Handling of Bulk Solids and Packaging of Solids and Liquids

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INTRODUCTION

During the period between this edition and the sixth, notable changes have taken place which influence packaging and material handling in the chemical industry. These are: Rapid change in the technologies involved; the impact of governmental regulations on both packages and equipment; and the global nature of the chemical industry. These are all interrelated and must be taken into account by the chemical engineer who is planning and choosing packages for chemical products and the packaging machinery and material handling equipment which will be used. Packaging and material handling technology—which had largely been an art, blending science and engineering—has seen dramatic changes. Influencing these are: The advent of special purpose and personal computers; availability of software which allows the rapid calculation and presentation of data and control of processes; and the unusual degree of development of sensing devices.

With these technologies, literally anything in the operation of a packaging or material handling system can be sensed and then via computer, using most often commercially available software, incredible levels of calculations can be performed. These can be used to control the process producing the data and can present operators, engineers, and managers with data and calculations describing virtually any facet of the packaging or material handling systems operation. Closely akin to these is the advent of robots which can carry out many human tasks. Robots are controlled by computers, under the direction of software which relies on sensors and computers. A further outgrowth of this technical revolution occurs in the management and control of inventories—whether they be in the raw material stage, in processing, or in a finished goods sales warehouse. Automatic storage and retrieval equipment under the direction of a special-purpose computer allows unbelievable degrees of identifying all items in the inventory: Where they are, their age, and which inventory to choose to optimize the profit plan of the corporation which owns them. Underlying the control of this sophisticated inventory-management system is an emerging technology known as **bar coding.** This is a logical outgrowth of the development of the personal computer and the software for its operation. The placing of lasers into printing devices has created the ability to produce labels with bar codes. Production of labels has become a real-time packaging-line-type operation rather than an operation in which the labels have to be ordered and inventoried, as was the case before the dramatic technical revolution just described.

The weighing and proportioning of liquids and solids has also benefited from this technical revolution. Sensing devices and special-purpose computers give a level of precision and speed not possible in the era of electromechanical devices. The net result is that packaging and material handling systems now have the sophistication of chemical processes.

All of this gives the chemical engineer new levels of ability to design, operate, and manage complex material handling and packaging systems. Since it is still incumbent on the engineer to define production and performance requirements, some definitions of productivity are useful.

PHYSICAL-DISTRIBUTION CONCEPT

Systems Approach **Physical distribution** is a term applied to a systems concept that comprises the entire spectrum of materials movement. The system begins with the storage and handling of raw materials and follows right on through the packaging and disposition of the finished product. The aim is the attainment of the **lowest overall cost** for the system as a whole, comprising the expenses borne by the manufacturer, transport carrier, warehouser, distributor, and customer. Even the manner in which the customer will handle the product is often taken into account.

Two main benefits accrue from a systems approach to materials handling and packaging. First, a trade-off of investment and operating costs is made possible; higher costs in some parts of a system become permissible in return for much lower costs in other parts. The net result is usually the lowest overall cost. If this is not the case, the reasons for incurring the higher costs can be identified and justified. The second benefit is that customers are not offended by ill-conceived packages, delivery vehicles, or product characteristics.

Mathematical modeling, using digital computers, aids in performing a systems-type analysis for either the entire system or parts of it. By means of integer or linear-programming techniques, optimum systems can be identified. The dynamic performance of these can then be determined by simulation techniques.

Determining the capacities of material-handling and packaging equipment is a primary consideration. Many **interacting variables** often are involved, such as an ever-changing or intermittent material-delivery rate, the capacity of intermediate storage and receiver bins, random stoppage or failure of equipment in the system, and the setup and cleanup time between product grades or blends. Variables frequently interact in such complex ways that conventional capacity analyses are impossible, especially if the interaction varies with time. Under such conditions the question of whether the system will deliver the required output can be answered only by simulation techniques.

Even when a total system analysis is unnecessary, the methodology of mathematical modeling is useful, because by considering each component of a system as a block of a flow sheet, the interrelationships become much clearer. Additional alternatives often become apparent, as does the need for more equipment-performance data.

Capacity Definitions In any analysis, the capacity per unit time of dynamic equipment (such as conveyors and bagging machines), as well as the rates at which they actually perform, must be defined more precisely and realistically than by a mere statement of kilograms or pounds per hour. Some useful definitions employed by the equipment industry are the following:

Instantaneous Rate This is a short-term rate when the equipment operates at the design rate or faster. Typical is the average weight handled over a short period of time, not exceeding 5 min.

Hourly Rate This intermediate rate takes into account equipment stoppages due principally to mechanical downtime rather than the equipment's idle time while it waits for action by other parts of the system.

Shift Rate A long-term rate, this reflects all causes of downtime, including idle time. Thus, the average per shift will vary, but by examining its range the practical capacity can be determined. Production time lost due to scheduling of the equipment affects the shift rate. On certain days the equipment has a shift rate close to the hourly rate, while on other days this rate is only half of the hourly rate. Examination of the reasons for this difference often identifies scheduled events as being responsible: the equipment was shut down for cleanup between product grades, product was unavailable for packaging because a bulk order had to be filled, or the product scheduled had a production rate which was half of the products normally made.

These capacity definitions are used to define responsibilities of both vendors and buyers. For instance, often a vendor is called in to examine a piece of equipment that does not perform at the "guaranteed" rate. Records of shift production are offered as proof. Yet the vendor then makes a test and shows that the guaranteed rate is met over a short interval. Who is correct? By defining rates the engineer responsible for the installation not only can avoid these situations but can obtain a better appreciation of potential plant situations.

CONVEYING OF BULK SOLIDS

CONVEYOR SELECTION

Selection of the correct conveyor for a specific bulk material in a specific situation is complicated by the large number of interrelated factors that must be considered. First, the alternatives among basic types must be weighed, and then the correct model and size must be chosen. Workability is the first criterion, but the degree of performance perfection that can be afforded must be established.

Because **standardized equipment designs** and complete engineering data are available for many common types of conveyors, their performance can be accurately predicted when they are used with materials having well-known conveying characteristics. However, even the best conveyors can perform disappointingly if material characteristics are unfavorable. It is often true that conveyor engineering is more of an art than a science; problems involving unusual materials or equipment should be approached with caution.

Many preengineered conveyor components can be purchased off the shelf; they are economical and easy to assemble, and they perform well on conventional applications (for which they are designed). However, it is advisable to check with the manufacturer to be sure that the application is proper.

Capacity requirement is a prime factor in conveyor selection. Belt conveyors, which can be manufactured in relatively large sizes to operate at high speeds, deliver large tonnages economically. On the other hand, screw conveyors become extremely cumbersome as they get larger and cannot be operated at high speeds without creating serious abrasion problems.

Length of travel is definitely limited for certain types of conveyors. With high-tensile-strength belting, the length limit on belt conveyors can be a matter of miles. Air conveyors are limited to 305 m (1000 ft); vibrating conveyors, to hundreds of meters or feet. In general, as length of travel increases, the choice among alternatives becomes narrower.

Lift can usually be handled most economically by vertical or inclined bucket elevators, but when lift and horizontal travel are combined, other conveyors should be considered. Conveyors that combine several directions of travel in a single unit are generally more expensive, but since they require only a single drive, this feature often compensates for the added base cost.

Material characteristics, both chemical and physical, should be considered, especially flowability. Abrasiveness, friability, and lump size are also important. Chemical effects (e.g., the effect of oil on rubber or of acids on metal) may dictate the structural materials out of which conveyor components are fabricated. Moisture or oxidation effects from exposure to the atmosphere may be harmful to the material being conveyed and require total enclosure of the conveyor or even an artificial atmosphere. Obviously, certain types of conveyors lend themselves to such special requirements better than others.

Processing requirements can be met by some conveyors with little or no change in design. For example, a continuous-flow conveyor may provide a desired cooling of the solids simply because it puts the conveyed material into direct contact with heat-conducting metals. Screen decks can be readily attached to vibrating conveyors for simple sizing and scalping operations, and special flights or casings on screw conveyors are available for a wide variety of processing operations such as mixing, dewatering, heating, and cooling.

Initial cost of a conveyor system is usually related to **life expectancy** as well as to the flow rate chosen. There is a great temptation to overdesign, which should be resisted. The first really long-distance belt conveyor was designed and fabricated to extremely high standards of quality. After 35 years it was still in operation with almost all its original components. Had this operation been planned for only a 10-year life, the conveyor system would have represented a bad case of overdesign. While there is a market for used conveyor equipment, it is extremely limited. Thus, it is important to choose conveyor quality for expected life of project.

Comparative costs for conveyor systems can be based only on studies of specific problems. For example, belt-conveyor idlers are available in a range of qualities that may make the best unit cost three times as much as the cheapest. Bearing quality, steel thickness, and diameter of rolls all affect cost, as does design for easy maintenance and repair. Therefore, it is necessary to make cost comparisons on the basis of a specific study for each conveyor application.

As a general guide to conveyor selection, Table 21-1 indicates **conveyor choices** on the basis of some common functions. Table 21-2 is designed to aid in **feeder selection** on the basis of the physical characteristics of the material to be handled. Table 21-3 is a coded listing of **material characteristics** to be used with Table 21-4, which describes the conveying qualities of some common materials. While these tables may serve as valuable guides, conveyor selection must be based on the **as-conveyed characteristics** of a material. For instance, if packing or aerating can occur in the conveyor, the machine's performance will not meet expectations if calculations are based on an average weight per cubic meter. Storage conditions, variations in ambient temperature and humidity, and discharge methods may all affect conveying characteristics. Such factors should be carefully considered before making a final conveyor selection.

To obtain a reliable **measurement of bulk density,** any wide-mouthed vessel with a capacity of 1 ft^3 or more may be used. When such a determination must be made often, it is worthwhile to con-

TABLE 21-1 Conveyors for Bulk Materials*

Function	Conveyor type
Conveying materials horizontally	Apron, belt, continuous flow, drag flight, screw, vibrating, bucket, pivoted bucket, air
Conveying materials up or down an incline	Apron, belt, continuous flow, flight, screw, skip hoist, air
Elevating materials	Bucket elevator, continuous flow, skip hoist, air
Handling materials over a combination horizontal and vertical path	Continuous flow, gravity-discharge bucket, pivoted bucket, air
Distributing materials to or collecting materials from bins, bunkers, etc.	Belt, flight, screw, continuous flow, gravity-discharge bucket, pivoted bucket, air
Removing materials from rail cars, trucks, etc.	Car dumper, grain-car unloader, car shaker, power shovel, air

*From FMC Corporation, Material Handling Systems Division.

TABLE 21-2 Feeders for Bulk Materials*

Material characteristics	Feeder type
Fine, free-flowing materials	Bar flight, belt, oscillating or vibrating, rotary vane, screw
Nonabrasive and granular materials, materials with some lumps	Apron, bar flight, belt, oscillating or vibrating, reciprocating, rotary plate, screw
Materials difficult to handle because of being hot, abrasive, lumpy, or stringy	Apron, bar flight, belt, oscillating or vibrating, reciprocating
Heavy, lumpy, or abrasive materials similar to pit-run, stone, and ore	Apron, oscillating or vibrating, reciprocating

*From FMC Corporation, Material Handling Systems Division.

TABLE 21-3 Classification System for Bulk Solids*

	Material characteristics	Class
Size	Very fine—< 149 μm (100 mesh)	A
	Fine—149 μm to 3.18 mm (100 mesh to ⅛ in)	B
	Granular—3.18 to 12.7 mm (⅛ to ½ in)	C
	Lumpy—containing lumps > 12.7 mm (½ in)	D
	Irregular—being fibrous, stringy, or the like	H
Flowability	Very free-flowing—angle of repose up to 30°	1
	Free-flowing—angle of repose 30 to 45°	2
	Sluggish—angle of repose 45° and up	3
Abrasiveness	Nonabrasive	6
	Mildly abrasive	7
	Very abrasive	8
Special characteristics	Contaminable, affecting use or salability	K
	Hygroscopic	L
	Highly corrosive	N
	Mildly corrosive	P
	Gives off dust or fumes harmful to life	R
	Contains explosive dust	S
	Degradable, affecting use or salability	T
	Very light and fluffy	W
	Interlocks or mats to resist digging	X
	Aerates and becomes fluid	Y
	Packs under pressure	Z

*From FMC Corporation, Material Handling Systems Division.

Example: A material which is granular, very free-flowing, mildly abrasive, and mildly corrosive would fall in classes C, 1, 7, and P, making its classification C17P.

struct a test box from wood or light metal having a dimension of exactly 1 ft for length, width, and depth. The material to be weighed is poured into the test box to overfill it slightly. After the material has been leveled, the test box and its contents are weighed, and after adjustment has been made for the tare weight, the weight obtained is equivalent to the bulk density in the loose or flowing condition. If a loose density is to be determined, care should be exercised in filling the test box so as not to rap or vibrate the material. When a settled density is needed, the filling portion of the procedure is accompanied by rapping the walls of the box until no more material can be added. The density value obtained by this experiment (pounds per cubic foot) can be directly converted to SI units by multiplying by 16.02, giving density in kilograms per cubic meter.

Conveyor Drives Conveyor drives may account for from 10 to 30 percent of the total cost of the conveyor system, depending on specific job requirements. They may be of either fixed-speed or adjustable-speed type. **Fixed-speed drives** are used when the initially chosen conveyor speed does not require change during the course of normal operation. Simple sheave or sprocket changes suffice should minor speed alterations be needed. However, for major adjustments motor or speed-reducer changes are required. In any event, the conveyor must be shut down while the speed change is made. **Adjustable-speed drives** are designed for changing speed either manually or automatically while the conveyor is in operation, to meet variations in processing requirements.

The number of **speed reductions** is another way to classify conveyor drives. Most common of the speed-reduction methods is the two-step system, in which the motor is coupled to a speed reducer and the slow-speed shaft of the reducer is connected to the conveyor-drive shaft by a V belt or a roller chain. The second reduction not only permits the use of a simpler speed reducer but also allows a more flexible layout of the motor and reducer mounting plate. On many installations this eliminates the need for a specially designed drive mount.

Since it is good practice to maintain a selected inventory of spare parts for drives, economy can be achieved by **standardizing conveyor drives** throughout the plant. For example, intermediate speed reduction by means of V belts, sheaves or chains, and sprockets can frequently permit using the same speed-reducer size for several drives. Thus, it may be necessary to keep only one repair-stock speed reducer for a number of conveyors.

Conveyor Motors Motors for conveyor drives are generally three-phase, 60-Hz, 220-V units; 220/440-V; 550-V; four-wire, 208-V. Also common are 240- and 480-V ratings. Although many adjustable-speed drives use alternating-current induction motors, powered by ac alternators or ac-driven eddy-current clutches, there is a strong preference for direct-current motors when speed adjustments are required over a wide range at extremely accurate settings.

The **silicon-controlled rectifier** with a dc motor has become predominant in adjustable-speed drives for almost all commonly used conveyors when speed adjustment to process conditions is necessary. The low cost of this control device has influenced its use when speed synchronization among conveyors is required. This can also be done, of course, by changing sheave or sprocket ratios.

The **squirrel-cage motor** is most commonly used with belt conveyors and with drives up to 7.457 kW (10 hp); across-the-line starting is generally specified. Between 7.457 and 37.285 kW (10 and 50 hp), squirrel-cage motors are usually started by means of a manual reduced-voltage starter or a magnetic primary-resistance starter. Normal-torque motors are generally specified, with the assumption that if power is sufficient to drive the belt, sufficient starting torque can be developed. Motor selection for large conveyors should be based on a careful study, with particular emphasis on starting conditions.

Auxiliary Equipment Elevating conveyors must be equipped with some form of **holdback** or **brake** to prevent reversal of travel and subsequent jamming when power is unexpectedly cut off. Ratchet and wedge roller-type holdbacks are commonly used. Solenoid brakes and spring clutches may also be employed.

Another problem with most conveyors is to cut out the driving force when a conveyor jams. **Torque-limiting devices** are often used, as are electrical controls which cut power to the drive motor. However, because of the high inertia of the motor rotor, it is sometimes desirable to eliminate the torque surge which may occur when the conveyor jams. A shear-pin hub is generally used in these cases, power being transmitted through a set of pins which are designed to shear at a fixed maximum torque. While equipment remains down until the pins can be replaced, there is an immediate disconnect between motor and conveyor which may prevent serious equipment damage. Special clutches are also used.

Unless a material discharges freely, **cleaners** are required on belt conveyors and may be helpful on others. Common types use a rotating brush, powered from the conveyor head-pulley shaft or independently, or a spring-mounted blade. The latter is applicable only at some point where the belt conveyor lies reasonably flat. Whenever cleaners are used, provision should be made for catching and chuting the material back into the main discharge stream or to a collecting container which can be periodically emptied.

Control of Conveyors Control has been enhanced considerably with the introduction of process-control computers and programmable controllers, which can be used to maintain rated capacities to close tolerances. This ability is especially useful if feed to the conveyor tends to be erratic. Through variable-speed drives, outputs can be adjusted automatically for changes in processing conditions. When the control devices are used in conjunction with strain-gauge or load-cell weight-sensing devices, actual discharge rates can be measured and employed in process calculations made by these devices, and output adjustments can be made automatically and accurately.

SCREW CONVEYORS

The screw conveyor is one of the oldest and most versatile conveyor types. It consists of a helicoid flight (helix rolled from flat steel bar) or a sectional flight (individual sections blanked and formed into a helix from flat plate), mounted on a pipe or shaft and turning in a trough. Power to convey must be transmitted through the pipe or shaft and is limited by the allowable size of this member. Screw-conveyor capacities are generally limited to around 4.72 m^3/min (10,000 ft^3/h).

In addition to their conveying ability, screw conveyors can be adapted to a wide variety of **processing operations.** Almost any degree of mixing can be achieved with screw-conveyor flights cut, cut and folded, or replaced by a series of paddles. Use of ribbon flights allows sticky materials to be handled. Variable-pitch, tapered-flight, or stepped-flight units can give excellent control for feeder applications

TABLE 21-4 Material Classes and Bulk Densities*

Material	Average bulk density, lb/ft^3†	Class‡
Alum, lumpy	50–60	D26§
Alum, fine	45–50	B26§
Alumina	60	B28
Alumina gel	45	B27
Aluminum hydrate	18	C26
Ammonium chloride, crystalline	52	B26
Ammonium sulfate	45–58	§
Antimony powder		B27
Asbestos shred	20–25	H37WZ
Ashes, coal, dry, 3 in. and under	35–40	D37
Asphalt, crushed, ½ in and under	45	C26
Bagasse	7–10	H36WXZ
Baking powder	41	A26
Bark, wood, refuse	10–20	H37X§
Bauxite, crushed, 3 in and under	75–85	D28§
Bentonite, 100 mesh and under	50–60	A27Y§
Bicarbonate of soda	41	A26
Boneblack, 100 mesh and under	20–25	A27§
Bonechar, ⅛ in and under	27–40	B27
Bonemeal	55–60	B27
Borate of lime		A26§
Borax, fine	53	B26
Boric acid, fine	55	B26
Calcium carbide	70–80	D27
Carbon black, pelletized	20–25	B16TZ§
Carbon black, powder	4–6	§
Casein	36	B27§
Cast-iron chips	130–200	C37
Cement, Portland	65–85	A27Y
Cement clinker	75–80	D28§
Chalk, lumpy	85–90	D37Z
Chalk, 100 mesh and under	70–75	A37YZ
Charcoal	18–25	D37T
Cinders, coal	40	D28§
Clay (see bentonite, fuller's earth, kaolin, and marl)		
Coal, anthracite	60	C27P
Coal, bituminous, mined, 50 mesh and under	50	B36P
Coal, bituminous, mined, sized	50	D26PT
Coal, bituminous, mined, slack, ½ in and under	50	C36P
Coke, loose	23–32	D38TX§
Coke, petroleum, calcined	35–45	D28X
Coke breeze, ¼ in and under	25–35	C38
Copper sulfate		D26
Cork, fine ground	12–15	B36WY
Cork, granulated	12–15	C36
Cryolite	110	D27
Cullet	80–120	D28§
Dicalcium phosphate	43	A36
Dolomite, lumpy	90–100	D27§
Ebonite, crushed, ½ in and under	63–70	C26
Epsom salts	40–50	B26
Feldspar, ground, ⅛ in and under	65–70	B27
Ferrous sulfate	50–75	C27
Flour, wheat	35–40	A36K§
Fluorspar	82	C37
Fly ash, dry	35–45	A18Y§
Fuller's earth, oil filter, burned	40	B28
Fuller's earth, oil filter, raw	35–40	B27
Fuller's earth, oil filter, spent	60–65	§
Glass batch	90–100	D28§
Glue, ground, ⅛ in and under	40	B27
Graphite, flake	40	C26
Graphite, flour	28	A16Y
Gypsum, calcined, ½ in and under	55–60	C27
Gypsum, calcined, powdered	60–80	A37
Gypsum, raw, 1 in and under	90–100	D27
Ice, crushed	35–45	D16
Ilmenite	140	B28
Kaolin clay, 3 in and under	163	D27
Lead arsenate	72	B36R
Lignite, air dried	45–55	D26
Lime, ground, ⅛ in and under	60	B36Z
Lime, hydrated, ⅛ in and under	40	B26YZ
Lime, hydrated, pulverized	32–40	A26YZ
Lime, pebble	53–56	D36
Limestone, agricultural, ⅛ in and under	68	B27§
Limestone, crushed	85–90	D27§
Limestone dust	75	A37Y§
Magnesium chloride	33	C36
Manganese sulfate	70	C28
Marl	80	D27§
Mica, flakes	17–22	B17WY
Mica, ground	13–15	B27
Mica, pulverized	13–15	A27Y
Muriate of potash	77	B28
Naphthalene flakes	45	§
Oxalic acid crystals	60	B36L
Oyster shells, ground, ½ in and under	53	C27
Oyster shells, whole		D27X
Phenol-formaldehyde molding powder	30–40	A36
Phosphate rock	75–85	D27§
Phosphate sand	90–100	B28
Phthalic anhydride flakes	30–35	C36XZ
Polyethylene pellets, high-density	35–45	C16K
Polyethylene pellets, low-density	28–40	C16K
Polypropylene pellets	35–50	C16K
Polystyrene cubes	35–40	C16K
Polyvinyl chloride pellets, compounds	35–55	C16K
Polyvinyl chloride resin, dispersion-type	12–18	A36KPY
Polyvinyl chloride resin, solvent, non-solvent, suspension types	20–35	A26KY
Potassium nitrate	76	C17P
Pumice, ⅛ in and under	42–45	B38§
Salt, common dry, coarse	45–50	C37PL§
Salt, common dry, fine	70–80	B27PL§
Salt cake, dry, coarse	85	D27
Salt cake, dry, pulverized	65–85	B27
Saltpeter	80	B26S
Sand, bank, dry	90–110	B28
Sand, silica, dry	90–100	B18
Sawdust	10–13	§
Shale, crushed	85–90	C27
Shellac, powdered or granulated	31	B26K§
Silica gel	45	B28
Slag, furnace, granulated	60–65	C28
Slate, crushed, ½ in and under	80–90	C27
Slate, ground, ⅛ in and under	82	B27
Soap beads or granules		B26T
Soap chips	15–25	C26T§
Soap flakes	5–15	B26T§
Soap powder	20–25	B26§
Soapstone talc, fine	40–50	A37Z
Soda ash, heavy	55–65	B27
Soda ash, light	20–35	A27W
Sodium nitrate	70–80	§
Sodium sulfate (see salt cake)		
Starch	25–50	§
Steel chips, crushed	100–150	D38
Sugar, granulated	50–55	B26KT
Sugar, raw, cane, or beet	55–65	B36Z§
Sugar-beet pulp, dry	12–15	§
Sugar-beet pulp, wet	25–45	§
Sulfur, crushed, ½ in and under	50–60	C26S§
Sulfur, lumpy, 3 in and under	80–85	D26S§
Sulfur, powdered	50–60	B26SY§
Talcum powder	40–60	A27Y
Trisodium phosphate	60	B27
Vermiculite, expanded	16	C37W
Vermiculite ore	80	D27
Wood chips	10–30	H36WX§
Wood flour	16–36	§
Zinc oxide, heavy	30–35	A36Z§
Zinc oxide, light	10–15	A36WZ§

*Data supplied mostly by FMC Corporation, Material Handling Systems Division. To convert pounds per cubic foot to kilograms per cubic meter, multiply by 16.02.
†Weights of material, loose or slightly agitated. Weights are usually different when materials are settled or packed as in bins or containers.
‡These classes represent observations under general conditions. Specific conditions may vary because of manufacturing processes and handling.
§Class may vary considerably because of conditions.

or on conveyors when precise control of the transport rate is required. Short-pitch screws are used for inclined and vertical conveying applications, and double-flight short-pitch units effectively deter flushing action. In addition to a wide variety of designs for components, screw conveyors may be fabricated in materials ranging from cast iron to stainless steel.

Use of hollow screws and pipes for circulating hot or cold fluids allows the screw conveyor to be used for heating, cooling, and drying operations. Jacketed casings may be used for the same purpose. It is relatively easy to seal a screw conveyor from the outside atmosphere so that it can operate outdoors without special protection. In fact, the conveyor can be completely sealed to operate in its own atmosphere at positive or negative pressure, and the casing can be insulated to maintain internal temperatures in areas of high or low ambient temperature. A further advantage is the fact that the casing can be designed with a drop bottom for easy cleaning to avoid contamination when different materials are to be run through the same system.

Since screw conveyors are usually made up of standard sections coupled together, special attention should be given to bending stresses in the couplings. Hanger bearings supporting the flights obstruct the flow of material when the trough is loaded above their level. Thus, with difficult materials, the load in the trough must be kept below this level, or special hanger bearings which minimize obstruction should be selected. Since screw conveyors operate at relatively low rotational speeds, the fact that the outer edge of the flight may be moving at a relatively high linear speed is often neglected. This may create a wear problem; if wear is too severe, it can be reduced by the use of hard-surfaced edges, detachable hardened flight segments, rubber covering, or high-carbon steels.

Power calculations for screw conveyors are well standardized. However, each manufacturer has grouped numerical constants in a different fashion and assigned slightly different values on the basis of individual design variations. Thus, in comparing screw-conveyor power requirements it is advisable to use a specific formula for specific equipment.

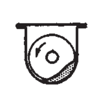
Required power is made up of two components, that necessary to drive the screw empty and that necessary to move the material. The first component is a function of conveyor length, speed of rotation, and friction in the conveyor bearings. The second is a function of the total weight of material conveyed per unit of time, conveyed length, and depth to which the trough is loaded. The latter power item is in turn a function of the internal friction and friction on metal of the conveyed material.

