

SYNERGIC COMBINATION OF DEPRESSANTS FOR IRON ORE FLOTATION ¹

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Abstract

The present work describes the effect of combining depressants to enhance selectivity and recovery in the reverse cationic flotation of iron ores. Cationic reverse flotation of iron ores employs starches and their derivatives as selective depressants during the amine flotation of quartz at alkaline pH conditions. A novel polymeric depressant added in conjunction with starch can improve overall flotation performance. The current work is based on several bench scale test programs carried out with three separate iron ore samples from the Iron Ore Quadrangle of Minas Gerais State. These programs were initially aimed at selecting the novel polymer that would be adequate for this application. After selection of the best co-depressant, confirmation tests were performed to investigate the effect of the ratio of mixing starch and the alternative depressant in order to secure the best possible results for the flotation separation of a typical itabiritic iron ore sample. The results obtained in the present investigation show that combination of the novel co-depressant with traditionally used cornstarch improved both iron recovery and the selectivity at economically attractive ratios and dosages. The results tend to show that a relatively small participation of the novel co-depressant adds percentage points of gain in iron recovery at similar or improved selectivity levels. The novel reagent is non-toxic, biodegradable and is very soluble in water, which potentially will also reduce sodium hydroxide consumption during starch gelatinization.

Key words: Flotation; Depressants; Iron ore.

COMBINAÇÃO SINÉRGICA DE DEPRESSORES NA FLOTAÇÃO DE MINÉRIOS DE FERRO

Resumo

O presente trabalho descreve o efeito de combinar depressores para melhorar a seletividade e a recuperação na flotação catiônica reversa de minério de ferro. A flotação catiônica reversa de minérios de ferro emprega amidos e seus derivados como depressores seletivos durante a flotação de quartzo com amina em condições alcalinas de pH. Um novo depressor polimérico, adicionado em conjunto com amido pode melhorar o desempenho global desse sistema de flotação. O presente trabalho é baseado em diversos programas de testes realizados com três amostras de minério de ferro do Quadrilátero Ferrífero de Minas Gerais. As campanhas de teste procuraram selecionar primeiro o melhor depressor para o sistema em estudo. Depois da seleção, testes de confirmação foram feitos com o melhor co-depressor, investigando-se então as melhores relações de mistura do depressor com amido para a maximização do desempenho do sistema de separação de minério de ferro por flotação catiônica reversa. Os resultados obtidos tendem a mostrar que mesmo com uma participação relativamente baixa do novo depressor na mistura com amido ganhos significativos de recuperação de ferro com níveis similares ou superiores de seletividade foram alcançados. O novo reagente depressor não é tóxico, é biodegradável e muito solúvel em água o que potencialmente poderá reduzir o consumo de hidróxido de sódio na preparação do amido por gelatinização química.

Palavras-chave: Flotação; Depressores; Minérios de ferro.

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INTRODUCTION

Iron ores need to be processed in order to reach required chemical and physical specifications. High-grade ores, which are becoming everyday more difficult to find, generally require only size classification in order to meet market standards. Lower grade ores, especially those with mineral liberation taking place only at size ranges below 0.15 to 0.106mm (100# to 150# Tyler), when hematitic in nature, are generally processed by reverse cationic flotation of gangue minerals, mostly quartz. High-grade concentrates (generally known as pellet feed fines), amenable for pelletizing, can be achieved. Selective separation by flotation of iron oxides from siliceous gangue is obtained by employing a combination of chemicals that necessarily include a depressant, a collector and a pH modifier.⁽¹⁻⁴⁾ Other reagents, as frothers, may also be required and are sometimes employed.⁽⁵⁻⁶⁾

