Examination of the preliminary gravity dressing influence on the Shalkiya deposit complex ore

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Recently, the ore base of the Republic of Kazakhstan has been characterized by involvement of rebellious and off-balance ores into processing. In this regard, much attention is paid to the methods of preliminary enrichment of mineral raw materials. The use of various methods of preliminary ore beneficiation allows removing a part of barren rock as well as harmful impurities from processing, thereby increasing quality of the feedstock, both in terms of metal content and material composition. The barren rock removal in the head of the process, as a rule, improves the mineral flotation conditions, reduces the consumption of reagents and operating costs for further processing, as well as allows involving the off-balance and rebellious ores into processing. This article presents the results of the heavy suspension gravity dressing of the Shalkiya deposit widely classified lumpy lead-zinc ore, and the study of grindability of both the original ore and gravity dressing products according to the Bond procedure. When studying the lead-zinc ore gravity dressability, it has been found that the grade with size grade of 40–8 mm is optimal, and it has been determined that the optimal separation density required for the floating fraction precipitation is equal to 2730 kg/m^3. As a result of gravity dressing, the material with a high content of waste minerals in the form of quartz, carbonates and coaly substances, with permissible minimum zinc and lead losses, is released to the floating fraction. According to the Bond procedure, the Wi Bond ball mill work index has been determined for original ore, sinking and floating fractions. It has been established that the barren rock removing in the head of an engineering process will allow to increase the content of non-ferrous metals in the sinking fraction relative to their content in the ore, to reduce power inputs for the sinking fraction grinding in comparison with the original ore grinding and, correspondingly, to increase the cost-performance of further ore processing.
Key words: dressability, heavy suspension, floating fraction, sinking fraction, lead, zinc, silicon dioxide, Bond procedure, grindability, work index.
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Introduction

Grinding of mineral raw materials of different composition in drum mills with rolling steel tumbling medium is one of the main processes for liberation of mineral complexes and preparation of raw materials for beneficiation. It is known that grinding is one of the most expensive and energy-intensive operations at the ore-preparation process stage. Capital and operational outlays at this stage may reach up to 70% of the factory-wide indicators. In this connection, the reduction of power consumption for the mineral ore-preparation, and especially for grinding, is the topical problem in the mineral dressing technology [1–2].

On a global scale, the Bond work index procedure is most often used to determine the ore grinding power consumption [3].

The scientific literature describes many ways to reduce the ore grinding costs [4–10].

Thus, in [4] the currently central line of solving the problem of improving the efficiency of crushing and grinding processes through the use of modern grinding and classification model-oriented adaptive control system is illustrated by the example of copper-molybdenum ores. The ore grade of quality on-line rating algorithm application for managing the processes is the main approach in this direction. The stability of regulation and quality of grinding of copper-molybdenum ores increases by 5–7% owing to application of such an approach to the industrial process.

The principle of crushing in high-pressure rolls (HPR), which allows one to obtain a fine feed for mills, is of practical interest. The emergence of HRP has allowed modifying a multi-stage crushing scheme. The HRP crushing products are characterized not only by a diminished size, but also by a high content of small size grades and increased fissuring, which makes it possible to lessen the volume of mills during subsequent grinding by 30...50% [5].

The authors of [6] present the laboratory studies on the grinding efficiency depending on the grinding bodies used (balls or rods) for various parameters such as granulometric composition, lithological type of copper ore.

The authors report that the determination of the grinding medium type impact on the material grinding efficiency is of great practical importance in developing an optimal grinding scheme and allows one to improve the technological and economic indicators of the copper ore beneficiation process.

The results of research on grindability of non-ferrous metal ores with the use of energy actions are listed in [7–10]. The authors of [7] recommend to use to use catholyte (the product of water electrolysis) as a liquid phase during grinding and magnetic-discharge ore treatment before grinding. The authors have established that application of energy deposits allows to increase the calculated size grade content and productivity of the mills.

The Shalkiya deposit ore composition includes hard-to-grind dolomites, containing up to 50% of silicon dioxide. To reduce the power consumption of the Shalkiya deposit ore grinding, the authors propose to use lumpy gravity dressing in the ore-preparation cycle.

