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AIR BUBBLES CREATION AND BEHAVIOR IN A VIBRATORY-ACOUSTIC FIELD

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ABSTRACT

The paper presents the mechanism of air bubbles creation in a vibratory column flotation machine at the aerator vibration in vertical direction and the influence of its constructive parameters on the gas phase dispersion. The vibratory field distribution along the water column according to the applied to the aerator oscillations in water medium and air bubbles presence is researched. A hypothesis explaining the deceleration of the gas bubbles emerging velocity in a vibratory field with a vibrations energy absorption of the bubbles at their vibration as a result of the changeable sound wave pressure and the change in the interaction between the bubbles and the liquid is expressed.

INTRODUCTION

The air bubbles creation in liquids is a wide used method for different technological processes realization and it is a basic process at the mineral products processing floatation.

Regardless the aeration process application its efficiency is determined by the shared surface at the bound gas-liquid, for which formation a definite energy has to be used up. Besides, conditions for the obtained bubbles size, which determines their ability to transport a definite number of solid particles to the froth layer are laid down by the process application at flotation processing.

Mechanical, pneumatic, hydraulic and other combined methods for the gas phase dispersion by different energy types are used for the process realization. Because of the continuous contact time of the dispersed gas phase and solid particles it turns out that there are mechanically transported particles in the froth layer so an additional water sprinkling of the froth layer is used for the concentrate quality improvement.

In the University of Mining and Geology "St. Ivan Rilski" – department "Mineral technologies" a disperser at which the gas phase is realized by the use of vertical vibrations with defined frequency and amplitude has been developed. The dispersion method created as a result of the long work in the department on the use of the vibratory-acoustic technologies for the technological processes intensification gives the opportunity to affect not only the bubble formation process but the tree phases in the entire work chamber volume as well.

GAS PHASE DISPERSION

The gas phase dispersion in liquid medium is realized by its transmission through an annular slot in the upper disperser part fig. 1. The air quantity (fig.1 - 1) depends on the pressure difference in the supplied air and the water column in the flotation machine

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When the disperser does not vibrate the air is dispersed in big bubbles, which are obtained at random places on the annular slot (fig. 1 - 2) due to its inability to limit bubbles of a certain size because of the slot type. At the disperser vibration the bubble formation process character considerably changes – when the vibrations frequency and amplitude increase there is a decrease in the obtained bubbles size and an increase in their number. By the experiments and surveillances it has been ascertained that the bubbles number and respectively – their size depend on the vibrations velocity $u = \frac{dx}{dt} = A\omega\cos(\omega t + \varphi)$, which could be identified with the expression u_V=Af – a product of the amplitude and frequency oscillations.

At the disperser vibration the growing bubble from a random annular slot sector is affected by two forces: the lifting force of the liquid removed by the bubble and the resistance force caused by the liquid flow circumfluent the bubble and moving on the inclined disperser face. The former has always had up direction, while the latter is alternating –- depending on the oscillations phase it could be directed as the lifting force is or in the opposite direction. There is an increase in the lifting force with the bubble diameter growth. There is also an increase in the resistance force but it changes in accordance with a sinusoidal law.

The bubbles formation itself is not definite in coordinates because it is not formed by nozzles but by an annular slot as a result of the determining factors accidental alterations. The above mentioned predetermines the complex character of bubbles formation at a vibratory effect at a certain disperser construction.

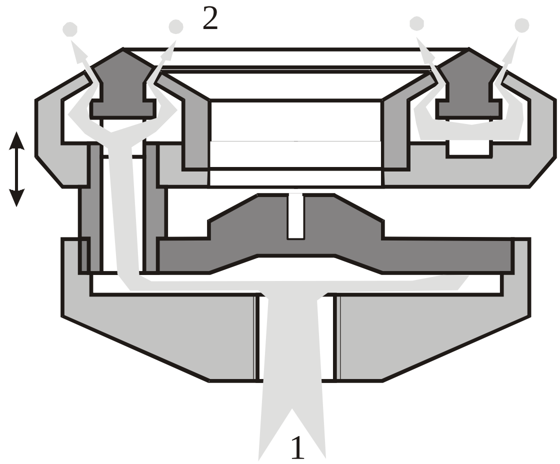

Figure 1. The vibratory air-dispersing unit

The determination of the forces, which affect a bubble formation at applied vibratory effect, is based on the fact that at a bubble formation by a nozzle it detaches when the lifting force becomes bigger than the surface tension force:

$$F_{\text{отк}} = \frac{1}{6} \square p d^3 \qquad (1)$$

Where: F_{OTK} – the force detaching the bubble from the nozzle;

d – the bubble diameter;

r – liquid density.

