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Automated contact time apparatus and measurement procedure for bubble-particle interaction analysis

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ABSTRACT

The novel Automated Contact Time Apparatus (ACTA) presented in this paper serves as a diagnostic tool that allows the detection of changes in bubble-particle attachment probability and therefore floatability caused by alterations in the chemical environment and particle properties.

The apparatus consists of six identical capillaries where bubbles with defined size are produced simultaneously in a measurement chamber. The bubbles at the needle tips are placed in contact with the submerged particle bed for specific time periods, controlled with the help of automatic actuators. The advantage of the instrument is that hundreds of bubble-particle contacts can be measured automatically within a short time period. Microscopy pictures of each measured bubble are taken while recording the movement of the bubble before, during and after contact with the solid particles. The recorded pictures can be used to determine the actual bubble size and its corresponding deviation, and to detect the attachment of particles. The attached particles are collected in a detachable chamber for subsequent characterization. Furthermore, the device is portable and can be taken to the mineral processing plants for quick evaluation of particle-bubble attachment efficiency with particles and process water sampled directly from real processes.

1. Introduction

The attachment between hydrophobic particles and gas bubbles is an important phenomenon in froth flotation, which is a widely-used separation technique applied not only in mining industry but also on e.g. in pulp and paper industry. The attachment efficiency, together with the collision and the stability efficiencies form the overall efficiency of the flotation process. To understand and optimize flotation processes in any system or field of industry, reliable data on bubble-particle interaction needs to be gathered on multiple different parameters. The concept of bubble induction time, introduced by Sven-Nilsson (1934), has been observed to be a reliable indicator for flotation efficiency (Jowett, 1980). The most widely used attachment time measurement device was developed by Glembotsky (1953) and has been used by many authors (Gu et al., 2003; Ye et al., 1989; Yoon and Yordan, 1991a) to study different minerals and oil processing related systems.

Previously published works dealing with induction time measurements in various bubble-particle-gas systems revealed that the induction time is a sensitive function of numerous factors such as bubble size (Wang et al., 2005; Yoon and Luttrell, 1989), bubble movement (Gu et al., 2003), temperature (Yoon and Yordan, 1991b) in addition to the intrinsic physicochemical properties of the particles and the liquid. For this reason, a reliable standard for measuring bubble-particle induction time upon which flotation parameter optimization can be based is relevant.

Particle-bubble attachment efficiency in flotation is influenced by many factors, water quality being one of the most important of them. In flotation research experiments are often performed in the laboratory, in artificially created, "synthetic plant water" systems (Biçak et al., 2012; Corin and Wiese, 2014; Manono et al., 2013). However, experiments done in laboratory conditions commonly do not reproduce all the effects occurring in process waters around real flotation plants. Also, experiments done in plant water taken from the plant into the laboratory do not correspond to the actual process water, as microbiological action and continuing, kinetically-controlled reactions of dissolved species alter the quality of these waters within time periods as short as a few hours (Levay et al., 2001; Levay and Schumann, 2006). Therefore, reliable flotation efficiency evaluation demands a tool that allow quick diagnostic testing of the effect of water quality on particle-bubble attachment efficiency at flotation plants with freshly taken process waters.

In this paper, we present a novel experimental setup named Automated Contact Time Apparatus (ACTA). The device has been

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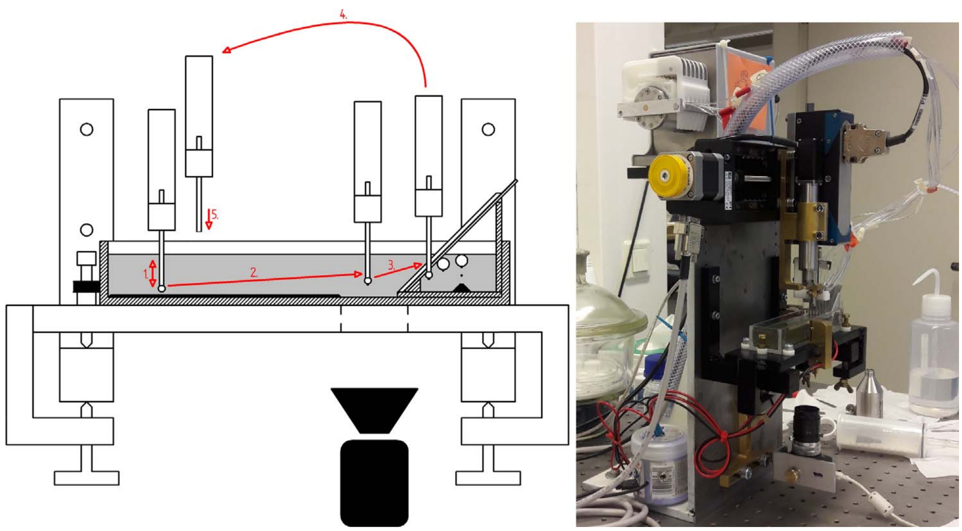

