The Method for Preliminary Enrichment of Gold-Containing Ore

Mikheil Gamtsemlidze 1, Roin Enageli 2, Demur Talakhadze 2, Asmat Shekiladze 1, Manana Tutberidze 1

1 LEPL G. Tsulukizde Mining Institute, 7, E. Mindeli Str., 0186, Tbilisi, Georgia
2 Georgian Technical University, 77, Kostava Str., 0160, Tbilisi, Georgia

sabcbo@mining.org.ge

Abstract. In recent years the separation of the tails with minimal content of valuable components at the processing of the minerals before expensive enrichment has attracted considerable attention. This will be favourable for increasing the ore enrichability as well as significant reducing the costs of the further operations for enrichment. The samples for investigation have been taken from the gold-containing polymetallic ores of Georgian Bektakari deposit (Bolnisi district) with the content of gold – 5.61g/ton, of lead – 1.65%, of zinc – 2.43%. At the preliminary preparation of the samples the following was taken into consideration: the crushing of the coarse-grained fragments to the classes of +8, 8-3 and 3-0 mm; separation of the 8-3 mm class from the crushed fragments and their enrichment for obtaining of the tails on the modernized high-frequency diaphragm precipitating machine (Georgian Patent #U 2018 1962 Y) of improved construction. The novelty of the machine lies in the fact that together with the main oscillation, frequency of water oscillation, water discharge) the additional controlling parameters are introduced in the process, such as water low-amplitude high-frequency oscillations, velocity of water downflow. The first one is obtained as the result of the impacts of eccentric axis and diaphragm frame. It should be also noted that the above-mentioned oscillations reduce the frictional force between the suspended grains. As the result the minerals of various density freely move in their own layers, increasing the efficiency of the minerals separation. In the second section of the precipitating machine the enhanced velocity of water downflow is obtained by compressing of the spring fixed on the frame which imparts the various accelerations to the minerals of the different densities and is favourable for their efficient separation. Along with it, the compression of the spring enhances the force of the frame impact as well as the frequency of low-amplitude oscillation. In the course of the investigations on the enrichment of 8-3 mm classes, when the amplitude of water main oscillation comprised: A=16 mm, oscillation velocity n = 420 rpm and water discharge was 5.5 l/min, in the second section of the precipitating machine the product was obtained by the yield – 22.3% by gold content Au=0.4 g/ton. On this basis the mentioned product may be isolated. It may be considered as the tails and the investigation on the enrichment may be performed for residual product. On the basis of the analysis of experimental data the action of the controlling and disturbing parameters for the control of precipitation process was revealed. The optimal control of the process is performed by the requirements of technological criterion: retention of such vales of controlling parameters which provide the maximum content of gold (minimum content of gold in the tails) in the concentrate in spite of the variation of distributing actions. For this reason, the goal function and mathematical model were derived on the basis of which the method for automatic control was elaborated.
1. Introduction
The research on enrichment of gold-containing polymetallic ore has been carried out on minimal mass of the sample retaining mainly those properties (content of extractable useful component, densities of useful and waste minerals, enrichability, etc.) that are typical for entirely enriching ore. For the mentioned ore, the weight of minimal sample has been defined by fragments of 250-0 mm size. The conducted research showed that gold polymetallic sulfide ore is characterized with the most complicated mineral content, as well as with different type of waste rocks effecting on gold extraction and selection of the technological process of polymetallic ore processing.

From this point, it is necessary to separate a big number of tails (with minimal content of useful components) from the ore of such complexity by preliminary enrichment. This will be favourable for increasing the ore enrichability, and at the same time, for significant reducing the costs of the further operations for enrichment [1].

Before enrichment, the coarse-grained fragments have been crushed in the jaw crusher up to 30 mm. From the crushed product, through sifting, 30-8 mm, 8-3 mm and 3-0 mm size classes were separated. The study of the mentioned classes showed that content of gold in 3-0 mm class is much higher compared to others. The research showed that in crushed fragments, fine- spotted gold is unevenly spread (in some fragments, gold is in big content) allowing separation of a big amount of tails (with less content of useful components) by preliminary enrichment of such fragmented class. The given circumstances indicate the topicality of preliminary processing of difficult-to- enrich ore.

