A plant with a rotary jet grinder to produce small fractions of mineral raw material

A D Bardovsky*, L M Valeeva and I I Basyrov

National University of Science and Technology “MISiS”, Leninskiy prospekt, 4, Moscow, 119049, Russia

*bardowski@yandex.ru

Abstract. This paper presents the results of studying a set of equipment including a centrifugal mill and a separator. It presents data on the plant’s design and operation, defines a rational shape of the working surface of the mill’s accelerating discs providing highly effective collision of particles moving in oncoming flows. As a result of theoretical studies, we established that the generatrix of such a surface should have the form of a logarithmic curve. Experimental studies have shown that the best quality of the plant operation is achieved with certain combinations of parameters, such as rotor speed, the distance between the ends of rotating rotors, and the air flow rate.

1. Introduction

Fine mineral powder is a filler made by grinding carbonate rocks followed by its drying. It is one of the necessary and most demanded products in road construction; it can be also used as filler for the production of roofing materials and as an additive to dry building and concrete mixes. This mineral powder is used in asphalt concrete that may contain clay particles, which reduces the road construction costs [1-4].

High rates of development of all engineering industries [5-38] require improvement of production at industrial enterprises with the solution a number of technological and organizational problems. One of the promising types of equipment for the production of finely-ground mineral powder is a centrifugal self-grinding mill with accelerating discs (rotors), which, in combination with precipitation devices, represents a plant that allows to get a high-quality product with minimal energy consumption (figure 1) [39, 40].

The plant includes the following devices mounted on a common frame: mill 2, inertial separator 3, source material feed hopper 1 with two screw feeders 11, cyclone 4, bag hose 5, fan 8, dust pipes with appropriate fittings. Two screw feeders 11 have a common drive from electric motor 10, gearbox 9, V-belt transmission 13 with a set of pulleys mounted on the output shaft of gearbox 9 and shafts of feeders 11 and providing step-by-step speed control of feeder screws.

As the mill’s drive, two electric motors 6 are used that are connected to the shafts of accelerating cones by V-belt transmission 12 using a set of pulleys of various diameters, which allows to provide step-by-step speed control of accelerating cones. For transporting grinded product with compressed air, console fan 8 is used, where the impeller is mounted directly on motor shaft 7.
The centrifugal rotary jet grinding mill (figure 2) includes welded body 1 with two accelerating cone rotors 5, that are console mounted therein on coaxial horizontal shafts 2 and driven by V-belt transmission 6 and two receiving pipes 3 for feeding the source material to accelerating cones 5. Receiving pipes 3 are mounted integrally with bearing units 4 of horizontal shafts 2 on a common support. Each accelerating cone 3 has a truncated shape with holes at its smaller base for passage of the source material. Between accelerating discs 3, there is an end clearance $\delta$ which can be adjusted by mutual axial movement of the discs.

The plant operates as follows. The source material is supplied to hopper 1 (figure 1); then, through screw feeders 11 and mill inlets 2, it is fed to its working bodies – accelerating discs 5 (figure 2). Moving on the inner surface of conical discs that quickly rotate in opposite directions, accelerated
material particles, under the influence of centrifugal forces, are supplied to the final sections of the discs; when separated from the latter, particles acquire a significant amount of kinetic energy. Accelerated particles converging on the surface of one rotor are grouped in the form of a fan, colliding with fan particles converging on the surface of the second rotor. Material self-grinding process is carried out when particles collide in the annular space between rotors 5.

Air supplied from fan 8 (figure 1) removes the grinded material from mill 2, which is sent to separator 3 to separate particles not grinded to the desired size. These particles are sent back to mill 2 for grinding, whereas conditioned particles (the finished product) are sent to cyclone 4, where finished fractions of the material are precipitated. Air purified from particles in cyclone 4 and then in bag hose 5 is sent back to fan 8, thereby providing a closed grinding cycle. Particles precipitated in cyclone 4 are sent to the finished product receiving tank.

