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An exponential decay relationship between micro-flotation rate and back-calculated induction time for potential flow and mobile bubble surface

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ABSTRACT

Flotation researchers have long hypothesised that particles have inherently different flotation rates under the same operating conditions because they have different induction times in the flotation cell. The relationship between flotation rate constant and induction time, however, has yet to be explored. Here we analysed the relationship between micro-flotation rate and back-calculated induction time for galena and sphalerite particles. The floatability of the particles was controlled by depression with potassium chromate (galena) and activation with copper sulphate (sphalerite). The bubble rise velocity vs. size in the micro-flotation experiments was determined by high speed video microscopy and followed the prediction for bubbles with the fully mobile air–water interface. Therefore, the theoretical analysis of the micro-flotation results was carried out, based on the potential flow model for water flow around a mobile bubble surface. The relationship between micro-flotation rate constant and back-calculated induction time was found to rapidly decay exponentially. In this model, flotation rate constant is highly sensitive to induction time. For example, a doubling or tripling of induction time results in an order-of-magnitude decrease in flotation rate constant.

1. Introduction

A long held hypothesis among flotation researchers is that particles have inherently different collection zone rate constants (k_c) and hence different overall flotation rate constants (k) under the same operating conditions (e.g. air flow rate, agitation and froth height), because they have different induction times (or attachment times) in the flotation cell. Such a hypothesis can be deduced from the pioneering works of Sutherland, 1948 and Finch and Dobby, 1990. While the hypothesis provides an explanation as to why particles have different flotation rates, it does not tell us how flotation rate varies with induction time. To date, the relationship between flotation rate constant and induction time has not received any attention. Previous model studies have explored the relationship between attachment efficiency and induction time (Nguyen et al., 1998; Ralston et al., 1999) but not the relationship between flotation rate and induction time. The flotation literature currently offers no insight into the relationship between flotation rate constant and induction time. For example, it is not known if the relationship is linear or exponential.

This paper takes a step towards providing an answer by analysing the relationship between micro-flotation rate and back-calculated induction time for a potential flow model of water flow around a mobile bubble surface. The definition of induction time adopted in this work is the minimum contact time needed for a particle to attach to a bubble after collision for a given hydrodynamic environment. This definition involves all three elementary steps of particle–bubble attachment (Albijanic et al., 2010; Nguyen et al., 1997; Ye et al., 1989). It recognises that three-phase-contact expansion is an integral part of the particle–bubble attachment process.

2. Experimental section

2.1. Experimental method and procedure

Micro-flotation tests without a froth phase were carried out using a University of Cape Town (UCT) micro-flotation cell (Bradshaw, 1997, pp. 132–133; Bradshaw and O'Connor, 1996; Giesekke and Harris, 1985; Min, 2010, pp. 48–51). Fig. 1 shows a schematic diagram of the cell. The latest detailed description and operation of the UCT micro-flotation cell can be found in Min's thesis (Min, 2010, pp. 48–53).

Briefly, the UCT micro-flotation cell is a single bubble stream flotation cell that allows for flotation without a froth zone. The single bubble stream is achieved by introducing air into the base of the cell via a gas-tight micro-litre syringe (Hamilton Model No.

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Nomenclature

Roman symbols

A	micro-flotation cell internal cross-sectional area (cm^2)
D_b	diameter of bubble (mm)
D_{cell}	micro-flotation cell internal diameter (cm)
D_p	diameter of particle (mm)
E_a	attachment efficiency
E_c	collision efficiency
E_{cg}	collision by gravity
E_{ci}	collision by interception
E_s	stability efficiency
$\mathbf{e}_r$	unit vector in radial direction
$\mathbf{e}_\varphi$	unit vector in tangential direction
g	gravitational constant or acceleration (m/s^2)
J_g	superficial gas velocity, i.e. volumetric air flow rate divided by cell cross-sectional area (m/s)
k	overall flotation rate constant (min^{-1})
k_c	collection zone rate constant (min^{-1})
k_f	rate constant of fast floating component (min^{-1})
k_s	rate constant of slow floating component (min^{-1})
m_f	mass fraction of fast floating component in feed
m_s	mass fraction of slow floating component in feed
m_{tail}	mass fraction of non-floating component in feed
N_p	concentration of particles
Q	volumetric air flow rate into the micro-flotation cell (mL/min, cm^3/min)
R	flotation recovery
R_a	attachment radius
R_b	radius of bubble (mm)
R_c	collision radius
R_p	radius of particle (mm)
Re_b	bubble Reynolds number
r	dimensionless scaled radial distance
r^*	radial distance
t_{sl}	sliding time
U_b	bubble rise velocity (m/s)
V_s	particle settling velocity
$V_{s,\varphi}$	particle settling velocity in the tangential direction
V_φ	particle velocity in tangential direction
V_{rel}	velocity of bubble relative to the particles (cm s^{-1})
W_φ	water velocity in the tangential direction