2. Preliminary enrichment of gold-containing polymetallic ore
Preliminary enrichment of gold-containing polymetallic ores, namely, 8-3 mm class fraction for the purpose to separate the waste rock was carried out on the modernized high-frequency МОД – 47 precipitation machine [2].

The novelty is that together with the main controlling parameters, the additional ones are introduced in the process, such as water main oscillation amplitude and water low-amplitude high quality oscillations (the latest is reachable as a result of impacts of eccentric axis and frame); Movement of the frame caused by effect of a spring fixed on a frame enhances water low-amplitude oscillations.

The research has determined the influence of changes of main and additional controlling parameters on enrichment indicators. The outcomes of testing are given in table 1. Based on the given data, dependence pair was designed: between A amplitude of water main oscillation in a chamber of precipitation machine (together with additional oscillations) and a yield of tails \( \gamma_t \) in II division.

\[
\gamma_t = -0.241A^2 + 6.081A - 12.13 .
\] (1)

The relevant graph is given on figure 1.

Between frequency of \( n \) oscillation of a precipitation machine frame and yield of tails \( \gamma_t \)

\[
\gamma_t = -2.24 \times 10^4 n^2 + 0.133n + 6.784 .
\] (2)

The relevant graph is given on figure 2.

Between the volume of movement of a precipitation machine frame and yield of tails \( \gamma_t \)

\[
\gamma_t = -0.2961^2 \times 4.1881 + 12.54 .
\] (3)
The relevant graph is given on figure 3.

As it is shown from table 1, as well as from the obtained dependence pair, comparably low quality tails with yield $\gamma_t = 22.3\%$ (gold content $A_u = 0.4$ g/t) are isolated when the main amplitude of water oscillation together with additional oscillations is 16 mm, water oscillation frequency 420 osc$^{-1}$, and frame movement from spring compressing is 10.1 mm.

**Table 1.** The results of experiments of the precipitation process for preliminary enrichment of 8–3 mm class fraction.

