

IMPACT OF FROTH STRUCTURE ON IRON ORE FLOTATION¹

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Abstract

Flotation is used for beneficiation of iron ore. The common practice is to use cationic collectors, such as etherdiamines, for removal of silicates by reverse flotation, especially from magnetite ores. The froth phase which contains the gangue is often voluminous and stable. This creates problem in the process, especially when the froth phase should be further processed to improve the iron recovery. The froth properties are affected by the chemistry of the collector, the water quality and also by particle size and shape of floated minerals. To evaluate froth properties in laboratory scale Akzo Nobel Surface Chemistry measures froth formation and stability in addition to performing traditional flotation tests. The result of these combined measurements gives improved knowledge about froth properties for different cases of magnetite flotation and collector chemistries. Furthermore, the aim is to also reduce problems with froth properties upon scaling up of laboratory procedures. This improves our ability of taking froth characteristics into account when tailor-making collectors.

Key words: Flotation; Iron ore; Froth properties.

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1 INTRODUCTION

Froth characteristics as structure and stability are very important factors in mineral flotation. The flotation process can be divided in many sub steps; the flotation cell can be divided in two zones: i) pulp zone and ii) froth zone. In the pulp zone all interactions between solid particles, flotation reagents as depressants, collectors, frother and air bubbles are formed. Collector molecules adsorb on the desired particle surfaces which become hydrophobic and attach to the air bubbles forming the so-called particle-bubble aggregate. This aggregate then rises to the pulp-froth surface leading to a formation of a froth which is removed from the flotation cell. The particle stabilized froth characteristics, reviewed by Pugh,⁽¹⁾ is very important for flotation performance. Factors of importance are: the ability to carry over desired mineral particles with minimal entrainment of valuable mineral and the froth shall burst when entering the froth launder to facilitate its removal and following froth product processing.

This paper will focus on reverse flotation of iron ore, removing silicates from magnetite ore with cationic collectors. The most common flotation collectors for this application are etheramines. AkzoNobel offers this type of collector under the names Lilafлот® D 817M (etherdiamine) and Lilafлот® 811M (etheramine). Both products are partially neutralized as amine acetate to improve solubility in water.

Other cationic surfactants as alkyl amine, quaternary ammonium compounds and amidoamine are also collectors for silica minerals but the group of etheramines are today preferred for removal of silicates from iron ores, both hematite and magnetite.

Etheramine collectors generate normally enough froth in flotation and it is not necessary to add additional frother⁽²⁾. In many cases, too much stable froth is formed. This will create problems in handling the froth product, especially if this froth should be processed further with grinding and magnetic separators to improve the iron recovery. The ideal froth will immediately burst when entering the froth launder.

One strategy to optimize the performance of flotation collector is to use formulations of surfactants to improve the grade and recovery of desired mineral. Efficiency is also an important parameter.

This applies also when optimizing reverse flotation of iron ore.

Three major factors influencing the froth characteristic have been identified and will be discussed in this paper:

- ore features, especially particle size distribution and presence of very fine particles. Particle shape contributes also to froth stability;
- process water, high ionic strength gives increased formation and stability of froth;
- flotation collector, by modifying the structure and also the formulation it is possible to change the froth properties. The dosage of collector will also have an impact on froth characteristic. High dosage will give increased frothing.

One way to handle stable froths is the addition of defoamers. This may cause problems if the froth product should be further processed and re-floated. Another approach is to find the right frothing properties when designing the collector by modification of the collector or by adding additives.

In order to be able to make better assessment of froth characteristic and to improve the success factor when scaling up laboratory tests, AkzoNobel started to use an additional test method developed to measure the froth quality. The froth formation and breakage is followed by using a transparent column. Similar methods are described by Zanin, Grano.⁽³⁾ and Triffet, Cilliers⁽⁴⁾ The froth measurement method is

used together with traditional laboratory flotation tests for evaluation of new ore types and developing new collectors.

