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FEED AIR JET – A CAVITATION SPARGER SYSTEM FOR ENHANCED FLOTATION RECOVERY[1]

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Abstract

Cavitation is a process of formation, growth and subsequent collapse of gas and/or vapor-filled cavities, or microbubbles, in a fluid. Several fundamental studies about this phenomenon have shown that microbubbles generated on mineral surfaces facilitate bubble-particle attachment, and ultimately improves flotation performance. This work presents the Feed Air Jet, a feed pre-aeration cavitation sparger system developed by Eriez. Using coal, cavitation was applied to a flotation feed stock studied in laboratory setting in the USA. This feed pretreatment technique resulted in a significant increase in recovery and flotation kinetics. The Feed Air Jet was also installed at an industrial plant in Brazil and enhanced the overall metallurgy by increasing the mass recovery of the iron (Fe) values while reducing the amount of entrained iron in the tailings stream.

Key words: Feed air jet; Cavitation; Pre aeration; Flotation.

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1 INTRODUCTION

Froth flotation is a process widely used to selectively separate mineral particles according to their surface properties. This process is also used for the separation of iron ore from silica and other gangue material. The iron ore flotation process started from direct anionic flotation, which was later largely replaced by the more efficient reverse cationic flotation route, where silica and other impurities are floated and removed with the froth, while iron ore concentrate is collected as the underflow.

Flotation has been studied for more than 100 years and several developments have been made since then. However, the efficiency of the process, especially product mineral grades and recoveries, is dependent on several factors, including, but not limited to, particle size, particle hydrophobicity, pulp hydrodynamics, aeration, bubble size, froth thickness and mobility, froth stability, and the chemical environment in the pulp and on particle surface. Most of these factors are interdependent and, as a result, optimization can be a challenge.

One of these challenges involves the increase in flotation recovery of coarse and fine material. Actually, it is well known that coarse and fine particles typically present lower recovery than particles of intermediate size.[1] This is due to two different phenomena. Coarse particles are simply more massive and less buoyant and require stronger superficial forces to keep their link to the rising air bubbles. In other words, coarse particles will require a higher level of hydrophobicity to overcome the greater detachment forces that are generated due to their weight. For fine particles, the reason is different. Decreasing particle size results in a decrease in collision efficiency as particles are not able to deviate from fluid streamlines to collide with bubbles. Put differently, fine particles possess insufficient kinetic energy to displace the intervening liquid layer between the colliding particle and bubble. [2]

Common approaches used to optimize and improve the flotation recovery of both coarse and fine particles include increasing agitation to improve collision rates of fine particles and/or increasing collector dosage to promote greater hydrophobicity for coarse particles. Unfortunately, these approaches may conflict with one another and be counterproductive. For instance, increasing agitation in a flotation cell can disrupt the coarse particle-bubble aggregates and ultimately increase detachment. Similarly, excess collector can favor the flotation of gangue (in case of direct flotation) or valuable mineral (in case of reverse flotation), and ultimately reduce concentrate grade and/or recovery.

Therefore a means to simultaneously improve the kinetic efficiency of flotation of all size classes must be developed. Research efforts by the Eriez Flotation Division have shown that one such novel method includes the use of cavitation to promote bubble-particle attachment. This work presents results of laboratory studies on cavitation pre-treatment of coal and of the Feed Air Jet, a cavitation sparger system developed by Eriez, applied to iron ore flotation.

Cavitation is a process of formation, growth and subsequent collapse of gas and/or vapor-filled cavities, or microbubbles, in a fluid. One of the mechanisms to generate cavitation occurs when the pressure in a specific point of a fluid is reduced to below its vapor pressure. As a result, a void filled with vapor (i.e., a very small bubble) will be created, to compensate for the low pressure. Local pressure differences can be created through ultrasonic energy, laser energy or through changes in liquid velocity. In this last case, the phenomenon is called hydrodynamic

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cavitation[3]. In the absence of any stabilization factor, bubbles will collapse when pressures increases back to its initial state.