| No | Water oscillation (mm) | Oscillation frequency  (osc$^{-1}$) | Frame movement (mm) | $A_u$, % | I division concentrate | II division tails | Concentrate | Tails |
|----|-----------------------|--------------------------------------|---------------------|-------|-----------------------|------------------|-------------|-------|
|    |                       |                                      |                     |       | Yield $\gamma_t$, %   | Yield $\gamma_t$, % | Content $\beta$ | Content $\Theta$ | EExtraction $\varepsilon$ | Extraction $\varepsilon$ |
|    |                       |                                      |                     |       | $\text{Pb, }$ % | $\text{Zn, }$ % | $\text{Au, }$ g/t | $\text{Pb, }$ % | $\text{Zn, }$ % | $\text{Au, }$ g/t | $\text{Pb, }$ % | $\text{Zn, }$ % | $\text{Au, }$ g/t |
| 1  | 12                    | 320                                  | 5.5                 | 5.92  | 73.40 | 2.22 | 3.46 | 7.59 | 0.98 | 1.09 | 1.13 | 88.20 | 89.70 | 94.1  | 13.80 | 0.30 | 5.90 |
| 2  | 14                    | 420                                  | 7.2                 | 5.92  | 76.20 | 2.26 | 3.51 | 7.42 | 2.30 | 0.30 | 0.55 | 91.10 | 94.50 | 95.5  | 18.90 | 5.50 | 4.50 |
| 3  | 16                    | 450                                  | 10.1                | 5.92  | 78.10 | 2.34 | 3.54 | 7.40 | 21.90 | 0.28 | 0.30 | 0.65 | 96.70 | 97.60 | 97.6  | 3.30 | 2.30 | 2.40 |
| 4  | 18                    | 480                                  | 12.3                | 5.92  | 81.40 | 2.24 | 3.38 | 6.96 | 18.60 | 0.36 | 0.42 | 1.37 | 96.50 | 97.20 | 95.7  | 3.50 | 2.80 | 4.30 |
| 5  | 16                    | 320                                  | 9.5                 | 5.92  | 72.29 | 2.24 | 3.53 | 7.69 | 27.71 | 0.98 | 1.01 | 1.3  | 85.68 | 90.17 | 93.9  | 14.30 | 9.83 | 6.10 |
| 6  | 16                    | 350                                  | 12.0                | 5.92  | 75.30 | 2.29 | 3.51 | 7.52 | 24.70 | 0.67 | 0.76 | 1.03 | 91.24 | 93.39 | 95.7  | 8.76 | 6.61 | 4.30 |
| 7  | 16                    | 380                                  | 12.0                | 5.92  | 77.70 | 2.33 | 3.51 | 7.32 | 22.30 | 0.36 | 0.46 | 1.05 | 95.79 | 96.37 | 96.1  | 4.21 | 3.63 | 3.95 |
| 8  | 16                    | 420                                  | 12.0                | 5.92  | 79.90 | 2.29 | 3.46 | 7.19 | 20.10 | 0.29 | 0.33 | 0.89 | 96.81 | 97.69 | 97.0  | 3.19 | 2.31 | 3.01 |
| 9  | 16                    | 460                                  | 12.0                | 5.92  | 80.20 | 2.26 | 3.42 | 7.11 | 19.80 | 0.39 | 0.44 | 1.12 | 95.90 | 96.92 | 96.3  | 4.10 | 3.08 | 3.73 |
| 10 | 16                    | 420                                  | 7.5                 | 5.92  | 68.64 | 2.53 | 3.81 | 7.75 | 31.36 | 0.43 | 0.62 | 1.91 | 92.79 | 93.12 | 89.9  | 7.21 | 6.88 | 10.10 |
| 11 | 16                    | 420                                  | 7.2                 | 5.92  | 77.23 | 2.29 | 3.52 | 7.24 | 22.77 | 0.41 | 0.58 | 1.46 | 94.98 | 95.40 | 94.4  | 5.02 | 4.60 | 5.61 |
| 12 | 16                    | 420                                  | 10.1                | 5.93  | 73.95 | 2.47 | 3.72 | 7.81 | 26.05 | 0.21 | 0.26 | 0.59 | 97.09 | 97.60 | 97.4  | 2.91 | 2.40 | 2.63 |
| 13 | 16                    | 420                                  | 12.3                | 5.93  | 86.48 | 2.09 | 3.21 | 6.61 | 13.52 | 0.48 | 0.66 | 1.45 | 96.53 | 96.90 | 96.7  | 3.47 | 3.10 | 3.31 |
| 14 | 16                    | 420                                  | 5.5                 | 5.91  | 85.10 | 2.15 | 3.55 | 6.50 | 14.90 | 0.35 | 0.55 | 1.30 | 96.20 | 97.20 | 93.7  | 4.20 | 2.80 | 6.30 |

**Figure 1.** Dependence $\gamma=f(A)$
3. Research of the precipitation process for automation

On a base of the analysis of conducted experiments’ outcomes, controlling and disturbing parameters effected on a precipitation process were revealed. These parameters should be taken into account while the process is controlled. Namely, in a chamber of the precipitation machine, water pulsing (oscillation) amplitude and frame oscillation frequency were obtained as controlling effects. In enriching ore, gold content of useful mineral and ore average size were obtained as disturbing effects. According to the latest, most probably, the physical-mechanical properties of enriching ore can be evaluated that is essential during enrichment through the gravitation method [3].

For process controlling in the optimal regime, it is necessary to follow the requirements of technological criterion, namely, $\gamma_t \rightarrow max$ content in the given case $A_0 \mathrm{g/t} = \text{const}$, that implies finding such values of controlling effects that despite the change of disturbing effects, provide in tails gold minimal content (i.e. its maximum content in concentrate).
To achieve this goal, it is necessary to study the process for automation purpose and to design its mathematical model. For this, at first, between the given parameters, the pair and multiple interdependences were set. For this purpose, the experiments’ data are used.

As it was mentioned above, for process controlling, in addition to pair dependences, multiple dependence was set between controlled and controlling volumes. In our case, this dependence has a face:

$$\gamma_i = f(A, n, l, \alpha_{Au}, d).$$

In the automatic control system designed according to the given dependence, uninterrupted automatic measuring of all five parameters is significant. Measurement of controlling effects - A, n, l - is possible, but during the technological process, there are no technical means for continuous measurement of ore size and gold content in it. Therefore, it should be reasonable to carry out their oblique measure (evaluation) through spacer loosening of a precipitating machine. The device measuring this volume was developed and tested at the laboratory conditions.

