PARTICLE AGGREGATION EFFECT ON MINERAL PASTES[1]

Christian A. Hernández[2]
Eugenio A. Pizarro[3]
Armando C. de Araujo[4]
George E. S. Valadão[5]

Abstract

Only a small number of mineral processing plants currently dispose tailings as pastes in Latin America. Most plants, inclusive of all iron ore beneficiation facilities, utilizes conventional sub-aqueous disposal of tailing on the basins of tailings dams. This is the case in Chile as well as in Brazil. Several advantages of paste disposal in comparison to conventional methods can be listed with technical, environmental, social and economical repercussions. Research developed at UFMG and UNAP has established that some of the most important factors that influence mineral pastes made iron ore and copper ore tailings are the solid content, size distribution and the addition of aggregants (type and dosage). Slump, flume and viscometry test programs were performed to determine paste consistence, fluidity, settling rate and rheology. This paper presents and discusses results that indicated that it is feasible to enhance some characteristics related to fluidity and settling of mineral pastes with the addition of aggregants to iron and copper ore tailings cases.

Key words: Aggregation; Mineral paste; Flocculant.

EFEITO DA AGREGAÇÃO DE PARTICULAS EM PASTAS MINERAIS

Resumo

Atualmente na América Latina apenas um reduzido número de usinas de procesamento mineral faz a disposição de seus rejeitos em forma de pastas minerais. A grande maiora das usinas emprega bacias de rejeitos para realizar a disposição convencional subaquática. Esse é a realidade tanto em Chile quanto no Brasil. Muitas são as vantagens da disposição em forma de pastas em comparação aos métodos convencionais com repercussões técnicas, ambientais, sociais e econômicas. Pesquisas realizadas na UFMG e na UNAP têm estabelecido que alguns dos fatores mais importantes que podem influenciar as pastas minerais preparadas com rejeitos da mineração de ferro e de cobre são: conteúdo de sólidos, distribuição granulométrica e adição de agregantes. Foram programados testes de abatimento, de canaleta e viscometria para determinar consistência, fluidez, velocidade de sedimentação e reologia da pasta. Este trabalho apresenta e analisa os resultados que indicaram que é possível melhorar as características de fluidez e velocidade de sedimentação de pastas minerais com a adição de agregantes para casos de minérios de ferro e de cobre.

Palavras-chave: Agregação; Pasta mineral; Floculante.

[1] *Technical contribution to the 2nd International Symposium on Iron Ore, September 22 – 26, 2008, São Luís City – Maranhão State – Brazil*
[2] *Metallurgical Eng., Dr., Departamento de Engenharia, Universidade Arturo Prat – UNAP. Av. Arturo Prat 2120 – Iquique – Chile – Tel. 56-57-394204 – chernand@unap.cl*
[3] *Metallurgical Eng., Departamento de Engenharia, Universidade Arturo Prat – UNAP. Av. Arturo Prat 2120 – Iquique – Chile – Tel. 56-57-316441 – eugenio.pizarro@unap.cl*
[4] *Mining Eng., Ph. D., Departamento de Engenharia de Minas, Universidade Federal de Minas Gerais – UFMG. Espirito Santo 35, Belo Horizonte, MG, Brasil, armando@demin.ufmg.br*
[5] *Mining Eng., Dr., Departamento de Engenharia de Minas, Universidade Federal de Minas Gerais – UFMG. Espirito Santo 35, Belo Horizonte, MG, Brasil, gvaladao@demin.ufmg.br*

1 INTRODUCTION

Currently, most of tailings produced by the mining in South American countries, as the cases of the iron ore and copper plants in Brazil in Chile, are normally disposed in sub-aquatic form, being deposited in tailings basins. In some countries such as Australia, Canada, United States and South Africa, tailings from mineral processing are disposed in mineral paste form, for its superficial disposition or the generation of "pastefill", which is used to fill up cavities of the underground mining. Several advantages technical, economical, social and environmental are offered by this last disposition alternative. Examples of their advantages are the greater recovery of water process and their smaller impacts to environment, especially if the footprint of the areas required for disposal are taken into account.

