

Research Article

Effect of Grinding Fineness on Concentrate Grade and Metal Recovery in Copper-molybdenum Ore Beneficiation

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Abstract

This study examines the influence of grinding fineness on concentrate grade, product yield, and copper, molybdenum, and gold recovery during flotation beneficiation of copper-molybdenum ore from the Kalmakyr deposit. Five grinding conditions were compared, corresponding to 57%, 60%, 65%, 70%, and 80% by mass passing 0.074 mm. The evaluation was based on the reported assays, yields, and recoveries of flotation products under the investigated flowsheet. Increasing the proportion of material passing 0.074 mm from 57% to 70% raised copper recovery from 83.79% to 88.73%. At 70% passing 0.074 mm, the combined concentrate yield was 7.76%, with grades of 3.82% Cu, 0.039% Mo, and 5.02 g/t Au; corresponding recoveries were 88.73% Cu, 82.61% Mo, and 77.80% Au. At 80% passing 0.074 mm, copper, molybdenum, and gold recoveries increased further to 89.01%, 83.14%, and 79.67%, respectively, while the combined concentrate yield was 7.72%. Thus, the finer grinding condition delivered the highest reported recoveries, whereas the 70% condition provided a slightly coarser alternative with recoveries close to those obtained at 80%. Without grinding-energy or operating-cost measurements, an economic optimum cannot be demonstrated from these data alone. The manuscript also discusses staged addition of spindle oil, regrinding, and the possible inclusion of centrifugal gravity concentration. These process modifications are distinguished from the grinding-fineness comparison and should not be interpreted as verified improvements without matched experimental controls. The findings provide an experimental basis for comparing practical grinding targets for the investigated ore and identify the additional measurements required before final process optimization.

Keywords

Copper-molybdenum Ore, Kalmakyr Deposit, Grinding Fineness, Flotation, Copper Recovery, Molybdenum Recovery, Gold Recovery, Gravity-flotation

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1. Introduction

Copper-molybdenum sulfide ores are typically ground before flotation, and liberation, particle-size distribution, pulp chemistry, and reagent conditions influence metal recovery [1, 4, 5]. Grinding that is too coarse can limit liberation, while unnecessary fine grinding may increase energy demand [1, 2, 8]. Process-mineralogical investigations indicate that flotation of molybdenite depends on its association with copper sulfides and the process environment [3, 5, 6]. Recent studies address selective Cu-Mo flotation through depressants [10-12], oxidation-based separation [13, 14], and the composition of circulating water during grinding and flotation [15]. These studies illuminate mechanisms governing Cu-Mo separation, but their reagent systems and ore contexts differ from the grinding-fineness comparison reported here. The specific question addressed in this work is how the fraction passing 0.074 mm affects the combined-concentrate grade, yield, and Cu, Mo, and Au recoveries for Kalmakyr ore under the reported flotation flowsheet. [7, 9, 15] Five fineness levels were compared; the results were interpreted without assuming that the greatest recovery necessarily yields the lowest overall processing cost.

2. Materials and Methods

Terminology is standardized throughout this manuscript as follows: grinding fineness refers to the mass percentage of ground ore passing 0.074 mm; concentrate grade denotes the content of a specific metal in the concentrate; concentrate yield denotes the concentrate mass relative to the feed; metal recovery denotes the percentage of a metal in the feed reporting to a specified product; combined concentrate denotes the aggregate of the separately collected flotation-stage concentrates; and mass balance denotes the accounting of feed and product masses and contained metals. Regrinding refers specifically to subsequent grinding of a flotation product. Slime generation during finer grinding is a potential process effect but was not directly measured in this study; it is not used to explain the product-yield balance.

The test material was copper-molybdenum ore from the Kalmakyr deposit. Five ground-feed conditions were evaluated, with 57%, 60%, 65%, 70%, and 80% by mass passing 0.074 mm. The products were processed according to the flotation arrangement in Figure 1, which identifies successive flotation stages and nominal stage durations. The combined concentrate yield, Y (%), denotes 100 times the mass of combined concentrate divided by the feed mass. Metal recovery, R (%), was evaluated from product mass yield and the corresponding metal assays relative to the feed metal assay: $R = Y \times G_c / G_f$, where G_c and G_f are concentrate and feed grades

in consistent units. Table 1 reports the product yields, grades, and recoveries as supplied in the study data. The available manuscript does not document feed sample mass, grinding equipment and duration, pulp solids concentration, flotation cell specifications, complete reagent dosages, pulp pH, independent replicate count, or uncertainty estimates; these parameters must be provided from the laboratory records for full reproducibility. The staged spindle-oil and gravity-concentration proposals are discussed separately from the five-condition grinding series; the reported material does not establish a matched-control experimental comparison for these proposed modifications.