The practice of beneficiation of complex ores in heavy suspensions shows that it makes sense to carry out the heavy-medium beneficiation process on the product of the second stage of crushing at a size of 50–70 mm [11]. Taking into account the fine lead and zinc dissemination in the Shalkiya deposit ores and the previously implemented studies of gravity dressing, it was found that the fragmentation size, at which the lead and zinc losses do not exceed 6–10% and the floating fraction yield of at least 20% of the ore is kept, equals to 40–50 mm. Considering mine extraction of the Shalkiya deposit ore, the original ore fragmentation size in question may be obtained at the second stage of crushing.

The barren rock removal at the head of the process usually improves mineral flotation conditions, and also cuts down the crushing, grinding and flotation operating costs [12–13].

In this regard, the authors have set the following goals:

a) to carry out the Shalkiya deposit ore grade size of 40–8 mm separation in heavy suspensions;

b) using the Bond procedure, to determine power inputs required for grinding the original ore, sinking fraction combined with riddlings and floating fraction.

Experimental technique and materials used

Drum, cone and wheel separators are the most common devices applied for beneficiation of lumpy ores in dense media.

A laboratory wheeled heavy-medium separator has been used to enrich the Shalkiya deposit lead-zinc ore grade of 40–8 mm.

The authors have previously studied the Shalkiya deposit lead-zinc ore gravity dressability [14]. As a result, it was found that the grade with size grade of 40–8 mm is optimal, and it has been also determined that the optimal separation density required for the floating fraction precipitation, in which the lead and zinc extraction losses are minimal and do not exceed 6–10% for each metal, is equal to 2730 kg/m^3. The grade beneficiation was performed according to the scheme depicted in Fig. 1.

Grindability of the obtained products has been studied by the Bond procedure [3].

According to the given procedure, a sample of the material under consideration with a size of less than 3.33 mm (6 mesh) with a volume of 700 cm^3 was refined in a batch mill $D{\cdot}L$ = 305×305 mm, operating at a speed of 70 rpm and equipped with a revolution counter.

The grinding medium has consisted of 285 pieces of iron balls with a total weight of 20.1 kg, among which there were:

– 41 ball (about 9.23 kg) with a diameter of about 23 mm;

– 101 ball (about 6.89 kg) with a diameter of about 25.5 mm;

– 143 balls (about 4.03 kg) with a diameter of about 19 mm.

Grinding was carried out on simulating closed cycle with a screen, equipped with the screens with mesh sizes of 0.1 mm, at a circulating load of 250%.

The grinding duration was estimated by the number of drum revolutions, the grinding speed – by the number of the newly formed product, the size of which is less than a mesh of the "limiting screen" per revolution of the mill.

The 80% size of the products was determined graphically from the granulometric composition of the finished products and the initial sample as well as W_i Bond ball mill work index was calculated according to the following empirical formula:

$$W_i = 1.1 \cdot \frac{44.5}{\left((d)^{0.23} \cdot (G)^{0.82} \cdot \left(\frac{10}{\sqrt{P}} - \frac{10}{\sqrt{F}}\right)\right)}$$

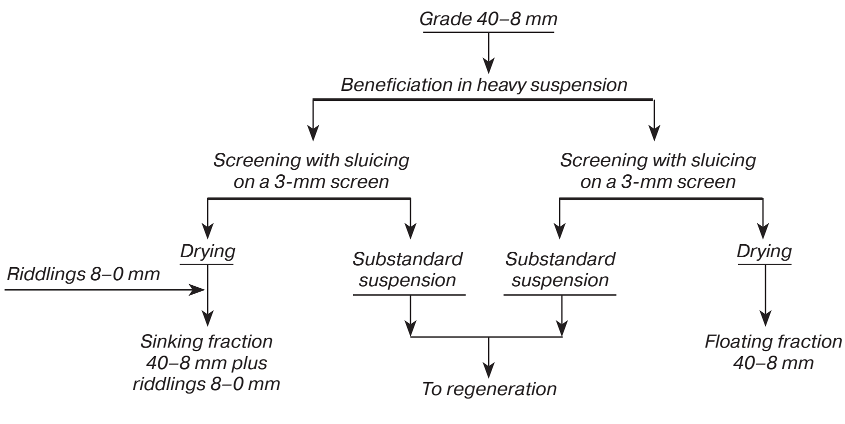

Fig. 1. Scheme of the experiment on heavy-medium beneficiation

where d is a mesh size of the screen on which the finished product separation was carried out, mm; G is an amount of the newly formed "minus A" product per revolution of the drum, g/Rev; F and P are the 80% size of the raw and finished product respectively, mm.

