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# Performance of Low-Molecular Weight Cationic Polymers in Iron Ore Flotation

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ABSTRACT

The depressant action of three cationic polymers of low molecular weight (with oxygenated carbonyl functional groups, esterified oxygen and nitrogen atoms, classified as polyamine-polyamides) in flotation of iron ore was investigated and compared with the performance of the traditional starch/amine system. Dosing of starch and amine and pH value was firstly adjusted in laboratory tests with flotation cell. Laboratory tests were also performed by partially replacing starch by the cationic polymers and also by adding small dosages of them to the starch/amine adjusted condition. The cationic polymers showed lower performance relative to the traditional starch/amine system when partially replacing starch. However, gains of up to 4% in mass and metallurgical recoveries were obtained when they were added to the adjusted starch/amine system. This is probably due to adsorption of cationic polymers to the surface of iron oxides via hydrogen bonds and dipole-dipole interaction, added to synergistic effects with starch molecules. Two pilot tests were performed with column flotation, the first one with the starch/amine system adjusted in laboratory, and the second one by adding 70 g/ton of the cationic polymers with the best performance in laboratory tests. The gains by using cationic polymers were also observed in pilot scale.

***Keywords: iron ore, flotation, and depressant.***

## 1. INTRODUCTION

Cationic reverse flotation of iron ore under alkaline conditions using amine as silicate gangue collector and starch as depressant of iron oxides is used since 1960 (Houot, 1983). Starch, especially from corn, is traditionally used in industrial iron ore concentration plants (Chaves, 2006), because of its great depressant and flocculants performance. Moreover it is biodegradable, stable, non-toxic, generally inexpensive, and very available. Many studies have attempted or are attempting to partially or totally replace corn starches in this process, especially the use of starches from other sources, modified starches, polyacrylamide, carboxymethyl cellulose, guar gum, lignosulfonate, etc. (Castroet al., 2005; Souza et al., 2010; Araujo et al., 2008). According to Prasad (1992) depressants are compounds that increase the interaction of mineral particles not desired to float with water molecules and inhibits adsorption of collector, keeping the hydrophilicity (wettability) required for particles to remain in contact with the aqueous phase. Therefore, they are selectivity agents of utmost importance between oxides-hydroxides of iron and quartz. Mechanisms governing the adsorption of organic depressants on mineral surfaces include electrostatic interactions, hydrogen and covalent bonds, and formation of metal-depressant complexes (Prasad 1992).Nunes and Peres (2011) showed that organic agents have within their structures highly hydrophilic polar groups such as -OH and -COOH, which are directed toward the aqueous phase, rendering the adsorbate hydrophilic. Effects attributed by Hanna and Somasundaran (1976) to flotation depressants are: reduction of collector adsorption on the surface covered by the depressant layer; modification of surface properties of minerals, such as adsorption capacity and zeta potential; and modifying the chemical composition of the pulp.Depressants studied in this paper are cationic polymers of low molecular weight, containing functional oxygen carbonyl groups, etherified oxygen and nitrogen, classified as polyamine-polyamides (Figure 1).The depressing effect on iron minerals is due to their unique chelating action on Fe2+ions and Fe3+ (Souza et al., 2010; Xu et al., 2012). Adsorption on the surface of iron minerals is the result of hydrogen bonds and dipole-dipole interactions, added to the likely synergistic effects with starch molecules.Souza et al. (2010) and Araujo et al. (2008) showed gains in flotation performance of different iron ore samples using cationic polymers of low molecular weight as co-depressants weight as co-depressants.

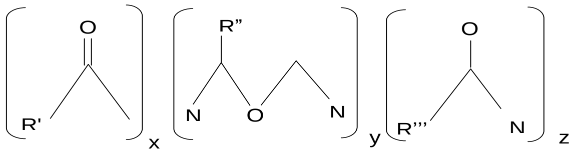

**Figure 1 - General formula of cationic polymer of low molecular weight.**

## 2. MATERIALS AND METHODS

### 2.1. Materials

The ore sample was a friable banded iron formation from an industrial plant in QuadriláteroFerrífero, Minas Gerais, Brazil. It was received comminuted and deslimed.

The collector agent used was Flotigam EDA (monoamine ether) supplied by Clariant.The depressant used was Flotamil 75 (corn starch) supplied by Caramuru. The cationic polymers of low molecular weight were Talon® 6515, GPR-855 e GPR-860 supplied by Georgia Pacific. Sodium hydroxide solution was used as pH regulator.

