COLLECTORLESS FLOTATION APPROACH TO A LOW GRADE GOLD ORE

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ABSTRACT

In this study, flotation behavior of low grade dry ground gold ore was investigated comparatively without (collectorless) and with collector. The effects of pH and frother dosages were studied in collectorless flotation. Lime was used to adjust pH and AF70 was employed as a frother. Flotation tests with collector, potassium amyl xanthate (PAX), were performed at optimum conditions determined in collectorless flotation. Based on the results of those rougher flotation tests, open circuit flotation tests were carried out with and without (collectorless) collector. Final concentrate containing 112.39 g/t Au 12.11% Cu 13.72% Fe and 12.27% S were obtained with recoveries of 53.79% 38.64%, 1.78% and 5.71%, respectively in the case of collectorless flotation while obtaining a final concentrate having 85.80 g/t Au, 9.59% Cu, 35.16% Fe and 36.45% S with recoveries of 59.14%, 46.12%, 6.81% and 25.54% flotation with collector. It was also possible to obtain alternative final concentrate containing 221.57 g/t Au, 21.08 % Cu, 19.41% Fe and 21.32% S with recoveries of 43.89%, 31.55%, 0.99% and 4.22%, respectively by lowering the frother dosage in collectorless flotation.

Keywords: Low grade gold ore, gold flotation, collectorless flotation

INTRODUCTION

Flotation is used for gold processing in the world for many years with success (Fuerstenau et al., 2007). However, it's rather difficult subject to generalize due to the complex mineralogy of gold ores (Klimpel, 1999). Therefore, selecting proper parameters for gold flotation are strongly depended on ore mineralogy. According to Allan and Woodcock (2001) occurrence of gold can be categorized in five classes.

- Visible native gold particles; such as native gold, various forms of gold, silver and copper alloys,
- Relatively rare gold minerals; gold tellurides and gold-carbon associations etc.,
- Gold in iron sulfides (pyrite, pyrrhotite and arsenopyrite etc.),
- Gold in base metal sulfides; such as copper, zinc, lead, also bismuth and antimony is common,
- Gold - gang mineral associations; quartz, mica and iron oxides etc.

Native gold, disseminated in quartz veins, most commonly found with chalcopyrite, pyrite, arsenopyrite, galena and sphalerite, which are also referred as gold carriers (Chryssoulis and McMullen, 2016). Gold particles may occur in these minerals by many forms due to the difference in genetic types of gold deposits. Grain sizes may vary from large nuggets to sub-microscopic particles, which can be locked in the lattice of host mineral. These types of ores are the subject of this study.

There are numerous references (Aksoy and Yarar, 1989; Dunne, 2005; Gul et al., 2012; Chryssoulis and McMullen, 2016) reporting that naturally occurring gold surfaces are usually hydrophobic and almost readily found to be floated with a little or no collector addition at natural or near natural pH. As a result, most of the problems in gold flotation, are related to gold bearing minerals

rather than flotation of native gold and its alloys. Therefore, choice of proper flotation scheme according to ore mineralogy strongly dependent to chemistry (reagent type, pulp pH etc.) of the pulp (Adams, 2016).

As for gold-copper ores, xanthates are the most common collectors. Dithiophosphates, thionocarbomates, mercaptans and dialkyl sulfides are also employed as secondary collectors, in combination with xanthates (Klimpel, 1997). According to Bulatovic (2010), flotation of gold-copper ores containing pyrite, recovery of gold is strongly related to pyrite recovery. Pyrite is once reacted with collectors, it's rather difficult to depress and separate it from gold and chalcopyrite (Zheng and Manton, 2010). In industrial applications lime is widely used to control pH and to depress pyrite in cleaner stages, however using excessive amounts of lime also decreases the gold recovery.

In this study, flotation behavior of low grade gold ore containing certain amount of sulfides (mainly chalcopyrite and pyrite) were investigated comparatively without (collectorless) and with collector.

MATERIAL AND METHOD

Ore used in this study, were sampled from deposit and shipped to Eskisehir Osmangazi University Department of Mining Engineering Laboratory. Samples were previously dry ground to P_{80} size of 100 µm. They were split into 1000 g test charges for bench scale flotation tests. Samples were kept in freezer when not being handled.

