principle is used extensively in pressure-fluidizing-type valve-bag-packing machines.

Nomographs for Preliminary Design A useful set of nomographs* for determining conveyor-design parameters is given in Fig. 21-13. With these charts, conservative approximations of conveyor size and power for given product bulk density, conveyor equivalent length, and required capacity can be obtained. Because pneumatic conveyors and their components are subject to continual improvements by a fast-changing supplier industry, manufacturers should be invited to submit alternative designs to that resulting from the use of the nomograph. Some large users of pneumatic conveyors have found it expedient to write computer programs for calculating system parameters.

* Nomographs prepared from data supplied by Flotronics Division, Allied Industries.

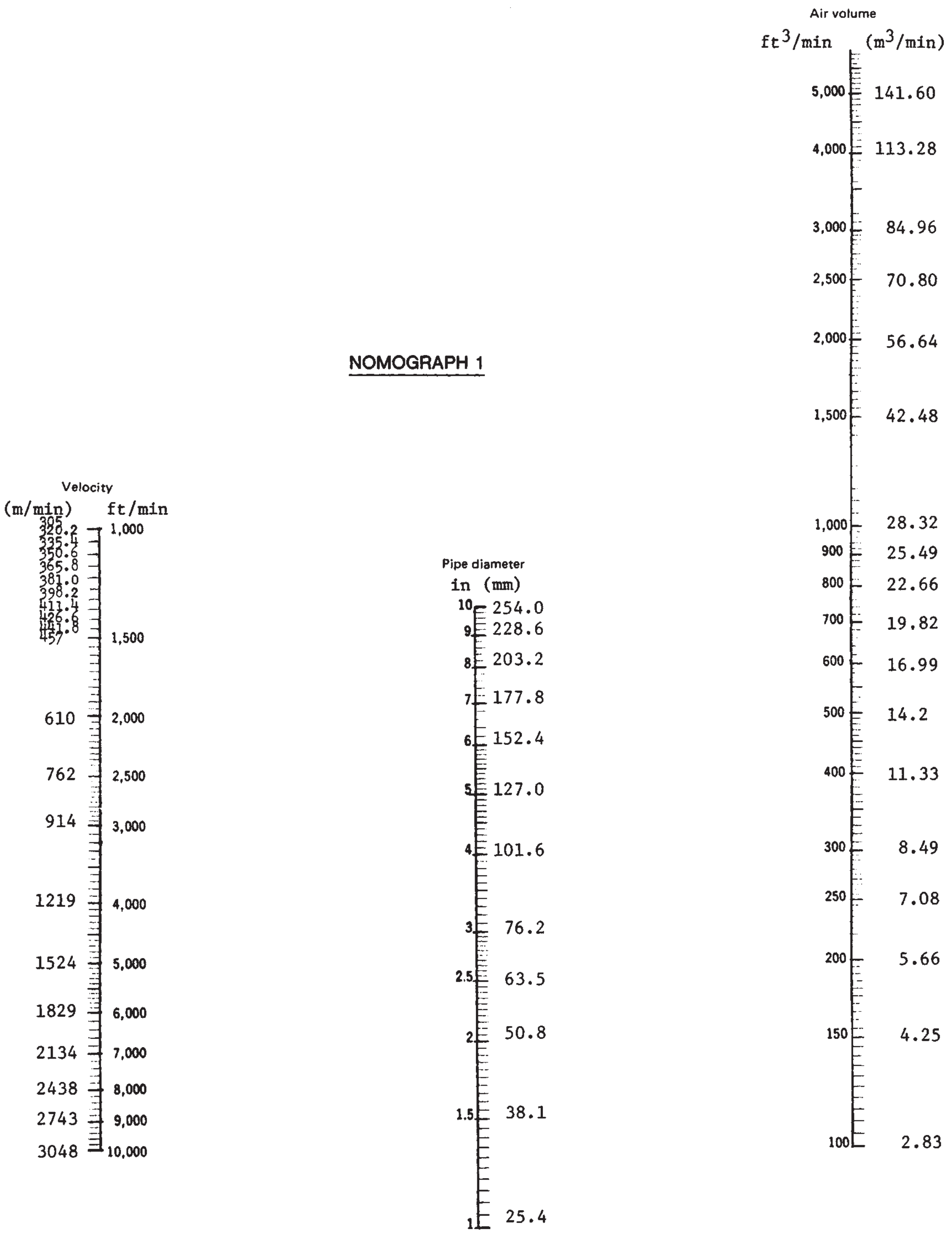

FIG. 21-13 Nomographs for determining conveyor-design parameters.

