Experience in Retrofitting the Mineral Processing Equipment to Intensify the Gravity Recovery of Gold

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Abstract. The experience of replacing a Knelson concentrator with MOD 2 and MOD 3 jigs at the gold recovery plant of the Karalveem deposit is described. Due to the change in the source product quality (an increase in the amount of finely disseminated gold from 17 to 75 % of the total gold obtained), the Knelson concentrator performance at stages 4 and 5 was unsatisfactory. It was decided to retrofit the equipment and replace the Knelson concentrator with the MOD 2 and MOD 3 jigs. The gold in the Karalveem deposit ore was briefly characterized by size as fine, dust, and medium-round gold, and the mineral composition of the Karalveem deposit ore samples considered. Statistically significant results of testing before and after retrofitting (replacing the Knelson concentrator with MOD 2 and MOD 3 jigs) have been represented. The efficiency of the MOD type jig installation has been evaluated. The authors have concluded that industrial testing the recovery of fine, dust, and medium-round gold on the MOD type jigs can be performed at any mine to process this type of ores, and these jigs may compete with Knelson concentrators that have already gained popularity.

1. Introduction
In these days, the quality of raw materials in the gold recovery industry decreases. It is primarily associated with involving ores with low gold content in the processing or mining losses during operation as compared with exploration data [20, p. 29].

The Karalveem Mine Recovery Plant is not an exception. Thus, during 1995-1997, when mining the richest ores, the enterprise operated quite successfully. In 1996, the Karalveem Mine Recovery Plant was launched by Ruda CJSC (Bilibino). From 1996 to 1999, 3.8 tons of gold were mined, including 0.5, 1.8, 0.8, and 0.7 tons in 1996, 1997, 1998, and 1999, respectively. In 1999, the company was on the verge of bankruptcy due to the non-fulfillment of gold mining plans caused by a sharp deterioration of the salable ore quality [5, 6].

The majority of gold recovery companies in Russia have chosen FLSmidth Knelson equipment (in particular, Knelson concentrators) for the gravity gold recovery [1, 2, 7, pp.17-21, 4]. Thus, V.V. Pelikh and V.M. Salov emphasize: “Gravity centrifugal concentrators, and particularly FLS Knelson ones, have proven themselves as an extremely efficient link in the process chains of modern enterprises” [14]. The practical experience of many gold recovery plants shows a positive effect from the use of the FLS Knelson concentrators.
Meanwhile, the discussion on the choice of recovery equipment remains relevant, and in our opinion, the answer to the question of what is more advantageous - the use of jigs or concentrators is simple, i.e. there are deposits and conditions where jiggling is more profitable and those where the use of concentrators is more advantageous. Each equipment has a specific effective application area.

Addressing the paper subject is the authors’ desire to share their experience in solving this issue. In the paper, the results of using Knelson concentrators at the Karalveem Recovery Plant from 2015 to 2017, and their replacement with the MOD type jigs to intensify the gravity gold recovery are represented.

2. Brief description of the Karalveem gold deposit
As is said above, during the Karalveem deposit exploitation period, gold recovery has reduced; in this regard, we have considered the mineral composition of the Karalveem ore samples, which are 90.0-99.0 % represented by rock-forming minerals. The main one is quartz, the amount of which in the samples is within 35.0-72.0 %. The mass fraction of mica, chlorites, and feldspars is 8.0-38.5 %. Carbonates are represented by dolomite, calcite, and ankerite in the amount of 8.0-17.0 %. The ore mineralization is represented by sulfide and oxidized minerals. Their total amount is within 0.5-8.5 %. The amount of sulfides is 0.4-8.2 %. They are mainly represented by pyrite and arsenopyrite. Pyrrhotine, chalcopyrite, galena, and sphalerite are noted as single grains. By the amount of sulfides, the samples studied correspond to a poor sulfide type of ores. Oxidized minerals are represented by iron hydroxides in an amount from single grains to 5.8 %.

The most common deposit vein textures are banded, combined with impregnated ones. They are caused by the alternation of quartz and sulfide bands. On the lower horizons of the Promoin field, the most thin-banded textures are developed, which are replaced upward by breccia ones. In contrast, in the impregnated ore zones, the texture pattern is characterized by crushing processes with the widespread development of pyritic veinings, numerous insets of substantially pyritic composition, and more rare fine gold ones [9, p. 35].

Table 1 represents the granulometric composition and gold content in the Karalveem deposit ore.

| Grain Size, mm | -1.6 | -0.5 | -0.25 | -0.15 | -0.10 | -0.074 | -0.05 | Total % wt. |
|---------------|------|------|-------|-------|-------|--------|-------|------------|
| Gold Content  | 31.7 | 7.0  | 11.9  | 9.5   | 2.1   | 1.1    | 36.7  | 100        |

According to Table 1, the bulk of gold (62.2 %) is represented by gravity size particles (+0.074 mm). Of them, the majority is concentrated in the large size class +0.5 mm - 31.7 %. The maximum size of a particle detected in the gravity concentrate is 1.75x1.6 mm. The charge contains a significant amount of fine gold with a grain size of -0.05 mm. Its share is 36.7 % of the total gold recovered into concentrate. In general, the gold in the Karalveem deposit ore is characterized by size as fine, dust, and medium-round gold (according to Petrovskaya classification).

