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Study on Efem Cukuru Gold Ore Deposit and Recovery of Gold by Flotation

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This study reports the information about Efem cukuru gold ore deposit and the results of the flotation experiments. Classical first-order kinetic flotation model was used for the evaluation of the experimental data, recovery and flotation rate constants describing the flotation time-recovery profiles for different reagent combinations.

Key Words: Gold, Flotation, Flotation chemicals.

INTRODUCTION

The recovery of gold has been a challenge almost since the beginning of time. The mineralogy and particle liberation size are the important factors in determining the best recovery process for a specific gold ore. It can be proposed that flotation with its high output at relatively low capital and operating costs has always been an important alternative in the development of the flow sheets for the gold ores. The method provides high mineral selectivity, the abundance of the alternatives in choosing the effective reagents and a wide range of the application methodology[1]. Previous studies on the flotation of native and free gold have focused on many different factors affecting the gold recovery[1-14].

The choice of collector type and dosage is an important factor in gold flotation. Klimpel *et al.*[2] reported that the uncharged and water-insoluble collectors are the most effective collectors in free gold flotation applied at or near the natural pH. Thiocarbamates, xanthogen formates, mercaptans, dialkyl sulphides are the useful uncharged and water-insoluble collectors used in gold flotation. Some charged and water-soluble collectors such as xanthates and dithiophosphates are used in gold flotation too. According to Allan and Woodcock[6], xanthate and dithiophosphate mixtures are effcient for both suphides and native gold.

In this study, the effect of different reagent combinations has been investigated by using the combinations with copper sulphate ($CuSO_4$) and sodium sulphide (Na_2S) separately. The use of sodium sulphide (Na_2S) in the correct concentration can

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function as an activator. Otherwise, it can prevent the adsorption of xanthate or other collector on the gold surface and could also act by poisoning the reduction of oxygen, although this would only apply with certain types of collectors[6-10]. Copper sulphate oxidizes xanthate to dixanthogen. It has been noted in past research that dixanthogen is a more powerful collector than metal xanthates but is less selective. If the dixanthogen formed in significant amounts it can affect the frothing characteristics of the pulp. Increasing the amount of dixanthogen in the pulp may result some increase for particles entrained into the concentrate[6]. On the other hand, Bulatovic *et al*.[3] and Monte *et al*.[4] have reported that the use of $CuSO_4$ in the flotation of gold ores containing high amount of clay minerals doesn't help to improve the recovery. Conversely, it may have a negative effect on the flotation of gold particles.

Efem cukuru (Izmir-Turkey) ore deposit is a vein-type epithermal gold deposit with related stockwork and replacement mineralization[15]. In polygenetic hydrothermal vein breccia the clasts are bound by the matrix of manganaxinite-tinzenite, rhodonite, rhodochrosite, quartz and calcite association. The matrix supported breccia consists of volcanic rock, shale-sandstone and ore clasts. The clasts of the hydrothermal breccia are coated by alternation of manganaxinite-tinzenite, rhodonite, rhodochrosite, quartz and calcite bands to form cocade structures. Disseminated ore-bearing breccia is crosscut by individual axinite and quartz bearing veins (Figs. 1A and B).

Pyrite is one of the most common and earliest-formed sulfides in the veins of Efem cukuru (Fig. 1C). Euhedral pyrites are surrounded and replaced by other common sulfur minerals such as sphalerite, chalcopyrite and galena. There is some paragenetic overlap between pyrite and sphalerite as these minerals enclose one another. But more frequently euhedral pyrites were replaced by sphalerite (Fig. 1D). The cavities of pyrite crystals are filled by sphalerite and galena crystals which represent the later ore bearing fluids.

Sphalerite is generally found as second earliest-formed ore mineral accompanying to or nearly after pyrite (Fig. 1D). However in some parts of mineralization it is also observed that the replacement of both euhedral pyrite and surrounded chalcopyrite by sphalerite. However generally chalcopyrite and galena appear to partially replace sphalerite along its fractures and cavities.