Table 21-5 indicates **screw-conveyor performance** on the basis of material classifications as listed in Table 21-4 and defined in Table 21-3. Table 21-6 gives a wide range of **capacities** and **power requirements** for various sizes of screws handling 801 kg/m^3 (50 lb/ft^3) of material of average conveyability. Within reasonable limits, values from Tables 21-5 and 21-6 can be interpolated for preliminary estimates and designs.

Typical **feed arrangements** are shown in Fig. 21-1. Plain spouts (Fig. 21-1*a*) may be used when the feed rate is fairly uniform and controlled by preceding equipment. The capacity of the conveyor should be well above the maximum rate of feed from either single or multiple feed points. The rotary cutoff valve (Fig. 21-1*b*) is an enclosed dust-tight quick-acting valve for free-flowing materials. The rotary-vane feeder (Fig. 21-1*c*) delivers a uniform predetermined volume of material and may be driven from the screw or independently by constant- or variable-speed drive. Rack-and-pinion gates (Fig. 21-1*d*) are well suited to free-flowing materials in bins, hoppers, tanks, or silos and are also used as side inlet gates (Fig. 21-1*e*) for heavy or lumpy materials.

Typical **discharge arrangements** are shown in Fig. 21-2. Plain discharge openings (Fig. 21-2*a*) equipped with a discharge spout (Fig. 21-2*b*) are most common, although the open-end trough (Fig. 21-2*c*) is frequently used, as is the discharge-trough end (Fig. 21-2*e*). Open-bottom troughs (Fig. 21-2*g*) are often used for spreading material uni-

TABLE 21-5 Screw-Conveyor Capacities and Loading Conditions*

Material class†	Screw diam., in	Max. lump size, in: 25% lumps	Max. lump size, in: 100% lumps	Capacity, cu ft/hr‡: At 1 rpm.	Capacity, cu ft/hr‡: At max. rpm.§	Approx. area occupied by material¶
A, B, C, D, and H 16, 26, 36	6	¾	½	2.27	375	
	9	1½	¾	8.0	1,200	
	12	2	1	19.3	2,700	
	14	2½	1¼	30.8	4,000	
	16	3	1½	46.6	5,600	
	18	3	2	66.1	7,600	
	20	3½	2	95.0	10,000	45%
A, B, C, D, and H 17, 27, 37	6	¾	½	1.5	75	
	9	1½	¾	5.6	280	
	12	2	1	13.3	665	
	14	2½	1¼	21.1	1,055	
	16	3	1½	31.4	1,570	
	18	3	2	45.4	2,270	
	20	3½	2	62.1	3,105	30%
A, B, C, D, and H 18, 28, 38	6	¾	½	0.75	25	
	9	1½	¾	2.8	90	
	12	2	1	6.7	200	
	14	2½	1¼	10.5	300	
	16	3	1½	15.7	425	
	18	3	2	22.7	590	
	20	3½	2	31.1	780	15%

*FMC Corporation, Material Handling Systems Division. To convert cubic feet per hour to cubic meters per hour, multiply by 0.02832; to convert screw diameter in inches to the nearest screw size in centimeters, multiply by 2.5. See elsewhere for conversion of particle sizes from one measurement system to another.

†These classifications cover a broad list of materials that generally can be handled in a screw conveyor. Special consideration must be given to applications handling materials with the following characteristics:

Highly corrosive, Class N
Degradable, affecting use or salability, Class T
Interlocks or mats, Class X
Highly aerated or of fluid nature, Class Y

‡Capacity for horizontal conveyor uniformly fed. Volumetric capacity is based on material slightly agitated or fluffed. Material highly fluffed or aerated will decrease in weight and increase in volume.

§Maximum capacity for economical service.

¶Percentages higher than those indicated will result in excessive wear on hanger bearings and couplings.

TABLE 21-6 Screw-Conveyor Data for 50-lb/ft³ Material and Pipe-Mounted Sectional Spiral Flights*

Capacity†		Diam. of flights, in	Diam. of pipe, in‡	Diam. of shafts, in	Hanger centers, ft	Max. size of lumps			Speed, r/min	Max. torque capacity, in·lb	Feed section diam., in	hp at motor§					Max. hp capacity at speed listed
Tons/h	ft³/h					All lumps	Lumps 20 to 25%	Lumps 10% or less				15-ft. max. length	30-ft max. length	45-ft max. length	60-ft max. length	75-ft max. length	
5	200	9	2½	2	10	¾	1½	2¼	40	7,600	6	0.43	0.85	1.27	1.69	2.11	4.8
10	400	10	2½	2	10	¾	1½	2½	55	7,600	9	0.85	1.69	2.25	3.00	3.75	6.6
15	600	10	2½	2	10	¾	1½	2½	80	7,600	9	1.27	2.25	3.38	3.94	4.93	9.6
		12	2½	2	12	1	2	3	45	7,600	10	1.27	2.25	3.38	3.94	4.93	5.4
		12	3½	3						16,400		1.27	2.25	3.38	3.94	4.93	11.7
20	800	12	2½	2	12	1	2	3	60	7,600	10	1.69	3.00	3.94	4.87	5.63	7.2
			3½	3						16,400		1.69	3.00	3.94	4.87	5.63	15.6
25	1000	12	2½	2	12	1	2	3	75	7,600	10	2.12	3.75	4.93	5.63	6.55	9.0
			3½	3						16,400		2.12	3.75	4.93	5.63	6.55	9.0
		14	3½	3		1¼	2½	3½	45	16,400	12	2.12	3.75	4.93	5.63	6.55	11.7
30	1200	14	3½	3	12	1¼	2½	3½	55	16,400	12	2.25	3.94	5.05	6.75	7.50	14.3
35	1400	14	3½	3	12	1¼	2½	3½	65	16,400	12	2.62	4.58	5.90	7.00	8.75	16.9
40	1600	16	3½	3	12	1½	3	4	50	16,400	14	3.00	4.50	6.75	8.00	10.00	13.0

*Fairfield Engineering Co. data in U.S. customary system. To convert cubic feet per hour to cubic meters per hour, multiply by 0.02832; to convert tons per hour to metric tons per hour, multiply by 0.9078; and to convert screw size in inches to the nearest screw size in centimeters, multiply by 2.5.

†Capacities are based on screws carrying 31 percent of their cross section and, in the case of feed sections with half-pitch flights, based on 100 percent of their cross section.

‡Pipe sizes given are for ¼-in (6.35-mm) flights.

§Horsepowers listed are calculated for average conditions and are of the proper motor size with factors for length of conveyor, momentary overloads, etc., taken into consideration.

formly over a storage area. Flat-bottomed rack-and-pinion gates (Fig. 21-2*f*) allow selective discharge, as do hand slide gates (Fig. 21-2*d*). However, for perishable materials, the curved slide gate (Fig. 21-2*h*) eliminates the dead-storage pocket. Enclosed rack-and-pinion gates (Fig. 21-2*j*) give dust-tight operation, and rotary cutoff valves (Fig. 21-2*i*) allow quick shutoff and are readily adaptable to remote control. Air-cylinder-actuated gates have become more and more prominent because of the low investment required and the ease of connecting to automatic process-control centers.

BELT CONVEYORS

The belt conveyor is almost universal in application. It can travel for miles at speeds up to 5.08 m/s (1000 ft/min) and handle up to 4539 metric tons/h (5000 tons/h). It can also operate over short distances at speeds slow enough for manual picking, with a capacity of only a few kilograms per hour. However, it is not normally applicable to processing operations, except under unusual conditions.

Belt-conveyor slopes are limited to a maximum of about 30°, with those in the 18 to 20° range more common. Direction changes can occur only in the vertical plane of the belt path and must be carefully designed as vertical curves or relatively flat bends. Belt conveyors inside the plant may have higher initial cost than some other types of conveyors and, depending on idler design, may or may not require more maintenance. However, a belt conveyor given good routine maintenance can be expected to outlast almost any other type of conveyor. Thus, in terms of cost per ton handled, outstanding economy records have been established by belt conveyors.

Belt-conveyor design begins with a study of the material to be handled. Since weight per cubic meter or foot is an important factor, it should be accurately determined with the material in an as-handled condition. It is not wise to rely solely on published tables of weight per cubic meter or foot for various materials, since many processing operations will affect this by fluffing or compacting the material. Lump size is important, too. For a 600-mm (24-in) belt, uniform lump size can range up to about 102 mm (4 in). For each 152-mm (6-in) increase in belt width, lump size can increase by about 51 mm (2 in). If material contains around 90 percent fines, lump size can be increased by around 50 percent. However, care should be taken to maintain uniform flow of material, with fine material reaching the belt first to protect it from impact damage. The larger the lump, the more danger of its falling off the belt or rolling back on inclines. With the belt running horizontally or sloping only slightly at the feed point, the problem of lumps falling off is minimized, especially if particular care is taken with feed-chute design.

Temperature and chemical activity of the conveyed material play important roles in **belt selection.** For example, natural rubber should be avoided with oily materials even when the material does not present an obviously oily surface. Special rubber, cotton, and asbestos-fiber belts are available to meet varying degrees of material temperature, and they should be used whenever high temperatures exist. Belts can be seriously and quickly damaged by high temperature, and the investment in what at first glance seems to be an extremely high-priced belt may prove most economical in the long run. There are many superperformance elastomers available for belt construction. These include neoprene, Teflon, Buna N rubber, and vinyls. Manufacturers are able to test products to be handled and often recommend several elastomer grades that will perform satisfactorily, each grade having a different first-cost–operating-life relation.

Moisture may create poor discharge conditions because of material sticking to the belt and to chutes, or it may even reduce capacity if it is present in enough quantity to give the material fluid properties. Even though abrasion may create problems with belt conveyors, these are easier to solve with properly designed belt systems than with most other conveyors.

In establishing belt-conveyor **tonnage requirements** it is important to work with peak rather than average loads. Only occasionally, because of intentional or accidental variations in production rates, are these two figures identical. The belt that runs empty half the time must carry twice the average load when it is working.

When a belt conveyor must **change direction,** it is often easier to use more than one conveyor. However, vertical curves can be designed and upward changes of direction accomplished with a pair of snub pulleys. If the belt pull is downward on the idlers, a simple flat pulley can be used for minor directional changes. In any case, using a single continuous belt eliminates the need for more than one drive. With a pair of snub pulleys, the carrying face of the belt is brought in contact with the pulley; hence special care must be taken to get a good discharge. When bending the belt over a flat pulley, belt speed must be slow enough to keep material from flying off the belt. In many situations the smooth curve, either concave or convex, is preferable. For a 61-cm (24-in) belt the minimum curve radius is about 61 m (200 ft),

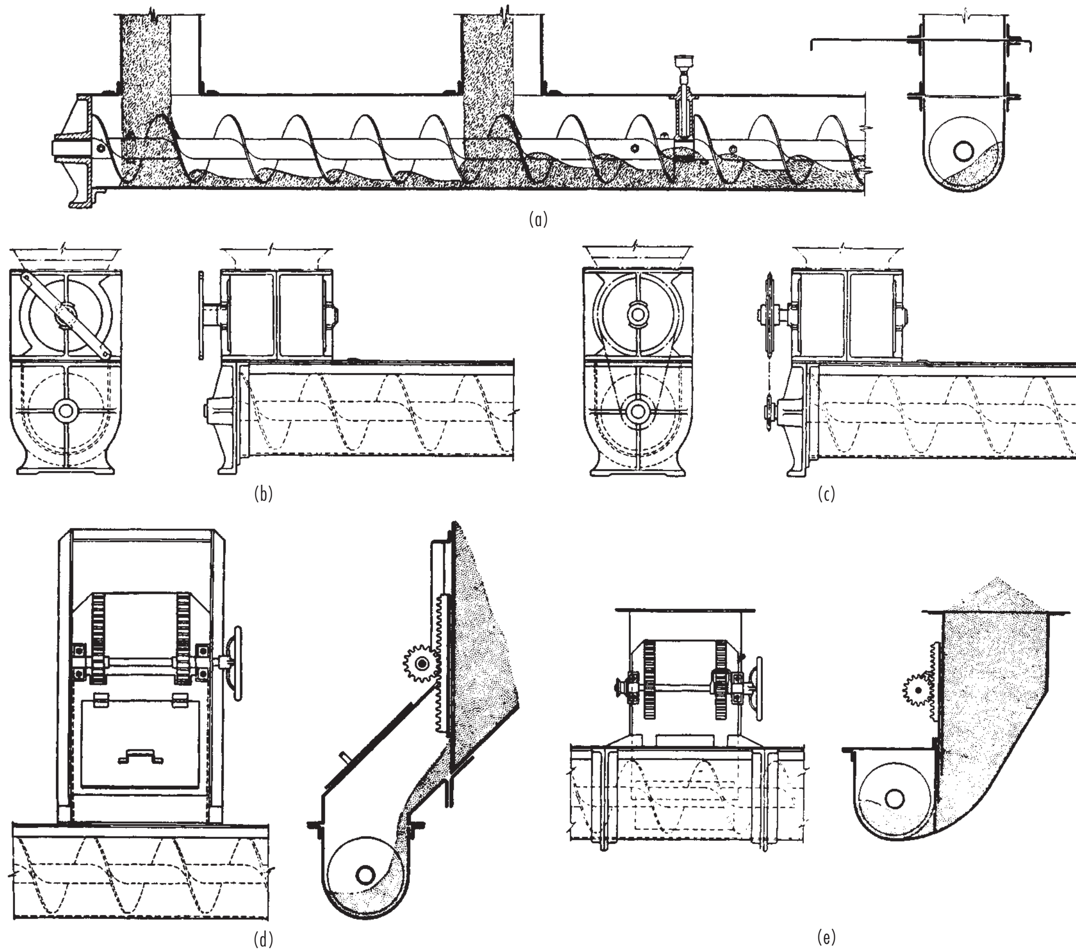


FIG. 21-1 Typical feed arrangements for screw conveyors. (*a*) Plain spouts of chutes. (*b*) Rotary cutoff valve. (*c*) Rotary-vane feeder. (*d*) Bin gate. (*e*) Side inlet gate. (*FMC Corporation, Material Handling Systems Division.*)

but for best operating conditions the curve should be carefully designed.

Operating conditions which affect belt-conveyor design include climate, surroundings, and hours of continuous service. Temperature and humidity extremes may dictate total enclosure of the belt; surroundings which involve such conditions as high temperature or corrosive atmosphere can affect belt, machinery, and structure; and continuous service may require extremely high-quality components and even specially designed equipment for servicing while the belt is in operation. For example, idlers may be obtained with tilting stands which allow them to be tipped out of the way for service while the belt is running.

Belt width and **speed** are functions of bulk density of the material and lump size. Lowest first cost can often be obtained by using the narrowest possible belt for a given lump size and operating it at maximum speed. However, speed often may be limited by dusting, and sometimes it may be better economy to use a wider belt with fewer plies to combine the necessary tensile strength with good belt-troughing characteristics. Abrasiveness of the material can strongly affect speed and also lump size, for at higher speeds abrasive wear is increased and there is greater danger of lumps rolling off the belt. Ideally a belt should run with lump size, slope, and load of less than recommended maximums and with uniform feed introduced to the belt centrally as nearly as possible in the direction and speed of belt travel.

Power to drive a belt conveyor is made up of five components: power to drive the empty belt, to move the load against friction of the rotating parts, to raise or lower the load, to overcome inertia in putting material into motion, and to operate a belt-driven tripper if required. As with most other conveyor problems, it is advisable to work with formulas and constants from a specific manufacturer in making these calculations. For estimating purposes, typical data are given in Table 21-7.

Belt selection depends on power and development of the required tensile strength. Knowing drive-shaft power, belt tension can be calculated and a belt selected. However, since various combinations of width and ply thickness will develop the required strength, final selection is influenced by lump size, troughability of the belt, and ability of the belt to support the load between idlers. Thus it is necessary to use an empirical approach to arrive at a belt selection which meets all requirements.

Once final belt selection has been made, **idlers** and **return rolls** can also be selected. Figure 21-3 indicates the wide variety of belt supports for bulk-handling applications. Figure 21-3*a* and *b* consists of flat-belt arrangements of rollers or plate which allow material to be discharged by simple V-shaped plows. The flat plate-supported belt allows sidewalls to be erected to prevent dribble or to build up larger loads on the flat belt. As in Fig. 21-3*f*, larger capacity can also be achieved by troughing the plate. The 20° troughing idler with equal-length rolls (Fig. 21-3*c*) is the most common, with lighter materials adaptable to 45° idlers with short or long side rolls (Fig. 21-3*d* and *e*).

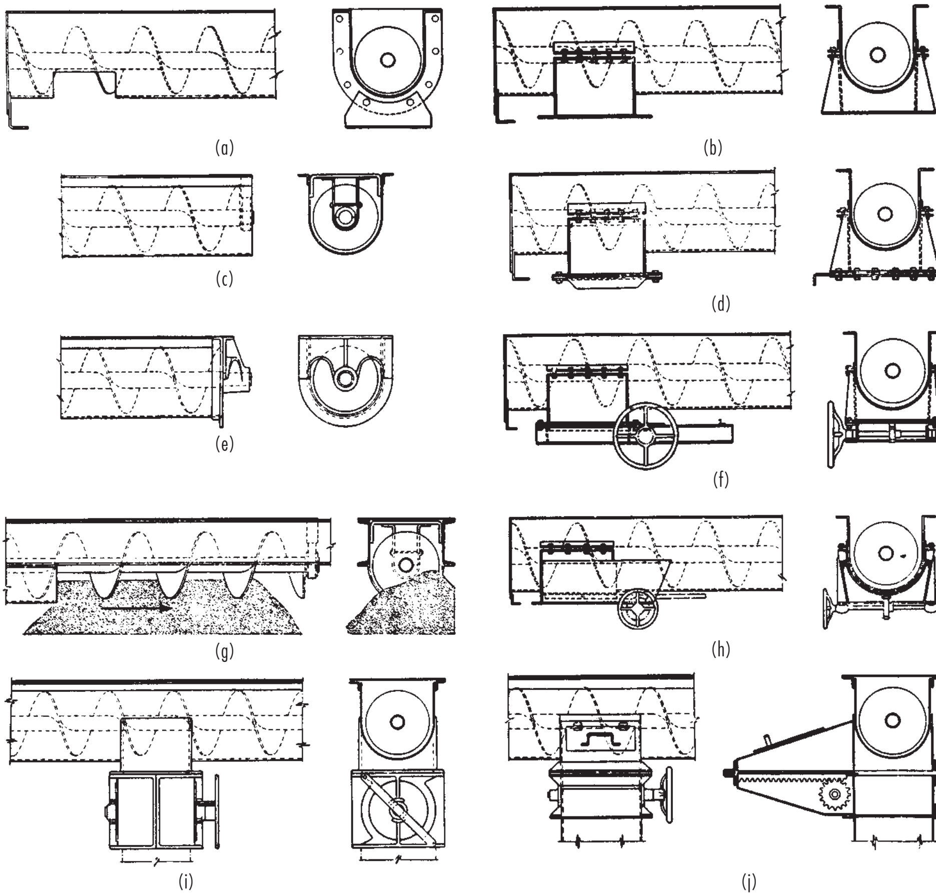


FIG. 21-2 Typical discharge arrangements for screw conveyors. (*a*) Plain discharge opening. (*b*) Discharge spout. (*c*) Open-end trough. (*d*) Hand slide gate. (*e*) Discharge trough end. (*f*) Rack-and-pinion flat side gate. (*g*) Open-bottom trough. (*h*) Rack-and-pinion curved slide gate. (*i*) Rotary cutoff valve. (*j*) Enclosed rack-and-pinion gate. (*FMC Corporation, Material Handling Systems Division*.)

Since the lighter materials do not require stiff belts for tensile strength, there is usually no problem with troughing.

With the proper idlers selected for size and service conditions, the most important step is to locate them properly. For long belts the tension varies considerably, and idlers should be spaced to hold belt sag to reasonable limits along the full length of travel. Too much belt sag can cause a significant power loss, but for most belts of ordinary length it is usually satisfactory to space idlers fairly closely at the feed point and then farther apart and uniformly for the rest of the conveyor length.

Loading and discharge points on belt conveyors need to accommodate several factors. Figure 21-4*a* shows details for one type of rubber seal on a metal skirt plate. It is particularly important that material be loaded onto the belt in its center and in the direction of its travel, preferably with lumps falling on a layer of fine material. Fines can be delivered to the belt first by notching the feed chute or installing a screen section or grizzly bars. Figure 21-4*b* shows a heavy-duty loading-section design using not only rubber idler rolls but an additional short pad belt. Mass-flow bins and/or bin-flow-assisting devices are often used to minimize segregation of fines and to assure a uniform feed from a hopper onto a conveyor belt.

A clean discharge is vital to good belt life. On the return run the carrying side of the belt is in contact with the return rollers, and any material adhering to it is ground in or deposited on the roller. Extremely sticky material may require a belt-cleaning device in the form of a revolving brush, spring-mounted steel scrapers, rubber scraper blades, or sometimes a taut wire. When these devices are used, care should be taken that the dribble does not fall on the belt. Refer to the subsection "Storage and Weighing of Solids in Bulk," which deals with the criteria for bin design. For non-free-flowing materials, the combination of correct bin-discharge design and feeder-loading design is often a critical relation in which a slight error in either may produce a system in which the material will not flow at all.

BUCKET ELEVATORS

Bucket elevators are the simplest and most dependable units for making vertical lifts. They are available in a wide range of capacities and may operate entirely in the open or be totally enclosed. The trend is toward highly standardized units, but for special materials and high capacities it is wise to use specially engineered equipment. Main variations in quality are in casing thickness, bucket thickness, belt or chain quality, and drive equipment.

Spaced-Bucket Centrifugal-Discharge Elevators These elevators (Fig. 21-5*a*) are the most common. They are usually equipped with the style 1 or 2 buckets shown in Fig. 21-5*h*. Mounted on a belt or a chain, the buckets are spaced to prevent interference in loading or discharging. This type of elevator will handle almost any free-flowing fine or small-lump material such as grain, coal, or dry chemicals. Buckets are loaded partly by material flowing directly into them

TABLE 21-7 Belt-Conveyor Data for Troughed Antifriction Idlers*

Belt width	Cross-sectional area of load	Belt speed, ft/min (m/min)		Belt plies		Maximum lump size, in (mm)			Capacity and hp for 100-lb/ft³ material			
in (cm)	ft² (m²)	Normal	Maximum	Minimum	Maximum	Sized material, 80% under	Unsized material, not over 20%	Belt speed, ft/min (m/min)	Capacity tons/h (metric tons/h)	hp/10-ft (3.05-m) lift	hp/100-ft (30.48-m) centers	Add for tripper hp†
14 (35)	0.11 (.010)	200 (61)	300 (91)	3	5	2.0 (51)	3.0 (76)	100 (30.5)	32 (29)	0.34	0.44	
								200 (61.0)	64 (58)	0.68	0.68	2.0
								300 (91.5)	96 (87)	1.04	1.32	
16 (40)	0.14 (.013)	200 (61)	300 (91)	3	5	2.5 (64)	4.0 (102)	100 (30.5)	44 (40)	0.46	0.56	
								200 (61.0)	88 (80)	0.90	1.12	2.5
								300 (91.5)	132 (120)	1.36	1.68	
18 (45)	0.18 (.017)	250 (76)	350 (107)	4	6	3.0 (76)	5.0 (127)	100 (30.5)	54 (49)	0.58	0.70	
								250 (76.2)	134 (122)	1.42	1.76	3.0
								350 (106.7)	190 (172)	2.00	2.42	
20 (50)	0.22 (.020)	250 (76)	350 (107)	4	6	3.5 (89)	6.0 (152)	100 (30.5)	66 (60)	0.70	0.84	
												3.20
								250 (76.2)	164 (148)	1.72	2.06	
								350 (106.7)	230 (209)	2.44	2.90	
24 (60)	0.33 (.030)	300 (91)	400 (122)	4	7	4.5 (114)	8.0 (203)	100 (30.5)	98 (89)	1.02	1.02	
								300 (91.5)	294 (267)	3.06	3.04	3.5
								400 (121.9)	392 (356)	4.08	4.04	
30 (75)	0.53 (.049)	300 (91)	450 (137)	4	8	7.0 (178)	12.0 (305)	100 (30.5)	158 (143)	1.60	1.50	
								300 (91.5)	474 (430)	4.80	4.50	5.0
								450 (137.2)	710 (645)	7.20	6.74	
36 (90)	0.78 (.072)	400 (122)	600 (183)	4	9	8.0 (203)	15.0 (381)	100 (30.5)	230 (209)	2.44	1.59	
								400 (121.9)	920 (835)	9.74	6.36	7.0
								600 (182.9)	1380 (1253)	14.60	9.52	
42 (105)	1.09 (.101)	400 (122)	600 (183)	4	10	10.0 (254)	18.0 (457)	100 (30.5)	330 (300)	3.50	2.28	
								400 (121.9)	1320 (1198)	14.00	9.12	9.5
								600 (182.9)	1980 (1797)	23.20	13.68	
48 (120)	1.46 (.136)	400 (122)	600 (183)	4	12	12.0 (305)	21.0 (533)	100 (30.5)	440 (399)	4.66	3.04	
								400 (121.9)	1760 (1598)	18.70	12.14	12.8
								600 (182.9)	2640 (2397)	28.00	18.20	
54 (135)	1.90 (.177)	450 (137)	600 (183)	6	14	14.0 (356)	24.0 (610)	100 (30.5)	570 (517)	6.04	3.94	
								450 (137.2)	2564 (2328)	27.20	17.70	20.0
								600 (182.9)	3420 (3105)	36.20	23.60	
60 (150)	2.40 (.223)	450 (137)	600 (183)	6	16	16.0 (406)	28.0 (711)	100 (30.5)	720 (654)	7.64	4.98	
								450 (137.2)	3240 (2941)	34.40	22.40	23
								600 (182.9)	4320 (3921)	45.80	29.90	

*Fairfield Engineering Co. data in U.S. customary system. Metric conversion is rounded off. For inclined conveyors, add lift horsepower to center horsepower for total horsepower. For terminals multiply horsepower by the following factors: 0–50 ft (15.2 m), 1.20; 51–100 ft (30.5 m), 1.10; 101–150 ft (45.7 m), 1.05. For countershaft drives, multiply horsepower by 1.05 for each reduction (cut gears).