All the head samples and flotation test products were analyzed at Bureau Veritas Commodities Canada Ltd., Vancouver, BC, Canada by ICP-ES/ICP-MS and by fire assay for gold. The average head assay results for gold and other major elements are summarized in Table 1.

Table 1. Head sample assays of gold and major elements

Au	g/t	1.4
Ag	g/t	1.1
Cu	%	0.2
Fe	%	5.2
S	%	1.4

Mineralogical analysis performed on polished and thin sections of drill core samples revealed that sulfide mineralization is dominated by pyrite and chalchopyrite. Chalcopyrite liberation is high at greater than 90%. Non-liberated chalchopyrite occurs as interstitial grains to subhedral to euhedral pyrite grain boundaries. Trace amounts of sphalerite and sometimes galena is also present at some sections. The native gold particles are associated with chalcopyrite. They either occur, at chalcopyrite-pyrite contacts or proxies for chalcopyrite in pyrite. Gold grains are in the 30 µm and finer size range. As for gang minerals, quartz and mica are the most abundant minerals with moderate amounts of feldspar, carbonates and pyrite. There are also minor amounts of clay and Mg silicates are present.

Bench scale flotation tests were conducted in a 1.5-litre standard laboratory Denver cell, operated at an impeller speed of 1000 rpm and air rate of 5 l/min. Tap water was used to make up approximately 35% solids by weight. The slurry pH was adjusted by using lime. Aerofroth 70 (AF70, Cytec Industries Inc., MIBC equivalent) as frother. The pulp was agitated for a period of 9 min., so that any differences in pH between each test would be stabilized. Frother was added and conditioned for 1 min. before the air entered the pulp. Scraping of the froth was performed every 30 s. Concentrates were collected over a 180 s. at roughing stages. In the case of flotation tests with collector, potassium amyl xanthate (PAX) was utilized. Conditioning time was 3 min. after the pH adjustment. Finally, open circuit

flotation tests with two cleaning stages were performed with and without collector at determined conditions. At cleaning stages, froth collection times were 120 and 90 s. at 1st and 2nd cleaning stages, respectively.

RESULTS AND DISCUSSIONS

At rougher stage, collectorless flotation conditions were optimized for pH and frother dosage. Three levels of pH (natural pH of ore, pH 8, pH 9) and frother dosages (12, 24 and 48 g/t) were tested. The effects of frother dosage is given for different levels of pH in Figure 1.