Galena often shows signs of plastic deformation and curvilinear cleavage traces are frequent. There are two different phases of galena crystallization. The early galena (Galena I) is replaced by sphalerite and chalcopyrite in some parts of the samples (Fig. 1D). Galena II crystallized later than both sphalerite and chalcopyrite.

Although copper content is low in overall mineralization. It is represented by chalcopyrite. Fahlore group minerals are observed in minor amounts as a late ore phase. In most parts of the mineralization, chalcopyrite replaces pyrite and sphalerite along crystal boundries, fractures and is, in turn, replaced by sulphosalts, chalcocite, covellite and goethite. The totally oxidized surface of the veins consists of quartz, amorphous manganese wad and iron oxides. Goethite after pyrite and chalcopyrite

is the most common mineral in iron oxides and hydroxides in Efem cukuru (Fig. 1E). Euhedral pyrites are replaced pseudomorphly by goethite in oxidized ore. Manganese oxides are abundant as fillings, coatings and in between quartz bands where rhodonite is oxidized in alternation of banded structures. Hematites are observed as leaf, needle-shape structures and also formed as veins and veinlets. They essentially changed to siderite and goethite. Visible gold is also associated with the oxide paragenesis indicating enrichment by supergene processes (Fig. 1F).

EXPERIMENTAL

Natural gold ore samples averaging 10.8 g/t Au grades (100 % passing 180 μ) from Efem cukuru ore deposit, Izmir, Turkey. The most of the gold is very fine (2.5-50 μ), occurring as free grains in quartz and carbonate. Characterization studies of the samples (Table-1) were conducted at Mining Engineering Department, Dokuz Eylul University, while the mineralogical examinations (Fig. 1) were performed at Geological Engineering Department, Dokuz Eylul University, Izmir, Turkey.

TABLE-1
IZMIR-EFEM CUKURU GOLD ORE SAMPLE

Constituents	Contents
Au	10.8 ppm
Ag	13.4 ppm
Cu	193 ppm
Zn	1065 ppm
Pb	1125 ppm
MnO	16.62 %
Fe_2O_3	5.60 %
SiO_2	65.52 %
CaO	3.35 %
S	1.08 %
Al_2O_3	2.37 %
LOI	3.43 %

Detection method: Mineralogical characterization of the ore was carried out by optical microscopy, chemical analyses was conducted by using aqua regia to dissolve the gold. The gold assay was determined by using an AnayltikJenaAG novAA 330 atomic absorption spectrometer.

General procedure: The sample was crushed below 2 mm by a jaw crusher and ground below 0.18 mm by a ball mill. The ground ore was split into the new samples weighing 1000 g by an automatic sample splitter.

Flotation studies were run at natural pH of the gold ore. The Outokumpu laboratory scale flotation machine was used for the flotation tests. 2.5 L/min aeration rate has been applied and the experiments were carried out in a round shaped flotation cell (2 L). 1000 g of gold ore sample ground below 0.180 mm subjected to the flotation experiments. KAX (50 g/t) and Aerofloat 208 (50 g/t) and one more different