†Tripper horsepower is based on material bulk density of 100 lb/ft³ (1602 kg/m³) and a belt speed of 300 ft/min (91.4 m/min).

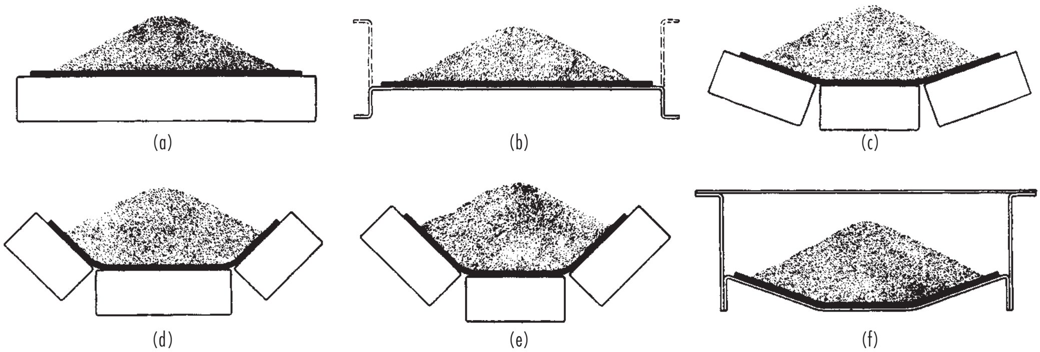
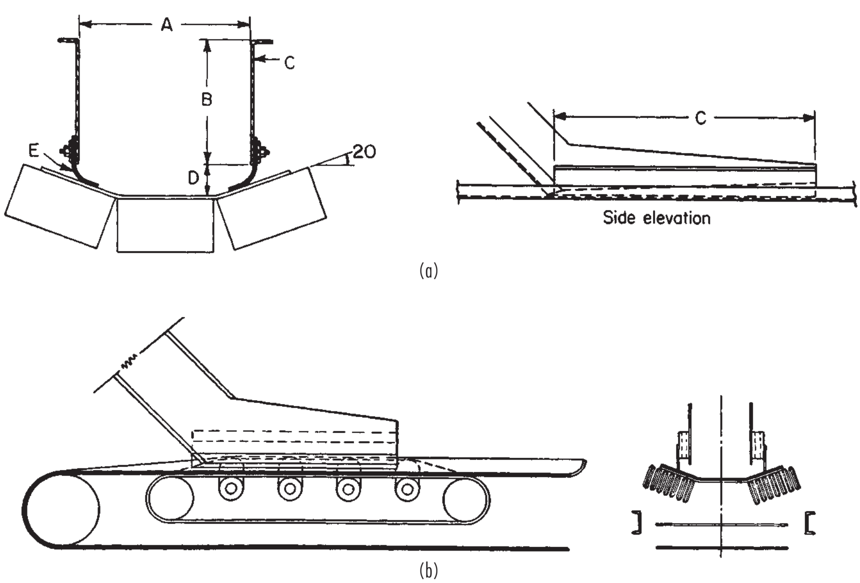


FIG. 21-3 Typical belt-conveyor idler and plate-support arrangements. (*a*) Flat belt on flat-belt idlers. (*b*) Flat belt on continuous plate. (*c*) Troughed belt on 20° idlers. (*d*) Troughed belt on 45° idlers with rolls of unequal length. (*e*) Troughed belt on 45° idlers with rolls of equal length. (*f*) Troughed belt on continuous plate. (*FMC Corporation, Material Handling Systems Division.*)



Skirt Plate and Seal Dimensions

Symbol	Name	Dimensions
A	Trough width	See table for (*a*).
B	Skirt depth	Minimum: 6 in (150 mm); maximum: 12 in (300 mm)
C	Skirt length	Minimum: 6 ft (1.8 m); maximum: 8 ft (2.4 m)
D	Skirt-to-belt clearance	See table for (*a*).
E	Seal specification	0.25-in- (6-mm-) thick live rubber, 6 in (150 mm) × *C*

Belt width, in (cm)	14 (35)	16 (40)	18 (45)	20 (50)	24 (60)	30 (75)	36 (90)	42 (110)	48 (125)	54 (140)	60 (155)
Trough width *A*, in (cm)	9 (23)	11 (28)	12 (30)	13 (33)	16 (41)	20 (51)	24 (61)	28 (71)	32 (81)	36 (91)	40 (102)
Skirt seal *D*, in (cm)	2.0 (5.1)	2.25 (5.7)	2.25 (5.7)	2.88 (7.3)	2.88 (7.3)	3.13 (8.0)	3.63 (9.2)	4.0 (10.1)	4.38 (11.1)	4.75 (12.1)	5.25(13.3)

FIG. 21-4 Belt-conveyor loading details. (*a*) Typical skirt-plate design and dimensions. (*b*) Pad belt and special roller-bearing idlers for heavy-duty loading. (*Stephens-Adamson Division, Allis-Chalmers Corporation.*)

and partly by scooping material from the boot as shown in Fig. 21-5*e*. Speeds can be relatively high for fairly dense materials but must be lowered considerably for aerated or low-bulk-density materials [under 641 kg/m^3 (40 lb/ft^3)] to prevent fanning action.

Spaced-Bucket Positive-Discharge Elevators Elevators of this type (Fig. 21-5*b*) are essentially the same as centrifugal-discharge units except that the buckets are mounted on two strands of chain and are snubbed back under the head sprocket to invert them for positive discharge. These units are designed especially for materials which are sticky or tend to pack, and the slight impact of the chain seating on the snub sprocket combined with complete bucket inversion is generally sufficient to empty the buckets completely. In extreme cases, knockers may be used to hit the buckets at the discharge point to help free material. The speed of these units is relatively slow, and buckets must be larger or more closely spaced to reach capacity levels of the centrifugal style.

Continuous-Bucket Elevators These elevators (Fig. 21-5*c*) are generally used for larger-lump materials or for materials too difficult

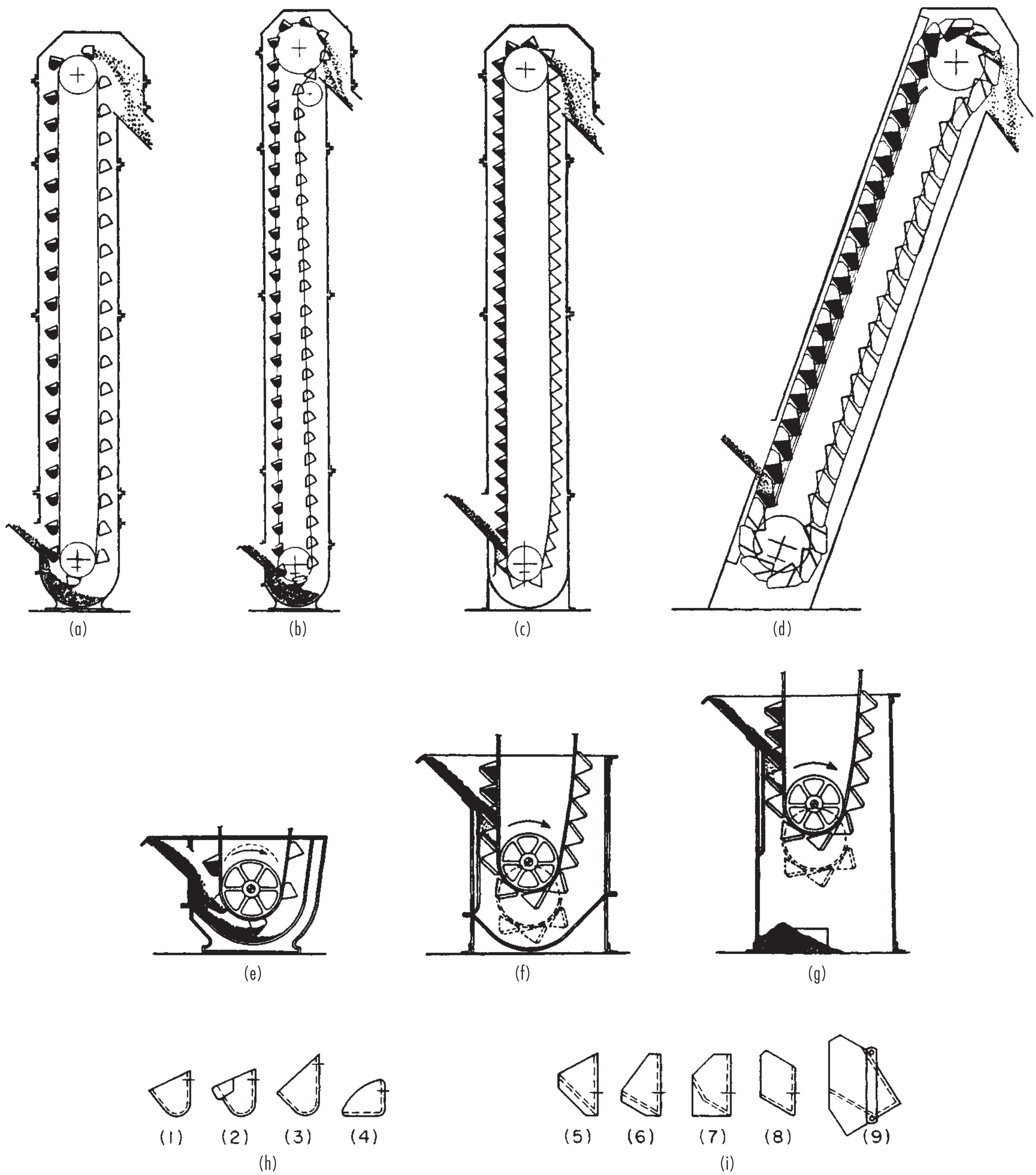


FIG. 21-5 Bucket-elevator types and bucket details. (*a*) Centrifugal-discharge spaced buckets. (*b*) Positive-discharge spaced buckets. (*c*) Continuous bucket. (*d*) Supercapacity continuous bucket. (*e*) Spaced buckets receive part of lead direct and part by scooping from bottom. (*f*) Continuous: buckets are filled as they pass through loading leg, with feed spout above tail wheel. (*g*) Continuous: buckets in bottomless boot, with cleanout door. (*h*) Malleable-iron spaced buckets for centrifugal discharge. (*i*) Steel buckets for continuous-bucket elevators. (*Stephens-Adamson Division, Allis-Chalmers Corporation*.)

to handle with centrifugal-discharge units. Buckets are closely spaced, with the back of the preceding bucket serving as a discharge chute for the bucket which is dumping as it rounds the head pulley. Close bucket spacing reduces the speed at which the elevator must run to maintain capacities comparable with the spaced-bucket elevator. Gentle discharge prevents excessive degradation and makes this type of elevator effective for handling finely pulverized or aerated materials. Two boot styles and typical loading conditions are illustrated in Fig. 21-5*f* and *g*.

Supercapacity Continuous-Bucket Elevators Elevators of this type (Fig. 21-5*d*) are designed for high lifts and large-lump material. They handle high tonnages and are usually operated at an incline to improve loading and discharge conditions. Operating speeds are low, and because of the heavy loads the bucket-supporting chain is usually guided on the elevating and return runs.

Buckets for spaced-type elevators (Fig. 21-5*h*) are available in both malleable iron and steel in a variety of styles. Style 1 is standard, with style 2 identical except for a reinforced lip. Styles 3 and 4 are low-front designs for wet, stringy, or sticky materials which are difficult to discharge.

Continuous-type buckets (Fig. 21-5*i*) are generally back-mounted to chain or belt at close intervals. They are usually fabricated of steel. Style 5 is standard for normal materials, with style 6 a low-front type for better discharge of difficult materials. Style 7 buckets are used for additional capacity or large lumps, and style 8 for inclined crusher-type elevators. Style 9 buckets are designed for extremely high capacities and are usually side-mounted and hinged together.

Bucket-elevator horsepower can be calculated quite easily. For spaced buckets and digging boots it is equal to the desired capacity in tons per hour multiplied by the lift in feet and divided by 500. For continuous buckets with loading leg, the divisor is increased to 550. Both formulas include normal drive losses as well as loading pickup losses and are applicable for vertical and slightly inclined lifts. For estimating purposes, general bucket-elevator specifications are given for centrifugal units in Table 21-8 and for continuous units in Table 21-9.

V-Bucket Elevator-Conveyors These are still used for handling heavy materials, for coal, and, in light-duty designs, for lightweight free-flowing materials. Similar to the V-bucket type, but with buckets swinging freely on supporting shafts mounted between two strands of roller chain, is the pivoted-bucket conveyor. This type can be equipped with a fixed or movable tripper to dump buckets by overturning them. While considerably more expensive than the V-bucket conveyor, it eliminates the abrasion created by dragging material along in a trough and operates more smoothly at lower power per ton for heavy materials.

The most common chain conveyor is the bucket elevator already discussed, but there are a wide variety of special chain conveyors which are used so infrequently that they should be selected only on the specific recommendation of a qualified materials-handling engineer.

Skip Hoists These hoists, which operate on a batch rather than continuous principle, are not so widely used as in the past. However, for high lifts and extremely lumpy or hot materials, the skip hoist is still an economical and practical device.

Skip hoists may be designed to operate automatically or from a manual push-button station. They are usually classified as uncounterweighted, counterweighted, or balanced. Both the latter systems reduce operating-power requirements, and the balanced unit, using two buckets, can operate at twice the capacity of the others. Figure 21-6 illustrates these types as well as some of the common paths of travel which skip hoists may follow. Speed of operation is also a basis for skip-hoist classification, with multispeed motors required on high-speed operations to slow down bucket travel speed at loading and discharge points.

VIBRATING OR OSCILLATING CONVEYORS

Most vibrating conveyors are essentially directional-throw units which consist of a spring-supported horizontal pan vibrated by a direct-connected eccentric arm, rotating eccentric weights, an electromagnet, or a pneumatic or hydraulic cylinder. The motion imparted to the material particles may vary, but its purpose is to throw the material upward and forward so that it will travel along the conveyor path in a series of short hops.

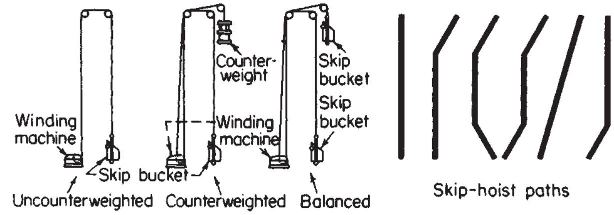


FIG. 21-6 Types of skip hoists and skip-hoist paths. (*Fairfield Engineering Co.*)

The **capacity** of directional-throw vibrating conveyors is determined by the magnitude of trough displacement, frequency of this displacement, angle of throw, slope of trough, and ability of the material to receive and transmit through its mass the directional throw of the trough. The material itself is the most important factor. To be conveyed properly it should have a high friction factor on steel as well as a high internal friction factor so that conveying action is transmitted through its entire depth. Thus deep loads tend to move more slowly than thin ones. Material must also be dense enough to minimize the effect of air resistance on its trajectory, and it should not aerate. Tests have shown that granular materials handle better than pulverized materials and flat or irregular shapes better than spherical ones.

Classification of vibrating conveyors can probably best be based on drive characteristics as shown in Fig. 21-7. All these types transmit vibration to their supporting structures, but the direct, or positive, drive is the worst offender and should be mounted on a heavy supporting structure if it is not counterbalanced. Semipositive- and nonpositive-drive types reduce vibration effects because thrust is transmitted over the entire support length rather than at a specific point. Regardless of drive type, care should be taken to mount the conveyor properly so that supporting structures will not be damaged. The frequency of vibration of the conveyor should in no case be at or near the natural frequency of the supporting structure.

Mechanical vibrating conveyors are designed to operate at specific frequencies and do not perform well at other frequencies without carefully designed alterations. Thus they are not adapted to frequent capacity changes except by varying the depth of material fed to the trough. Positive eccentric drives maintain their frequency and magnitude of stroke regardless of load, and serious drive damage can result from overloading. Rotating eccentric weights can also provide the motive force, and although they maintain a constant frequency, the magnitude of stroke is definitely affected by the load. Directional-throw mechanical vibrating conveyors are used primarily for conveying and do not usually perform well as feeders.

Electrical vibrating conveyors are characterized by the fact that there is no contact between the drive and the conveying medium. They operate on a pull-release cycle or a pull-push cycle, using direct current and pulsating electromagnets or alternating current combined with electromagnets and permanent magnets. While most electrical vibrating units are used as feeders, they also work well as conveyors. Most of them offer the advantage of capacity regulation through control of the electric current magnitude via rheostats. Figure 21-8 gives capacities as a function of pan size and power consumption.

Pneumatic and **hydraulic vibrating conveyors** have as their greatest asset elimination of explosion hazards. If pressurized air, water, or oil is available, they can be extremely practical since their drive design is relatively simple and pressure-control valves can be used to vary capacity either manually or automatically.

The **capacity** of vibrating conveyors is extremely broad, ranging from thousands of tons down to grams or ounces. Since so many variables affect their ability to convey, there is no simple formula for figuring capacity and power. Available data are generally the results of

TABLE 21-8 Bucket-Elevator Specifications for Centrifugal-Discharge Buckets on Belt, Malleable-Iron, or Steel Buckets*

Size of bucket, in (mm), and bucket spacing, in (mm)†	Elevator centers, ft‡	Capacity, tons/h (metric tons/h)§	Size of lumps handled, in (mm)¶	Bucket Bucket speed, ft/min (m/min)	r/min, head shaft	hp required at head shaft	Additional hp/ft for intermediate lengths	Head	Tail	Head	Tail	Belt width, in
6 × 4 × 4¼ – 12	25	14 (12.7)	¾ (19.0)	225 (68.6)	43	1.0	0.02	1 15/16	1 11/16	20	14	7
	50	14 (12.7)	¾ (19.0)	225 (68.6)	43	1.6	0.02	1 15/16	1 11/16	20	14	7
(152 × 102 × 108) – (305)	75	14 (12.7)	¾ (19.0)	225 (68.6)	43	2.1	0.02	1 15/16	1 11/16	20	14	7
8 × 5 × 5½ – 14	25	27 (24.5)	1 (25.4)	225 (68.6)	43	1.6	0.04	1 15/16	1 11/16	20	14	9
	50	30 (27.2)	1 (25.4)	260 (79.2)	41	3.5	0.05	1 15/16	1 11/16	24	14	9
(203 × 127 × 140) – (356)	75	30 (27.2)	1 (25.4)	260 (79.2)	41	4.8	0.05	2 7/16	1 11/16	24	14	9
10 × 6 × 6¼ – 16	25	45 (40.8)	1¼ (32.0)	225 (68.6)	43	3.0	0.063	1 15/16	1 15/16	20	16	11
	50	52 (47.2)	1¼ (32.0)	260 (79.2)	41	5.2	0.07	2 7/16	1 15/16	24	16	11
(254 × 152 × 159) – (406)	75	52 (47.2)	1¼ (32.0)	260 (79.2)	41	7.2	0.07	2 15/16	1 15/16	24	16	11
12 × 7 × 7¼ – 18	25	75 (68.1)	1½ (38.1)	260 (79.2)	41	4.7	0.1	2 7/16	1 15/16	24	18	13
	50	84 (76.3)	1½ (38.1)	300 (91.4)	38	8.9	0.115	2 15/16	1 15/16	30	18	13
(305 × 178 × 184) – (457)	75	84 (76.3)	1½ (38.1)	300 (91.4)	38	11.7	0.115	3 7/16	2 7/16	30	18	13
14 × 7 × 7¼ – 18	25	100 (90.8)	1¾ (44.5)	300 (91.4)	38	7.3	0.14	2 15/16	2 7/16	30	18	15
	50	100 (90.8)	1¾ (44.5)	300 (91.4)	38	11.0	0.14	3 7/16	2 7/16	30	18	15
(355 × 179 × 184) – (457)	75	100 (90.8)	1¾ (44.5)	300 (91.4)	38	14.3	0.14	3 7/16	2 7/16	30	18	15
16 × 8 × 8½ – 18	25	150 (136.2)	2 (50.8)	300 (91.4)	38	8.5	0.165	2 15/16	2 7/16	30	20	18
	50	150 (136.2)	2 (50.8)	300 (91.4)	38	12.6	0.165	3 7/16	2 7/16	30	20	18
(406 × 203 × 216) – (457)	75	150 (136.2)	2 (50.8)	400 (121.9)	38	16.7	0.165	3 15/16	2 7/16	30	20	18

*From Stephens-Adamson Division, Allis-Chalmers Corporation.

†Bucket size given: width × projection × depth. Assumed bucket linear speed is 150 ft/min (45.7 m/min).

‡Elevator centers to nearest SI equivalent are 25 ft ≃ 8 m, 50 ft ≃ 15 m, and 75 ft ≃ 23 m.

§Capacities and horsepowers are given for materials having bulk densities of 100 lb/ft^3 (1602 kg/m^3). For other densities these will vary in direct proportion: a 50-lb/ft^3 material will reduce the capacity and horsepower required by 50 percent.

¶If the amount of lump product is less than 15 percent of the total, lump size may be twice that given.

TABLE 21-9 Bucket-Elevator Specifications for Continuous Buckets on Chain*

Size of bucket and bucket spacing, in (mm)†	Elevator centers, ft‡	Capacity, tons/h (metric tons/h)§	Size of lumps handled, in (mm)¶	r/min, head shaft	hp required at head shaft	Additional hp/ft for intermediate lengths	Head	Tail	Head	Tail
8 × 5½ × 7¾ – 8	25	35 (31.7)	1 (25.4)	28	1.8	0.06	1 15/16	1 11/16	20½	14
(203 × 140 × 197) – (203)	50	35 (31.7)	1 (25.4)	28	3.4	0.06	2 7/16	1 11/16	20½	14
	75	35 (31.7)	1 (25.4)	28	5.0	0.06	2 15/16	1 11/16	20½	14
10 × 7 × 11¾ – 12	25	60 (54.5)	1½ (38.1)	23	3.0	0.10	2 7/16	1 15/16	25	17½
(254 × 178 × 298 – (305)	50	60 (54.5)	1½ (38.1)	23	5.5	0.10	2 7/16	1 15/16	25	17½
	75	60 (54.5)	1½ (38.1)	23	8.0	0.10	2 15/16	1 15/16	25	17½
12 × 7 × 11¾ – 12	25	70 (63.5)	1½ (38.1)	23	3.5	0.12	2 7/16	1 15/16	25	17½
(305 × 178 × 298) – (305)	50	70 (63.5)	1½ (38.1)	23	6.5	0.12	2 15/16	1 15/16	25	17½
	75	70 (63.5)	1½ (38.1)	23	9.5	0.12	3 7/16	2 7/16	25	17½
14 × 7 × 11¾ – 12	25	80 (72.6)	1¾ (44.5)	23	4.0	0.14	2 7/16	2 7/16	25	17½
(356 × 178 × 298) – (305)	50	80 (72.6)	1¾ (44.5)	20	7.5	0.14	2 15/16	2 7/16	29	17½
	75	80 (72.6)	1¾ (44.5)	20	11	0.14	3 7/16	2 7/16	29	17½
14 × 8 × 11¾ – 12	25	100 (90.8)	2 (50.8)	20	5.0	0.17	2 15/16	2 7/16	29	17½
(356 × 203 × 298) – (305)	50	100 (90.8)	2 (50.8)	20	9.3	0.17	3 7/16	2 7/16	29	17½
	75	100 (90.8)	2 (50.8)	20	13.3	0.17	3 15/16	2 7/16	29	17½
16 × 8 × 11¾ – 12	25	115 (104.4)	2 (50.8)	20	6.0	0.20	2 15/16	2 7/16	29	17½
(406 × 203 × 298) – (305)	50	115 (104.4)	2 (50.8)	20	11	0.20	3 15/16	2 7/16	29	17½
	75	115 (104.4)	2 (50.8)	20	16	0.20	4 7/16	2 7/16	29	17½
18 × 8 × 11¾ – 12	25	130 (118.0)	2 (50.8)	20	7	0.22	2 15/16	2 7/16	29	17½
(406 × 203 × 298) – (305)	50	130 (118.0)	2 (50.8)	20	13	0.22	3 15/16	2 7/16	29	17½
	75	130 (118.0)	2 (50.8)	20	20	0.22	4 7/16	2 7/16	29	17½

*From Stephens-Adamson Division, Allis-Chalmers Corporation.
†Bucket size given: width × projection × depth. Assumed bucket linear speed is 150 ft/min (45.7 m/min).
‡Elevator centers to nearest SI equivalent are 25 ft ≃8 m, 50 ft ≃15 m, and 75 ft ≃23 m.
§Capacities and horsepowers are given for materials having bulk densities of 100 lb/ft^3 (1602 kg/m^3). For other densities these will vary in direct proportion: a 50-lb/ft^3 material will reduce the capacity and horsepower required by 50 percent.
¶If the total amount of lump product is less than 15 percent of the total, lump size may be twice that given.

experiments and empirical equations, with most manufacturers providing selection charts for specific types of conveyors and materials. A typical leaf-spring unit is shown in Fig. 21-8, along with the graphical information required to select a standard unit. Conveyor lengths are limited to about 61 m (200 ft) with multiple drives and about 30.5 m (100 ft) with a single drive. There are many exceptions to these general limitations, and they should not preclude study of a specific problem when vibrating conveyors seem desirable.

Processing operations of many types can be carried out in vibrating conveyors because their simple conveying troughs can be modified quite easily. While tube and flat-pan troughs are most common, troughs can be provided in a wide variety of shapes and materials. Although conveying action is usually so gentle that abrasion problems do not arise, such problems can be easily solved when they do occur by the use of special materials or liners. Troughs are easily sealed to prevent contamination or for operation under positive or negative pressure. With screen or perforated deck plates, vibrating conveyors can dewater, rough-screen, scalp, or dry. Heating and cooling can also be handled by the use of air streams blowing over or through the material, infrared panels, resistance-heating panels, or contact with air- or water-cooled or heated trough casings. Special vibrating-conveyor designs are available for elevating at relatively steep slopes or up a spiral trough. There is probably no other conveyor so readily adaptable to the solution of processing problems.