Material-balance interpretation: flotation-stage concentrates in Table 1 are intermediate component streams that are included in the reported combined concentrate. Only the final combined concentrate and flotation tailings are summed to assess overall yield. The mass recovery balance is therefore not obtained by summing every row of Table 1. In Tables 2 and 3, the corrected values provided by the authors are used. Where feed, concentrate, and tailings assays differ slightly on reconstruction, the distinction reflects the numerical precision shown; direct verification against laboratory records is recommended. The reported values do not provide all raw masses, flotation conditions, or replicate statistics, and these cannot be reconstructed reliably from the summary tables.

3. Results and Discussion

3.1. Effect of Grinding Fineness on Flotation Performance

To assess the effect of grinding fineness on flotation performance, the proportion of material passing 0.074 mm was varied at five levels: 57%, 60%, 65%, 70%, and 80% by mass. The experimental flotation flowsheet is shown in Figure 1.

Raising the fraction passing 0.074 mm from 57% to 70% increased copper recovery from 83.79% to 88.73%. At 80% passing 0.074 mm, copper recovery increased further to 89.01%; the corresponding differences between 70% and 80% were 0.28 percentage points for Cu, 0.53 for Mo, and 1.87 for Au.

At 70% passing 0.074 mm, the combined concentrate contained 3.82% Cu, 0.039% Mo, and 5.02 g/t Au, with respective recoveries of 88.73%, 82.61%, and 77.80% and a yield of 7.76%. This setting is a candidate for limiting additional grinding because recoveries were close to those observed at 80%; however, no grinding-energy or cost data are reported to justify designating 70% as an established economic optimum.

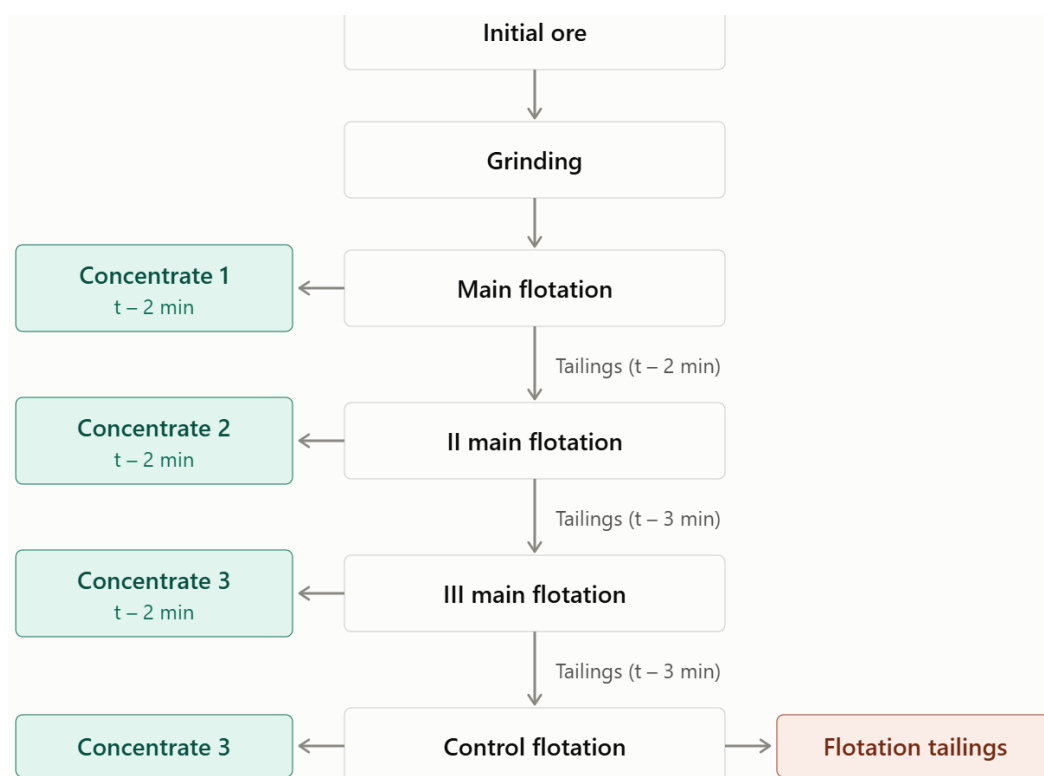


Figure 1. Principal flowsheet for flotation beneficiation of the ore samples.