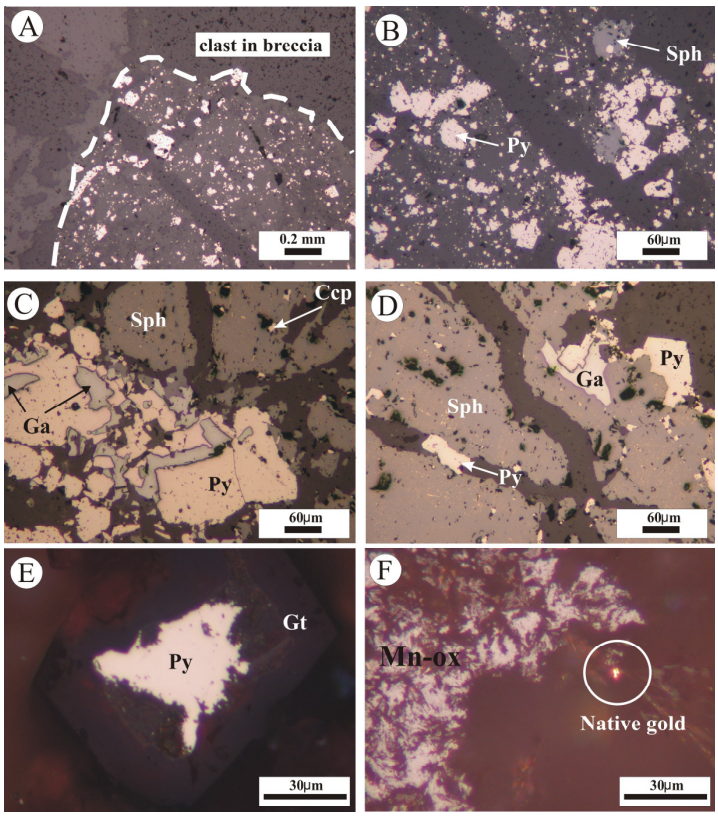

Fig. 1. Izmir-Efem cukuru gold ore mineralogy [(Sph), galena (Ga), pyrite (Py), chalcopyrite (Ccp), goethite, (Gt)]

collector (50 g/t) were used in each experiment. Sodium sulphide (70 g/t) was used as a sulphidiser and copper sulfate was used as an activator (150 g/t) were used separately. Na_2SiO_3 (400 g/t) was used as depressant and Aerofroth 70 (25 g/t) was used as frother.

25 min of total conditioning time and 8 min of total flotation time have been applied for kinetic flotation tests.

RESULTS AND DISCUSSION

The results have been evaluated by classical first-order flotation model[2]. The flotation process can be considered as a time-rate recovery process. Therefore mathematical flotation models that incorporate both a recovery and a rate function can completely describe flotation time-recovery profiles. Kinetic models are generally used to analyze batch flotation data. The models can be used to evaluate the effect of various parameters like flotation chemicals or operating conditions for flotation process. First order flotation model considers the general rate equation for flotation and it may be written as:

$$\frac{dC_p(t)}{dt} = -k(t)C_p^m(t)C_b^n(t) \quad (1)$$

$C_p(t)$ and $C_b(t)$ are the concentrations of the particles and bubbles at time t, respectively.

The exponent, m and n are the respective orders for particles and bubbles and k(t) is a pseudo rate constant. If the material to be floated consist of particles whose k's could be expressed by a continuous distribution function, f(k), the recovery at time t will be equal to:

$$R(t) = R_\infty \left[1 - \int_0^\infty f(k)\exp(-kt)dk \right] \quad (2)$$

here, R_∞ is the ultimate recovery at long times, R(t) is fractional recovery[2] at time t.

Fig. 2 shows that concentrate gold grade tends to decrease after 0.5 min while concentrate gold recovery increasing by the flotation time. The gold recovery was poor and the grade of the concentrate was very low. Ultimate recovery and flotation rate were 54.68 % and 0.55, respectively.

