medium and coarse crystals having little material less than 100 mesh, deoiling of proteinaceous solids, and removal of solids from fruit and vegetable pulps and other feed slurries. By use of larger screen perforations, skin and seeds alone may be removed from chopped fruit and vegetable pulps to produce smooth food purees such as applesauce, tomato pulp, and various baby foods.

A third type of cone screen centrifuge operates with bowl angles of 13 to 18° and assists solids discharge by a vibratory motion of the bowl or bowl and casing. These units usually have under-driven bowls with the 20 to 42 in. larger diameter at the upper end; diameter-to-length ratios range from 1 to 2. Operating speeds are normally 300 to 500 rpm and solids capacities range from 25 to 150 ton/hr. Pressurized units are not available and operating temperatures range to 200°F. Power requirements are 20 to 30 hp. Bar screens are frequently used and applications are largely in the field of coal dewatering where particle sizes from about 1.25 in. down to 60 mesh are readily handled. The centrifuges also find application in dewatering of potash and other crystalline solids.

Operating conditions of continuous screen centrifuges used in various applications are given in Table 9.

Gas Centrifugal Separation

A gas subjected to a centrifugal field experiences a force of $M\rho'\omega^2r$ per unit volume where ρ' is the molal density, M the molecular weight, r the radius, and ω the angular velocity of the rotor. The pressure gradient in the gas is $dp/dr = M\rho'\omega^2r = Mp/(RT)(\omega^2r)$. In general for ideal gases if $p_j(r)$ and $p_j(0)$ are the partial pressures of a gas of molecular weight M_j at radius r and at the axis, respectively, then

$$p_j(r) = p_j(0) \exp (M_j\omega^2r^2/2RT)$$

where R is the gas constant and T the absolute temperature. In the case of a binary mixture with molefraction c of the lighter gas M_l it has been shown, both theoretically (13,23,24) and experimentally (5,7) that at equilibrium

$$\left(\frac{c}{1-c}\right)_{r=0} = \left(\frac{c}{1-c}\right)_{r=r_3} \exp\left[(M_h - M_l)\omega^2r_3^2/2RT\right] \tag{35}$$

In order to calculate the effectiveness of a centrifuge or cascade of centrifuges for separating isotopes or gases as well as to compare them with other methods of separation, it has been found convenient to determine the so-called separative power or the rate of doing separative work (13). Separative work is a measure of the amount of separation performed by a separation unit (such as a centrifuge) or cascade of such units in making N_P moles of product and N_W moles of waste from N_F moles of feed material and is defined (8) as

$$U = N_W(2c_W - 1)\ln\frac{c_W}{1-c_W} + N_P(2c_P - 1)\ln\frac{c_P}{1-c_P} - N_F(2c_F - 1)\ln\frac{c_P}{1-c_P} \tag{36}$$

Cohen (13) has shown that the separative power of a centrifuge is

$$(\delta U) = \frac{Dp}{RT}\left(\frac{(M_h - M_l)\omega^2r_3^2}{2RT}\right)^2 \frac{\pi l}{2} f \tag{37}$$

where l is the length of the centrifuge, D the diffusion constant, and f a flow factor which depends upon the internal flow pattern and has a maximum of one. Consequently, $U/(t)(\delta U)$ gives the number of centrifuges required to perform a given job of separation in a given time t.

It will be observed that the separative power δU increases directly as the length of the centrifuge bowl and as the fourth power of ωr_3 or the peripheral velocity of the rotor. Therefore, the centrifuge tube should be as long as practicable and should be spun as rapidly as possible. Also, δU increases directly as the difference in masses $(M_h - M_l)^2$ rather than their ratio. Consequently, the method should be effective for heavy gases as well as light ones if the mass differences are appreciable.