The highest reported Cu, Mo, and Au recoveries occurred at 80% passing 0.074 mm (89.01%, 83.14%, and 79.67%). Selection between 70% and 80% therefore requires an explicit technical or economic criterion, including measured energy demand, operating cost, or a product specification. See Table 1.

Table 1. Results of selecting the optimal grinding fineness for flotation.

Grinding fineness	Product	Yield, %	Grade, %			Recovery, %		
			Au, g/t	Cu	Mo	Au	Cu	Mo
57% -0,074 mm	Rougher flotation concentrate I	0.88	17.06	18.56	0.085	31.28	52.68	22.01
	Rougher flotation concentrate II	4.45	2.9	1.40	0.029	26.90	20.03	37.84
	Rougher flotation concentrate III	1.60	2.38	1.32	0.027	7.93	6.80	12.70
	Scavenger flotation concentrate	1.00	2.9	1.33	0.014	6.05	4.28	3.97
	Combined flotation concentrate	7.93	4.37	3.28	0.033	72.17	83.79	76.51
	Flotation tailings	92.07	0.15	0.075	0.0009	27.83	16.21	23.49
60% -0,074 mm	Feed ore	100.00	0.48	0.32	0.0034	100.0	100.0	100.0
	Rougher flotation concentrate I	1.23	17.09	16.27	0.104	42.30	62.55	32.09
	Rougher flotation concentrate II	4.90	2.43	1.10	0.025	23.99	16.81	30.31
	Rougher flotation concentrate III	1.25	2.20	1.11	0.033	5.54	4.32	10.42
	Scavenger flotation concentrate	0.70	1.74	0.91	0.014	2.45	2.00	2.45
	Combined flotation concentrate	8.08	4.57	3.39	0.037	74.28	85.67	75.28
	Flotation tailings	91.92	0.14	0.05	0.001	25.72	14.33	24.72

Grinding fineness	Product	Yield, %	Grade, %			Recovery, %		
			Au, g/t	Cu	Mo	Au	Cu	Mo
65% -0,074 mm	Feed ore	100.00	0.497	0.335	0.004	100.0	100.0	100.0
	Rougher flotation concentrate I	1.19	18.41	18.39	0.118	43.29	64.55	35.91
	Rougher flotation concentrate II	4.65	2.52	1.15	0.022	23.20	15.71	25.72
	Rougher flotation concentrate III	1.55	2.34	1.24	0.031	7.17	5.66	12.47
	Scavenger flotation concentrate	0.65	2.22	1.08	0.017	2.85	2.07	2.78
	Combined flotation concentrate	8.04	4.81	3.71	0.037	76.50	87.98	76.28
	Flotation tailings	91.96	0.13	0.04	0.001	23.50	12.02	23.12
70% -0,074 mm	Feed ore	100.00	0.506	0.339	0.0039	100.0	100.0	100.0
	Rougher flotation concentrate I	1.31	16.76	17.76	0.128	43.82	69.65	45.27
	Rougher flotation concentrate II	4.75	2.89	0.94	0.022	27.43	13.31	28.14
	Rougher flotation concentrate III	1.10	1.93	1.24	0.024	4.24	4.08	7.11
	Scavenger flotation concentrate	0.60	1.93	0.95	0.013	2.31	1.70	2.10
	Combined flotation concentrate	7.76	5.02	3.82	0.039	77.80	88.73	81.79
	Flotation tailings	92.24	0.12	0.04	0.0007	22.20	11.27	17.39
80% -0,074 mm	Feed ore	100.00	0.501	0.334	0.0037	100.0	100.0	100.0
	Rougher flotation concentrate I	1.33	17.19	17.9	0.139	45.44	70.66	47.52
	Rougher flotation concentrate II	4.79	2.90	0.89	0.022	27.57	12.67	27.44
	Rougher flotation concentrate III	1.00	2.16	1.33	0.022	4.29	3.95	5.73
	Scavenger flotation concentrate	0.60	1.99	0.97	0.016	2.37	1.73	2.45
	Combined flotation concentrate	7.72	5.19	3.89	0.042	79.67	89.01	83.14
	Flotation tailings	92.28	0.11	0.04	0.0007	20.33	10.99	16.86
	Feed ore	100.00	0.503	0.337	0.00388	100.0	100.0	100.0