Microbubbles are highly energetic and their attachment to particles is faster and stronger than bubbles of a larger size. A possible reason for this effect is that tiny bubbles have a high surface energy seeking to be released which can be achieved through the bondage to mineral surface [4]. Microbubbles do not have the force to suspend the particles; however, several fundamental studies have shown that microbubbles generated on mineral surfaces through cavitation facilitate the attachment of bubbles of typical flotation size (~0,1-1-mm) and improves flotation performance**.**

For coarse particles, the most accepted attachment mechanism considers that once microbubbles become strongly locked on a solid surface, the attachment between a bubble and the solid occurs through the coalescence of the bubble with several microbubbles on the solid [5]. The coalescence results in an increase in contact area, because the contact base of the tiny bubbles with the solid cannot be moved easily [1]. Therefore, the final bondage is stronger, and may ultimately reduce the amount of collector required for attachment. For fine particles, the microbubbles act as bridge among several particles, forming larger aggregates which, due to the apparent increase in size, present a higher probability of effective collection with the larger bubbles generated by the sparging device.

The cavitation pre-treatment and the operation of Feed Air Jet are based on the same principle of a Venturi tube and is illustrated in Figure 1. As liquid passes through the cylindrical throat, it is higher in flow velocity and lower in pressure than the liquid at the entrance of the sparger, thereby resulting in cavitation. The differential pressure between the entrance of the sparger and the cylindrical throat measured by manometers is indicative of cavitation behavior. The presence of tiny pockets of undissolved gas in crevices and cracks on the mineral particles assists the cavitation as a result of the expansion of these gas pockets under the negative pressure. Addition of organic chemicals such as frothers produces smaller and more copious microbubbles by stabilizing the cavity and preventing bubble collapse and coalescence. In the Feed Air Jet, additional air injection allows for the formation of bubbles of a size typical for mineral flotation.

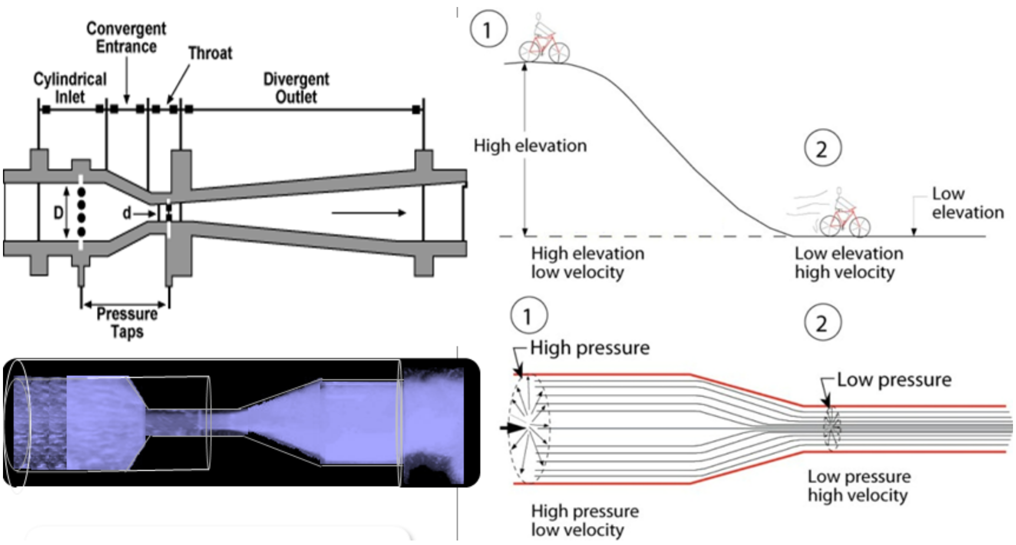

Figure 1. Diagram showing the pressure difference in a cavitation tube and effect on bubble size

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In this work, the effect of cavitation on flotation feed was tested on a laboratory scale for coal concentration in the USA. In addition, the Feed Air Jet was installed at an iron ore concentration plant at Companhia Siderúrgica Nacional – CSN, Brazil, to investigate the metallurgical improvements that can be realized through cavitation pretreatment of a mineral slurry.