### 2.2. Methods

The iron ore sample was mineralogical, chemical, and granulometrically characterized. Semi-quantitative mineralogical analysis was performed by X-ray diffraction using a Rigakudiffractometer of D/MAX-ULTIMA. Chemical characterization (Fe and SiO2) was performed by X-ray fluorescence (EDX-720 spectrometer, Shimadzu).Particle size analysis included combined wet and dry sieving for classification of particles between 37 and 210 □m. The fraction smaller than 37 □m was analyzed in Cyclosizer.

Flotation tests were carried out in laboratory flotation cell (Darma) with samples of 1.0 kg.Pulps formed with 60% solids were conditioned for 5 minutes with Flotamil 75 and the respective co-depressants and then with Flotigam EDA for 3.0 minutes.After adjustment of the content of solids to 30% and correction of pH, aeration and collecting of floated fraction were performed for 7.0 minutes.Pilot flotation tests were performed in single stage using a column of 10.16 cm diameter and 4.6 m height. A feeding rate of 80 kg/h, pH 10.5, and superficial air velocity of 1.0 cm/s were used, the percentage of solids in conditioning was 60% and in flotation was 45%.The dosages werethe same of the laboratory tests, i.e., 800 g/ton Flotamil 75, 70 g/ton Flotigam EDA, and 70 g/ton Talon® 6515.Several samples of the feeding and output were collected formass and metallurgical balances. Figure 2 shows the rougher flotation circuit flowsheet employed

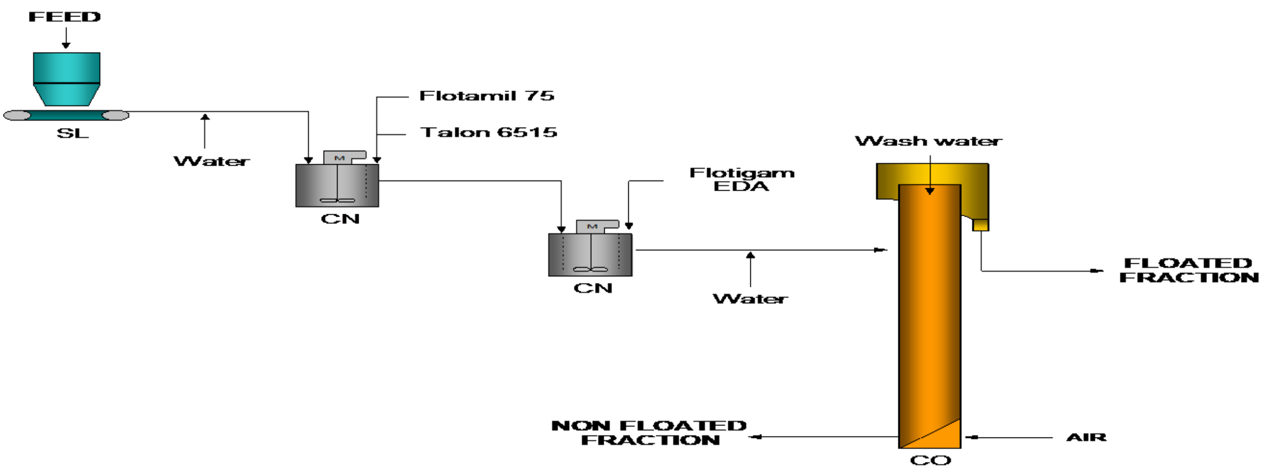


**Figure 2 -Rougher flotation circuit flow sheet.**

**Gaudin selectivity index, SI, was calculated by**

$$SI = \left(\frac{(R_{Fe} \, . \, R_{SiO_2})}{(100 - R_{Fe}).(100 - R_{SiO_2})}\right)^{0,5}$$

Where $R_{Fe}$ is iron recovery in concentrate and $R_{SiO_2}$ is silica recovery in waste.

## 3. RESULTS AND DISCUSSION

### 3.1 Sample characterization

X-ray diffraction of the ore sample identified hematite (predominant) and quartz.Figure 3 shows the results of the chemical analysis of the iron ore sample, 83% Fe2O3 (58% Fe) and 12% SiO2.The particle size distribution (Figure 4) shows that only 8.0% of the particles are larger than 105 μm and 4.2% are smaller than 8.4 μm.

