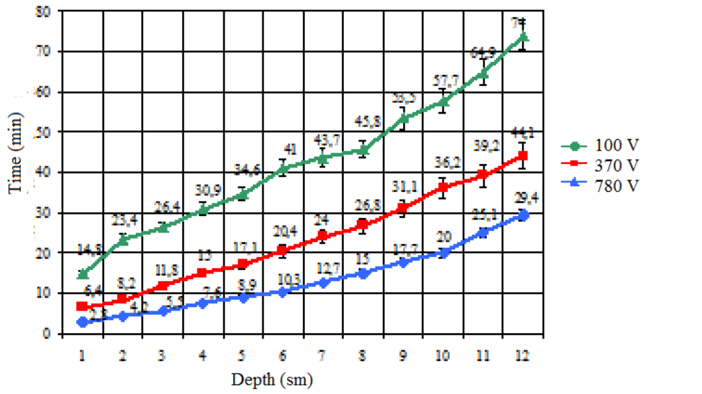
F=100 kHz

Figure 3. Mean times (t) of filling specimen № 2, L=12 sm

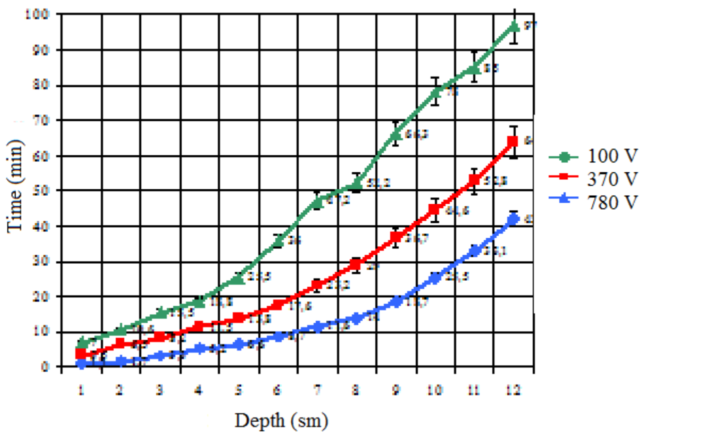
The increase of the impregnation time is caused by the growth of the ultrasound frequency, which leads to the wave decrement. This causes the reduction of the ultrasonic power as the depth of filling increases. As a result the time of impregnation increases.



F=20 kHz



F=60 kHz



F=100 kHz

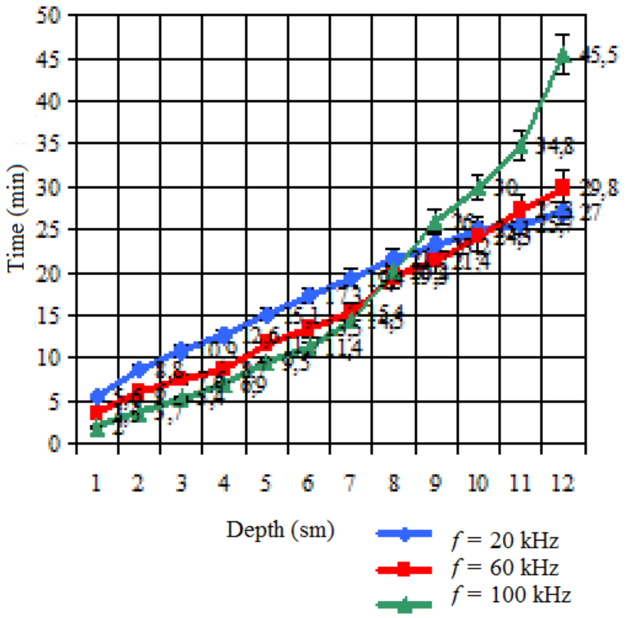
Figure 4. Mean times (t) of filling specimen № 3, L=12 sm

The interpretation of the fill-up time of the porous material from the frequency shows, that the time grows as the frequency increases. That is illustrated by figures 5,6 and 7. At the beginning of the process the velocity of flow is proportional to the ultrasonic frequency, but then the time of filling up slows down due to reduction of power.

