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The FF (flocculation–flotation) process

Jailton J. da Rosa, Jorge Rubio *

Laboratório de Tecnologia Mineral e Ambiental, Departamento de Engenharia de Minas, PPGEM-Universidade Federal do Rio Grande do Sul., Av. Osvaldo Aranha 99/512, 90035-190 Porto Alegre, RS, Brazil

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Abstract

A new on-line flocculation system (FF) has been developed which is coupled with a rapid flotation to remove the aerated flocs (flocs with entrained and entrapped bubbles). These aerated flocs are formed only in the presence of high molecular weight polymers and bubbles and under high shearing (and head loss) in special "flocculators". The air excess air abandons the flotation tank (a centrifuge or a column) by the top and the flocs float after very short residence times (within seconds). The aerated flocs are large units (some millimetres in diameter) having an extremely low-density. Process efficiency was found, in all cases, to be a function of the trilogy, head loss, type (and concentration) of flocculants and air flow rate. Mechanisms involved appear to include small bubble formation and their rapid occlusion (entrapment) within flocs, nucleation of bubbles at floc/water interfaces, polymer coiling as a result of "salting out" effects at the aqueous/air interface and plug flow type of mixing (flocculation) instead of perfect. Successful examples of emulsified oil and solids removal from water are shown and because in all cases were obtained high efficiencies (>90% removal), at high hydraulic loadings (>130 $m\,h^{-1}$) it is believed that this kind of flocculation–flotation appears to have a great potential in solid/liquid or liquid/liquid separation.

Keywords: Flocculation; Flotation; Wastewater treatment; Environmental

1. Introduction

Flocculation and flotation processes in the mineral industry are primarily designed to separate one particle type from another. In contrast, for wastewater treatment, the flotation is designed to remove all particles—generally encountered as very fine emulsions, suspended solids, microorganisms and colloidal dispersions. Thus, processes are optimized by the maximum recovery of cleaned water with the lowest concentration of pollutants and sludge containing low percentage of solids (or oils) (Rubio, 2003).

Industrial effluents and even flotation tailings commonly bear wastewater that contains a mixture of suspended particles and stable oil emulsions. It is well known that it is difficult to remove fine colloidal particles and highly emulsified oil from process wastewater. Oil can be present as a "free", non-dispersed surface layer, usually floating at the air/water interface. The oily layers can be readily separated off by gravity but the separation, as in the case of fine particle dispersions, is always very poor in the case of oil-in-water emulsions, especially if oil is present as a physically dispersed phase in the form of fine droplets, say <10 μm. The separation is even more difficult when emulsions are stabilized with surfactants or other emulsifying agents (Toyoda et al., 1999).

Flotation of organic fluids such as oil spills, oily sewages or oil-in-water emulsions has been known for decades in various fields but is not commonly used in the

* Corresponding author. Tel.: +55 51 3316 3540; fax: +55 51 3316 3530.
E-mail address: jrubio@ufrgs.br (J. Rubio).
URL: http://www.lapes.ufrgs.br/ltm

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mining and/or metallurgy industries. Oil in water may be dispersed, emulsified or soluble in concentrations usually up to 1000 $mg\,L^{-1}$. Here, residual oily waste-waters are common in the form of flotation and solvent extraction reagents losses, free wasted oil and oil spills in process waters (Gu and Chiang, 1999; Capps et al., 1993; De Oliveira, 1995).

The flotation separation of very fine oil droplets (<10 μm) or dispersed fine solids is even more complicated and usually requires fine bubbles, efficient flocculants, and quiescent hydrodynamic conditions in the cell separation zone (Gopalratnam et al., 1988). This is due to collection and adhesion factors, which makes the process very slow, especially when treating high flow-rates.