2 MATERIAL AND METHODS

2.1 Material

The iron ore used for the tests is concentrated magnetite, equivalent to flotation feed, concentrated by grinding and applying a low intensity magnetic separation. Two ores from different deposits are used and the characteristics are summarized in Table 1.

Table 1. Magnetite ore, flotation feed magnetic concentrate

Ore Magnetite	K ₈₀ (mm)	Fe(%)	SiO ₂ (%)	Al ₂ O ₃ (%)
#1	0.034	60.8	11.5	0.4
#2	0.031	59.4	12.6	2.9

The different water qualities used in the tests are deionized or of the same composition as used in the respective mine. Sea water is also included in the study, as can be seen in Table 2.

Table 2. Process water composition

Water	pH	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	Cl mg/L	SO ₄ mg/L	HCO ₃ mg/L
#1	7.5 - 8	800	200	40	50	1100	620	150
#2	7.5 - 8	600	250	650	40	650	2320	50
Sea	7.5 - 8	10560	380	400	1270	2650	2650	140

Lilafлот® D 817M is used as silica collector, it is a branched etherdiamine partly as amine acetate, commonly used as collector for reverse flotation of iron ore especially magnetite. On the other hand, Lilafлот® 628M is a new etherdiamine formulation developed to be a less frothing alternative to Lilafлот® D 817M. This new product is currently applied for patent.⁽⁵⁾

2.2 Methodology

The flotation parameters are studied using a combination of laboratory flotation tests and froth tests. Laboratory flotation tests follow a standardized procedure which is set up for each case. The outcomes from these tests are metallurgical results as grade, recovery and efficiency of used chemicals.

The froth formation and bursting are studied in a special designed cylindrical column whose the bottom is fitted with a stator and a rotor (also known as impeller). The rotor speed is electronically adjustable. The controlled air flow enters through a tube in the middle of the turbulent zone. The air flow is measured with a flow meter working at 5 bar pressure. The scale is calibrated to show the actual flow at normal atmospheric pressure. This minimizes the fluctuations caused by the flowing mineral slurry. The slurry volume is set to 1.3 liter and pulp density is similar to those used in regular flotation tests about 35% solids by weight. The impeller speed is constant during the test in the range 650 – 1000 rpm. The column is equipped with a scale to measure the froth height.

The normal test procedure is as follows:

- conditioning: collector and mineral slurry are mixed for 1 - 5 minutes.
- aeration: air flow, constant at a rate of 0.5 up to 3.0L/min. The froth formation is followed for 10 - 12 minutes or until the maximum height is reached and stabilized.
- pictures are taken every 20 seconds with a camera equipped with automatic sequence exposure.
- air stop: froth bursting is registered followed with pictures every 20 seconds. The rotor is not turned off.

One of following methods is used when following the burst:

- self bursting;
- addition of wash water from top;
- mechanical stress, by a slowly rotating (3 rpm) agitator following the wall from the pulp surface and up.

Figure 1 illustrates the froth test column during one test wherein can be seen the conditioning step, the froth build up phase and finally the bursting phase. Mechanical stress is applied by an agitator in this case.

