In Figure 5.8, when D = 10 mm, the slug-flow regime is further diminished in size by the stratified/stratified wavy flow regimes lying below the slug-flow regime. Thus, if the tube diameter is too large, the slug-flow region becomes too small to allow for flexible and robust operation. Also, the higher flow rate necessary for slug flow would require longer tubes to assure adequate residence times. The calculation of the stratified flow boundaries in the figure were made with procedures reported in Taitel and Dukler[16] and Barnea *et al.*[17] For tube diameters $D \leq 0.004$ m, the stratified flow regimes lie below U_{LS} = 0.01 m s^{-1} and are absent from Figures 5.5 to 5.7.

5.3 Control Slug Geometry for Recirculation

Internal recirculation is one of the key reasons for using slug flow (minimizing clogging). Internal recirculation depends on the slug size and shape (Subsection 5.3.1), whose determining factors also affect the slug stability. Flow analysis for recirculation inside slugs is detailed in Subsection 5.3.2.

5.3.1 Control Slug Size and Shape for Crystallization Purpose

The shape of slugs refers to both the size and the contact angle of slug. The slug geometry can be approximated as a cylinder (Figure 5.3), with slug length (along the tubing) the cylinder height. The slug size refers to the aspect ratio of the slug, which is the ratio between the length of slugs with respect to the inner diameter of tubing. Once the tubing size is chosen, the slug cylinder's bottom area is fixed, and the slug size is largely determined by the flow rate ratio between the air and liquid streams within the stable operation regime in Section 5.2. Generally speaking, the larger the air/liquid ratio, the smaller the slug size.

In practice, slug size has some variability. Potential causes of variability include the oscillating flow of both air and liquid from peristaltic pumps. Flow pulsations can be reduced by replacing the peristaltic pump for cold liquid solution with a syringe pump, and by implementing offsetting dual heads of the peristaltic pump for the gas flow.[2] Minimization of the slug size variability assures similar crystallization conditions among different slugs.

The slug shape affects the recirculation flow pattern, which not only provides the mixing (distribution of temperature and concentration), but also pushes particles near the tubing wall towards the tubing center, without using a mixing blade (thus minimizing attrition).[2] The closer the slug shape is to a sphere (with an aspect ratio close to 1), the smaller the volume of any dead zone and the better the mixing, favoring uniform distribution of crystals inside slugs (Figures 5.3a and b).[2]

The slug contact angle depends on the surface affinity of liquid for the inner tubing wall. When the aqueous slugs are not moving, the surface properties dominate. For example, the front and back of the slugs are flat surfaces for the Pharma-80 silicone tubing (that is, each slug is very close to a