NEW ETHERAMINE COLLECTOR FOR THE REVERSE FLOTATION OF IRON ORE EFFECTIVE ON THE OVERFROTHING PREVENTION

ALBINO, K. I. P., TOLEDO, D.B., LIMA, O. A.
Mining Chemicals, AkzoNobel Surface Chemistry, Itupeva-SP, Brazil
kelly.albino@akzonobel.com, debora.toledo@akzonobel.com, odair.lima@akzonobel.com

RESUMO

A qualidade da espuma (volume, estabilidade e mineralização) é, juntamente com o desempenho metalúrgico, um dos principais fatores utilizados na avaliação de coletores em plantas industriais de flotação. A formação excessiva e a estabilidade da espuma usualmente causam sérios problemas nas operações da planta, tais como; a dificuldade de bombeamento do material flutuado, altos custos devido à necessidade de aplicar anti-espumante e problemas ambientais com autoridades governamentais. Com isso em mente, o objetivo deste trabalho é apresentar e discutir os resultados de flotação e qualidade de espuma obtidos com o mais recente coletor para flotação reversa de minério de ferro, Lilaflot 821M, desenvolvido pela AkzoNobel que mostrou uma alta seletividade na remoção de sílica para as amostras de minérios itabiríticos avaliadas neste trabalho, levando à obtenção de um concentrado final contendo alto teor de Fe (>68%), baixos teores de sílica (<1,3%) e recuperação metalúrgica em torno de 84%. Além disso, Lilaflot 821M levou à geração de uma espuma de maior qualidade no que tange ao seu volume e estabilidade quando comparada com as espumas geradas por duas outras "eteraminas convencionais" também testadas neste trabalho. Os testes de flotação foram feitos utilizando uma célula de flotação mecânica tradicional Denver de laboratório. Os testes de caracterização da espuma foram realizados usando uma coluna de caracterização de espuma desenvolvida pelo time da AkzoNobel Mining Chemicals onde os parâmetros tais como taxa de aeração, densidade da polpa, pH e dosagem de reagentes pudessem ser ajustados tal qual um teste regular de flotação. Os resultados apontaram que o Lilaflot 821M não somente leva a altos desempenhos, mas também apresenta uma maior qualidade de espuma (volume e estabilidade) em comparação com outras duas eteraminas convencionais investigadas neste trabalho.

PALAVRAS-CHAVE: Flotação; minério de ferro; espuma; coletor; itabirito.

ABSTRACT

Froth quality (volume, stability and mineralization) is, together with the metallurgical response, one of the main performance factors of collector evaluation in industrial flotation plants. The excessive froth formation and its stability might lead to serious problems in plant operations such as difficulties in the pumping of the float material, high costs due to the need of the application of defoamers and environmental problems with legal authorities. Bearing this in mind, the objective is this work is to present and discuss the flotation and frothing results achieved using the new etheramine based collector, Lilaflot 821M, developed for the reverse flotation of iron ore. Lilaflot 821M has showed a high selectivity towards silica leading to the attainment of final concentrate with a high Fe content (>68%), low silica level (<1.3%)

and a metallurgical recovery of around 84%. Additionally, Lilaflot 821M led to higher quality flotation froth in terms of volume and stability when compared to two “conventional etheramines” also tested in this work. The flotation tests were done using a classical Denver type mechanical flotation lab cell. The frothing characterization tests were performed using an in-house froth characterization column wherein parameters such as air rate, pulp density, pH and chemical dosages can be adjusted to mimic a regular flotation test. Results have pointed out that Lilaflot 821M not only leads to higher metallurgical performance but also to a higher flotation froth quality (volume and stability) in comparison to than the other two conventional etheramines covered in the scope.

KEYWORDS: Flotation; iron ore; froth; collector; itabirite.

1. INTRODUCTION

Froth quality is of paramount importance in flotation circuits. In industrial flotation systems, the excessive froth volume or stability has the potential to lead to huge problems that can vary from high cost solutions to control the froth, such as the utilization of defoamers to the compromising of the correct operation of some pieces of equipment which, in its turn, might affect the operation of the entire flotation plant. In some cases, froth issues also lead to environmental problems with local authorities.