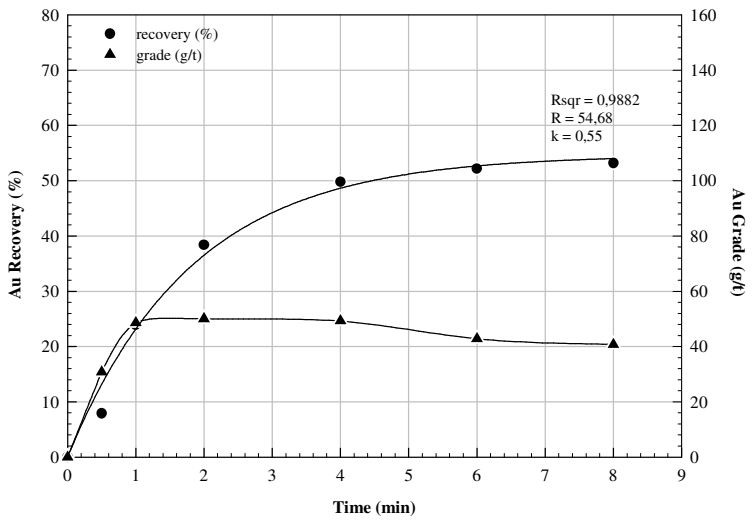

Fig. 2. Effect of 150 g/t $CuSO_4$ addition on the time-recovery curve for gold (collector combination: KAX-Aerofloat 208 and Aero 6697)

Fig. 3 shows that the gold grade decreases by the flotation time while recovery increases. By comparing Fig. 2 with Fig. 3, it is observed that concentrate gold grade and ultimate recovery values increased from 40.77-46.62 g/t and 54.68-64.54 %, respectively. The flotation rate value was the same, 0.55. The results in these experiments show that Na_2S addition to the pulp increases the concentrate grade and ultimate recovery values of the flotation with KAX-Aerofloat 208 and Aero 6697 and $CuSO_4$ combination but does not affect the flotation rate.

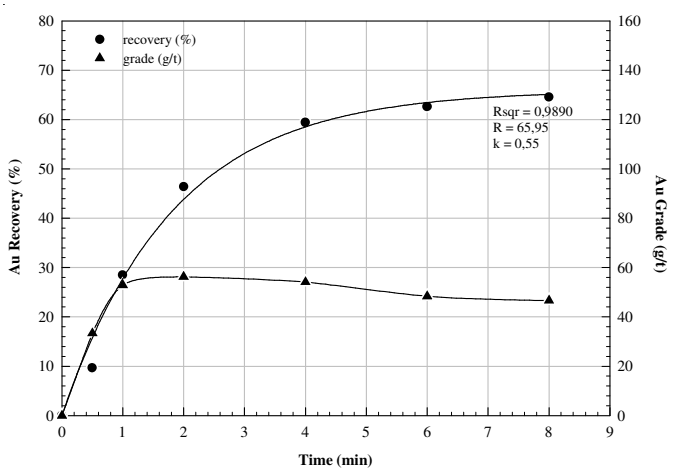

Fig. 3. Effect of 70 g/t Na_2S addition on the time-recovery curve for gold (collector combination: KAX-Aerofloat 208 and Aero 6697)

Concentrate grade affected slightly by the flotation time and the recovery values of the concentrates increased by the flotation time. KAX-Aerofloat 208 and Aero 412 combination produced a concentrate assaying 68.33 g/t Au with 63.76 % ultimate recovery (Fig. 4).

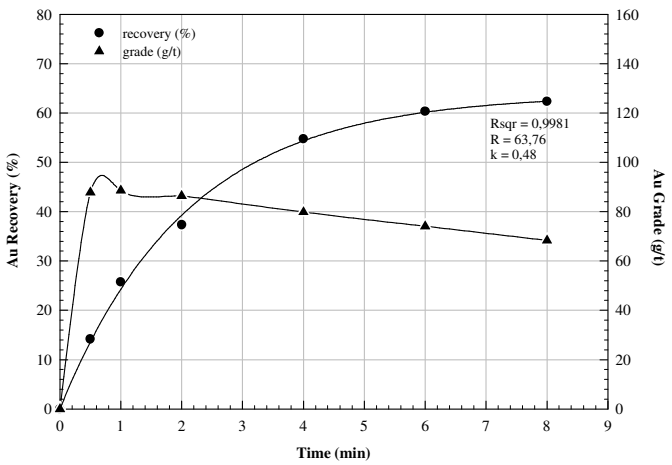

Fig. 4. Effect of 150 g/t $CuSO_4$ addition on the time-recovery curve for gold (collector combination: KAX-Aerofloat 208 and Aero 412)

Gold grade and ultimate recovery values were higher when Na_2S added to the pulp. Sodium sulfide addition also enhanced the flotation rate to 0.82. By comparing Fig. 4 with Fig. 5, it can be seen that the concentrate gold grade increased from 68.33 g/t to 73.58 g/t and ultimate gold recovery was also increased from 63.76 % to 65.04 %.