Starches and products derived from starch represent a well-established industry practice for depressant selection in cationic reverse flotation of iron ores. Discussion on the mechanism of action of starches in iron ore flotation systems can be found elsewhere.⁽⁷⁻¹⁵⁾ In summary, starches act by their ability to adsorb preferentially onto iron oxide particles making these surfaces unfit for successful adsorption of the collector species, general an etheramine, an etherdiamine or a combination of the two. For successful adsorption of a collector one should understand a surface concentration of surfactant species (ionic or, in many instances, a combination of ionic and non-ionic species) that transforms the particle surface character from hydrophilic to hydrophobic. The collector used in the reverse cationic flotation of iron ores, in the absence of a depressant like starch, would impart a certain degree of hydrophobicity to all mineral surfaces in the flotation pulp. Taking into account that hematite surfaces are generally transformed in a lesser extension by collector than quartz surfaces are (amines adsorb more strongly and extensively onto quartz surfaces than they do onto hematite surfaces), the required selectivity level for the separation is often not achieved without the help of a depressant.

MATERIALS, EQUIPMENT AND TECHNIQUES

Chemicals:

All tests employed the same collector, namely PA 14, which represents an acetate of etheramine supplied by Air Products (formerly Tomah). The collector was prepared weekly as a 1% aqueous solution (by weight) and stored in an electric refrigerator at 10°C.

Pure food-grade cornstarch ("*Maizena*" by Unilever) was also prepared at a concentration of 1% by weight after gelatinization with sodium hydroxide at a 4:1 weight ratio between cornstarch and sodium hydroxide (NaOH). Starch was prepared daily and solutions older than 4 hours were discarded.

Sodium hydroxide and hydrochloric acid were employed to modify pH are both reagent grade chemicals supplied by VETEC, Brazil.

Two samples of the alternative depressant were supplied by Georgia Pacific Resinas Internacionais Ltda., Jundiaí, Brazil. These samples were received as liquids and were prepared daily as 1% aqueous solutions that were labeled as GPR 850 and GPR 855. Both represent low molecular weight polymers that can be described generically as pertaining to the polyamide-polyamine family. GPR 855 possesses a lower viscosity than GPR 850. Figure 1 shows a generic representation of this type of reagent.

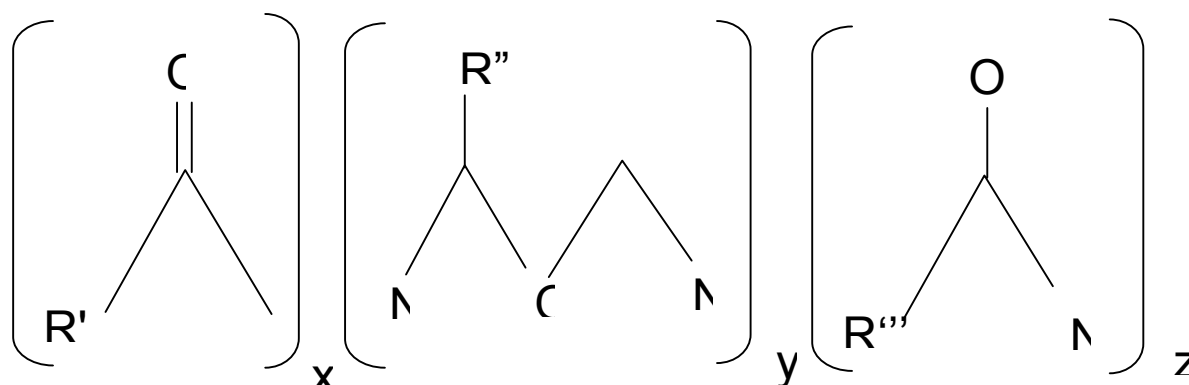


Figure 1 – Schematic representation of GPR depressant

From Figure 1 it is clear that this polymer presents a predominance of cationic sites.