2 MATERIAL AND METHODS

2.1 Laboratory-Scale Tests

A coal sample was acquired from a mining operation in Boone County, West Virginia, operated by Newtown Energy. The coal was from the Coalburg seam and is commonly characterized as having poor flotation characteristics due to oxidation. The samples were acquired from the operating plant and were considered flotation feed. No crushing or grinding was required prior to testing. For the laboratory scale tests, two samples were used, one from Boone County and other from Kanawha County. Tests were performed using a lab conventional flotation cell and a laboratory-scale column.

For the tests using the conventional cell, the coal slurry was suspended within a stirred tank with just enough mixing energy to maintain the slurry in suspension. As seen in Figure 2, the slurry was then pumped through a Cavitation Tube at sufficient pressure to induce hydrodynamic cavitation. Before entering the Cavitation-Tube, air was injected and the flow and pressure was measured utilizing simple pressure gauges and a rotameter. After the cavitation pretreatment, the pulp was conveyed to the bench-top flotation cell. The flotation tests were conducted in 4,3L Denver, D12 bench-top float cell using common diesel fuel as a collector and a glycol-based frothing agent. Samples of froth were collected in carefully timed fractions to evaluate kinetics. The conditions are summarized in Tables 1 through 3.

Table 1. General conditions for laboratory flotation using conventional cell

Cell Volume	4,3 L
Feed Solids Content	6%-8%
Collector Rate	250-500 g/tonne
Frother Rate	10-25 ppm
Conditioning Time	Collector: 15 min. Frother:1 min.
Cavitation-Tube	CT-100

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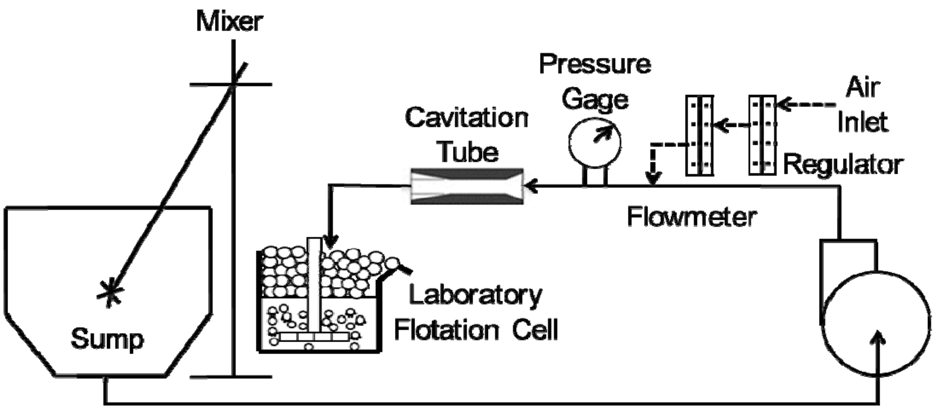

Figure 2. Scheme for lab flotation tests using bench-top conventional cell.