2. Main Methods and Results of the Study

Based on theoretical research, we determined a rational shape of the inner working surface of the rotors providing highly effective collision of particles that move in oncoming flows [39]. The generatrix of such a surface should have the shape of a logarithmic curve, which is described by the following equation (figure 3):

\[ \rho = r_0 \left\{ 0.5 \exp(x - c) / b + 1 \right\} - n \]  

Here: \( \rho \) is a variable radius of the disc working surface:  
\[ r \leq \rho \leq r_{max}, \]

where \( r_{max} \) is the largest radius of the disc inner surface;  
\[ b = \left( r_{max} - r_0 \right) / \tan \alpha_{max}, \]  

where \( \alpha_{max} \) is the maximum angle between the tangent to the generatrix and the disc rotation axis;  
\[ c = b \ln \left( r_0 / 2n \right), \]  

where \( n \) is the value determined by the maximum size of the grinded particles \( k_{max} \):  
\[ n = A k_{max}^{1.25}, \]  

where \( A = 40...55 \) is an empirical coefficient which depends on the grinded particle shape.

![Figure 3. View of the logarithmic curve: I – the maximum particle size \( k_{max} = 5 \) mm; II – the maximum particle size \( k_{max} = 10 \) mm.](image)

Experimental studies were carried out on the plant; as the source material, we used waste from the processing of raw materials of a carbonate quarry with a particle size of 0 to 10 mm. We analyzed
such parameters as the disc rotation speed \( n_d \), the end clearance between discs \( \delta \), and the air flow rate \( Q_v \) [40].

Based on the experimental results, we obtained a regression equation describing the dependence of the carbonate waste grinding performance in terms of the finished product \( Q_g \) on the above parameters:

\[
Q_g = -1820.67 + 0.6562n_d + 16,33\delta + 4,349Q_v - 77,33 \cdot 10^{-6}n_d^2 - 3,93\delta^2 - 9,4 \cdot 10^{-3}Q_v
\]  
(5)

Figure 4 shows the performance curves of \( Q_g \) depending on the disc revolution speed \( n_d \). Analysis of the graphs shows that, for rational values \( \delta \) and \( Q_v \) as determined when planning the experiments, the maximum performance in terms of the finished product reaches 85 % at a disc speed \( n_d = 4,200 \text{ min}^{-1} \). Changing the disc speed \( n_d \) with end clearance values \( \delta = 20 \text{ mm} \) and \( \delta = 4 \text{ mm} \) reduces the value \( Q_g \) by 3 to 8 %, and the performance maximum is shifted towards increasing the value of \( n_d \).

Figure 5 shows the performance curves \( Q_g \) depending on the end clearance \( \delta \) between accelerating discs. The analysis of these dependencies shows that the maximum performance \( Q_g \) is observed when \( \delta = 3 \text{ mm} \), which confirms the studies conducted using multifactorial planning. The highest grinding quality (82 to 86 %) was observed when \( \delta = 3 \text{...5 mm} \). With reducing \( \delta \), the performance is significantly decreased not only for \( Q_g \), but also for \( Q_v \) (for the source material). This is due to the difficulty of the grinded product passing through a rather narrow slot, which results in particles overflowing the volume enclosed inside the hollow rotors. On the contrary, increasing the value \( \delta \) up to more than 5 mm improves the grinded product passage through the slot, while reducing the probability of counter particles collision, which results in a decrease in \( Q_g \).

Figure 4. Dependence of the performance in terms of the finished product \( Q_g \) on the disc speed \( n_d \)

Figure 5. Dependence of the performance in terms of the finished product \( Q_g \) on the end clearance size \( \delta \) between accelerating discs.
3. Conclusions
1. Highly effective collision of particles, converging from the accelerating cones of a centrifugal mill and moving in oncoming flows, is provided with a shape of their working surface that has a generatrix in the form of a logarithmic curve.
2. The best quality of the pilot plant operation, when grinding waste carbonate rocks to obtain mineral powder, is achieved with the following parameters: rotation speed of accelerating discs $n_d = 4200 \text{ min}^{-1}$; the end clearance size $\delta$ between accelerating discs $\delta = 3 \text{ mm}$.

