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OPTIMIZING DISSOLVED AIR FLOTATION DESIGN SYSTEM

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Abstract - Dissolved Air (Pressure) Flotation-DAF, is a well-established separation process that employs micro-bubbles as a carrier phase. This work shows results concerning bubble generation at low working pressures in modified DAF-units to improve the collection of fragile coagula by bubbles. DAF of Fe $(OH)_3$ (as model) was studied as a function of saturation pressure in the absence and presence of surfactants in the saturator. DAF was possible at 2 atm by lowering the air/water surface tension. This fact, which leads to substantial energy savings, was explained in terms of decreasing the "minimum" energy required for bubble nucleation and cavity in the nozzle. More, bubbles-fragile coagula attachment was improved by dividing the recycling water into two: 1) the inclined inlet to the cell (traditional) and 2) inside the separation tank through a water flow inlet situated below the floating bed using a "mushroom" type diffuser. Because of the reduction observed in the degree of turbulence in the conventional collection zone, DAF performance improved yielding high precipitate recoveries.
Keywords: flotation; precipitate; air saturation system; surfactant

INTRODUCTION

Flotation had its beginning in mineral processing and as such has been used for a long time in solid/solid separation applications using stable froths to recover the mineral particles (Kitchener, 1982). Flotation can be incorporated with wastewater-treatment schemes in the following ways:

(1) As a unit process for removing contaminants not separated by other processes. Examples are found in the removal of metal ions from dilute solutions of the ions and in the selective separation of valuable ions (Rubio, 1998; Féris et al., 1998; Tessele et al., 1998; Da Rosa et al.,1999);

(2) As a pre-treatment unit ahead of primary sedimentation, a rougher-flash unit;

(3) As a primary treatment unit ahead of secondary treatment units, such as bio-oxidation lagoons;

(4) As a unit process for sludge thickening.

Those flotation applications include mainly the treatment of waste water but also microorganisms, coal, clays, corn, resin, proteins, fats, rubber, dyes, glass, plastics, etc (Matis, 1995; Smith, 1989).

Many factors influence the flotation process and the most important are: air hold-up, bubble size distribution and carryover, degree of agitation, residence time of bubbles in pulp, solids content, particle size and gravity, shape of particle, processing of the floated product, hydration of the solid surface, and flotation reagents (Matis, 1995; Rubio, 1998).

For many applications of flotation in the waste water treatment field, it is more efficient to use micro-bubbles generated by nucleation of dissolved air, rather than the dispersed air method used for minerals. Flotation offers process advantages over sedimentation, including better treated-water quality, rapid startup, high rate operation, and thicker sludges. DAF is considered not only an alternative to sedimentation plants, but also a clarification method to improve filtration.

In dissolved air flotation (DAF), the water saturated with air under pressure (higher than 3 atmospheres) passes through a nozzle whereby the bubbles are formed and reach the flotation chamber, which is at atmospheric pressure. The air becomes supersaturated and precipitates out of solution in the form of tiny bubbles. In industrial scale, the supersaturated water is forced trough needle-valves or special orifices, and clouds of bubbles having 0.01-0.15 mm in diameter are produced just down-stream of the constriction (Solari and Gochin, 1992; Bratby and Marais, 1977).

Because of the relatively small tank area and volume required in DAF installations compared with traditional settling plants, the capital cost is generally low. The total cost is largely determined by non-process factors, such as site conditions and costs of building works (Crocket and Muntisov, 1995).

The main disadvantage of DAF is the high-energy consumption compared to coagulation-sedimentation-filtration plants. Common operating saturation pressures range between 3 and 6 atmospheres and this stage is usually very costly. The energy consumption to pressurize the air saturated water for the dissolved air flotation process is in the range 0.01-0.02 $kw.hkL^{-1}$ compared with total plant usage, usually ranging between 0.02-0.04 $kw.hkL^{-1}$, depending on pumping involved (Crocket and Muntisov, 1995; Ives and Bernhard, 1995).

In the work reported, DAF studies were conducted to find out conditions to reduce the working pressure improving the bubble generation system. This was performed by lowering the air/fluid interfacial tension in the saturator and in the nozzle, where the bubbles are formed.

More, studies were conducted to compare the effect of different bubble diffusers and their position on the bubble-particle attachment. The traditional DAF geometry, with a bubble diffuser located in the inclined inlet to the cell as well as a "mushroom" type diffuser inside the separation cell were studied. The aim was to reduce aggregates breakage upon turbulence in the first diffuser.

