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# Advances in Gold Ore Processing

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## ABSTRACT

This paper presents a brief overview of some IRGIREDMET advances in gold hydrometallurgy.

Original impulse-percolation technology and equipment for intensive cyanidation of gravity concentrates have been developed and introduced into industrial practice by IRGIREDMET since 1980s (RF Patents N1593250). The process is based on leaching using special hydrodynamic and reagent conditions providing high dissolution rate for coarse gold particles. Gold and silver are precipitated from pregnant solution by cementation or electrowinning. There was also proposed an improved cementation method using zinc in a contact with electrically conductive material. The units including closed water recirculation, tails detoxification and semi-dry tails disposal were developed for the mines and operations without their own cyanidation facilities.

IRGIREDMET is well experienced in gold adsorption technology using ion exchange resins and activated carbons. The comparison of CIL and RIL processes were done for a number of gold mines, for example for Sukhoi Log gold deposit. The properties of prospective foreign and domestic adsorbents including strong-base, bi-functional and weak-base resins as well as activated carbons were studied. The Institute has developed some adsorption/elution technologies and equipment, such as a two stage RIP adsorption technology for gold/silver ores, an improved technology for gold elution from loaded resin and carbon, electrowinning cells for gold recovery from RIP and CIP eluates etc. Large scale “Resin In Pulp” tests using weak-base resin were finalized and process design criteria were developed. Gold plant design is on progress at the moment.

Improved technology for carbonaceous (preg-robbing) gold ores was developed. It was tested for some gold deposits including Sukhoi Log. It allows to overcome preg-robbing activities of ores treated and to improve dramatically performance of cyanidation and adsorption circuits.

The studies on refractory gold ore treatment including bio-oxidation, pressure oxidation, roasting and ultra-fine grinding were conducted.

Heap leach technology was tested and introduced by Irgiredmet for a number of Russian mines. Zinc cementation, activated carbon and ion-exchange resin adsorption were used for gold recovery from pregnant heap leach solutions. The options including combined technology “Heap leach/ RIL or CIP” for clay ores were also developed and tested. The plant using developed technology is at construction stage now.

The study on In-Situ gold leaching was conducted. The comparison of different gold lixiviants for this purpose was carried out. Gold recovery from pregnant leach solution by activated carbon and anionite including gold elution from loaded adsorbents etc. was also studied. In 2000 the In-Situ leaching technology was commissioned at Maminskoye gold deposit (Ural).

The technologies for treatment of complex ores and by-products were proposed. For example, the technology of gold, silver, copper and zinc recovery from calcines after sulphuric acid production was developed.

**Keywords:** *Gold; Preg-robbing; Complex and refractory ores; Intensive cyanidation; Adsorption; Activated carbons; Anionites; Heap leaching; In-situ leaching; Equipment for hydrometallurgy*

## INTRODUCTION

For many years IRGIREDMET (established in 1871) functioned as the head state research center for gold mining industry in Russia and the former Soviet Union and took an active part in the majority of Russian gold and diamond projects. At present Irgiredmet is an Open Joint Stock Company dealing with a full range of services including research and development, project design, engineering, equipment and reagent supply etc (from geology to gold refinery and tails detoxification). Since its foundation Irgiredmet has started to develop improved technologies and equipment for gold recovery. Some of this developments are described below.

## INTENSIVE CYANIDATION OF GRAVITY CONCENTRATES

In 1980s Irgiredmet developed a technology and equipment for intensive cyanidation of non-ground gravity concentrates which we call the intensive cyanidation unit.

Advantages of the unit developed are its simplicity, high gold recovery, closed water recirculation, use of the efficient technology of tails detoxification and semi-dry disposal which meet the demands of Russian environmental legislation (Mullov, Rashkovsky, 1993). Preliminary washing of concentrate to remove slimes is not required as the proposed unit prevents losses of fine gold with slimes. The intensive cyanidation unit was developed for mines and operations which have no their own cyanidation facilities. Of course it may be easily used for cyanidation gold plants too.