Table 2. Conditions for laboratory flotation using conventional cell for Boone County coal

Cavitation	**Collector (lb/t)**	**Frother (ppm)**
Without cavitation	0,5	10
With cavitation	0,5	10
Without cavitation	1,0	10
With cavitation	1,0	10
Without cavitation	1,0	25
With cavitation	1,0	25

Table 3. Conditions for laboratory flotation using conventional cell for Kanawha Coal

Cavitation	**Collector (lb/t)**	**Frother (ppm)**
Without cavitation	0,5	20
With cavitation	0,5	20
Without cavitation	1,0	10
With cavitation	1,0	10
Without cavitation	1,0	20
With cavitation	1,0	20

For the tests using column, coal pulp was prepared similarly as with the convention cell. In this case, after mixing in the stirred tank, the slurry pumped through the Cavitation Tube and a portion was directed to the laboratory-scale column as shown in Figure 3. In this case, the non-used portion was returned to the stirred tank. In these tests, a column measuring 75-mm diameter was utilized. Diesel fuel was utilized as a collector and a glycol-based frother was used to stabilize the bubble suspension. The conditions are summarized in Table 4.

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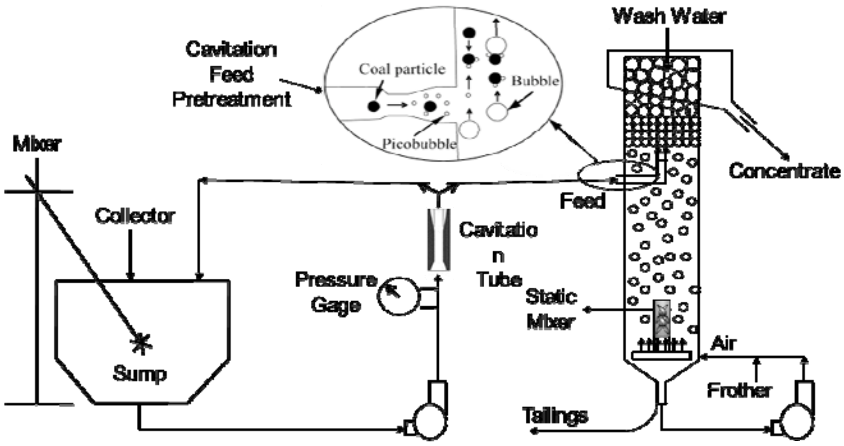

Figure 3. Scheme for lab flotation tests using columns.

Table 4. Conditions for laboratory flotation using column

Feed Rate(L/min)	0,3 to 2
Feed Solids Concentration	6% and 8%, respectively
Bias Factor	0,75
Collector Rate	500 g/tonne
Frother Rate	30 ppm
Superficial Gas Velocity	2 cm/s
Volumetric Wash Water	400 ml/min

2.2 Industrial Tests

Casa de Pedra is an iron ore mining operation of Companhia Siderurgica Nacional, CSN, located in Congonhas, in Minas Gerais State, Brazil. Reverse flotation is performed in columns and silica is collected in the froth. Full-scale evaluations were performed on samples from two different stockpiles, using a 4-m diameter and-10 m height rougher column. The ore treated was typical flotation feed and was generally 50%<44µm in size and is treated at 45% solids.

For these tests, a customized Feed Air Jet was fabricated to be easily incorporated into the CSN circuit so as not to impact product throughput if the tests did not provide the expected results. Also, to guarantee pumping control and a more precise reagent addition, instead of pumping ore pulp through the cavitation tube, water with a small amount of frother was submitted to cavitation and this flow was added to the pulp flux. This water was just displaced from another addition point and did not affect overall solid percentage in the whole circuit. This approach was considered the most viable to apply the cavitation concept to the CSN industrial column due to project scope and specific industrial circuit constraints. In this case, cavitation would generate microbubbles in water which would keep their smaller size reasonably stable by the added frother. These microbubbles, when added to the pulp, would have higher energy level to promote faster and stronger particle-bubble adhesion. Then, even not passing the pulp through the cavitation tube, this customized Feed Air Jet would be able to improve flotation performance.

The conditions are summarized in Table 5. Figure 6 shows a picture of Feed Air Jet and how it was assembled at CSN for testing.