Ore Samples:

Four different samples were employed. Three of them represent iron ores of various grades from mines located in the Iron Ore Quadrangle of Minas Gerais State, Brazil. The last sample is also an itabirite but from a deposit located outside the Iron Ore Quadrangle. Table 1 summarizes their chemical composition. Samples received the names of IB LG1, IB HG, IB LG2 and IB N LG3, with the letters standing for IB – itabirite, LG – low grade and HG – high grade. IB LG1 and IB HG were employed in a test program involving only GPR 850. The third sample, IB LG2 was used for the tests with combination of depressants. The fourth sample was tested only with GPR 855 and cornstarch in order to investigate conditioning time requirement.

Table 1 – Chemical characterization of ore samples

| Sample | %Fe | %SiO ₂ | %Al ₂ O ₃ | %P | %LOI |
|-----------|------|-------------------|---------------------------------|-------|------|
| IB LG1 | 51.8 | 22.15 | 1.02 | 0.037 | 1,61 |
| IB HG | 65.4 | 4.45 | 0.92 | 0.030 | 0.78 |
| IB LG2 | 46.8 | 32.00 | 0.26 | 0.016 | 0.45 |
| IB N LG 3 | 41.6 | 40.08 | 0.22 | 0.022 | 0.39 |

Techniques:

Laboratory batch flotation tests utilized a DENVER D-12 flotation machine. Test procedure was standardized throughout the program and flotation tests were carried out only as a rougher stage, unless otherwise noticed. Flotation was stopped only when no more froth could be collected. Airflow rate was kept constant at 5L/min in all tests. Rotational speed was set at a constant value of 1500 rpm. The order of adding chemicals was always depressant or depressants first and collector after. pH was adjusted after adding the depressants as well as just before airflow was initiated by employing NaOH or HCl 1% and 5% (by weight) aqueous solutions. After each test, floated and non-floated products were collected in trays, dried, weighed, sampled and pulverized as preparation for chemical analyses. Chemical assays were performed by X-ray fluorescence by a certified analytical laboratory (SGS Geosol, Belo Horizonte).

Measuring pH was accomplished employing a pH meter produced by Tradelab (model mPA-210) equipped with a combined glass electrode (KCl based). The equipment was calibrated before each set flotation tests against buffer solutions of

pH 7 and 10. Temperature was not controlled but varied only within the range from 20 to 25°C.

RESULTS AND DISCUSSION

Initially, GPR 850 was investigated as the sole depressant for flotation testing involving samples IB LG1 and IB HG. Cornstarch was used as the base case in all tests. Table 2 summarizes selected results.

Table 2 – Flotation testing with GPR 850 alone

| Depressant | Dosage (g/t) | Concentrate Yield (%) | Concentrate Grade | | Recovery of Fe (%) | Selectivity Index (FexSiO ₂) |
|----------------------|--------------|-----------------------|-------------------|----------------------|--------------------|--|
| | | | (%Fe) | (%SiO ₂) | | |
| SAMPLE IB LG1 | | | | | | |
| None | - | 42.2 | 67.5 | 1.00 | 54.9 | 8.10 |
| Cornstarch | 600 | 54.0 | 66.9 | 1.40 | 70.3 | 8.40 |
| GPR 850 | 300 | 44.0 | 66.5 | 1.60 | 55.5 | 6.04 |
| | 400 | 46.3 | 67.8 | 1.10 | 57.3 | 7.11 |
| | 500 | 48.7 | 67.5 | 1.00 | 60.2 | 7.72 |
| | 600 | 52.3 | 67.1 | 1.20 | 66.6 | 8.20 |
| SAMPLE IB HG | | | | | | |
| None | - | 46.9 | 68.1 | 0.86 | 48.9 | 3.10 |
| Cornstarch | 600 | 65.3 | 67.8 | 0.54 | 68.4 | 5.05 |
| GPR 850 | 300 | 54.9 | 67.5 | 0.91 | 56.3 | 2.92 |
| | 400 | 48.8 | 68.5 | 0.81 | 50.7 | 3.24 |
| | 500 | 66.2 | 67.4 | 1.20 | 68.2 | 2.97 |
| | 600 | 49.2 | 68.1 | 1.00 | 50.8 | 2.79 |

Test conditions: pH =10.5, 60g/t of collector (PA 14), 5 minutes conditioning of depressant, 1 minute for collector and RPM = 1500, rougher only.