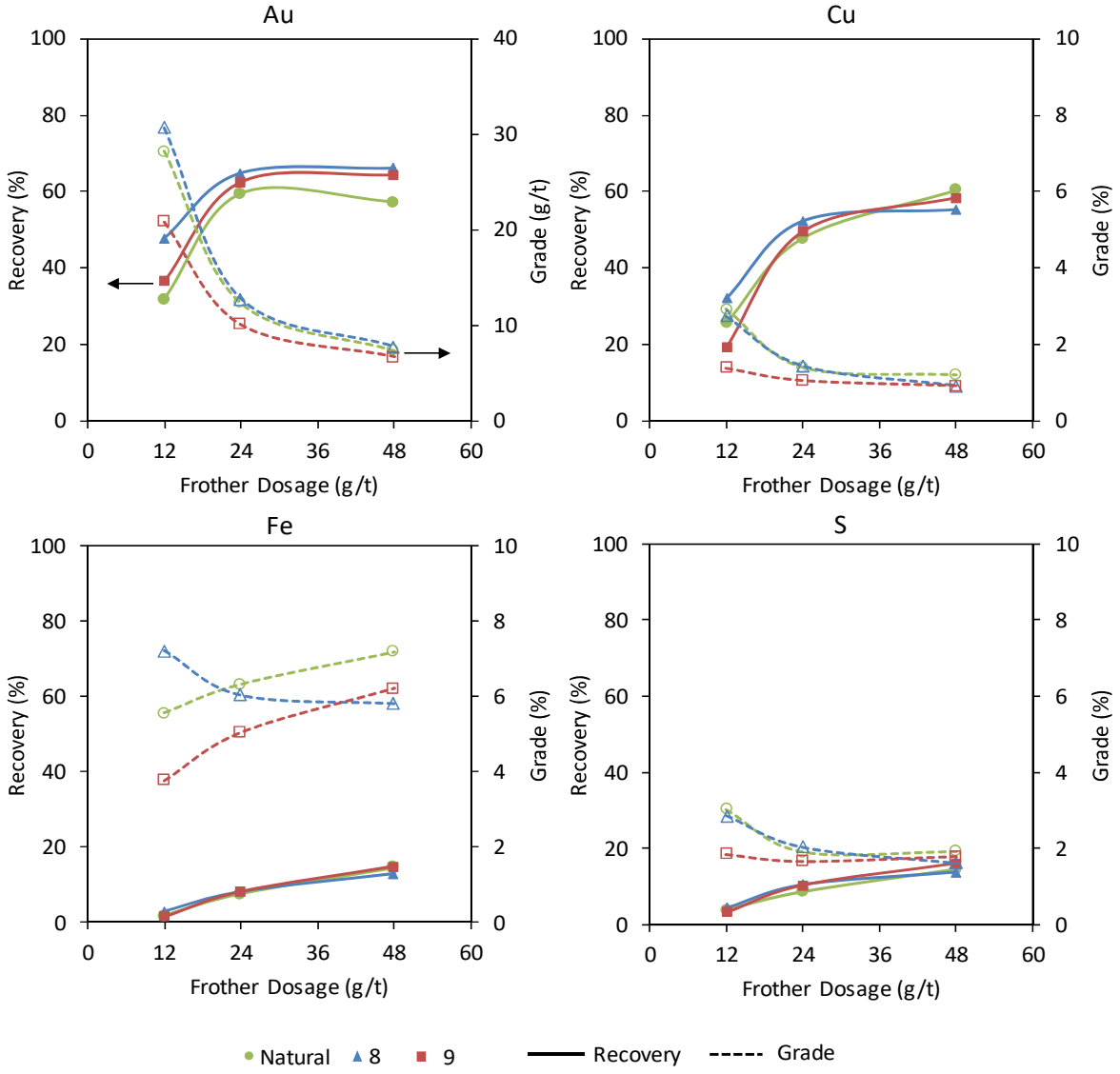


Figure 1. Effects of frother dosage at different levels of pH

It can be seen that recoveries increase with increasing frother dosages at all pH levels while corresponding grades relatively decreasing. In general, Au recoveries up to 65% were obtained. For all pH levels and frother dosages, Fe and S recoveries are below %15 while having 60% recoveries for Cu. Hence, it could be depicted that collectorless flotation is successful and selective against pyrite at certain level.

Regardless of the frother dosage, higher Au recoveries and grades were acquired at pH 8 compare to the natural pH of the ore and pH 9. Au grade is the highest at frother dosage of 12 g/t at pH 8. This scenario is similar for Cu grade as well except that it is slightly better at natural ore pH. As for Fe and S, studied pH levels don't create a significant impact on recoveries. However, at natural and pH 8, Fe and S grades are higher parallel to the Cu grades indicating selective chalcopyrite beneficiation at frother dosage of 12 g/t.

In collectorless flotation tests, pH 8 was determined to be the optimum pH value based on Au, Cu, Fe and S recoveries and grades. A new batch of tests were carried out using potassium amyl xanthate (PAX) as a collector. Two levels of collector (15, 30 g/t) and frother (12, 24 g/t) dosages were tested.

Flotation tests with a collector (PAX) were carried out in an effort to increase recoveries and grades obtained in the collectorless flotation tests. In Figure 2, effects of collector dosage at different frother dosages are presented comparatively with collectorless flotation tests. As it can be seen, collector addition increases recoveries at about 10-20% for both Au and Cu, while slightly decreasing Au grades without altering Cu grades. In the case of Fe and S, collector addition was resulted in an increased recoveries and grades significantly. This might suggest that pyrite also floated in presence of collector, even more compare to the native gold, chalcopyrite, and gold bearing chalcopyrite. Furthermore, increasing collector dosage from 15 g/t to 30 g/t did not affect the recoveries and grades

for all metals.