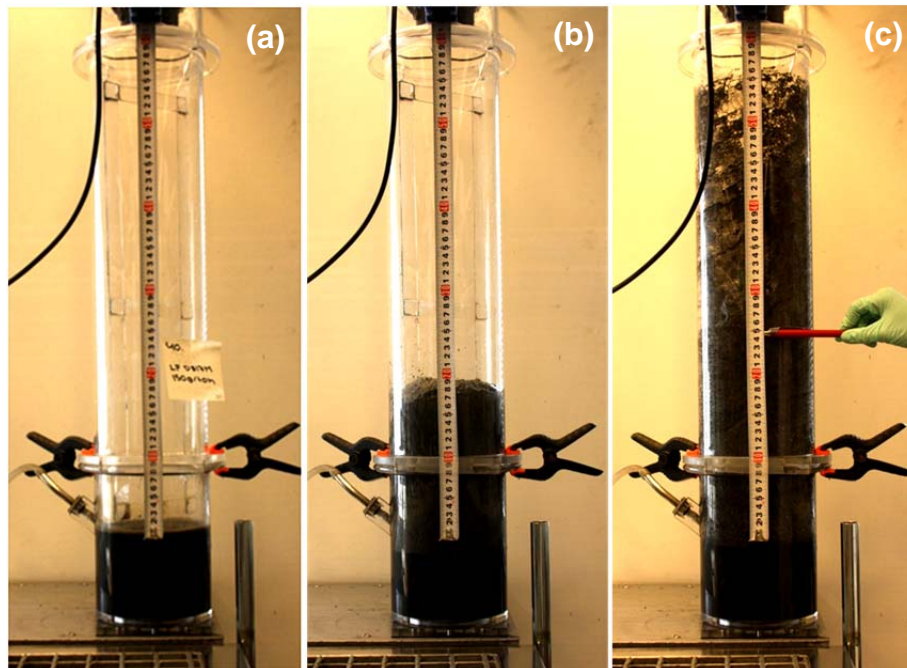


Figure 1. Froth measurement, formation and bursting. Mechanical agitator in the froth phase: (a) Conditioning, $t=0$; (b) Froth build up, air on; (c) Froth bursting, air off.

3 RESULTS

The influence on the froth formation by two different magnetite ores, type of water and influence of collector, Lilafлот® D 817M is studied by a serial of froth characterization tests. The air flowrate is set to 3.0 L/min and the rotor speed to 950 rpm. Normally the airflow is stopped after 720 seconds. There is a big difference in froth formation and maximum height. The combination of ore type #2 and water type #2 generates so much froth that the column height is not enough. This combination is used in the test with the two different collectors Lilafлот® D 817M and Lilafлот® 628M; consequently the airflow and impeller speed had to be decreased

(1.3 L/min and 650 rpm) in order to enable the measurement of the froth height within the column.

The results of the froth tests are shown in Figures 2 to 4. The froth level is plotted every 20 seconds. The maximum growth which is defined by the airflow is plotted as J_g .

There is a difference in froth formation caused by the ore type as illustrated in Figure 2. The maximum froth height is increasing from 100 – 150 mm for Magnetite #1 to about 375 mm for Magnetite #2. In both tests process water #1 is used.

The froth formation follows the theoretical rate J_g quite close. A deviation between the J_g and the growth rate is observed which suggests that froth formation and breakage are occurring in the growth phase.

The froth for each ore reaches a maximum and stays there until the air injection is switched off. Both froths burst in a similar way, in other words, Magnetite #2 collapses faster in the beginning but as the time goes by it reaches the same rate of breakage as Magnetite #1.