Several factors affect the quality of the flotation froth. According to Schwarz et al. (2002) apud Tsatouhas et al. (2006) the structure and stability of flotation froths depend mainly on the chemical used and on the quantity and nature of the particles suspended in the froth phase highlighting the particle size and hydrophobicity. Farrokhpay (2011) points out that the froth stability can be affected by factors such as water quality, air dispersion parameters and contact angle of the particles. Despite being widely investigated by several researchers as illustrated by Ata (2012), according to Farrokhpay (2011) the task of relating quantitatively frothing stability lab results with full operation practice is still a point of discussion amongst researchers so that process control strategies could be adopted.

When it comes to the flotation of iron ore, it is widely known that amine derivative compounds are the main collectors used to remove silicate from the ore mineral. Due to pulp conditioning and flotation pH´s and due to the amine hydrolysis and dissociation characteristics the amine derivatives compound act both as collector and frothers in such application (Fuerstenau et al., 1985). However, the frothing aspects of those collectors may sometimes lead to froth issues, which might be either overfrothing or high stability or both in full scale which not only cause several problems to plant operation but also affect the quality of the end product.

Being aware of the importance of froth quality in industrial flotation circuits, the mining team of AkzoNobel Surface Chemistry (ANSC) has worked intensively to develop new collectors that can both maximize the flotation response and also improve the quality of the flotation froths for different types of flotation systems such as phosphate, carbonate and iron ore flotation circuits.

The objective of this work to present the new ethermonoamine based collector, Lilaflot 821M, developed by ANSC for the reverse flotation of hematite and its performance both on the metallurgical results and on the froth quality in comparison with two so called conventional ethermonoamine collectors used for the same application. The metallurgical performance was assessed by means of the traditional bench flotation tests widely used to evaluate flotation reagents and process routes. The froth quality (stability and volume) was evaluated by means of froth characterization tests which were conducted in a device internally developed by ANSC mining team aiming at being a complementary tool to lab flotation trials in the development of new flotation collectors. The ore samples used in this work comprise two poor itabiritic iron ores from two different mines within Brazil.

2. MATERIALS AND METHODS

2.1 Flotation feed characterization

The ore samples used in this study were supplied by two different iron ore mines from the State of Minas Gerais, countryside of Brazil. For the purpose of this work, the ore samples were coded as Hematite 1 and Hematite 2. As part of the ore characterization, both ore samples were submitted to XRD assays in order to determine the mineral species in each sample. The two samples presented the same mineral species: Quartz (SiO_2) and Hematite (Fe_2O_3). The sample Hematite 1 also presented a small amount (possible presence) of talc, $Mg_3Si_4O_{10}(OH)_2$. The chemical composition of each flotation feed was determined using the XRF technique. Such results are depicted in Table 1.

Table 1. Chemical composition of the hematite ore samples.

Sample	Chemical composition, %							
	Fe	SiO_2	Al_2O_3	P	Mn	TiO_2	CaO	MgO
Hematite 1	58.8	16.0	0.43	0.01	<0.10	<0.10	<0.10	<0.10
Hematite 2	44.0	35.9	<0.10	0.02	<0.10	<0.10	<0.10	<0.10

To characterize the size range of the flotation feed, it was performed a wet particle size distribution through classical sieving. Figure 1 shows that both samples follow a similar particle size distribution. The preparation of this material comprised a drying at 40°C followed by a homogenization step by means of elongated piles where the 650g flotation feeds were then taken from.