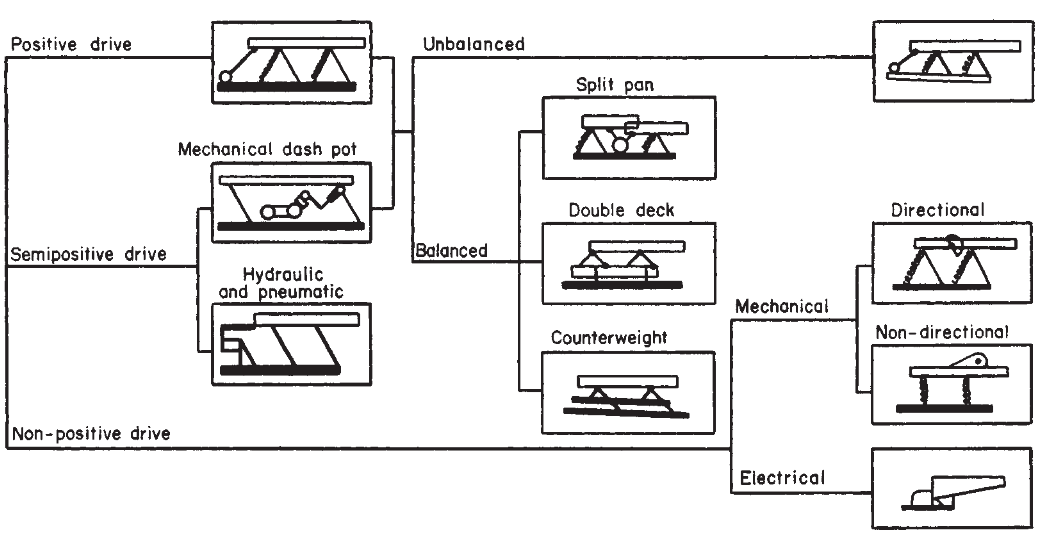
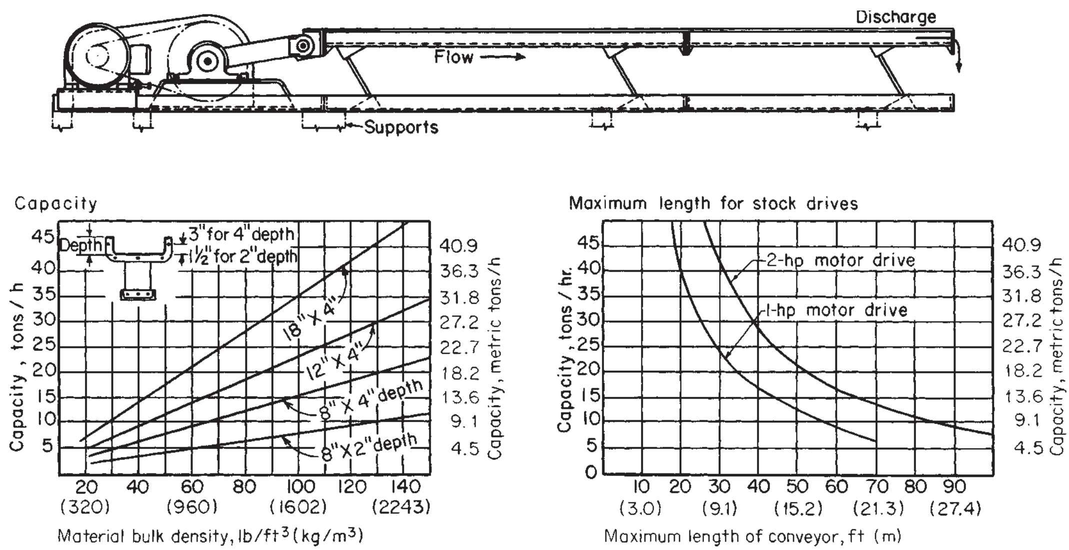


FIG. 21-7 Vibration-conveyor classification. (*Modern Materials Handling.*)



Pan width and stream depth: nearest metric equivalents

in	mm	in	mm
18 x 4	450 x 100	8 x 4	200 x 100
12 x 4	300 x 100	8 x 2	200 x 50

FIG. 21-8 Standardized leaf-spring mechanical oscillating conveyor with selection charts. Multiply pounds per cubic foot by 16.02 to get kilograms per cubic meter; multiply feet by 0.3048 to get meters. (*FMC Corporation, Materials Handling Systems Division.*)

CONTINUOUS-FLOW CONVEYORS

The principle of the continuous-flow conveyor is that when a surface is pulled transversely through a mass of granular, powdered, or small-lump material, it will pull along with it a cross section of material which is greater than the area of the surface itself. The conveying action of various designs of continuous-flow conveyors varies with the type of conveying flight but theoretically is not comparable with the action in a flight or drag conveyor. Flights vary from solid surfaces to skeleton designs, as shown in Fig. 21-9.

The continuous-flow conveyor is a totally enclosed unit which has a relatively high capacity per unit of cross-sectional area and can follow an irregular path in a single plane. These features make it extremely versatile. Figure 21-10 shows some typical arrangements and applications possible with these conveyors. Included is an example of the unit acting as a dewatering device (Fig. 21-10*c*).

These conveyors employ a chain-supported conveying element (some are cast integrally with the chain, which is designed with easily detachable knuckle joints). Thus the connecting element runs along the outside of the casing so that head and tail sections do not become excessively large because of projecting conveying elements. This means that the material feeding into the conveyor must fall past the chain element and travel in a reverse direction before passing into the actual conveying leg (see Fig. 21-10*c*). Since this affects the lump size that the conveyor can conveniently handle, the loop design (Fig. 21-10*c*) is sometimes used for better feeding conditions, or separate carrying runs and return runs are provided with inclined loading chutes to the lower carrying run. In any event, lump size and abrasive

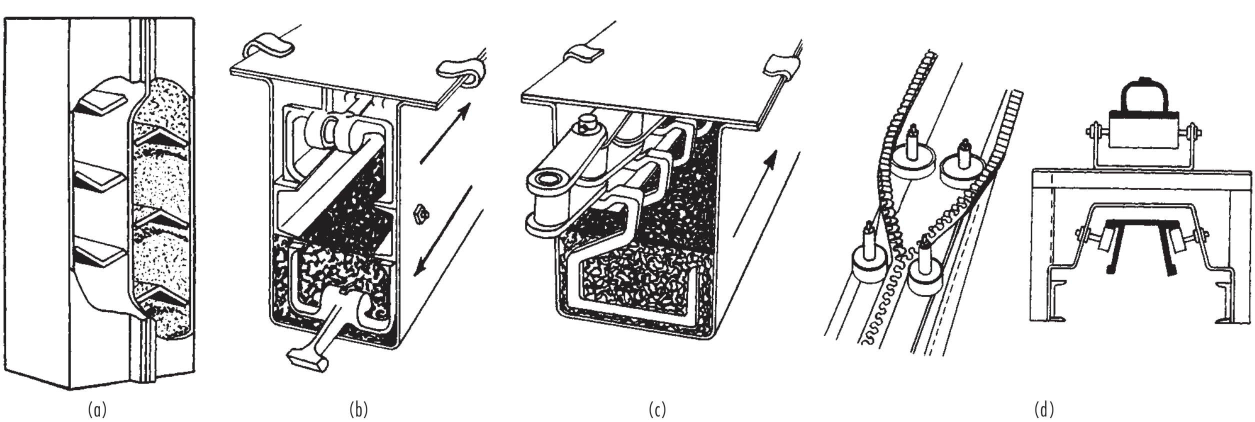


FIG. 21-9 Closed and open flights for continuous-flow conveyors. (*a*) and (*b*) Conveyor-elevator. (*c*) Horizontal conveyor with side-pull chain. (*d*) Detail of closed-belt conveyor; opening and closing rollers mesh and unmesh teeth in the same manner as a conventional clothing fastener. (*FMC Corporation, Material Handling Systems Division; Stephens-Adamson Division, Allis-Chalmers Corporation.*)

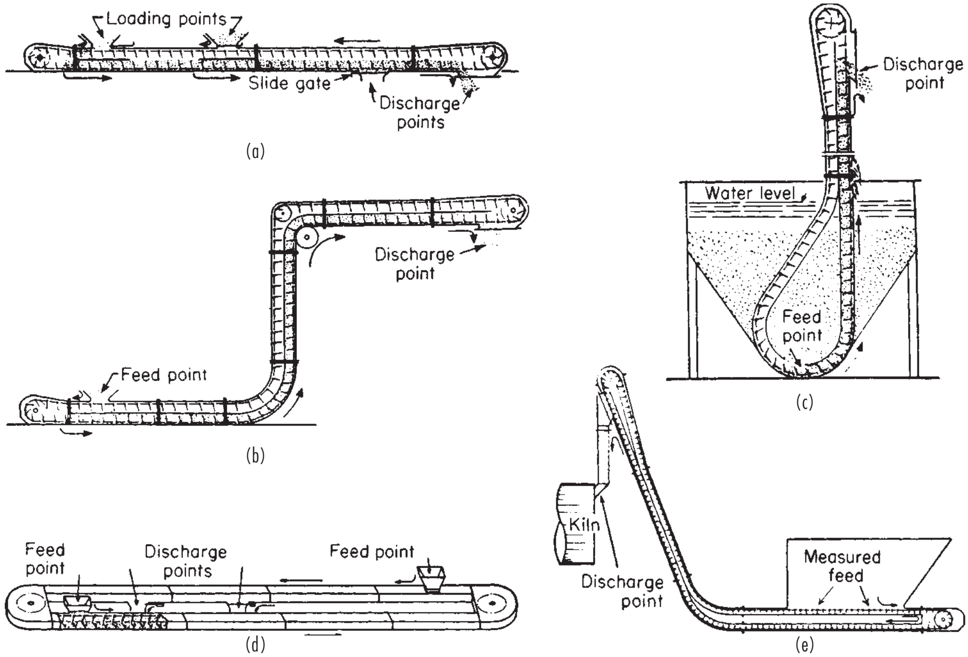


FIG. 21-10 Typical arrangements and applications for continuous-flow conveyors. (*a*) Horizontal conveyor. (*b*) Z-type conveyor-elevator. (*c*) Loop-feed elevator used for dewatering. (*d*) Side-pull horizontal recirculating conveyor. (*e*) Horizontal inclined conveyor-elevator. (*Stephens-Adamson Division, Allis-Chalmers Corporation*.)

characteristics of material are important considerations in the selection of continuous-flow conveyors.

The side-pull continuous-flow conveyor can follow a variety of paths in a horizontal plane, picking up and discharging material at many different points. Figure 21-9*c* is a detailed illustration of one type of conveying element, and Fig. 21-10*d* shows a typical arrangement with 180° turns. Triangular arrangements and rectangular layouts with 90° corners are also available.

The **capacity** of the continuous-flow conveyor is dependent on the particular design being considered. Limiting speeds are subject to considerable controversy. It is advisable to follow the manufacturer's recommendations closely for best conveyor service. **Power** calculations depend on a number of experimentally determined constants which vary for different conveyor designs. One factor contributing to total power requirements is the power required on bend corners where flights assume a radial position and tend to compress material which was fed between them when they were running in a parallel position. Noncompressible materials may require special clearances and feed conditions. Thus, while conveyor components have been well standardized, many materials will not convey well unless special design alterations are made.

Because of the fabrication required for casings and the precision fitting of conveying elements within it, the continuous-flow conveyor is normally an expensive unit. However, it occupies little space, needs little support because the casing forms a rigid box girder, may travel in several directions with only a single drive, is self-feeding, and can feed and discharge at several points. These factors may often compensate for what sometimes appears as a rather high cost per foot. Because it is adaptable to many processing operations, the continuous-flow conveyor is widely used in the chemical industry, in which there is a great deal of rehandling or requirements for many feed and discharge points. The conveyors can be designed for self-cleaning to allow different materials to be handled in the same unit without contamination.

Closed-Belt Conveyor This device, with zipperlike teeth which mesh to form a closed tube, is particularly adaptable to the problem of handling fragile materials which cannot be subjected to degradation. Since the belt is wrapped snugly around the material, it moves with the belt and is not subject to any form of internal movement except at feed and discharge. In addition, the belt can operate in many planes, with twists and turns to meet almost any layout condition within the fixed limit of curvature placed on the loaded belt. It can convey and elevate with only a single drive; multiple feed and discharge points are relatively easy to arrange.

The closed-belt conveyor is not readily adaptable to the handling of sticky materials, and special designs may be required for materials which are highly susceptible to aeration. Initial cost per foot is relatively high because of belting cost, but power requirements are low and with proper installation and maintenance belt life is good.

Since this type of conveyor is available in only one standard size, its capacity is determined by the belt speed and the fixed cross-sectional area. Tons-per-hour capacity is figured by multiplying the bulk density in pounds per cubic foot by the speed in feet per minute and a constant of 0.0021. Power requirements are quite low and figured in the same way as those for conventional belt conveyors.

Figure 21-9*d* illustrates a typical closed-belt-conveyor detail of the opening or closing mechanism and a cross section through a horizontal carrying-and-return run. Designs using two conventional conveyor belts have been developed to elevate material by pressing it between them, but their application is limited.

Flight Conveyors These devices are available in an almost infinite variety. Most flight-conveyor applications are open designs for rough conveying operations, but some are built with totally enclosed easings. Table 21-10 gives typical design and capacity information.

Apron Conveyors Probably the most common chain conveyors, these are available in a wide variety of designs for both horizontal and inclined travel. Their main application is the feeding of material at controlled rates, with lump sizes that are large enough to minimize dribble. The typical design is a series of pans mounted between two strands of roller chain, with pans overlapping to eliminate dribble, and often equipped with end plates for deeper loads. Pan design may vary according to material requirements. Figure 21-11 illustrates a typical apron-conveyor design, and Table 21-11 gives capacities for units with and without skirt plates. Apron-feeder applications range from fairly

TABLE 21-10 Flight-Conveyor Capacities*

Flight size and no. of strands, in (mm)	Maximum size of lumps: All lumps, in (mm)	Maximum size of lumps: 10% lumps, in (mm)	Capacity, tons/h (metric tons/h)† for various flight spacings, conveyor, horizontal, in (mm): 18 (460)	24 (610)	36 (915)	Design type‡
10 × 4 (255 × 100)—1	1½ (38)	3 (76)	32 (29)	25 (23)	16 (15)	1
12 × 5 (305 × 130)—1	1¾ (45)	3½ (89)	46 (42)	35 (32)	23 (21)	1
15 × 5 (380 × 130)—1	2 (51)	4 (102)	66 (60)	50 (45)	33 (30)	1
15 × 6 (380 × 155)—2	3½ (89)	7 (178)	87 (79)	67 (61)	44 (40)	2
16 × 8 (405 × 205)—2	4 (102)	8 (203)	110 (99)	82 (74)	55 (50)	2
18 × 8 (460 × 205)—2	5 (127)	9 (229)	124 (113)	93 (84)	62 (56)	2
20 × 10 (510 × 255)—2	6 (152)	10 (254)	— —	141 (128)	94 (85)	2
24 × 10 (610 × 255)—2	8 (203)	13 (305)	— —	176 (160)	116 (105)	2
30 × 10 (765 × 255)—2	10 (254)	14 (355)	— —	— —	250 (227)	2
12 × 5 (305 × 130)—1	1¾ (45)	3½ (89)	56 (51)	42 (38)	28 (25)	3
15 × 7 (380 × 180)—1	2½ (64)	4½ (114)	78 (71)	58 (53)	39 (35)	3
18 × 8 (460 × 205)—1	3 (76)	5 (127)	124 (113)	93 (84)	62 (56)	3
12 × 5 (305 × 130)—2	2 (51)	4 (102)	56 (51)	4 (38)	28 (25)	4
15 × 6 (380 × 155)—2	3 (76)	5 (127)	76 (69)	57 (52)	38 (34)	4
18 × 7 (460 × 180)—2	4 (102)	8 (203)	96 (87)	72 (65)	48 (44)	4
24 × 8 (610 × 205)—2	8 (203)	12 (305)	— —	124 (113)	83 (75)	4

*Data from Fairfield Engineering Co.
†Basis: 30-lb/ft³ (480-kg/m³) bulk density and conveyor velocity of 100 ft/min (30.5 m/min). For inclined conveyors capacities are reduced by factors given:

Slope off horizontal	Factor
15°	0.80
30°	0.55
45°	0.33

‡Type 1: malleable-iron conveyor flights; type 2: steel flights on roller chain; type 3: steel flights with wear shoes or rollers; type 4: steel flights on plain chain.

light-duty applications with light-gauge steel pans up to extremely heavy-duty applications requiring reinforced manganese steel pans with center supports. Table 21-11 values may be used in calculating capacities of other sizes, since this is a function of width of carrying surface, height of sides, speed, and bulk density. Apron-conveyor speeds are typically 0.25 to 0.38 m/s (50 to 75 ft/min). When these conveyors are used as feeders, velocities are kept in the 0.05- to 0.15-m/s (10- to 30-ft/min) range.

PNEUMATIC CONVEYORS

One of the most important material-handling techniques in the chemical industry is the movement of material suspended in a stream of air over horizontal and vertical distances ranging from a few to several hundred feet. Materials ranging from fine powders through 6.35-mm (¼-in) pellets and bulk densities of 16 to more than 3200 kg/m³ (1 to more than 200 lb/ft³) can be handled. A large, capable manufacturing

TABLE 21-11 Apron-Conveyor Capacities*

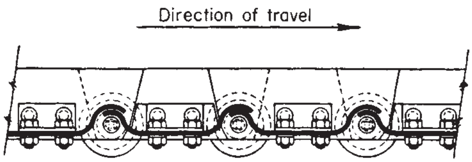
Capacity without skirts for various speeds and bulk densities for material depth of 4 in (102 mm) on pans

Apron width, in (mm)	50 ft/min (15.2 m/min): ft³/h (m³/h)	50 ft/min: tons/h, 50 lb/ft³ (801 kg/m³)	50 ft/min: (metric tons/h), 100 lb/ft³ (1602 kg/m³)	100 ft/min (30.5 m/min): ft³/h (m³/h)	100 ft/min: ton/h, 50 lb/ft³ (801 kg/m³)	100 ft/min: (metric tons/h), 100 lb/ft³ (1602 kg/m³)
18 (460)	1125 (31.9)	28 (25)	56 (51)	2250 (63.7)	56 (51)	112 (102)
24 (610)	1500 (42.5)	38 (34)	75 (68)	3000 (85.0)	75 (68)	150 (136)
30 (765)	1875 (53.2)	47 (43)	94 (85)	3750 (106.2)	94 (85)	188 (171)
36 (915)	2250 (63.7)	56 (51)	113 (102)	4500 (127.4)	113 (102)	226 (205)
42 (1070)	2625 (74.3)	66 (60)	131 (119)	5250 (148.7)	131 (119)	262 (238)
48 (1220)	3000 (85.0)	75 (68)	150 (136)	6000 (170.0)	150 (136)	300 (272)
54 (1370)	3375 (95.6)	85 (77)	169 (153)	6750 (191.2)	169 (153)	338 (307)
60 (1525)	3750 (106.2)	94 (85)	188 (171)	7500 (212.4)	188 (171)	376 (341)

Capacities with skirts for various material depths, 0.75 loaded cross section and 10-ft/min (3-m/min) velocity

Pan width, in (mm)	Width between skirts, in (mm)	Max. lump size, in (mm)	Capacity, tons/h (metric tons/h); 50-lb/ft³ (801-kg/m³) bulk-density material; material depth on pans, in (mm): 4 (105)	8 (205)	12 (305)	18 (460)	21 (535)	24 (610)
18 (460)	16 (410)	3 (76)	5.0 (4.5)	10.0 (9.1)	15.0 (13.6)	22.5 (20.4)	26.3 (23.9)	30.0 (27.2)
24 (610)	22 (560)	4 (102)	6.9 (6.3)	13.7 (12.4)	20.6 (18.7)	31.0 (28.1)	36.1 (32.8)	41.2 (37.4)
30 (765)	28 (715)	6 (152)	8.8 (8.0)	17.5 (15.9)	26.2 (23.8)	39.3 (35.7)	45.9 (41.7)	52.5 (47.7)
36 (915)	34 (865)	8 (203)	10.7 (9.7)	21.3 (19.3)	32.0 (29.1)	48.0 (43.6)	56.0 (51.8)	64.0 (58.1)
42 (1070)	40 (1020)	10 (254)	12.5 (11.3)	25.0 (22.7)	37.5 (34.0)	56.3 (51.1)	65.7 (59.6)	75.0 (68.1)
48 (1220)	46 (1170)	12 (305)	14.4 (13.1)	28.8 (26.1)	43.2 (39.2)	64.8 (58.8)	75.6 (68.6)	86.3 (78.3)

*Data from Fairfield Engineering Co.



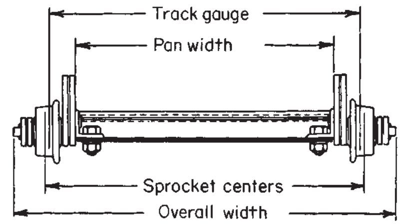


FIG. 21-11 Apron conveyors. (*Fairfield Engineering Co.*)

industry supplies complete systems as well as components that users can incorporate into their own designs. Much engineering information is available from this industry in the form of brochures, data sheets, and nomographs.

The **capacity** of a pneumatic-conveying system depends on (1) product bulk density (and particle size and shape to some extent), (2) energy content of the conveying air over the entire system, (3) diameter of conveying line, and (4) equivalent length of conveying line.

Minimum capacity is achieved when the energy of the conveying air is just sufficient to move the product through the line without stoppage. To prevent such stoppage, it is good practice to provide an additional increment of air energy so that a factor of safety exists that allows for minor changes in product characteristics. An **optimum system** is one that repays, through operating economies, all design features above the minimum required, within the return-on-investment criteria set by the owner.

While successful and economical system designs can be devised by experienced process engineers, the competent technical aid available from equipment suppliers has led to a growing trend toward the purchase of complete systems, even on small jobs, rather than in-plant assembly from components on the basis of in-house designs. An idea of the change in **capital investment** for typical pneumatic-conveyor systems as a function of increasing transfer rates is given in Table 21-12.

Conveyor installations may be permanent or a combination of permanent and portable. The latter kind is often mounted on a bulk-delivery vehicle, which permits fast unloading into the customer's silo by the carrier without effort or equipment from the customer. Controls range from simple motor starters and hand-connected hoses to sophisticated, microprocessor-electropneumatic control systems.

Types of Systems Generally, pneumatic conveyors are classified according to five basic types: pressure, vacuum, combination pressure and vacuum, fluidizing, and the blow tank.

In **pressure systems** (Fig. 21-12*a*), material is dropped into an air stream (at above atmospheric pressure) by a rotary air-lock feeder. The velocity of the stream maintains the bulk material in suspension until it reaches the receiving vessel, where it is separated from the air by means of an air filter or cyclone separator.

Pressure systems are used for free-flowing materials of almost any particle size, up to 6.35-mm (¼-in) pellets, where flow rates over 151 kg/min (20,000 lb/h) are needed and where pressure loss through the system is about 305 mmHg (12 inHg). These systems are favored when one source must supply several receivers. Conveying air is usually supplied by positive-displacement blowers.

Vacuum systems (Fig. 21-12*b*) are characterized by material moving in an air stream of pressure less than ambient. The advantages of this type are that all the pumping energy is used to move the product and that material can be sucked into the conveyor line without the need of a rotary feeder or similar seal between the storage vessel and the conveyor. Material remains suspended in the air stream until it reaches a receiver. Here, a cyclone separator or filter (Fig. 21-12*c*) separates the material from the air, the air passing through the separator and into the suction side of the positive-displacement blower or some other power source.

Vacuum systems are typically used when flows do not exceed 6800 kg/h (15,000 lb/h), the equivalent conveyor length is less than 305 m (1000 ft), and several points are to be supplied from one source. They are widely used for finely divided materials. Of special interest are vacuum systems designed for flows under 7.6 kg/min (1000 lb/h), used to transfer materials short distances from storage bins or bulk containers to process units. This type of conveyor is widely used in plastics and other processing operations where the variety of conditions requires flexibility in choosing pickup devices, power sources, and receivers. Capital investment can be kept low, often in the range of $2000 to $7000.

Pressure-vacuum systems (Fig. 21-12*c*) combine the best of both the pressure and the vacuum methods. A vacuum is used to induce material into the conveyor and move it a short distance to a separator. Air passes through a filter and into the suction side of a positive-displacement blower. Material then is fed by a rotary feeder into the conveyor positive-pressure air stream, which comes from the blower discharge. Application can be very flexible, ranging from a central control station, with all interconnection activities electrically controlled and sequenced, to one in which activities are handled by manually changing conveyor connections. The most typical application is the combined bulk vehicle unloading and transferring to product storage (Fig. 21-12*d*).

Fluidizing systems generally convey prefluidized, finely divided, non-free-flowing materials over short distances, such as from storage bins or transportation vehicles to the entrance of a main conveying

TABLE 21-12 Approximate Pneumatic-Conveyor Costs*

Flow rate, lb/h (kg/h)	Conveyor pipe, inside diameter, in (mm)	Power required, hp	Range of investment, $†	
			Manual‡	Automatic§
10,000 (4,536)	4 (100)	25	83,000	46,000
25,000 (11,340)	6 (155)	60	135,000	89,000
50,000 (22,680)	6 (155)	125	200,000	155,000
100,000 (45,360)	8 (205)	200	356,000	312,000

*Product: Plastic pellets, ⅛-in (3.2-mm) cubes, 30-lb/ft^3 (481-kg/m^3) bulk density; equivalent length of system, 600 ft (183 m)

†1995 costs. Equipment includes motor and blower package, cyclone receivers, railcar-unloading connections, high-level interlocks for stopping the motor and blower combination when the silos reach a full level, and all necessary piping. Installation is not included.

‡System includes a minimum control package, with most activities person-actuated, including the changing of feed lines to storage silos.

§System includes automatic actuation of most activities, with changing of feed lines to silos accomplished by diverter valves controlled automatically by process control computer.

system. A particular advantage in storage-bin applications is that the bottom of the bin is permitted to be nearly horizontal. Fluidizing is accomplished by means of a chamber in which air is passed through a porous membrane that forms the bottom of the conveyor, upon which the material to be conveyed rests. As air passes through the membrane, each particle is surrounded by a film of air (Fig. 21-12*e*). At the point of incipient fluidization the material takes on the characteristics of free flow. It can then be passed into a conveyor air stream by a rotary feeder.

Prefluidizing has the advantage of reducing the volume of conveying air needed; consequently, less power is required. The characteristics of the rest of this system are similar to those of regular pressure- or vacuum-type conveyors. Of special concern is the tendency of material to stick to and build up on surfaces of the system components. The most common application of this type of conveyor is the well-known railroad Airslide covered hopper car.

