

Study of new commercial collectors for the recovery of coarse quartz particles in iron ore flotation

Geraldo Lisboa de Oliveira ¹, Gilberto Rodrigues da Silva ²

¹ Postgraduate Program in Metallurgical, Materials and Mining Engineering, Professional Master's Degree, Federal University of Minas Gerais, MG, Brazil

² Department of Mining Engineering, Federal University of Minas Gerais, MG, Brazil

Corresponding author: grsilva@demin.ufmg.br (Gilberto Silva)

Abstract: Currently, a small range of commercial collectors is available for the use in reverse iron ore flotation at Vale. This input represents a considerable unit cost, being essential for the concentration of low content itabiritic iron ores. The present work evaluated the reverse cationic flotation of an itabiritic ore with low iron content (39.6 % Fe) from the Iron Quadrangle (BR) in bench scale tests, focusing on the use of new collectors to remove coarse quartz. The sample presents 19% of its particles as oversize in the 0.150 mm sieve. The poor flotation of coarse quartz particles (>0.150 mm) causes significant problems in various iron ore flotation circuits by contaminating the concentrate. The study evaluated the performance of 10 new collectors from the etheramine family with different degrees of neutralization and at different collector dosages. The flotation process variables were set as industrially practiced at the Cauê iron ore plant (BR). In tests varying the specific collector dosage, the non-neutralized etheramines showed improved performance compared to the current 50% neutralized etheramine used in the plant, achieving industrial targets: concentrate SiO₂ content rate lower than 4.5% (1.4%), tailings iron content lower than 23% (18.94%), metallurgical recovery greater than 66% (74.8%), and Gaudin Selectivity Index greater than 6.6 (10.5). The 0.150 mm oversize in the concentrate, mostly coarse quartz particles, was reduced from 5.7% down to 1.2%, indicating the potential for the industrial application of non-neutralized etheramines in the recovery of coarse quartz.

Keywords: flotation, new collectors, amine, iron ore, coarse quartz

1. Introduction

Iron ores are the primary source of iron for the world's iron and steel industries. As almost all (98%) iron ore is used in steelmaking, the metal is essential for steel production, crucial to maintain a strong industrial base. Iron ore is mined in approximately 50 countries, whereas the seven largest of these producing countries account for approximately three-quarters of the total world production. Australia and Brazil together dominate the world's iron ore exports, each having approximately one-third of total exports (USGS, 2023). According to Global Data, Brazil was the world's second-largest producer of iron ore in 2022, accounting for 18% of global production, being Australia, India, China, and Russia also large producers. Iron ore exports from Brazil increased by 0.28% in 2022 over 2021, with the highest share being exported to China (GlobalData, 2023). The high metal content (60.0 to 67.0% in hematites and 50.0 to 60.0% in itabirites concentrates) sets the Brazilian iron ore apart from other countries, mostly due the use of concentration technologies which are constantly being optimized.

Flotation is the most effective solution, both technologically and economically, in the production of iron concentrates (Matos et al., 2022). The growing demand for pellet feed with a limited content of silica, alumina and other impurities has led to an increase in the use of flotation compared to other methods. The technique is also widely applied in the concentration of various ores (Filippov et al., 2014).

The flotation selectivity is based on the fact that the surface of different mineral species has varying degrees of chemical affinity to water, known as hydrophilicity. The less intense this property, the more hydrophobic the mineral and the greater the ability of mineral particle to interact with the bubbles

present in the system (Peres et al., 2007). Selectivity is then achieved when a difference in the degree of hydrophobicity of the minerals present in the ore is reached. Since most valuable and non-valuable minerals are hydrophilic, it is necessary to add chemical reagents into the process that can adsorb at the solid-liquid interface and change the surface characteristics of the desired particles from hydrophilic to hydrophobic. These reagents are called collectors (Peres et al., 2007).

Fatty amines and their derivatives are the basis for the main cationic collectors used in reverse iron ore flotation, at which quartz is floated and recovered in the froth, making up the tailings, whereas hematite is depressed and kept in the pulp, being recovered as concentrate. Fatty amines are defined as a compound derived from aliphatic ammonia, whose main raw materials are oils or fats, saturated or not, classified as primary, secondary, or tertiary and which have a hydrocarbon chain with an even number of carbon atoms ranging from eight to twenty-two. They are classified into 5 categories: fatty amines, fatty diamines, etheramines, etherdiamines and condensed amine compounds (Pearse, 2005). The fatty amines and etheramines are supplied, or prepared in the plant, as acetates or quaternary chloride salts partially neutralized with acetic or hydrochloric acid, respectively. Although fatty amines were used in iron ore flotation in the past, etheramines, which are more selective and more soluble in water, are the most used quartz collectors in the reverse cationic flotation of iron ores currently (Pearse, 2005; Matos et al., 2022a). Etherdiamines are considered more efficient in the recovery of quartz compared to primary monoamines or ethermonoamines, although presenting a higher cost. This can be related to the collector's structural characteristics, with two polar groups, allowing adsorption onto more surface sites than ethermonoamines, as well as better froth properties (Matos et al., 2022; Matos et al., 2022a; Matos et al., 2022b). Substitutions to amines have been investigated mainly due to problems associated to the control of frothing properties and the high cost of the collector (Matos et al., 2022; Kapiamba & Kimpiab, 2021).

The two main challenges faced in the reverse cationic flotation process used in iron ore concentration regarding particle size are: (i) - coarse quartz particles do not respond well to the collecting action of amines; (ii) - fine (ultrafine) iron oxide particles do not respond well to the action of corn starch depressant (Vieira & Peres, 2021).

The poor flotation of coarse quartz causes significant problems in various iron ore flotation circuits, at which it is observed that quartz particles larger than 0.150 mm show a poor response to flotation, contaminating the concentrate (Vieira & Peres, 2015). Coarse particles present low recovery in flotation due to bubble-particle detachment events and poor recovery in the froth. In this sense, the recovery of coarse quartz particles is said to depend on hydrodynamics conditions in flotation, but also on froth characteristics, which is driven by the role of the surfactants used in the system (Safari et al., 2020; Rahman et al., 2012).

The flotation behavior of coarse quartz particles is said to be significantly sensitive to changes in hydrophobicity. Reduced flotation recovery has been shown to be a result of lower contact angles due to the attachment of more hydrophilic fine particles, being the use of desliming stages or high viscosity systems beneficial to improve the recovery of coarse quartz (Xu et al., 2012). The favourable effect of high viscosity was attributed to changes the mean bubble size, bubble size distribution, dissipation, and fluid velocity. Also, a reduction in the critical contact angle of coarse particles was observed in high viscosity pulps (Xu et al., 2011).

