Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

Special Issue

COMPLEX RESEARCH OF ACOUSTIC IMPACT ON GAS-DUST FLOW IN VORTEX-ACOUSTIC DISPENSER

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Published online: 24 November 2017

ABSTRACT

Introduction The processing of wastes from mining operations is usually related to the needs of related industries in raw materials. The results of numerous studies on the complex processing of various man-made materials have confirmed the feasibility of their use to ensure resource-saving and obtain new types of products [1-3].

One of the most promising areas of industrial waste utilization is their integrated use in the production of building materials, which allows to meet the demand for raw materials up to 40% for this most important industry. The use of industrial waste allows to reduce costs for the manufacture of building materials 10-30% in comparison with their production from natural raw materials. The saving of capital investments makes 35-50% in this case [4-5].

In modern technology of building materials production, fine powders are one of the fundamental components that significantly affect the quality of finished products [6]. The fineness of material grinding is important for the intensification of various technological processes. However, the obtaining of a highly dispersed product is difficult due to increased energy consumption for material grinding, as well as their abrasiveness at an intensive abrasion, which causes a high wear of grinding bodies and other parts of a grinding unit. This leads to the increase of the grinding process cost, as well as to the obtaining of a poor-quality, contaminated product [7,8]. According to the data [9-10], the energy costs for the grinding of various materials reach 20% of the total energy consumption for production.

The most promising method for fine and ultrafine grinding of various materials used in low-tonnage and innovative technologies is the jet method of grinding [11-12].

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doi: http://dx.doi.org/10.4314/jfas.v9i7s.81

The principle of jet mill operation is based on the use of compressed gas energy. The latter acquires a high speed during expansion used to disperse the particles of the material to be crushed. The destruction of particles in countercurrent jet mills takes place due to their frontal collision with each other or with a barrier. This method allows to use the advantages of high-speed selective grinding of multicomponent material mixtures. The advantages of this method are low material intensity, the possibility of classifying particles by size, the possibility of combining grinding with other processes (chemical treatment, drying, roasting) and the absence of moving parts in a grinding unit [13-14].

However, with all these advantages, the problematic issues of a process energy intensity reduction, an abrasive wear of working organs, the increase of an aspiration system efficiency, etc. remain unresolved.

In our opinion, one of the promising types of jet mills are vortex-acoustic dispersants with a complex dynamic effect on the material to be crushed. In such mills, the grinding of the starting material is intensified by the creation of sound and ultrasonic vibration zones transverse to a rotating gas-dispersed flow [15-18], which leads to fatigue failure of the crushed particles and a highly dispersed product obtaining.

Acoustic effect on a flow. In order to intensify the process of particle destruction in a system, sound emitters are introduced in a system - dynamic (rotating ones) and static (whistle) sirens. The static sirens are represented, in particular, by such generators of acoustic vibrations as vibration jet whistles. In the case of oscillation generators, the process of motion is accompanied by an acoustic radiation. The literature [19-20] points out that acoustic radiation can influence the motion of a swirling flow with particles.

A force action on particles is reduced to the following options. First of all, the absorption of sound radiation by particles. The radiation of high frequencies is better absorbed by small particles of a solid phase, and the radiation of small frequencies is absorbed by large particles [21]. Absorption increases the level of stress in the particles. Such effects are useful for the destruction of particles during an impact or even during their self-destruction. Acoustic disturbances introduce additional mechanisms into the process of destruction [22]. Secondly, there is some effect of an alternating load from sound radiation on a particle. Acoustic radiation results in the impact of the following forces on a particle: the radiation-drift force conditioned by the action of radiation pressure; the drift forces conditioned by a periodic change of a medium viscosity; the force conditioned by the difference between a particle and a carrier medium density [21]. This effect leads to the fact that the particles less than 0.01 mm, which move at some distance from a wall, can be involved in the vibrational motion of a high-speed flow under the action of compression and discharge waves [21]. Under the action of these waves, the particles undergo alternating compressive and tensile stresses [23]. All this leads to the increase of an internal stress-strain state of the particles, contributes to the multiplication and the growth of microdefects of an internal structure of particles and their destruction [24]. In this case, the physical property of solid crystalline materials is used successfully - their fatigue strength is lower than the static strength [25], that is, in order to accelerate the process of fatigue volume fracture of particles, it is advantageous to increase both the frequency and the amplitude of high-frequency cyclic perturbations of flow parameters in a grinding area in addition to the quasistatic (unstressed) periodic loads increase.

The influence on a flow. The effect of acoustic oscillations on a current leads to friction resistance coefficient change. A vibrational motion near a wall leads to an energy carrier consumption increase along a section. Consequently, the value of frictional resistance coefficient should be less than that of a plane semi-bound jet. Under the influence of acoustic oscillations, the braking of a semi-bound swirling jet is much slower for a flow, and the decrease of friction resistance coefficient makes the velocity profile along a wall gentler in comparison with the flow without the influence of acoustic vibrations [26]. This leads to the reduction of energy loss, a flow increase and to the reduction of the number of particle impacts on chamber walls.