References
[1] Sulimenko L M, Akimova T N and Makaeva A A 2016 *Tekhnologiya proizvodstva mineral'nykh vyazhushchikh materialov (A Method for the Production of Mineral Binders)* (Orenburg: Orenburg State University) p 156
[2] Khodakov G S 1972 *Tonkoe izmel'chenie stroitel'nykh materialov (Fine Grinding of Building Materials)* (Moscow: Building Literature Publishing House) p 239
[3] Bardovsky A D 1996 Analysis of Carbonate Quarry Waste Used for Manufacture of Commercial Products In collection of papers “Improving the Complex Mineral Enrichment Method” (Moscow: Moscow State Mining University) pp 108–11
[4] Basyrov I I and Bardovsky A D 2020 *Mining Informational and Analytical Bulletin (Gorny Informatsionno-Analiticheskiy Byulleten)* 2 pp 121–9 DOI: 10.25018/0236-1493-2020-2-0-121-129
[5] Bardovsky A D, Gerasimova A A and Basyrov I I 2020 *IOP Conference Series: Materials Science and Engineering* 709 (2) 022015 DOI: 10.1088/1757-899X/709/2/022015
[6] Bardovskii A D, Gerasimova A A, Keropyan A M and Bibikov P Y 2018 *Izvestiya Ferrous Metallurgy* 61 (9) 678–82 DOI: 10.17073/0368-0797-2018-9-678-682
[7] Bratan S, Kolesov A, Roshchupkin S and Stadnik T 2017 *ICMTMTE 2017. MATEC Web of Conferences* 129 01078 DOI: 10.1051/matecconf/201712901078
[8] Bratan S and Roshchupkin S 2018 *ICMTMTE 2018. MATEC Web of Conferences* 224 01133
[9] Bratan S, Roshchupkin S and Novikov P 2017 *Procedia Engineering* 206 pp 1419–25 DOI: 10.1016/j.proeng.2017.10.655
[10] Roshchupkin S and Kharchenko A 2018 *ICMTMTE 2018. MATEC Web of Conferences* 224 01001
[11] Bardovsky A D and Gerasimova A A 2019 *Mining Informational and Analytical Bulletin (Gorny Informatsionno-Analiticheskiy Byulleten)* 7 pp 132–9 DOI: 10.25018/0236-1493-2019-7-0-132-139.
[12] Bast J, Gorbatyuk S M and Kryukov I Yu 2011 *Metallurgist* 55 (1-2) pp 116–8 DOI: 10.1007/s11015-011-9399-1
[13] Bardovsky A D, Gerasimova A A and Basyrov I I 2019 *ICIE 2018. Lecture Notes in Mechanical Engineering* I pp 133–9 DOI: 10.1007/978-3-319-95630-5_14
[14] Gerasimova A, Gorbatyuk S and Devyatiarova V 2018 *Solid State Phenomena* 284 SSP pp 1284–90 DOI: 10.4028/www.scientific.net/SSP.284.1284
[15] Gerasimova A, Mishedchenko O and Devyatiarova V 2020 *IOP Conference Series: Materials Science and Engineering* 709 (2) 022016 DOI: 10.1088/1757-899X/709/2/022016
[16] Keropyan A, Gorbatyuk S and Gerasimova A 2017 *Procedia Engineering* 206 pp 564–9 DOI: 10.1016/j.proeng.2017.10.517
[17] Bibikov P Y, Bardovskiy A D and Keropyan A M 2019 *Materials Today: Proceedings* 19 pp 2552–4 DOI: 10.1016/j.matpr.2019.08.207
[18] Surina N V and Mnatsakanyan V U 2019 *Gornyi Zhurnal* 7 pp 90–5
[19] Osadchiy V A, Albul S V, Kuprienko N S and Kirillova N L 2020 *IOP Conference Series: Materials Science and Engineering* 709 (4) 044079 DOI: 10.1088/1757-899X/709/4/044079
[20] Basygin A M 2020 *ICIE 2019. Lecture Notes in Mechanical Engineering* pp 231–7 DOI: 10.1007/978-3-030-22041-9_27
[21] Kobelev O A, Albul S V and Kirillova N L 2020 IOP Conference Series: Materials Science and Engineering 709 (4) p 044104 DOI: 10.1088/1757-899X/709/4/044104