The use of different flotation machines and operational conditions, *i.g.*: agitation, froth height, solids concentration, collector and depressant dosage, superficial gas velocity, superficial water rate, bed particle size, bed-level and feed rate, as well as the use of fine hydrophobic particles and nanobubbles obtained in the presence of Dodecylamine and various frothers have been investigated to improve recovery in coarse quartz flotation (Safari et al., 2020; Nazari & Hassanzadeh, 2020; Safari et al., 2022; Ding et al., 2023, Dankwah et al., 2022). Improvements in the hydrophobicity and/or recovery of coarse quartz particles was obtained using nanobubbles, fine hydrophobic particles, increased collector dosage, agitation, and optimum froth height and superficial gas velocity (Nazari & Hassanzadeh, 2020; Safari et al., 2022), whereas no significant improvement was observed in investigations on feed rate and solids concentration (Safari et al., 2020; Safari et al., 2022). The application of new collectors, however, has not yet been evaluated in this regard.

Vale's mineral processing plants have a small number of tested commercial collectors with proven efficiency in the reverse flotation of iron ore, which was a preponderant factor in the development of this work. In addition, collectors represent the second highest OPEX cost in the Southeast System plants in Brazil, with average unit price (AUP) only lower than that of grinding bodies. This encourages a technical-financial study to expand the range of approved commercial collectors. The present study aimed to evaluate new amine-based collectors for the reverse cationic iron ore flotation, focusing on the performance in the recovery of coarse quartz particles, currently a major source of contamination to the concentrate.

2. Materials and methods

2.1. Materials

The iron ore sample used in this study consists in an itabirite with iron content between 39 and 43%. The ore was sampled in Itabira Mine (BR), located in the Brazilian Iron Quadrangle. The ore went through crushing, grinding and desliming operations, being the sample collected as a slurry in the flotation feed pumping system of the Cauê Plant. The sample went through a preparation process, where its humidity was reduced using a vacuum filter and it was dried in an oven at a temperature of 105°C. The sample was then homogenized using conical piles and the mass was reduced using the bench quartering method.

2.2. Methods

2.2.1. Particle size analysis

The particle size distribution of the sample used in this study was obtained via wet sieving in a suspended sieve shaker with pneumatic drive (Dialmática, BR). The equipment used a set of 9 round Tyler sieves from 1.0 mm to 0.053 mm, plus the 0.045 mm sieve, and a bucket to collect and quantify the material passing through the 0.045 mm sieve.

In the test, an aliquot of 120 g was added to the sieve set, the lid was locked to secure the sieves, the water flow rate was adjusted, and the test was conducted for 10 minutes. After sieving, the set of sieves was placed on a container, the edges washed, and the retained masses were collected on trays and dried in an oven. The 0.045 mm undersize collected in the bucket was also filtered and dried in an oven. After drying the samples, the masses retained in each sieve were weighed and the particle size distribution calculated.

2.2.2. Chemical characterization

Prior to the chemical analyses, the samples were pulverized in a LM2 vibratory mill (FLSmidth, DK), suitable for reducing the size of materials with 6.0 mm top size, for 120 seconds. Afterwards, 40g were collected for further dry pulverization in a HSM100 pulverizing mill (Herzog, BR) for 90 seconds. After this time, the mass was transferred to a desiccator to cool for 30 minutes. Once room temperature had been reached, 0.6800 ± 0.0002 g of the sample and 5.4400 ± 0.004 g of lithium borate mixture flux were weighed and mixed until a uniform and homogenized mixture was obtained. This mixture was then transferred to a platinum crucible (95% PT /5% AU) for fusion, forming a molten pastille which was taken to a Simultix 14 X-ray fluorescence spectrometer (Rigaku, JP) to quantify the elements present in the ore sample.

2.2.3. Mineralogical characterization

The ore mineral composition was determined using reflected light microscopy, in DMLP, DM2500P and DM6000M petrographic microscopes (Leica, DE). To identify the minerals via reflected light microscopy, qualitative properties were evaluated: colour, internal reflections, hardness, and morphology. To quantify the mineral phases, a specific objective lens was used, allowing at least 20 particles to be seen per visual field, being 25 fields analysed. This number was determined to cover a statistically representative portion of the polished section analysed. Initially, the focus of the lens was

positioned at the intersection of the section dividers using the 50x objective. The magnification was then adjusted to the appropriate lens for analysis, positioning the focus on the first visual field.

2.2.4. Bench flotation

Initially, the collector solutions (1% w/w) were prepared and homogenized using a magnetic stirrer for 7 minutes. The depressant, Flokit 335, was then prepared, also at a concentration of 1% w/w. A refractometer was used to ensure that the concentration of the prepared solutions was in line with the proposed values.

To carry out the flotation tests on bench scale, a CFE-100 flotation cell (CDC, BR) was used. Initially the iron ore sample was added, and the pH value of the pulp was measured. The depressant solution was added, the pulp pH adjusted and kept at 9.8 and conditioning was performed for 3 minutes, then the collector solution was added, followed by 1 minute conditioning. A container was positioned to collect the tailings (foam), after which the air was injected, time recordings were initiated, and flotation was conducted for 180 seconds. The floated material was collected manually using collection paddles, and during flotation water was added (at the pH of the test) to replenish the pulp level whenever necessary. After flotation was finished, the final pH of the pulp was recorded.

The concentrate and tailings samples were filtered, dried, weighed, and sent for chemical analyses. To carry out the flotation tests, 10 amines from 4 different suppliers were used, as shown in Table 1.

Table 1. List of collectors used in bench flotation tests

ID	Collector	Classification	Neutralization degree
Col A	Flotigam 7100	Ethermonoamine	50%
Col B	Flotigam 10138	Ethermonoamine	0%
Col C	Flotigam 18000	Ethermonoamine	0%
Col D	Lilaflot 811 M	Ethermonoamine	10-30%
Col E	Lilaflot 822 M	Ethermonoamine	10-30%
Col F	Flotasil R2OPX51	Ethermonoamine	15-30%
Col G	Colmin C10R30	Ethermonoamine	30%
Col H	Colmin E107-2	Ethermonoamine	15-30%
Col I	Arosurf MG70A30	Ethermonoamine	30%
Col J	Tomamine M4713	Ethermonoamine	30%

In the flotation tests, all the process parameters were set, except for the type of collector and its specific dosage. The experiment was conducted in a 1,250 mL vat, at 1,100 RPM agitation, 55% solids concentration by weight, 180 seconds collection time, 5/1 starch/NaOH ratio, 380 g/t corn starch and pH of 9.8. All the collectors listed in Table 1 were used in the study in three different trials, with different specific collector dosage: 90 g/t, 100 g/t and 110 g/t.

