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Dependency of liquid overflow rate upon humidity of a pneumatic foam

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ABSTRACT

In this work, the liquid flowrate in an overflowing pneumatic foam is studied as a function of environmental humidity. It is found that in general, liquid flowrate is greater when the relative humidity of the air above the foam is high. This observation is attributed to bubble coalescence on the surface of the foam. Because the evaporation rate is diminished when the relative humidity is high, less bubbles collapse on the surface of the foam. Because no experiments have been conducted on mineralised flotation froths, a dependency on the operation of froth flotation devices on environmental humidity cannot be directly asserted; although the effect is so important in demineralised foams that it should not be overlooked in the context of flotation. The authors know of no laboratory or plant studies of froth flotation that have controlled or measured the environmental humidity.

1. Introduction

Froth stability is well-known to influence the performance of flotation devices. In a model that attempted to describe many elements of the physics that underpin froth flotation, Neethling and Cilliers (2003) gave a method for predicting the rate at which bubbles burst at the surface of a flotation froth. Extending this treatment, Neethling and Cilliers (2008) give a deterministic method predicting bubble coalescence by writing a force balance on the films and assuming that there is a critical pressure above which films fail. However, this model was not experimentally proven in a quantitative manner. Ireland (2009) has asserted that the coalescence process is probabilistic, and that non-equilibrium rupture mechanisms are responsible for coalescence in pneumatic foam. Crucially, for the purposes of the current work, the effects of humidity upon coalescence rate at the surface of the foam were not considered by Neethling and Cilliers (2003, 2008).

Because foam stability is so important to the performance of flotation, a device that is based upon the Bikerman (1938, 1973) test of "foamability" has been patented by Triffett and Cilliers (2004). They place a transparent vertical tube into the pulp, and foam rises up the column. By tracking the column height as a function of time, as well as the steady height that the foam can attain in the column, knowledge of intrinsic foam stability is obtained. The connection between flotation performance and froth stability, as well as how measuring the evolution of froth height can illuminate these considerations has been extensively studied by Barbian et al. (2003, 2005, 2006) and Aktas et al. (2008) who concluded that "flotation performance can be attributed to changes in froth stability".

However, Li et al. (2010) have shown that the rate at which pneumatic foam rises in a column, as well as the steady height that it attains, is strongly dependent upon the humidity gradient within the freeboard (i.e. the space between surface of the foam and the top of the column). If the humidity gradient is large (so as to promote evaporation from the surface of the foam) then the stability of the foam is low and *vice versa.*

The effect of temperature upon flotation performance has been well-studied. Lazarov et al. (1994) found that flotation kinetics are enhanced with respect to smaller particles with increasing temperature, but there was no apparent dependency with respect to larger particles. They measured the temperature dependency of dynamic contact angle and surface tension, and attributed the improved flotation kinetics to differences in the times for three-phase contact line expansion and induction.

Choung et al. (2004) investigated the equilibrium of a non-overflowing pneumatic foam made from recycle process water from an oil sand flotation plant. They found that equilibrium height (and therefore froth stability) decreases markedly with increasing temperature. They attributed this observation to the formation of an insoluble precipitate of surfactant at high temperature, thereby reducing concentration. Whilst the explanations of their observations given by Choung et al. (2004) and Lazarov et al. (1994) may well be valid, we will investigate whether the rate of evaporation from the free surface of the foam can have a fundamental effect on the hydrodynamic state.

The liquid flux in an overflowing pneumatic foam is, *inter alia,* governed by the rate at which bubbles burst on the surface (Stevenson, 2007). If the bubbles on the foam surface are less stable, then the liquid flux is diminished as is the flux of gas–liquid interface; this must surely

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have an important impact upon flotation performance. In addition, increased temperature decreases liquid viscosity and this increases liquid drainage rate in the foam, thus decreasing liquid flux. Bhattacharya and Pascoe (2005) performed an extensive review upon the effect of temperature upon the flotation of coal, and noted that viscosity decreased with increasing temperature.

The increasing temperature has another important effect that has been overlooked: At constant humidity ratio (i.e. value of absolute humidity), not only does increasing temperature increase the enthalpy of the liquid (thereby promoting evaporation), but it also decreases the relative humidity of the air (thereby increasing the driving force for evaporative mass transfer). Relative humidity is defined as the quotient of the observed partial pressure of water vapour and the saturated partial pressure of water vapour at the same temperature and pressure. For example, by reference to a psychrometric chart for the air–water system at one standard atmosphere we find that at an absolute humidity of 0.006 kg/kg bone dry air the relative humidity is 78.5% at 10 °C (dry bulb) but only 13.0% at 40 °C. (In fact these calculations were performed using CYTSoft Psychrometric Calculator 1.0 software.) Thus on a cool night, the air is relatively close to being saturated with water and consequently the driving force of evaporation is low. However on a hot day, the relative humidity at the same value of absolute humidity becomes relatively low, and this increases the driving force for mass transfer and therefore evaporation rate.