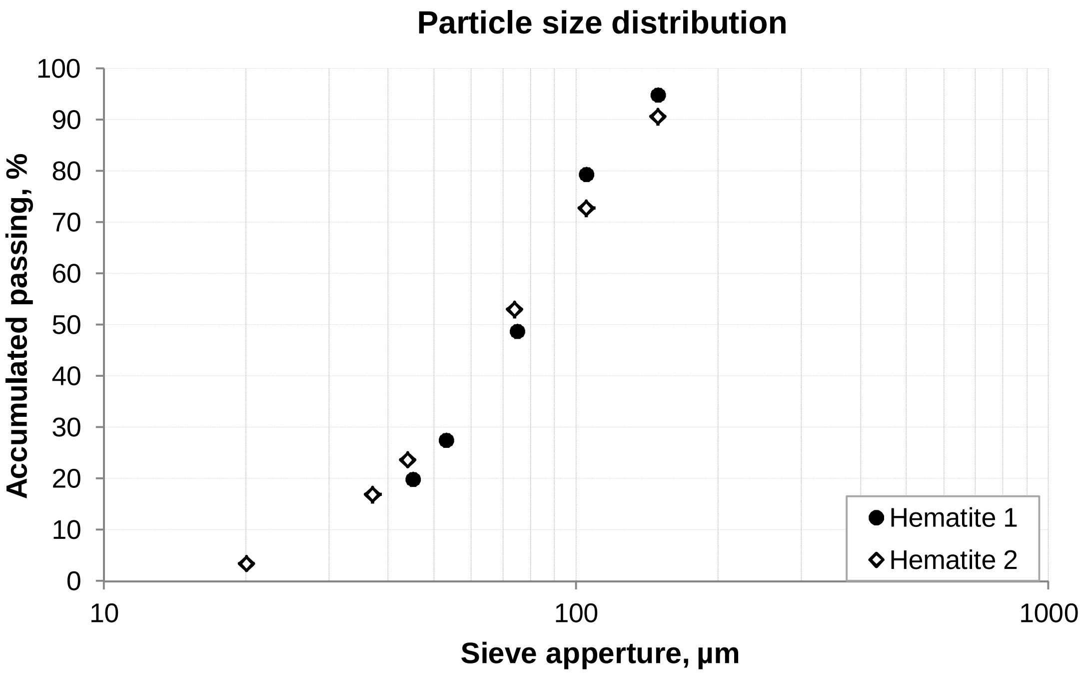

Figure 1. Particle size distribution – Hematite 1 and Hematite 2.

Size-by-size chemical analyses were also done. However, since the main goal of this work is to show the effectiveness of Lilaflot 821M in preventing froth issues, the chemical analysis in each size was done only for the iron ore sample Hematite 2 due to the fact that only this sample presented a frothing behavior that could lead to problems in full scale. Table 2 brings the results achieved in such tests.

Table 2. Size-by-size chemical analysis of Hematite 2.

Size distribution			Chemical assay		Distribution	
Sieve aperture, µm	Mass retained, g	% Retained	Fe	SiO_2	Fe	SiO_2
149	47.6	9.29	18.5	72.3	3.89	18.5
105	91.2	17.8	25.7	62.9	10.4	30.9
74	101.2	19.8	34.7	49.8	15.5	27.1
44	150.5	29.4	53.2	23.7	35.4	19.2
37	34.5	6.75	62.2	9.08	9.51	1.69
20	69.3	13.5	66.1	5.58	20.3	2.08
20	17.5	3.42	64.0	5.08	4.96	0.48
	511.8	100.0	44.1	36.3	100.0	100.0

2.2 Reagent system

The following cationic collectors were used in this work: Lilaflot 821M, an etheramine developed by AkzoNobel Mining Chemicals and two ethermonoamines (coded as Etheramine I and Etheramine II) used to reverse flotation of iron ore. Lilaflot 821M is a new ethermonoamine based collector partially neutralized with acidic acid developed for the reverse flotation of iron ore that can lead to superior results when compared to other ethermonoamine collectors, which in the body of this text will be referred to as “conventional etheramine”. Lilaflot 821M was designed to be non-flammable, more dosage effective and generate less froth than conventional etheramines. Table 3 summarizes the main physical properties of Lilaflot 821M.

Table 3. Main physical properties of Lilaflot 821M.