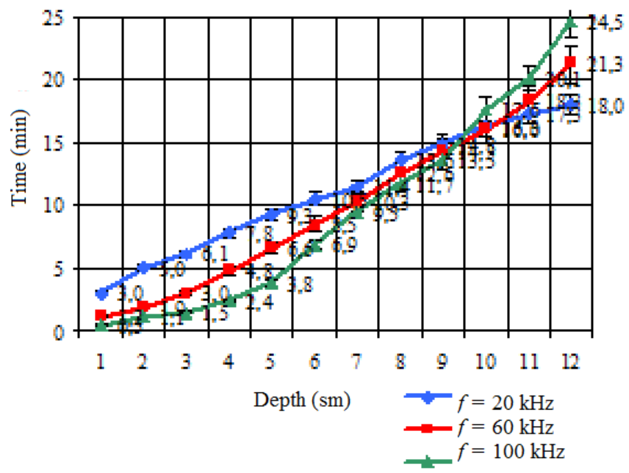
Figure 5 shows the dependence of the average filling-up time from the depth of penetration at different frequencies (20 kHz, 60 kHz and 100 kHz) and different signal amplitudes (100 V, 370 V and 780 V, that correspond to values of sound-energy-flux density of $2\cdot10^4$ Wt/m^2, $4\cdot10^4$ Wt/m^2 and $8\cdot10^4$ Wt/m^2.

Figure 5 is for specimen №1, L=12 sm, figure 6 is for specimen №2, L=12 sm and figure 7 shows these dependences obtained for specimen №3, also for L=12 sm.

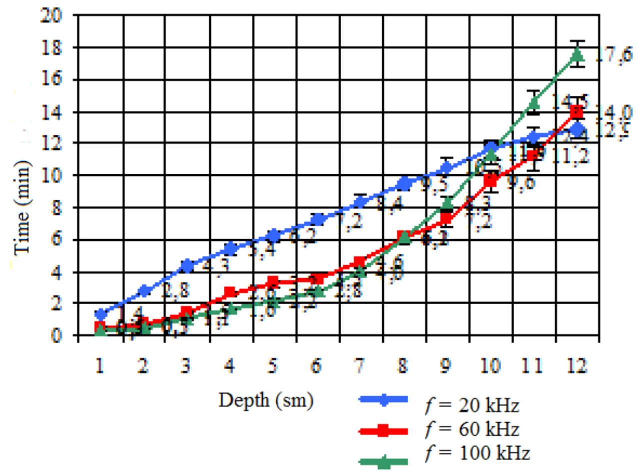
All dependences are in good accordance with that of figures 2,3 and 4.