Experimental runs were carried out on a DAF pilot unit, to separate $Fe(OH)_3$ precipitates, and the process efficiency was monitored by measuring the residual content of metal and the supernatant turbidity. This was studied as an example of removing colloidal and fragile precipitates.

EXPERIMENTAL

Materials and Reagents

Reagents. $FeCl_3.H_2O$ was used as solute to form the hidroxo-precipitates. Sodium Oleate was used to modify the solution/air surface tension. Solution pH was adjusted using NaOH.

Methods

Dissolved Air Flotation, DAF

DAF tests were carried out using batch and pilot units (Figure 1 and 2). Process efficiency was evaluated by measuring the residual content of metal (using atomic absorption) and supernatant turbidity (nephelometer HACH model 2100). The surface tension was monitored with a tensiometer (Krüss model 8431).

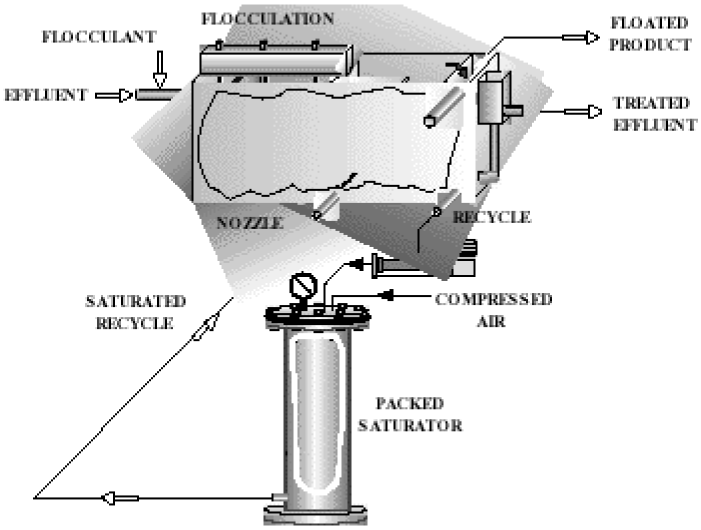

Figure 1: Dissolved Air Flotation (DAF) pilot unit.

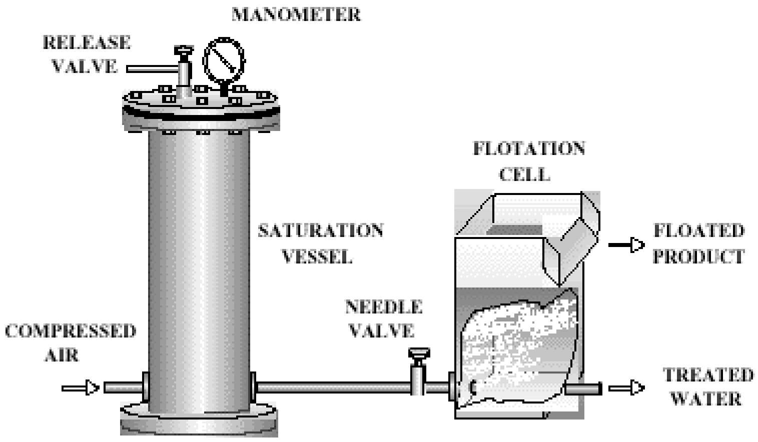

Figure 2: Batch Dissolved Air Flotation (DAF) unit. 1.5 L flotation cell and a 2.2 L saturator.

Figure 3 shows the DAF modified unit endowed with the two different types of diffusers.

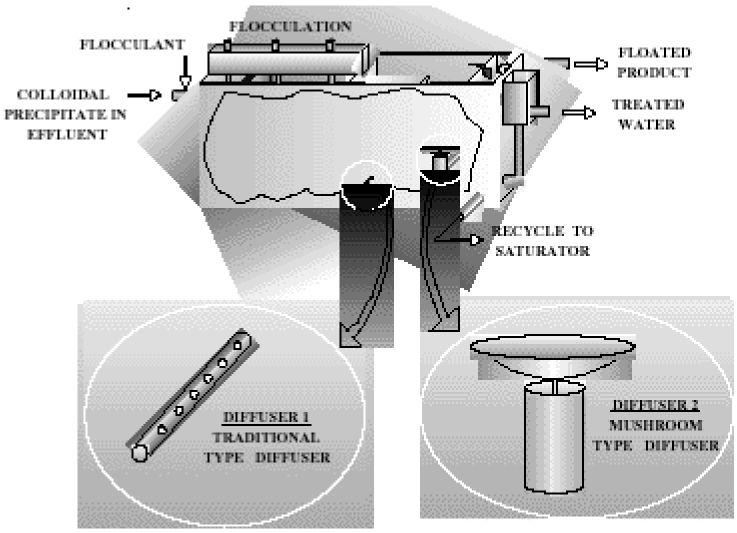

Figure 3: DAF unit showing both the traditional and the mushroom type diffusers.