In this study, we investigate how the liquid overflow rate (i.e. liquid flux) in a gas–liquid foam varies with the humidity at the top of the column. We will argue that, by changing the humidity of the air at the top surface of the foam, whilst keeping the temperature constant, under some circumstances the liquid flux in the column can be manipulated. This is because the evaporation rate from the surface of the foam, and therefore the stability, is dependent upon relative humidity. We have not studied mineralised froths, and this is the subject of current investigation. Of course, if particle coverage of the surface is complete then there will be no evaporation at all. This work builds on that of Li et al. (2010), who showed that the behaviour of a non-overflowing pneumatic foam was dependent upon humidity gradient in the freeboard, by investigating the behaviour of a demineralised overflowing foam as a function of air humidity. This in turn, will provide a basis for future investigations into whether the hydrodynamic condition of mineralised flotation froth is dependent upon environmental humidity.

2. Experimental method

A schematic representation of the experimental apparatus is shown in Fig. 1. The arrangement was similar to that employed by Stevenson and Stevanov (2004). A Perspex column of internal dimensions 70 mm(d) × 80 mm(w) × 1150 mm(h) was utilised, the height is that between the top of the column and the pulp/froth interface which was maintained at a constant level by manipulating the rate of the peristaltic pump that feeds the bottom of the column. The system was isolated from the ambient environment by attaching an enclosed lid to the launder vessel so that the humidity of the air next to the top surface of the foam can be manipulated, and the humidity and temperature inside the closed launder was monitored through the use of a digital thermometer/hygrometer (Lutron HT-3009). Although an opening remains in this box to collect the overflowing foam, the separation from the external environment was maintained through the creation of a positive pressure environment by flowing conditioned air through a rotameter followed by a separate valve and out through this hose. Solutions of sodium dodecylsulphate (SDS) at concentrations of 8.33 mM (2.4 g/l), 4.17 mM (1.2 g/l) and 2.09 mM (0.6 g/l) were prepared in batches of 20 l for each experiment; the critical micelle concentration of SDS is approximately 2.4 g/l. Air was supplied at superficial velocities of approximately 9, 12, 15, 18, 21 and 27 mm/s.

Humidity conditioning of the supplied environmental air was achieved by the use of a drierite cell packed with $Na_2SO_{4(s)}$ for dry air, and by bubbling through 2 sequential containers of saturated $NaCl_{(aq)}$. A constant flowrate of conditioned air to the top of the column was maintained. Prior to foam generation, the apparatus' internal environment was conditioned for 10 min with the appropriate air for that test. The temperature of each experiment was also monitored

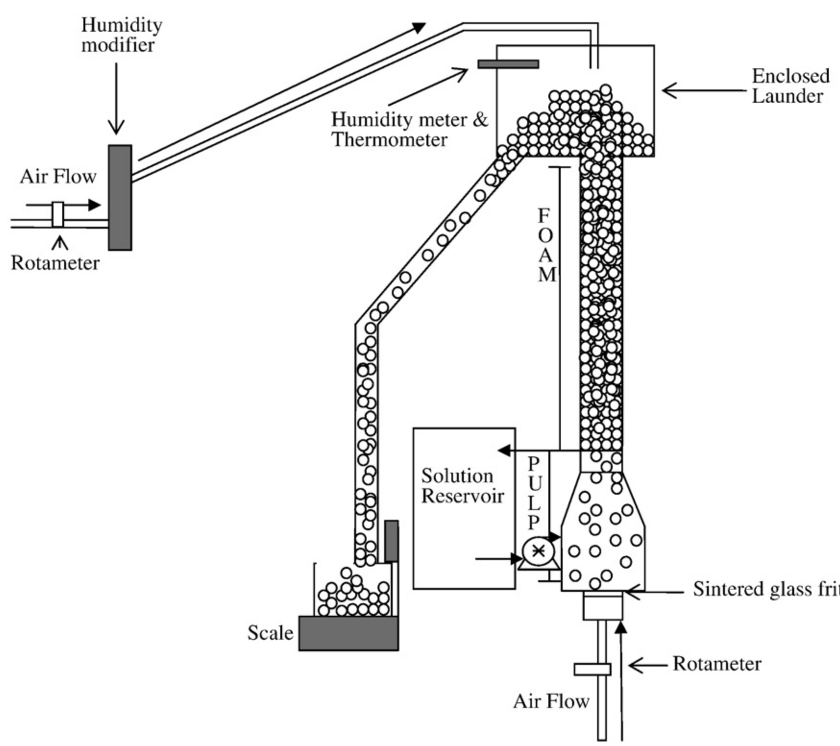

Fig. 1. Schematic diagram of experimental apparatus.