Table 1 presents the yields and metal recoveries of individual flotation-stage concentrates together with their aggregate, the combined flotation concentrate. The individual stage concentrates are component products already included in the combined concentrate and must not be counted again when calculating the overall mass balance. The overall product-yield balance was therefore assessed using only the combined flotation concentrate and final flotation tailings. For grinding fineness levels of 57%, 60%, 65%, 70%, and 80% passing 0.074 mm, the reported concentrate and tailings yields total 100.00% in each case. In particular, at 80% passing 0.074 mm, the combined concentrate yield is 7.72% and the final tailings yield is 92.28%, giving a total of 100.00%. The approximately 7-9 percentage-point apparent excess arises only if the intermediate concentrates are added again to the already aggregated

concentrate. These product-yield balances should be distinguished from metal-recovery balances, which require separate verification using product assays and feed composition. The reported results do not provide evidence that slime generation caused losses in the measured products.

A staged spindle-oil dosage totaling 20 g/t (10 g/t during initial grinding and 10 g/t during concentrate regrinding) is proposed for further evaluation. The original manuscript also mentions 7.5 g/t as a reference dosage, but does not provide a complete controlled test series establishing the incremental impact of this change. Accordingly, the suggested scheme is a process hypothesis rather than a demonstrated causal improvement.

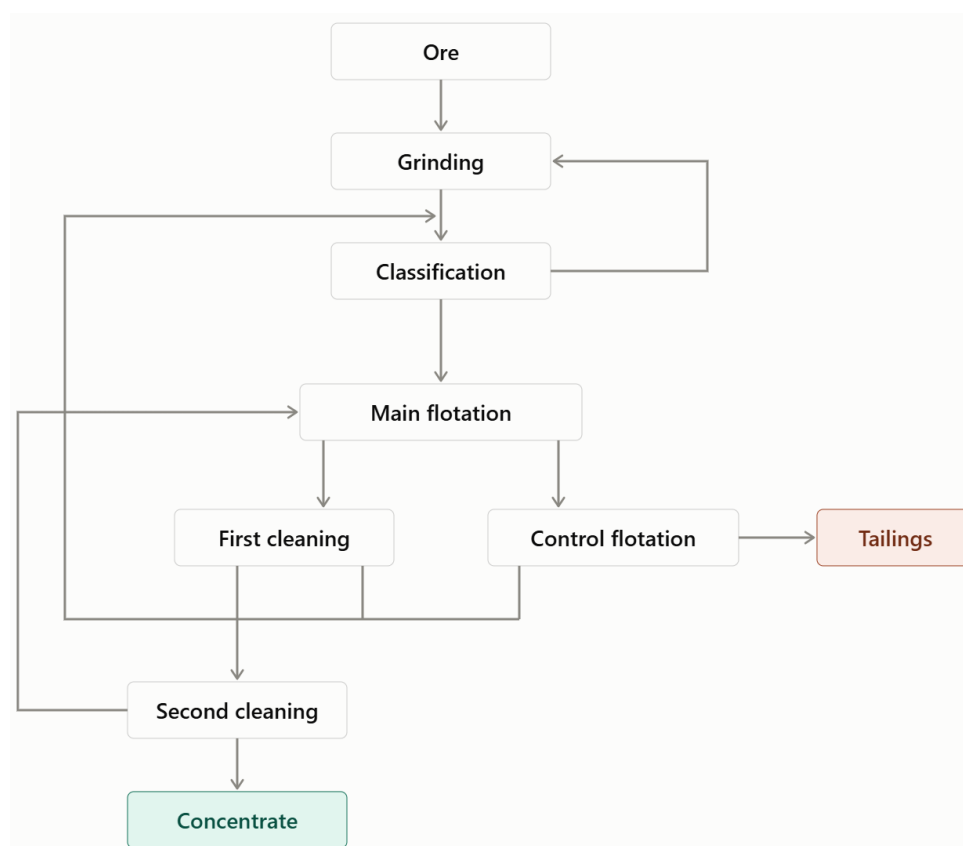


Figure 2. One-stage flotation flowsheet for copper ore beneficiation.

Figure 2 and the revised Table 2 present the reported single-stage flotation configuration and its Cu-Mo combined concentrate. The table has been replaced with the author-supplied revised dataset. Concentrate and tailings yields sum to 100%,

and reported Au, Cu, and Mo recoveries each sum to 100%. These data describe the reported operating scheme, but do not by themselves isolate the effect of staged reagent addition without a matched controlled comparison.