An early application of pneumatic conveying was the **blow tank.** This device functions by introducing pressurized air on top of a head of material contained in a pressure vessel. If the material is free-flowing, it will flow through a valve at the bottom of the chamber and move through a short conveying line, usually limited to a maximum of 16 m (50 ft), depending on the product, although systems as long as 457 m (1500 ft) are in use. Of special concern when using this system are the surges of air caused either by the tank emptying or by the air breaking through the product.

The blow-tank principle can be used to feed regular pneumatic conveyors. Use of an Airslide or other fluidizing device at the bottom of the blow tank permits handling non-free-flowing materials. This

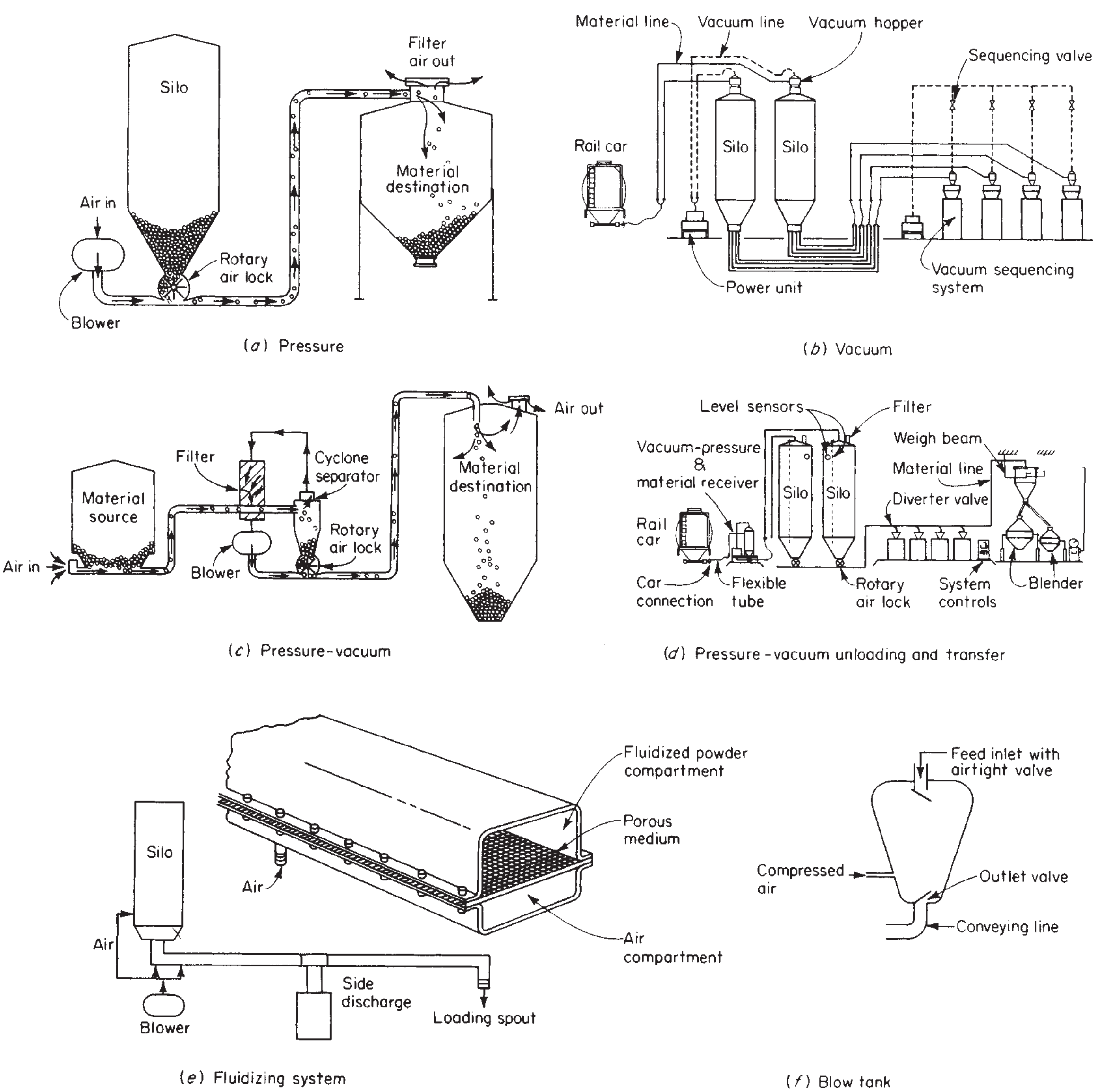


FIG. 21-12 Types of air-conveying systems. (*a*) Pressure. (*b*) Vacuum. (*c*) Pressure-vacuum. (*d*) Pressure vacuum unloading and transfer. (*Whitlock, Inc.*) (*e*) Fluidizing system. (*Fuller Co.*) (*f*) Blow tank.

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.

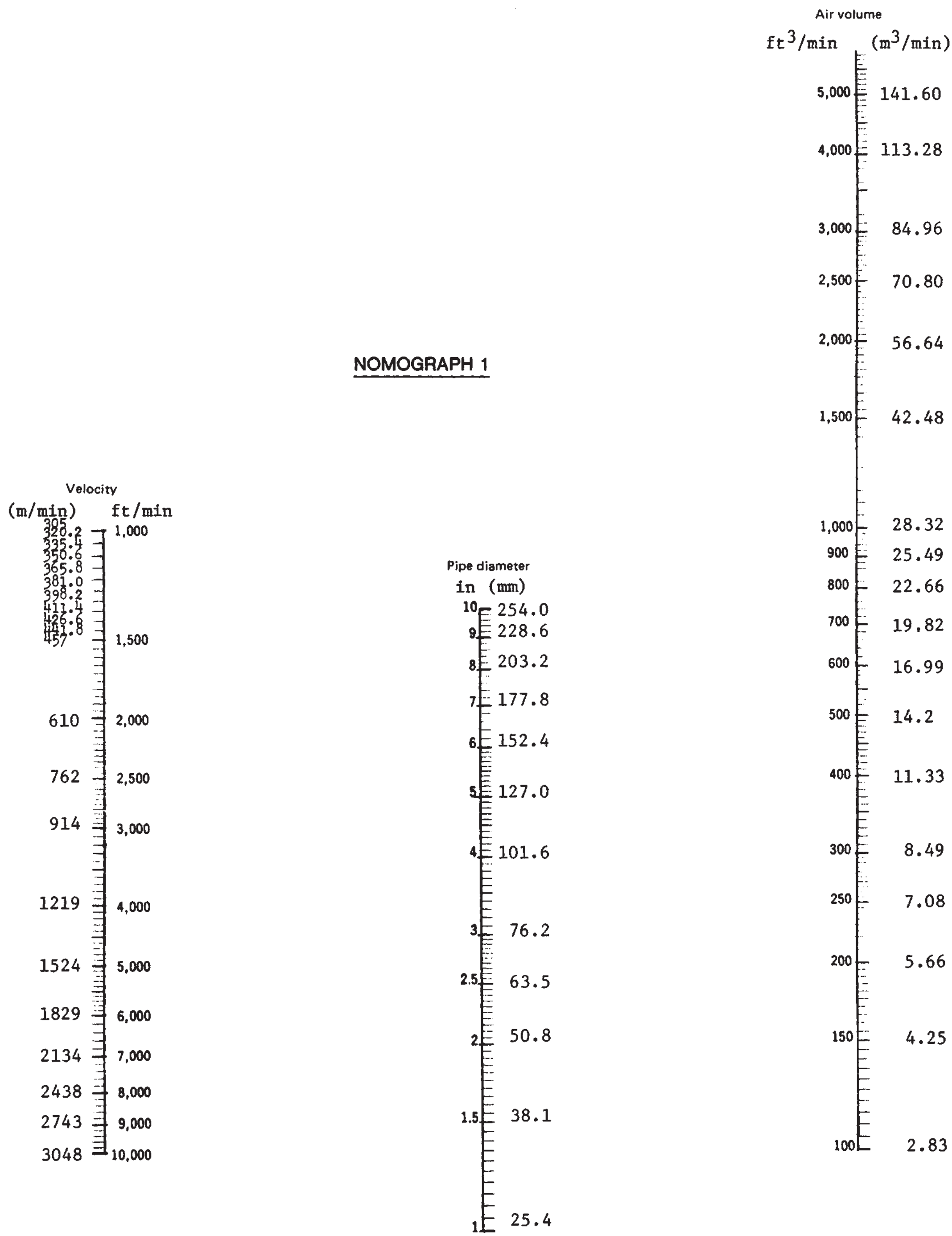


FIG. 21-13 Nomographs for determining conveyor-design parameters.

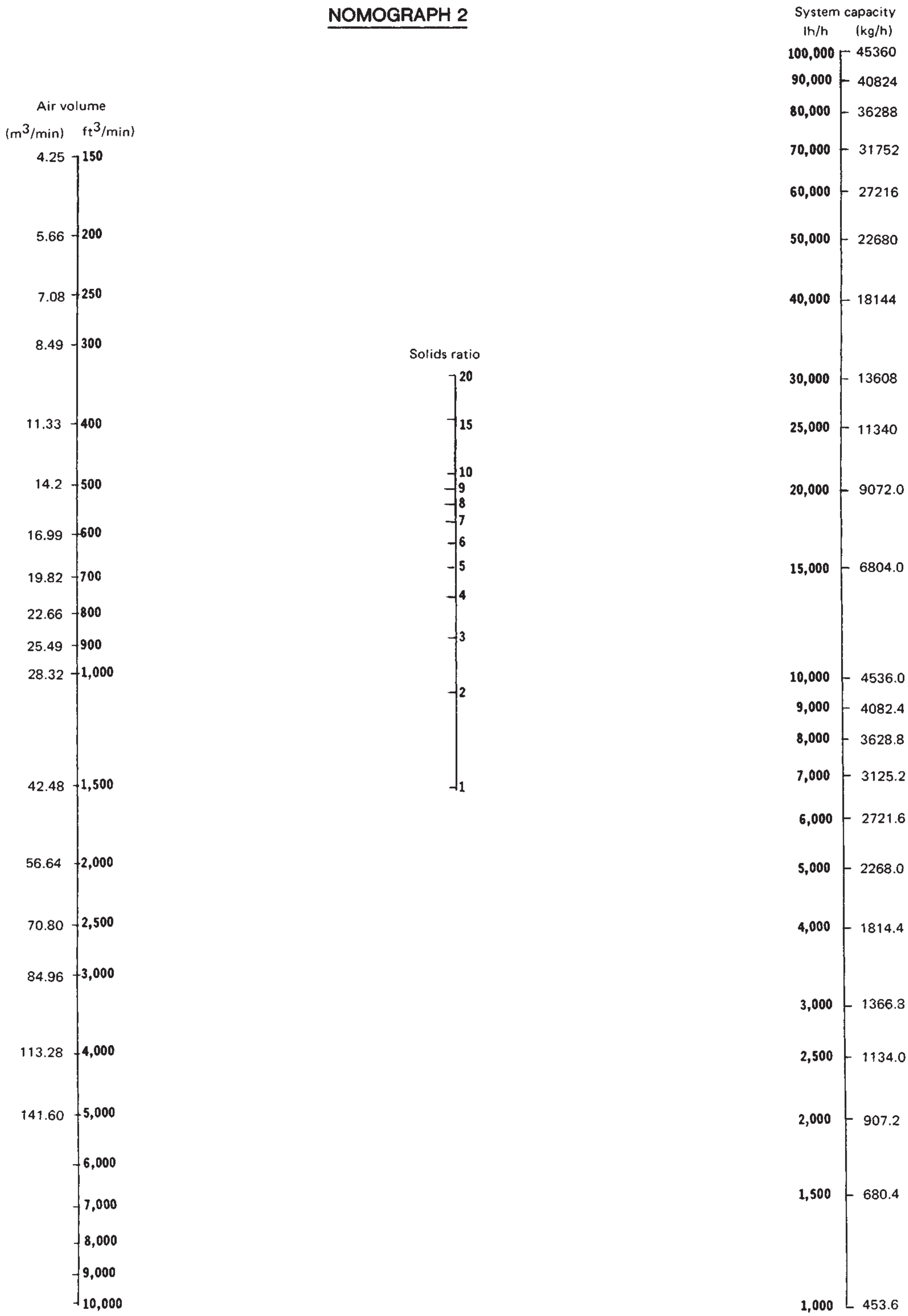


FIG. 21-13 *(Continued)*

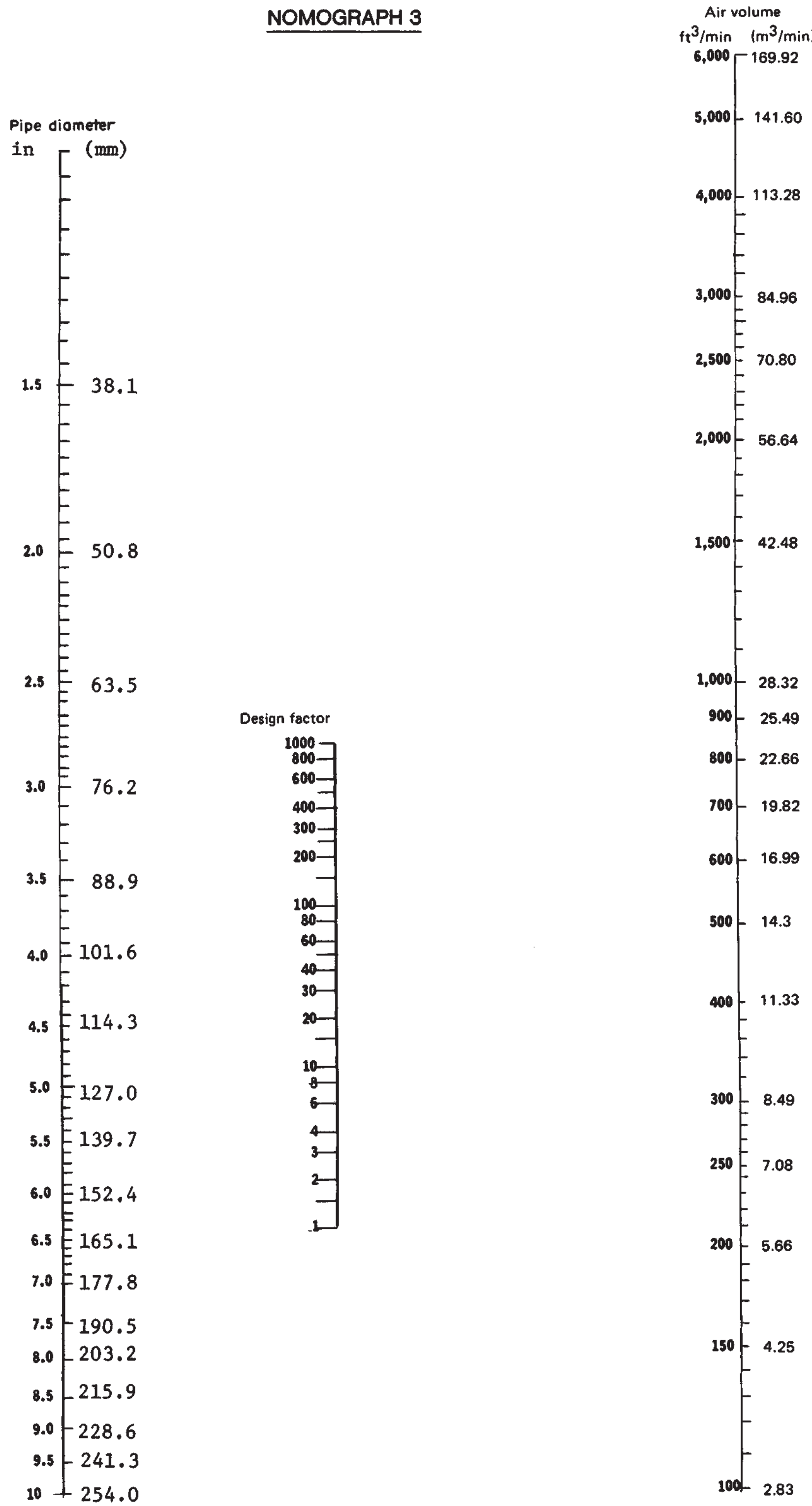


FIG. 21-13 *(Continued)*

NOMOGRAPH 4

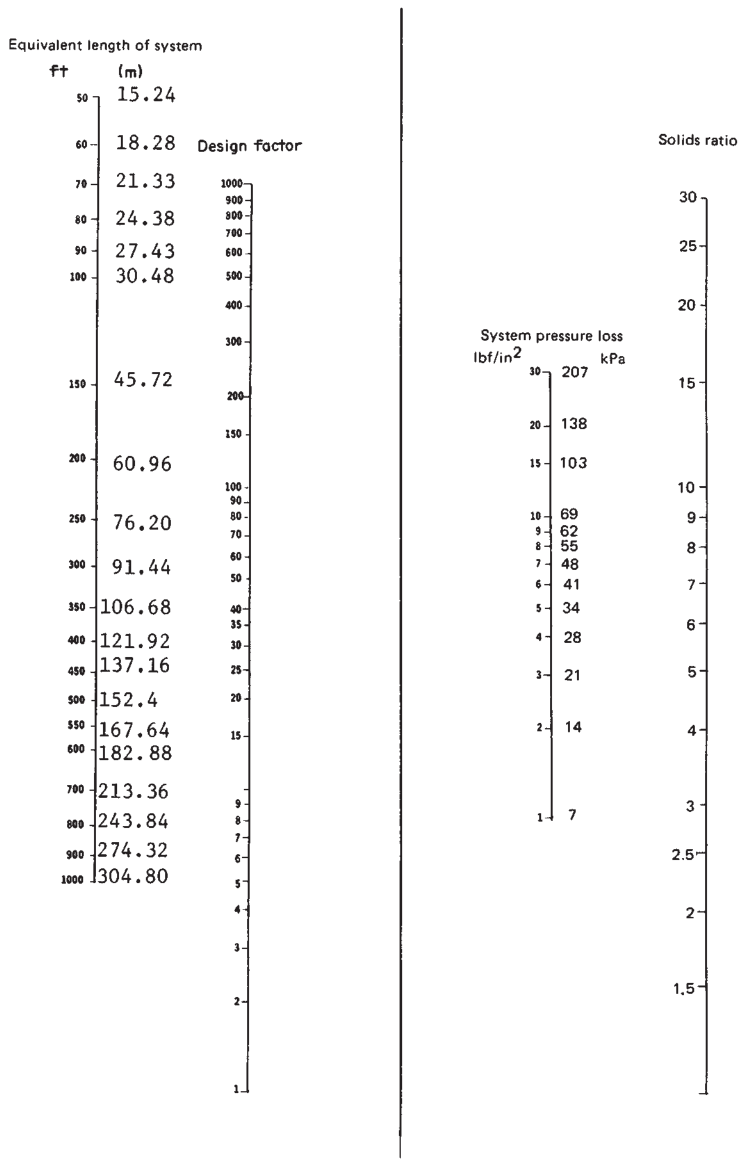


FIG. 21-13 (*Continued*)

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

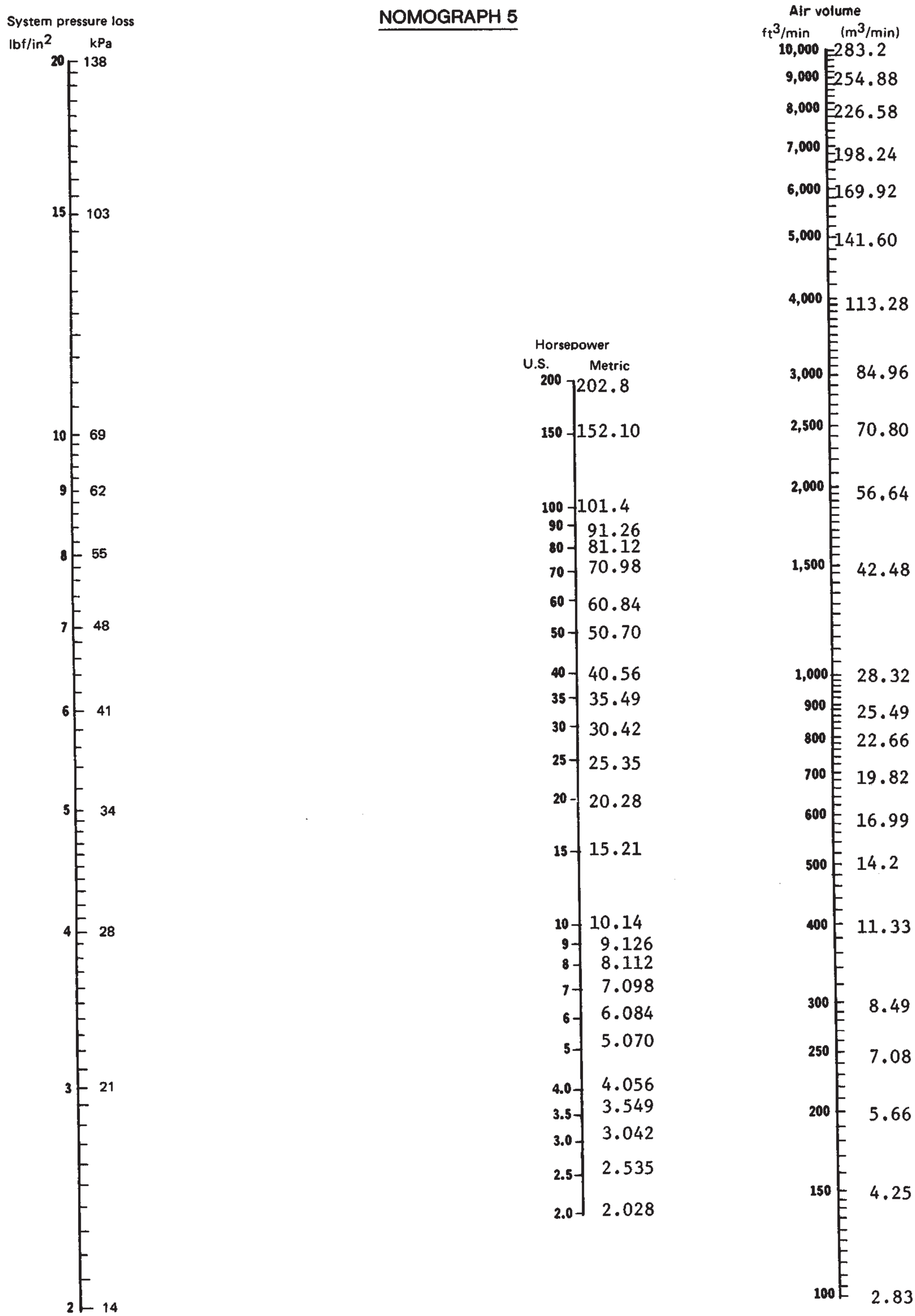


FIG. 21-13 *(Continued)*

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

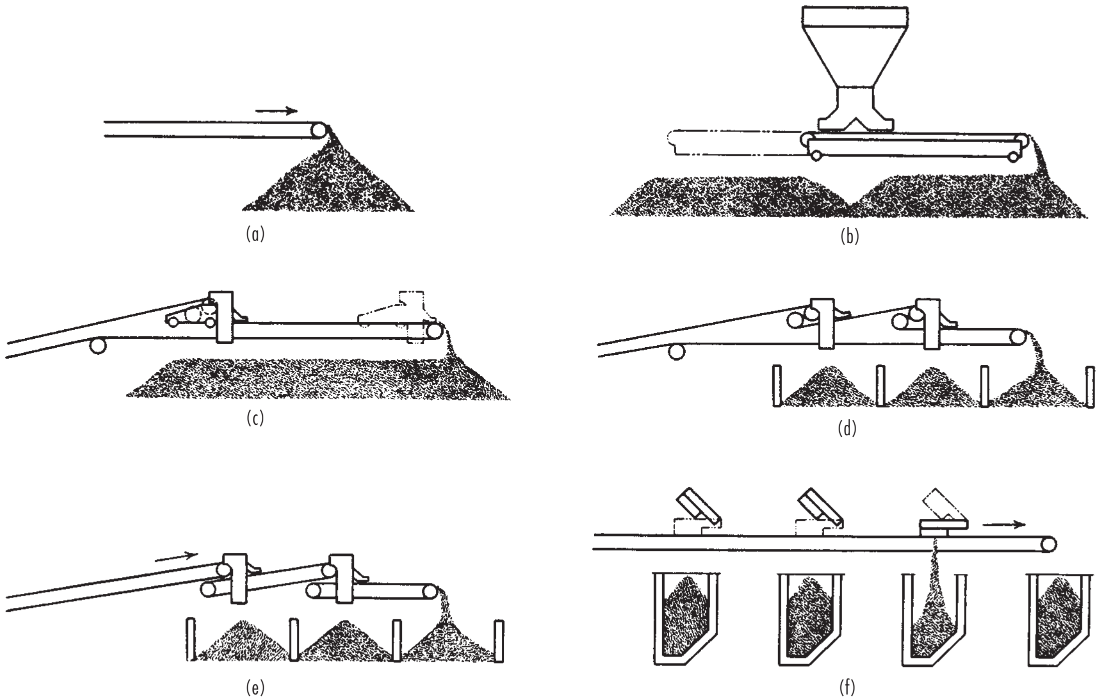


FIG. 21-14 Belt-conveyor discharge arrangements. (*a*) Discharge over an end pulley forms a conical pile at the end of the belt. (*b*) Discharge over either end pulley to distribute lengthwise by a reversible-shuttle conveyor. (*c*) Discharge through a traveling tripper, with or without a cross conveyor, to distribute material to one or both sides of the conveyor for the entire distance of tripper travel. Trippers can be propelled by a conveyor belt or by a separate motor. Motor-propelled trippers can also be automatically reversing to distribute material evenly or can be manually controlled to discharge at any desired point. (*d*) Discharge through fixed trippers, with or without a cross conveyor to one or both sides of the belt, to fixed bin openings or pile locations. This can also be done with multiple conveyors as shown in (*e*) or by stopping traveling trippers in the desired position. (*e*) Discharge from multiple conveyors through fixed discharge chutes, with or without a cross conveyor to one or both sides of the belt, to fixed bin openings or pile locations. (*f*) Discharge by hinged plows to one or more fixed locations along one or both sides of the conveyor. Plows may be adjusted to divide the discharge in several places simultaneously in the proportion desired. (*FMC Corporation, Material Handling Systems Division.*)

as in the rest of the process plant. His quantitative methods may be used to determine (1) whether the vessel will function with mass or funnel flow and (2) the outlet dimensions of the hopper so that product will flow. His methods also provide criteria for making engineering trade-offs between mass flow and funnel flow when product characteristics, space limitations, etc., dictate against design for mass flow.