**Table 2. Loosening transmitter**

| $d_{Au}$, mm | h, mm | Au, g/t (l) | $\alpha_{Au}$ |
|--------------|-------|-------------|---------------|
| 3.10         | 3.20  | 0.85        | 5.92          |
| 3.80         | 3.35  | 1.11        | 5.92          |
| 4.50         | 2.20  | 0.65        | 5.92          |
| 5.10         | 3.85  | 0.55        | 5.92          |
| 5.35         | 4.30  | 0.48        | 5.92          |
| 4.50         | 5.00  | 0.55        | 5.92          |
| 4.80         | 5.45  | 0.42        | 5.92          |
| 6.00         | 3.50  | 0.65        | 5.92          |
| 6.38         | 5.85  | 0.58        | 5.92          |
| 6.90         | 6.25  | 0.45        | 5.93          |
| 7.45         | 6.85  | 0.65        | 5.93          |
| 7.85         | 8.75  | 0.59        | 5.93          |
| 4.25         | 9.50  | 0.85        | 5.93          |
| 8.00         | 8.35  | 1.10        | 5.91          |
| 6.50         | 3.00  | 0.58        | 5.90          |

In table 2, there are the testing results of the mentioned transmitter. According to the obtained data, the dependence was set:

$$h(\alpha, d) = a\alpha^b d^c$$

where, $h$ – is the amplitude of a float (sensitive sunk element of loosening transmitter) oscillation.

The experimental data were elaborated through the method of minimal quarters, resulted:

$$h = 0.472\alpha^{0.5971}d^{0.7727}.$$
If in a formula (5), $\alpha$ and $d$ mean values are inserted in turns, there will be:

$$h = 1.364d^{0.7727}. \tag{7}$$

$$h = 1.724\alpha^{0.5971}. \tag{7}$$

The relevant graph shows a face on figure 4 and figure 5.

\[\begin{align*}
\text{Figure 4. } & h \text{ versus } \alpha \text{ graph} \\
\text{Figure 5. } & d \text{ versus } h \text{ graph.}
\end{align*}\]

According to the graphs, gold content in enriching ore and ore average size significantly influence on the amplitude of a loosening transmitter’s float oscillation, and accordingly, on a volume of spacer loosening. Taken into consideration this circumstance, the dependence of float’s oscillation amplitude of spacer loosening transmitter with a process controlling effects is set:

$$h(A, n) = aA^n n^\alpha. \tag{8}$$
According to the experimental data (tables 1, 2), numerical meanings of unknown coefficients of this image have been determined. As a result, the image has been received with a face:

\[ h(A,n) = 14.243A^{0.2122}n^{-0.461} \]  \hspace{1cm} (9)

If in (8) formula, A and n meanings are separately inserted, there will be:

\[ h(A) = 0.894A^{0.2122}, \]
\[ h(n) = 25.55n^{-0.461}. \]  \hspace{1cm} (10)

According to the obtained formulas, dependence of controlling effects on spacer loosening has been determined:

\[ A(h) = 1.696 \cdot h^{4.713}, \]
\[ n(h) = 1130 \cdot h^{-2.169}. \]  \hspace{1cm} (11)

The received dependences (9) represent the controlling laws, according of which, with the corresponding regulators, by a signal of loosening transmitter located in the first chamber of a precipitating machine, A amplitude of water pulsing (oscillation) and frequency of n oscillation of a machine’s frame will be regulated. Figure 6 shows a structure of an automatic controlling system operating by the accepted controlling laws.

In the first chamber of a precipitation machine, spacer loosening is measured by m transmitter. Its proportional h signal is transferred to the functional block of a regulator, where (5) - imaged dependence is determined. And finally, according to this signal (8), controlling laws will be formed, realization of which is happened by amplitude and frequency regulators.

\[ Q_m = f(\alpha, d) \]
\[ A = f(h) \]
\[ n = f(h) \]

**Figure 6.** The structural scheme of automatic control.

4. Conclusions
Thus, through the precipitation process from a fraction of the mentioned class, the yield of final tails are obtained \( \gamma = 22.3 \% \), as well as minimal contents of valuable components: Pb – 0.24 %, Zn – 0.32 % and Au – 0.4 g/t.
Finally, on a base of the conducted research, it can be concluded that 8 – 3 mm sized class is a subject to enrichment (removal of final tails).

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