

the powder to avoid spillage. A lip on the mouth of the tube containing the powder has proved useful, but requires that the dispensing tube is returned to an exact orientation. This can be accomplished by notching both tube and rack sufficiently to guarantee return to a constant orientation. The tilt angle at which the tube is held also determines the rate at which the solid is dispensed. Accurate addition of solid depends on an appropriate combination of tilt angle, vibration intensity, vibration duration, and a knowledge of the physical properties of the solid.

To pour powder, the robot grips the powder tube and tilts it to an initial angle over the container. A vibration pulse follows, after which the tube is weighed. A lag time usually occurs, representing the time required for the solid to reach the tip of the tube. If only a small fraction of the target weight has been reached, the tilt angle is increased. The hand vibrates and powder is added. A comparison between the target weight and the amount added is made. As the target weight is approached, both the vibration intensity and duration are decreased and the pouring routine continued. When the target weight is obtained, the pouring routine is stopped, and the net weight of solid calculated. By using this technique, we have obtained good reproducibility with target weights as low as 0.05 g.

Liquids. Liquids can be dispensed using automatic, gas-tight syringes that are commercially available and capable of dispensing accurate volumes. Typically, these syringes are computer-controlled to position a valve so that the desired volume of liquid can be pulled from a reservoir into the barrel of the syringe. The valve is then switched and the liquid dispensed through Teflon tubing into a robot hand-held sample tube. Because the syringe drive is subdivided into approximately 1000 positions, the reproducibility of the volume delivered will be 0.1% of the total syringe volume. Thus, if a 10-ml syringe is used, the volume delivered will be ± 0.01 ml; 5.0-, 2.5-, and 1.0-ml syringes can readily be substituted to provide greater accuracy. Although volumes can be accurately dispensed, it is best to weigh each sample tube after each liquid addition. This allows an exact accounting of what is added into (or adhered onto) the tube by eliminating volume errors that may result from air in the syringe lines or unpurged syringes. Because all of the input and output compositions are recorded in terms of weight percents, a numerical conversion from weight to volume is necessary before each liquid addition. This requires knowledge of the density of the liquid being dispensed. Approximate density values, such as those given in Table 2, are usually sufficient for this conversion. The dispensing of nonviscous liquids (viscosity less than 1 cp) is