The **relation between mass and funnel flows** for conical bins is shown in Fig. 21-20. The angle of kinematic friction ϕ', which is a measure of the friction coefficient between the solid and the material of construction used for the conical-shaped hopper, is measured with the "flow-factor tester." The degree of finish of the metal surface can have a large effect in determining whether the vessel will function in mass or funnel flow. Finer degrees of finish are being used more frequently, mostly because intuition has recommended this course. The kinematic angle of friction is also related to the degree of compression that the product undergoes in storage.

Once a decision for mass or funnel flow has been made or a compromise made by including an expanded-flow bin, the hopper outlet and the type of feeder must be considered. Jenike's teaching on the flow through the bin opening is that materials that can be compacted (as opposed to being free-flowing) will be compacted because of storage-vessel shape and the packing characteristics of the product. When this happens, the material forms an arch that is capable of withstanding considerable stress.

Since the arch transfers the load to the hopper walls and in doing so applies so much pressure to them, the kinematic coefficient of friction

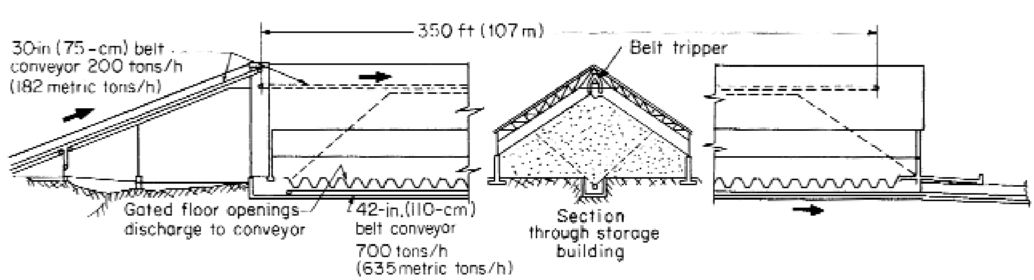


FIG. 21-15 Belt-conveyor storage and reclaiming in a flat-floor building. (*Stephens-Adamson Division, Allis-Chalmers Corporation.*)

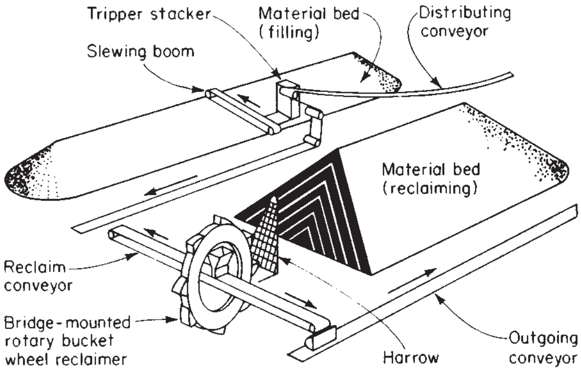


FIG. 21-16 Bucket-wheel reclaimer. Digging buckets mounted on wheel discharge on a belt conveyor for material transfer. (*Courtesy of* Mechanical Engineering.)

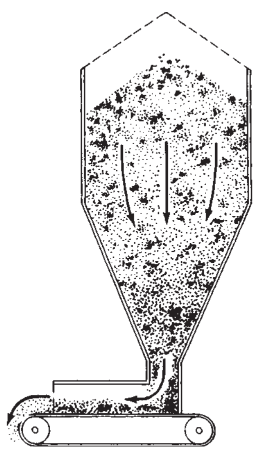


FIG. 21-17 Mass-flow bin. The material does not channel on discharge. (*Courtesy of* Chemical Engineering.)

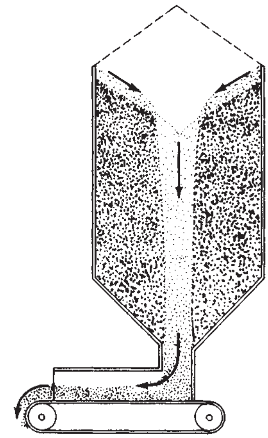


FIG. 21-18 Funnel-flow bin. The material segregates and develops ratholes. (*Courtesy of* Chemical Engineering.)

ϕ' becomes great. The net result is that the "dome" or "bridge" that forms prevents any flow from the vessel. Force must then be applied to the arch so that it will collapse and flow will begin, even if erratically.

According to Jenike, when the strength of the arch f is exceeded by the internal stress s generated by a force applied above the dome, flow takes place. Summarizing:

When $f < s$, flow occurs.
When $f > s$, there is no flow.
When $f = s$, the critical point is reached.

To make a **flow analysis** when $f < s$, an element of material is observed as it moves through a storage vessel (Fig. 21-21). The pressure p on the element increases from zero at the entrance to a maximum value at the transition from the bin to the hopper. The pressure then decreases to zero linearly at the vertex of the hopper cone. The resultant strength f follows a similar pattern, though usually it has some value greater than zero. The stresses induced in the material in the hopper bottom by the weight of material above it are constant but decrease linearly to zero at the cone vertex. The f and s curves intersect at a point corresponding to the critical dimensions of the **bin opening** B.

Reducing this analysis to a technique for determining B, Jenike's method provides a practical way to measure and interpret the strength

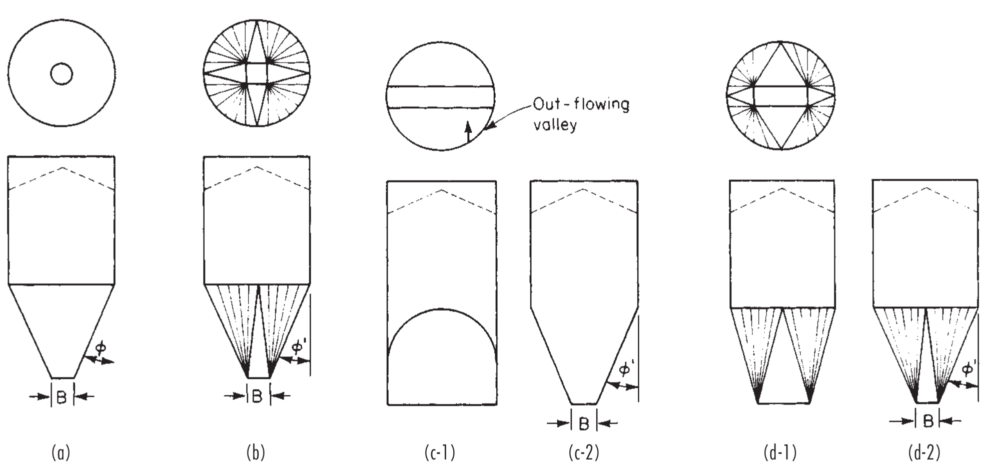


FIG. 21-19 Types of mass-flow bins. Type c is simple but has a valley. Although more difficult to make, type d has no valleys and is usually recommended. (*Courtesy of* Mechanical Engineering.)

TABLE 21-14 Principal Characteristics of Mass-Flow and Funnel-Flow Bins

Mass-flow bins	Funnel-flow bins
1. Particles segregate, but remit on discharge	1. Particles segregate and remain segregated
2. Powders deaerate and do not flood when the system discharges	2. First portion in is last one out
3. Flow is uniform	3. Product can remain in dead zones until complete cleanout of the system
4. Density of flow is constant	4. Product tends to bridge or arch, and then to rat-hole when discharging
5. Level indicators work reliably	5. Flow is erratic
6. Product does not remain in dead zones, where degradation can occur	6. Density can vary
7. Bin can be designed to yield non-segregating storage, or to function as a blender	7. Level indicators must be placed in critical positions so they will work properly
	8. Bins perform satisfactorily with free-flowing, large-particle solids

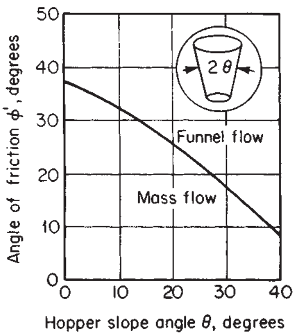


FIG. 21-20 Relation between mass and funnel flows for conical bins. (*Courtesy of* Chemical Engineering.)

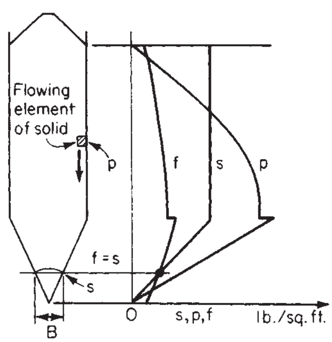


FIG. 21-21 Flow analysis is made by observing an element of material as it moves through the bin. (*Courtesy of* Chemical Engineering.)

of a bulk solid as a function of consolidating pressure. To develop this relation, Jenike developed a **shear tester** that gives a flow function *FF,* which is a curve through a locus of points resulting from values of *f* and *p* obtained by the shear tester. This *FF* curve is plotted against a flow factor *ff* for the particular hopper being designed, as shown in Fig. 21-22.

The method makes use of the principle that a constant ratio of induced stress *s* in the stored contents to the consolidating pressure *p* exists. Thus, for any hopper design for which the *ff* curve is available, the shear-tester results can be plotted, and the point where $f = s$ is located. Since the distance at which this occurs above the hopper vertex is also known, these values become the hopper dimensions at that point.

A useful approximation of *B* for a conical hopper is $B = 22f/\alpha$, where α is the bulk density of the stored product. The apparatus for determining the properties of solids has been developed and is offered for sale by the consulting firm of Jenike and Johansen, Winchester, Massachusetts, which also performs these tests on a contract basis. The flow-factor *FF* tester, a constant-rate-of-strain, direct-shear-type machine, gives the locus of points for the *FF* curve as well as φ′, the

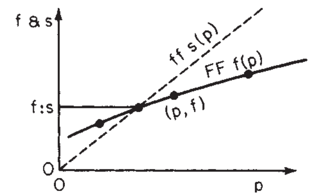


FIG. 21-22 Flow takes place only where *FF* lies below *ff.* (*Courtesy of* Chemical Engineering.)

kinematic coefficient of friction. A consolidating bench is used to prepare samples having different degrees of compaction for the flow-factor tester. This can be supplemented with the same bench enclosed in a controlled-temperature cabinet.

It is possible for some materials to produce an *FF* plot having no intersection with the *ff* curve. This indicates that a different hopper-bin design is needed or that the material cannot be made to flow. Figure 21-23 shows *FF* curves for several materials.

Jenike's method allows the chemical engineer to design bulk-storage vessels and to weigh cost versus performance with a high level of confidence that if the conditions in the real storage system are the same as those prevailing during the tests, the product will flow. It is up to the engineer, however, to establish the bounds of conditions that the product will encounter and to make appropriate tests. A product may not flow if its characteristics change, if radical temperature changes are encountered at the plant, or if moisture is left from an underdesigned dryer.

A further use of the Jenike method is its extension to the critical **structural design** of storage vessels. Because pressures can be calculated, it is possible to design for actual conditions rather than estimates. Also, flow-corrective devices may be designed by using his theory.

Specifying Bulk Materials for Best Flow Many flow problems can be eliminated at the source by rigid, accurate, and sensible specification of the physical characteristics of the material.

Particle size is one of the most common and controllable factors which affect the flowability of a given material. In general, it may be assumed that the larger the particle size and the freer the material is from fines, the more easily the material will flow. Specifications can dictate the desired particle size and uniformity of particle size for purchased raw materials. Stage grinding in the plant can reduce waste and improve flowability by producing a ground material with a mini-

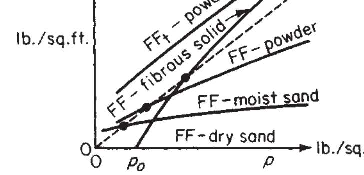


FIG. 21-23 *FF* curves for various materials. Multiply pounds-force per square foot by 0.0479 to get kilopascals. (*Courtesy of* Chemical Engineering.)

mum of fines, but this involves extra operations which may not be economically defensible.

Handling ease is often enhanced by **pelleting** the raw materials. The large particle size, uniformity of particle size, and hard, smooth surface of pellets all contribute to good flow.

Moisture content is another common and controllable flow factor. Most materials can safely absorb moisture up to a certain point; further addition of moisture can cause significant flow problems. Specifications can control the amount of moisture content present in purchased raw materials. Moisture content can be lowered in the plant by including a drying operation in the process line. The costs incurred in drying may be offset by more efficient flow, lower shipping cost, and control of deterioration losses.

Moisture control can also be effected by replacing the air in the material container or bin with a dry, stable gas—nitrogen, for example. This technique is also used to protect the material from certain types of deterioration, such as vitamin loss from food materials.

High temperatures can cause serious flow problems in some materials which contain glutens, sugars, or other soluble or low-melting-point components. These materials become sticky at high temperatures, and it may be necessary to install cooling equipment. As with drying equipment, a study should be made to determine if the additional cost of cooling can be offset by the savings effected by improved flow. Other possible advantages, such as the keeping qualities of the product at lower temperatures, should of course be considered.

Age appears to improve the flowability of certain materials. This is probably the result of particle-surface oxidation, more even moisture distribution, and the rounding of particle corners caused by handling.

Oil content does not materially decrease flowability. For example, the addition of oils and fats to animal-feed ingredients improves the quality of pellets made from these materials, making the pellet surfaces harder and enabling the pellets to resist attrition.

Gates (Fig. 21-24) are used to control flow from bins, hoppers, and processing equipment to feeders or directly to conveyors. They are available in a wide range of styles, from the simple hand slide gate (which can frequently be very difficult to operate by hand) to the precision rack-and-pinion design, which is usually tightly sealed against dust and dribble. The rack-and-pinion gate operates manually with a minimum of effort and is easily adapted to electric, pneumatic, or hydraulic operation. The lever-operated quadrant gate is most often used when a quick-opening gate is desired. It is not designed to control the flow of material but rather to allow the free discharge of lumpy materials. There are hundreds of gate styles to select from, and when properly applied they can often eliminate the need for a more expensive feeder.

Solids-level controls are important for determining the level of materials in bins and hoppers and can also protect conveyors from damage due to jamming if placed in transfer and discharge chutes. They may simply activate an audio or visual warning signal, or they may be electrically tied into the conveying system to start or stop conveyors automatically. Many designs are available, based on principles such as ultrasonics, lasers, radar, and switches operated by diaphragms or paddles. The two designs shown in Fig. 21-25 depend on limit switches, with activation from a pendant cone on one and from a stainless-steel diaphragm on the other. In either case, the presence of material resting against the cone or diaphragm opens or closes the switch, activating a warning signal in the latter case and turning off power to the conveyor in the former.

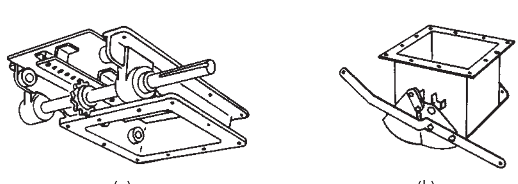


FIG. 21-24 (*a*) Rack-and-pinion gate. (*b*) Double-quadrant gate.

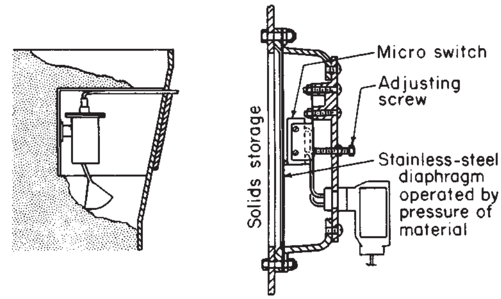


FIG. 21-25 Bin-level-control units.

FLOW-ASSISTING DEVICES AND FEEDERS

Often there are situations in which mass-flow bins cannot be installed for reasons such as space limitations and capacity requirements. Also, sometimes the product to be stored has an *FF* flow function that lies below the flow factor *ff*, bridging takes place, and unassisted mass flow is not possible. To handle these situations, a number of **flow assisters** are available, the most desirable of which use a feeder and a short mass-flow hopper to enlarge the flow channel of a funnel-flow bin. The choice of feeder or flow assister should always be made as part of the storage-vessel analysis. The resulting systems are then usually as effective as the mass-flow types.

Vibrating hoppers are one of the most important and versatile flow assisters. They are used to enlarge the storage-bin opening and to cause flow by breaking up material bridges. Figure 21-26 shows this type of feeder. Two basic types of vibrating hoppers are common: the gyrating kind, in which vibration is applied perpendicularly to the flow channel, and the whirlpool type, which by providing a combined twist and lift to the material, causes bridging to break. One version of this type of flow assister is a bin that vibrates or oscillates in its entirety. Such bins are usually limited to a capacity of about 2.8 m^3 (100 ft^3).

Screw feeders are also used to assist in bin unloading and in producing uniform feed. Of importance here is the need for a variable-pitch screw to produce a uniform draw of material across the entire hopper opening (Fig. 21-27). For uniform flow to occur, the screw-feeder opening-to-diameter ratio should not exceed 6.

Belt or apron feeders can also be used to give uniform feed from a bin, but care must be taken that dead spots are not produced in the

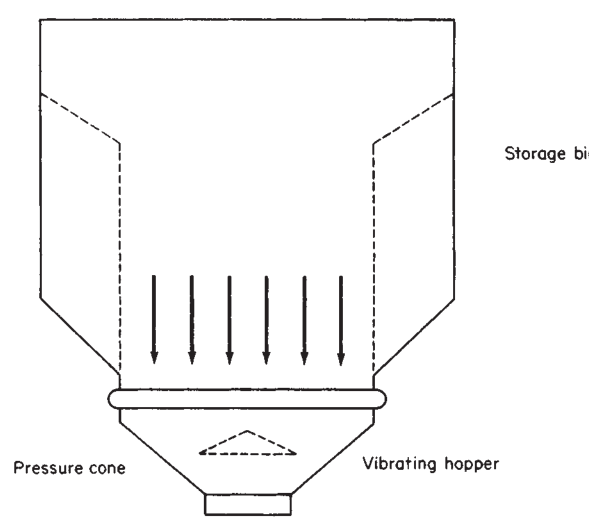


FIG. 21-26 Vibrating hopper. It enlarges the storage-bin opening and breaks up material bridging. (*Courtesy of* Mechanical Engineering.)

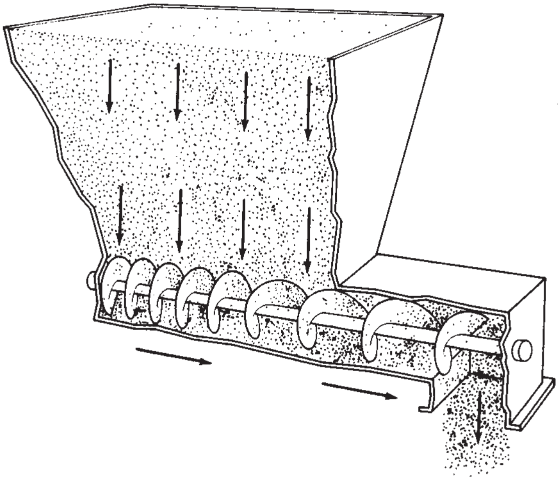


FIG. 21-27 Screw feeder. It needs a variable-pitch screw to produce a uniform draw of material. (*Courtesy of* Chemical Engineering.)

flow channel above the feeder belt (Fig. 21-28). The capacities of these feeders can be increased by tapering the outlet in the horizontal and vertical planes. To ensure the flow of non-free-flowing solids along the front bin wall, a sloping striker plate at the front of the hopper is necessary. Taper may be in one direction only. An apron feeder for large rock, for instance, would have bin skirts tight against the pan to prevent the rock from wedging between the hopper and feeder, and the taper would be in the horizontal plane only. For long slots, however, increasing slot width to provide taper becomes impractical.

Belts have been used successfully under slot openings as long as 30 m (100 ft), with a constant slot width of 205 mm (8 in). Provisions should be made for field adjustment of the space between the skirt and the belt to provide uniform flow along the entire length. Since the minimum distance between the skirt and the belt should allow the largest particle to pass under, very long belt feeders are limited to the finer solids.

The same principles apply to **table feeders.** The skirt is raised above the table in a spiral pattern to provide increased capacity in the direction of rotation (Fig. 21-29). The plow, located outside the bin, plows only the material that flows from under the skirt.

Vibratory feeders also provide uniform flow along a slot opening of limited length (Fig. 21-30). Here also, the distance between the feeder pan and the hopper is increased in the feed direction. Slot length is limited by the motion of the feeder. Because in long slots the upward component of motion is not relieved by the front opening, solids tend to pack. This can cause flow problems with sticky solids as well as a large demand of power for free-flowing materials. To circumvent these difficulties, vibratory feeders and reciprocating-plate feeders are designed to feed across the slot. Although this kind of feeder may require several drives to accommodate extreme width, the drives are small because of the feeder's short length.

Star feeders with a collecting-screw conveyor (Fig. 21-31) provide highly uniform withdrawal along a slot opening. A vertical section of at least one outlet width should be added above the feeder to ensure uniform withdrawal across the opening.

Other methods of aiding bin unloading are rotating-arm units and air fluidizing pads.

WEIGHING OF BULK SOLIDS

Automatic weighing has largely replaced manual weighing in the chemical-process industries because of the advent of larger-capacity processes and the need to economize on labor. Also, the dependability of weighing equipment has increased markedly, and investment cost has decreased. Both batch and continuous weighing are used.

Batch Weighing In batch weighing, a given unit of weight is measured, and then the desired total weight is obtained through multiples of the given unit. Batching scales find use when small weighings are carried out either singly or a few in sequence.

Most batch scales involve a vessel mounted on a weigh beam, which is counterbalanced by a set of weights approximately equal to the desired weighing. A feed source mounted over the weigh vessel is activated or stopped by a signal generated by motion of the scale beam. Straight mechanical scale-control systems have largely been replaced by those having air or hydraulic-cylinder control of the feed source and weigh-vessel discharge. These are activated by electrical controls.

The **principle of operation** of batch-type scales is based on the concept that a flowing stream of material has constant density. If this is true, then if at some point in advance of the desired batch weight the stream is cut off, the amount of material flowing will remain con-

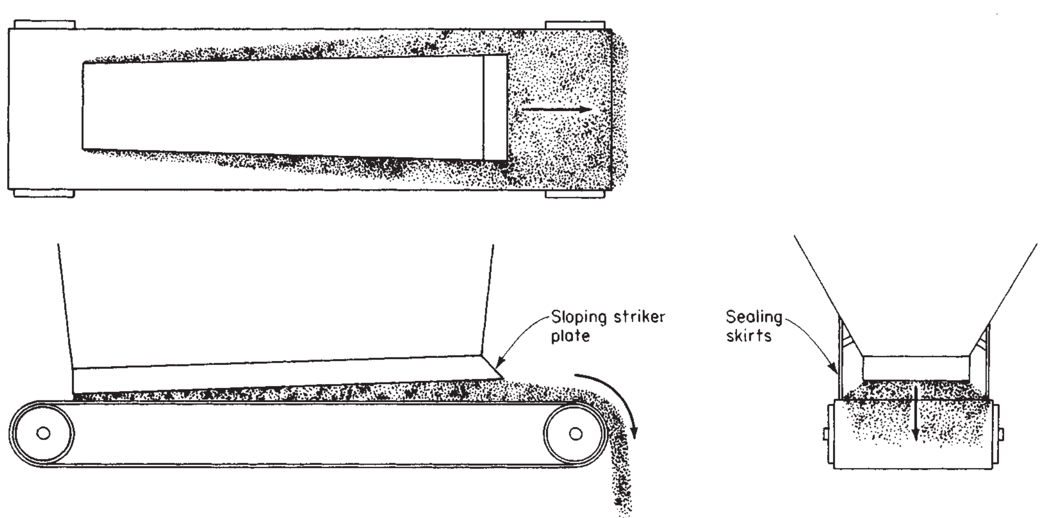


FIG. 21-28 Sloping striker plate in the belt of an apron feeder ensures the flow of non-free-flowing solids. (*Courtesy of* Chemical Engineering.)

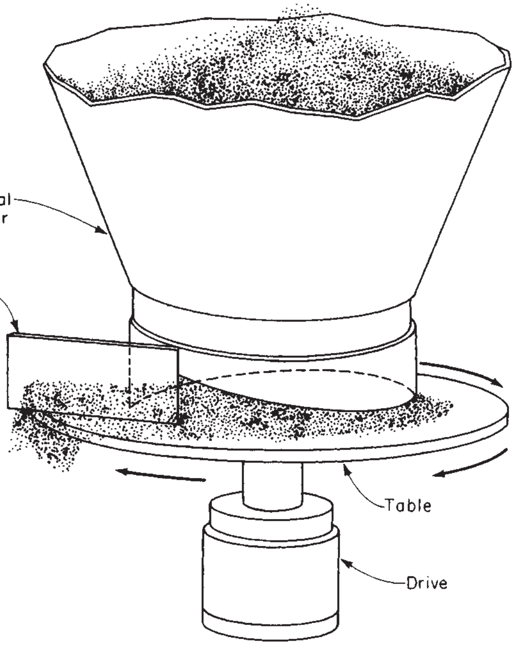


FIG. 21-29 Table feeder. The skirt is raised in a spiral pattern for increased capacity in the direction of rotation. (*Courtesy of* Chemical Engineering.)

stant between the time when the weight is sensed and the time when the flow is stopped. The total weight in the weigh vessel is the sum of the charge due to flow and the amount that flows during the cutoff period. For this reason, feed conditions to the scale are important. **Uniform flow** is essential for accurate batch weighings.

If the material is free-flowing, a mass-flow hopper (Fig. 21-32) can be used. If it is not free-flowing, an appropriate feeder such as a screw, belt, or vibratory feeder should be used. These feeders are described in the subsection "Flow-Assisting Devices and Feeders."

Of special interest in scale-control systems is the type in which the motion of the scale beam is sensed by a differential transformer or a group of load cells. The output of such devices is proportional to the displacement of the scale beam, which in turn is proportional to the amount of material in the weigh bucket. Many designs use load-sensing devices such as strain gauges or transducers. These eliminate the need for a scale-beam mechanism. The weigh vessel is mounted directly on the load-sensing devices. This provides many benefits in

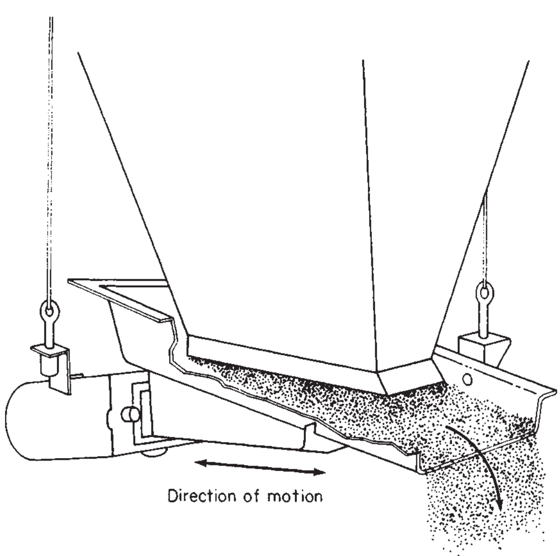


FIG. 21-30 Vibratory feeder. The distance between the feeder pan and the hopper is increased in the direction of feed. (*Courtesy of* Chemical Engineering.)