The circumfluence Robt resistance force is determined by the formula:

$$F_{\text{обт}} = cS\frac{\rho v^2}{2} \qquad (2)$$

c – resistance coefficient;
S – the bubble cross-section in a plane perpendicular to the liquid movement direction;
V – liquid velocity.

The liquid velocity changes according to a sinusoidal law. If the slot plane is parallel to the vibrations direction the circumfluence velocity is equal to the vibratory velocity:

$$V_{\text{обт}} = A\omega\cos\omega t \qquad (3)$$

At the other bound case – the slot plane is perpendicular to the vibrations direction – the circumfluence velocity is equal to zero (in the ideal case). In the general case – when the slot plane and the vibrations direction form a certain angle ß the velocity of the bubble circumfluence by the liquid is:

$$V_{\text{обт}} = 2\pi Af\cos\omega t\sin\beta \qquad (4)$$

The resistance force at circumfluence is:

$$F_{\text{обт}} = \frac{1}{2}c\rho\pi^3 d^2 A^2 f^2\cos^2\omega t\sin^2\beta \qquad (5)$$

As it was mentioned, the force F_{OTK} needed for the bubble to be detached from the nozzle refers to a bubble formation in calm liquid and a determined nozzle size. In this way the force needed for the surface tension surmounting is determined. It is preliminarily accepted that the application of the same force to a bubble forming at the same nozzle the diameter d_1 of the obtained bubble will be different, i. e. by $F_{\text{отк}} = F_{\text{обт}}$

$$kd^3 = kd_1^2 A^2 f^2\cos^2\omega t \qquad (6)$$

and the diameter d_1 of the newly obtained bubble will be:

$$d_1 = \frac{d\sqrt{2}}{A^2 f^2\cos^2\omega t} \qquad (7)$$

b

The value of the expression $A^2f^2\cos^2$□t is in the limit:

A^2f^2 ⊛ $A^2f^2\cos^2$◆t ⊛ 0 (8)

At the disperser oscillations upper and the lower points, when the movement direction changes the vibratory velocity $u_{\text{виб}}$=0.and the forming bubbles have the opportunity to grow to a bigger diameter. From this point the vibratory velocity increases and reaches the maximal value at a distance equal to the vibrations amplitude A. After that it again decreases to zero. The obtained bubbles diameters alter according to this harmonic law.

With the disperser vibration the resistance that the air flow experiences increases because of the faces circumfluence by the water layer. As a result of the increased resistance for the air at the annular slot outlet begins bubble formation on its entire perimeter. The air pressure pulsations are synchronous with the oscilations – the pressure decrease at the upper and lower points of the disperser movement (at increase of the slot flow capacity due to resistance decrease) and increase at acceleration.

According to the above worked out dependences the vibrations use gives the opportunity for gas bubbles diameters regulation in accordance with the vibratory effect, which allows the flotation process optimization by the gas phase dispersion improvement. This positively influences the air dispersion in a column flotation machine, where the water column height definitely stipulates conditions about the initial gas bubbles diameter.

EXPERIMENTAL RESEARCHES

Series of experimental researches are carried out in order the vibratory-acoustic influence on the air bubbles formation at vertical holes with different diameters at a vertical vibrations direction and different air flow to be determined. Measurements of the gas bubble emerging at different water column height and gas bubble diameter in a model of a column flotation machine are carried out. The vibratory field values are determined according the water column height for monophase and diphase systems.