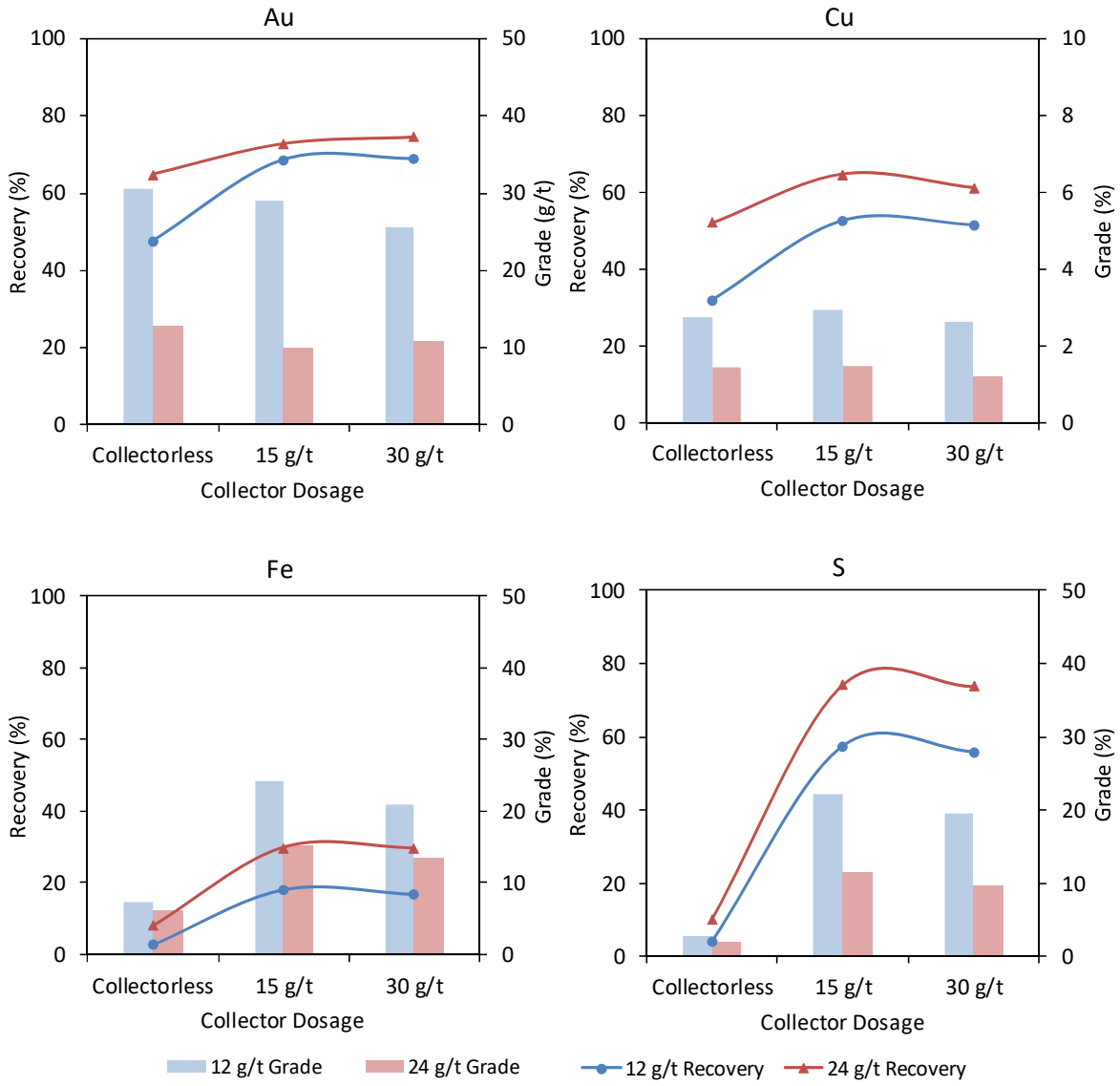


Figure 2. The effect of collector dosage at 12 and 24 g/t frother dosages

Open circuit flotation tests with two cleaner stages were performed with and without collector (Table 2). At cleaning stages, pH is increased to 10 by using lime for depressing pyrite.