It is very important to define the mineral paste concept. A mineral paste can be conceptually defined as a colloidal or almost colloidal system, that resembles a homogeneous fluid, in which size segregation does not take place, and if the material is disposed smoothly on stable surfaces, it does not show significant water drainage. According to Araujo et al.(1) aspects related to fluidity and consistency during the deposition of pastes can be determined by means of techniques such as flume and slump test. The cone slump test, that originally was used to determine the consistency of a mixture of concrete, is very much used at present time by the mineral industry. It can be employed to characterize that property in the case of pastes of underground filling and superficial tailings. A conical geometry can also be used. The cylindrical shape, for its enhanced simplicity, and because it presents some advantages, according to some authors, as in Clayton et al.(2) and Jung and Biswas,(3) is preferred however.

In the case of the rheological characteristics, such as the yield stress and the apparent viscosity of paste, it is very important to indicate the existence of a critical solid value concentration, above which, the increase of the viscosity or yield stress becomes very significant. Obviously, depending on the material that constitutes the paste, this critical value of the solid concentration can change significantly, as shown in the work of Sofrá and Boger.(4)

The visual aspect of a mineral paste used in mineral industry disposed on an impermeable surface can be observed in the Figure 1-a according to Vietti and Dunn.(5) Figure 1-b shows a laboratory cylinder of PVC and slump test applied to mineral paste, according to Hernandez et al.(6)

The use of aggregants, as polymeric flocculants and coagulants, helps the solid-liquid separation process, generating a beneficial effect in the mineral paste production, for example improving the characteristics of fluidity or rheology of the system. The addition of flocculants, for instance, can affect in different forms the properties of mineral paste.

a b

Figure 1 – a) superficial disposition of industrial mineral paste, Vietti and Dunn (5); b) Slump laboratory cylinder.[6]

For example, Boger[7] shows in the Figure 2 the effect of addition of different flocculants on yield stress, in function to solid concentration.

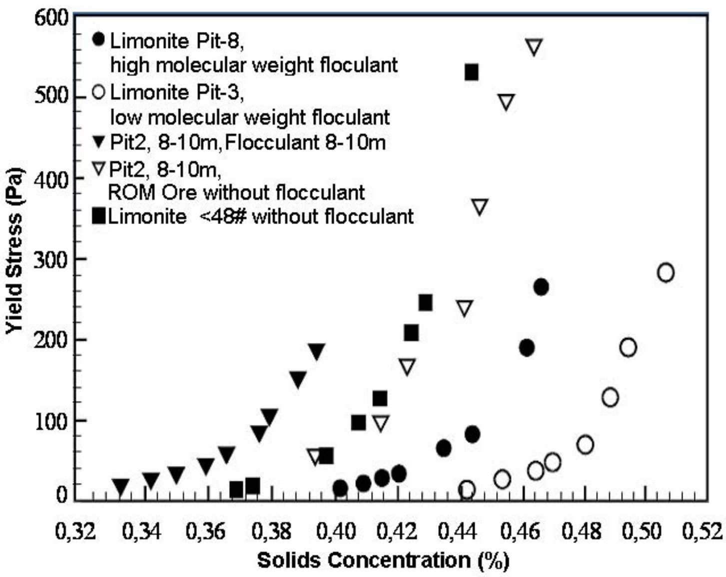


Figure 2 – Flocculation effect on yield stress behavior versus solid concentration.[7]

From Figure 2 it can be observed that a greater addition of flocculant implies a greater water content (smaller solid concentration) to produce a significant increase in the rheological answer expressed like yield stress. This indicates an increase between 4 to approximately 5% as water requirement, because a greater presence of floccules has produced greater water retention.

2 METHODOLOGY

Mineral samples came from S.C.M Collahuasi (Chile) taken before tailing thickener, and an iron ore beneficiation plant from Urucum RDM-CVRD (Brazil) take at same position on the flowsheet. Equipment and methods applied in current research are summarized in Table 1

Table 1 Characterization of solid and pastes tests.

