Effects of Relative Humidity on Substrate Wettability

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Introduction

The general wettability of many minerals is known to some degree; however, accepted values were typically found under ambient conditions. In order to characterize wettabilities under different conditions, the contact angles of water on several differently-treated surfaces may be measured.

Contact angles relate to surface tension as shown by Young's equation[4]:

$$\gamma^{SV} = \gamma^{SL} + \gamma^{LV}\cos\theta$$

where SV, SL, and LV denote the solid-vapor, solid-liquid, and liquid-vapor surface tensions of a sessile drop and θ represents its contact angle. In turn, the surface tensions may be used in Kelvin's Equation to determine nucleation critical radii as well as the energy barrier associated with this nucleation[4].

General wettability is an important factor when considering inverted or "frothless" flotation, as these equations, when combined, suggest a lower energy barrier to nucleation as hydrophilicity increases[4]. When considering the effect of water condensation on particles, an increase in mass, and thereby particle diameter and density, should occur. This leads to an increase in minimum fluidized velocity[5].

Froth Flotation

Froth flotation is a mineral separation process used for over a century to great efficiency and thoroughness[1,3]. Ore is fed in a slurry to a tank with aerated water and chemicals, called frothers, that maintain the bubbles, and others called surfactants that alter certain minerals' hydrophobic or hydrophilic natures.

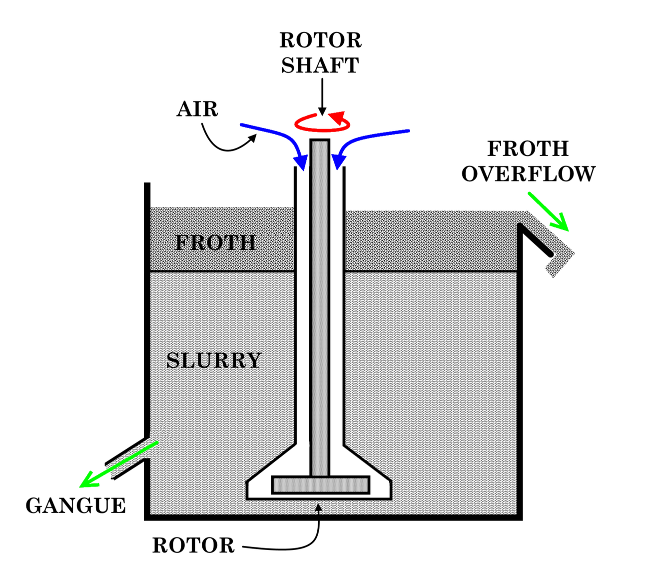

Fig. 1 A typical froth flotation process includes several chambers shown below as a means of purification. While water used is unknown, millions of tons of ore are processed yearly[3]. *Graphic* author's work

Inverted Flotation:

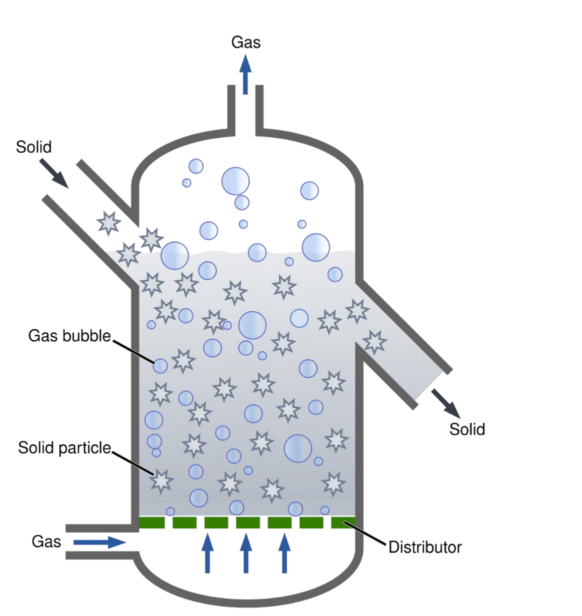

Fig. 2 A fluidized bed reactor operates by pushing gas (in our case, humid air) through the reactor to allow particles to float. *Graphic courtesy* Wikimedia Commons

Because froth flotation consumes untold amounts of water, the concept of inverted flotation was developed. It is theorized to use humid air rather than aerated water, and would utilize a fluidized bed reactor. Water might possibly condense more easily on a hydrophilic particle, allowing separation through its subsequent increase in mass and therefore minimum fluidized velocity[5].