Research results

a) *Separation of the Shalkiya deposit ore grade of 40–8 mm in heavy suspensions*

For beneficiation in heavy suspensions, a sample of the original ore weighing 150 kg selected at the field, with a lead content of 0.82–0.83% and zinc of 3.75–3.77% was used. The granulometric composition of the sample under consideration is given in Table 1.

Table 1
Particle size distribution of the sample

Size grades, mm	Yield	
	kg	%
40–20	72.39	48.26
20–10	39.44	26.29
8–2.5	11.82	7.88
2.5–1.25	7.49	5.00
1.25–0.63	6.27	4.18
0.63–0.0	12.59	8.39
Total	150.0	100.0

According to the results of the granulometric composition analysis, the yield of a 40–8 mm grade in the ore sample studied was 74.55%.

As a result of the grade of 40–8 mm separation in heavy suspension, by density of 2730 kg/m^3, the process indicators shown in Table 2 have been obtained.

According to the gravity dressing results for the grade of 40–8 mm, the float yield was 20.60% with a content of lead 0.39%, zinc 1.51% and quartz 69.50%, at the recovery of lead 9.80%, zinc 8.29% and quartz 28.92%.

The sinking fraction yield was 54.85% with a content of lead 0.96%, zinc 4.43% and quartz 42.50 %, at the recovery of lead 64.15%, zinc 64.74% and quartz 47.09%.

The total sinking fraction yield after combining with riddlings of 8–0 mm was 79.40% with an average content of lead 0.93%, zinc 4.33% and quartz 44.31%.

As a result of gravity dressing with the floating fraction separation, the content of non-ferrous metals in the sinking fraction has increased, with reference to their content in the ore, and the content of quartz has decreased.

b) *The Bond procedure application for determining the energy consumption for grinding the original ore, sinking fraction combined with riddlings and the floating fraction*

The initial ore and gravity dressing products in amount of 10 kg each were crushed to a coarseness of 3.3 mm with the determination of their granulometric composition (Table 3).

Table 2
The process indicators of a 40–8 mm grade gravity dressing in heavy suspension

Product	Yield, %	Content, %			Recovery, %		
		Pb	Zn	SiO_2	Pb	Zn	SiO_2
Float	20.60	0.39	1.51	69.50	9.80	8.29	28.92
Sink	54.85	0.96	4.43	42.50	64.15	64.74	47.09
Riddlings grade 8–0 mm	24.55	0.87	4.12	48.36	26.05	26.97	23.99
Sink combined with riddlings	79.40	0.93	4.33	44.31	90.20	91.71	71.08
Ore	100.0	0.82	3.75	49.50	100.0	100.0	100.0

Table 3
Mesh analysis of the original ore and gravity dressing products crushed to 3.3 mm

Size grade, mm	Original ore		Sinking fraction combined with riddlings		Floating fraction	
	Grade yield, %	Minus yield, %	Grade yield, %	Minus yield, %	Grade yield, %	Minus yield, %
–3.3+2.5	8.64	100.0	7.84	100.0	11.84	100.0
–2.51+2.5	39.80	91.36	37.50	92.16	49.00	88.16
–1.25+0.63	21.33	51.56	21.66	54.66	20.00	39.16
–0.63+0.315	10.07	30.23	10.45	33.00	8.56	19.16
–0.315+0.16	7.01	20.16	7.55	22.55	4.84	10.60
–0.160+0.10	1.79	13.15	1.85	15.0	1.56	5.76
–0.10+0.074	2.78	11.36	3.23	13.15	1.00	4.20
–0.074+0.044	2.90	8.58	3.34	9.92	1.10	3.20
–0.044+0.0	5.68	5.68	6.58	6.58	2.10	2.10
Total	100.0	–	100.0	–	100.0	–