The aim of the tests was to evaluate the impact of the collector characteristic and dosage on the metallurgical recovery, selectivity index, SiO₂ content in the concentrate, iron content in the tailings and % >0.150 mm in the concentrate.

2.2.5. Statistical Analysis

Once conducted the experiments, the data was compiled in Minitab® 17 software to insert the variables and data from the study. The data was then analysed using the Individual Control Chart, a tool that uses statistics to graphically analyse the variability of process variables. Subsequently, the regression tool was used to determine the correlation between SiO₂ content and % >0.150 mm in the concentrate. An interval graph was also used to evaluate the collection power of the amine collectors to recover coarser quartz according to the degree of neutralization and specific collector dosage.

3. Results

3.1. Particle size distribution of flotation feed

The particle size distribution of the flotation feed obtained from the Cauê flotation plant, is shown in Fig. 1. The result of the analysis shows a top size of 250 μm , D_{50} of approximately 65 μm and P_{80} of approximately 150 μm , being the 150 μm oversize of approximately 19.9% of the ore sample. Industrially, the iron ore reverse flotation feed usually presents a P_{80} of approximately 106 μm . A coarser particle size distribution generates disturbances in the collection of quartz, contaminating the concentrate and consequently generating pellet feed outside the specification limits.

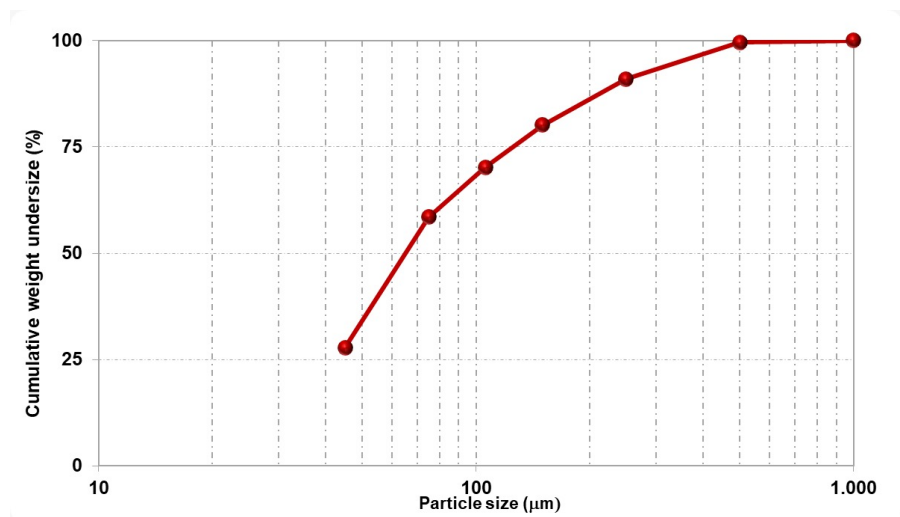


Fig. 1. Particle size distribution of the Cauê flotation feed.

3.2. Chemical analysis

The chemical analyses (Table 2) indicate the predominance of Fe and SiO_2 as major components in the ore samples, as well as the presence of P, Al, Mn, Ti, Ca, and Mg as minor contaminants. There was little loss ignition, indicating the presence of carbonates and goethite.

Table 2. Chemical analysis of the Cauê flotation feed.

Fe	SiO_2	P	Al_2O_3	Mn	TiO_2	CaO	MgO	PPC
39.60	41.73	0.013	0.400	0.140	0.031	0.110	0.090	0.01

3.3. Mineralogical analysis

The ore sample is mostly constituted of hematite and quartz, with the main hematite grains being characterized as compact and the main morphologies described as specular and lamellar, as indicated in Fig. 2.

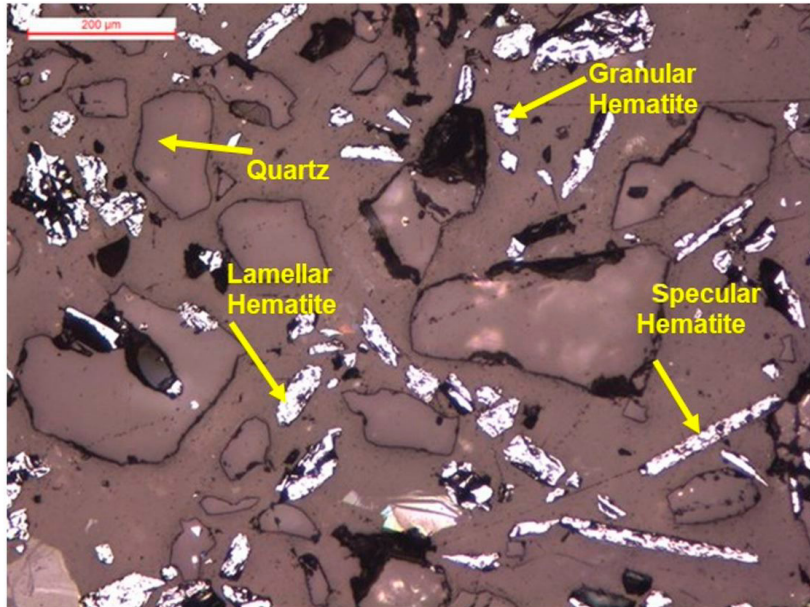
3.4. Bench flotation

In the bench flotation testes, 30 experiments tests were carried out, using 10 different collectors, and varying the specific collector dosage (90 g/t, 100 g/t and 110 g/t). All the other process variables were fixed so that there would be no inconsistency in evaluating the results.

The results of the iron content in the tailings (Fig. 3), measured through chemical analysis, indicate that the best results were obtained in the tests with Collector B at a specific dosage of 90 g/t, with 19.8% Fe content; Collector C at a specific dosage of 110 g/t, which showed 21.3% Fe content and Collector C at a dosage of 90 g/t, which obtained the best result in this regard, 18.9% Fe content. Industrially, the upper limit for iron content in the flotation tailings from the Cauê plant is 23%. Values above this level have a considerable impact on the performance of the magnetic separation stages, generating richer

final tailings from the plant and, consequently, reducing overall metallurgical recovery. Based on the iron content in the tailings shown in Fig. 3, 5 tests carried out at this stage indicate the potential for industrial replication.