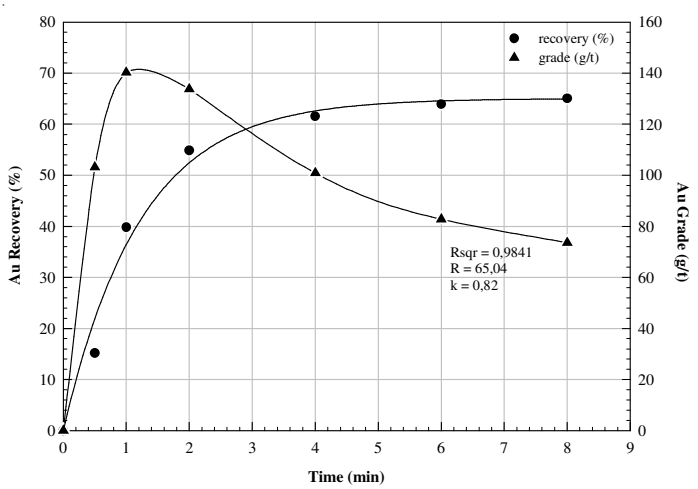

Fig. 5. Effect of 70 g/t Na_2S addition on the time-recovery curve for gold (collector combination: KAX-Aerofloat 208 and Aero 412)

Fig. 6 illustrates that the addition of Aerofloat 242 to the combination increased the grade and the recovery of the gold concentrate. A concentrate assaying 148.81 g/t Au was recovered with 62.90 % gold recovery.

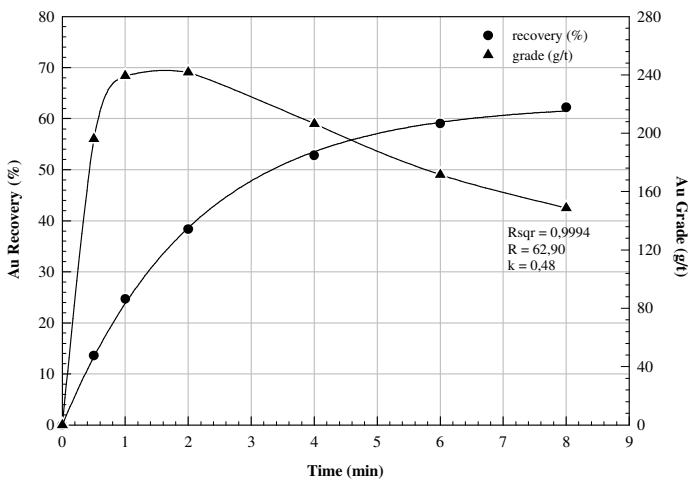

Fig. 6. Effect of 150 g/t $CuSO_4$ addition on the time-recovery curve for gold (collector combination: KAX-Aerofloat 208 and Aerofloat 242)

Fig. 7 shows the effect of Na_2S addition to the KAX, Aerofloat 208 and Aerofloat 242 reagent combination. Sodium sulfide addition to the pulp increased the ultimate recovery to 67.89 %. Flotation rate increased from 0.48 to 0.65. A concentrate with 92.22 g/t Au grade was obtained.