Determination of flow aerodynamic characteristics

The main current (a flow core). Since a vortex chamber is a cylinder with a gas rotating in it, the motion of the air flow can be described in the form of the Navier-Stokes equations in conjunction with the equation of continuity in a cylindrical coordinate system.

$$\frac{\partial V_r}{\partial t} + V_r \frac{V_r}{\partial r} + \frac{V_\varphi}{r}\frac{\partial V_r}{\partial \varphi} + V_z \frac{\partial V_r}{\partial z} - \frac{V_\varphi^2}{r} = F_r - \frac{1}{\rho}\frac{\partial p}{\partial r} + \\ + \nu\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial V_r}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 V_r}{\partial \varphi^2} + \frac{\partial^2 V_r}{\partial z^2} - \frac{V_r}{r^2} - \frac{2}{r^2}\frac{\partial V_\varphi}{\partial \varphi}\right), \quad (1)$$

$$\frac{\partial V_\varphi}{\partial t}+V_r\frac{\partial V_\varphi}{\partial r}+\frac{V_\varphi}{r}\frac{\partial V_\varphi}{\partial \varphi}+V_z\frac{\partial V_\varphi}{\partial z}+\frac{V_r V_\varphi}{r}=F_\varphi-\frac{1}{\rho r}\frac{\partial p}{\partial \varphi}+ \\ +\nu\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial V_\varphi}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 V_\varphi}{\partial \varphi^2}+\frac{\partial^2 V_\varphi}{\partial z^2}-\frac{V_\varphi}{r^2}+\frac{2}{r^2}\frac{\partial V_r}{\partial \varphi}\right), \quad (2)$$

$$\frac{\partial V_z}{\partial t}+V_r\frac{\partial V_z}{\partial r}+\frac{V_\varphi}{r}\frac{\partial V_z}{\partial \varphi}+V_z\frac{\partial V_z}{\partial z}=F_z-\frac{1}{\rho}\frac{\partial p}{\partial z}+ \\ +\nu\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial V_z}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 V_z}{\partial \varphi^2}+\frac{\partial^2 V_z}{\partial z^2}\right), \quad (3)$$

$$\frac{1}{r}\frac{\partial}{\partial r}(rV_r)+\frac{1}{r}\frac{\partial V_\varphi}{\partial \varphi}+\frac{\partial V_z}{\partial z}=0. \quad (4)$$

Suppose that a vortex chamber is filled with a viscous fluid that rotates around the central axis at a constant angular velocity. According to [26], the flow of a liquid in a vortex chamber can be assumed to be laminar and established with missing mass forces, and the motion of a two-phase flow can be regarded as the motion of a single fluid with the properties of a bearing flow.

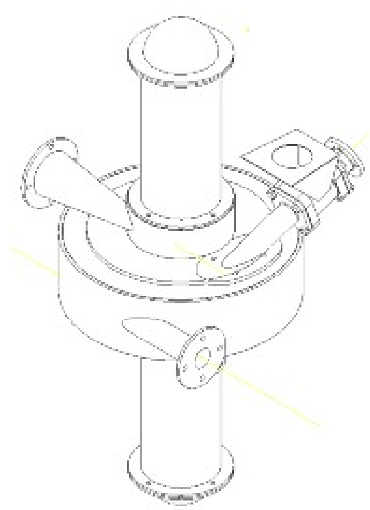


Fig.1. The scheme of a patent-protected design of a vortex-acoustic dispersant.

Under these assumptions, we obtain the following system from the system (1) - (4):

$$\frac{dp}{dr} = \rho \frac{V_\varphi^2}{r}, \tag{5}$$

$$\frac{d^2 V_\varphi}{dr^2} + \frac{1}{r}\frac{dV_\varphi}{dr} - \frac{V_\varphi}{r^2} = 0, \tag{6}$$

the solution of which is the equation [26] for tangential velocity and pressure:

$$V_\varphi(r) = V_{\varphi max}\left(\frac{r}{R_c}\right)^{\frac{k}{k-1}}, p(r) = \frac{\rho}{2}\frac{k-1}{k}\left(\frac{r}{R_c}\right)^{\frac{2k}{k-1}} V_{\varphi max}^2 + p_0, \tag{7}$$

where $k = {c_p}/{c_V}$, a R_c is the radius of a vortex chamber. Formula (7) describes the general structure of the flows characteristic for a forced vortex. The velocity distribution is shown on Fig. 2.

Boundary layer. The velocity distribution in a near wall flow is determined from the Karman theory and for a steady flow the velocity is determined by the relation [27]

$$V_x = U\left(\frac{3}{2}\frac{y}{\delta} - \frac{1}{2}\left(\frac{y}{\delta}\right)^3\right). \tag{11}$$

where δ is the thickness of a boundary layer, $U = (V_x)_{y=\delta}$ is the velocity at the boundary layer. Fig. 3 and 4 show the velocity distribution in a boundary layer and the velocity profile in a vortex chamber.