Property	Technique	Equipment
Specific gravity	Picnometry	Liquid pycnometer
Size distribution	Sieving	Standard vibratory sieving apparatus.
Chemical composition	Spectrophotometry	Flame Spectrophotometry and FRX
Paste consistency	Slump test	100mm height by 100mm diameter slump cylinder
Paste fluidity	Flume test	Plexiglass flume apparatus
Paste viscosity	Viscosity	Rotational viscometer (Brookfield)
Settling rate	Sedimentation test	Graduated cylinder (1 L)

2.1 Slump Test

As shown in Table 1, a cylinder with 100mm of height and 100mm of diameter, made of PVC, was used for all tests in the laboratory. The paste was initially prepared at high solid concentration (between 70 to 82% solids), and with the addition of tap water to a previously dried and weighed tailings sample. The procedure employed, as recommended by Brazilian Standard NBR NM 76, 1998.[8] Determination of the % of slump (%ABT) is given by equation (1), as follows:

$$\%ABT = s / H \times 100 \qquad (1)$$

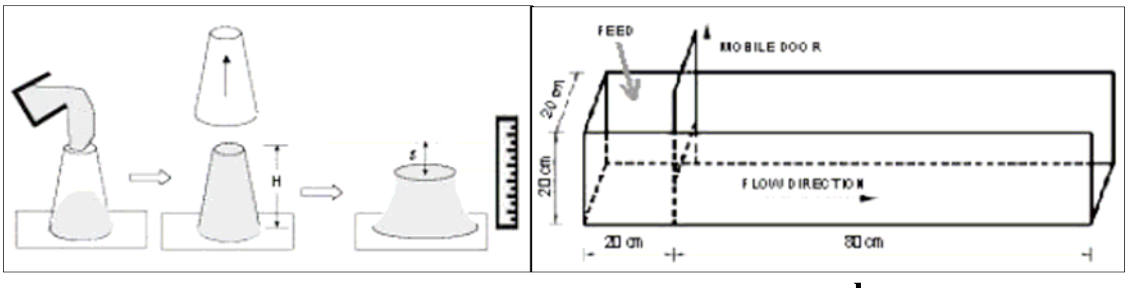
Where: "*s*" is the interval between the height of the cylinder and the height of the slump for the testes paste and "*H*" is the total height of the cylinder. This procedure show at Figure 3a, according Clayton et. al.[9]

2.2 Flume Testing

A Plexiglass flume laboratory size apparatus with 1000 mm of length, 200 mm of width and 200 mm of height was used for testing of the repose angle. Solid-liquid mixtures were prepared at specific solid concentration (w/w). Figure 3b shows a picture of the apparatus. Equation 2 shows the way the repose angle of the paste (θ_R) can be calculated, according Kwak et al.:[10]

$$\theta_R = arctg\ [(h_1 - h_2) / L] \qquad (2)$$

Where: "h_1" is the height of the flume initial point; "h_2" is the height of the flume final point and "*L*" corresponds to the length of paste deposited on the flume after the paste sliding movement ends.



a **b**

Figure 3 - a) Slump test procedure; b) Flume test procedure

2.3 Rheology and Settling

A Brookfield model DV-II pro (Chile) and DV-III (Brazil) viscometer was employed to evaluate the apparent viscosity of the pastes and high-density slurries. Spindle rotation was varied and viscosity measurements were taken considering a rheological cycle of 20-100-20 rpm (Chile) and 1-20-1 rpm (Brazil) in order to determine the rheological behavior of these solid mixtures obtained with and without the use of aggregants. The experiment was performed taking into consideration as responses settling rate, apparent viscosity and rheological behavior.

3 RESULTS

The results obtained for both samples are presented in this section.

3.1 Specific Gravity

The tested mineral sample presented an average specific gravity of 3.62 g/cm^3 for iron ore tailing and 2.61 g/cm^3 for copper ore tailing.

3.2 Chemical and Mineralogical Composition

Only the copper sample was tested on flame spectrophotometry. The results obtained are shown in Table 2.

Table 2 Spectrophotometry results for copper tailing sample.

Element	Concentration
Cu	28.3 mg/L
Fe	0.34 g/L

Table 3 shows the chemical composition of the iron ore tailing used in this investigation.