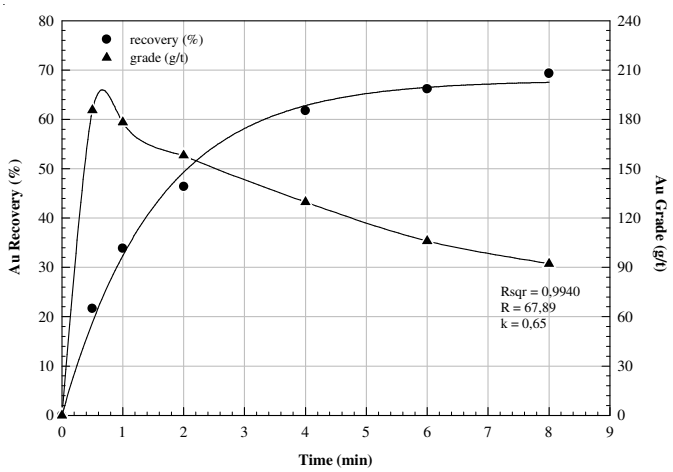

Fig. 7. Effect of 70 g/t Na_2S addition on the time-recovery curve for gold (collector combination: KAX-Aerofloat 208 and Aerofloat 242)

A high grade concentrate obtained at 0.5 min flotation time, a tendency to decrease by the flotation time could be observed in concentrate grades (Fig. 8). A concentrate containing 89.02 g/t gold was produced at the end of the flotation time. Ultimate recovery was calculated as 61.19 % and flotation rate was achieved as 0.71.

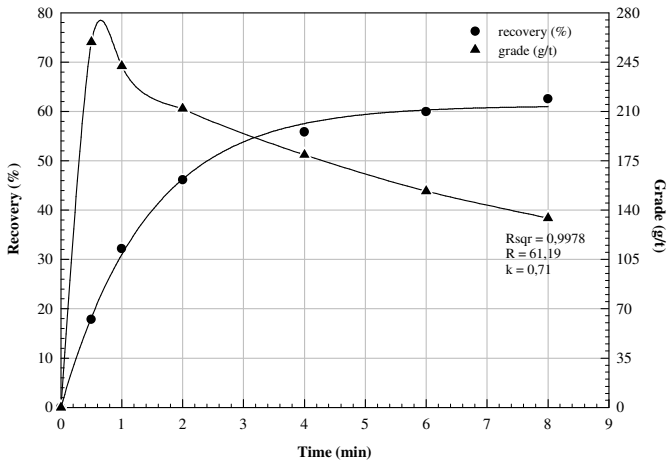

Fig. 8. Effect of 150 g/t $CuSO_4$ addition on the time-recovery curve for gold (collector combination: KAX-Aerofloat 208 and Aerophine 3418A)

Comparing Fig. 8 and Fig. 9 shows that the concentrate gold grade has been decreased to 57.20 and recovery value increased from 61.19 % to 75.21 %. The flotation rate value was increased to 1.02. Sodium sulfide addition to the pulp enhanced the gold recovery while speeding up the gold particles attachment to the gas bubbles.

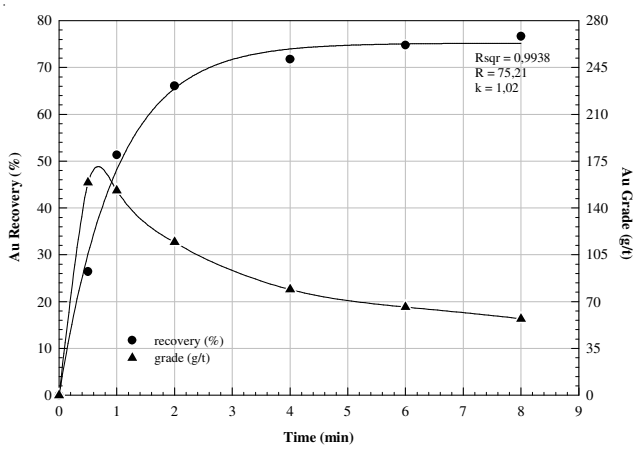

Fig. 9. Effect of 70 g/t Na_2S addition on the time-recovery curve for gold (collector combination: KAX-Aerofloat 208 and Aerophine 3418A)

Conclusion

Flotation studies were performed to investigate the effect of reagent synergism on the gold recovery. Table-2 and Fig. 10 represent the overall results of the experiments.