RESULTS AND DISCUSSION

Effect of Surface Tension

The addition of a surfactant in the pressurized water to lower the air/water surface tension in the saturator highly improved the separation process. As shown in Table 1 and Figure 4, without surfactants, the minimum saturation pressure required for DAF to occur was found to be 3 atm.

Table 1: Removal of $Fe(OH)_3$ by DAF (batch) without surfactants in the saturator. Conditions: pH ≅ 7; R=20%. ***1 atm = 1.13.10^5 Pa.***

Pressure (atm)	Ion concentration (mg/L)		Removal (%)	Turbidity (NTU)		Flotation rate (cm/s)
	Initial	Final		Initial	Final	
1.8	30.6	30.6	0	3.9	4.4	0
2	29.9	29.9	0	2.6	2.5	0
3	29.6	2.1	93.0	2.4	1.7	0.13
4	29.9	1.0	96.5	2.2	0.8	0.14

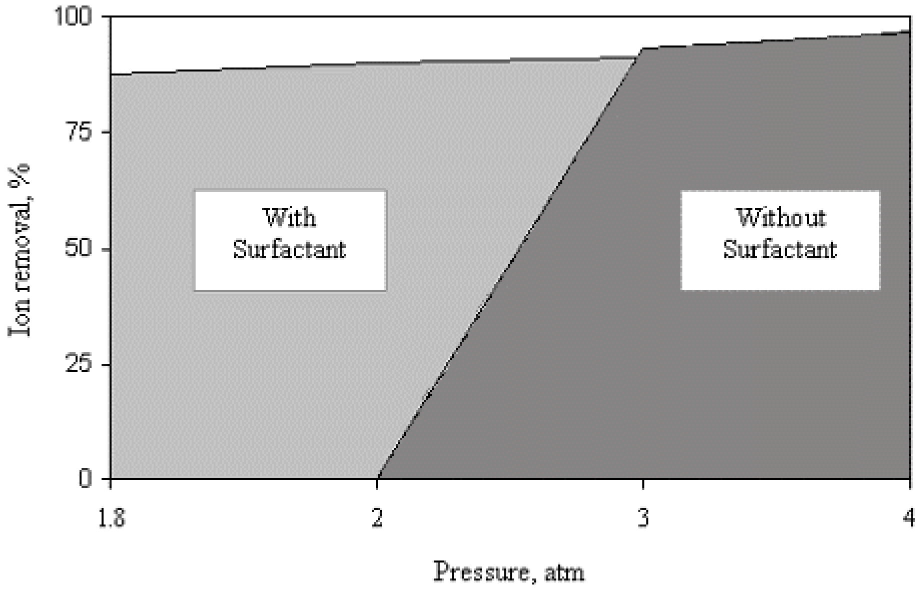

Figure 4: Effect of Sodium Oleate addition (15 mg/L) on removal of $Fe(OH)_3$ by DAF (batch) as a function of saturation pressures. Conditions: pH ≅ 7; R=20%.

But, by lowering the air/water surface tension in the saturator, DAF was possible at 2 atm saturation pressures. This behavior was found to occur in batch and pilot DAF operation tests. Dissolved air flotation takes advantage of the effect of pressure on the solubility of gases in liquids. At high pressure more gas is soluble in the liquid than at lower pressures, meaning that the extra gas dissolved at high pressure must come out of solution when pressure is reduced. Regarding the micro-bubbles, when the discharge or transfer pressures increases, there is a bubble size decrease and an increase of the number of bubbles. The excess pressure over the friction loss has shown to provide the energy for bubble nucleation and surface formation. In pure water only (not much pressure transfer), large bubbles are formed but the addition of a small amount of a surface active agent provides low energy nucleation sites such that very minute bubbles, with a cloud-like appearance are generated.

This explains the fact that DAF operating at 2 atm or less, does not provide sufficient energy to overcome attrition and nucleation to yield bubbles. The visual result is that no bubble formation occurs at 2 atm saturation pressure with common tap or distilled water.