It is known [26] that a sound wave makes the main effect on a current in a boundary layer. A plane sound wave produced by an acoustic oscillation generator has the following form [28]

$$v_x = v_{0x}(y)\cos(\omega t - kx), v_y = v_{0y}(y)\cos(\omega t - kx). \tag{12}$$

The effect of a sound wave on the main flow leads to a flow velocity change in a thin boundary layer. In a standing wave, a sound wave in a boundary layer causes a current that is reduced to the development of vortices of a certain magnitude [28]. The velocity of such a flow is provided by the following formula:

$$v_x = -\frac{v_0^2}{4c_0}\left(\mu - \mu^2\right)\sin(2kx),\ v_y = -\frac{v_0^2}{4c_0}k\delta\mu^2\cos(2kx), \tag{13}$$

where $\mu = \frac{y}{\delta}$.

According to V.G. Akuna's data [29], 10 - 15 standing waves are developed in a single-phase jet. Therefore, the flow (13), caused by a sound wave in a boundary layer, covering the flow (11), will rather lead to velocity decrease. At that, several acoustic oscillation generators arranged in succession will lead to a greater deceleration of a flow as compared to a single one.

The addition of (11) and (13) will give the velocity in a boundary layer when the main flow is covered caused by a sound wave

$$v_x = U\left(\frac{3}{2}\mu - \frac{1}{2}(\mu)^3\right) - \frac{v_0^2}{4c_0}\left(\mu - \mu^2\right)\sin(2kx),\ v_y = -\frac{v_0^2}{4c_0}k\delta\mu^2\cos(2kx). \tag{19}$$

The field of velocities (19) is shown on Fig. 5. Figure 6-7 show a flow nature in a boundary layer.