Table 2. Open circuit test conditions

Test	Stage	pH	PAX (g/t)	AF70 (g/t)	Flotation Time
Collectorless (Low Frother Dosage)	Rougher	8	-	12	180
	1st Cleaner	10	-	-	120
	2nd Cleaner	10	-	-	90
With Collector	Rougher	8	15	12	180
	1st Cleaner	10	-	-	120
	2nd Cleaner	10	-	-	90
Collectorless (High Frother Dosage)	Rougher	8	-	24	180
	1st Cleaner	10	-	-	120
	2nd Cleaner	10	-	-	90

Results of open circuits flotation tests are represented in Table 3 and Figure 3

Figure 3.Results of open circuit flotation tests. As seen, overall metal recoveries are higher about 15% with collector while having similar Au and Cu grades indicating that overall sulfide flotation is enhanced. This shows loss in selectivity as evident by quiet higher Fe recovery and grade obtained with collector. After two cleaning stages, in collectorless flotation, final concentrate having 221.57 g/t Au and 21.08 % Cu was obtained with 43.89% and 31.55% recoveries respectively while having 85.80 g/t Au and 9.59 % Cu with 59.14% and 46.12% recoveries respectively, with collector. Fe recovery and grade were considerably higher with collector implying that significant amount of pyrite is recovered.

Table 3. Results of open circuit flotation tests

Conditions	Stage	Assays (Au in g/t, Cu, Fe and S %)				Distributions (%)			
		Au	Cu	Fe	S	Au	Cu	Fe	S
Collectorless 12 g/t Frother	Rougher	28.09	2.94	8.00	3.80	50.51	39.88	3.71	6.82
	1st Cleaner	128.96	12.91	14.63	13.88	47.31	35.78	1.39	5.09
	2nd Cleaner	221.57	21.08	19.41	21.32	43.89	31.55	0.99	4.22
With Collector 12 g/t Frother	Rougher	29.46	3.35	26.25	25.07	68.51	54.37	17.15	59.26
	1st Cleaner	49.73	5.56	39.43	41.25	66.45	51.82	14.81	56.03
	2nd Cleaner	85.80	9.59	35.16	36.45	59.14	46.12	6.81	25.54
Collectorless 24 g/t Frother	Rougher	10.45	1.35	6.14	2.36	63.44	54.45	10.11	13.94
	1st Cleaner	51.00	5.83	9.29	6.49	56.82	43.31	2.81	7.03
	2nd Cleaner	112.39	12.11	13.72	12.27	53.79	38.64	1.78	5.71

In an effort to increase recoveries, frother dosage was increased to 24 g/t in collectorless flotation. As can be seen from the Table 3 and Figure 3, this lead to about 10% higher Au and Cu recoveries while having lower grades. However, the obtained Au and Cu grades and recoveries are competitive to the values obtained with collector. Selectivity in terms of pyrite rejection were quiet high as well. A final concentrate containing 112.39 g/t Au and 12.11 % Cu was obtained with 53.79% and 38.64% recoveries respectively.