[22] Gorbatyuk S M, Osadchii V A and Tuktarov E Z 2011 Metallurgist 55 (7-8) pp 543–6 DOI: 10.1007/s11015-011-9465-8

[23] Gorbatyuk S M, Morozova I G and Naumova M G 2017 Steel in Translation 47 (5) pp 308–12 DOI: 10.3103/S0967091217050047

[24] Gorbatyuk S M and Kochanov A V 2012 Metallurgist 56 (3-4) pp 279–83 DOI: 10.1007/s11015-012-9571-2

[25] Naumova M G, Morozova I G and Borisov P V 2019 Materials Today: Proceedings 19 pp 2405–8 DOI:10.1016/j.matpr.2019.08.044.1

[26] Gorbatyuk S M, Morozova I G and Naumova M G 2016 Metallurgist 60 (5-6) pp 646-50 DOI: 10.1007/s11015-016-0345-0

[27] Keropyan A, Albul S and Zarapin A 2020 ICIE 2019. Lecture Notes in Mechanical Engineering 11 pp 651-8 DOI: 10.1007/978-3-030-22063-1_69

[28] Gorbatyuk S, Kondratenko V and Sedykh L 2019 Materials Today: Proceedings 19 pp 2361–4 DOI: 10.1016/j.matpr.2019.07.695

[29] Gorbatyuk S M, Pavlov S M, Shapoval A N and Gorbatyuk S M 1998 Metallurg 5 pp 32–5

[30] Gorbatyuk S, Kondratenko V and Sedykh L 2019 Materials Today: Proceedings 11 pp 258–64 DOI: 10.1016/j.matpr.2018.12.140

[31] Gorbatyuk S M and Sedykh L V 2010 Metallurgist 54 (5-6) pp 299–301 DOI: 10.1007/s11015-010-9297-y

[32] Glukhov L M, Gorbatyuk S M, Morozova I G and Naumova M G 2016 Metallurgist 60 (3-4) pp 306–12 DOI:10.1007/s11015-016-0291-x

[33] Gorbatyuk S, Kondratenko V and Sedykh L 2018 ICMTMTE 2018. MATEC Web of Conferences 224 01035 DOI: 10.1051/matecconf/201822401035

[34] Naumova M G, Morozova I G, Zarapin A Y and Borisov P V 2018 Metallurgist 62 (5-6) pp 464–9 DOI: 10.1007/s11015-018-0682-2

[35] Naumova M G, Morozova I G and Borisov P V 2020 Solid State Phenomena 299 SSP pp 943–8 DOI:10.4028/www.scientific.net/SSP.299.943

[36] Keropyan A and Gorbatyuk S 2016 Procedia Engineering 150 pp 406–10 DOI: 10.1016/j.proeng.2016.06.753

[37] Gorbatyuk S, Pashkov A and Chichenev N 2019 Materials Today: Proceedings 11 pp 31–5 DOI: 10.1016/j.matpr.2018.12.102

[38] Zakharov A N, Gorbatyuk S M and Borisevich V G 2008 Metallurgist 52 (7-8) pp 420–3 DOI: 10.1007/s11015-008-9072-5

[39] Perevalov V S, Bardovsky A D and Kryazhev N M 2001 Optimization of the Working Surface Shape of Accelerating Rotors in a Centrifugal Mill Proceedings of the Fortieth Symposium “Simulation in Mechanics” (Poland: Silesian Technical University) 17 pp 157–62

[40] Kryazhev N M 2002 Opredelenie ratsional'nykh parametrov tsentrobeznoi mel'nitsy dlya tonkogo izmelnjeniya karbonatnykh otkhodov (Determining the Rational Parameters of a Centrifugal Mill for Fine Grinding of Carbonate Waste) Thesis for the degree of candidate of technical sciences (Moscow: Moscow State Mining University) p 212