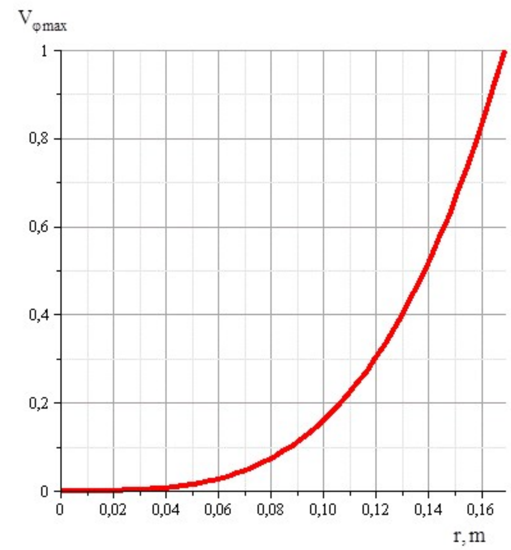


Fig.2. The distribution of the tangential velocity along the chamber radius

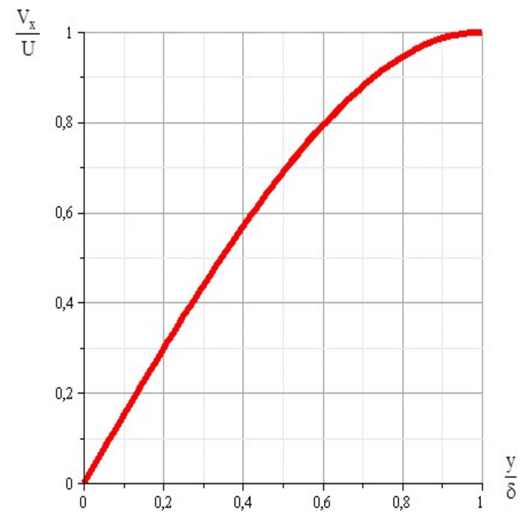


Fig.3. The distribution of the tangential velocity in the boundary layer

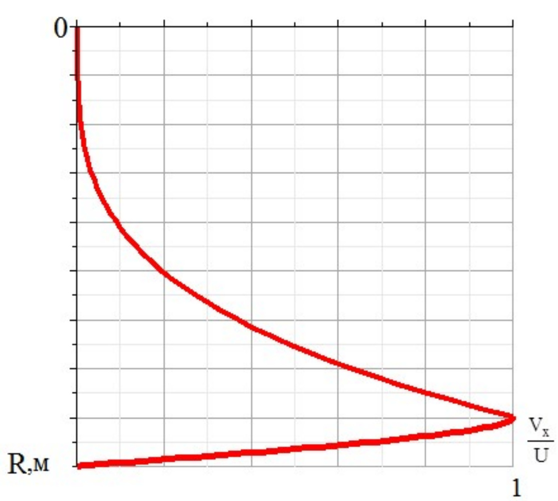


Fig.4. The velocity profile in a vortex chamber

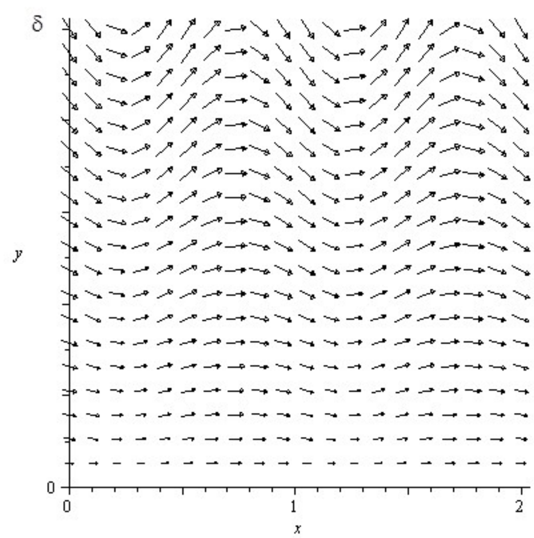


Fig.5. The field of velocities in a boundary layer

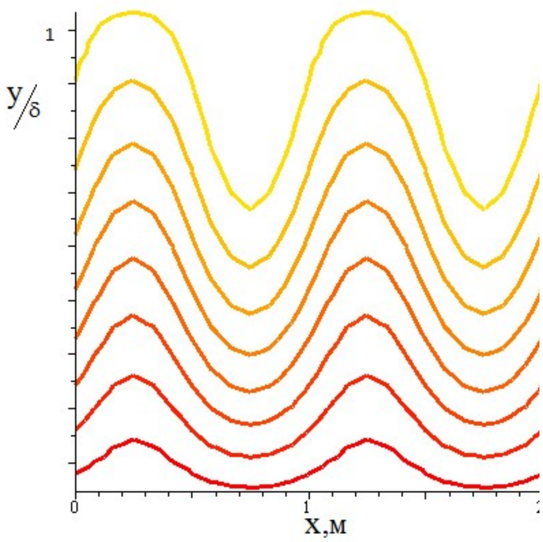


Fig.6. The velocity distribution v_x in a boundary layer

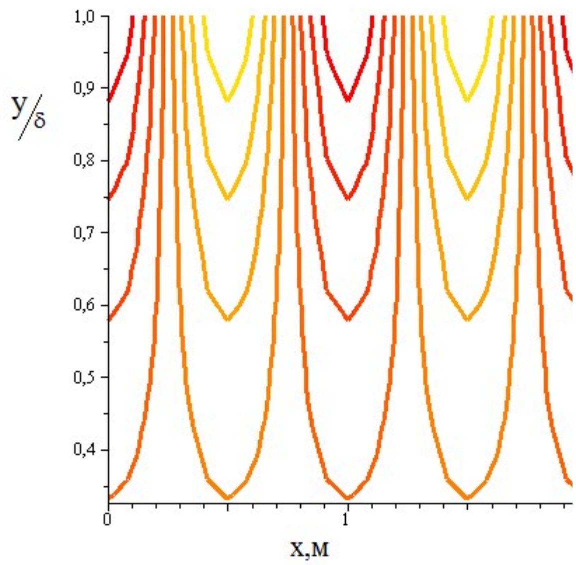


Fig.7. The velocity distribution v_y in a boundary layer

Flow motions in exhaustion-compression zones

Acoustic generators, which are the source of elastic vibrations, make the caverns of a circular or a rectangular shape (Fig. 8). The flows near and inside two-dimensional caverns are characterized by flow separation at the anterior wall and its attachment at the posterior wall [30]. At that a recirculating flow occurs in a cavern. At that the zones of flow secondary separations appear in a cavity. This flow depends on the geometric parameters of a cavern.

Three-dimensional flows also have recurrent flows, similar to two-dimensional ones. A distinctive feature is the presence of topological structures of the "focus" type on the side walls [31]. At that, a focus can be a stable and an unstable one. A steady focus extends from a wall to a flow as a concentric vortex line, which has considerable energy. An unstable focus is the attachment of a vortex bundle to a wall. The presence of these structures suggests that the gas flow inside a cavity occurs around a vortex. However, since a significant flow of mass between the walls occurs through a vortex, this indicates a transverse flow within a cavity. Such a flow interacts with the main flow and leads to the appearance of a torus-like vortex. This vortex maintains the state of a flow three-dimensionality, makes an impact on a shear layer and leads to an asymmetric flow into a cavity.

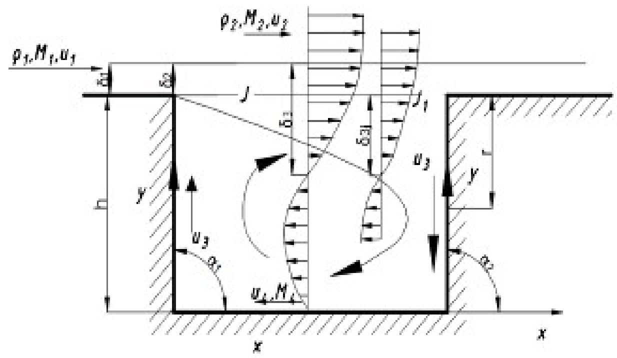


Fig.8. Flow direction scheme in a resonator chamber

According to the experiments, the flow inside a chamber is nonstationary one, and the process can be described as follows [31]. The flowing of the flow into the cavity near a back wall leads to the appearance of a return flow. This current interacts with the side walls, causing the formation of a transverse vortex. This vortex promotes the flowing of high-energy gas jet into a detachment region.