Figure 1 shows a graphical dependence between the gold content in ore samples and the degree of the gold recovery by amalgamation and cyanidation. From the plot, it follows that with increasing gold content in the ore, the degree of amalgamated and cyanidated gold increases.
The most real characteristic of centrifugal concentrators is gaining more and more popularity. It is emphasized that in the concentrator, Falcon designs of centrifugal concentrators used retrofitted to improve the recovery issues [3, 13, 16, 18], which in turn improves the indices of gold-bearing ore processing.

The gravity recovery efficiency depends on the size of the materials processed. Conventional equipment satisfactorily recovers only gold grains larger than 0.2-0.25 mm in the water stream. Fine gold, especially that finer than 0.1 mm, the content of which in the raw materials is increasing, is not satisfactorily recovered. Currently, the most realistic solution to the issue of extracting fine gold is developing technologies using centrifugal concentrators [3, p. 22].

However, the experience of the Karalveem Mine Gold Recovery Plant has shown the loss of fine gold due to the equipment with a low factor installed at recovery stages IV and V. At the Karalveem deposit plant, gravity recovery in the grinding cycle was performed using the below equipment:

- centrifugal concentrators Knelson KC-CD30 with periodic concentrate unloading (2-3 times per hour). The concentrator feed load at stage I is 34.0 t/h at V = 34.8 t/h. The concentrator capacity is up to 50-100 t/h.
- concentrator Knelson KC-XD48 with periodic concentrate unloading (2 times per hour). The concentrator feed load at stages II and III is 59.8 and 67.7 t/h, respectively. The concentrator capacity according to the datasheet is up to 200-400 t/h.
- concentrator Knelson CVD-42 at the recovery stage IV with continuous concentrate discharge. The concentrator capacity according to the datasheet is (by solids) is 40-100 t/h.

The recovery was performed according to the flowsheet given in Fig. 2.

The main retrofitting goal is to increase the gravity gold recovery at stages IV and V by installing continuous operation equipment and a high concentrate yield. Presumably, the MOD-3M and MOD-2M jigs with further re-cleaning on shaking tables could cope with this issue.

The main reasons for the need to retrofit the stages IV and V were:

- a change in the raw material base and an increase in the fine gold amount from 17 to 75 % of the total gold produced; these conclusions have been approved by testing the flow sheet in 2016 and 2017 at the Gold Recovery Plant and reporting statistics on the gold gravity concentrate and gold deposition.

**Figure 1.** Dependence of the Free and Cyanided Gold Recovery on the Metal Content in Ore.

### 3. Retrofitting the gravity recovery equipment for Karalveem deposit

The issue of intensifying the finely disseminated gold recovery is associated with the need to use new or improve conventional technologies and equipment for processing productive rock mass [8, 11, 12, 15, 17].

Both domestic (TSBK, STSV, STSM, Itomak, Beguschaya Volna) and foreign (Orocon, Knelson, Falcon) designs of centrifugal concentrators used at gold recovery plants are known, but lately, the Knelson concentrator is gaining more and more popularity. It is emphasized that in the concentrator, the concentrated layer is maintained in suspended condition preventing the concentrate compaction and the formation of ‘dead’ zones [9, 13, 16, 18], which in turn improves the indices of gold-bearing ore processing.

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in electrolyzer in the hydrometallurgical section. The gold deposition statistics by years are given in Fig. 3.

- Frequent emergency shutdowns and reduced (completely absent) concentrate yield on a Knelson CVD42 concentrator are associated with the technical peculiarities of the concentrator nozzles, which are blocked by particles larger than 0.5 mm. According to the process regulations, the finished class content should be up to 65% -0.074 mm, therefore, the presence of particles greater than 0.5 mm in the concentrator feed is considered normal. For stable concentrator operation, an additional screen for limiting elutriation should be installed, which leads to operational costs. Also, the grinding section has no optimal place for the screen and, if the latter is installed, additional equipment (sludgers, a pump tank) is required. During the Knelson CVD42 concentrator operation, emergency shutdowns are on average 2 times per shift 15 minutes each, which is -4.17% from the total operating time; the Knelson CD30 stops for concentrate unloading (periodic operation cycle) take 58 minutes per shift, which is -8% from the total operating time.

- High operating costs when operating Knelson concentrators (power, spare parts, maintenance) as compared with other types of equipment such as jigs, shaking tables, and spiral separators.

- Risks associated with the lack of spare parts for the Knelson CVD42 concentrator. Two notifications on the delay in supply of spare parts were received earlier, the delay in delivery was more than 6 months and threatened to shut the process equipment down. In connection with the above, the equipment operability recovery time increased, which entails an increase in unscheduled downtime and the cost of repair. Poor supply of spare parts for the Knelson CVD42 concentrator leads to frequent downtime and the need for auxiliary equipment, which in turn sharply reduces the equipment utilization rate. This became the ground for the decision to replace the Knelson CD30 concentrator at stages IV and V with a MOD-2M jig to reduce operating costs.