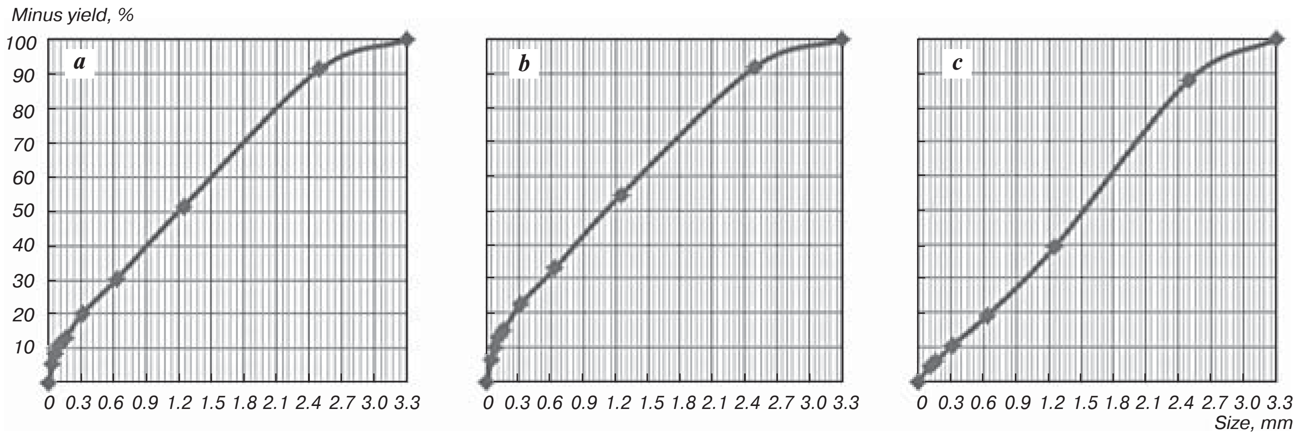

Fig. 2. Grading curves by minus of the raw products:
a — original ore; *b* — sinking fraction combined with riddlings; *c* — floating fraction

According to the ore and sinking fraction flotation technology, a screen with meshes of 0.1 mm was taken as a limiting one.

To determine the 80 percent size in the original ore and gravity dressing products, grading curves by minus have been constructed based on the mesh analysis results, with the use of which the values of F_{80} are determined graphically (Fig. 2).

From the results of the constructed grading curves it follows that the 80 percent size of the raw product F_{80} is equal to: for the original ore — 2100 μm, sinking fraction combined with riddlings — 2050 μm, floating fraction — 2250 μm.

The content of the finished class (β) corresponds to the "limiting" screen with a meshl of 0.10 mm and was: for the original ore — 0.1136 u.f., sinking fraction combined with riddlings — 0.1315 u.f., floating fraction — 0.042 u.f.

The bulk weight determined by shaking the measuring cylinder with a volume of 1000 cm^3, has amounted after three measurements: for the original ore — 1.74 g/cm^3, sinking fraction combined with riddlings — 1.777 g/cm^3, floating fraction — 1.611 g/cm^3.

According to the original Bond procedure [3], 7 grinding cycles were performed on the original ore and gravity dressing products.

On the products subjected to grinding, the cycle has closed after the 5th grinding period, i.e. the net weight of the screen throughs per 1 mill revolution has reached equilibrium.

According to the results of the 5th, 6th, 7th periods, the average mill productivity by the newly formed class of 0.10 mm (G_{av}) has amounted to: for the original ore — 0.87 g/Rev, sinking fraction combined with riddlings — 0.92 g/Rev, floating fraction — 0.75 g/Rev.

To calculate the W_i Bond ball mill work index, the 80% size of the finished product P_{80} was determined. For this purpose, mesh analysis of the screen throughs of the 7th grinding period of the original ore and gravity dressing products were performed (Table 4).

To determine the 80 percent size in the original ore and gravity dressing products, grading curves by minus have been constructed based on the mesh analysis results, with the use of which the values of P_{80} are determined graphically (Fig. 3).

From the results of the constructed grading curves it follows that the 80 percent size of the finished product P_{80} is equal to: for the original ore — 70 μm, sinking fraction combined with riddlings — 69 μm, floating fraction —70 μm.

The W_i Bond ball mill work index has been calculated according to the results obtained by empirical formula.

Table 4
Mesh analysis of the screen throughs of the 7th grinding period

Size grade, mm	Original ore		Sinking fraction combined with riddlings		Floating fraction	
	Grade yield, %	Minus yield, %	Grade yield, %	Minus yield, %	Grade yield, %	Minus yield, %
–0.1+0.074	16.63	100.0	16.50	100.0	17.16	100.0
–0.074+0.063	8.67	83.37	8.62	83.50	8.89	82.84
–0.063+0.05	11.85	74.7	11.81	74.88	12.01	73.95
–0.05+0.04	22.11	62.85	23.20	63.07	21.74	61.94
–0.04+0.0	40.74	40.74	39.87	39.87	40.20	40.20
Total	100.0	–	100.0	–	100.0	–