Looking at the silica content in the concentrate, shown in Fig. 4, the best performances were observed in the tests with Collector B at a specific dosage of 100 g/t, with a SiO₂ content of 1.9%, Collector B at a specific dosage of 110 g/t, which had a SiO₂ content of 1.4% and Collector E, at a specific dosage of 110 g/t, with a SiO₂ content of 2.3%.



Hematite distribution (%)				Quartz distribution (%)			Porosity (%)	Caption SH = Specular hematite LH = Lamellar hematite GH = Granular hematite SiH = Sinuos hematite	FQ = Free quartz MQ = Mixed quartz KA = Kaolinite
SH	LH	GH	SiH	FQ	MQ	KA			
31.35	50.79	17.70	0.16	97.75	1.60	0.64	19.76		

Fig. 2. Photomicrograph of the Cauê flotation feed

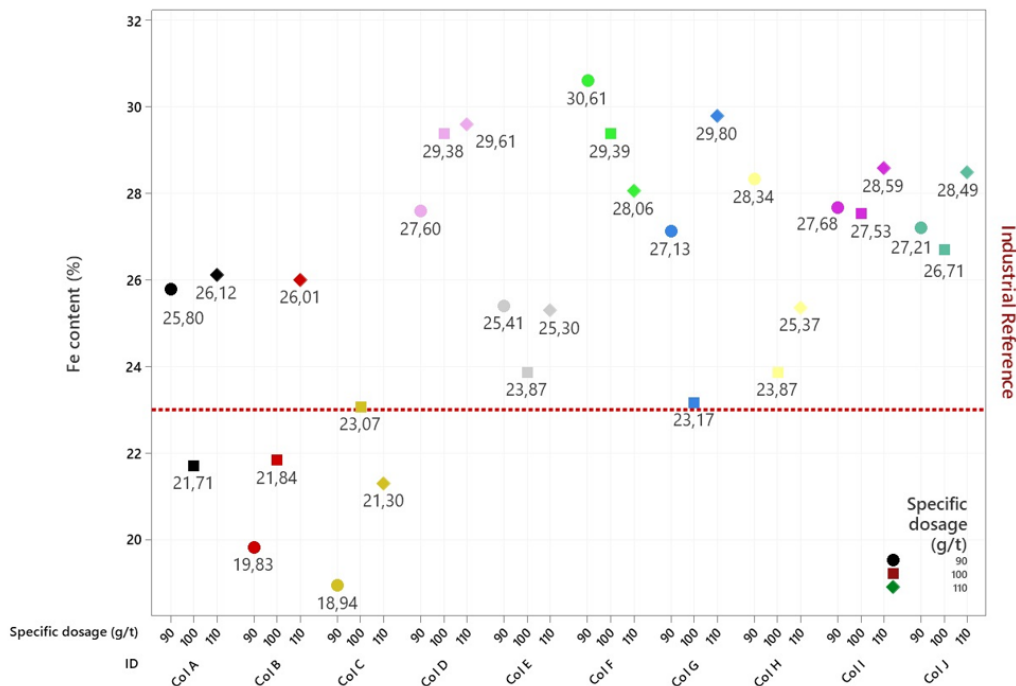


Fig. 3. Iron content in the tailings, for tests with each collector at different specific dosage

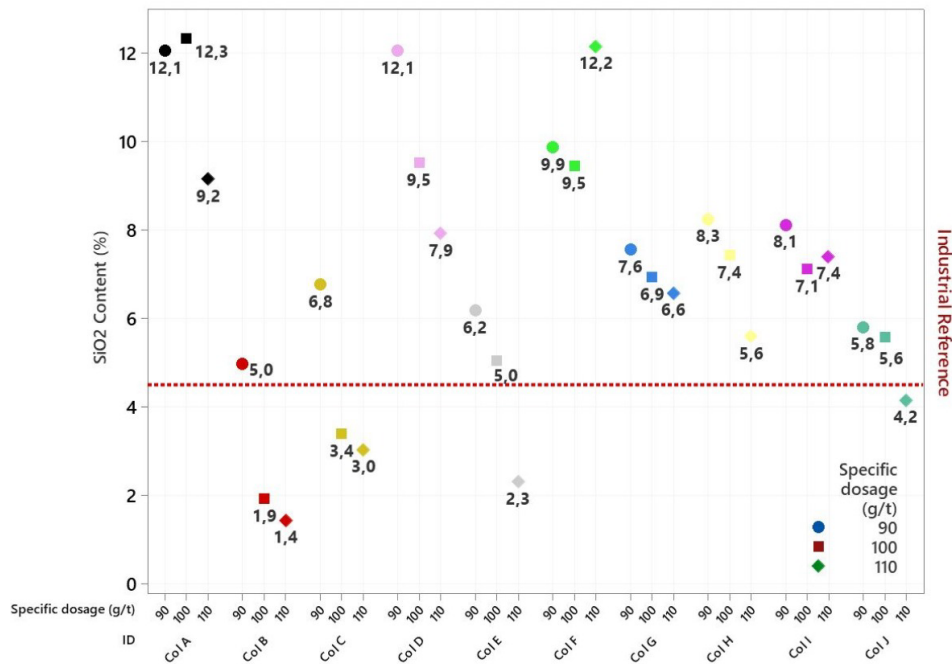


Fig. 4. Silica content in the concentrate, for tests with each collector at different specific dosage

On an industrial scale, the upper limit for SiO₂ content in the flotation concentrate from the Cauê plant is 4.5%. Contents above this threshold make the production of pellet feed unfeasible in terms of quality, because even if the concentrate is sent for high-frequency sieving, the product would still be outside Vale's internal market specification (<1.1% SiO₂ for direct reduction <2.5% SiO₂ for blast furnace). Analysing results in Fig. 5, 5 conditions indicated better results than that obtained industrially, including the results from Collector C, with 3.0% and 3.4% SiO₂ content for 100 g/t and 110 g/t, respectively.

Considering the metallurgical recovery data, it can be seen that the best results were achieved in tests with Collector B at a specific dosage of 90 g/t, with 72.3%, Collector C at a specific dosage of 90 g/t, 74.8% and Collector A at a specific dosage of 100 g/t, with 71.2%.