The Irgiredmet unit for intensive cyanidation consists of a cyanidation reactor made as a cone (pyramid), a circuit for a processing of pregnant leach solutions by zinc precipitation or electrowinning and a tails detoxification unit. The reactor for intensive cyanidation have no moving parts, therefore it is simple and robust in operation (Fig. 1). Concentrate grains are mixed by a flow of leach solution pumped by short impulses. Intensive mixing and gold leaching occur in the bottom of the reactor. Superficial velocity of solution in the upper part of the reactor is much lower therefore concentrate particles are held inside the reactor. The leach solution from the reactor overflows to a sump and after its filling is automatically fed by a pump to the leach reactor. Solution is circulated through the system during a sufficient period for gold leaching. The concentrate is treated at optimum parameters such as concentration of cyanide, leach time, mixing intensity, frequency of impulses and duration of settling of a concentrate slurry to provide leach efficiency not less than 90% ~ 95 %, even without the use of leach aid reagents.

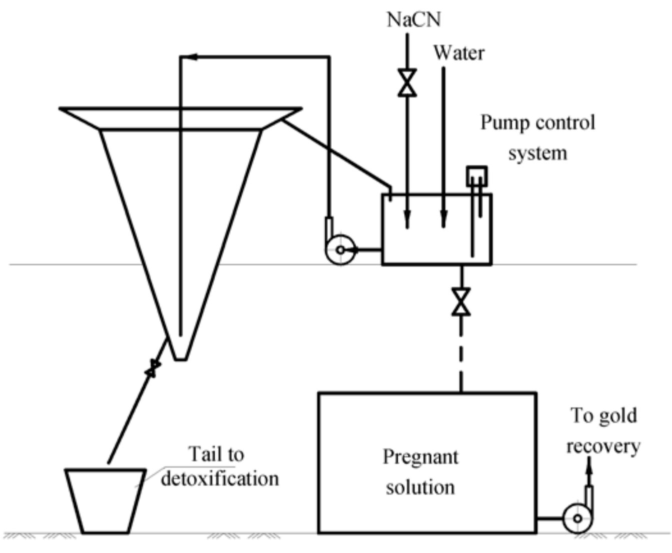


Fig. 1 Intensive cyanidation scheme

Electrowinning cells designed by Irgiredmet are used for gold precipitation from pregnant leach solutions. Irgiredmet also proposed an improved cementation method using zinc in contact with electrically conductive material. Gold precipitates generated by this method contain not less than 50 % of gold and may be easily smelted to Dore metal.

The unit provides low power requirements for cyanidation, processing of pregnant solutions and drying and smelting of precipitates - no more than 2~4 kWh per ton concentrate.

Irgiredmet intensive cyanidation units were supplied to 11 Russian gold operations including Samartinsky gold plant, Buryatia; Valunisty mine, Chukotka and others. (Fig. 2)

Fig. 2 Intensive cyanidation unit view

## GOLD ADSORPTION TECHNOLOGY USING ION EXCHANGE RESINS AND ACTIVATED CARBONS

Irgiredmet has a good experience on gold adsorption technology using ion exchange resins and activated carbons (Dementyev, Voiloshnikov, 1998). Both adsorbents were compared for processing of ores, concentrates, bio-oxid- ation products etc. The comparison of CIL and RIL processes was done for some gold mines, for example for Sukhoi Log gold deposit. The properties of prospective foreign and domestic adsorbents including strong-base, bi-functional and weak-base resins as well as activated carbons were studied. The Institute has developed some adsorption/elution technologies and equi- pment, such as a two stage RIP adsorption technology for gold/silver ores, an improved technology for gold elution from loaded resin, electrowinning cells for gold recovery from RIP and CIP eluates etc (Dementyev, Voiloshnikov, 2005).

Both adsorbents have their advantages and disadvantages (Table 1). So the final decision on adsorbent selection has to be done on the base of economical evaluation results.

The method of gold elution from loaded carbon by alkaline solution under pressure was developed in cooperation with Irkutsk Technical University. The advantages of the developed elution process are the high rate and high gold recovery (duration of the process is about one hour; residual gold loading of eluted carbon –50 g/t) and absence of cyanide in eluent (Table 2). The CIP technology based on the above mentioned elution method was successfully implemented at Lebedinsky plant (Aldanzoloto Company, 1984), at Samartinsky plant (Buryatzoloto Company, 1998), Valunisty mine (Chukotka), Novo-Kochkarsky plant (Ural) and others.