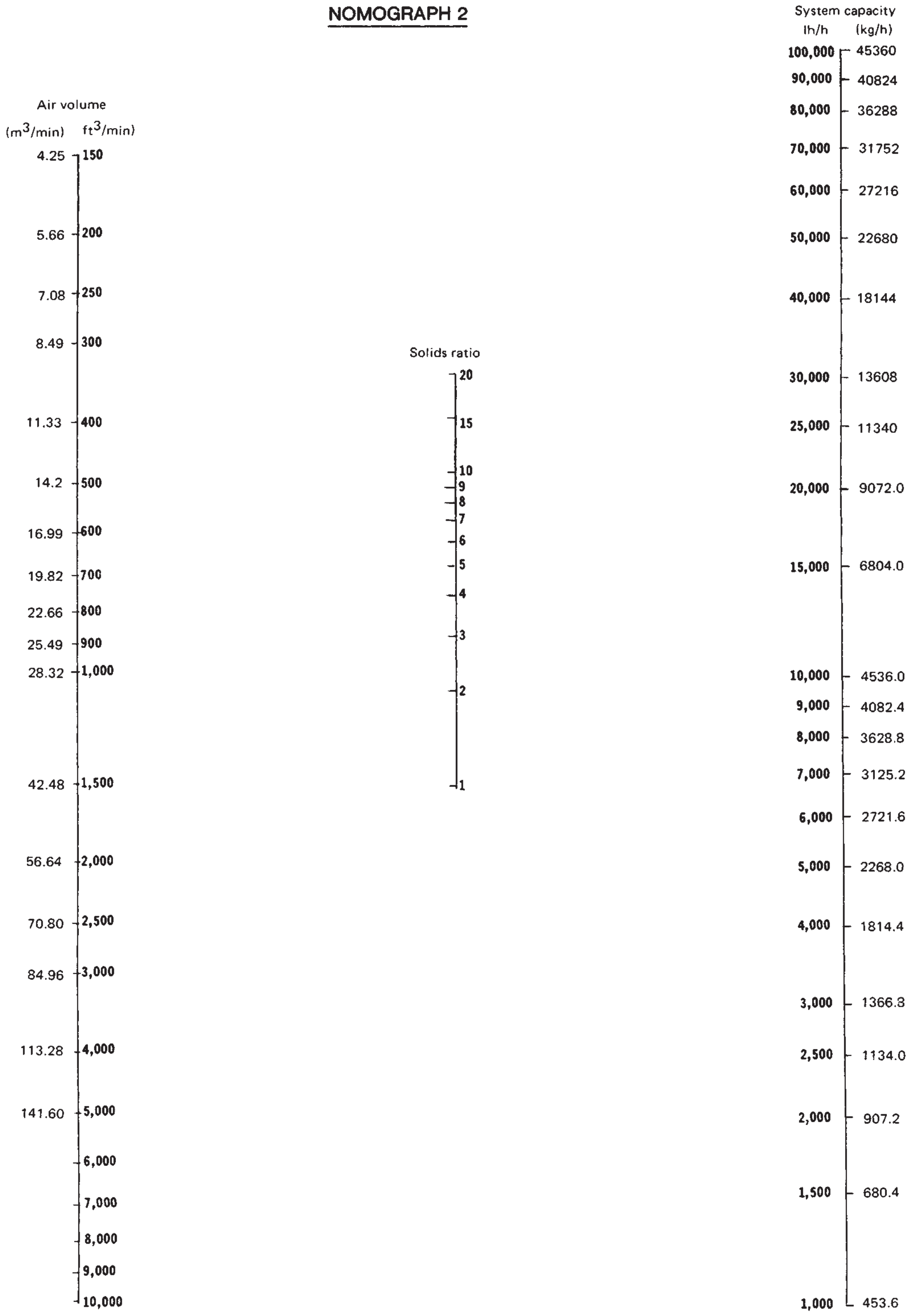

FIG. 21-13 *(Continued)*

NOMOGRAPH 3

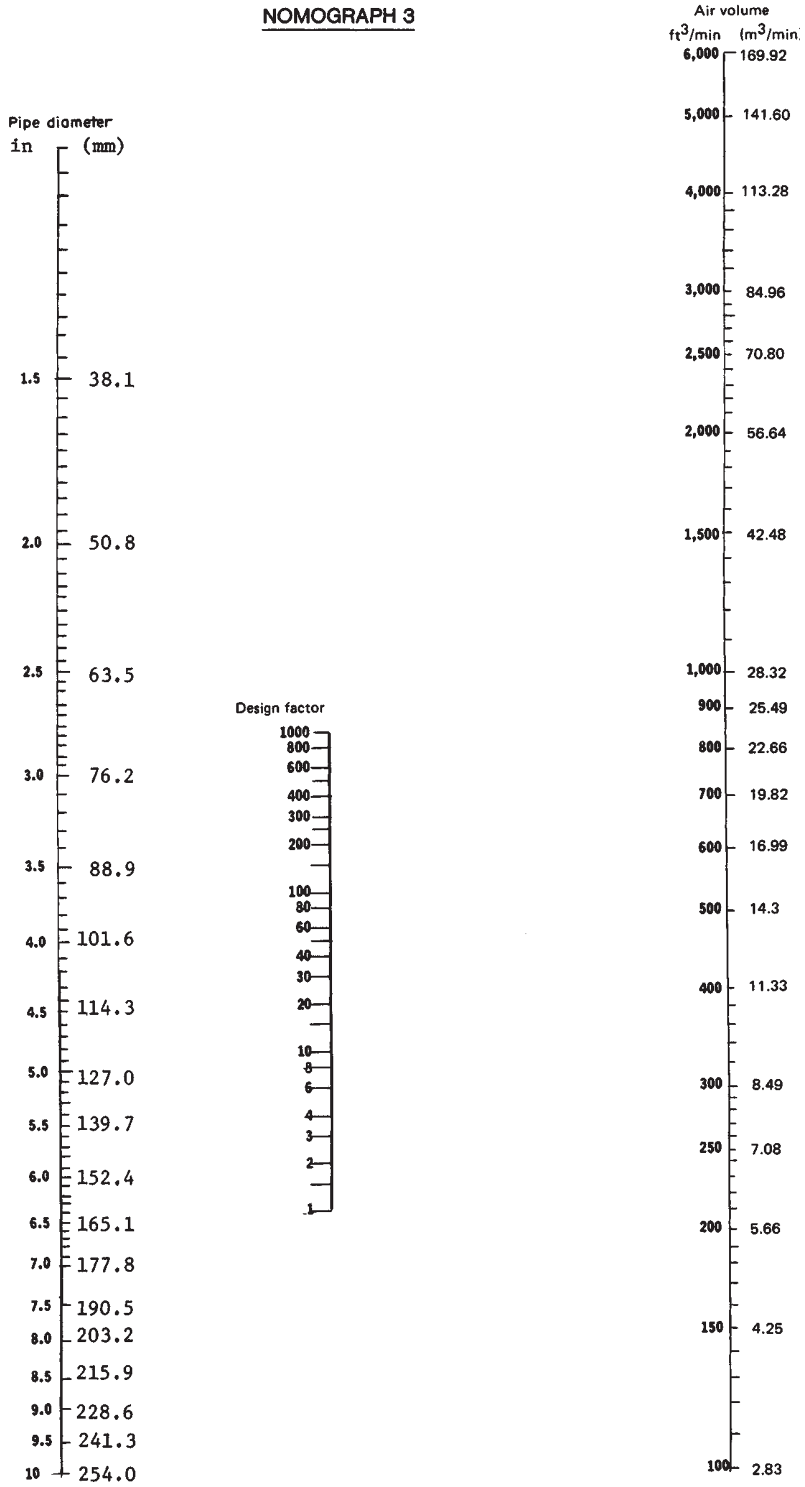

FIG. 21-13 *(Continued)*

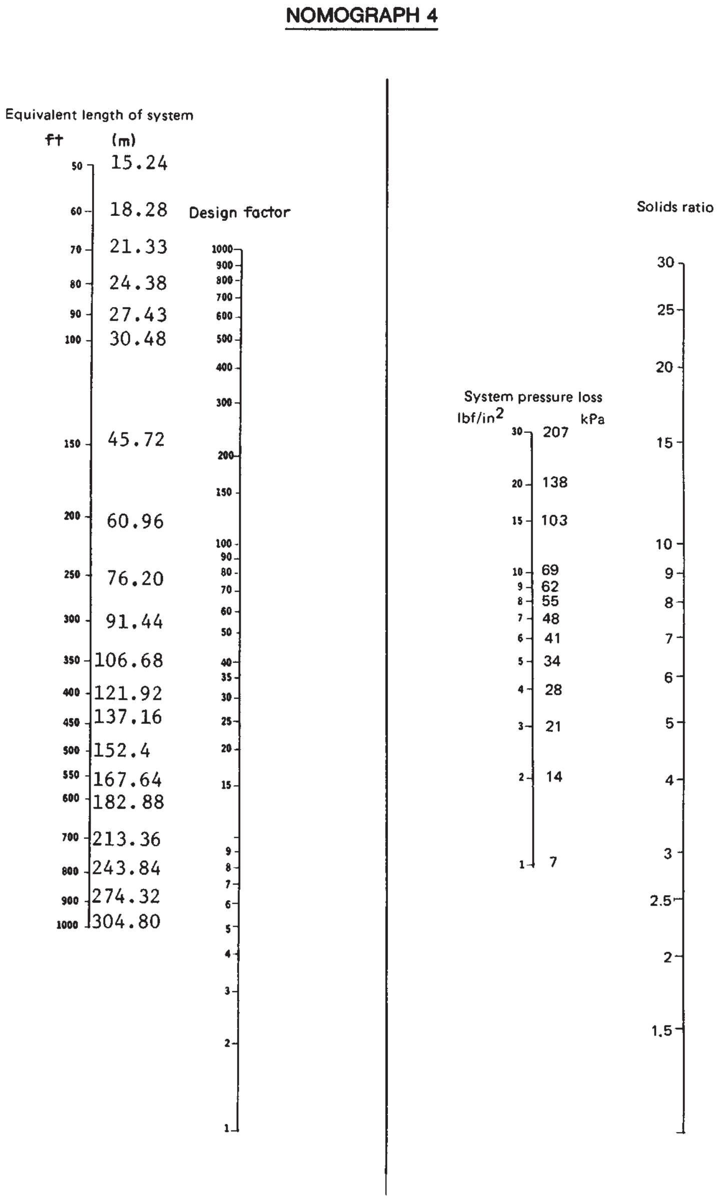

FIG. 21-13 (*Continued*)

To begin preliminary calculations, first determine the equivalent length of the system being considered. This length is the sum of the vertical and horizontal distances, plus an allowance for the pipe fittings used. Most common of these fittings are the long-radius 90° elbow pipe [equivalent length = 25 ft (7.6 m)] and the 45° elbow [equivalent length = 15 ft (4.6 m)].

The second step consists of choosing from Table 21-13 an initial air velocity that will move the product. An iterative procedure then begins by assuming a pipe diameter for the required capacity of the system.

Referring now to Nomograph 1, draw a straight line between the air-velocity and the pipe-diameter scales so that when the line is extended it will intersect the air-volume scale at a certain point.

Turn now to Nomograph 2 and locate in their respective scales the air volume and the calculated system capacity. A straight line between these two points intersects the scale in between them, thus providing at the intersection point the value of the solids ratio. If the solids ratio exceeds 15, assume a larger line size.

Locate in Nomograph 3 the pipe diameter and the air volume found in Nomograph 1. A line between these two points yields the