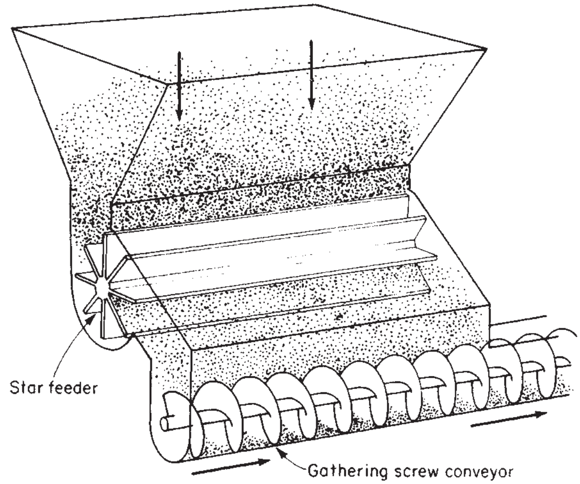


FIG. 21-31 Star feeder. The collecting screw ensures uniform withdrawal. (*Courtesy of* Chemical Engineering.)

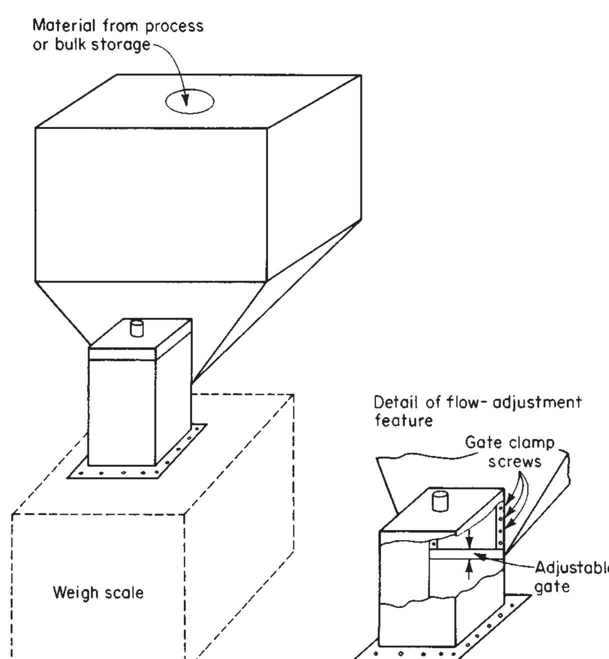


FIG. 21-32 Mass-flow hopper for free-flowing products, used with simultaneous fill-and-weigh and preweigh scales.

addition to accurate weights. One of the most notable is the ability to use the output to indicate actual weight in the weigh vessels or, through a different calibration, to read variations from the desired weight.

Use of microprocessors allows this signal to be employed in a variety of useful ways: controlling weight, adjusting the scale to accommodate the slight changes in bulk density inherent in flowing bulk materials, and activating recording devices, printing heads, and label printers. These features were not possible with straight mechanical scales. Because the microprocessor can perform arithmetic operations and be programmed by using algebraic logic, many products previously considered difficult or impossible to weigh accurately can now be weighed with accuracies equal to those for free-flowing materials. This permits weighing to be done by **addition** or by **subtraction.** With the **additive-**type scale, material is **added** to the weigh vessel, which is being sensed by the scale-control system. With a **loss-of-weight scale,** material flows out of a vessel which is being continuously weighed.

When extreme accuracy of weighings is required, the feed to the weigh vessel is divided into two successive portions: a large **bulk charge,** followed by a final short **dribble feed,** which should have a flow rate of about 0.01 percent of the bulk rate.

A typical application of batch scales is the weighing of charges for packaging machines. Another is the weighing of given amounts of raw material and then dropping these into the next process unit, such as a mixer or an autoclave. Batch weigh scales are capable of a weighing accuracy of within ±0.1 percent when they are equipped with bulk and dribble controls. When also equipped with high-sensitivity weight-sensing devices and microprocessor control, with the latter continuously plotting actual versus desired weight, batch weigh scales are capable of ±0.001 percent accuracy within 3 sigma limits.

Additive Weigh Scale The sequence of operations involved in weighing a charge of material (Fig. 21-33) is as follows. A free-flowing product is available in the scale feed hopper (1). On depressing the manual start switch (19), the bulk gate (5) and the dribble gate (6) open. The product flows into the scale weigh bucket (2). Weight is sensed by strain gauges (13), (14), whose analog output is converted to a digital output by a circuit in the microprocessor (18), which reads the weight X times each second, depending on the sensivity needed. When a preset bulk weight (approximately 98 percent of the desired weight) is reached in the scale bucket (2), the microprocessor closes the bulk gate (5) and opens the dribble gate (6). Dribble feed commences, and when the desired weight is reached, the microprocessor causes the dribble gate to close, completing the weight measurement. The scale bucket gate automatically opens, discharging the product weighed to the next process stage. The microprocessor then displays the actual weight of the charge (20) and records, lists, prints (21), and signals any discrepancy in weight if this is outside the tolerance desired. It also can print a label for the batch if desired.

Loss-of-Weight Scale The sequence of operations in this scale (Fig. 21-34) is as follows: Depressing the initializing switch (1) causes the feeder (2) to fill the weigh hopper (3) until the level-control switch (5) opens, stopping the flow, closing the interlocking switch (5), and measuring and recording the initial weight W_0 in the weigh hopper (3). Depressing the start button (6) causes the feeder (4) and the bag packer to start simultaneously. The product is conveyed by the feeder (4) into the packer (7) and by the bag packer into the bag (not shown). The microprocessor (8) reads the analog-to-digital-converter signal (8), which is connected to the strain-gauge load cell (9), and subtracts weight W_i in the hopper (3) at time t_i from the initial weight W_0. The weight difference W_j is summed and recorded. When $W_j = W_s$, the desired weight, the microprocessor stops the feeder (4) and, X seconds later, the bag packer (7). The microprocessor then displays the value of weight W_f (10) and records, lists, and prints (11) any discrepancy between the desired weight and W_f, the weight actually obtained. The packaging system shown is designed for handling products which have very poor or erratic flow characteristics. In addition to its use with packaging equipment, the **loss-of-weight scale** can be employed for a wide variety of process applications.

Continuous Weighing This procedure involves a device that is sensitive both to the total amount of material flowing and to changes in the flow. The material is continuously brought over the weight-sensing elements of the continuous-weigh scale, which is capable of keeping track of the flow and its changes and eventually accounts for these when totaling them. Continuous-weighing scales use a section of a belt conveyor, over which the material to be weighed passes.

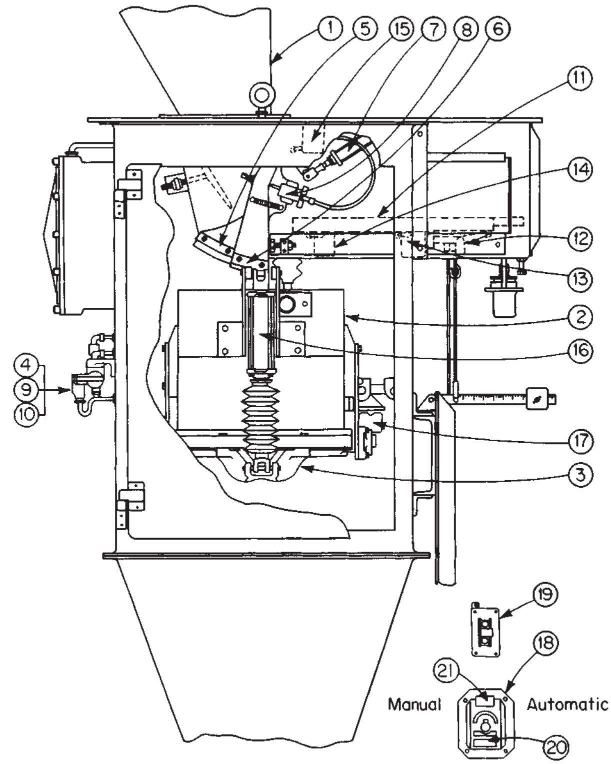


FIG. 21-33 Typical batch-type additive automatic scale. Components: (1) Bin. (2) Scale bucket. (3) Bucket gate. (4) Solenoid valve. (5) Bulk gate. (6) Dribble gate. (7) and (8) Air cylinders powered by solenoid-operated valves. (9) and (10) Solenoid-operated valves. (11) Scale beam. (12) Booster device. (13) and (14) Load cells. (15) Microswitches. (16) Air cylinder. (17) Proximity switch. (18) Microprocessor. (19) Manual start switch. (20) Weight display of the most recent weighing. (21) Average weight display for all weighments of the current product batch.

The belt is mounted on a weight-sensitive platform, typically equipped with load cells, which can detect minute changes in the weight of material passing over the belt. The load-cell output (which is usually a change in resistance proportional to weight) is integrated over short intervals and the condition of flow given. This may be a rate of flow or, at the end of a weight measurement, the total weight. Figure 21-35 shows a continuous weigher, sometimes referred to as a proportioner. Continuous-weighing scales are used mostly to feed materials to continuous processes at uniform, measured rates. They are capable of weighing within ±1 percent error or even within 0.1 percent error under certain conditions.

TABLE 21-15 Weight Sensing Devices and Sensitivity

Device	Sensitivity (one part in)
Beam-Microswitch	1,000
Beam-Differential Transformer	10,000
Strain Gauge Type Load Cell	20,000
Magnetic Force Restoration Transducer	500,000
Variable Capacitance Transducer	1,000,000

Data courtesy of Kg Systems, Inc., Bloomfield, NJ.

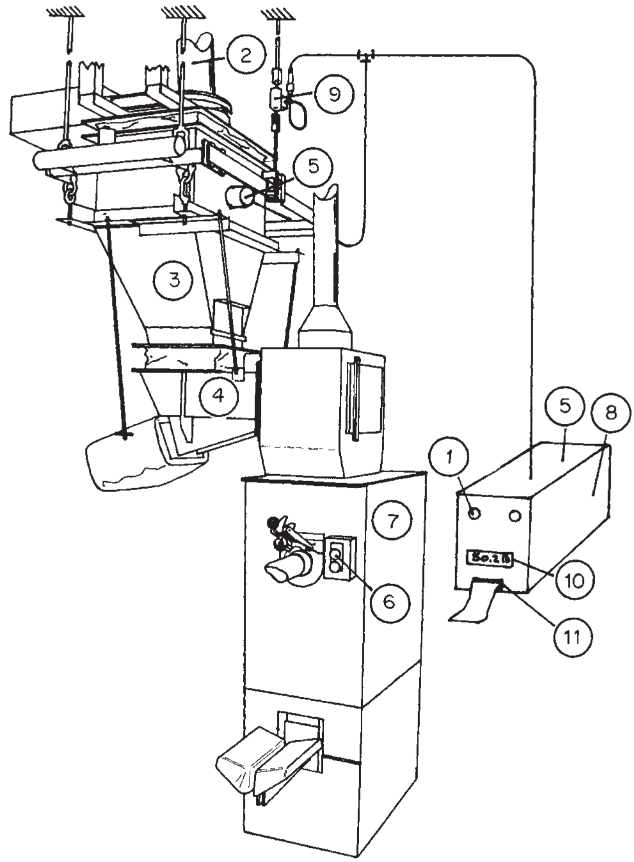


FIG. 21-34 Loss-of-weight-type scale used with a bag-packaging machine for non-free-flowing products. (*Courtesy of H. F. Henderson Industries, Inc., Caldwell, NJ.*)

All scales require continuous monitoring to assure that the desired set weight is maintained and does not drift off because of changes in product bulk-density or flow characteristics. Microprocessors can perform this task automatically.

Weight Sensing These devices have been the subject of intensive research, development, and applications. Increased sensitivity and reliability have been the result of this effort, which has been driven by the increased availability of special purpose computers and the data processing capability of low-cost personal computers. Table 21-15 lists those commonly available and gives their sensitivity. As a result of this, custom-designed weighing equipment has become an important alternative to standardized or "off the shelf" designs. This is especially true when there is a necessity to modify a standard design, which often is more expensive than a custom design.

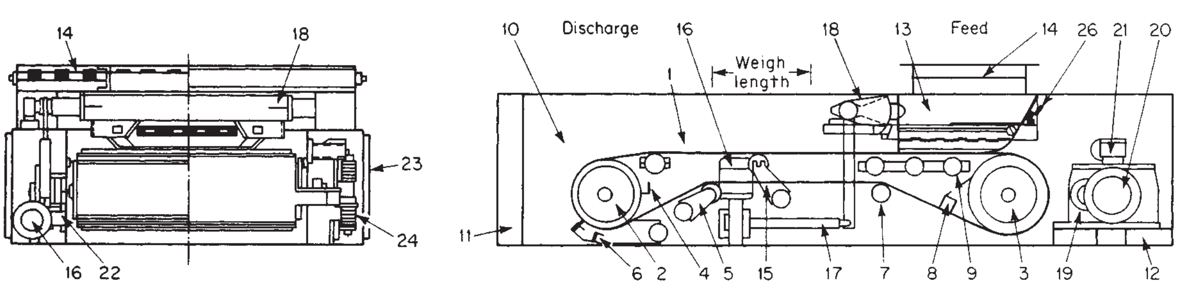


FIG. 21-35 Bulk continuous weigher. (1) Conveyor belt. (2) Head pulley. (3) Tail pulley. (4) Pulley scraper. (5) Spring-loaded take-up assembly. (6) Outer belt scraper (spring-loaded). (7) Belt tracking control. (8) Belt scraper (inner). (9) Pulley scraper. (10) Side channel. (11) Cross channel. (12) Cross channel. (13) Transition chute (optional). (14) Feed-cutoff gates. (15) Weigh idlers. (16) Gate-screw drive motor. (17) Gate screw. (18) Manual gate-adjustment screw. (19) Tachogenerator (optional). (20) Variable-speed drive. (21) Speed adjustment for motor drive (20). (22) Coupling. (23) Side cover. (24) Weight-sensing elements. (25) Hopper storage (optional). (26) Adjustable heel plate (optional). (*Howe Richardson Company.*)

PACKAGING OF SOLID AND LIQUID PRODUCTS AND HANDLING OF PACKAGES

Packaging is often defined by the chemical industry as including all packages or containers which will hold 2 metric tons (4400 lb) of product or less. These containers include bags, cartons, drums and pails, cans, bottles, bulk bags, and metal tanks. Materials of construction can be paper, plastic, metal, glass, wood, or composites of these. A representative list showing the wide variety of containers available for chemical products is given in Table 21-16, which includes typical specifications and representative 1995 costs.

Packaging information has assumed a new importance as the chemical industry in the United States has downsized and the position of the professional packaging engineer has virtually disappeared. Often, the chemical engineer without packaging experience is faced with a project in which the package must be designed and specified and the packaging machinery chosen. Useful sources of information are texts which deal specifically with the subject of packaging. Prominent among these are: *The Wiley Handbook of Packaging Engineering*, published by John Wiley & Sons; *The Handbook of Packaging Engineering* by Joseph Hanlon, published by Technomic Publishing Co., Inc.; and *Fundamentals of Packaging Technology* by Walter Soroka, published by the Institute of Packaging Professionals (IOPP). These and other useful texts are sold by the packaging bookstore of IOPP which has an extensive catalog available. The *IOPP Directory of Packaging Consultants* gives services and skills available in chemical packaging and labeling. Address: Institute of Packaging Professionals, 481 Carlisle Drive, Herndon, VA 22070-4823, 703-318-8970, FAX 703-318-0310.

The Gottscho Packaging Information Center at Rutgers, The State University of New Jersey, College of Engineering, Center for Packaging Science and Engineering, Building 3529, Busch Campus, Piscataway, NJ 08855 is a unique library devoted to packaging and related subjects. A literature search service is available.

Ecology concerns have resulted from an environmentally conscious world. In many countries, laws regulate the type of packaging that can be used and the manner in which it must be disposed of. In Europe, the German packaging law has become a model for the control of packaging and its disposal. It has been copied by many nations. While consumer packaging is the principal aim of this law, industrial packaging is also controlled. Arrangements must be made for the safe and approved disposal of used packaging. The effect of this has caused the chemical industry to reexamine whether disposable packaging should be used in view of the cost of disposal. By way of example, a wood pallet, used to contain one metric ton of product in multiwall paper bags, might have a purchase price in the United States of $12.00. The disposal costs for such a pallet could range between $30 and $65. This gives rise to the use of returnable packaging components which would also include steel drums and pails, plastic drums and pails, pallets, bulk corrugated boxes, corrugated shipping containers, and woven mesh bulk bags. Because this is such a rapidly changing field it is incumbent on those involved with package design, development, and logistics to know the local regulations where the package will be sent. Logistics is an important consideration. If returnable packages are to be used, their return must be planned and the costs for such return developed. An option for package disposal where returnable packages are involved is to sell them for reuse in the country they are destined for. Further complicating the disposal of packages is any residue of the product which they originally contained. For example, it is not uncommon to find a 55 gal (208 liter) steel drum after unloading, containing a "heel" of 1 to 4 liters of product. The collection and disposal of such materials is highly regulated in the United States by the Environmental Protection Agency (EPA) CFR 40 and state and local laws. Similar regulations are in effect in most of the developed nations.

Regulation of packaging during the past decade has changed significantly. There are more governmental units involved, innumerable regulations which must be complied with, and substantial penalties for failure to comply. This applies to packaging regulations especially in the United States but also in the rest of the world. The United Nations (UN) acts as a worldwide regulatory agency. Most industrialized nations have their own governmental units which regulate packaging based on UN regulations.

In the United States, the Department of Transportation (U.S. DOT) regulates the packaging, handling, and transport of all materials which are regarded as hazardous or dangerous. In addition the Environmental Protection Agency (EPA), the Occupational Safety and Health Act (OSHA), the Food and Drug Administration (FDA), the Nuclear Regulatory Commission (NRC), and the U.S. Department of Agriculture (USDA) all exercise a regulatory influence over packaging for materials or products which by law are mandated to them. Those regulatory agencies with whom the practicing chemical engineer involved with packaging must contend are principally the U.S. DOT and to some extent, the EPA and OSHA. In the pharmaceutical and food industries, the FDA is the primary regulator. In the alcoholic beverages industry, the U.S. Department of the Treasury's Bureau of Alcohol, Tobacco, and Firearms (ATF) branch regulates the packaging used for these products. Most notably, however, is the impact of the regulations of the U.S. DOT. During the past two decades the U.S. DOT has changed the approach to packaging regulations from one of strict packaging material specifications to that of requiring specific package performance. Under the former, construction features of a package required for a specific hazardous material was spelled out in minute detail. Under the performance-packaging approach the same size and type container must now be capable of handling performance tests without failure for the particular packing group that is required for the hazardous nature of the product.

The specific regulations of the U.S. DOT are found in the Code of Federal Regulations (CFR) Title 49, Parts 100–199. A key part of CFR 49 is Part 172.101 a portion which is illustrated as Table 21-17.

Where a product is not deemed as hazardous and thus not regulated by any of the above governmental bodies, in the United States, acceptable packaging is defined by industry associations for the different transportation modes which might transport the product. Their interest is in protecting the product from damage and, consequently, claims against the transportation companies for improper handling and for loss or damage to the product. The National Motor Freight Classification (NMFC) of the American Trucking Associations, Inc. and the Uniform Freight Classification of the Association of American Railroads are two such regulatory bodies. Failure to comply with their regulations does not carry the penalties of law, but it does allow the transportation company to disallow payment of claims for loss or damage to freight while in their care. In addition to these, other agencies are involved in the regulation of packaging. Table 21-18 summarizes these.

The CFRs can be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, telephone 202-783-3238. The National Motor Freight Commission booklet 6000 may be obtained from the American Trucking Associations, Inc., 7200 Mill Road, Alexandria, VA 22314. The Uniform Freight classification, ratings, rules, and regulations for railroad shipment can be obtained from the Uniform Freight Classification Commission, Tariff Publishing Officer, Suite 1160, 222 South Riverside Place, Chicago, IL 60606. UN regulations are contained in the publication *Recommendations on the Transport of Dangerous Goods*, which is available from the UN Publications Section, UN Plaza, New York, NY 10017.

The United States has moved to follow the approach established by the United Nations to performance-based specifications for the packaging and packaging materials used for hazardous materials. The U.S. DOT, through Rule Making Docket HM 181 defined the United States position for performance-oriented packaging. Through many hearings and requests for industry comment, the DOT has now published in CFR 49 the changes necessary to bring U.S. packaging specification for hazardous materials in compliance with the United Nations specifications.

The nature of the change to performance-tested packaging is best illustrated with an example of a shipment of ethyl alcohol in a 55-gallon (208 liter) steel drum. Under the old rules one could look up

TABLE 21-16 Typical 1996 Cost of Containers for Chemical Products

Container size and description	Unit cost,[i] US$	Usable volume ft³	Usable volume m³
Metal drums[a,b,c]			
55 gal (208 L), steel, tight head, 18-20-18 gauge,[d] DOT-P.G. II	$50.15	7.35	0.208
55 gal (208 L), steel, tight head, all 16 gauge, DOT P.G. I	75.00	7.35	0.208
55 gal (208 L), steel, open head, 18 gauge, Rule 40[e]	55.71	7.35	0.208
55 gal (208 L), steel, open head, 16-18-18 gauge, DOT-P.G. III	70.15	7.35	0.208
55 gal (208 L), steel, tight head or open head, 18 or 18-20-18 gauge, used, reconditioned	22.80	7.35	0.208
55 gal (208 L), Type 304 stainless steel, tight head, 16 gauge, DOT P.G. I	985.00	7.35	0.208
30 gal (113 L), steel, tight head, 20 gauge, DOT	41.28	4.00	0.113
30 gal (113 L), steel, open head, 20 gauge, Rule 40[e]	33.23	4.00	0.113
16 gal (61 L), steel, open head, lug cover, without fittings, 22 gauge	21.71	2.14	0.061
55 gal (208 L), steel, dip-galvanized, tight head, 18 gauge, DOT	100.00	7.35	0.208
56.1 gal (204 L), steel, with 40-mil PE insert, external fittings, 18-20-18 gauge, 55-gal usable volume, DOT, open head[e]	89.00	7.20	0.204
56.1 gal (204 L), but tight head	90.75	7.20	0.204
55 gal (208 L), of blow-molded high-density PE,	45.15	7.20	0.204
Cans and pails[b]			
Pail, 5 gal (19 L), steel, tight head, 26 gauge, black steel, PE pour spout, unlined	$10.91	0.67	0.019
Pail, 5 gal (19 L), 26 gauge, black steel, open head, unlined, lug cover, wire-bail handle.	8.15	0.67	0.019
Can, 1 gal (3.8 L), friction-wedge lid, handle (paint can)	1.90	0.1335	0.004
Can, 1 qt (0.95 L), friction-wedge lid (paint can)	0.79	0.034	0.001
Can, 1 gal (3.8 L), oblong F style, handle, 1¼-in (32-mm) screw cap	2.90	0.1335	0.004
Can, 1 pt (0.48 L), oblong F style, 1-in (25-mm) screw cap	1.05	0.0167	0.0005
Square can, 5 gal (20 L), blow-molded PE with 2¾-in cap (often called "5-gal squares", or Jug)	7.43	0.67	0.019
Can, 1 pt (0.48 L), round-cone-top style, with 1-in (25-mm) cap	1.15	0.0167	0.0005
Fiber drums[b,f]			
61 gal (231 L), 9 ply, 400-lb (181-kg) load limit, dry products only, Rule 403	$22.50	8.15	0.231
55 gal (208 L), 9 ply, 400-lb (181-kg) load limit, dry products only, Rule 403	20.67	7.35	0.208
47 gal (178 L), 9 ply, 400-lb (181-kg) load limit, dry products only Rule 403	19.89	6.28	0.179
41 gal (155 L), 9 ply, 400-lb (181-kg) load limit, dry products only, Rule 403	18.24	5.48	0.155
30 gal (113 L), 9 ply, 400-lb (181-kg) load limit, dry products only, Rule 403	16.20	4.00	0.113
30 gal (113 L), 7 ply, 225-lb (102-kg) load limit, dry products only, Rule 403	14.48	4.00	0.113
15 gal (56.8 L), 6 ply, 150-lb (68-kg) load limit, dry products only Rule 403	10.75	2.00	0.057
55 gal (208 L), 9 ply, PE barrier, 400-lb (181-kg) load limit, Rule 403	21.05	7.35	0.208
55 gal (208 L), 9 ply, PE-aluminum foil liner, 400-lb (181-kg) load limit, Rule 403	31.32	7.35	0.208
55 gal (208 L), 10 ply, blow-molded, 15-mil PE liquidtight liner, tight head, steel cover with 2-in and ¾-in NPT1 openings, 600-lb (272-kg) load limit,	47.31	7.35	0.208
30 gal (113 L), 9 ply, same as preceding except 450-lb (204-kg) load limit	36.51	4.00	0.113
30 gal (113 L), 8 ply, 300-lb (136-kg) load limit, removable fiber cover, no barrier	17.28	4.00	0.113
15 gal (56.8 L), 6 ply, same as preceding except 150-lb (68-kg) load limit	11.41	2.00	0.057
1 gal (3.8 L), 5 ply, same as preceding except 150-lb (68-kg) load limit	5.01	0.1335	0.004
55 gal (208 L), 9 ply, 400-lb (181-kg) load limit, semisquare removable fiber cover, Ro-Con style	20.21	7.35	0.208
45 gal (170 L)	12.21	6.01	0.170

Remarks

Black steel drums lined at extra cost:

Lining	No. coats	Cost/drum, $
Baked resin,	1	7.00
pigmented	2	9.60
Epoxy phenolic composite	2	11.14

Prices shown include ¾-in and 2-in fittings and are for unlined drums; add $1.25 per drum for delivery.