The focal vortex, interacting with the side walls of a chamber, leads to the formation of a torus-like vortex. After that, the process of gas ejection from a cavity takes place and the process is repeated.

The flow pattern near a cavity, obtained as the simulation result is shown on Fig.8. The nonstationary nature of the flow is shown near the cavity.

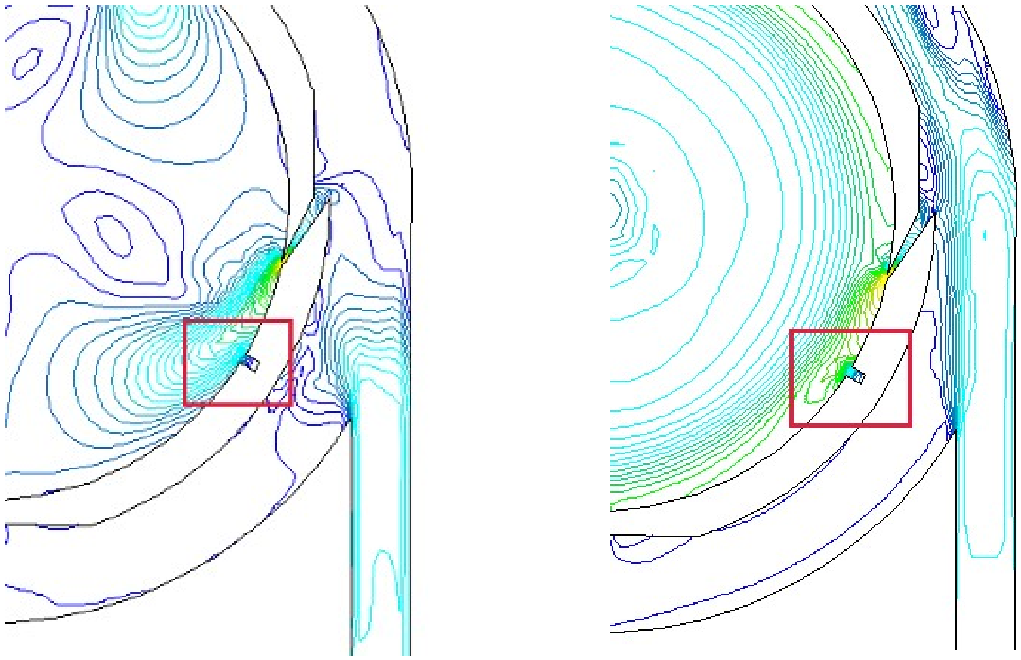
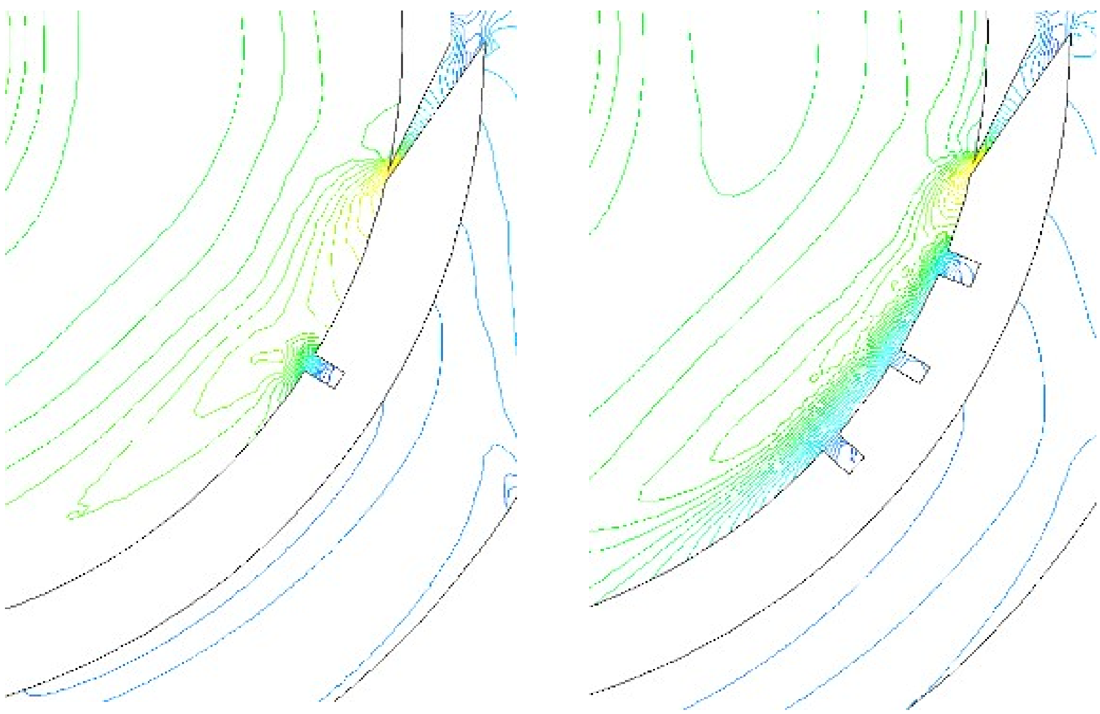


Fig.9. Flow dynamics near a cavern

Fig. 10 shows the flow pattern of one and several acoustic oscillation generators.



a) б)

Fig.10. Flow pattern around a) one and b) three caverns

As can be seen from the figures several caverns located in succession slow down the flow considerably as compared to one cavern.