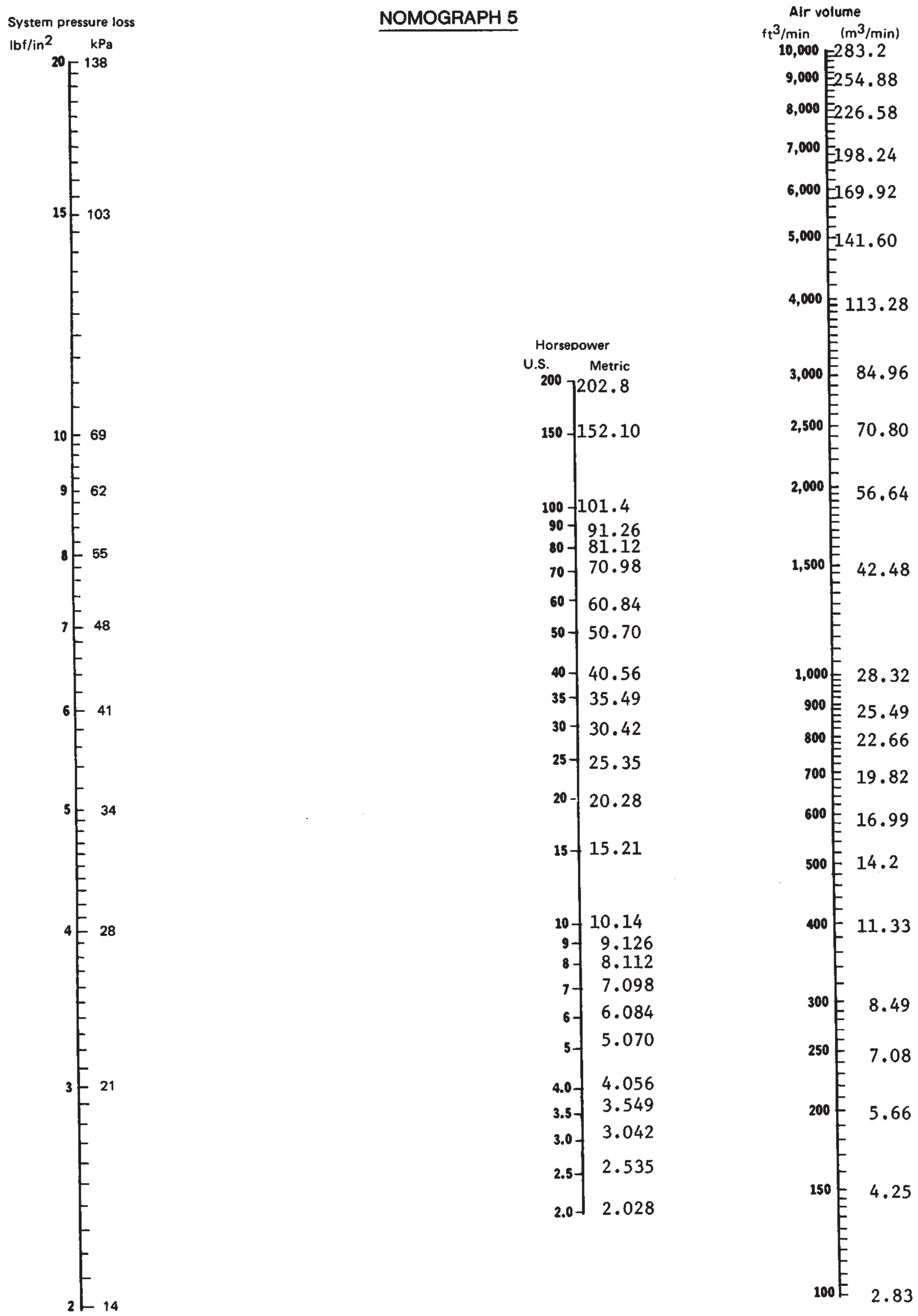

FIG. 21-13 *(Continued)*

TABLE 21-13 Air Velocities Needed to Convey Solids of Various Bulk Densities*

Bulk density		Air velocity		Bulk density		Air velocity	
lb/ft^3	kg/m^3	ft/min	m/min	lb/ft^3	kg/m^3	ft/min	m/min
10	160	2900	884	70	1120	7700	2347
15	240	3590	1094	75	1200	8000	2438
20	320	4120	1256	80	1280	8250	2515
25	400	4600	1402	85	1360	8500	2591
30	480	5050	1539	90	1440	8700	2652
35	560	5500	1676	95	1520	9000	2743
40	640	5840	1780	100	1600	9200	2804
45	720	6175	1882	105	1680	9450	2880
50	800	6500	1981	110	1760	9700	2957
55	880	6800	2072	115	1840	9900	3118
60	960	7150	2179	120	1920	10500	3200
65	1040	7450	2270				

*Courtesy of Flotronics Division, Allied industries.

design factor, or *P* 100 (30.5), the pressure drop per 100 ft (30.5 m), at the intersection of the center scale.

Locating now in their respective scales on Nomograph 4 the design factor (from Nomograph 3) and the calculated equivalent length, draw an extended straight line to intersect the pivot line in the center. Now connect this point in the pivot line with the solids-ratio scale (from Nomograph 2), and read the system pressure loss.

If the value of this loss exceeds 10 lb/in^2 (70 kPa), assume a larger pipe diameter and repeat all these steps, beginning with Nomograph 1. After a pressure drop of 10 lb/in^2 (70 kPa) or less is found, turn to Nomograph 5 and locate this pressure loss, as well as the corresponding air volume (from Nomograph 2), and draw a straight line between the two points. The intersection of the horsepower scale will provide the value of the power required. From this, the system cost can now be approximated by consulting Table 21-12.