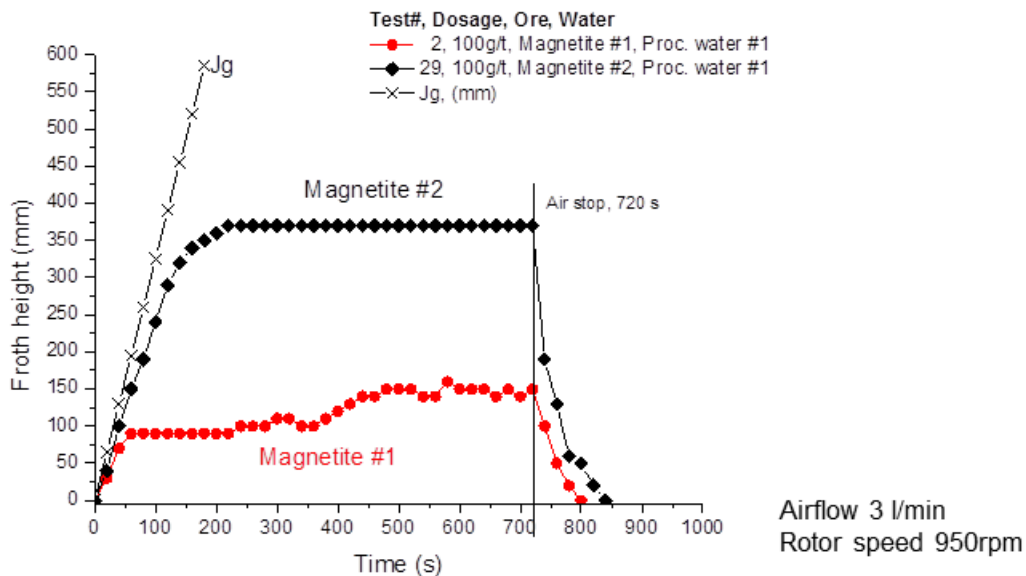


Figure 2. Effect of ore type on froth formation and bursting, mechanical agitator used in froth phase Collector Lilafлот D817M, dosage 100 g/t, process water #1.

Water quality plays a bigger role on both froth height and its stability rather than the magnetite ore type. By increasing the content of ions in water leads to a higher voluminous froth. Figure 3 depicts the results for the ore type Magnetite #1 only, due to the fact that the ore type Magnetite #2 generates too much froth so that no measure was possible to be taken. It can also be seen in Figure 3 that de-ionized water and process water #1 showed similar effect on froth formation, the maximum froth height reached 100-150 mm and the froth bursting is also quite similar. Process water #2 gives more froth formation; the maximum height 300-350 mm is reached after 200-300 seconds. The froth level is then stabilized for some time before it starts to collapse again down to a lower level where it stabilizes again.

When sea water is used a big difference is observed. The test had to be stopped when the froth reaches the maximum column height of 550 mm. The bursting rate is much slower compared with the other waters. The test is stopped when the height still is around 50 mm after about 1100 seconds of bursting time. The other tests are much faster; all froth has burst after 50 to 200 seconds.

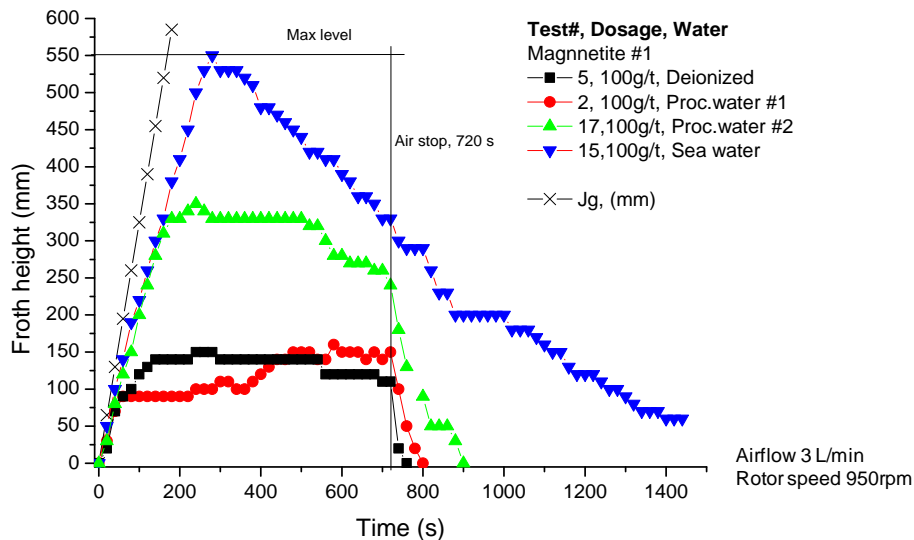


Figure 3. Effect of process water on froth formation and bursting, mechanical agitator used in froth. Collector Lilafлот D817M, dosage 100 g/t and ore type Magnetite #1.

Lilafлот® D 817M is used as collector in the previous tests and the froth properties varies a lot with the different magnetite ores and water qualities. Introducing the new collector Lilafлот® 826M shows that it is possible to reduce the froth formation as can be seen in Figure 4.

