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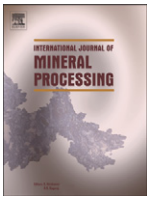

Behaviour of a galena particle in a thin film, revisiting dippenaar

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ABSTRACT

Advances in technology over the past 30 years have drastically increased the frame rate and resolution at which the dynamics of thin film rupture and particle interaction can be imaged.

A high speed camera (Phantom V7.1) was used to capture the bridging and rupture of a thin capillary film containing a particle of galena, revisiting work first published by Dippenaar (Dippenaar, A. 1982. The destabilisation of froth by solids. I. The mechanism of film rupture. Int. J. Min. Process., 9, 1–14.). The images were then compared to rendered models generated from simulations of an orthorhombic particle and capillary film under the same conditions, using the *Surface Evolver* program. These two sets of data are then used to build a more detailed picture of the behaviour of particles with sharp edges and corners as they bridge both sides of a thin liquid film.

It has been observed that the liquid–vapour interface is highly distorted around the particle and that under certain conditions it can appear that the particle is drawing the film together to failure, whereas, in fact the film is being forced together behind the particle. The film failure is then due to contact between the opposite liquid–vapour interfaces, not the bridging dewetting mechanism as postulated by Dippenaar (1982).

1. Introduction

The mechanism through which particles stabilise or destroy films in a flotation froth is difficult to identify due to both the size and speed at which the phenomena occur. The particle-film interaction at the point of film rupture is a hugely important part of a flotation froth's evolution and has a major impact on its physical properties and rheology as well as the efficiency of the whole process. It has therefore been the focus of much research to aid in the development of bubble film stability models. This paper revisits work published by Dippenaar (1982) that investigated the behaviour of a single galena particle in a thin liquid film. By using powerful modern modelling and imaging techniques it is possible to gain further insight into the interaction between the particle and the film at the moment of rupture.

Previous analyses of the particle–film interaction have focused on the simplified two-dimensional case (2D) using circular particles in a single layer in a film (Ali et al., 2000; Denkov et al., 1992) in which the particle will destroy the film if the contact angle is greater than 90°. Garrett (1979) proposed the bridging dewetting mechanism that causes the failure of the bubble film; however, this also assumed spherical particles, flotation froths contain particles with irregular shapes and asperities which can interfere with this mechanism and complicate their interaction with the film.

It is currently computationally intractable to simulate anything but the simplest of particle shapes attached to a liquid–vapour interface. Morris et al. (2011a) used *Surface Evolver* (Brakke, 1992) to develop a method of simulating orthorhombic particles in a thin liquid film which were used to identify the stable orientations of cubes (Morris et al., 2010) and oblongs (Morris et al., 2011b) and their effect on film stability. De Graaf et al. (2009) also developed a numerical technique based on triangular tessellation to identify the adsorption free energy landscape for spheroidal, cylindrical and ellipsoidal particles at liquid–vapour (LV) interface. Lewandowski et al. (2008) also used *Surface Evolver* to investigate the self ordering of micro-particles at a liquid vapour interface. It is therefore well established that the interplay between a particle's shape and contact angle can have a large effect on its behaviour in the LV interface.

Whilst it is relatively easy to analyse the shape of the film surrounding spherical particles in an ordered arrangement, when orthorhombic ones are considered the complexity of the LV-interfaces topology greatly increases. The interaction between the particles and the point at which the film fails becomes much more difficult to identify. Dippenaar (1982) investigated this using high speed imaging of a single galena particle sitting in a thin film supported by a capillary. The two stable orientations for a cubic particle at contact angles between 45° and 90° were identified (diagonal and horizontal) using a 2D analytical method. Morris et al. (2010) has since used 3D numerical simulation to identify a third energetically stable orientation (rotated) for a cubic particle, all three are shown in Fig. 1.

Dippenaar's analysis of the high speed footage showed that the particle would adopt either a diagonal or horizontal orientation in the film when it bridged only one LV interface. As the film thinned and the lower part of the particle came into contact with the opposite LV interface it would react differently depending on the orientation; if it was horizontal it would move off to the side of the film until it thinned enough to

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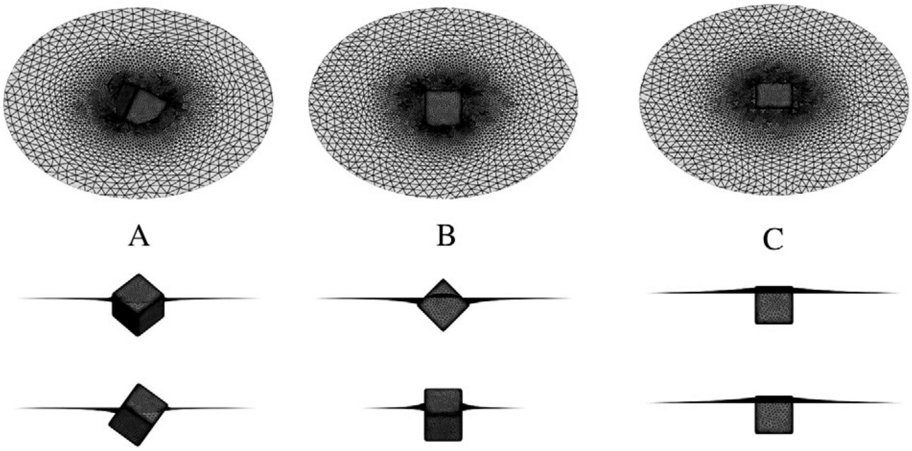