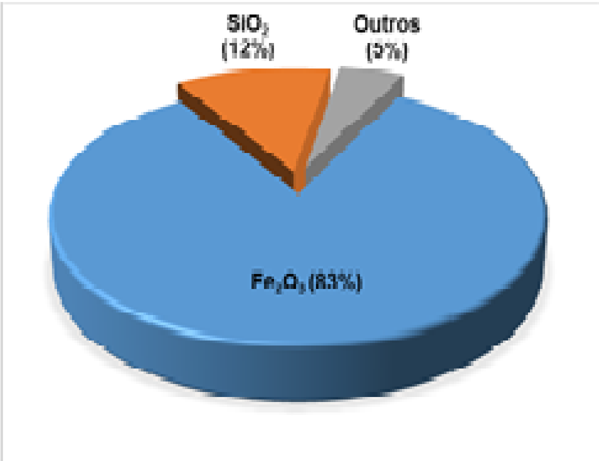


Figure 3 - Chemical composition of the iron ore sample

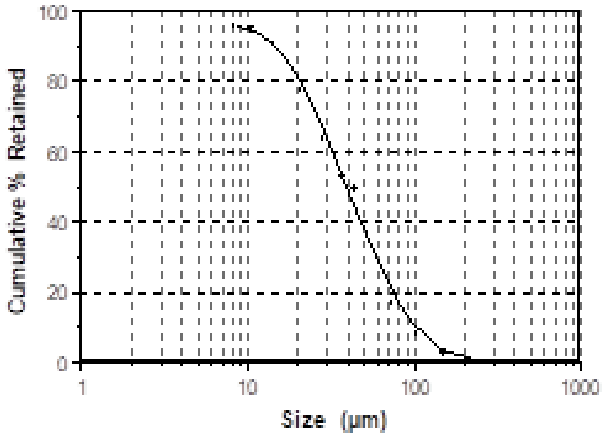


Figure 4 -Size distribution of the iron ore sample.

### 3.2 Flotation tests in laboratory

First, tests were carried out to optimize the dosages of Flotamil 75 and Flotigam EDA, as well as the pH, based on information of the mining company that supplied the iron ore sample. The variation of corn starch dosage (Figure 5) showed that increasing dosage resulted in a slight increase in Fe recovery. By increasing amine dosage (Figure 6), there was a reduction of SiO2grade in concentrate, and, of course, an increase in Fe grade in the concentrate, improving the selectivity of the process. There was also a small reduction in Fe recovery. Finally, as shown in Figure 7, the increase of pH from 10.0 to 11.2 has slightly changed the results. There for the best conditions were: dosage of 800 g/ton of corn starch, 70 g/ton of amine, and pH 10.5.Five tests were performed using these conditions. The mean grades in concentrate by weight were 66.7% Fe and 2.64% SiO2, and the mean recoveries were 78.9% mass and 91.3% Fe.The Gaudin selectivity index was 7.9.

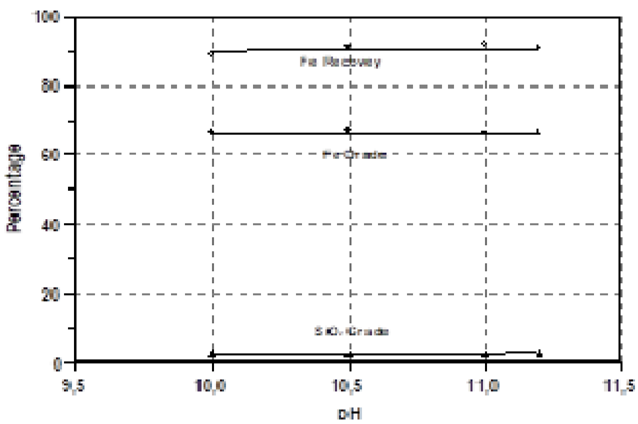


**Figure 7 – Effect of pH**

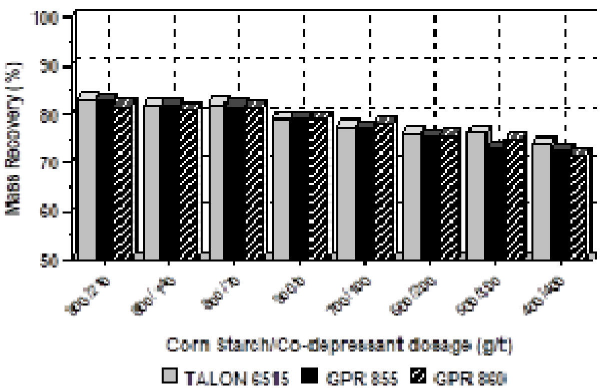


**Figure 8 - Mass recovery as a function of co-depressant type and dosage**

Figure 10 shows that the results of Fe grades in concentrate under different conditions were in the 66-67% range.Therefore, the addition or partial replacement of starch by co-depressants little changed this response variable.