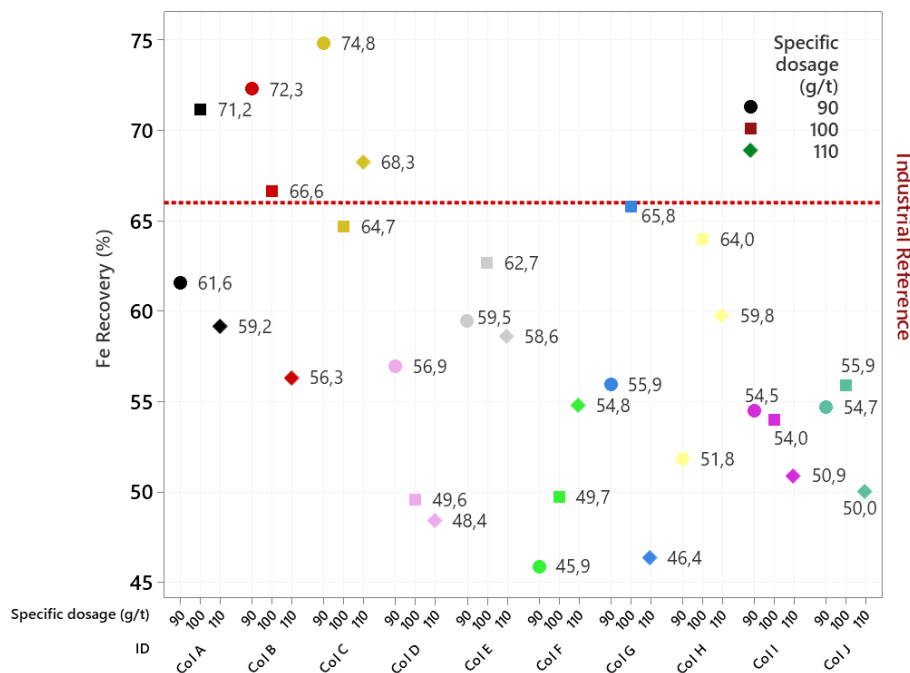


Fig. 5. Metallurgical recovery, for tests with each collector at different specific dosage

The metallurgical recovery benchmark for Cauê flotation is 66%. Values below this limit indicate disturbances in the process, either in the previous stages (grinding and desliming) or even in the flotation itself. Regarding this parameter, 5 tests showed promising results, including those obtained for Collector B at 100 g/t and Collector C at 110 g/t.

Analysing the Gaudin selectivity index (GSI), the most promising results were found in tests with Collector B at a specific dosage of 100 g/t, with GSI of 10.4 and 110 g/t with GSI of 10.5; in addition to Collector E, at a specific dosage of 110 g/t, which obtained a selectivity index of 8.4.

The Gaudin selectivity index reference for industrial Cauê flotation is 6.5. Values below this level indicate flaws in the settings of the process variables. Considering the results in Fig. 6, 6 tests carried out at specific dosages were superior to the industrial reference, including tests with Collector C, at 100 and 110 g/t, and Collector B, at 90 g/t.

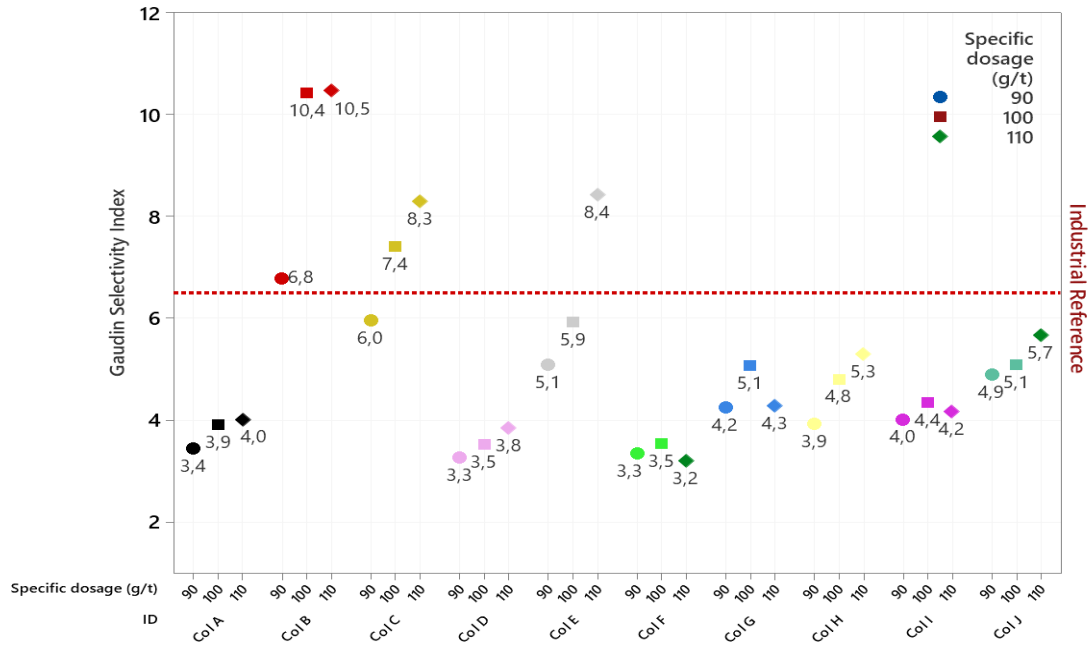


Fig. 6. Gaudin Selectivity, for tests with each collector at different specific dosage