Table 2. Results of the revised one-stage flotation scheme (author-supplied corrected material balance).

Product	Yield (%)	Grade			Recovery, %		
Feed ore	100.00	0.33	0.0037	0.5	100.00	100.00	100.00
Combined Cu-Mo concentrate	1.69	15.87	0.1507	18.4	81.27	68.85	62.19
Final tailings	98.31	0.063	0.00117	0.192	18.73	31.15	37.81

Mass-balance verification (revised Table 2): product yields total 1.69% + 98.31% = 100.00%; Au, Cu, and Mo recoveries total 100.00% for each metal. The values are reproduced from the corrected table provided by the authors; primary analytical records should remain available for verification.

Using reported product yields and grades, approximate re-constructed feed assays are Cu 0.3302%, Mo 0.00370%, and

Au 0.4997 g/t; these agree with the listed feed assays within displayed precision.

The reported metallurgy is therefore arithmetically consistent at the shown precision; a causal attribution to a particular reagent strategy still requires comparative experiments.

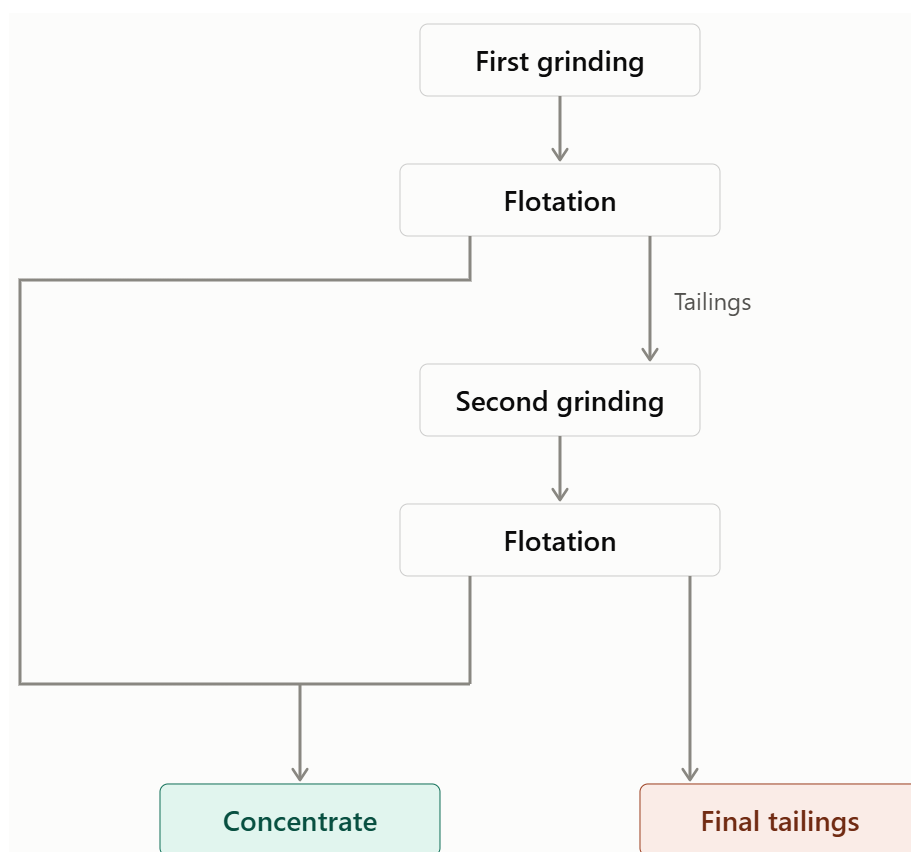


Figure 3. Two-stage flotation flowsheet for copper ore.

Table 3. Results of the revised two-stage flotation scheme (author-supplied corrected material balance).

Product	Yield (%)	Cu (%)	Mo (%)	Au (g/t)	Cu recovery (%)	Mo recovery (%)	Au recovery (%)
Feed ore	100.00	0.33	0.0037	0.5	100	100	100
Concentrate	5.0	5.28	0.0562	4.5	80	76	45
Tailings	95.0	0.070	0.00094	0.289	20	24	55

Mass-balance verification (revised Table 3): product yields total 5.0% + 95.0% = 100.0%, and reported Cu, Mo, and Au recoveries each total 100%. Product-grade-weighted feed assays are approximately 0.3305% Cu, 0.003703% Mo, and 0.49955 g/t Au, consistent with the rounded feed values.