Parameter	Value
Aspect@25ºC	Liquid
pH (product as such)	10.2
Specific gravity@25ºC	890 kg/m^3
Viscosity@25ºC	85 cP
Flash point	> 100ºC

Starch, from different sources, was used as depressant. For Hematite 1 corn starch (fubá) was used in a dosage of 1000g/t whereas for Hematite 2 cassava starch was used as depressant at a dosage of 600g/t. Such differences were needed in order to mimic as close as possible the actual flotation conditions. Tap water (Sabesp) was used in all tests.

2.3 Flotation procedure

Flotation tests were performed using a Denver type flotation machine. The operating conditions of each flotation test are summarized below. Each flotation test was conducted until exhaustion.

i. Flotation feed: 650g;
ii. Solid load in the conditioning: 50%;
iii. Solid load in the flotation: 30%;
iv. Impeller speed: 1200 rpm;
v. Depressant dosage: 600 - 1000g/t;
vi. Collectors dosage: 85 - 90g/t;
vii. Water temperature: 25^{o}C;
viii. Flotation pH: 10.3 – 10.5;
ix. Depressant conditioning time: 5 min;
x. Collector conditioning time: 1 min.

2.4 Frothing test procedure

Frothing tests were performed using a special designed cylindrical column whose bottom is fitted with a stator and a rotor (also known as impeller). In the body of the text, the froth characterization column is referred to as “frothing machine”. The rotor speed is electronically adjustable. The controlled air flow enters through a tube in the middle of the turbulent zone, and the air flow is measured with a flowmeter. A simple measuring tape was put on the column to enable the measurement of the froth height as a function of the length of time during froth formation, stabilization and bursting. The standard test procedure is as follows:

i. Conditions: Similar to flotation procedure;
ii. Impeller speed: 900 rpm;

iii. Aeration: Air flow, constant at 3.0L/min. The froth formation is followed for 7 minutes or until the maximum height is reached and stabilized. The froth height is measure every 20 seconds;
iv. Air stop: Froth bursting is registered followed the froth height each 5 - 10 seconds.

Frothing tests were performed using the same iron ore samples used in the flotation tests. Figure 2 illustrates the frothing machine and its main components.