Table 3 Chemical Analyses

Component	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI
Grade (%)	8.3	0.08	60.7	0.14	0.25	0.14	< 0.1	0.38	28.2	0.36	3.46

LOI = loss on ignition

For the iron ore tailing sample, X-ray diffraction showed only quartz and hematite as clearly defined phases. SEM/EDS of particles of the sample also showed the presence of an aluminum bearing phase, likely gibbsite**.**

3.3 Particles Size Distribution

For iron and copper tailings samples, are presented size distribution on Figures 4 and 5.

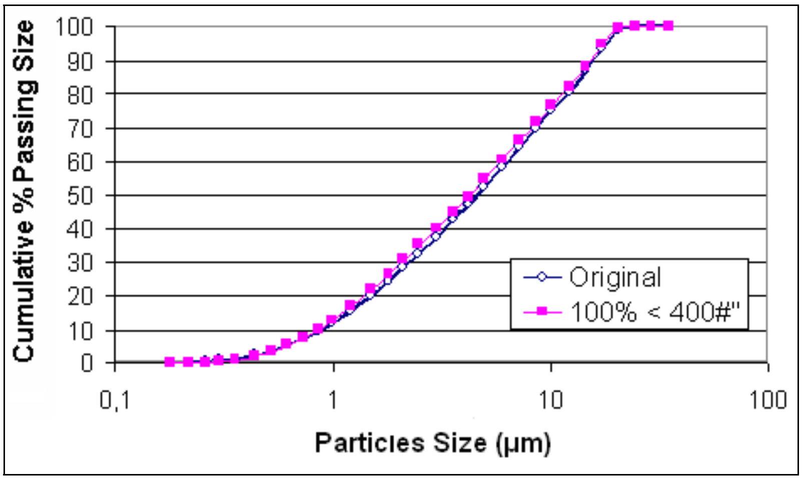


Figure 4 Particle size distribution for iron sample.

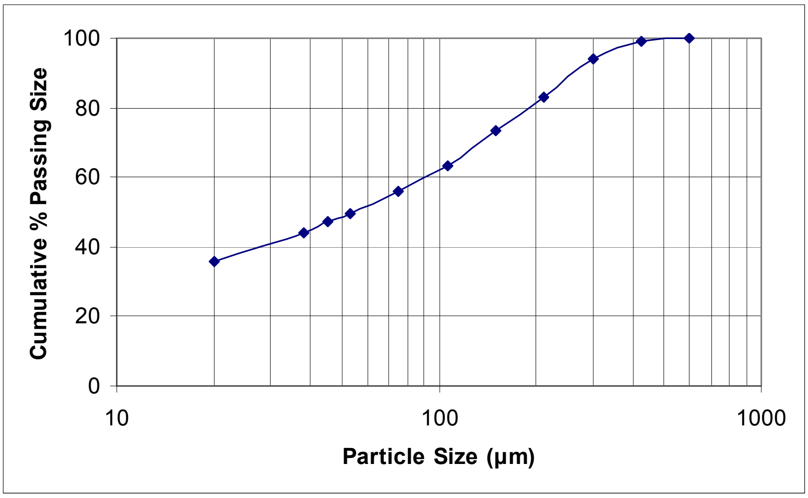


Figure 5 Particle size distribution for copper sample.

3.4 Paste Consistence

By slump tests, Figures 6 and 7 present results for iron and copper tailings samples:

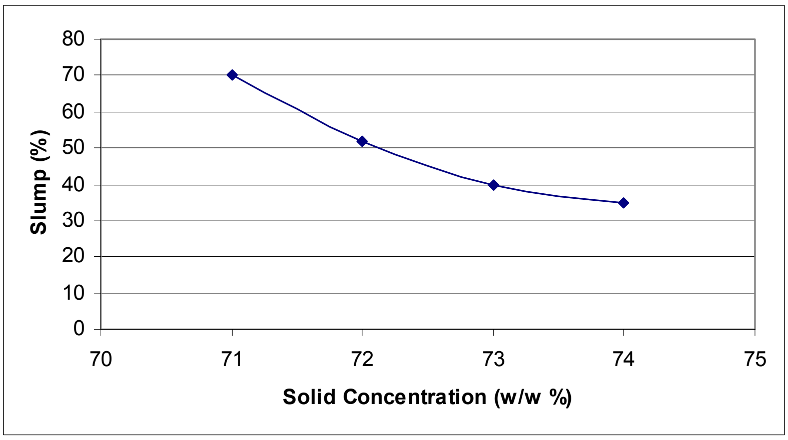


Figure 6 Slump test results for iron sample.