![Diagram of Gold Recovery Flow Sheet before Retrofitting](image)

**Figure 2. Gold Recovery Flow Sheet before Retrofitting.**

![Gold Deposition Statistics Diagrams by Years](image)

**Figure 3. Gold Deposition Statistics Diagrams by Years.**
In November 2016, the Knelson CD30 concentrator was shut down and replaced with the MOD-2M jig, which allowed increasing the commercial concentrate yield by 2 times or +40 g/day, i.e. considering the average finished product yield of 4 kg/day, this was +1 % recovery.

In May 2017, the Knelson CVD42 concentrator was shut down and replaced with the MOD-3M jig. Table 2 shows the testing results.

Table 2. Testing Results before Retrofitting.

| Class, mm         | Weight, g | Yield, % | Au distribution by classes, % | Au content in the class, g/t |
|-------------------|-----------|----------|-------------------------------|-----------------------------|
| -1.0 + 0.5        | 6         | 1.1      | 4.49                          | 9.14                        |
| -0.5 + 0.2        | 25        | 4.8      | 20.20                         | 9.87                        |
| -0.2 + 0.1        | 20        | 3.8      | 5.53                          | 3.38                        |
| -0.1 + 0.071      | 15        | 2.9      | 1.64                          | 1.34                        |
| -0.071 + 0.045    | 25        | 4.8      | 2.63                          | 1.29                        |
| -0.045            | 435       | 82.7     | 65.50                         | 1.84                        |
| Totally           | 526.00    | 100.0    | 100.00                        | 2.32                        |

Note: the class -0.071 mm yield is 87.5 %; The gold losses for the class -1.0 mm+0.2 mm is more than 9 g/t.; Content in the class -0.071 mm is 1.81 g/t., Content in the class +0.071 is 5.9 g/t; General tailings are 2.32 g/t

Table 3. Testing Results after Retrofitting.

| Class, mm         | Weight, g | Yield, % | Au distribution by classes, % | Au content in the class, g/t |
|-------------------|-----------|----------|-------------------------------|-----------------------------|
| tailings MOD 2 +0.071 | 115      | 19.66    | 11.79                         | 0.88                        |
| tailings MOD 2 +0.045 | 60       | 10.26    | 12.72                         | 1.82                        |
| tailings MOD 2 -0.045 | 410     | 70.09    | 75.48                         | 1.58                        |
| tailings MOD 3 +0.071 | 65       | 11.61    | 4.49                          | 0.56                        |
| tailings MOD 3 +0.045 | 80       | 14.29    | 6.91                          | 1.7                         |
| tailings MOD 3 -0.045 | 415     | 74.11    | 88.6                          | 1.73                        |

Note: the class -0.071 mm yield is 84.27 %; Content in the class -0.071 mm is 1.67 g/t., Content in the class +0.071 is 0.76 g/t; General tailings are 1.52 g/t

The table data allow drawing the below conclusions: the particle size distribution in both cases is the same, but when using the MOD-3M and MOD-2M jigs, the commercial product yield is over 20 t/h, while for CVD-42 under the same conditions it is no more than 10 tons.

- the total increase in gold recovery under similar conditions is 27.2 g/h, or 652.8 g/day, or 19,584 g/month, or 19.584 kg/month.

The efficiency of retrofitting the equipment and the use of MOD-2M, MOD-3 M jigs are given in Table 4.
Table 4. Evaluating the MOD Jigs Installation Efficiency.

| Parameter                                      | Unit of measure | Flowsheet with Knelson concentrators | Flowsheet with MOD |
|------------------------------------------------|-----------------|--------------------------------------|--------------------|
| Line productivity according to the flowsheet  | t/h             | 34                                   | 34                 |
| Annual yield                                   | t/y             | 285,600                              | 285,600            |
| Au content in tailings                         | g/t             | 2.32                                 | 1.52               |
| Δ Au content in tails                          | g/t             | -0.80                                |                    |
| Δ recovery from operation                       | g/t             | 34 %                                 |                    |
| Δ Au recovery                                   | kg/y            | 228                                  |                    |
| Total operating costs                          | $/y             | 21,461                               | 655                |
| Revenue growth                                 | RUB/y           | 520,082                              |                    |
| Change in operating costs                      | RUB/y           | 20,807                               |                    |
| The economic effect of replacing equipment     | RUB/y           | 540,889                              |                    |

4. Conclusion
Based on the data analysis and the enterprise experts’ conclusion, an increase in the gold recoverability at the Karalveem Gold Recovery Plant has been achieved by retrofitting the equipment at stages IV and V, which ensured a continuous operation mode and a high concentrate yield.

Although industrial tests have been conducted on a specific deposit, we assume that when recovering fine, dust, or medium-round gold, MOD type jigs may be used to process industrial products at any mine and can be a real competitor to Knelson concentrators that have already gained popularity.

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