Greek letters

μ	viscosity of liquid (kg/m s)
ρ_l	liquid or continuous phase density (kg/m^3)
ρ_p	particle density (kg/m^3)
τ	induction time (ms)
φ	collision angle or angle of contact
φ_a	critical angle of attachment

1002). The bubbles collect the particles as they pass through the pulp zone and rise to the upper section of the cell, where they are deflected by the conical part to the side of the cell above the concentrate launder. On reaching the surface of the solution, the air bubbles loaded with particles break up and drop their load into the surrounding concentrate launder.

The particles in the pulp zone are kept suspended by means of upward circulatory flow (in the direction against gravity) of the pulp solution, achieved using a peristaltic pump with variable flow rates. The use of a circulating solution to suspend the feed particles resembles a fluidised particle bed. The dual functions of the circulating flow are as follows: it suspends the feed particles in the pulp zone and reduces the bubble size by shearing and breaking the large air bubbles introduced into the cell into small ones.

Flotation in the cell could be paused at any time by terminating the air supply to the cell by removing the micro-litre syringe from

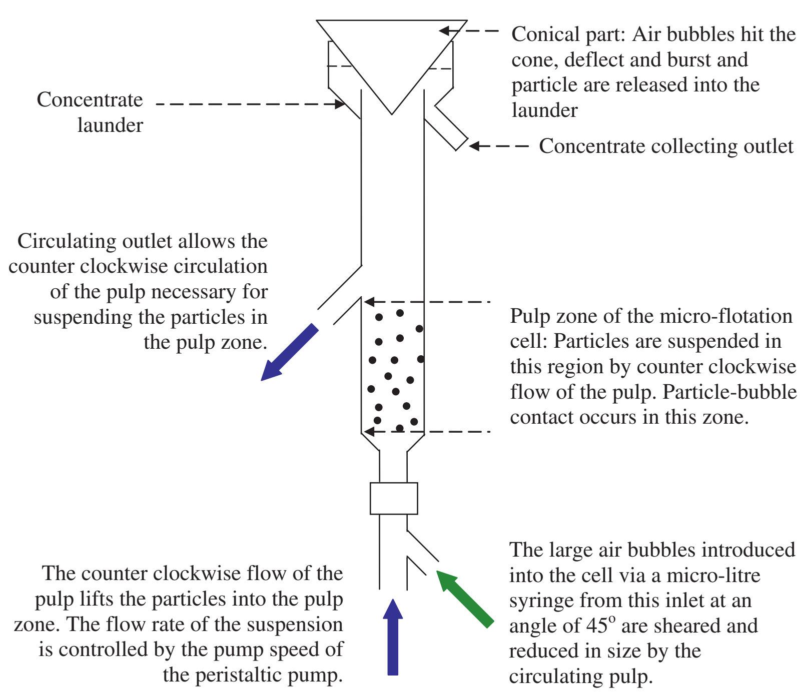

Fig. 1. Schematic of the UCT micro-flotation cell used in the experiments. The key dimensions of the cell: inner diameter = 30 mm and height = 180 mm; of the pulp zone: inner diameter = 30 mm and height = 50 mm; and of the concentrate launder: cone angle = 35°, inner diameter = 60 mm and height = 70 mm.