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Table 5 . Conditions for industrial flotation tests

Column Feed Rate (m^3/h)	240 m^3/h
Feed Solids Concentration	45%
Collector Rate	60g/t
Frother Rate	2g/t
Air flow rate at feed air jet	45 Nm^3/h
Air pressure	2,5 kg/cm^2
Water flow rate	40 m^3/h

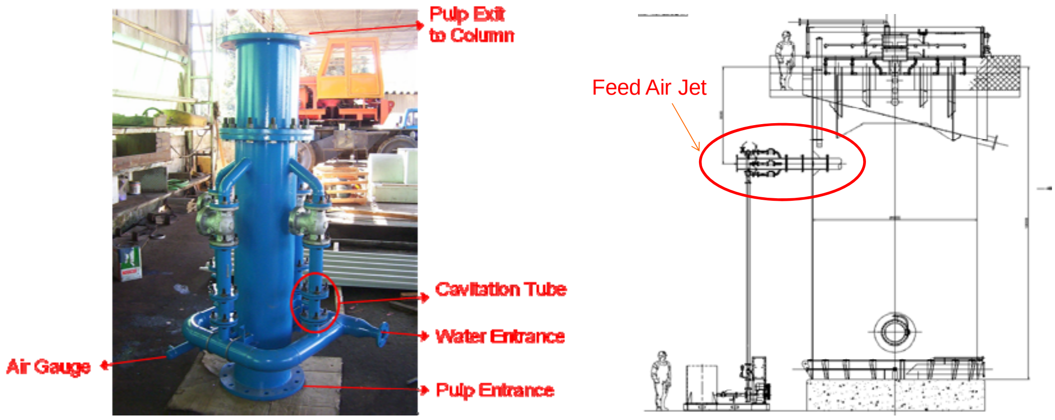

Figura 6. Photo of Feed Air Jet and scheme used for industrial flotation. Tests.

3 RESULTS

3.1 Laboratory Tests

3.1.1 Conventional cell testwork - coal

Kinetic results from the bench-top coal tests showed higher recoveries for all conditions tested and for each coal sample as seen in Figure 7. These results show a noticeable improvement in overall recovery and in flotation rate. Combustible recoveries increased anywhere from 6% to 17%. In addition, and as seen in Tables 6 and 7, the rate of flotation was also increased significantly, varying between 20 and 38%.

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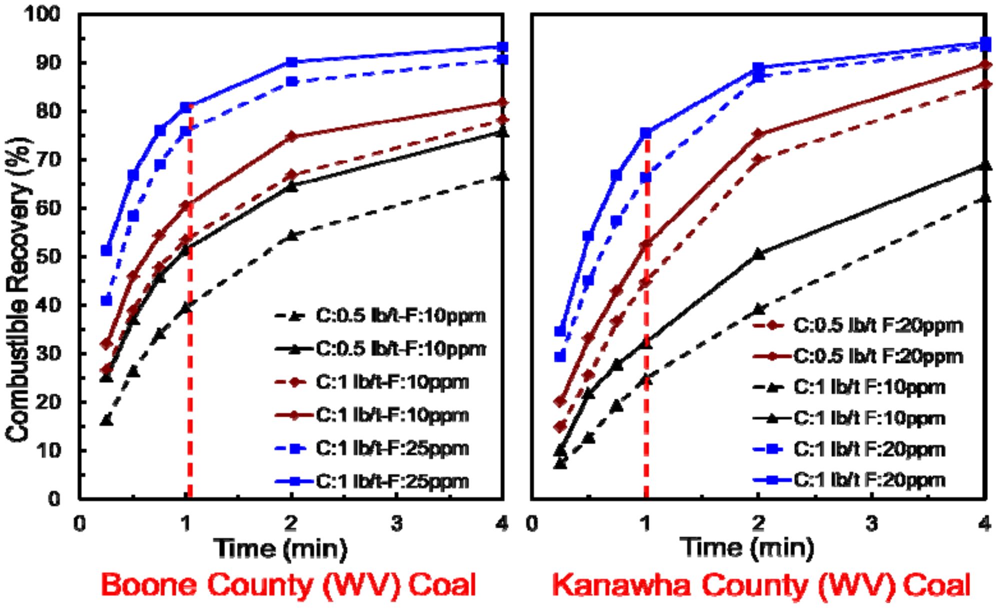