There was designed a column type reactor for cyanidation and adsorption processes operating as a plug-flow reactor instead of stirred tanks (Fig. 3). It is a vertical column divided by horizontal plates of special design into several sections. The column reactor allows to eliminate

**Table 1 Comparative characteristics of activated carbons and anion exchange resins**

| Characteristics | Adsorbent type | |
|---|---|---|
| | activated carbon | anion exchanger |
| Sensitivity to ion composition of pulp (solution) treated | lower | higher |
| Sensitivity to availability of organic compounds | lower | higher |
| Particle size (size of screen aperture used)/mm | +1.0 | +0.5 |
| Abrasion hardness/% | lower (85~90) | higher (>96) |
| Adsorption kinetic | slower | faster |
| Bulk density/(kg/L) | 0.5 | 0.33 |
| Adsorbent cost | lower (1,700~2,500 $) | higher 10,000~12,000 $ |
| Necessity of thermal reactivation | present | no |
| Specific gravity of wet particle (important for use column with fluidized bed of adsorbent)/(g/cm$^3$) | 1.4~1.5 | 1.1 |
| Reagents used for gold elution | NaCN, NaOH | $H_2SO_4$, $CS(NH_2)_2$, NaOH |
| Elution temperature/°C | 95~175 | 60 |
| Elution column constructive material | Steel | Titanium or rubber lined |
| Adsorbent losses/(g/t) | higher | lower |
| Gold recovery from flotation concentrates | improved | - |
| Environmental problems (tails detoxification and others) | easier | more complicated |

**Table 2 Comparative parameters of gold elution methods**

| Process parameters | Elution method | | | | |
|---|---|---|---|---|---|
| | AARL (RSA)* | Zadra (USA) | | IPS (Australia) | Irgiredmet (Russia) |
| | | under pressure ** | ambient pressure | | |
| Presoaking | necessary | no | no | no | no |
| Presoaking solution | 2%~3% NaCN 2% NaOH | – | – | – | – |
| Bed volume/BV | 0.6 | – | – | – | – |
| Duration/h | 0.5~1.0 | – | – | – | – |
| Temperature/°C | 110~120 | – | – | – | – |
| Gold elution | | | | | |
| Eluent composition | High quality softened water (<300 mg/L Na) | 0.2%~0.5% NaCN 1%~2% NaOH | 0.1%~0.3% NaCN 1%~2% NaOH | 2%~4% NaOH | 0.2%~0.4 % NaOH |
| Temperature/°C | 110~120 | 120~127 | 93~95 | 145~155 | 165~175 |
| Eluent flowrate/(BV/h) | 0.8~2.7 | 2.1~2.6 | 1~2 | 2~2.5 | 10 |
| Duration/h | < 8 | 13~20 | 48~72 | 11~14 | 1 |
| Number of BV | 5~10 | 40~50 | >50 | 25~35 | 8~10 |
| Reagent consumption/ per 1 t of carbon | | | | | |
| NaCN/kg | 60 (82.5) | 30 | >30 | – | – |
| NaOH/kg | 35 (51.3) | 60 | >60 | 50 | 40~80 |
| Power/kW h | 1500 (2883) | 3533 | >3500 | 1000~1900 | 2160~2880 |

short circuiting of feed to discharge point. It was tested in 1987 at Sovetsky gold plant (Krasnoyarsk Region) and commissioned later at Olimpiada (RIL-process, Krasnoyarsk Region) and Novo-Kochkarsky gold plants (CIL-process, Ural) (Fig. 4). Use of columns allows to decrease the number of equipment units in comparison with conventional stirred tanks for the same gold recovery and gold adsorbent loading. Resin losses in RIL- process using the column reactor were decreased from 3%~5% down to 0.8 % due to more "delicate" agitation in comparison with air agitated adsorption tanks (Pachukas).

Detailed design drawing were developed for column reactors with capacities of 20 $m^3$, 40 $m^3$, 100 $m^3$, 210 $m^3$ and 400 $m^3$.

Electrowinning cells for gold deposition from acidic thiourea eluates generated during gold elution from loaded resin and alkaline cyanide eluates from carbon adsorption technology were developed. The peculiarities of the electrowinning cells are as follows: cathode precipitates are generated as slimes which allow to discharge precipitates without stoppage of electrowinning process and to achieve 96%~98% gold recovery per pass (20~30 minutes).