The results shown in Table 2 demonstrated that the total replacement of starch by the new depressant would not be feasible. Similar results testing other Georgia Pacific reagents of the same family were reported by Tao (2007),⁽¹⁶⁾ when the same iron ore samples were tested at bench scale. For IB LG1 sample, at equal dosage of GPR 850 and cornstarch (600g/t), the results are similar but iron recovery still almost two percentage points below the level reached for starch. For the high grade itabirite sample although the recovery level of starch was almost reached for the test with 500g/t of GPR 850, inferior levels of selectivity were reached for the alternative depressant. The same trend was observed in experiments performed with GPR 855.

The second phase of the test program involved the combination of starch and the new depressant at different ratios. The main reason why the test program was not initiated by testing combination of both depressants is that the first successful application (inclusive of current industrial continuous use) of this new reagent involved the total replacement of another natural polymer – guar gum – in potash flotation with extremely good results (Tao and co-workers, 2007 and 2008).^(17,18)

Table 3 summarizes selected results obtained by the combined use of starch and GPR 855 on the bench scale flotation testing of sample IB LG2. All tests are rougher only and used 60g/t of collector (PA 14). Flotation was performed at pH 10.5. The results presented are, in most cases, average of two tests. The performance of GPR 855 was superior to GPR 850 and, for space limitations, only the results with the first were presented in this paper.

Table 3 – Flotation testing with GPR 855 in combination with starch.

| Depressant | Dosage (g/t) | Concentrate Yield (%) | Concentrate Grade | | Recovery of Fe (%) | Selectivity Index (FexSiO ₂) |
|-------------------------------------|----------------|-----------------------|-------------------|----------------------|--------------------|--|
| | | | (%Fe) | (%SiO ₂) | | |
| Cornstarch | 400 | 56.2 | 60.2 | 12.40 | 73.6 | 3.23 |
| | 600 | 52.6 | 65.7 | 5.63 | 73.5 | 5.26 |
| | 700 | 52.9 | 68.4 | 1.50 | 77.8 | 11.74 |
| Combination of GPR 855 + Cornstarch | 400+100 | 49.0 | 63.3 | 8.46 | 65.6 | 3.57 |
| | 600+100 | 49.8 | 64.3 | 7.86 | 66.9 | 3.80 |
| | 500+200 | 55.9 | 65.4 | 7.30 | 76.1 | 4.65 |
| | 300+200 | 51.1 | 67.0 | 2.48 | 70.8 | 7.36 |
| | 200+300 | 54.3 | 66.3 | 4.07 | 75.4 | 6.31 |
| | 400+300 | 54.9 | 67.1 | 3.95 | 77.8 | 6.90 |
| | 100+400 | 52.0 | 67.0 | 1.92 | 73.4 | 9.00 |
| | 300+400 | 47.5 | 68.6 | 1.15 | 70.4 | 12.03 |

Test conditions: pH =10.5, 60g/t of collector (PA 14), 5 minutes conditioning of depressant, 1 minute for collector and RPM = 1500, rougher only.

From Table 3, one can observe that the combination of GPR 855 and starch did improve all flotation performance indicators of specific tests, increasing iron recovery, iron grade and selectivity. The synergy of employing both reagents indicates that either the new reagent is playing itself a new role in the system as a depressant or it is improving adsorption characteristics of starch to make it more selective. For instance, when 100g/t of GPR 855 was added in combination with 400g/t of cornstarch, at basically the same iron recovery level (73.4 against 73.6), the concentrate increased its iron grade in almost 7 percentage points and selectivity almost tripled. Adding an extra dosage of GPR 855 but maintaining the cornstarch a 400g/t, selectivity improved further by 3 points and iron and silica grade of the concentrate achieved the best values among all tests shown in Table 3.