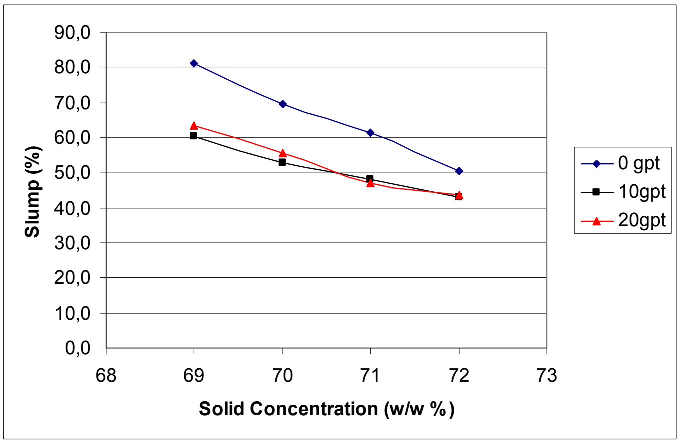


Figure 7 Slump test for copper sample

3.5 Paste Fluidity

Figures 8 and 9 present results of flume tests for iron and copper tailings samples:

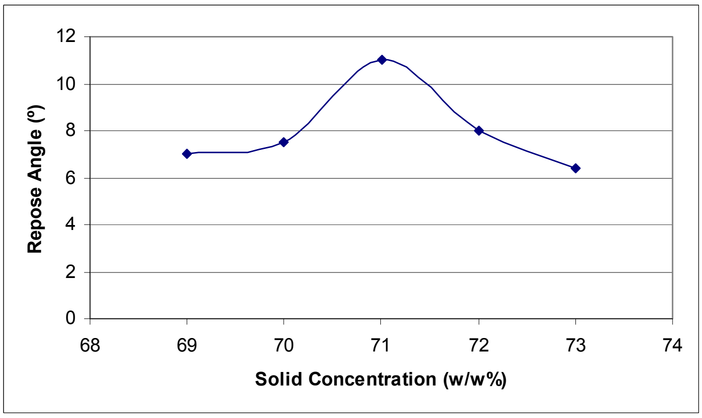


Figure 8 Flume test for iron sample

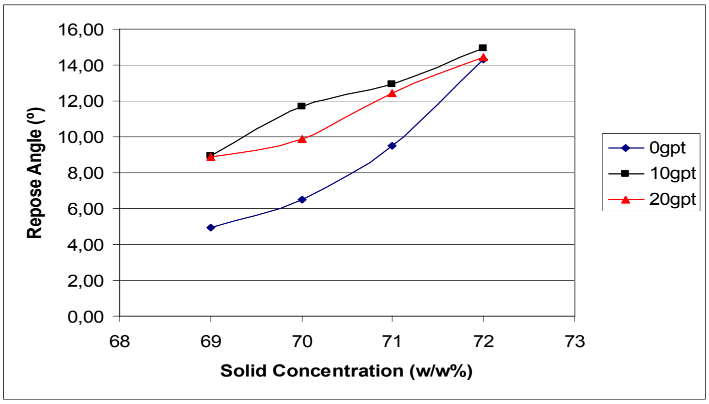


Figure 9 Flume Test for Copper Sample

3.6 Rheological and Settling Tests

A Table 4 presents results of aggregation effect in settling rate and rheological behavior on ore iron mineral pastes. A Figure 10 shows the results of rheological cycles for ore copper tailings pastes.

Table 4 Effect of aggregants on the settling rate and rheological behavior of paste mineral (70% w/w) prepared with iron sample (Brazil).