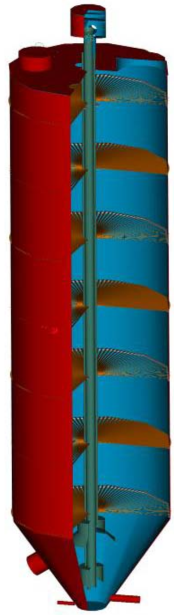

Fig. 3 Column type reactor

Fig. 4 CIP column type reactor – capacity 210 $m^3$ each (Kochkarsky gold plant, Ural)

Electrowinning cell with the cathodic surface area of 120$m^2$ and the capacity of 2 $m^3$/hour was developed for RIP eluates. Anodic and cathodic areas are devided by cation exchange membrane to prevent thiourea oxidation. Sulphuric acid solution is used as anolite. Electric current for cell is from 1000 A to 2000 A. The designed cells were used at Karamkensky gold plant (Magadan Region) and are in use at Mnogovershinny and Olimpiada RIL plants.

Two types of electrowinning cells were designed for CIP eluates. The cathodes for first type of the cells are made as stainless steel plates and for the second type as stainless steel screen. Plated cathode electrowinning cells are used at Samartinsky gold plant (Buryatia) and Kochkarsky gold plant (Ural). Screen cathode electrowinning cells with cathode surface area of 250 $m^2$ and capacity 2~3 $m^3$ / hour are used at Valunisty mine (Chukotka).

Large scale "Resin In Pulp" tests using weak-base resin were finalized and process design criteria were developed. Gold plant design is on progress at the moment.

## REFRACTORY GOLD ORE TREATMENT

### Improved technology for carbonaceous (preg-robbing) gold ores

The refractory ores often contain naturally-occurring carbonaceous material which can adsorb gold-cyanide complexes from solutions. In Russia 30 % of the total gold ore reserves are made up of these refractory ores.

The following methods were proposed to treat the preg-robbing ores depending on their preg-robbing activity:

- direct cyanidation under the special conditions which completely or almost completely prevents gold adsorption from solutions by the carbonaceous material (Lodeischikov, 1998);
- chemical (fast chlorination) or thermochemical (roasting) oxidation of the carbonaceous material with subsequent cyanidation (Lodeischikov, 1999);
- carbonaceous material extraction from the ore by mechanical processing of the ore including classification, desliming and flotation to produce low-grade products with subsequent cyanidation.

Test results and gold plant practice showed that preg-robbing carbonaceous ore slimes particles of less than 0.01 mm which are amenable to overgrinding can be removed by classification (desliming) (Lodeischikov, 1999).

High gold recovery from some preg-robbing gold ores and concentrates can be achieved by cyanidation using organic cyanides, surfactants (kerosene, cresylic acid, combustible oils, acetone etc.) and some chemical reagents which are used for gold elution from pregnant activated carbons.

Irgiredmet JSC developed an improved technology of processing and cyanidation of concentrates produced from preg-robbing ores. This technology was tested using ores of a Russian gold deposits (Dementyeva, Mullov, Vinokurova, 2007).

The developed technology of flotation concentrate recleaning by cycloning/flotation allowed the reduction in the preg-robbing activity as well as the 2.5 % reduction in the mass yield of the flotation concentrate (Fig.5). The total gold mass in the recycling products was about 1 % of the ore feed grade. Some of this gold was recovered during ore processing. The total gold recovery from ore with the head grade of 0.8 g/t was 83.9 % including 53 % from the high-grade concentrate and 30.9% by CIL of gravity middlings and intensive cyanidation tailings. The gold loading onto the activated carbon from CIL-process was 6.500 g/t.

Recleaning of flotation concentrate by cycloning and flotation allows significantly improve the indices of hydrometallurgy for concentrates. The test results showed that the proposed technology can be efficiently used for refractory carbonaceous gold ores including low-grade ores.

### Bio-oxidation, pressure oxidation, roasting and ultra-fine grinding

Irgiredmet has conducted extensive multiyear study on gold recovery from refractory ores and concentrates by different methods (bio-oxidation, pressure oxidation, roasting and ultra-fine grinding). The results was summarized in monograph (Lodeischikov, 1999).

## HEAP LEACH TECHNOLOGY

Heap leach technology was tested and introduced by Irgiredmet for a number of Russian mines (Dementyev, Druzhina, Gudkov, 2004). Zinc cementation, activated carbon and ion-exchange resin adsorption were used for gold recovery from pregnant heap leach solutions. The options including combined technology “Heap leach/RIL or CIP” for clay ores were also developed and tested. It consists of ore disintegration into a slime and sand fractions which are treated separately (the sands - by heap leaching and slimes - by RIP or CIP). The plant using developed technology is at construction stage now.