In addition to the number of caverns, the size of a cavern also plays an important role in energy costs. The effect of the cavern b width on the energy consumption in a dispersant with different diameter of the suspended particles is shown on Fig. 10.

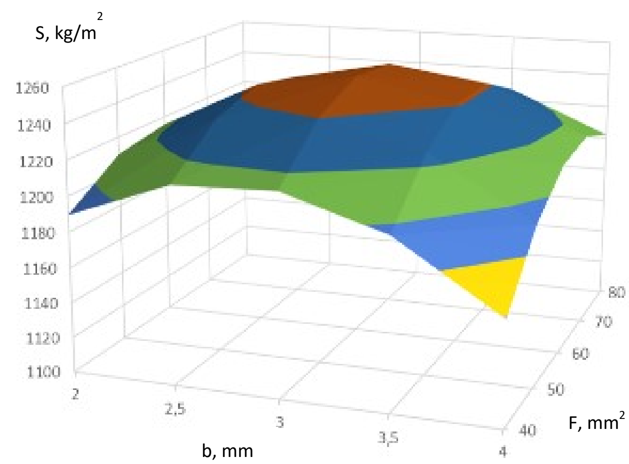


Fig.11. The dependence of the specific surface area of quartzite-sandstone particles on the value of the acoustic resonator width and the area of nozzles.

Technological line for grinding and dressing of iron-ore materials using a vortex-acoustic dispersant

The creative team of authors developed low-tonnage technological lines and the equipment for the production of mechanically activated natural and technogenic materials [8, 15-18, 2, 32, 33].

The tests of vortex-acoustic dispersants (VAD) with various materials: quartzite sandstones, calcareous components, the waste of iron industries, etc. So the grinding of ferruginous quartzites of the Yakovlevsky deposit was carried out at LLC "OxiBel". The general form of the dispersant is shown on Fig. 12. A crushed product (less than 40 μm) is used to produce the pigments for the production of paints in accordance with GOST.

Fig.12. General view of a pilot-industrial sample of a vortex-acoustic dispersant

VAD has the following specifications:

Efficiency		kg/h	25 – 30
Specific energy consumption (calculated)		kg/kg	0,65
Energy carrier pressure		MPa	0,3 – 0,5
Energy carrier consumption		m^3/h	80 – 100
Initial material dimensions		mm	2,5 – 3
Grinding finess, $\Sigma_{R0.045}$		%	<0,3
Dimensions	length	mm	400
	width	mm	400
	height	mm	500

The dispersant operated by an open grinding scheme, which is shown on Fig. 13.

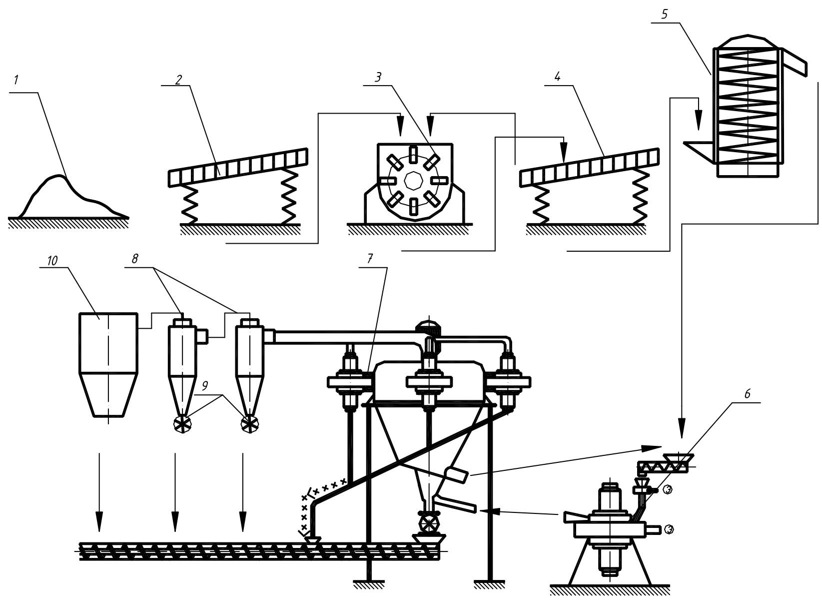


Fig.13. Experimental production line for the production of fine iron ore

Initial ore with the material size of 20 mm enters the storage warehouse after the crushing and sorting factory. For more complete extraction of ore mineral, the industrial product is subjected to two-stage grinding. The first step is carried out in a hammer crusher 3 to the size of "-3 mm". The separation of the product is carried out using a sieve screen 4. The prepared concentrate is sent for drying to a vertical dryer 5. After drying, the residual moisture content of the material should be no more than 2%.