Figure 11 shows SiO2grades in concentrate as a function of the type and dosage of co-depressants. In tests where the co-depressants partially replaced starch there was a reduction in SiO2grade in the concentrate, but not translated into a practical benefit due to reduction in recoveries. On the other hand, when co-depressants are added to the starch optimum dosage, there was an increase in the SiO2gradein concentrate. By adding 70 g/ton of co-depressant, there was no significant impairment in SiO2grade, resulting in increase in mass and metallurgical recoveries. Finally, Figure 12 shows the Gaudin selectivity index as a function of the type and dosage of depressant. It is noted that the partial replacement of the starch by co-depressants caused a reduction in selectivity and that the addition of these agents in the system increased the selectivity of the process.

Based on laboratory studies, only the addition of low molecular weight cationic polymer to the optimized conditions has resulted gains in mass and metallurgical recoveries, as well as in process selectivity.Probably, these gains stem from the chelating effect of these cationic polymers of low molecular weight to the surfaces of iron minerals, plus any likely synergistic effects with the starch molecules.Brandão (2005), explaining details of the selectivity in flotation of iron ore, proved via infrared spectrometry studies that the starch absorbs preferably in iron minerals. It plays as depressant, selectively giving hydrophilic properties to iron minerals, as well as flocculants. Once this flotation is reversed, i.e. quartz is floated and iron oxides are depressed, the selective flocculation contributes to a better performance of the process.

### 3.3 Pilot flotation tests

Two long-term pilot tests were performed in flotation column based on results of the laboratory studies. The T1 test was carried out in optimized condition. In T2 test 70 g/ton of Talon® 6515 was added to the reagent system. The results, shown in Table 1, confirm those obtained in laboratory studies. There was a gain in mass and Fe recoveries, as well as on the process selectivity, when Talon® 6515 was added, without impairing the quality of the concentrate.

The results of this study, both laboratory as pilot, confirm those obtained by Souza et al. (2010) and Araujo et al. (2008) with different samples of iron ore. These authors reported gains in performance of flotation using co-depressants. However, the good results obtained in this study were only achieved when the co-depressants were added to the optimum flotation condition and not when partially replacing starch, as reported by Souza et al. (2010).

**Table 1 - Results of pilot tests in flotation column**

| Test | Co-depressant (g/ton) | Grade (%) | | | | Recovery (%) | | SI |
|---|---|---|---|---|---|---|---|---|
| | | Concentrate | | Waste | | | | |
| | | Fe | $SiO_2$ | Fe | $SiO_2$ | Mass | Fe | |
| T1 | - | 67,19 | 1,66 | 20,56 | 63,73 | 74,2 | 90,4 | 11,2 |
| T2 | Talon® 6515 (70 g/ton) | 67,19 | 1,76 | 13,68 | 72,79 | 78,0 | 94,6 | 14,3 |

## 4. CONCLUSION

This study, conducted in laboratory and complemented on pilot scale, evaluated the performance of low molecular weight cationic polymers as co-depressants in reverse flotation of a sample of iron oreflotation from QuadriláteroFerrífero, Minas Gerais, Brazil. These reagents partially replaced corn starch or were added in small dosages to an optimized reagent system. The partial substitution of starch by the co-depressants led to losses in mass and iron recoveries, as well as in selectivity. Moreover, significant gains in mass and Fe recoveries (about 4%) without loss of the concentrates chemical specification were obtained when they were added in small dosages together with corn starch depressant. The selective depressant effect observed on iron particles generated by cationic polymers of low molecular weight arises probably from chelating action on the Fe2+ ions and Fe3+, added to synergistic effects with starch molecules, resulting in gains in performance of flotation.

## 5. ACKNOWLEDGEMENTS

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