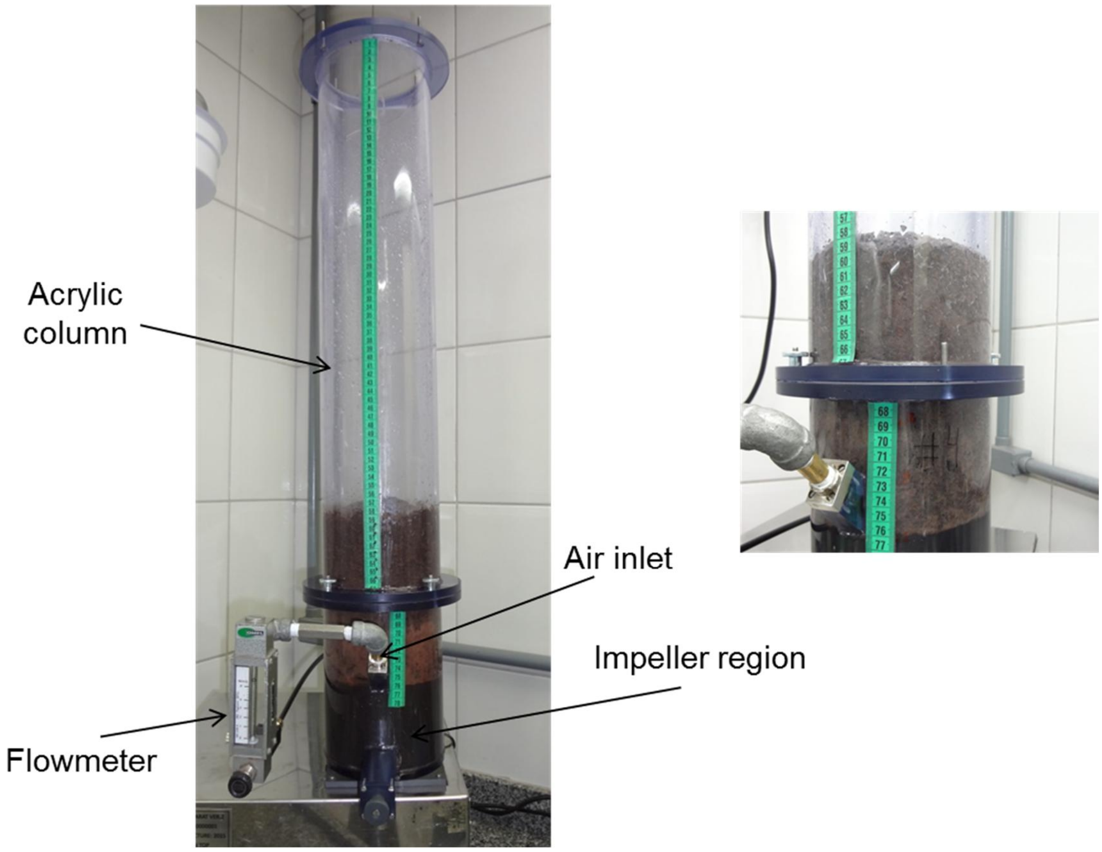

Figure 2. Frothing machine. Detail of a frothing test.

3. RESULTS AND DISCUSSION

3.1 Flotation results

Flotation tests were performed with the two different ores using the collectors Etheramine I, Etheramine II and Lilaflot 821M. Figure 3 illustrates the flotation response in each test wherein it can be observed that Lilaflot 821M led to significantly better results in terms of SiO_2 removal for the two types of iron ores. For the sample Hematite 2, the results show that Lilaflot 821M leads to a Fe grade as high as 69.4% while the conventional Etheramines I and II led to only 46% and 61%, respectively. Additionally, the Fe recovery achieved when Lilaflot 821M was used as collector was also high (Fe Rec ~ 83.4%) and the silica grade was only ~0.82% in the final concentrate. For Hematite 1, Lilaflot 821M once again led to the lowest silica level in the hematite concentrate (%SiO_2 ~1.27%) when compared to the results achieved by the collectors Etheramines I and II whose lowest silica grade was 2.84% achieved by Etheramine I, which is, at least, twice as much the value presented by

Lilaflot 821M. Its superior performance can also be observed by the high values for the Fe metallurgical recovery for both iron ore samples. Such results demonstrate the dosage efficiency of this new etheramine, Lilaflot 821M, especially when it is observed the results for the sample Hematite 2.