In order to ensure a uniform feed of materials, a screw feeder is used in the vortex-acoustic dispersant 6 during the second grinding stage. The iron ore concentrate is crushed in the grinding chamber of the dispersant with an energy carrier pressure up to 0.5 MPa, supplied from the factory network of compressed air.

After grinding, the material enters the turbine-vortex separator 7, and the undersized material is returned for re-grinding in a vortex-acoustic dispersant 6. The finished fine material is secured in an aspiration system consisting of successively mounted cyclones 8 and a bag filter 10. The monitoring the material granulometric composition in production conditions was carried out by sieving the pigment on sieves with a minimum particle size less than 40 μm.

The granulometric composition of the crushed ferrous quartzite is presented on Table 1.

Table 1. The granulometric and chemical composition of the initial iron ore

Size, mm	Composition, %	Composition				
		Fe	Fe_2O_3	SiO_2	Al_2O_3	loi
+30	10,9	63,93	91.03	2,78	1,94	4,25
+18	12	64,5	91.69	2,75	1,84	3,72
+12	4,6	65,29	94.2	2,58	1,53	1,69
+8	2,9	66,27	95.36	1,34	1,21	2,09
+5	3,8	67,36	95.73	1,23	1,17	1,87
+3	21,4	67,03	96.53	0,81	1,09	1,57
+1	40,8	66,53	95.15	1,95	1,28	1,62

Iron ore for the production of iron oxide powder (rusk) has a reddish shade without a metallic luster, and for the production of iron ore concentrate it has black color with a characteristic metallic luster.

The Yakovlevsky iron ore deposit is characterized by a high content of iron oxide, according to the data of the Table 1.

After the iron ore grinding in a vortex-acoustic dispersant, the granulometric composition of iron-oxide powder and iron-ore concentrate made

Class, micrometers	+40	-40
Output, %	1,3 2,7	98,7 97,3

Note: the numerator of iron oxide powder, the denominator of iron ore concentrate.

The chemical composition of the powders is shown in Table 2

Components	Fe	Fe_2O_3	$Fe(OH)_3$	SiO_2	Al_2O_3	loi
Iron oxide powder						
Content, %	65,2	92,1	4,2	0,7	0,1	2,9
Iron ore concentrate						
Content, %	69,6	98,81	0,3	0,4	0,1	0,39

In the process of iron ore enriching, non-metallic interlayers and host rocks are distinguished.

The granulometric composition of the iron oxide powder and iron ore concentrate is homogeneous one, with all fractions represented by the aggregates of hematite grains slightly cemented with hydrohematite and carbonates.

After the conducted studies, Fe203 content in iron ore increased from 96% to 98.81%.

CONCLUSIONS

Complex theoretical, experimental and experimental-industrial studies are performed concerning the processes of material dispersion in the patent-protected design of vortex-acoustic dispersion.

The simulation of an acoustic action flow on a swirling flow is performed in a vortex-acoustic dispersant. It is established that an acoustic effect on a flow current leads to its inhibition. At that the stream flow in the boundary layer takes on an oscillatory character.

Simulation has made it possible to establish the character of acoustic oscillation distribution when single and sequentially located acoustic wave generators and an enhanced effect of their inhibition are used.

The results of theoretical and experimental studies are realized in production conditions during a pilot industrial line testing.

REFERENCES

1. Mosinets V.N. Mining and environment. / V.N. Mosinets, M.V. Gryaznov // - M.: Mysl, 1978. - 293 p.

2. Laskorin B.I. Wasteless technology of mineral raw materials processing. System analysis / B.I. Laskorin, L.A. Barsky, V.Z. Persits // - M.: Nedra, 1984. - 334 p.

3. Sittigue M. The extraction of metals and inorganic compounds from waste, trans. from English, M.: Metallurgy, 1985. - 408 p.

4. Donenov B. Mineral resources in modern economy of Kazakhstan NTSMI: report. - Almaty, 2004. - 136 p.

5. Golikov V.I. Tsidaev T.S., Tsidaev B.S. Tailings of metallurgical ore enrichment as raw materials for the production of building materials // Dry building mixtures. 2015. № 4. - pp. 21-25.

6. Lvov V.V. New technologies in fine and ultrafine grinding of mineral raw materials. The notes of Mining Institute. - 2013. V. 202. - pp. 115-117.

7. Berezovsky S.N., Berezovsky N.I. Integrated development, the use of raw materials and overburdens for the production of building materials. Bulletin of Belarusian-Russian University. 2009. - №3. - pp. 155-161.

8. Perelygin D.N., Sevostyanov V.S., Boychuk I.P., Kuznetsov I.A. The study of abrasive particle impact contact with the lining of a vortex-acoustic disperser. Bulletin of BSTU named after V.G. Shukhov. 2015. № 2. - pp. 122-125.

9. Goncharov S.A., Ananyev P.P. Energy saving in the preparation of ores for the enrichment at iron ore and gold ore mining and processing plants. News of higher educational institutions. Mountain magazine. 2009. - №3. - pp. 91-95.