Figura 7. Results of kinetic flotation tests in conventional cells– Dashed lines indicate tests without cavitation. Solid lines correspond to tests with cavitation

Table 6 . Kinetic results for tests with conventional cells for Boone County coal

Test Identification (0-1min.)	**Flotation Rate (min^{-1})**	**Flotation Recovery (%)**	**Increase in rate**	**Increase in recovery**
Without Cavitation – C:1lb/t- F:10ppm	0,72	53,5	38%	13%
With Cavitation – C:1lb/t-F:10ppm	0,99	60,5		
Without Cavitation – C:1lb/t-F:25ppm	1,53	75,9	20%	6%
With Cavitation – C:1lb/t-F:25ppm	1,84	80,8		

Table 7 Kinetic results for tests with conventional cells for Kanawha County coal

Test Identification (0-1min,)	**Flotation Rate (min^{-1})**	**Flotation Recovery (%)**	**Increase in rate**	**Increase in recovery**
Without Cavitation – C:0,5lb/t-F:20ppm	0,60	44,7	25%	17%
With Cavitation – C:0,5lb/t-F:20ppm	0,75	52,3		
Without Cavitation – C:1lb/t-F:20ppm	1,13	66,5	29%	14%
With Cavitation – C:1lb/t-F:20ppm	1,46	75,5		

3.1.2 Column testwork - coal

The tests conducted on the laboratory column cell also showed a significant increase in recovery for all feed rates, and all residence times. For a rate of 1000 ml/min, the increase in recovery was approximately 12% for the Boone County coal and about 8,5% for the Kanawha County sample as seen in Figure 8 .

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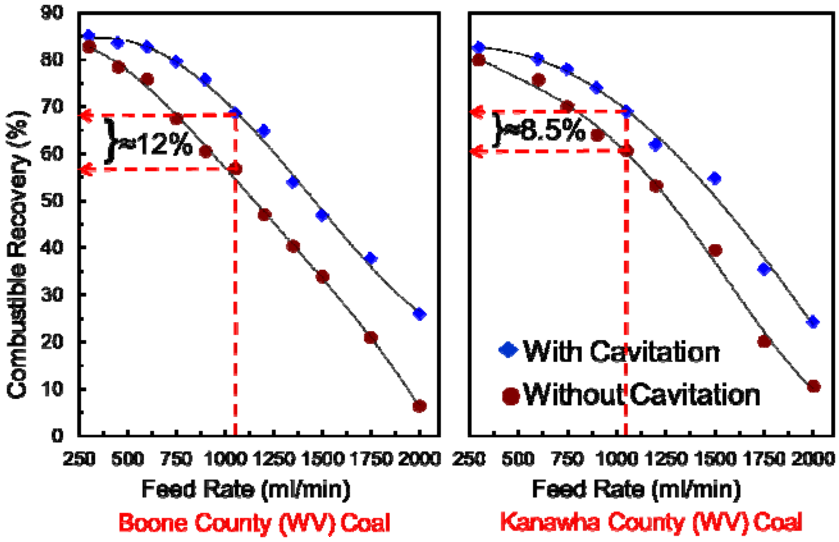
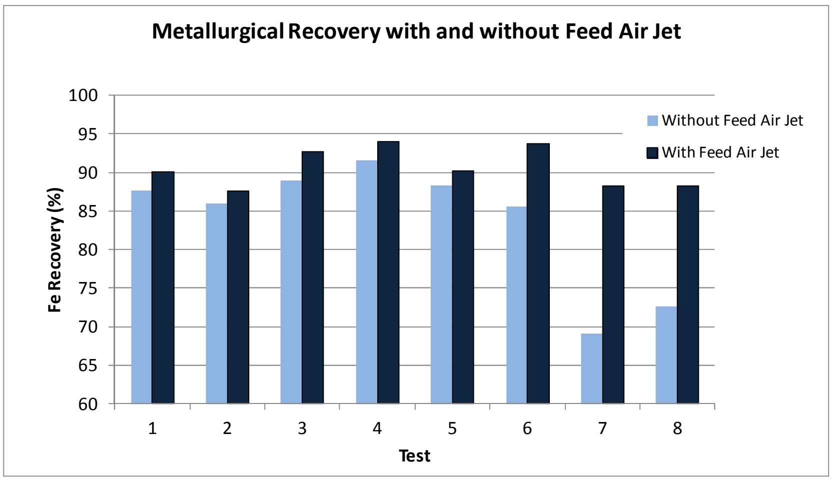