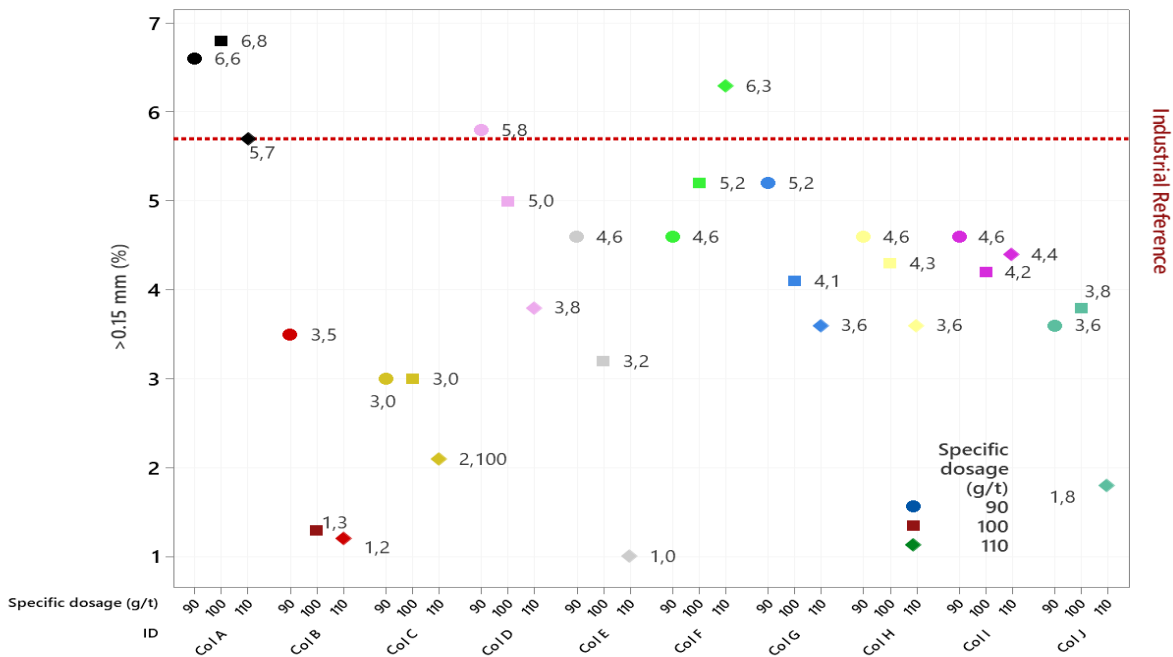


Fig. 7. Oversize (>0.150 mm) in the iron ore concentrate, for each collector at different dosages

Particle size analyses of the iron ore concentrate were also carried out, showing that the tests with the greatest capacity for collecting coarse particles were Collector E at a specific dosage of 100 g/t, with 1.0%, Collector B at a specific dosage of 110 g/t, which had 1.2% >0.150 mm and Collector B at a specific dosage of 100 g/t, with a 1.3% oversize. The results in Fig. 7 also show that Collector C performs promisingly, displaying 0.150 mm oversize of 2.1 % and 3.0%.

Industrially, coarse particle sizes in iron ore concentrates show a greater presence of quartz than finer particles size ranges. As the collectors' power to remove coarse particles (>0.150 mm) from the concentrate was evaluated in Fig. 7, a correlation analysis was carried out to assess the influence of particle size on the SiO₂ content in the concentrate and unveils the collectors' role in coarse quartz flotation and their potential to improve the iron ore concentrate. The R² of 89.9% showed that the SiO₂ content in the concentrate is directly proportional to the particle size (Fig. 8), indicating that the contamination in the ore presents larger particle size than the valuable minerals. These results prove that, along with the reduction in the 0.150 mm oversize, the collectors B, C and E also greatly reduce the coarse quartz content in the iron ore concentrate.

It can be seen from the interval graph in Fig. 9 that the non-neutralized collectors showed greater collection power for coarse particles. Collectors with a degree of neutralization between 10 and 30% showed similar particle collection capacity. Finally, the collector with 50% neutralization proved to be inefficient at collecting coarse quartz particles.

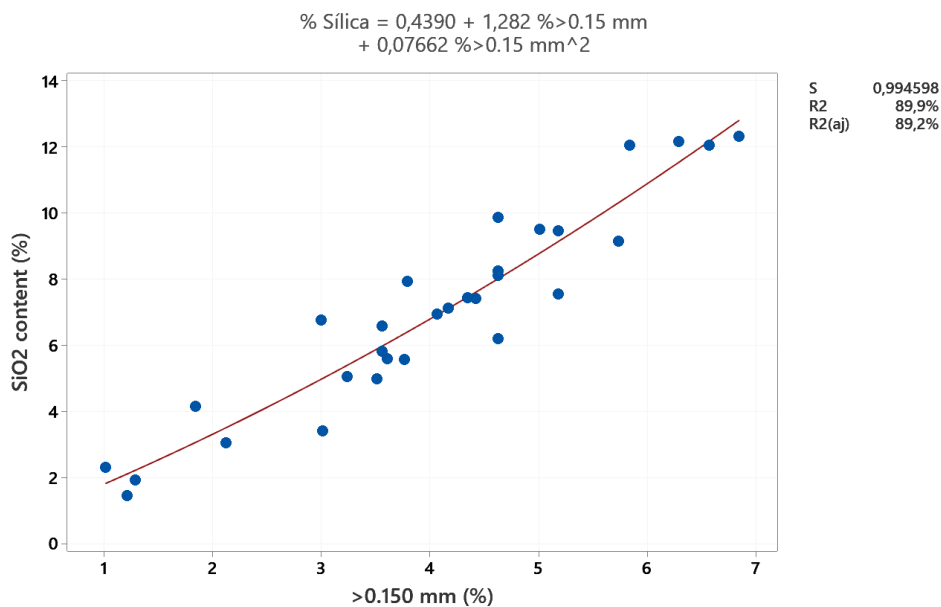


Fig. 8. Correlation between SiO₂ content and particle size in the iron ore concentrate

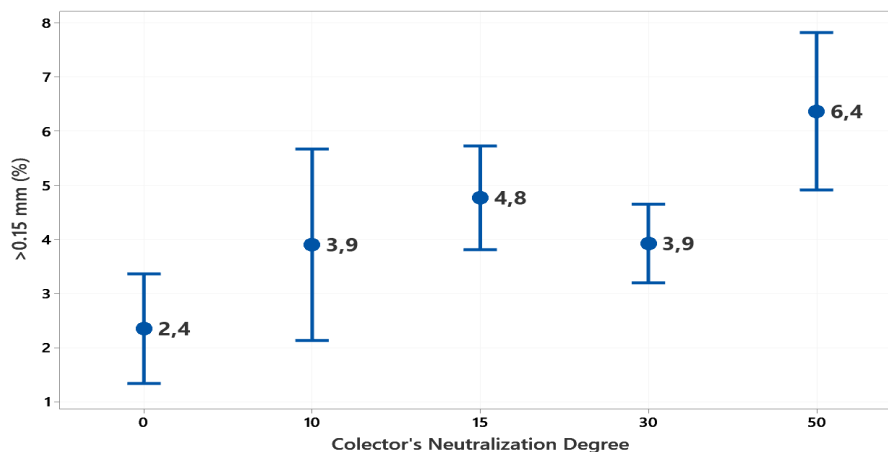


Fig. 9. Oversize (>0.150 mm) in the concentrate as a function of collector neutralization degree. Error bars with 95% CI

The interval graph regarding the effect of collector dosage (Fig. 10) shows, as expected, that the tests with the highest collector specific dosage present the greatest potential to reduce coarse particles (mostly quartz) in the concentrate, which is a result of greater recovery of coarse quartz particles in the froth. The significant variability indicated by the error bars is expected, as each specific dosage aggregates the results of all 10 collectors and Figs. 3 to 9 indicated that these reagents present different collecting power for coarse quartz.