10. Rakaev A.I., Shumilov P.A. The regularities of poor copper-nickel ore crushing in drum mills. The bulletin of the Murmansk State Technical University. - 2009. V. 12. - № 4. - pp. 638-643.

11. Postnikova I.V., Blinichev V.N., Kravchik Ya. Jet mills. Modern high technologies. Regional annex. - 2005. - №2 (42). 144-151.

12. Kravchenko V.P. The activation of blast furnace slags. The bulletin of Priazov State Technical University. Technical sciences. - 2010. - №2. - pp. 17-20.

13. Fedotov K.V., Dmitriev V.I. The change of ore technological properties during the grinding in counter-current-vortex jets. The news of higher educational institutions. Mountain magazine. - 2010. - pp. 129-132.

14. Garabzhiu A.A. The development and the research of a vortex mill with continuous flow classification of a finished product: Abstract from the thesis of tech. science candidate / Minsk, 2000.

15. RF patent No. 2226432. Vortex-acoustic dispersant / Sevostyanov V.S., Lesovik V.S., Perelygin D.N., Gorlov A.S., Nechaev S.P. 10.04.2004, Bul. №10.

16. Russian Federation patent №2250138. Vortex-acoustic disperser / Gridchin A.M., Sevostyanov V.S., Lesovik V.S., Gorlov A.S., Perelygin D.N., Fedorenko B.Z. 20.04.2005, Bul. №11.

17. RF patent No. 2317147. Vortex-acoustic dispersant-mixer (variants) / Sevostyanov V.S., Gridchin A.M., Nechaev S.P., Lesovik V.S., Gorlov A.S., Perelygin D.N. 28.02.2008. Bul. №5

18. Sevostyanov V.S., Perelygin D.N., Uralsky V.I., Gorlov A.S., Glagolev E.S., Babaevsky A.N. The development and the research of energy-saving grinding equipment for high-dispersion grinding of materials / Scientific publication "Bulletin of BSTU": a scientific and theoretical journal: Belgorod. BSTU publishing house, 2014. - № 3. - pp. 76-80.

19. RF patent 2013134. Gas-dynamic device for fine grinding / Artemyev V.K. 28.02.2008. Bul. №5

20. RF patent No. 2103070. The method of fine or superfine grinding of polydisperse particles of crystalline materials / Kardanov Yu.Kh.

21. Zakharov Yu.A. The crushing of dispersed materials in vortex mills under the influence of acoustic oscillations: Abstract from the dissertation of tech. science candidate. St. Petersburg, 2001. 18 p.

22. RF Patent No. 96109854/03, May 14, 1996. Shostak V.V., Kulakov M. Pa. The method of material grinding in the energy carrier flow and the device of vortex grinding for its realization // Russian Federation patent No. 2100082. 1997.

23. RF patent № 93053658/33, 06.12.1993. Artemyev V.K.; Kardanov Yu.Kh. The method of ultrafine grinding of materials // Russian Federation patent No. 2070094. 1996.

24. Fundamentals of ultrasound physics and technology / B.A. Agranat, M.N. Dubrovin, N.N. Khavsky. - M.: Higher education, 1987. 352 p.

25. Goldstein M.E. Aeroacustics. -M.: Mechanical Engineering, 1981. -294 p.

26. Kochin N.E., Kibel I.A., Roze N.V. Theoretical Hydromechanics, Part 2 - Moscow: Fizmatgiz, 1963. - 728 p.

27. Agranat B.A. Fundamentals of ultrasound physics and technology, Moscow. High School, 1987. - 352.

28. Kochin N.E., Kibel I.A., Roze N.V. Theoretical hydromechanics. M.: Fizmatgiz, 1963. - 728 p.

29. Akunov V.I. Jet mills. Elements of theory and calculation. M: State scientific and technical publishing house of machine-building literature, - 1962. - 265 p.

30. Zheng P. Control of detachment flow. - M.: translation from English, World. - 1979.

31. Antonov A.M. Numerical and experimental study of supersonic flow around a notch. Author's abstract from the diss. for the academic degree of physic-mathematic sciences candidate in 1994, Moscow.

32. Gridchin A.M., Sevostyanov V.S., Lesovik V.S., Gorlov A.S., Perelygin D.N., Romanovich A.A., Kolesnikov A.V. Energy-resource-saving facilities of fine and ultrafine grinding of materials. News of higher educational institutions. Building. 2006. - No. 11-12. - pp. 60-68.

33. Uralsky A.V., Kolesnikov A.V., Perelygin D.N., Sinitsa E.V. Technological modules for complex grinding of materials. Bulletin of BSTU named after V.G. Shukhov. - 2007. - №3. - pp. 113-118.

How to cite this article:
Sevostyanov V S, Boychuk I P, Perelygin D N, Martakov I G. Complex research of acoustic impact on gas-dust flow in vortex-acoustic dispenser. J. Fundam. Appl. Sci., 2017, 9(7S), *888-905*.