STORAGE AND WEIGHING OF SOLIDS IN BULK

STORAGE PILES

Discharge Arrangements Open-yard storage is probably best handled by belt conveyor when tonnages are large. Figure 21-14 shows some of the many discharge arrangements possible for single, multiple, or moving-tripper discharge from belt conveyors. Also shown is a tilting-plow arrangement for discharging flat belts. Most of these discharge methods are equally applicable for indoor storage. Large traveling stackers may also be used for outdoor storage. They may move along the length of a belt, forming a pile on one or both sides of the belt, or pivot about a fixed axis to form a circular pile.

Reclaiming Underground-tunnel belts fed by special gates (Fig. 21-15) are often used for reclaiming, as is mobile shovel equipment. Cable-drag scrapers are also used for large outside storage areas and sometimes on inside storage when large, flat areas are used. A drag-scraper system may follow a single fixed cable line, or back posts may be provided to allow relocation of the cable line to cover almost any storage-space shape.

One development for handling large tonnages of bulk materials from storage is the **bucket-wheel reclaimer,** which consists of a series of buckets placed about the periphery of a large wheel that is carried by a fixed propulsion unit. The buckets empty onto a removal conveyor, usually of the belt type, which takes the product to further processing or handling. Bucket-wheel reclaimers capable of handling as little as 150 tons/h to as much as 20,000 tons/h (see Fig. 21-16) have been built.

Mobile equipment is often preferred to fixed types. Front-end loaders, scrapers, and bulldozers are used with increasing frequency, especially on projects of short duration or when capital investment must be limited. Front-end loaders are especially advantageous because of their ability to carry material as well as to plow or bulldoze it.

Angle of repose is the angle at which a material will rest on a pile. It is useful for determining the capacity of a bin or a pile. The angle of the cone that develops at the top of the pile when a bin is being filled will be somewhat flatter than the angle of repose because of the effect of impact.

STORAGE BINS, SILOS, AND HOPPERS

Probably no section of the materials-handling and -storage art advanced as far in a decade (the 1960s) as did that of bin storage of bulk materials. Prior to this time, **storage-bin design** was a hit-or-miss empirical affair, in which success was assured only if the product was free-flowing. This was changed radically as a result of research led by Andrew W. Jenike. This work, which resulted in identifying the criteria that affect material flow in storage vessels, was first reported in Jenike's paper "Gravity Flow of Bulk Solids" (Bull. 108, University of Utah Engineering Experiment Station, October 1961). This paper set forth the equations defining bulk flow and the coefficients affecting flow.

Continuing experimentation verified these criteria, and in Bulletin 123 (November 1964) the subject was further defined by providing flow factors for a number of bin-hopper designs as well as specifications for determining experimentally the characteristics of bulk material affecting flow and storage. Along with the theory, Jenike produced a method of applying it, which includes equations and the physical measurement of material characteristics.

In what follows, a storage vessel is considered as consisting of a bin and a hopper. A bin is the upper section of the vessel and has vertical sides. The hopper, which has at least one sloping side, is the section between the bin and the outlet of the vessel.

Material-Flow Characteristics Two important definitions of the flow characteristics of a storage vessel are **mass flow,** which means that all the material in the vessel moves whenever any is withdrawn (Fig. 21-17), and **funnel flow,** which occurs when only a portion of the material flows (usually in a channel or rathole in the center of the system) when any material is withdrawn (Fig. 21-18). Some typical mass-flow designs are shown in Fig. 21-19.

Mass-flow bins feature the most sought-after characteristics of a storage vessel: unassisted flow whenever the bottom gate is opened. A funnel-flow bin may or may not flow but probably can be made to flow by some means.

Until Jenike developed the rationale for storage-vessel design, a common criterion was to measure the angle of repose, use this value as the hopper angle, and then fit the bin to whatever space was available. Too often, bins were designed from an architectural or structural-engineering viewpoint rather than from the role they were to play in a process. Economy of space is certainly one valid criterion in bin design, but others must be considered equally as well. Table 21-14 compares the principal characteristics of mass-flow and funnel-flow bins.

Although a mass-flow bin is obviously preferable to a funnel-flow vessel, the additional investment generally required must be justified. Often, this can be done by the reduced operating costs. But when installation space is limited, a compromise must be made, such as providing a special hopper design and sometimes even a feeder. Certainly, with mass-flow bins the feeder is not required for flow, but it might still be used for other reasons, such as conveying the material to the next process step.

Design Criteria Jenike's criteria permit an **engineering-economic analysis of storage** with about the same confidence level