Fig. 1. Stable orientations for an orthorhombic particle, A—rotated, B—diagonal, and C—horizontal.

rupture, but if it was diagonal it would either rotate to horizontal and behave as before or adopt a rotated orientation. When the particles adopted a rotated orientation the opposite sides of the LV interface would draw up the sides of the particle and rupture the film. This bridging dewetting phenomenon was proposed by Garrett (1979), but was developed with spherical particles where the film distortion around the particle is much less pronounced. The phenomenon of particles moving out of the centre of the film was also noted by Qu (2012) who observed hydrophobic coal particles being forced out of the centre of the film as it thinned, leaving an area of empty, thin film before rupture.

The distortion of the film surrounding non-spherical particles can be quite severe, causing them to exhibit interesting packing phenomena. Botto et al. (2012)) whereby their contact angle and shape interact with the curvature of the LV interface to allow some control on their behaviour in the film. This interaction of non-spherical particles in a liquid film is beyond the scope of this paper; however, it will affect their packing arrangement and therefore the film loading and stability (Bournival and Ata, 2010; Morris et al., 2011c). It also highlights the rather extreme distortion that a LV interface can undergo when close to a particle.

2. Materials and methods

2.1. High speed photography rig

The rig used to capture the videos of particle film bridging is shown in Fig. 2. It consists of a capillary holder (machined from Perspex) for the film mounted with control in 3 axes to position the area of interest in front of the camera. A Vision Research Phantom V7.1 (on loan from the EPSRC equipment loan pool) was used to capture the images and was mounted with a Canon EOS Macro Lens. For horizontal filming the camera was mounted on a sliding bed which was used to focus on the capillary film and particle along the Y-axis (this setup is shown in Fig. 2). For vertical filming the camera was mounted on a tripod and rotated down to image down the Z-axis, videoing from above the film (this setup is not shown in Fig. 2). Finally a Solarc GE ELSV-60 RVI Light Source was used to illuminate the area of interest. The whole setup for filming horizontally is shown in Fig. 2.

2.2. Procedure

Liquid was drawn from the capillary, or injected into it, using a manually operated syringe. It was possible to accurately control the thickness of the film by monitoring it in the camera viewer. The film was thinned until the lower point of any attached particle was within 40 μm of the opposite LV interface. After this point the film was allowed to thin naturally due to evaporation whilst being filmed by the camera. The camera was mounted in one of two positions, horizontally or vertically. In the former, the film could be videoed from the side and the movement of the three point contact (TPC) over the particle surface captured accurately. In the latter, the exact point where the film ruptures can be identified, as well as the particle position at the point of film failure.

2.3. Materials

The films in the capillary were made with de-ionised water and the galena particles were hand ground in a pestle and mortar with water. The freshly ground particles were then wet sized and mixed in a stirred solution of 100 ppm sodiumisobutylxanthate (SIBX) for 1 h after which they were washed several times with de-ionised water and stored in a

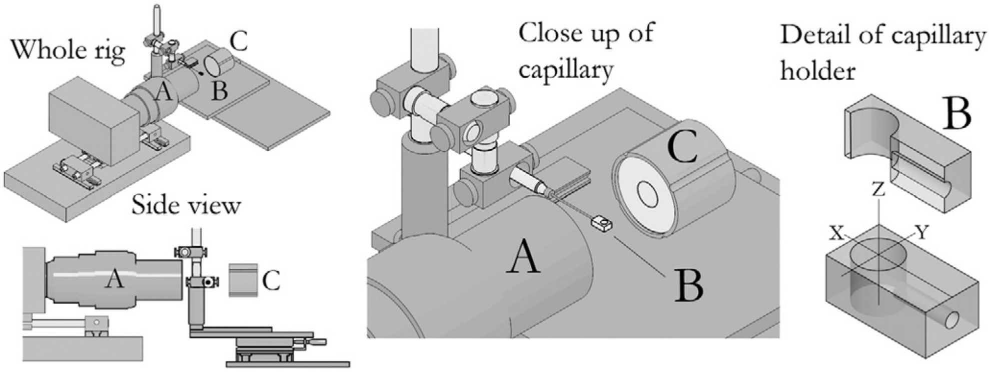

Fig. 2. The high speed rig used to capture the moment a film breaks with the particle in it. A—camera/lens, B—capillary/area of interest, and C—light source. X, Y and Z in the detail of the capillary holder show the axis used to discuss film shape and particle positions.