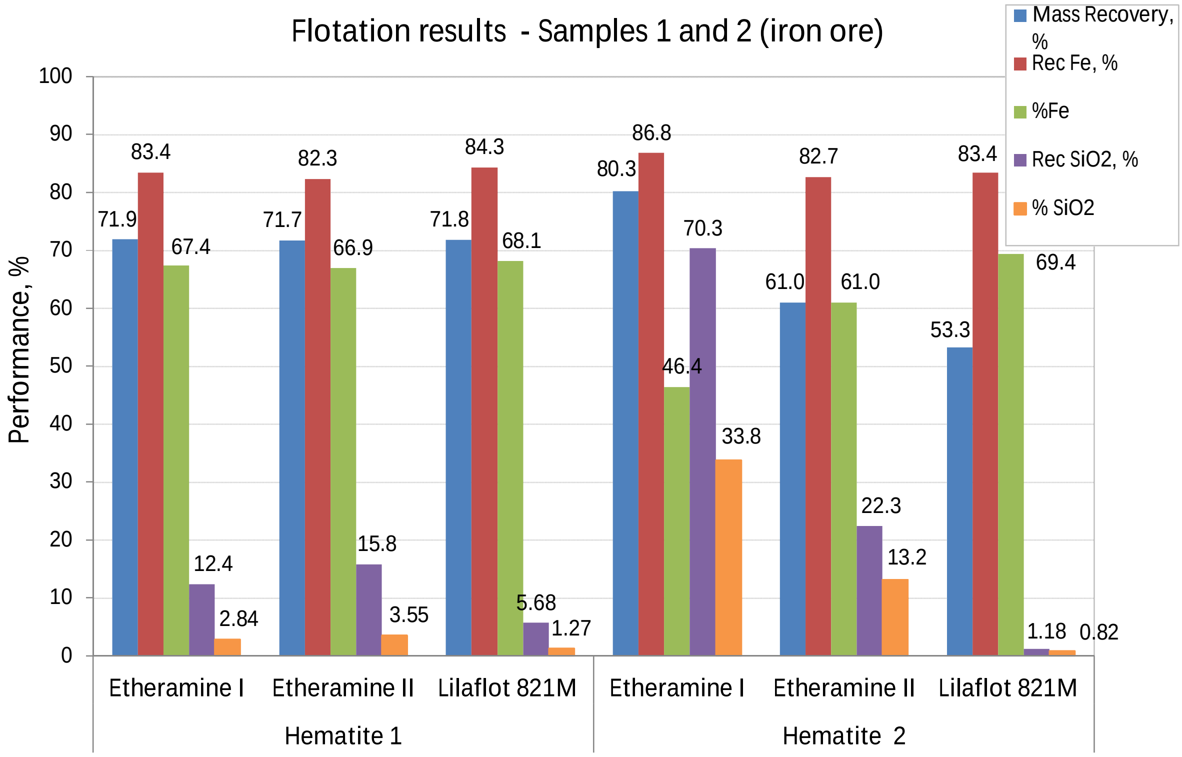

Figure 3. Comparative flotation results using Lilaflot 821M and conventional etheramines based collectors.

Lilaflot 821M also led to the lowest Fe losses in the flotation tailings in comparison with the other etheramines tested. Considering only the rougher flotation, for Hematite 1 the Fe losses for Lilaflot 821M was around 32% against 34% and 36% for Etheramine I and II, respectively. For Hematite 2, the Fe losses were 15%, 28% and 20% for Lilaflot 821M, Etheramine I and Etheramine II, respectively. Detail data on the performance showed by each collector can be found in Table 3, wherein it can be also observed that Lilaflot 821M presented the highest Gaudin selectivity index.

Table 3. Flotation data.

Ore	Collector	Flotation Feed		Tailings		Gaudin selectivity Index
		%Fe	% SiO_2	%Fe	% SiO_2	
Hematite 1	Etheramine I	58.1	16.5	34.2	51.3	6.0
	Etheramine II	58.3	16.1	36.4	47.8	5.0
	Lilaflot 821M	58.0	16.0	32.4	53.7	9.4
Hematite 2	Etheramine I	42.9	38.6	28.7	58.0	1.7
	Etheramine II	45.0	36.0	20.0	71.7	4.1
	Lilaflot 821M	44.3	37.0	15.7	78.1	20.5

It is worth mentioning that no dosage optimization process was included in the scope of this work.

3.2 Frothing results

As mentioned previously, frothing tests were conducted with both ore types (Hematite 1 and Hematite 2) using the ethermonoamine based collectors, however, only one of them showed froth issues. The froth profile for the iron ore sample Hematite 1 did not show any problem regarding froth quality for all the three collectors tested in this investigation. Conversely, the iron ore Hematite 2 showed considerable different froth profiles for each collector used. Therefore, only the frothing results achieved for Hematite 2 will be presented and discussed.
The frothing characterization results are depicted in Figure 4 where it can be seen that the collectors Etheramine I and Etheramine II lead to higher froth volumes (specially Etheramine II) in comparison with the froth profile showed by Lilaflot 821M. No froth stability issues was observed for the three collectors tested since the froths burst completely after a certain length of time. However, due to the high froth volume observed for Etheramine II its froth takes longer to burst so that it is expected that froth problems will appear when treating this ore in full scale operations.