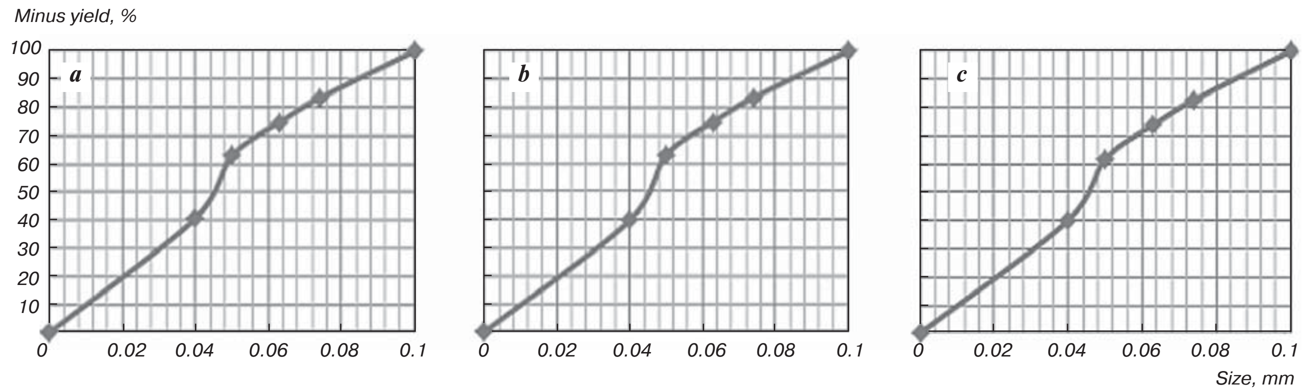

Fig. 3. Grading curves by minus of the finished products:
a — original ore; *b* — sinking fraction combined with riddlings; *c* — floating fraction

Table 5
Grindability parameters of the original ore and gravity dressing products

Parameter	Original ore	Sinking fraction with riddlings	Floating fraction
F_{80} — size of raw product, μm	2 100	2 050	2 250
P_{80} — size of the finished product, μm	70	69	70
G — productivity by the newly formed grade — 0.1 mm, g/Rev	0.87	0.92	0.75
d — the limiting screen size, μm	100	100	100
W_i — Bond work index, kWt·h/t·μm$^{0.5}$	19.5	18.51	21.85

The obtained parameters and grinding results are given in Table 5.

The results show that pieces of rock with a high content of quartz, which requires a higher power consumption for grinding 21.85 kWt·h/t·μm$^{0.5}$ (ore 19.5 kWt·h/t·μm$^{0.5}$) are removed to the floating fraction during the Shalkiya deposit original complex ore gravity dressing.

Power consumption for the sinking fraction grinding is lower by 0.99 kWt·h/t·μm$^{0.5}$ in comparison with that for the original ore.

The estimated output for the the Shalkiya deposit complex ore processing is 4 million tons of ore per year. At the floating fraction yield of 20.6%, the amount of the material withdrawn from the process will be 824 thousand tons per year. The withdrawal of such an amount of floating fraction will diminish the inputs for the third stage of crushing and grinding, reduce the flotation front and consumption of flotation reagents. When processing the sinking fraction together with riddlings, the energy saving for the grinding process alone will be 3.144 million kW per year.

Conclusion

The Shalkiya deposit lead-zinc ore heavy medium beneficiation has resulted in the following process indicators:

— the floating fraction yield has amounted to 20.6% with content of lead 0.39%, zinc 1.51% and quartz 69.50%, at recovery of lead 9.80%, zinc 8.29% and quartz 28.92%;

— yield of the sinking fraction combined with riddlings has come to 79.40% with content of lead 0.93%, zinc 4.33% and quartz 44.31%, at recovery of lead 90.20%, zinc 91.71% and quartz 71.08%.

Determined are the power inputs for grinding the ore and gravity heavy medium dressing products according to the Bond ball mill work index procedure, which has amounted to: for the original ore — 19.5 kWt·h/t·μm$^{0.5}$, floating fraction — 21.85 kWt·h/t·μm$^{0.5}$, sinking fraction — 18.51 kWt·h/t·μm$^{0.5}$.

When processing the sinking fraction, the energy consumptions is lower by 0.99 kWt·h/t·μm$^{0.5}$ in comparison with that for the original ore.

The cost-effectiveness calculation on the use of preliminary gravity dressing is planned to be observed after elaboration of a processing regulations based on the results of the implemented studies.

It has been proved that the barren rock removal in the head of the engineering process will allow one to reduce the power consumption for grinding and further beneficiation.

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