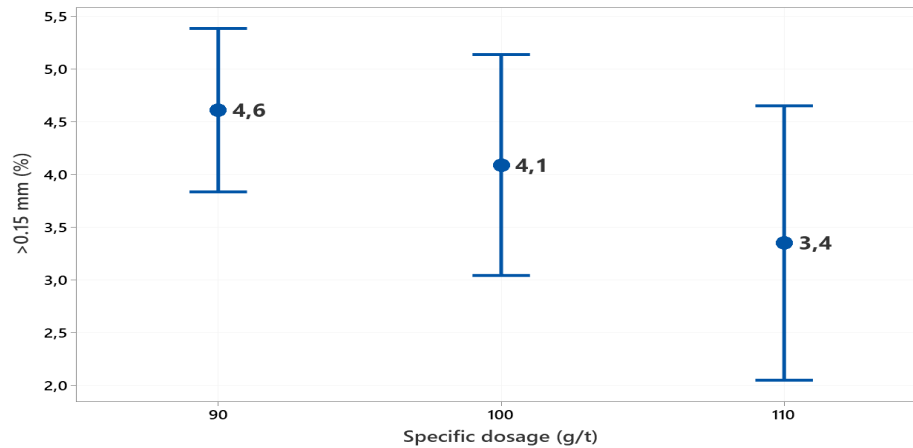


Fig. 10. Oversize (>0.150 mm) in the concentrate as a function of collector specific dosage. Error bars with 95% CI

4. Discussions

In the flotation of coarse particles, ethermonoamines are said to be more selective in the pH range from 9.5 to 10.5, where the quartz surface is highly negative, with the greatest difference in surface charges between hematite and quartz (Numela & Iwasaki, 1986). These molecules are also reported to be more powerful collectors and more selective frothers than etherdiamines, generating more hydrodynamic motion and dragging more water to the foam (Matos et al., 2022; Matos et al., 2022a). This can be negative features for the flotation of fine particles; however, it can reduce particle-bubble detachment, which is regarded as the main reason for the decreased recovery of coarse quartz particles in cationic iron ore flotation (Vieira & Peres, 2015). In this regard, the flotation tests were performed at the more selective conditions to float coarse quartz particles, at pH 9.8 and using ethermonoamines.

The results observed for Fe content in the tailings, SiO₂ content in the concentrate, Fe recovery, and Gauding Selectivity Index indicate that the overall performance of non-neutralized collectors (B and C) showed improvements for the itabirite iron ore flotation, compared to the industrial practice reference (Flotigam 7100, with degree of neutralization of 50%). The degree of neutralization of etheramines significantly impact iron ore flotation performance, which has been explained by the influence of neutralization on the collector ionization behaviour (Magriotis, 1995). Although collector speciation is driven by the pulp pH during conditioning and flotation, a previous neutralization is expected to interfere in this process due to the short conditioning time, leading to different amounts of molecular and ionic ethermonoamine available in the system. While the ionic species are expected to adsorb at the solid-liquid interface, working as collector, the molecular species preferably adsorbs at the liquid-air interface, having a frother role (Matos et al., 2022; Matos et al., 2022a; Matos et al., 2022b). Both species are also reported to adsorb at the solid-liquid interface as ionomolecular compounds, in a synergistic process which can reduce repulsion of cationic amine molecules and improve the stability of the hydrophobic layer (Pattanaik & Venugopal, 2018; Nunes et al., 2019). As the ionomolecular complexes present high activity between pH 9 and pH 11 (Finch & Smith, 1973) and the experiments were performed at pH 9.8 in this work, the degree of neutralization should impact the collector speciation and, consequently, the role of ionomolecular complexes in the stabilization of coarse quartz particles and detachment during transport to the froth.

Since ethermonoamines also play the role of frother in the cationic reverse flotation of iron ores, the non-neutralized collector could favour the presence of molecular species and influence bubble size, favouring bubble-particle collision, and the collection and recovery of quartz particles in the froth

(Matos, 2022). Furthermore, coarse quartz particle recovery decreases almost linearly with increasing froth height due to increased detachment particles in the froth phase (Safari et al., 2020), which is dependent on frother properties and concentration.

In general, the Gaudin selectivity index increases with increasing collector dosage, especially in the tests with a specific dosage of 110 g/t, which achieved the greater amount of quartz removed to the froth. Also, as expected, hematite loss and quartz recovery increase with increasing collector dosage. The increase in the recovery of quartz is higher than the corresponding increase in hematite loss. This increment is because increasing collector dosage results in a more remarkable increase in mass recovery, as quartz recovery is due to true flotation whereas hematite loss is primarily due to entrainment. The recovery of quartz is relatively constant up to around 150 μm . After this point, it decreases significantly, as commonly observed in the literature (Vieira & Peres, 2015). However, increasing collector dosage significantly affects both the coarser quartz and hematite particles, with coarse quartz recovery increasing by 30%. This outcome is probably due to the increased hydrophobicity of coarser quartz particles, resulting in less bubble particle detachment (Safari, 2022).

5. Conclusions

This study investigated the potential of new commercial collectors for applications in the reverse cationic flotation of coarse quartz. In tests with different specific collector dosages, the non-neutralized ethermonoamines showed enhanced performance compared to collectors currently used industrially, with 50% neutralization. Metallurgical recovery was, on average, 17% higher in the tests using non-neutralized collectors, which were also able to float 62% more coarse quartz particles than the other ethermonoamines studied.

Also, the tests with the highest specific dosage (110 g/t) showed, on average, better concentrate quality and, consequently, greater power to recover coarse quartz particles in the tailings, compared to the tests with the lowest specific collector dosage. Increasing collector dosage results in an increase in quartz recovery, particularly for the coarser quartz where recovery increases by nearly 38%.

The use of industrially non-neutralized ethermonoamines shows substantial technical potential. The study indicates the possibility of reducing the specific dosage compared to neutralized ethermonoamines, as well as optimizing the operation of high-frequency sieves currently used to remove coarse quartz from the concentrate.