KAX-Aerofloat 208-Aerofloat 242 and $CuSO_4$ combination is the most selective combination for the recovery of gold from Efem cukuru gold ore (148.81 g/t Au grade). KAX-Aerofloat 208-Aerophine 3418A-Na_2S combination is the most effective combination for the gold recovery (75.21 %). The same combination (KAX-Aerofloat 208 Aerophine 3418A-Na_2S) also produced the concentrate with the highest flotation rate value (1.02 1/min).

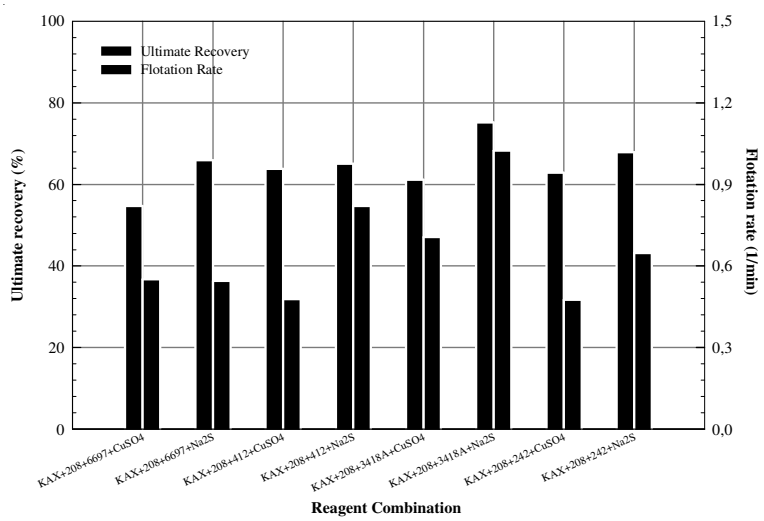

Fig. 10. Overall presentation of the effect of reagent synergism on the recovery of gold for Izmir-Efem cukuru ore

TABLE-2
OVERALL PRESENTATION OF THE EFFECT OF REAGENT SYNERGISM ON THE RECOVERY OF GOLD FROM EFEM CUKURU ORE

Reagents	Concentrate (8 min flot time)			
	Weight (%)	Grade (g/t)	R (%)	K (1/min)
KAX-Aerofloat 208-Aero 6697-$CuSO_4$	8.89	40.77	54.68	0.55
KAX-Aerofloat 208-Aero 6697-Na_2S	9.35	46.62	65.95	0.55
KAX-Aerofloat 208-Aero 412-$CuSO_4$	6.47	68.33	63.76	0.48
KAX-Aerofloat 208-Aero 412-Na_2S	7.34	62.34	65.04	0.82
KAX-Aerofloat 208-Aerofloat 242-$CuSO_4$	4.71	148.81	62.90	0.48
KAX-Aerofloat 208-Aerofloat 242-Na_2S	6.19	92.22	67.89	0.65
KAX-Aerofloat 208-Aerophine 3418A-$CuSO_4$	7.88	89.02	61.19	0.71
KAX-Aerofloat 208-Aerophine 3418A-Na_2S	8.26	57.20	75.21	1.02

It can be concluded that the use of copper sulphate in the combinations produced a stabilized froth by providing a clean separation zone in the froth phase and increased the selectivity. However, the weight and ultimate recovery values and the flotation rate of the concentrates were low. Employing Na_2S in the combinations enhanced the concentrate ultimate recovery and flotation rates. The weight recovery of the concentrates was also improved but the selectivity decreased eventually. The use of Na_2S in the combinations provided better recovery values than using copper sulphate.

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