Table1 A gas bubble emerge velocity with and without vibrations

F, [Hz]	A, mm	V, cm/s	V, cm/s	%	V, cm/s	V, cm/s	%
		without vibrations	with vibrations		without vibrations	with vibrations	
		S = 120 cm; d = 4,0 mm			S = 90 cm; d = 4,0 mm		
20	0,5	26,43	25,21	3,7	26,55	25,86	2,6
	1,00	25,92	25,26	3,5	26,87	25,71	3,1
	1,5	26,43	25,26	3,5	26,47	25,28	4,7
	2,00	26,2	25,00	4,5	26,39	24,66	7,1
	2,5	26,3	24,84	5,1	26,39	25,00	5,8
25	0,5	26,14	25,42	2,9	26,47	25,42	4,2
	1,00	26,09	25,1	4,1	26,63	25,42	4,2
	1,5	26,32	25,00	4,5	26,55	24,66	7,1
	2,00	26,26	24,74	5,5	26,47	25,14	5,3
	2,5	26,03	25,1	4,1	26,32	25,21	5,00
30	0,5	26,49	25,59	2,2	26,55	24,66	7,1
	1,00	26,2	24,84	5,1	26,63	24,19	8,9
	1,5	26,2	24,44	6,6	26,55	23,94	9,8
	2,00	25,97	23,81	9,00	26,55	23,56	11,20
	2,5	26,09	23,12	11,7	26,39	23,32	12,1
35	0,5	26,61	25,81	1,4	26,87	26,16	1,4
	1,00	26,32	25,26	3,5	26,71	26,01	2,00
	1,5	25,97	24,39	6,8	26,55	25,35	4,5
	2,00	26,03	24,59	6,00	26,55	25,00	5,80
	2,5	26,03	24,69	5,7	26,47	25,07	5,5
40	0,5	26,32	25,37	3,1	26,71	25,77	2,9
	1,00	26,26	24,9	4,9	26,39	25,07	5,5
	1,5	26,14	24,05	8,1	26,63	24,73	6,1
	2,00	26,2	24,29	7,2	26,47	24,32	8,4
	2,5	25,97	24,29	7,2	26,47	23,75	10,5
45	0,5	26,55	25,53	2,4	26,87	25,94	2,3
	1,00	26,14	24,54	6,2	26,63	24,39	8,1
	1,5	26,09	23,81	9,00	26,63	24,00	9,60
	2,00	25,92	23,72	9,4	26,32	23,20	12,6
	2,5	26,03	23,76	9,2	26,32	22,84	13,9

DETERMINATION OF THE VIBRATIONS EFFECT ON THE GAS BUBBLES EMERGING VELOCITY

At the gas phase dispersion the bubble is affected by the vibrations at two moments: at the formation, when the bubble shape and diameter is altered by the vibrations effect; at the emerging, when the emerging velocity is decreased.

Measurements in two regimes – with and without vibrations at air bubbles different size and different water column height have been carried out to determinate the vibrations effect on the gas bubble emerging velocity. The module for singular bubbles creation provides the opportunity for micrometric air supply through changeable nozzles with a certain hole diameter in order gas bubbles with determined initial diameter to be obtained. The vibratory effect on the gas bubble is applied after its detaching from the nozzle. The measurements results are presented in the table 1, where the emerging velocity difference with and without vibrations is percent computed.

The gas bubble emerging velocity without vibrations is higher than that with vibrations. Vibrations contribute to the gas bubble emerging velocity decrease, i. e. extend its stay in the column flotation machine.

DETERMINATION OF THE VIBRATIONS AMPLITUDE ACCORDING TO THE WATER COLUMN HEIGHT

The dispersed vibration at the column flotation machine lower part causes oscilations distribution in the water column depending on the pipe elasticity and the water column height as well as on the determined vibrations frequency and amplitude. The amplitude value according the height is a variable quantity.