Fig. 1. Experimental steps: 1 – bubbles are formed at the tips of the needle array and pushed against the particle bed; 2 – bubble-particle aggregates are transported above the digital camera for imaging; 3 – the bubbles are taken to the sample collector and detached from the needle; 4 – the needles are lifted above the surface and moved horizontally then lowered into the liquid above an untouched spot on the particle bed for the next measurement cycle.

developed in order to create an automated system, that allows the collection of large amount of data for statistical analysis within a relatively short time period. The instrument is transportable and can be taken to mineral processing plants to serve as diagnostic tool. Therefore, measuring the effect of different process water qualities on the particle-bubble attachment efficiency in freshly taken and altered process waters is feasible.

2. Experimental

2.1. Description and operation of the experimental setup

The operating principle of the ACTA in some respects resembles the one presented by Glembotsky (1953), however the mechanical setup of the instrument differs notably from the previous arrangements. Furthermore, multiple novel features has been developed improving the functionality as well as the diversity of the data produced. Fig. 1 presents schematics the operation principle of ACTA, together with a picture of the actual device.

The steps presented in Fig. 1 are performed automatically and the measurement cycles are repeated until the entire length of the particle bed has been sampled. Using, for example, a 1 mm step distance between the bubble-particle bed contact points, 65 measurement cycles or 390 measured bubbles are collected in a single measurement run.

The novel features of the instrument involve the array of six needles connected to a two-directional motor assembly, an automated plough for particle bed levelling, the particle collecting mechanism, fully programmable bubble movement during wave function and an automated image capturing and analysis system for the bubble size measurement and detection of particle-bubble attachments. The detailed operation of the instrument and the details about its mechanical construction are described below.

2.1.1. Particle bed preparation

The first step in the experimental procedure is the preparation of the particle bed. After the solid particles are conditioned in the solution of interest, part of the slurry is filtered in order to produce a clear liquid where the experiments can be done without compromising the image quality of the photos taken for bubble size evaluation. The particles are introduced into the cell with the help of a large pipette and the cell is filled up with the filtered experimental solution. In order to produce reliable measurement data, a flat and even particle bed is crucial. However, manual levelling and smoothening was found to be an extremely cumbersome and tedious task. Therefore, an automated plough attached to a MP-20 Micro Pusher (Physik Instrumente (PI) GmbH & Co. KG) with PI SMC pollux controller was designed and built. The reference position of the plough is set by the position of the tips of the needle array for improved accuracy. Once a completely flat particle bed is formed, the plough can move over the bed several times to improve packing of solid particles at the surface.

2.1.2. Bubble formation and particle-bubble contacting

After the particle bed is prepared, the actual measurement can be started. First, air bubbles with a set size are produced at the end of each needle in the six-needle array and the bubbles are then pressed against the particle bed (Fig. 1, step 1). With this arrangement, notably more data can be collected in a single measurement cycle. An Ismatec™ Reglo Digital peristaltic pump has been applied to pump the air through Tygon® LMT-55 hoses (0.25 mm ID) into the needles to create the bubbles. The pumping time for the bubble formation is set as constant for a single measurement run. The warming of the hoses during pumping has been observed to have impact on the variation in the bubble size. For this reason, careful warm up and the lowest possible pumping time is used during the experimental run to create bubbles with equal size. The peristaltic pump is used in this setup because, in addition to bubble formation, the detachment of the bubbles from the end of the needles and the drying of the needles by purging air through them between the measurement cycles can be done with it.

A V-273 PIMag® Voice Coil Linear Actuator attached to C-413 PIMag® Motion Controller is applied for moving the needle array vertically. The maximum velocity of the V-273 PIMag® actuator moving the needle array vertically is 200 mm/s and the maximum acceleration of the needle array is 100 m/s^2 setting the physical limitations for the induction time measurement. The movement is fully programmable and any shape of wave function is possible within the given operational limitations characteristic of the actuator. The horizontal movement is produced by a PLS-85 Precision Linear Stage actuator and a PI SMC Pollux controller. All the actuators and control electronics are produced by Physik Instrumente (PI) GmbH & Co.

In addition to contact time (T_c), the parameters controlled and recorded during the measurements with ACTA are the approach-(V_a) and detachment velocity (V_d) of the bubble to/from the particle bed, the approach-(D_a) and the retreat distance (D_d), and bubble diameter (D_D) (Fig. 2).

2.1.3. Bubble imaging, bubble size measurement and particle detection

As the flotation efficiency is sensitive to the diameter of the bubble (Wang et al., 2005), the precise value for the of the bubble diameters needs to be measured. Furthermore, as represented schematically in Fig. 2, the real approach distance (D_a) depends on the fraction of the