Yet, studies on bubble growth and nucleation reported by Takahaschi et al. (1979) show that the minimum "energy", ΔF, to be transferred to the liquid phase to form bubbles by a cavity phenomenon (arising from the liquid turbulence), is given by the following equation:

$$\Delta F = \frac{16}{3} \cdot \pi \cdot \gamma^3 \Big/ (P_o - P_a)^3 \qquad \text{(Joules)} \qquad (1)$$

Where

γ = Air/Water surface tension (Nm^{-1});

P_a = Atmospheric pressure (atm or Pascal units);

P_o = Saturation pressure (atm or Pascal units)

This equation shows that the energy transferred to form micro-bubbles will be smaller when lower is the air/liquid interfacial tension and higher the pressure difference of the liquid phase with respect to the atmospheric. Thus, by lowering the air/liquid interfacial tension, smaller will be the liquid/solid attrition, higher the flow fluid velocity and faster the kinetic of bubble formation. Recently, Dupre et al. (1998) reported that DAF users observe a reduction in the diameters of the bubbles in the tanks when using "polyelectrolytes" and consider this and the use of surfactants a complex matter. However, no approach or mention on the energy transfers phenomena in the bubbles formation were considered.

Effect of Type and Position of Diffusers

Table 2 shows results of DAF of iron hydroxides under various conditions using the traditional and the "mushroom" type diffusers separately (see Figure 5).

Table 2: Removal of $Fe(OH)_3$ by DAF (pilot unit) with sodium oleate addition to the saturator. Conditions: pH=5; Q_e = 4 L/min, R=20%, P = 3 atm, 30.5 mg/L sodium oleate.

T (min)	Ion concentration (mg/L)		Removal (%)		Turbidity (NTU)	
	TD *	MD	TD	MD	TD	MD
0	57.2	48.4	0	0	17.3	18.9
15	1.5	1.3	97.2	99.2	4.2	4.8
30	1.3	0.4	97.6	98.8	4.9	3.3
45	1.1	0.6	98.0	99.0	4.7	2.2
60	1.1	0.5	98.0	99.0	4.4	1.8
75	2	0.6	96.5	99.0	4.9	3.4
90	1.6	0.6	96.7	98.8	4.9	3.0

* TD = Traditional Diffuser; MD = *Mushroom* Diffuser.

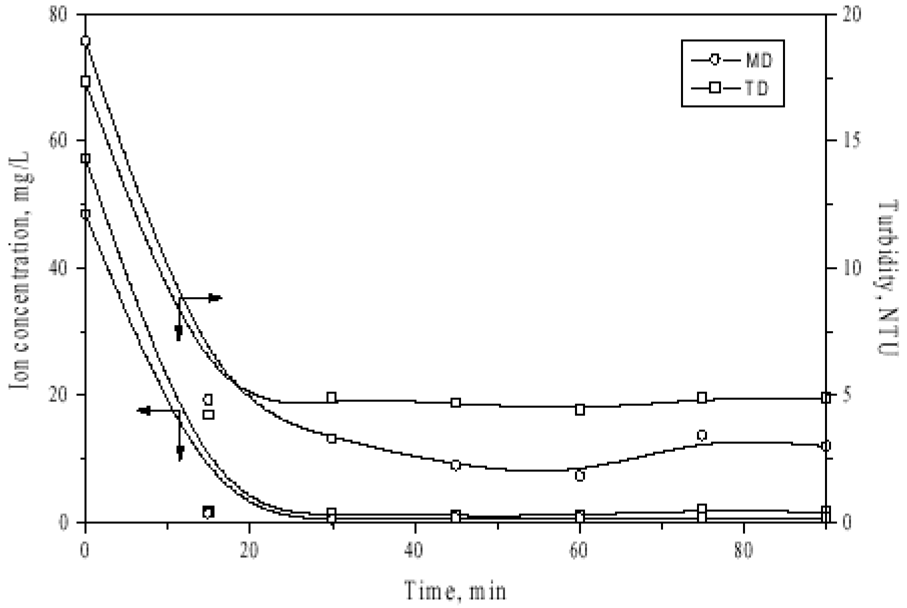

Figure 5: Effect of Sodium Oleate addition on flotation kinetics of $Fe(OH)_3$ by DAF. Conditions as in Table 2.