## IN-SITU GOLD LEACHING

The innovative technology for gold recovery from hard rock and placer deposits which are too low in grade to justify mining and transportation expenditures is In-Situ leaching.

Irgiredmet has conducted the study on In-Situ gold leaching (Panchenko, Dementyev, Khmelnitskaya, Lodeishikov, 2003). The com-

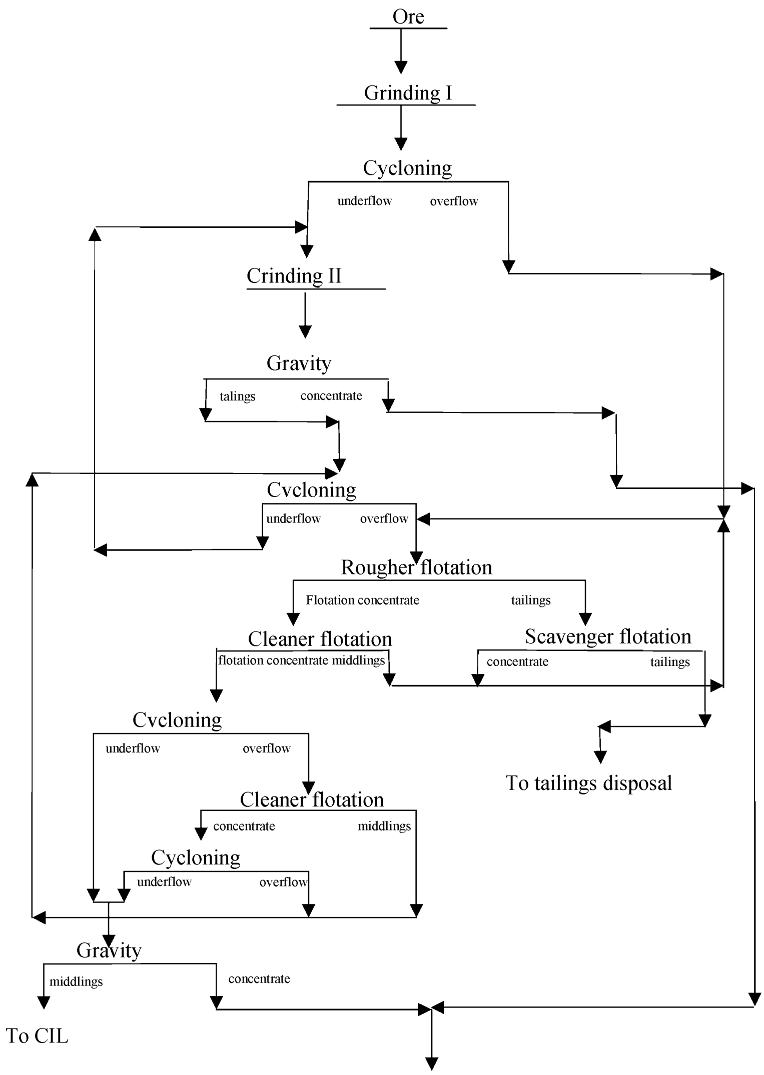


Fig. 5 Ore concentration flowsheet including flotation concentrate recleaning

parison of different gold lixiviants for this purpose was done (Lodeischikov, Dementyev, Khmelnitskaya, Chikina, Lanchakova, 2006). Gold recovery from pregnant leach solutions by activated carbon and anionite including gold elution from loaded adsorbents etc. was also tested.

The basic criteria required for an underground deposit to be considered suitable for leaching in place are as follows: ore body must be enclosed between impermeable strata that will prevent losses of solution; it must be permeable to leach solution. Two technologies are used: spraying when ore body is exposed and injection when it is buried.

In 2000 IRGIREDMET in cooperation with the Ural Mining and Geological Company developed process design criteria as well as project design and commissioned into pilot operation the in-situ leaching technology by oxychloride solutions from Maminskoye deposit ores (Ural) (Fig. 6).

Maminskoe gold oxidized ore deposit was chosen as the object for In-Situ leaching as it is ideally suited for this purpose due to its mineral composition and hydrogeology. The ore reserves within the In-Situ block are 90,000 t with average gold grade of 0.7 g/t.