Acknowledgments

The authors are thankful for the technical support from the Universidade Federal de Minas Gerais (UFMG), the Curso de Especialização em Engenharia de Recursos Minerais (CEERMIN) and Vale.

References

- DANKWAH, J. B., ASAMOAH, R. K., ZANIN, M., & SKINNER, W., 2022. *Influence of water rate, gas rate, and bed particle size on bed-level and coarse particle flotation performance*. Minerals Engineering, 183, 107622.
- DING, S., YIN, Q., HE, Q., FENG, X., YANG, C., GUI, X., & XING, Y., 2023. *Role of hydrophobic fine particles in coarse particle flotation: An analysis of bubble-particle attachment and detachment*. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 662, 130980.
- FILIPPOV, L. O.; SEVEROV, V. V; FILIPPOVA, I. V., 2014. *An overview of the beneficiation of iron ores via reverse cationic flotation*. International Journal of Mineral Processing, 127.
- FINCH, J. A., & SMITH, G. W., 1973. *Dynamic surface tension of alkaline dodecylamine solutions*. Journal of Colloid and Interface Science, 45 (1), 81-91.
- GlobalData. (2023, August 28). *Brazil Iron Ore Mining Market by Reserves and Production, Assets and Projects, Fiscal Regime including Taxes and Royalties, Key Players and Forecast, 2021-2026*. <https://www.globaldata.com/store/report/brazil-iron-ore-mining-market-analysis>.
- KAPIAMBA, K.F., KIMPIAB, M., 2021. *The Effects of Partially Replacing Amine Collectors by a Commercial Frother in a Reverse Cationic Hematite Flotation*. Heliyon, 7, 1-8.
- MAGRIOTIS, R. S., 1995. *Efeito do tipo de amina na flotação catiônica reversa de um minério itabirítico*. Master's thesis Federal University of Minas Gerais. 75p.

- MATOS, V. E., 2017. *Reagent selectivity in iron ore reverse flotation*. Master's thesis Federal University of Minas Gerais. 116p.
- MATOS, V. E., 2022. *Froth properties in cationic flotation performance flotation of iron ore*. Doctoral dissertation Federal University of Minas Gerais. 131p.
- MATOS, V. E., NOGUEIRA, S. C., SILVA, G. R., & PERES, A. E., 2022. *Effects of surfactants combination on iron ore flotation*. *Minerals Engineering*, 190, 107910.
- MATOS, V. E., NOGUEIRA, S. D. C. S., KOWALCZUK, P. B., SILVA, G. R. D., & PERES, A. E. C., 2022a. *Differences in etheramines froth properties and the effects on iron ore flotation. Part I: Two-phase Systems*. *Mineral Processing and Extractive Metallurgy Review*, 43(2), 209-216.
- MATOS, V. E., NOGUEIRA, S. D. C. S., SILVA, G., KOWALCZUK, P. B., & PERES, A. E. C., 2022b. *Differences in etheramines froth properties and the effects on iron ore flotation. Part II: three-phase systems*. *Mineral Processing and Extractive Metallurgy Review*, 43(2), 243-250.
- NAZARI, S., & HASSANZADEH, A., 2020. *The effect of reagent type on generating bulk sub-micron (nano) bubbles and flotation kinetics of coarse-sized quartz particles*. *Powder Technology*, 374, 160-171.
- NUMELA, W.; IWASAKI, I., 1986. *Iron ore flotation*. In: *Advances in Mineral Processing*. Colorado: Ed. Littleton, SME.
- NUNES, A. P. L., PERES, A. E. C., CHAVES, A. P., & FERREIRA, W. R., 2019. *Effect of alkyl chain length of amines on fluorapatite and aluminium phosphates floatabilities*. *Journal of Materials Research and Technology*, 8 (4), 3623-3634.
- PATTANAİK, A., & VENUGOPAL, R., 2018. *Investigation of adsorption mechanism of reagents (surfactants) system and its applicability in iron ore flotation—an overview*. *Colloid and Interface Science Communications*, 25, 41-65.
- PEARSE, M. J., 2005. *An overview of the use of chemical reagents in mineral processing*. *Minerals Engineering*, 18, 139-149.
- PERES, A. E. C., SALUM, M. J. G., VALADÃO, G. E. S., ARAUJO, A. C., 2007. *Métodos de concentração*. In: VALADÃO, G. E. S. (Org.); ARAUJO, A. C. (Org.). *Introdução ao tratamento de minérios*. Belo Horizonte: Editora UFMG, Cap. 6.
- RAHMAN, R. M., ATA, S., & JAMESON, G. J., 2012. *The effect of flotation variables on the recovery of different particle size fractions in the froth and the pulp*. *International Journal of Mineral Processing*, 106, 70-77.
- SAFARI, M., HOSEINIAN, F. S., DEGLON, D., LEAL FILHO, L. S., & PINTO, T. S., 2020. *Investigation of the reverse flotation of iron ore in three different flotation cells: Mechanical, oscillating grid and pneumatic*. *Minerals Engineering*, 150, 106283.
- SAFARI, M., HOSEINIAN, F. S., DEGLON, D., LEAL FILHO, L., & PINTO, T. S., 2022. *Impact of flotation operational parameters on the optimization of fine and coarse Itabirite iron ore beneficiation*. *Powder Technology*, 408, 117772.
- USGS. (2023, August 28). *Iron Ore Statistics and Information*. <https://www.usgs.gov/centers/national-minerals-information-center/iron-ore-statistics-and-information>.
- VIEIRA, A. M.; PERES, A. E. C., 2007. *The effect of amine type, pH, and size range in the flotation of quartz*. *Minerals Engineering*, 20, 1008-1013.
- VIEIRA, A.M., PERES, A.E.C., 2015. *Influência de variáveis de flotação na recuperação de quartzo fino, médio e grosso*. Encontro Nacional de Tratamento de Minérios e Metalurgia Extrativa. Belo Horizonte.
- XU, D., AMETOV, I., & GRANO, S. R., 2012. *Quantifying rheological and fine particle attachment contributions to coarse particle recovery in flotation*. *Minerals Engineering*, 39, 89-98.
- XU, D., AMETOV, I., & GRANO, S. R., 2011. *Detachment of coarse particles from oscillating bubbles – The effect of particle contact angle, shape and medium viscosity*. *International Journal of Mineral Processing*, 101 (1-4), 50-57.