Figure 8. Results of flotation tests in laboratory-scale column.

3.2 Industrial Tests

The industrial-scale tests showed an increase in iron recovery for both samples while the amount of entrained iron in the froth was decreased. On average, iron recovery increased about 6 percentage points and mass recovery increased around 5 percentage points. It was also noted that the iron content in froth tailings and silica content in iron concentrate were reduced indicating an improvement in selectivity. Figures 9 to 11 present the main results.



Source: CSN

Figure 9. Metallurgical recovery in industrial tests with and without Feed Air Jet.

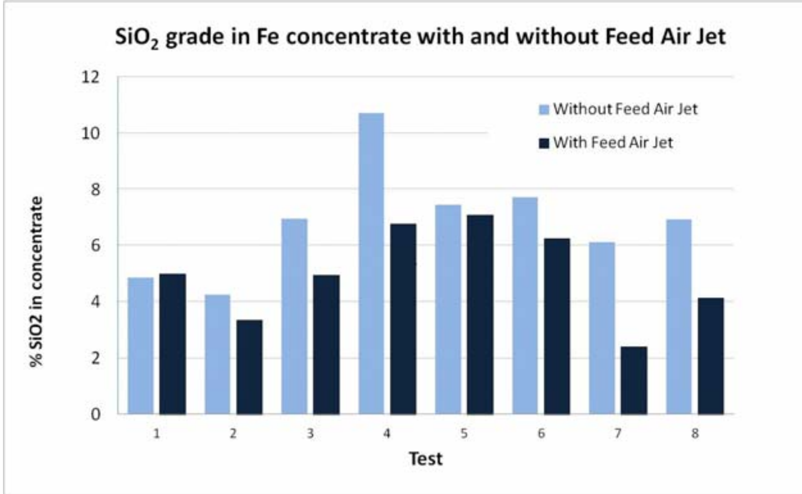


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Figure 10. Average SiO_2 grade in concentrate in industrial tests with and without Feed Air Jet.

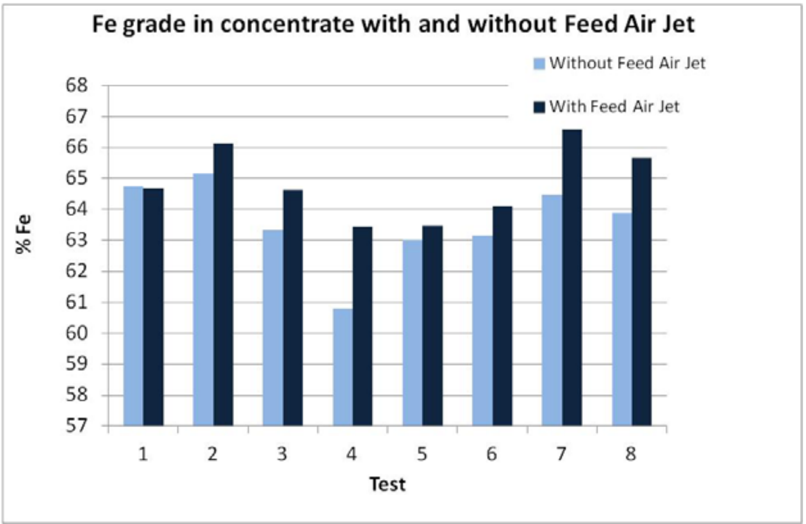

Figure 11. Average Fe grade in concentrate in industrial tests with and without Feed Air Jet.