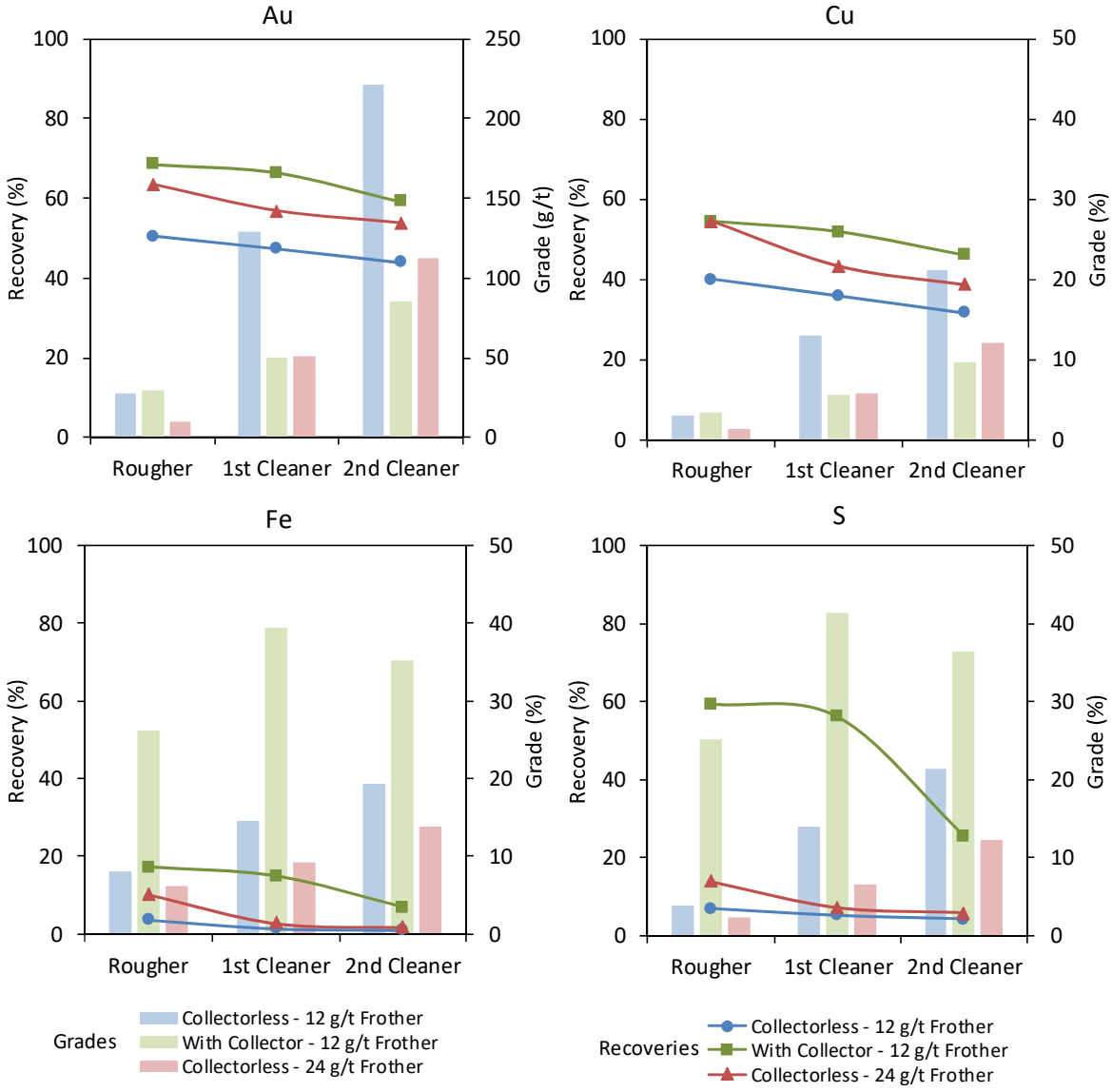


Figure 3.Results of open circuit flotation tests

CONCLUSIONS

Final concentrate containing 112.39 g/t Au, 12.11 % Cu, 13.72% Fe and 12.27% S was obtained with 53.79%, 38.64%, 1.78% and 5.71% recoveries, respectively in open circuit collectorless flotation tests with two cleaning stages. In flotation tests with collector, final concentrate having 85.80 g/t Au, 9.59 % Cu, 35.16% Fe and 36.45% S was obtained with 59.14%, 46.12%, 6.81% and 25.54% recoveries, respectively. Fe recovery and grade were considerably lower in collectorless flotation implying improved

flotation selectivity. It was also possible to obtain even cleaner final concentrate containing 221.57 g/t Au, 21.08 % Cu, 19.41% Fe and 21.32% S with 43.89%, 31.55%, 0.99% and 4.22% recoveries, respectively with lower frother dosage in collectorless flotation.

Collectorless flotation could certainly be an option for ores with suitable mineralogy for the differential flotation of gold. It also inhibits pyrite flotation without necessitating usage of high amount of lime which could also depress gold in certain extent. Bearing in mind that this study was performed with dry ground samples, comparison of the effect of grinding conditions (dry vs wet) prior to flotation is a subject of ongoing research.

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