Methodology

For this experiment, both glass and quartz were examined as substrates. Increased hydrophobicity was sought with several surface treatments, with procedures guided by others' experimentation[2,6,7]. After a sample was treated and had dried or cooled, it was placed in an environmental chamber with saturated salt solutions which maintained predictable relative humidities.

Following the equilibration of the sample in the chamber for 2 h, the humidity within the chamber was recorded and the contact angles of multiple 3 µL drops placed on the substrate were measured using an analog ramé-hart contact angle goniometer.

<u>Surface Treatments</u>

- Each substrate was cleaned with ethanol, deionized water, and acetone, followed by 30 min air-fed plasma cleaning
- Heated to 200°C for 6 h
- Soaked for 1 h in a 4 x 10^{-5} M dodecylamine solution with pH 10
- Soaked for 30 min in a 0.2 % by volume trichlorododecylsilane solution

Salt	Expected Humidity
Lithium Chloride	11.5 %
Magnesium Chloride	32.8 %
Magnesium Nitrate	52.9 %
Sodium Chloride	75.3 %
Potassium Chloride	84.3 %
Potassium Sulfate	97.3 %

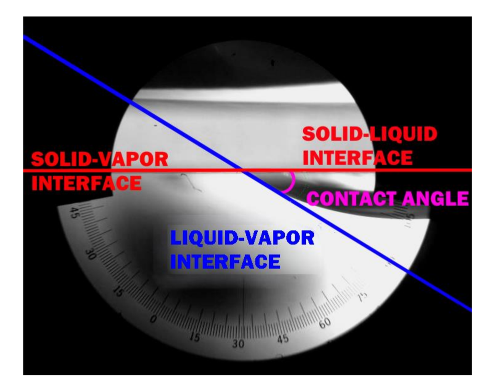

Fig. 3 The typical view for a low contact angle reading using a contact angle goniometer. *Photo* author's work

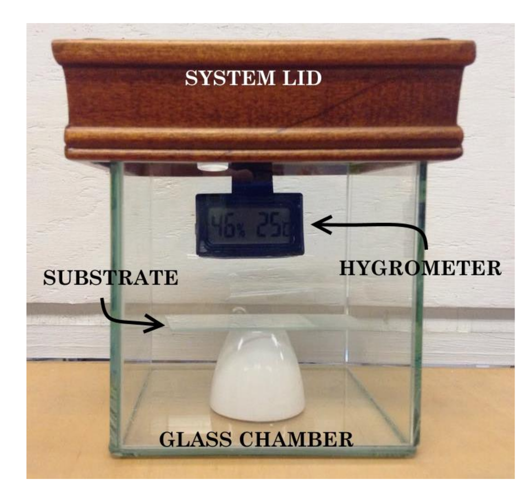

Fig. 4 The humidity chamber, shown without regulating salt caps on floor. *Photo* author's work

References:

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Results & Discussion:

Fig. 5 Contact Angles of Untreated Glass

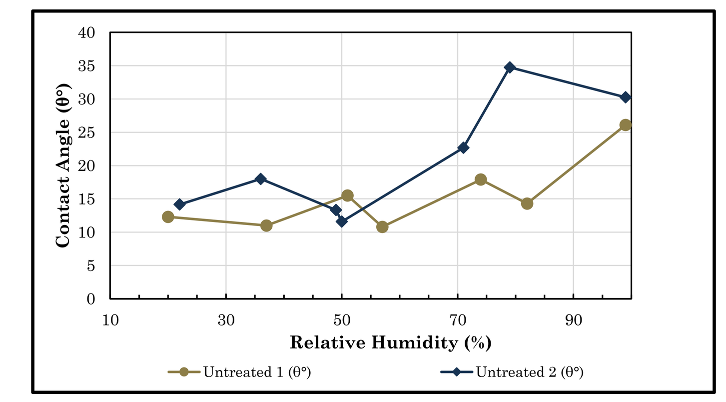


Fig. 6 Contact Angles of Treated Glass

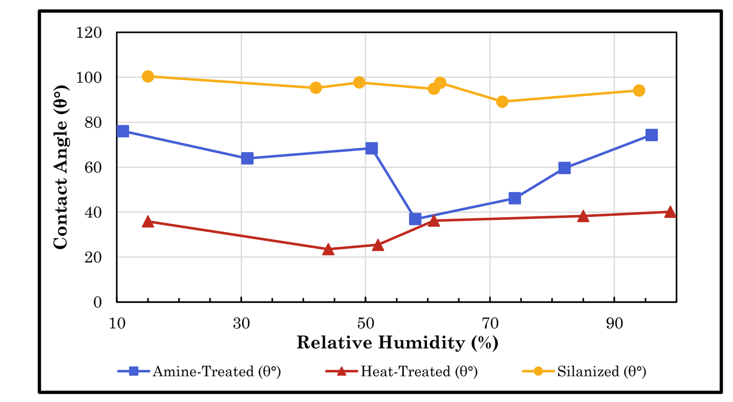


Fig. 7 Contact Angles of Untreated Quartz

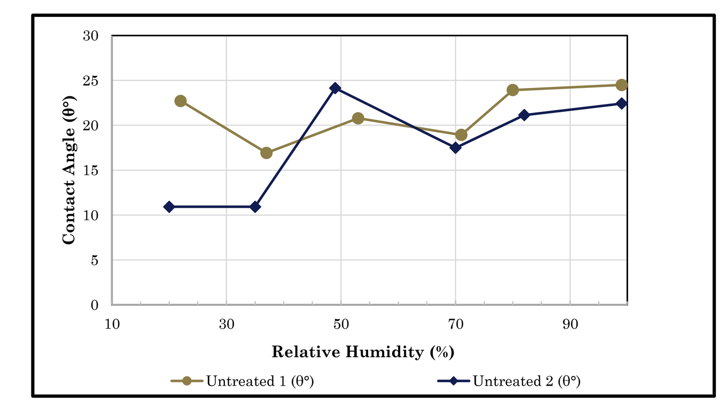
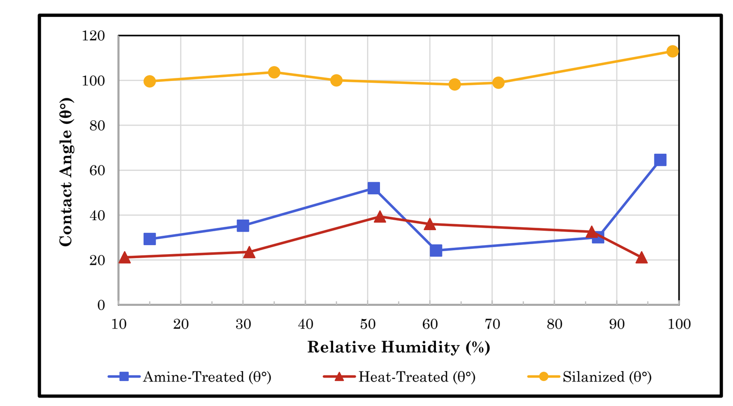


Fig. 8 Contact Angles of Treated Quartz



- Although relatively inconsistent, untreated glass generally presents higher hydrophobicity at higher humidities; surface treatments appear to negate the effect (Fig. 5, 6).
- Again, quartz displays an increase in hydrophobicity at higher humidities: this applies especially to untreated and amine-treated samples (Fig. 7, 8). Heat treatment and silanization seem to reduce the humidity effects.
- Standard deviations for data sets were mainly consistent and low, with few values exceeding 5 degrees for 28 data points in most sets. High humidity silanized quartz displayed the largest variances (13°), although cosine variances were minimal.

Conclusions:

- The wettabilities of glass and quartz with various surface treatments were found, with at least a general trend toward lower wettabilities at higher humidities. This follows expectations given from Kelvin and Young equations.
- Wettabilities decreased with all treatments, regardless of humidity; however, heat treatment gave similar values at each humidity extreme.

Future Work:

- More characterization of minerals and surface treatments may be done to further refine possible reactor conditions
- Talc, covellite, and chalcopyrite represent several surfaces of interest moving forward; hydrophilicity-inducing surface treatments also merit attention
- Bench-scale fluidized bed processing may begin with silica and mica surfaces thanks to ongoing tandem research