100 V

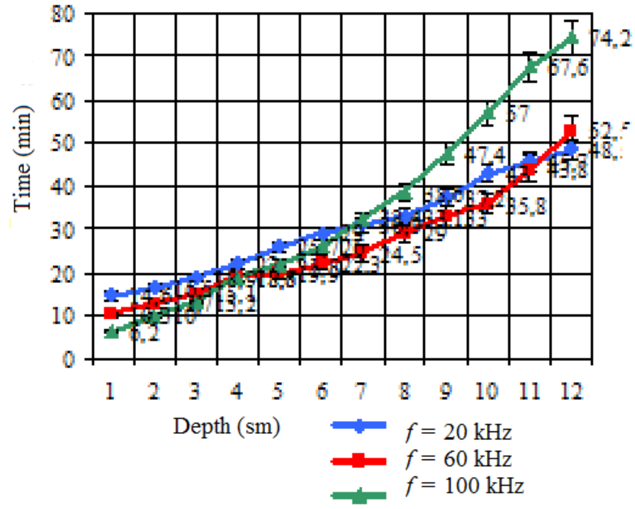


370 V

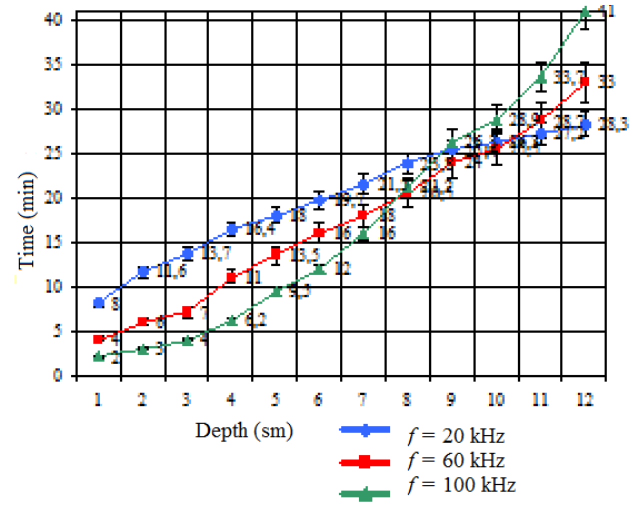


780 V

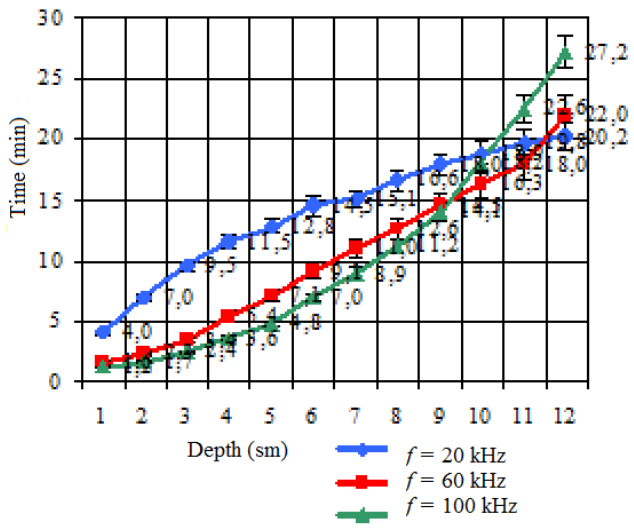
Figure 4. Mean times (t) of filling specimen № 1, L=12 sm for different frequencies and different signal amplitudes



100 V



370 V



780 V

Figure 5. Mean times (t) of filling specimen № 2, L=12 sm for different frequencies and different signal amplitudes

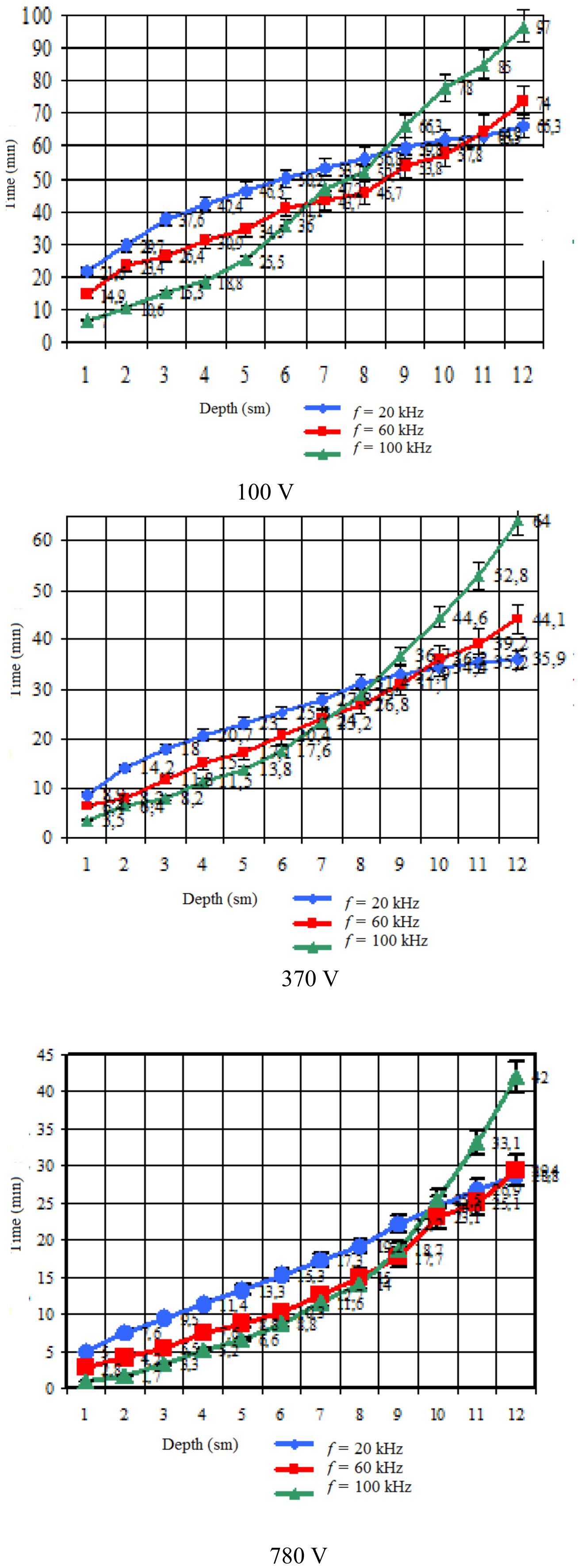


Figure 6. Mean times (t) of filling specimen № 3, L=12 sm for different frequencies and different signal amplitudes

5 Conclusion

In conclusion we can say, that the results of this investigation provide new possibilities to water-repellent treatment of brick walls and concrete foundations. The time of hydrophobic liquid fill-up under the influence of ultrasound is about 8-10 times less than without the ultrasound, in the course of natural capillary seepage. Generally speaking, the ultrasonic effect on the fluid flow is complex. The acceleration of the rate of the impregnation can be explained by different effects. Among these effects the most important ones seem to be the capillary wall vibrations, the influence of ultrasound on the meniscus in the capillary channel, changes in physic-chemical properties of the fluid, acoustical pressure and cavitation.

Similar results were obtained for different other porous materials, including concrete, ceramics, and some natural porous materials, such as marble and polycrystalline rocks, some natural facing materials.

Acknowledgments

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