Table 2. The vibrations amplitude along the water column height (H=150cm)
A1 - amplitude measured by the sensor on the vibrator

A2   amplitude measured by the sensor in the water
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h - the sensor height in the water

№	Frequency	The vibrations amplitude along the water column height																					
		h=20cm		h=30cm		h=40cm		h=50cm		h=60cm		h=70cm		h=80cm		h=90cm		h=100cm		h=110cm		h=120cm	
		A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2
	Hz	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1.	25	0,50	0,3	0,50	0,4	0,50	0,3	0,50	0,4	0,50	0,4	0,50	0,3	0,50	0,3	0,50	0,4	0,50	0,6	0,50	0,6	0,50	0,7
		1,00	0,5	1,00	0,7	1,00	0,5	1,00	0,6	1,00	0,7	1,00	0,5	1,00	0,5	1,00	0,9	1,00	1,4	1,00	1,2	1,00	1,5
		1,50	0,6	1,50	1	1,50	0,6	1,50	0,8	1,50	1,00	1,50	0,8	1,50	0,8	1,50	1,3	1,50	2,5	1,50	2,00	1,50	2,4
		2,00	0,7	2,00	1,2	2,00	0,9	2,00	1,00	2,00	1,3	2,00	1,3	2,00	1,3	2,00	2,00	2,00	4,6	2,00		2,00	3,8
2.	30	0,50	1,4	0,50	0,6	0,50	2,4	0,50	2,3	0,50	2,5	0,50	2,7	0,50	2,3	0,50	2,3	0,50	2,00	0,50	1,4	0,50	1,5
		1,00	1,5	1,00	1,2	1,00	3,2	1,00	3,7	1,00	3,4	1,00	4,00	1,00	2,9	1,00	3,4	1,00	1,8	1,00	2,6	1,00	2,6
		1,50	1,6	1,50	2,2	1,50	2,8	1,50	4,1	1,50	3,3	1,50	4,3	1,50	3,5	1,50	4,4	1,50	3,6	1,50	4,4	1,50	4,2
		2,00	1,7	2,00	2,4	2,00	2,4	2,00	2,8	2,00	2,4	2,00	4,2	2,00	4,6	2,00	4,8	2,00		2,00		2,00	
3.	35	0,5	0,9	0,50	0,8	0,50	0,9	0,50	0,6	0,50	1,00	0,50	0,70	0,50	0,7	0,50	0,9	0,50	1,00	0,50	1,1	0,50	1,1
		1,00	1,5	1,00	1,5	1,00	1,6	1,00	1,4	1,00	1,8	1,00	1,40	1,00	1,4	1,00	1,7	1,00	1,9	1,00	2,1	1,00	2,00
		1,50	2	1,50	2	1,50	2,2	1,50	2,00	1,50	2,6	1,50	2,1	1,50	2,1	1,50	2,4	1,50	2,8	1,50	2,9	1,50	2,8
		2,00	2,5	2,00	2,6	2,00	2,6	2,00	2,5	2,00	3,4	2,00	2,80	2,00	2,8	2,00		2,00		2,00		2,00	
4.	40	0,50	0,4	0,50	0,5	0,50	0,6	0,50	0,4	0,50	0,5	0,50	0,5	0,50	0,5	0,50	0,5	0,50	0,8	0,50	0,8	0,50	0,8
		1,00	0,9	1,00	1	1,00	1,2	1,00	0,9	1,00	1,00	1,00	0,9	1,00	0,8	1,00	1,1	1,00	1,6	1,00	1,7	1,00	1,6
		1,50	1,2	1,50	1,3	1,50	1,8	1,50	1,40	1,50	1,6	1,50	1,4	1,50	1,4	1,50	1,9	1,50	2,2	1,50	2,4	1,50	2,2
		2,00	1,6	2,00	1,7	2,00	2,4	2,00	2,2	2,00	2,2	2,00	1,9	2,00	2,00	2,00		2,00	2,9	2,00		2,00	

Measurements researches with a vibratory sensor have been done along the water layer for the amplitude values according the water column determination. In order the influence of the water densities difference and the vibratory sensor the latter was put into a water-isolated Styrofoam sphere with a diameter making the sensor density equal to that of the water. In this way the difference between the real and the measured values of the amplitude of the phases oscillations difference is avoided.

The measurement has been carried out at different water column height in the column flotation machine and in two regimes: without air bubbles (table 2) and with air bubbles (table 3). A part of the obtained results are presented in tables 2 and 3.