The tubular centrifuge has been used in several different ways to separate the isotopes as well as to purify different gases. The first successful separation of isotopes was carried out with the evaporative centrifuge method (5). Later the concurrent and countercurrent methods were developed. Cohen (13) has shown theoretically that the countercurrent method produces the maximum amount of separative work when properly used. As a result, countercurrent flow has been employed almost exclusively in recent years. In the countercurrent method, the gaseous or vapor mixture is made to flow in two streams along the direction of the length of the spinning tube. For example, one stream flows from bottom to top near the axis of the tube and the other stream flows from top to bottom along the periphery of the tube. As a result of the centrifugal and diffusive action in the gaseous mixture, the stream near the axis has the lighter isotope enriched while that flowing down along the periphery has the heavier isotope enriched. This causes a buildup in enriched material, for example, at the top of the centrifuge, until back diffusion between top and bottom counterbalances the separation. As a result, the enrichment at the upper end is many times that given by equation 35. The axial streams are found to be stable over comparatively long axial distances so that centrifuges several meters long may be used. During World War II, centrifuge tubes of various lengths were used to test the theory both in the U.S. (7) and in Germany (9). Uranium hexafluoride was used as the gas in most of the tests. For example, with a centrifuge tube 11 ft long and 7.6 in. ID used in countercurrent operation it was found (8) that the factor f in equation 37 was between 0.8 and 0.9. Since that time, the technique of gaseous centrifuging has been greatly developed (7,9,22,38). New and much stronger rotor materials have become available, which make it possible at least to double the peripheral speed. It can be seen from equation 37 that the separation, consequently, should be increased sixteen times. The method still has very great undeveloped potential for the separation of isotopes of the heavier elements and gas mixtures which are difficult or very expensive to separate by other methods. See also Diffusion separation methods.

Nomenclature

a = distance between adjacent discs measured normal to disc surface
c = mole fraction
C = discharge coefficient of nozzle
d = diameter of particle or drop
$\bar{d}$ = mean particle diameter
D = diffusivity
e = efficiency factor
E = energy contained in rotating body
f = flow factor for gas centrifuge

g = acceleration of gravity
G = ratio of centrifugal acceleration to acceleration of gravity
h = cake thickness
I = moment of inertia of rotating bowl about axis of rotation
k = experimental coefficient in equation 25
k' = experimental coefficient in equation 27
K = cake permeability coefficient, mass/(time)^2
l = axial length of bowl
m = torque
M = molecular weight
n = number of discs
N = molal rate
p = partial pressure
P = power
q = volume of undrained liquid (mother liquor)/unit volume of solid, %
q_∞ = volume of undrained liquid (mother liquor)/unit volume of solid at infinite time, %
Q = volumetric rate
r = radius
R = universal gas constant
s = external surface area/weight of solids
s' = surface area/volume of cake
S = fraction of void volume occupied by liquid at time t
S_∞ = fraction of void volume occupied by liquid at infinite time
t = time during which material is exposed to separation effect
t' = time at which free liquid enters the cake in Nenninger and Storrow equation 26
T = absolute temperature
U = separative power of gas centrifuge
v = velocity
V = volume
α = cake resistance constant in pressure filtration, length/volume
Δ = difference
ϵ = void fraction
μ = viscosity
ω = angular velocity of rotation motion
φ = wetting angle
ϕ = angle between direction of the nozzle and tangent to circle intersecting nozzle axis at discharge section
ρ = mass density = mass/unit volume
ρ' = molal density, mole/cm^3
σ = surface tension
Σ = theoretical capacity factor
θ = half included angle of discs

Subscripts

B	refers to bottle centrifuge
C	refers to cake
D	refers to disc centrifuge
f	refers to film flow
F	refers to feed
g	refers to settling velocity of particle in gravity field
h	refers to heavy phase
i	refers to interface
j	refers to j$^{\text{th}}$ component
l	refers to light phase
L	refers to liquid medium
m	refers to motor
M	refers to filter medium
N	refers to nozzle
O	refers to overflow
P	refers to product
s	refers to settling velocity of particle in centrifugal field
S	refers to solid
T	refers to tubular centrifuge
W	refers to waste
1	refers to inside measure of disc
2	refers to outside measure of disc
3	refers to inside measure of bowl shell

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