The metallurgical results by laboratory flotation using Lilafлот® 628M is presented in Table 3. The laboratory procedure for the flotation test is described by Gustafsson, Juberg.⁽⁵⁾ The silica grade is given as acid insoluble. The analytical sample is boiled in hydrochloric acid and the insoluble residue is weighted and defined as silica content. Fe grade and recovery is calculated by using the acid insoluble value. The results are therefore to be seen as indicative.

Table 3. Flotation results, Magnetite ore #2 in process water #2, Grade Silica as acid insoluble residue (A.I.).

Test	Reagent	Dosage, g/t		W- rec, %		Fe-rec, %		Grade Fe, %		Grade Silica, A.I.%	
40	Lilafлот D 817M	98	148	63.2	46.4	69.7	52.4	66.5	68.2	7.1	4.7
41	Lilafлот D 817M	96	144	64.2	44.5	71.0	50.6	66.7	68.5	6.8	4.3
58	Lilafлот 628M	99	148	64.3	48.2	70.0	53.8	66.8	68.6	6.7	4.3

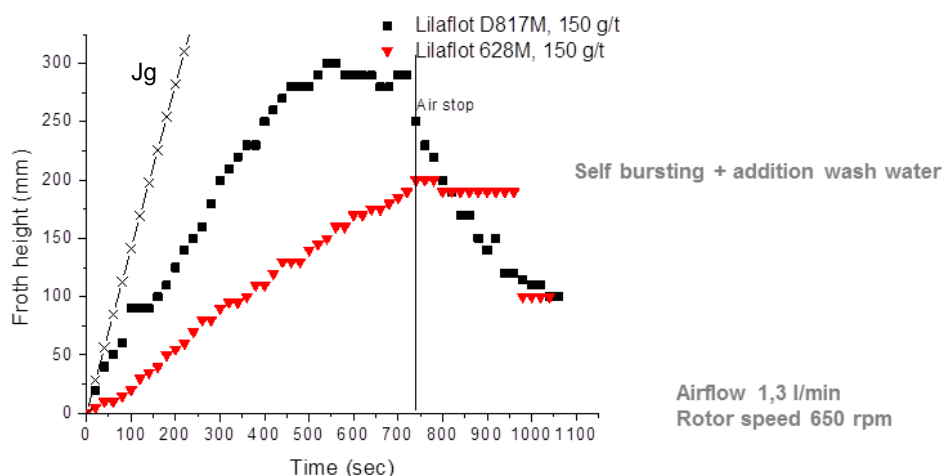


Figure 4. Effect of flotation collector Lilafлот D 817M and Lilafлот 628M, 150g/t, on froth formation and bursting, Magnetite #2 and process water #2 are used.

The tests illustrated in Figure 4 were done at lower airflow rate and rotor speed in order to keep the froth within the column height. When using a lower airflow it was observed an increase of the difference between Jg growth and actual froth growth. Lilafлот® 628M has a lower growth rate and maximum froth height compared with Lilafлот® D 817M. The lower growth rate indicates that the bursting is faster for Lilafлот® 628M. In this test there is no mechanical stress applied to the froth by the slowly rotating agitator. Only self-bursting and adding of wash water is used. The time of bursting is longer and there is still a lot of remaining froth (100 mm) when the test is stopped after about 1000 seconds. This is a typical behavior when self-bursting is used to be compared with the other tests where the froth is agitated during the bursting phase.

4 CONCLUSION

The introduction of batch-wise froth measurement with the froth characterization column has improved the possibility to evaluate froth properties by allowing the measurement of maximum froth height, velocity of formation and bursting. The method can be further developed and fine-tuned. The results obtained in this work show that the new product Lilafлот® 628M generated less froth than the Lilafлот® D817M. Besides, the results also show that the ore type, the water quality and the type of collector used have a great impact on the froth properties.

The methodology developed in this work by the AkzoNobel team can be used as an useful tool to complement the traditional laboratory flotation tests currently used worldwide.

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