Figure 2 shows the visual difference between concentrate and tailings obtained from the test that involved 100 g/t of GPR 855 and 400 g/t of cornstarch.

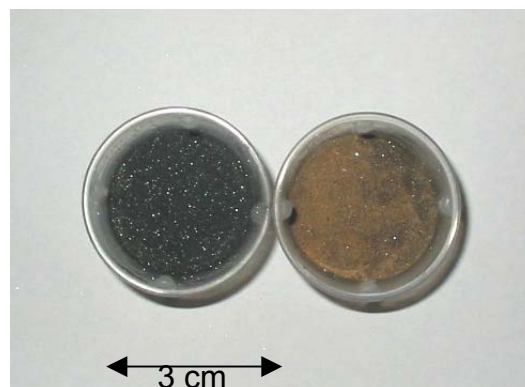


Figure 2 – Concentrate and tailings from the test combining 100g/t of GPR 855 and 400 g/t of cornstarch

Conditioning Time

After all tests were performed with the 3 samples already described, a set of new tests addressed the issue of conditioning time. For this series of tests, yet another itabirite sample was employed – IB N LG3, representing an even lower iron grade samples than the ones used before. Selected results (rougher only) are summarized on Table 4.

Table 4 – Decreasing the conditioning time with GPR 855 in combination with starch (all tests performed at pH 10.5 and utilizing 60g/t of PA 14 as collector).

| Flotation Data and Results | | | |
|----------------------------|-----------|------------------------------|----------|
| Cornstarch | 400 (g/t) | Depressant conditioning time | |
| GPR 855 | 300 (g/t) | 5 minutes | 1 minute |
| Concentrate Yield (%) | | 58.1 | 57.4 |
| Concentrate Grade (% Fe) | | 61.8 | 63.8 |
| Concentrate Recovery (%Fe) | | 86.1 | 86.4 |
| Selectivity Index | | 5.91 | 6.72 |
| Separation Efficiency | | 69.43 | 72.98 |

This last series of tests indicates that when both depressants are employed together there is a significant decrease in the requirement for conditioning time (decreased by 5-fold). This conditioning time decrease was accompanied by maintenance of yield and iron recovery values but increases in Fe grade, selectivity and separation efficiency.

CONCLUDING REMARKS

This work presents results obtained at bench scale that show significant improvement of iron ore cationic reverse flotation when two depressants are added together. These reagents include the traditional cornstarch and a new chemical of low molecular weight that acted as co-depressant improving flotation performance parameters such as iron recovery, iron grade and selectivity, creating relevant net economical value to the operation. This new chemical can be classified as a polyamide-polyamine copolymer, a non-toxic, biodegradable and water-soluble chemical.

The combination of reagents is customarily practiced by the mining industry in several applications. Moreover, enhanced performance by simply changing or adding reagents can be achieved almost immediately after a successful new reagent scheme is encountered. This is especially true in those cases where the new reagent is fully compatible with an existing one and its application just demands the installation of piping once both depressants can even be prepared together.

This work also presented preliminary evidence that indicates that when both polymers are added together into a flotation system, the relatively high conditioning time normally associated with the use of starch can be drastically decreased at the same time some performance parameters such as selectivity index and separation efficiency are improved. Conditioning is many times a critical operation. Long conditioning times, under proper mixing conditions, may lead to the generation of slimes. Reverse cationic flotation systems are very sensitive to the presence of slimes. Some itabirites are extremely soft in nature and the presence of clay-like aggregates is relatively common in some ores. These aggregates are physically disrupted by intense agitation levels are required for reagent conditioning.

Further studies are being currently carried out in order to explore different depressant ratios, the effect of the presence of slimes on controlled tests with and without the combination of depressants, collector consumption requirement and different preparation routines for adding both depressants. Other studies will also be started in a near future in order to bring some more fundamental understandings on the most likely mechanisms that are involved in this synergic interaction of reagents.

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