Induced air flotation, IAF and dissolved air flotation, DAF, have been used extensively in the removal of stable oily emulsions or fine particles suspensions (Strickland, 1980; Bennett, 1988; Van Ham et al., 1983). IAF utilizes bubbles sizing between (600–2000 μm), turbulent hydrodynamic conditions and has low retention times, normally <5 min. Conversely, DAF employs micro-bubbles (30–100 μm), and quiescent regimes. However, when retention times are higher (20–60 min) this process is inefficient when treating effluents having high volumes and high flow-rate. A new basis for the separation of oil-in-water emulsions, based on the concept of carrier flotation, has been reported (Rubio and Santander, 1997). Here, the carrier solids (coal or coal beneficiation residues) adsorbs or absorbs the oil extensively and flotation is used to separate off the loaded oily adsorbent.

The addition of polymeric flocculants may, sometimes, assist the particles settling but the efficiency highly decreases when dispersions are diluted or when particles are in the range of ultrafines or colloidal range (Rubio, 2003). The recovered water in most cases carries suspended particles affecting the clarity and quality. On the other hand, flotation, in those cases, is a more reliable technique for the removal of diluted (<4% solids content) suspensions and oily emulsions from wastewater (Da Rosa et al., 2002).

Yet, the classical dissolved air flotation (DAF) is still the most common process removing fine colloidal dispersions and oily emulsions, mainly in refinery wastewaters (Kiuru, 2001; Rubio et al., 2002b). In DAF, a stream of treated wastewater (recycle) is saturated with air at elevated pressures up to 5 atm (40–70 psig). Bubbles are formed by a reduction in pressure of the water pre-saturated forced to flow trough needle valves or special orifices, and clouds of bubbles, 30–70 μm in diameter, are produced just down-stream of the constriction (Rodrigues and Rubio, 2003). More, recently, DAF has been employed to remove suspended solids from neutralized AMD waters (acid mining drainage water) (Menezes et al., 2004) and to remove ions from copper concentrates filtered water (Rubio, 2003; Rubio et al., 2002a).

However, future technologies will have to deal with highly loaded (high solids by weight) process wastewaters, exiting mining and metallurgical industries, and DAF might not meet legislation standards and reuse efficiently the water, due to the low carrying power of the tiny bubbles and the low hold-up. For this reason, DAF may be considered a slow process with high residence time (minutes) and requiring high foot print space.

Various publications (Rubio et al., 2002a; Voronin and Dibrov, 1999; Matis, 1995; Mavros and Matis, 1992; Parekh and Miller, 1999), reviewed fundamentals and general features of flotation (usually accompanied by flocculation) for environmental applications. All publications show the great potential of conventional and upcoming novel separation concepts and devices. This article constitutes an advance within this line of research and development.

2. The FF (flocculation–flotation) process: development and main features

The flocculation–flotation system (FF®, Rubio et al., 2003) is composed of a turbulent "flocculator" to generate aerated polymeric flocs coupled with solid/liquid, solid/liquid/liquid$_2$ or liquid/liquid$_2$ separation devices (columns, tanks, centrifuges). Here, the basic concept is that of a reactor (zigzag or static mixer types) (Fig. 1) of flocculator (Fig. 2) and a floc flotation separator (Fig. 3). The resulting flocs are rapidly formed inside the flocculator, are very light because of the trapped air (see below). Yet, these "special" flocs are generated only in the presence of high molecular weight polymers, bubbles (from the injected air), high shearing forces (caused by the zigzag kind of flow) and a high head loss. Process efficiency was found, in all cases, to be a function of the trilogy, head loss, type (and concentration) of flocculants and air flow rate (Da Rosa et al., 2002; Rubio, 2003; Rubio et al., 2003).

In the flotation tank separator the floc float, within seconds, as large units (some millimeters in diameter) having very low densities. The exceeding air abandons the flotation device by the top through a special water seal (avoiding flow turbulence).

Conversely, in conventional flocculation, the polymeric floc (non-aerated) are commonly formed after polymer diffusion and adsorption at the solid particle/water interface under high stirring (agitation) stage, followed by flocs build-up and growth at slow mixing stage.

An advanced ASH (air sparger hydrocyclone) type of flotation, which appears to work similarly to FF has been reported in applications to remove oil, grease, BOD, etc. BAF, or bubble accelerated flotation system, uses the contactor-separation concept with very low detention times in the contactor (Owen et al., 1999).