The results from the measurement of the vibrations amplitude along the water column height provide the opportunity conclusions about the vibratory-acoustic influence distribution in the flotation machine volume to be made. The fact that the vibrations distribution is influenced by the column geometric dimensions and the resonance phenomena connected with its diameter, the faces thickness and the measurement distance from the vibratory disperser (fig. 2) is definitely corroborated. At the disperser oscillation frequency 40Hz and amplitude 1,0 mm, the liquid vibrations alter from 0,8 to1,7 mm with a clearly expressed corrugated character of the change along the height due to the resonance phenomena along the height.

The liquid amplitude measurement in presence of dispersed in the form of bubbles air shows the amplitude decrease in the bounds from 0,2 to 0,5 mm , which is also with a determined corrugated character, but its values are several times lower than those measured without air bubbles and even lower than the vibratory disperser amplitude.

This decrease of the liquid oscillations amplitude in a gas phase presence explains the air bubbles emerging velocity decrease. The energy dissipation, which is realized at a gas phase presence, causes gas bubbles fluctuation –decrease and increase in their diameter is obtained periodically, synchronous with the supplied vibrations frequency.

Due to the water layer pressure decrease the emerging gas bubble diameter continuously increases. As it is well known that the emerging bubble saves its spherical shape only at very small sizes. At the diameter increase the bubble shape changes providing the smallest moving resistance.

Table 3. The vibrations amplitude along the water column height at an air flow 200 l/h

h - the sensor height in the water

A1 - amplitude measured by the sensor on the vibrator

A2 - amplitude measured by the sensor in the water

№	Frequency	The vibrations amplitudes along the water column height																			
		h=20cm		h=30cm		h=40cm		h=50cm		h=60cm		h=70cm		h=80cm		h=90cm		h=100cm		h=110cm	
		A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2
	Hz	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1.	20	1,00	0,3	1,00	0,4	1,00	0,4	1,00	0,4	1,00	0,3	1,00	0,2	1,00	0,2	1,00	0,3	1,00	0,3	1,00	0,4
		2,00	0,3	2,00	0,4	2,00	0,4	2,00	0,4	2,00	0,3	2,00	0,3	2,00	0,3	2,00	0,4	2,00	0,4	2,00	0,5
		3,00	0,4	3,00	0,4	3,00	0,4	3,00	0,4	3,00	0,3	3,00	0,4	3,00	0,4	3,00	0,4	3,00	0,4	3,00	0,5
2.	25	1,00	0,3	1,00	0,4	1,00	0,4	1,00	0,4	1,00	0,4	1,00	0,2	1,00	0,3	1,00	0,3	1,00	0,4	1,00	0,4
		2,00	0,4	2,00	0,4	2,00	0,4	2,00	0,4	2,00	0,4	2,00	0,3	2,00	0,3	2,00	0,3	2,00	0,4	2,00	0,4
		3,00	0,4	3,00	0,4	3,00	0,4	3,00	0,5	3,00	0,4	3,00	0,4	3,00	0,3	3,00	0,4	3,00	0,4	3,00	0,4
3.	30	1,00	0,8	1,00	0,8	1,00	1,2	1,00	1,5	1,00	0,8	1,00	1,00	1,00	0,4	1,00	0,5	1,00	0,4	1,00	0,9
		2,00	1,9	2,00	1,8	2,00	2,1	2,00	1,9	2,00	1,6	2,00	1,7	2,00	1,2	2,00	0,8	2,00	0,6	2,00	1,5
		3,00	2,5	3,00	2,5	3,00	2,3	3,00	2,1	3,00	1,7	3,00	2,00	3,00	1,6	3,00	0,4	3,00	0,8	3,00	2,1
4.	35	1,00	0,7	1,00	0,7	1,00	0,4	1,00	0,6	1,00	0,4	1,00	0,4	1,00	0,3	1,00	0,4	1,00	0,3	1,00	0,4
		2,00	1,1	2,00	1,2	2,00	0,8	2,00	1,00	2,00	0,6	2,00	0,8	2,00	0,3	2,00	0,4	2,00	0,4	2,00	0,4
		3,00	1,1	3,00	1,4	3,00	1,4	3,00	1,3	3,00	1,2	3,00	1,3	3,00	0,7	3,00	0,6	3,00	0,7	3,00	0,6
5.	40	1,00	0,3	1,00	0,4	1,00	0,4	1,00	0,4	1,00	0,4	1,00	0,4	1,00	0,2	1,00	0,4	1,00	0,4	1,00	0,3
		2,00	0,4	2,00	0,6	2,00	0,6	2,00	0,7	2,00	0,6	2,00	0,5	2,00	0,3	2,00	0,6	2,00	0,5	2,00	0,6
		3,00	0,5	3,00	0,5	3,00	0,6	3,00	0,9	3,00	0,8	3,00	0,6	3,00	0,4	3,00	0,6	3,00	0,8	3,00	0,7
6.	45	1,00	0,4	1,00	0,4	1,00	0,5	1,00	0,3	1,00	0,3	1,00	0,2	1,00	0,3	1,00	0,4	1,00	0,4	1,00	0,4
		2,00	0,7	2,00	0,6	2,00	0,6	2,00	0,4	2,00	0,3	2,00	0,3	2,00	0,4	2,00	0,5	2,00	0,7	2,00	0,8
		3,00	1,00	3,00	0,9	3,00	0,9	3,00	0,5	3,00	0,5	3,00	0,4	3,00	0,5	3,00	0,5	3,00	0,7	3,00	1,00
7.	50	1,00	0,3	1,00	0,3	1,00	0,4	1,00	0,3	1,00	0,3	1,00	0,2	1,00	0,2	1,00	0,2	1,00	0,3	1,00	0,3
		2,00	0,5	2,00	0,4	2,00	0,4	2,00	0,4	2,00	0,4	2,00	0,3	2,00	0,3	2,00	0,2	2,00	0,4	2,00	0,4

