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Analysis of key mixing parameters in industrial Wemco mechanical flotation cells

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ABSTRACT

Flotation performance in mechanical cells is strongly influenced by hydrodynamics. Hydrodynamics is driven by the action of the impeller which is responsible for mixing in the cell. This paper evaluates key mixing parameters in three industrial Wemco mechanical flotation cells (#144, #164, #190; 14.2, 28.3, 42.5 m^3). Residence time distributions, circulation times, impeller pumping capacities, impeller Flow numbers and power intensities are presented. RTD studies are based on LiCl tracer measurements. RTD studies showed that the #190, #164 & #144 behave as 2.1–2.4, 1.2 and 1.0 tanks in series respectively. Circulation times for the #164 and #144 were much shorter than the #190. The #190 and #164 had the highest pumping capacities. Dimensionless Flow numbers varied from 0.12 to 0.22. Iron losses by entrainment of fine particles (< 45 μm) were higher in the #164, due to the higher intensity of mixing.

1. Introduction

Mechanical flotation cells are the work-horses of the flotation industry and, despite competition from a large variety of alternative flotation technologies, are still responsible for the bulk of world flotation. The performance of mechanical flotation cells is strongly influenced by hydrodynamics. Hydrodynamics is a broad term used to describe fluid flow, but generally refers to the bulk or macroscopic flow of fluid in the vessel. Hydrodynamics is largely driven by the action of the impeller which establishes a flow pattern, or average path of the bulk fluid flow. Flow patterns are governed by vessel characteristics, such as size and shape, and impeller properties such as geometry and rotational speed. Fluid leaves the impeller in axial, radial and tangential fluid jets which carry kinetic energy, in the form of fluid flow, into the bulk cell where they ultimately decay into turbulence and circulate back to the impeller. Historically, hydrodynamics in flotation has been described using a range of dimensionless numbers and key hydrodynamic parameters; e.g. power intensity, impeller tip speed, Power number, Froude number, tank-turnover time and Air flow number. Hydrodynamics is responsible for mixing which is important in mechanically agitated flotation cells. The mixing intensity must be suitable for creating favorable conditions for efficient solids suspension and gas/solids dispersion. Here, most mechanical flotation cells operate in the turbulent environment with a magnitude of $Re \sim 10^6$ (Schubert and Bischofberger, 1978; Harris, 1986). Mixing affects micro turbulence, generally associated with eddies generated in the vicinity of impeller region, which is responsible for the performance of flotation sub processes. Hydrodynamics and mixing are ultimately driven by the action of the impeller which must be optimized to promote three well established zones inside the equipment: 1. Turbulent zone (collision and attachment), 2. Quiescent zone (separation); 3. Froth zone (Schubert and Bischofberger, 1978; Massey et al., 2012; Tabosa et al., 2016).

The impeller used in industrial mechanical flotation cells has a different geometry to those used in conventional mixing processes such as Rushton turbines, propellers and pitched blade turbines. Harris (1986) reported that flotation cells generally have an aspect ratio (impeller to tank diameter) in the range of 0.25–0.5 while Arbiter et al. (1976) reported this range as between 0.25–0.64. McCabe et al. (2005) stated that the ratio of impeller to tank diameter suitable for gas dispersion should be around 0.25. Numerous studies have investigated the effect of impeller speed on flotation parameters such as the superficial gas velocity, bubble size and rate constant (Gorain et al., 1995, 1996; Schubert, 1999; Deglon et al., 1999; Deglon, 2005). These studies have often concluded that an increase in the impeller speed leads to an increase in the flotation rate for fine particles. The effect of agitation intensity on flotation performance also differs for fine and coarse particles as investigated by Ahmed and Jameson (1985), Schubert and Bischofberger (1978), and Schubert (1999). There are not many

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List of symbols

Re	Reynolds number [–]
RTD	residence time distribution [T]
t_{circ}	circulation times [T]
Q_b	impeller pumping capacity [L^3/T]
N_Q	impeller Flow number [–]
N	impeller speed [1/T]
D	impeller diameter [L]
T	tank diameter [L]
τ	spatial time [T]
V	tank volume [L^3]
Q	volumetric flow rate [L^3/T]
t_{avg}	average residence time [T]
S	standard deviation
C_∞	maximum tracer concentration [M/L^3]
ε_g	gas holdup [%]
wt	solid concentration [%]
V_{up}	upward pulp superficial velocity flux [L/T]
ρ	slurry density [M/L^3]

literature studies which investigate mixing in industrial mechanical flotation cells. This study investigates mixing in three different industrial Wemco mechanical cells in terms of the residence time distribution, circulation time, impeller pumping capacity, impeller Flow number and power intensity.