Test	Aggregation condition	Settling rate (cm/min)	Rheological behavior on an 1-20-1 rpm cycle
1	Blank Test	4.6×10^{-3}	Double (mostly rheotropic)
2	Addition of 20 g/t of coagulant (C)	13.3×10^{-3}	Double (mostly thixotropic and with smaller viscosities)
3	Addition of 20 g/t of flocculant (F)	5.6×10^{-3}	Double (mostly thixotropic and with smaller viscosities)
4	Addition of 20 g/t of (C) and 20 g/t of (F)	5.5×10^{-3}	Almost Newtonian (viscosities very close)
5	Addition of 10 g/t of (C) and 10 g/t of (F)	4.7×10^{-3}	Double (mostly rheotropic with increased viscosity)
6	Addition of 10 g/t of (C) and 10 g/t of (F)	4.9×10^{-3}	Double (mostly rheotropic with increased viscosity)

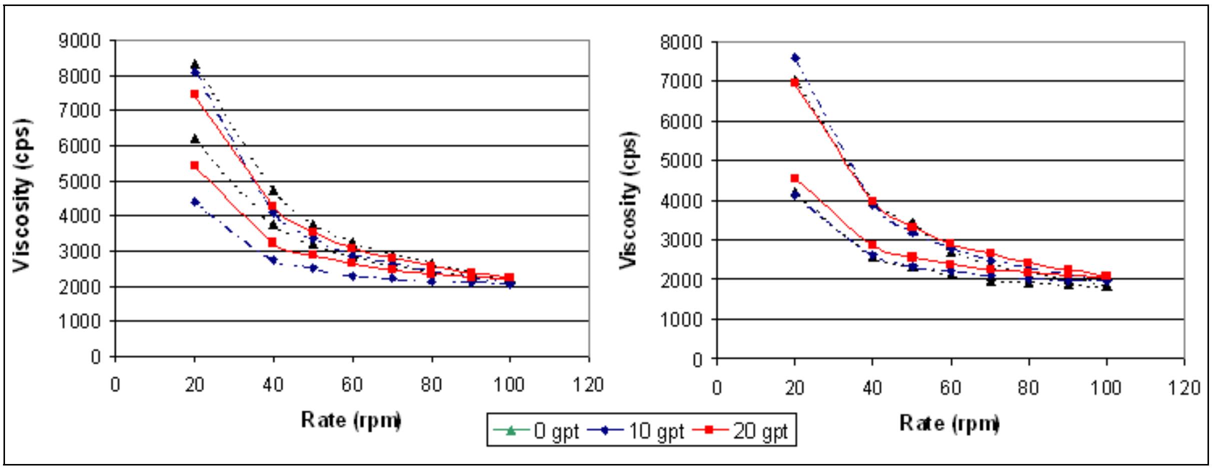


Figure 10 a) Rheological cycle at 72% of solid concentration (w/w); b) Rheological cycle at 71% of solid concentration (w/w) for copper tailings samples.

A Table 5 shows settling rates for copper ore tailings samples:

Table 5 Effect of aggregants on the settling rate at 20% solid weight concentration, prepared whit copper sample (Chile).

Test	Aggregation condition	Settling rate (cm/s)
1	Blank Test	0,014
2	Addition of 10 g/t of flocculant	0,15
3	Addition of 20 g/t of flocculant	0,35

4 DISCUSSION

4.1 For Iron Samples

From Table 4 it can be observed that the best aggregation condition corresponds to the addition of 20 g/t of coagulant $Al_2(SO_4)_3$ whenever settling rate and rheological behavior (smaller viscosities and a trend to thixotropic behavior) are taken into account. The combined addition of 10 g/t of each aggregants would represent the worst condition as the settling rate increased only 10% and the trend in rheological behavior was found to be towards rheotropic fluid. Transport of a rheotropic fluid is a much more complicated issue in comparison to a thixotropic one.

4.2 For Copper Samples

From Figure 7, a little different behavior between 10 and 20 (g/t) of flocculant dosage can be observed. In other hand, without flocculant, the mineral paste presented lower consistence (greater slump percentage).
From Figure 9, it can be observed that greater water additions imply greater differences between repose angles, for both the pastes with and without flocculant. In opposition, for denser pastes similar values are obtained for repose angle. By rheological test measurements (20-100-20 rpm), can be determined between 69 and 71% of solids, the addition of 20 (g/t) of flocculant is important on the aggregation of particles, showing greater values of apparent viscosity in flocculated paste. For the case of 72% of solids in weight, a high density of solid particles is had, which could explain the low effect of the flocculant in that mineral paste. Furthermore, in all the cases, the rheological behavior was thixotropic.