The capacity of pilot plant operation was 15 $m^3$/hour. Gold concentration in pregnant solu-

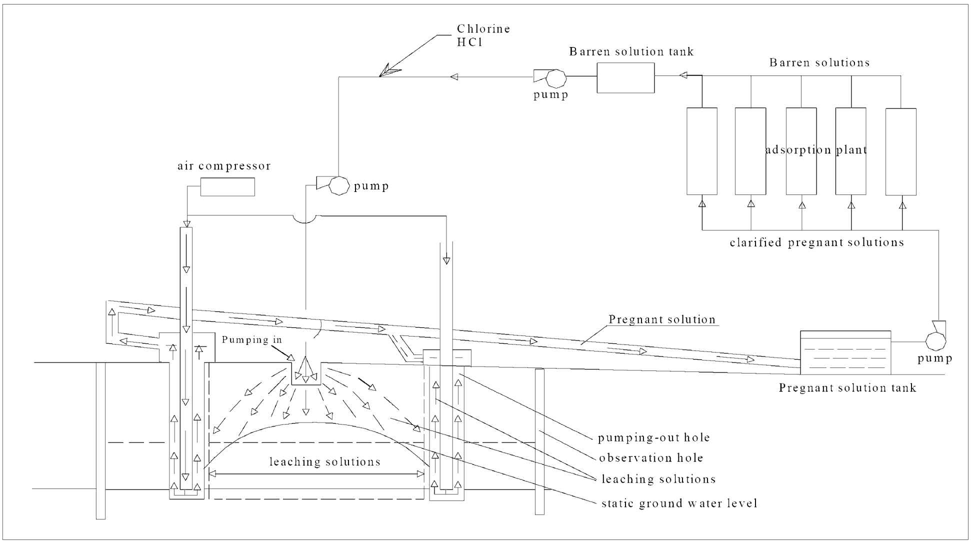


Fig. 6 In-Situ gold leaching process scheme

tion is 0.12 ppm~0.13 ppm, chlorine consumption is 3.5 kg per 1 g of recovered gold.

In comparison with conventional methods of gold ore processing In-Situ leaching allows to decrease investment costs in 2~4 times and to reduce the cost of gold production in 1.5~2.0 times.

The raw material for In-Situ leaching are small-sized and buried placers, cut-of-grade gold ores etc., which can not be treated cost effectively by conventional methods.

Irgiredmet Institute cooperates on In-Situ leaching technology with JSC “Geoprid”, “Northern” gold company, JSC “Gagarka-Au-PV”

## THE TECHNOLOGIES FOR TREATMENT OF COMPLEX ORES AND BY PRODUCTS

The studies on testing and development of technology for gold-bismuth ore treatment were conducted (Khmelnitskaya, Beskrovnaya,2007). As a results a process flowsheet including gravity, flotation, hydrochloric acid leaching of combined concentrate and its subsequent cyanidation was recommended. The saleable products generated were the following: bismuth bearing cathode precipitate (71%~79 % of Bi) and Dore metal. Overall gold, silver and bismuth recoveries were 84.8% ~ 86.5 %; 63.2% ~ 64.9% and 75.8% ~ 76.9 % respectively.

In comparison with direct cyanidation of concentrates preliminary hydrochloric acid treatment allows to achieve additional gold recovery 1.8% ~ 3.5%, silver recovery 22.7% ~ 24.4%, bismuth 15.8% ~ 16.9%.

Initial data for a bank feasibility study and plant designing were developed from test results.

Magnetic separation, flotation, bioleaching, cyanide, thiourea, sulphite leaching were tested to utilize valuables from burnt pyrites. The technology for valuables recovery from burnt pyrites was developed (Khmelnitskaya, Mullov, Komlev, Lanchkova, 2008). It includes water washing of soluble compoments by CCD process, lime treatment of washed residue with air sparging, gold and silver cyanidation. Copper and zinc are recovered from wash solution, gold and copper – from cyanide solution. SX/EW technology is used for copper recovery. The technology developed allows to recover 54 % of gold, 45 % of silver, 30% of copper and 50 % zinc.

Final tails may be used as iron bearing material in cement industry.

## CONCLUSIONS

High world gold price and depletion of free milling ores is stimulated development of improved technology and equipment for gold recovery. Brief overview of Irgiredmet developments on gold metallurgy is presented. It includes in particular the intensive cyanidation of gravity concentrate, adsorption/elution technology and equipment for RIP and CIP processes, improved technology for treatment of refractory and complex products (preg robbing ores, gold/bismuth ores, burnt pirytes etc.), In-Situ-Leaching for low grade gold ores etc. The majority of mentioned above advances are used efficiently in gold mining industry of Russia.

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