2. Background

Mechanical flotation cells are often characterized as continuous stirred tank reactors (CSTRs). Industrial mechanical flotation cells deviate from perfectly mixed CSTRs through short-circuiting and/or stagnant zones (Lelinski et al., 2002; Yianatos et al., 2008). This non-ideal behavior affects particle-bubble contacting through factors such as poor solids suspension or gas dispersion. Residence time distribution (RTD) studies are important for evaluating the quality of mixing and determining deviations from ideal CSTR behavior (Fogler, 1999; Patwardhan et al., 2003). Mixing aims to reduce the degree of non-homogeneity in the vessel (Uhl and Gray, 1966; Chhabra and Richardson, 1999). Flotation cells have three phases, solid-liquid-gas, and the extent of mixing influences contact between all phases. This affects parameters such as mixing patterns, rate of mixing, mixing times, power consumption and scale-up (Coulson and Richardson, 1999). There have been numerous hydrodynamic flotation studies in flotation cells of various size, from laboratory up to industrial cells (Arbiter, 2000). Here, researchers have found clear discrepancies in results. Perry and Green (2007) note that the difference between small and large scale vessels leads to significant differences in blending and circulation times, which tends to be higher in larger vessels. This is corroborated by Arbiter et al. (1976). A recirculation pattern also tends to develop in larger vessels resulting in a similar behavior to CSTRs (Perry and Green, (2007).

The flotation impeller is often modelled as a pump with a partly open case. Here, fluid is continuously transferred upwards to the top of the tank and then recirculated back to the impeller (Arbiter et al., 1976). The impeller's effectiveness in this regard is often evaluated by its pumping capacity (Q_b) or by the dimensionless Flow number (N_Q), as shown in Eq. (1). In the laminar and turbulent regime, the flow number is typically constant. For the transitional regime, the flow number is dependent of the impeller Reynolds number and the fluid properties. A high flow number (N_Q) indicates a high impeller pumping capacity and liquid circulation intensity thus generating better mixing (Joshi et al., 1982; Tatterson, 1991; Nienow, 1997).

$$N_Q = \frac{Q_b}{ND^3} \tag{1}$$

The extent of mixing is often evaluated in terms of the circulation time or tank turnover time which are affected by the impeller pumping capacity (Yianatos et al., 2008). A short circulation or tank turnover time means good dispersion of air and solids throughout the cell (Tatterson, 1991; Nienow, 1997; Deglon et al., 2000; Yianatos et al., 2008). The mean circulation time or tank turnover time is calculated as the effective volume of the flotation tank divided by the impeller pumping capacity. The reciprocal of this quantity is referred to as the circulation intensity (Deglon et al., 2000; Nelson and Lelinsk, 2000). The mixing time can also be determined by RTD (tracer) methods, as the time required for the disappearance of most of the tracer (typically 95%). The mixing time is usually in the range of 3–5 times the circulation time (Khang and Levenspiel, 1976; Joshi et al., 1982; Nienow, 1997; Carletti et al., 2016). However, some researchers have found the ratio of the mixing time to the circulation time to be slightly lower, in the range of 2–2.3 (Uhl and Gray, 1966). RTD studies can be performed by different techniques such as soluble tracer, conductivity or colorimetric methods (Nienow, 1997; Takenaka et al., 2005). The presence of gas in the flotation cell usually leads to an increase of the critical impeller speed and an increase in the circulation time (Joshi et al., 1982; Perry and Green, 2007). Wemco 1 + 1 brochures have this information for different cell sizes but for water only i.e. no gas or solids.

3. Experimental

RTD studies were performed in three industrial Wemco mechanical flotation cells of different size, as shown in Table 1. It is interesting to note that the impeller diameter in these cells is higher than standard for Wemco 1 + 1 cells. The #144 cell has a #164 impeller diameter and so on. This is typical of industrial practice but means that the impeller must be operated at different speeds to those suggested in the Wemco brochure. The Wemco #190 cell operates in a circuit removing silica elements containing MgO such as olivine, pyroxenes and phlogopite for producing a final product for the cement industry (MgO $<$ 5.5%). The circuit is fed with the tailings from a prior apatite flotation circuit. In this cell, RTD studies were conducted at three different impeller speed as the cell has a variable speed driver. The other two cell models (#164 and #144) operate in reverse flotation iron ore circuits, removing silica components (mainly quartz). Prior to conducting RTD studies, the cells were thoroughly characterized for gas dispersion parameters such as gas hold up, bubble diameter and gas superficial velocity using probes as described by Yianatos et al. (2001) and Deglon et al. (2000).

The first flotation cell in each industrial bank was evaluated. The banks consisted of 4 #190 cells (phosphate tailings circuit), 4 #164 cells (iron ore rougher circuit) and 3 #144 cells (iron ore cleaner circuit). RTD studies were conducted by adding a tracer (LiCl) as a pulse in the flotation cell feed box. The amount of tracer added to each cell was fixed at a known concentration (ppm) accordingly to the tank volume. Samples of pulp were taken at set time intervals in the cell corner

Table 1
Flotation cells used for the RTD studies.

Wemco model	Duty[a]	Imp. Dia. (m)	Imp. speed (rpm)	Cell Vol. (m^3)	Gas Holdup (%)	SiO_2 Rec/cell (%)
#190	RG	0.990	130	42.5	8	11
			140		10	18
			154		12	21
#164	RG	0.889	155	28.3	14	42
#144	CL	0.762	175	14.15	11	40

[a] RG = Rougher; CL = Cleaner.