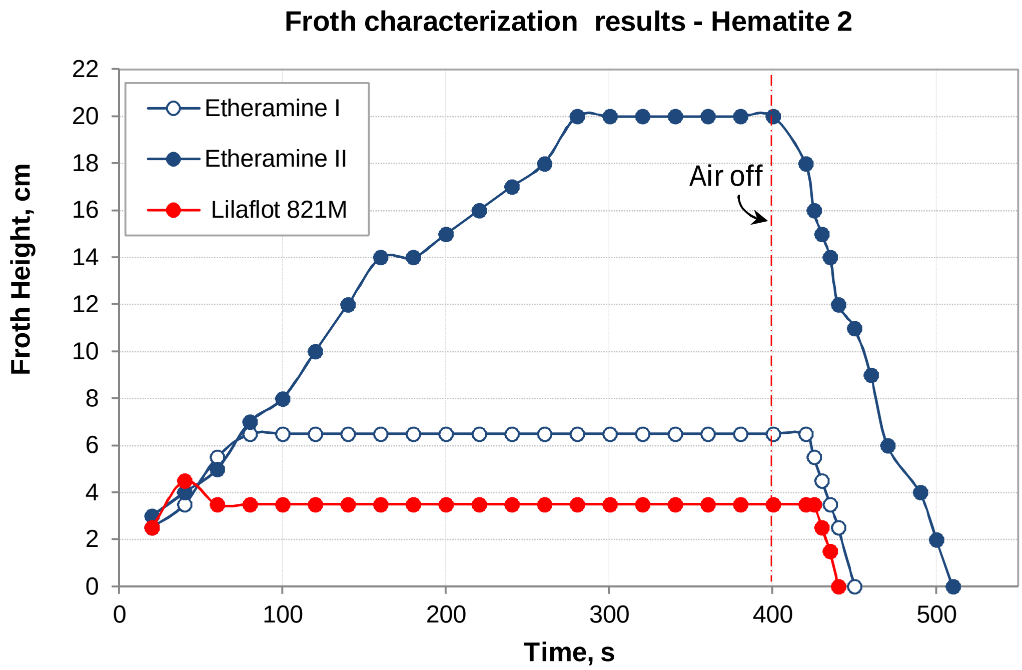

Figure 4. Frothing profiles for different etheramines.

5. CONCLUDING REMARKS

The following main conclusions can be addressed based on the results presented in this work:

i) The new ethermonoamine, Lilaflot 821M, developed by AkzoNobel Mining Chemicals has showed a superior metallurgical and frothing performance towards two itabiric ore samples, coded as Hematite 1 and Hematite 2, in comparison to results showed by other conventional etheramines used for the reverse flotation of iron ore;

ii) Considering only the rougher stage, Lilaflot 821M was able to reduce the silica content from 58% and 44% down to 1.27% and 0.82% for samples Hematite 1 and Hematite 2, respectively using a collector dosage of 85-90g/t. Lilaflot 821M was able to remove much more silica than other so called conventional ethermonoamines at the same dosage level, which demonstrates the dosage efficiency of the new collector;

iii) Only the iron ore sample Hematite 2 showed a potential problematic profile in the frothing test. For this ore sample, the conventional etheramines investigated in this work showed a froth profile whose froth volume is much higher than the one presented by Lilaflot 821M, especially the profile showed by the collector coded as Etheramine I;

iv) Lilaflot 821M led to the highest silica level in the gangue material in comparison to the conventional etheramines. Similarly, it also led to a reduction of the Fe losses in the tailings. Considering only the potentially problematic frothing ore (sample Hematite 2), this reduction ranged from around 25% up to ~46% vis-à-vis the results achieved by the other conventional etheramines;

v) Lilaflot 821M is also very selective in comparison to the other conventional etheramines evaluated in this study. While Lilaflot 821M showed a Gaudin selectivity index of around 20 and 9 for the samples Hematite 1 and 2, respectively, the highest value showed by the other etheramines was only 6, for Hematite 1.

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