5 CONCLUSIONS

5.1 For Iron Ore Tailing Tests

- The solid presents typical characteristics of slimes, very fine size distribution, and it is composed of hematite (60% w/w) and quartz (28% w/w).
- The effect of adding aggregants (coagulants and flocculants or both) was not perceivable in the test responses for paste consistency and repose angle.
- The settling rate was increased almost three times when adding 20 (g/t) of coagulant, and the rheological behavior was highly thixotropic in a rotational cycle 1-20-1 rpm, which represents a most favorable rheological condition.

5.2 For Copper Ore Tailing Test

- The flocculants effect, in general, meant to increase the consistency and to decrease the fluidity on mineral studied paste systems, effect that is lower when increasing the solids concentration of pastes.
- For the rheological cycle studied (20-100-20 rpm), all pastes prepared have shown a marked thixotropic rheological behavior.

Acknowledgements

The authors would like to express their gratitude for the support of the CNPq - Brazil for the doctoral scholarship (C.A.Hernandez) that made the major part of this investigation a reality. We would like to thank the participation of the students of Metallurgical Engineering in UNAP: Patricia Perez, Maria-Jose Zúñiga, Julio Molina and the technical workers of UNAP and UFMG: Sergio Durán and Alberto Lúcio Afonso, respectively.

REFERENCES

1 ARAUJO, A. C., VALADÃO, G. E. S., HERNÁNDEZ, C. A. Nueva Aplicación de los Relaves de Hierro In: 3th CONGRESO INTERNACIONAL DE MINERÍA, METALURGIA Y MATERIALES, Annals **in electronic media**, Iquique – Chile, 2004. 1 CD.

2 CLAYTON, S., GRICE, T. G., BOGER, D. V. Analysis of the Slump Test for on-site Yield Stress Measurement of Mineral Suspensions. **International Journal of Mineral Processing**, Melbourne – Australia, n. 70, p. 3-21 (2003).
3 JUNG, S. J., BISWAS, K. Review of Current High Density Paste Fill and its Technology. **Mineral Resources Engineering**, v. 11, n. 2, p. 165-182, 2002.
4 SOFRÁ, F., BOGER, D. V. Enviromental Rheology for Waste Minimisation in the Minerals Industry. **Chemical Engineering Journal**, Melbourne – Australia, v. 86, p. 319-330, 2002.
5 VIETTI, A., DUNN, F. The Thirsty Business of Diamond Mining. In: HIGH DENSITY & PASTE 2002 SEMINAR, Santiago - Chile, Annals **in electronic media,** Santiago, Apr-2002, 1 CD.
6 HERNANDEZ, C. A., ARAUJO, A. C., VALADÃO, G. E. S., AMARANTE, S. C. Pasting Characterics of Hematite/Quartz Systems. **Minerals Engineering**, v. 18, p. 935-939. 2005.
7 BOGER, D. V. First Workshop of Minerals Processing and Tailings Rheology. In: INTERNATIONAL SEMINAR ON PASTE AND THICKENED TAILINGS, Melbourne – Australia, **Annals in electronic media**, 2003, 1 CD.
8 ABNT – Associação Brasileira de Normas Técnicas. Norma para concreto – Determinação da consistência pelo abatimento do tronco de cone – NBR NM 67, Rio de Janeiro, p. 1 – 8, 1998.
9 CLAYTON, S., GRICE, T. G., BOGER, D. V. Analysis of the Slump Test for on-site Yield Stress Measurement of Mineral Suspensions. **International Journal of Mineral Processing,** v. 70, p. 3-21 (2003).
10 KWAK, M., JAMES, D. F., KLEIN, K. A. Flow Behavior of Tailings Paste for Surface Disposal. **International Journal of Mineral Processing**, v. 72, p. 1-15, 2005.