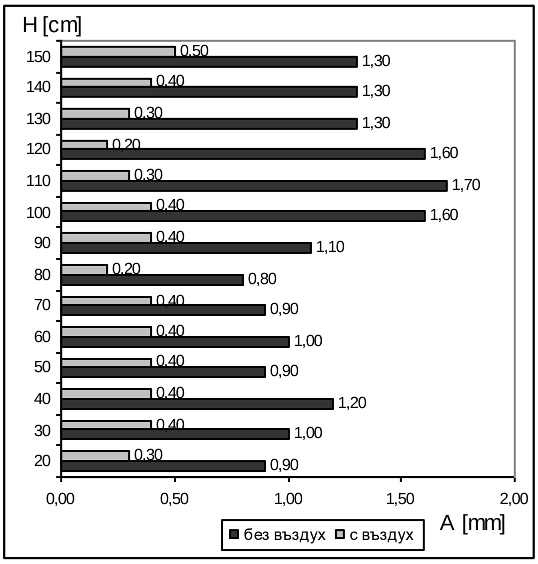

Figure 2. The vibrations amplitude along the water column height with and without gas bubbles

Because of the gas bubble vibration the hydrate layer is not allowed to accept that resistance decreasing shape so the emerging is realized with a shape close to the spherical, which under the defined circumstances creates higher resistance. That resistance is expressed in the bubble emerging velocity decrease.

The velocity decrease gives the opportunity for the bubble stay in the mineral particles contact zone time protraction. The hydrate layer vibrations give the opportunity for the elementary flotation act realization by providing higher relative velocities at a meeting of the bubble and the solid phase and because of the layer thickness as a result of the continuous increase and decrease of the bubble diameter.

CONCLUSION

The carried out vibratory-acoustic researches in the vibrations influence on the air bubbles creation, emerging and behavior in the flotation machine volume provide the opportunity definite interactions to be clarified as well as the question about the vibrations operation on the gas, liquid and solid phase in the column vibratory flotation machine. The results will be used in the final research stage – the technological tests by real products flotation and constructive and technological tests combination on order the vibratory-acoustic processes influence on the flotation process in a column flotation machine to be entirely clarified.

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