4 DISCUSSION

4.1 Laboratory Tests

As expected from theory, the use of cavitation promoted a faster coal flotation process. This finding implies that lower retention times can be utilized to achieve the same recovery when compared to the same process without cavitation. The difference in flotation rate was more significant at the on-set of the concentration process and lessened as the sample was exhausted. This finding indicates that cavitation facilitated the concentration of very hydrophobic particles and may prove beneficial in circuits that are currently overloaded or that are kinetically limited.

In the tests using the conventional cell, it was possible to verify that for the Boone County sample, with the lower frother dosage of 10ppm, the effect of using cavitation was nearly equivalent to an increase of collector dosage of 100%. This can be seen in Figure 7 where the kinetic curves of these two conditions are compared. For this sample, frother dosage also had an impact on the flotation rate and an increase from 10 to 25 ppm generated an improvement in both recovery and rate. Regardless, equivalent tests with cavitation provided superior results. The increase in

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flotation rate varied from 20% to 38% and increased combustible recovery from 6% to 13%.

The same trend was achieved when using the column flotation cell or for the results achieved while utilizing the Kanawha County sample. The increase in frother dosage improved rate and recovery, but in all cases, the gains achieved using cavitation were superior. It can be seen that reagent dosage had a relevant impact on results, but irrespective of this effect, cavitation provided a better improvement.

4.2 Industrial Tests

Industrial tests using the Feed Air Jet at CSN provided an increase of around 6 percentage points in total iron recovery, lowering the iron floated to tailings while promoting silica flotation. Considering that, in these tests, cavitation was applied to water with a small amount of frother, results were very effective, most probably due to the formation of the small microbubbles.

Smaller bubbles are more avid for hydrophobic particles, as it was demonstrated in the work of Dziensiewicz and Pryor[6], where smaller bubbles attached much more readily to a polished hydrophobic surface than large bubbles. One possible mechanism to explain this phenomenon is related to the higher surface free energy of smaller bubbles, that leads to a faster attachment to hydrophobic particles associated to energy release [4]. In this case, the microbubbles generated by cavitation and added to the pulp must have presented a faster and more specific interaction with silica. It is surmised that collection was more selective for silica, which ultimately reduced the silica content in concentrate while allowing for increases in iron recovery.

Additionally, when using the cavitation process for aeration, the bubble size is smaller nearest the froth/pulp interface. Throughout the froth zone, bubbles coalesce becoming larger on froth top. Some of the weakly attached particles – generally the least hydrophobic ones- detach due to the oscillation caused by the coalescence process and drain. Considering that most reattachment occurs in the froth pulp interface[7], the smaller bubbles near this interface will likely improve the selective reattachment of silica. As a result, the iron can be more effectively drained and released from the froth through the use of wash water.

5 CONCLUSION

The use of cavitation effectively provided higher recovery and flotation rates for the coal samples in laboratory for all reagent conditions tested. The separation process was faster and ultimately resulted in lower retention times given the same level of combustible recovery. The data also suggests that for a specific level of recovery, cavitation can reduce reagent requirements.

Feed Air Jet demonstrated the positive effects of cavitation and small bubble generation when applied in an industrial operation for iron ore, generating recovery gains of around 6 percentage points

Results of this work show that, when properly applied, the use of cavitation can lead to reductions in equipment size, higher recoveries or to lower reagent consumption.

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