Table 3 and Table 4 show the results obtained in DAF operation at pressures lower than 3 atm (see Figure 6) using both diffusers at the same time (50 % each flow). This modification enhances the solid/liquid displacement rate and the collection of fragile coagula by bubbles, avoiding its rupture. By reducing the flux, in the inclined part, a significant reduction in turbulence was observed. Here the flux was required to "rise" the precipitates to the floating layer.

Table 3: Removal of $Fe(OH)_3$ by DAF using both diffusers (pilot unit) with sodium oleate addition to the saturator. Conditions: pH=5; Q_e = 4 L/min, R=20%, P=2.5 atm, 30.5 mg/L sodium oleate.

T (min)	Ion concentration (mg/L)	Removal (%)	Turbidity (NTU)
0	30	0	12.7
15	0.9	97.0	3.1
30	0.8	97.3	2.4
45	0.7	97.7	2.1
60	0.8	97.3	3.9
75	1.3	95.6	4.3
90	1.3	95.6	3.4

Table 4: Removal of $Fe(OH)_3$ by DAF using both diffusers (pilot unit) with sodium oleate addition to the saturator. Conditions: pH=5; Q_e = 4 L/min, R=20%, P=2 atm, 30.5 mg/L sodium oleate.

T (min)	Ion concentration (mg/L)	Removal (%)	Turbidity (NTU)
0	28.5	0	16.1
15	1.3	95.4	4.2
30	0.8	97.1	4.8
45	0.7	97.5	3.8
60	0.9	96.8	3.5
75	1.4	95.0	4.3
90	1.7	94.0	4.7

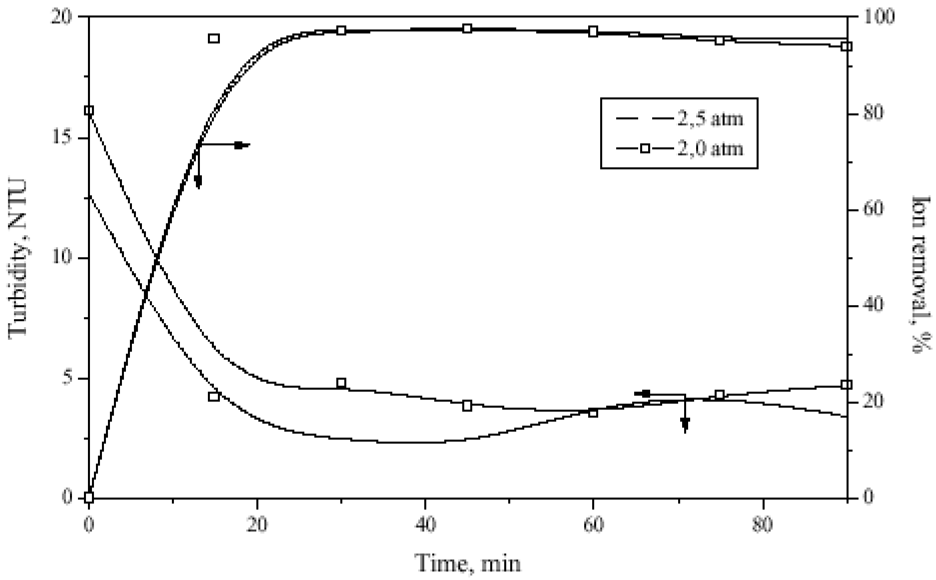

Figure 6: Effect of Sodium Oleate addition on removal of $Fe(OH)_3$ by DAF at low saturation pressures. Conditions as in Table 3 and 4.

As shown in Figure 5 and 6, DAF operation with surfactant addition at low saturation pressures using both diffusers achieved high ion removal levels and acceptable turbidity values (lower than 5 NTU, the Brazilian standard limit). This is due to the fact that turbulence in the inclined part was highly reduced and the "mushroom" type of diffuser allows the creation of a "cloudy" like bubble bed below the floating particles.

CONCLUSIONS

The use of surfactant addition to the saturator and the split of the recycling water into two different points enhanced DAF operation at 2 atm. These arrangements allowed the bubble generation at working pressures lower than 3 atm with high-energy savings and the reduction in the degree of turbulence, improving the collection with no rupture of fragile coagula by bubbles. It is believed that these alternatives have great potentialities.

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NOMENCLATURE

DAF	dissolved air flotation
P	saturation pressure, atmospheres
Q_e	effluent flow rate, L/min
R	recycle ratio, %
T	time, min
TD	traditional diffuser
TM	mushroom diffuser

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