In a centrifugal field, the terminal separation velocity of particles, U_{0c}, is given by the following equation, where the centrifugal acceleration is substituted for the gravitational acceleration:

$$U_{0c} = \frac{r\omega^2 \cdot D_p^2(\rho_p - \rho_f)}{18\mu} \tag{11.16}$$

or

$$U_{0c} = \frac{gZD_p^2(\rho_p - \rho_f)}{18\mu} = ZU_0 \tag{11.17}$$

where $Z = r\omega^2/g$ is the centrifugal factor, r is the radial distance from the central axis of rotation, and ω is angular velocity of rotation ($\omega = 2\pi Nr$).

The analysis presented so far is valid only for dilute cell suspensions where particle–particle interactions are negligible. When particle concentration is high, particles interact to form a swarm, and their terminal velocity decreases from U_0 to U. This is known as *hindered settling*. The separation of cells or particles in a centrifugal field is similar to hindered settling under gravity, since particle concentration is high under centrifugation conditions.

In hindered settling, the drag force on particles is

$$F'_D = \frac{1}{g_c} 3\pi\mu D_p U \left(1 + \beta_0 \frac{D_p}{L}\right) \tag{11.18}$$

where U is the terminal velocity of the particles under hindered-settling conditions, L is the average distance between adjacent particles, and β_0 is the hindered-settling coefficient. β_0 is 1.6 for a rectangular arrangement of particles. In dilute solutions, since $D_p/L << 1$, F'_D approaches F_D. Hindered settling becomes important when D_p and L are comparable.

The parameter β_0 is a function of α, the volume fraction of particles, and the shape of the particles. It can be shown that

$$\frac{U_c}{U_{0c}} = \frac{1}{1 + \alpha' \alpha^{1/3}} \tag{11.19}$$

where α' is empirically correlated with α and depends on particle shape also. U_c is the terminal velocity of the particles of a given size and shape in the centrifugal field under conditions of hindered settling.

When designing or sizing a centrifuge, we are concerned primarily with the capacity of the centrifuge to handle a given flow rate of broth. If we know both the velocity of the particle in the centrifugal field and the distance the particle must travel to be captured, then we can proceed with the design.

Examples of two popular centrifuges are shown in Fig. 11.7. Clearly, the geometry of the centrifuge influences the travel distance.

Consider a simple one-dimensional case where the distance of travel of a particle is

$$y = U_{0c} t \tag{11.20}$$

Substituting eq. 11.17 for U_{0c} and noting that the time of interest is $t = V_c/F_c$, we write