For the reported two-stage configuration, the revised Table 3 gives a concentrate yield of 5.0% and a final-tailings yield of 95.0%, with 80% Cu, 76% Mo, and 45% Au recovery to concentrate. The revised Table 2 represents a different reported configuration (1.69% concentrate yield, with 81.27% Cu, 68.85% Mo, and 62.19% Au recoveries), so the earlier statement that copper recovery necessarily rose from 75.3% to 80.0% is no longer supported by these two revised tables. An experiment-matched comparison is necessary before inferring improvements from regrinding or reagent staging.

3.2. Gravity-flotation Approach and Mineral Associations

A centrifugal gravity-concentration step is proposed as a possible means of recovering liberated gold prior to flotation. The present manuscript does not provide a fully specified comparative gravity-test dataset, equipment operating parameters, or recovery balance sufficient to quantify an improvement attributable to this addition. It is therefore identified as a proposed process option requiring experimental validation.

Mineralogical association analysis showed that the major portion of gold occurs in association with chalcopyrite and pyrite, accounting for 26.73% and 23.08%, respectively. A further 10.2% of the precious metal was associated with rock-

forming minerals. The relatively small amount of gold associated with other minerals indicates that their contribution to the overall distribution is limited.

4. Conclusions

The grinding tests demonstrated that the proportion of the -0.074 mm fraction is a key parameter controlling flotation performance of the investigated Kalmakyr copper-molybdenum ore.

At 70% passing 0.074 mm, the reported combined concentrate yield was 7.76%, with grades of 3.82% Cu, 0.039% Mo, and 5.02 g/t Au, and recoveries of 88.73% Cu, 82.61% Mo, and 77.80% Au. The data support 70% as a candidate compromise fineness, not a demonstrated universal optimum, because recoveries at 80% were higher.

The 80% passing 0.074 mm condition produced the highest reported metal recoveries, although the increases relative to 70% were relatively small (Cu +0.28, Mo +0.53, and Au +1.87 percentage points). The 70% condition may represent a practical alternative if the reduction in grinding demand is demonstrated to justify the recovery trade-off. Since grinding energy and cost were not measured in the reported dataset, an overall optimum cannot yet be established.

Staged spindle-oil addition, regrinding, and gravity concentration are proposed technological options; their benefits require controlled comparative trials and reconciled product balances before quantitative performance claims can be made.

Further work should report grinding energy, reagent and flotation conditions, experimental repeatability, and complete Cu-Mo-Au mass balances to confirm the preferred operating point.

Abbreviations

Cu	Copper
Mo	Molybdenum
Au	Gold

Author Contributions

Samadov Alisher Usmanovich: Methodology, Project administration, Supervision, Writing – review & editing

Khakimova Dilafruz Yuldashboy Qizi: Conceptualization, Methodology, Resources, Validation, Writing – review & editing

Ibragimov Izzatilla Sulaymonovich: Data curation, Formal Analysis, Investigation, Software, Validation

Abdusamiyeva Lobarkhon Nomonjon Qizi: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft

Data Availability Statement

The numerical data presented in the tables and figures are from the authors' experimental study and laboratory/industrial-test results.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



Samadov Alisher Usmanovich is a prominent Uzbek scientist, Doctor of Technical Sciences, and Professor. His scientific research focuses mainly on mineral processing, the beneficiation of copper and copper-molybdenum ores, and the improvement of technological processes and regimes in mineral beneficiation. He currently serves as a Professor at the Department of Engineering Communication, Tashkent University of Architecture and Civil Engineering, Tashkent, Uzbekistan. He has made significant contributions to scientific research in the field of mineral processing and continues to contribute to the development of scientific research and the training of young researchers.



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Research Field

Samadov Alisher Usmanovich: Metallurgy, Mineral Processing Technologies, Beneficiation of Non-Ferrous and Precious Metals, Flow-sheet Optimization

Khakimova Dilafruz Yuldashboy Qizi: Mineral Processing, Beneficiation Technologies, Ore Preparation, Grinding Fineness Optimization, Flotation Reagent Regimes

Ibragimov Izzatilla Sulaymonovich: Mineral Processing, Ore Beneficiation, Complex Processing of Polymetallic Ores, Flotation Circuits, Gravity Concentration

Abdusamiyeva Lobarkhon Nomonjon Qizi: Mineral Processing, Ore Beneficiation, Optimization of Flotation Regimes, Mineral Liberation, Recovery of Valuable Components