Approximate steel drums per truckload

55-gal size = 360 drums
30-gal size = 592 drums
16-gal size = 1225 drums

U.S. standard gauge equivalents

Gauge	in	mm
16	0.0598	0.0152
18	0.0478	0.0121
20	0.0359	0.0091
22	0.0299	0.0076
24	0.0239	0.0061

Approximate fiber drums per truckload

61-gal size = 300 drums
55-gal size = 318 drums
47-gal size = 424 drums
41-gal size = 552 drums
30-gal size = 592 drums
15-gal size = 1272 drums
1-gal size = 17,365 drums

Fiber drum type	Outside dimensions: Diameter, in	Diameter, cm	Height, in	Height, cm
55-gal lever top	21	53.3	40¾	103.5
55-gal lever top	23½	59.7	30¾	78.1
55 gal lever top	22	55.9	34¾	88.2
41-gal lever top	20½	45.1	30¼	76.8
30-gal lever top	19	48.3	26¼	66.7
6.28-ft³ rectangular	17⅝*	44.8	37½	95.3
55-gal liquid	22	55.9	37½	95.3
30-gal liquid	19	48.3	28	71.1
55-gal fiber	20⅜	51.8	40¾	103.5
30-gal fiber	17⅜	44.1	30¾	78.1

*Side dimension, square.

TABLE 21-16 Typical 1996 Cost of Containers for Chemical Products (*Continued*)

Container size and description	Unit cost, US$	Usable volume ft³	Usable volume m³
Bags: multiwall paper and polyethylene film[g]			
Pasted valve bag, 20½- × 22-in face, 5½-in top and bottom (520 × 560 × 140 mm) with 1-mil free film, 2/50, 1/60 kraft, PE internal sleeve	$0.51	1.33	0.038
Sewn valve bag, 15 × 5½ × 30¼ in, 5½-in PE internal sleeve (380 × 140 × 770 × 140 mm) with 1-mil free film, 2/50, 1/60 kraft	0.61	1.33	0.038
Pasted valve bag, 18½ × 22¾ in, 3½-in top and bottom (470 × 580 × 90 mm), PE internal sleeve, 3/50 kraft	0.36	0.84	0.024
Sewn open-mouth bag, 20 × 4 × 30¾ in (510 × 100 × 780 mm), 3/50, 1/60 kraft	0.49	2.00	0.057
Sewn valve bag, 19 × 5 × 33½ in, 5½-in tuck-in sleeve (480 × 130 × 850 × 140 mm), 3/50, 1/60 kraft	0.65	2.00	0.057
Pasted valve bag, 24 × 25¼ in, 8-in top and bottom (610 × 640 × 200 mm), tuck-in sleeve, 3/50, 1/60 kraft	0.61	2.00	0.057
Pasted open-mouth baler bags, 22 × 24 in, 6-in bottom (560 × 610 × 150 mm), 1/130 kraft (or 2/70)	0.36	1.33	0.038
Flat tube open-mouth bag, 10-mil PE film, plain, 20½ × 34¼ in (520 × 870 mm)	0.73	1.33	0.038
Square-end valve bag, 20½- × 22-in face, 5½-in top and bottom (520 × 560 × 140 mm), 8-mil PE film, plain	0.49	1.33	0.038
Pinch-style open-mouth bag, 20 × 4 × 30¾ (510 × 100 × 780 mm), 1/10 PE 50, 2/50, 1/60 kraft, plain, no printing	0.65	2.00	0.057
Small bags, pouches, and folding boxes[h]			
Pouch, 8¾ × 16¾ in (220 × 425 mm), 2-ply PE film, 2-mil- (0.05-mm) thickness per ply	$0.13	0.12	0.0034
Bag, sugar-packet style, 6 × 2¾ × 16¾ in (150 × 70 × 425 mm), 2/40-lb basis weight, natural kraft paper	0.11	0.12	0.0034
Bag, pinch style, 8¾ × 3 × 21 in (220 × 75 × 530 mm), 2/40-lb basis weight, natural kraft paper	0.11	0.12	0.0034
Folding box, 5 × 1 × 8 in (125 × 25 × 200 mm), reverse-tuck design, 12-point kraft board with bleached white exterior	0.23	0.028	0.0008
Folding box, 9½ × 4½ × 15 in (240 × 115 × 380 mm), full-overlap top and bottom, 30-point chipboard with bleached white exterior	0.47	0.37	0.0105

For tuck-in sleeve, add $0.05/bag. Unit cost is for unprinted bag. For printing add the following up charges. U.S. dollars per 1000 bags:

1 side, 1 color, $13.50
1 side, 2 colors, $16.85
1 side, 3 colors, $22.15
2 sides, 1 color, $16.85
2 sides, 2 colors, $22.15
2 sides, 3 colors, $28.50

Polyethylene-film gauges

mil	Actual mm	Nearest mm
0.5	0.0127	0.01
1.0	0.0254	0.03
1.5	0.0381	0.04
1.75	0.0445	0.04
2.0	0.0508	0.05
8.0	0.2032	0.20

Multiwall kraft-paper basis-weight equivalents

U.S. customary, lb/3000 ft² ream	SI, g/m²
40	65
50	81
60	97

Permeability of common packaging films*

Type of film	Water-vapor transmission†	Gas permeability‡			Water absorption
		O_2	N_2	CO_2	
Cellophane, nitrocellulose-coated	0.3	1	1	13	High
Nylon	19	25	160	160	Medium
Polycarbonate	11	300	50	1000	Medium
Polyester, oriented	1.7	4	1	16	Low
Polyethylene, low-density	1.3	550	180	2900	Low
Polyethylene, high-density	0.3	600	70	4500	Low
Polypropylene	0.7	240	60	800	Low
Saran	0.2	14	12	4	Low

*From J. R. Hanlon, *Handbook of Package Engineering*, Technomic Publishing Co., Lancaster, PA 17604, 1992 ed.
†g loss, 24 h/(100 in²·mil), at 95°F, 90 percent relative humidity.
‡cc, 24 h/(100²·mil), at 77°F, 50 percent relative humidity; ASTM D1434.

TABLE 21-16 Typical 1996 Cost of Containers for Chemical Products (*Concluded*)

Container size and description	Unit cost, US$	Usable volume ft³	Usable volume m³
Corrugated cartons and bulk boxes[h]			
Regular slotted carton (RSC), 24 × 16 × 6 in (610 × 405 × 150 mm), 275-lb-test double wall, stapled (stitched) joint	1.25	1.33	0.038
RSC, 16 × 6 × 24 in (405 × 150 × 610 mm), 275-lb-test double wall, stitched joint, end-opening style	0.90	1.33	0.038
Bag in box, RSC, 15 × 15 × 22 in (380 × 380 × 560 mm), 275-lb-test double wall, stitched liner, 600-lb-test double wall, 6-mil (0.15-mm) PE liner	3.80	2.86	0.081
Bulk box, 600/600 (test in lb for both pieces), laminated inner lining, approximately 41 × 34 × 36 in (1040 × 865 × 915 mm); includes special wood pallet and 8-mil (0.2-mm) blown low-density PE liner	35.00	5.00	0.142
Carboys, plastic drums, jars, and bottles[h]			
Carboy, 13½ gal (51 L), PE, blow-molded	39.90	1.35	0.038
Drum, PE, 15 gal (57 L), blow-molded,	41.00	2.00	0.057
Carboy, 15 gal (57 L), glass, nitric acid service, wooden crate	128.00	2.00	0.057
Jug, 1 gal (3.78 L), glass, with finger handle, plastic 38-mm cap, with corrugated reshipper carton	3.10	0.1335	0.004
Bottle, 1 qt (0.95 L), glass, Boston round, plastic 28-mm cap	1.50	0.034	0.001
Jar, 1 qt (0.95 L), glass, wide mouth, plastic 89-mm cap	1.60	0.034	0.001
Jar, 1 qt (0.95 L), glass, plastic 63-mm cap	1.42	0.034	0.001
Jar, 1 gal (3.78 L), PE, wide mouth, plastic 100-mm cap	1.47	0.1335	0.004
Bottle, 1 gal (3.78 L), round, PE, narrow neck, plastic 38-mm cap	1.85	0.1335	0.004
Bottle, 1 qt (0.95 L), PE, narrow neck, plastic 28-mm cap	0.94	0.034	0.001
Jar, 1 pt (0.47 L), PE, wide mouth, plastic 53-mm cap	0.71	0.017	0.0005

Cost US$[h]

	Expendable grade		Warehouse reusable grade	
	9-block type	Stringer type	9-block type	Stringer type
Pallets[h]				
40 × 48 in (1015 × 1220 mm)	11.76	10.90	17.78	16.32
35 × 42 in (890 × 1065 mm)	10.17	10.17	16.49	15.17
42 × 48 in (1065 × 1220 mm)	17.40	17.40	20.10	18.51
48 × 48 in (1220 × 1220 mm)	18.81	18.81	21.69	19.97
44 × 50 in (1115 × 1270 mm)	21.45	21.45	24.53	22.60

Wrap materials	US$/lb
Film, PE, Grade ADL, blown type	1.05
Film, PE, Grade ASF (shrinkable)	1.25
Film, polypropylene, shrinkable, yield before shrinkage = 31,100 in²/(lb·mil)	3.37
Paper, kraft, wrapping quality, 50-lb/ream basis-weight yield = 3000 ft²/ream	0.50
Film, PE, stretchable type for pallet wrap, 1.5 mil × 20 in (0.04 × 510 mm) wide	1.15

[a] Drum has 2-in and ¾-in national-pipe-thread (NPT) openings in head.
[b] Truckload quantity price, FOB east-coast manufacturer's plant.
[c] DOT = U.S. Department of Transportation. Also UN (United Nations).
[d] Sequence of top, body, and bottom gauges. For example, 18-20-18 = 18-gauge top, 20-gauge body, and 18-gauge bottom.
[e] Removable head secured with bolted ring with screw draw-up.
[f] Drums are of plain fiber, have steel cover and bottom, and have lever-operated closing ring.
[g] Truckload-quantity price, FOB buyer's plant.
[h] Truckload-quantity price, FOB east-coast buyer's plant.
[i] Prices given are adequate for comparing alternatives. For budget purposes, actual, recent vendor quotation must be used due marketplace fluctuations in prices.

Explanation of U.S. DOT term:
PACKING GROUP I, II, III
P.G. I Great danger
P.G. II Medium danger
P.G. III Minor danger

Polyethylene-film* yield table

Thickness in	Thickness mm	Yield in²/lb	Yield m²/kg
0.001	0.025	30,000	19.4
0.0015	0.040	24,000	15.5
0.002	0.050	15,000	9.7
0.003	0.075	10,000	6.5
0.004	0.100	7,500	4.8
0.008	0.200	3,750	2.4
0.010	0.250	3,000	1.9

*Flat sheeting.

TABLE 21-17 Abstract of Part 172-101 of Code of Federal Regulations (CFR) Title 49 to Illustrate the Ethyl Alcohol Example in the Text. (U.S. Government Printing Office)

Symbols (1)	Hazardous materials descriptionsand proper shipping names (2)	Hazard class or Division (3)	Identification Numbers (4)	Packing group (5)	Label(s) required (if not excepted) (6)	Special provisions (7)	(8) Packaging authorizations (§ 173.***)			(9) Quantity limitations		(10) Vessel stowage requirements	
							Exceptions (8A)	Non-bulk packaging (8B)	Bulk packaging (8C)	Passenger aircraft or railcar (9A)	Cargo aircraft only (9B)	Vessel stowage (10A)	Other stowage provisions (10B)
—	Ethanol *or* Ethyl alcohol *or* Ethanol solutions *or* Ethyl alcohol solutions.	den 3	UN1170	II	FLAMMABLE LIQUID.	T1	150	202	242	5 L	60 L	A	
		—	—	III	FLAMMABLE LIQUID.	B1, T1	150	203	242	60 L	220 L	A	

TABLE 21-18 Agency and Administrative Law

Title	Symbol	Regulate or affect
International		
United Nations	UN	Packages and labeling for products moving among member nations.
Intergovernmental Maritime Consultative Organization	IMCO	
Federal		
Department of the Treasury Bureau of Alcohol, Tobacco and Firearms, Title 27	ATF	Packages and labeling for alcohols, tobacco, firearms, and explosives.
Department of Transportation Transportation Safety Act, Title 49	DOT	Packaging and labeling for all hazardous materials shipped in interstate commerce.
U.S. Coast Guard, Title 46	USCG	Set packaging, labeling, blocking, and bracing for all freight moving by United States–registry ships on lakes, rivers, or oceans.
Department of Labor Occupational Safety and Health Act, Title 29	OSHA	Package-filling and -handling machinery, workplace design, warehouse practice, and acceptability of packages from workplace and warehouse viewpoint.
Food and Drug Administration Federal Food, Drug, and Cosmetic Act, Title 21	FDA	Packages, packaging machinery, and workplace from viewpoint of their effect on food and drug purity; package labeling and marking.
Environmental Protection Agency, Title 40	EPA	Packaging facilities, packaging and labeling, package disposal, workplace refuse disposal, cleanup and disposal of spills.
Clean Air Act	CAA	
Clean Water Act	CWA	
Resource Conservation and Recovery Act	RCRA	
Federal Insecticide, Fungicide, and Rodenticide Act	FIFRA	
Toxic Substances Control Act	TSCA	
Nuclear Regulatory Commission Title 10	NRC	Packaging and labeling for nuclear materials and wastes
State		
Department of Transportation Labor Environmental Protection Agriculture Others	Example: New Jersey Department of Transportation	Packaging, labeling, workplace, packaging machinery, etc., in *intrastate* commerce. Regulations generally parallel those of federal departments but frequently have important differences and additional requirements.
City		
Departments of Health Labor Fire Protection	City fire department; example: NYFD	Packages, packaging machinery, packaging facilities, and materials which are transported, stored, and handled in the city. These local laws are in addition to the requirements of state and federal law.
Industry associations		
Air Line Pilots Association	APA	Materials which can be carried on commercial aircraft piloted by Air Line Pilots Association members.
International Air Transport Association	IATA	Materials which can be carried on members' aircraft and packaging and labeling requirements for them.
International Civil Aviation Organization	ICAO	Materials which can be carried and the packaging and labeling for them.
Association of American Railroads Bureau of Explosives	AAR B of E	Packages and loading, blocking, and bracing for all hazardous products shipped by rail in the United States. Bureau standards are generally accepted by all railroads and are the basis for R. M. Graziano's Tariff *Hazardous Materials Regulations of the Department of Transportation by Air, Rail, Highway, and Water,* latest edition.
Uniform Freight Classification Committee, Rules 40 and 41	UFC	Set packaging standards for all freight moving by *rail.*
American Bureau of Shipping National Cargo Bureau	ABS	Packaging, labeling, loading, blocking, and bracing for all freight moving by United States–registry ships on lakes, rivers, or oceans.
National Motor Freight Traffic Association National Motor Freight Classification	NMFC	Set packaging standards for all freight moving by highway.
National Fire Protection Association	NFPA	Packages, packaging facilities, and warehouse designs and operation.
Special carriers		
United Parcel Service	UPS	Packaging, labeling, and size and weight of small packages carrying hazardous materials. Requirements meet DOT standards. Quantities generally do not exceed 1 gal (3.785 L).
U.S. Postal Service	USPS	Materials which may be shipped and packaging, labeling, and size and weight of small packages handled by parcel post.
Federal Express Corp.	FEDEX	Packaging and labeling for hazardous and nonhazardous materials and products which they will carry.

TABLE 21-19 Performance Testing of Steel Drums—Type 'A' for Packaging Group II

Test	CFR 49 reference	Criteria summary
Drop test	178.603(e); (ii)	1.2 Meters (3.0 ft.)—no leakage
Leak proofness test	178.604(e); (2)	20 kPA (3.9 PSIG)—no leakage
Hydrostatic test	178.605(d); (1)	100 kPA (15 PSIG)—no leakage
Stacking test (By compression machine)	178.606(c); (2), (ii)	2000 lbs. (907 kg)—no leakage
Vibration	178.608(b), (3)	1 in. (2.54 cm) Amplitude at resonant frequency for 1 hour—no leakage

This information is taken from CFR 49, issue of October 1, 1992. The table is intended to be illustrative of the use of CFR 49. It should not be used as the basis for choosing a drum or other type package. Each package and product requires specific analysis to identify the container which meets customer needs and complies fully with U.S. DOT and UN regulations.

ethyl alcohol in part 172.101 and find that the required packaging was described in parts 173.125 and 173.119. According to Part 173.119, a 55-gallon (208 liter) steel drum was authorized for ethyl alcohol and its specifications could be found in Part 178.116. The type 17E drum was completely specified in this section. Under the new performance-oriented specification approach, the packaging requirements are specified in Part 172.101 which states that ethyl alcohol falls into the hazard described under Packing Group II, and packaging authorizations are found in Part 173.202. This shows that a Type 1A1, 55-gallon (208 liter) drum which meets standards given in Part 178.504 and performance specified in 178 subpart M can be used. Table 21-19 summarizes the test criteria. Any drum which can meet these criteria is authorized and may be used for this product. The manufacturer of the drum and the seller of the drum must warrant that the drum does meet these criteria and that either they have tested this design on a routine basis to verify that it meets these criteria, or that a third party has done so. They must be able to produce records that these test requirements have been complied with.

Under the old regulations, the marking on the bottom of the 17E drum was as shown in Fig. 21-36. Under the new regulations the marking on the bottom of the drum is as shown in Fig. 21-37. After October 1, 1994 all packages must be marked only with the new marking. Those new packages which are in the distribution system and contain the old mark may be used until October 1, 1996. After this date only packages marked with the approved UN marking are authorized by the U.S. DOT.

Also of note is a growing trend among packagers of hazardous materials to determine quantitatively the degree to which the package they will use exceeds that minimum performance requirement as specified by the U.S. DOT or UN. Using programmable shock and vibration machines and the damage-boundary-curve method, it is possible to develop the fragility of any package which then permits comparison of one alternative design with another, on a quantitative and economic basis. Rutgers, The State University of New Jersey, Center for Packaging Science and Engineering has been conducting research in this field.

Competent advice on the correct packaging to use for hazardous materials or other products is obtainable from consultants in the field of packaging who are members of the Institute of Packaging Professionals, consultants counsel. A brochure listing the qualifications of member consultants is obtainable from the IOPP.

Whatever hazardous materials are involved, whether they be new products, an existing product in a new package type, hazardous waste, or any other hazard category, the proposed packaging and all conditions which are expected to be incident to its use should be reviewed by a competent attorney who specializes in distribution and packaging matters. In the larger corporations, the law department usually has such a specialist. If not, local bar associations can provide the names of attorneys with this specialty.

It cannot be overemphasized that in the packaging of hazardous materials, extra steps and precautions must be taken to provide absolute compliance with established regulations. The penalties for failure to do this are exceedingly high, but the potential for serious injury to people and damage to the environment are of greater significance. A publication which addresses changes and issues in the packaging and shipping of hazardous materials is *HAZMAT PACKAGER AND SHIPPER* published by Packaging Research International, Inc., PO Box 3144, West Chester, PA 19381-3144, phone 610-436-8292, FAX 610-436-9422. Changes in CFR49 occur often. Before being published, they appear in the *FEDERAL REGISTER* which is published five times per week. CFR 49 is published on October 1, of each year and incorporates changes of the previous year.

Once the package alternatives permitted by government or transportation companies have been determined and marketing and production considerations are known, performance and economic evaluation must be made. This evaluation should consider packaging as part of a system. Not only must the package itself be considered, but so must factors which affect the package or are affected by it. If a choice of shipping in bulk form or in packages exists, cost comparisons must be made (Table 21-20).

Metric-system dimensions for packaging are not used extensively in the United States, but initial steps are being taken to permit use of these dimensions. The subject is under intensive study by both the packaging-supply and the packaging-using industries. SI equivalents are usually available from package suppliers, but at present all ordering in the United States is done in the U.S. customary system. Table 21-21 gives the degree of expected metric conversion. In the United States suppliers are using millimeters as the principal metric measure. When a soft conversion is made, increments of 5 mm are used. A converted package dimension is rounded up or down to the nearest multiple of 5 mm. For example, a bag-face width of 16 in equals 406.4 mm, which would be rounded down to 405 mm.

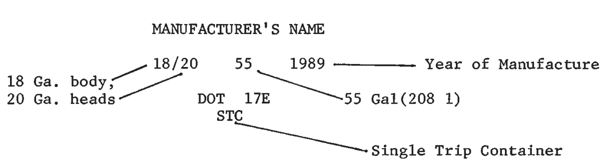


FIG. 21-36 Marking authorized by the U.S. DOT prior to October 1, 1994 prior to the change to performance-oriented specifications. Marking is found on the bottom head of the drum.

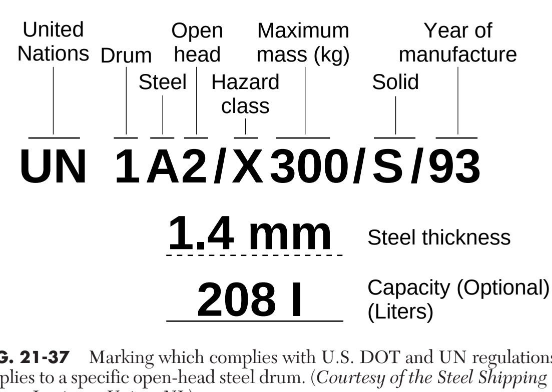


FIG. 21-37 Marking which complies with U.S. DOT and UN regulations and applies to a specific open-head steel drum. (*Courtesy of the Steel Shipping Container Institute, Union, NJ.*)

TABLE 21-20 Container Comparative Data[a]

Product: Thermoplastic pellets of 33-lb/ft^3 (528.7-kg/m^3) bulk density

Parameter	Domestic paper bag	Bulk corrugated-paper box	Intermediate bulk container	Bulk hopper truck	Ship container	Railroad hopper car	Intermediate bulk container
Construction	Multiwall pasted valve bag, 4-ply construction, with inner ply having an extrusion coating of low-density PE	Corrugated box, one-half RSC design, made of 600-lb burst-strength-test double wallboard, A-C flute laminated; includes cap, inner, and wood pallet	Flexible bag made of woven polypropylene of 2000 denier, 12 × 12 weave, with PE liner and nylon support straps	Welded-aluminum tank with pneumatic unloading pump; undercarriage equipped with pneumatic tires	Welded- or riveted-aluminum construction, with International Organization for Standardization (ISO) end castings for lifting by standard spreader	Welded-steel construction with plastic-coated interior, equipped with 100-ton trucks for 4-ft, 8½-in-gauge tracks	Rigid container made of welded-aluminum construction with butterfly discharge valve and fill port
Size	16 × 25 × 6.5 in (405 × 635 × 165 mm)	41 × 34 × 36 in (1040 × 865 × 915 mm)	53 in diameter × 53 in high (1350 × 1350 mm)	8 ft wide × 30 ft long (2.4 × 9.1 m)	8 × 8 × 35 ft (2.4 × 2.4 × 10.7 m)	5700 ft^3 (161.4 m^3)[b]	42 × 48 × 84 in (1070 × 1220 × 2135 mm)
Capacity, lb (kg)	55.1 (25)	900 (408)	2205 (1000)	42,000 (19,051)	50,000 (22,680)	180,000 (81,648)	2205 (1000)
Tare weight, lb (kg)	0.7 (0.32)	50 (22.7)	20 (9.1)	20,000 (9072)	4200 (1905)	100,000 (45,360)	255 (115.7)
Unit cost, US$	$0.55	$27.00	$59.00	$75,000	$16,000	$100,000	$2500
Lease cost, US$/month				$920	—	$685	$40[d]
Useful life	1 trip	1 trip	10 trips	15 years	5 years	25 years	10 years
Practical shipping radius, mi (km)	Any	Any	Any	250 (402) maximum	Any	300 (483) minimum	Any
Cost of typical system, US$/100 lb (45 kg)[e]	$6.81	$7.76	$5.08	$0.80	$0.80	$0.32	$4.63
Plant investment, US$ × 1000	$90–180[b]	$22–238	$27–252	$22–315	$45–315	$36–315	$27–252

[a]Based on 1996 prices.
[b]See Fig. 21-56 for typical plant layout.
[c]Mileage credit is paid to owners or lessees of this type of hopper car. To gain mileage credit car must be loaded. Rate is negotiable. A typical rate is $0.43 per loaded mile.
[d]Lease cost is based on a period equal to the useful life.
[e]Includes cost of container, filling, handling, and storage for minimum volume of 1000 tons per month (908 metric tons per month) but does not include freight or amortization of filling equipment.
[f]Represents typical investment in filling and handling equipment. Actual amount depends on plant layout and nature of existing facilities.

TABLE 21-21 Expected Metric Conversion of Packages for Chemical Products in the United States

Package type	Degree of conversion*
Bags (paper, plastic)	Hard
Boxes (paper)	Hard
Drums (fiber)	Hard
Drums (steel)	Soft
Pails (steel, plastic)	Soft
Cans (steel, fiber)	Hard
Bottles (glass, plastic)	Hard
Paper (kraft)	Hard

*Hard conversion: resized package dimensions to hold the nearest acceptable metric unit. Example: 50-lb (22.7-kg) multiwall paper bag changed to hold 25 kg (55.1 lb). Size can be limited by the maximum-size package available.

Soft conversion: the volume of the package is unchanged, and its metric equivalent is stated. Example: 55-gal drum equals 208 L.

For kraft paper, conversion will eventually be a hard conversion to two basis weights of 75 and 90 g/m^2, which will replace the 40-, 50-, and 60-lb basis weight currently used.

Package development involves the design, specification, and testing of packages. Sophistication of chemical and pharmaceutical industry products sold to industry and consumers is increasing. Package design takes into account four principal considerations. First is the preference of the customer for a particular type of package and whose preference is often opposed to that of the producer of the product. Second is compliance with applicable regulations. Third is the effect which a package choice will have on production-plant-operating conditions. A fourth consideration is the effect of atmospheric gases on the product itself, especially when the product is packaged in other than metal or glass. Of concern are water vapor, oxygen, and carbon dioxide, which can permeate most flexible package materials. There are thermoplastic films available that offer barrier properties which restrict atmospheric gases from entering a package. Additionally, the thermoplastic films can be combined with aluminum foil to produce impermeance. Aluminum foil has the propensity to stress crack when used in flexible packages. To overcome this problem the film industry has devised a method of depositing vaporized aluminum directly onto a thermoplastic film. This notably improves its permeation properties. Table 21-16 lists some of the common thermoplastic films and their barrier properties. Where pharmaceutical products are involved, and this would also include intermediate chemicals used in their formulation, the FDA requires that any reactions between the packaging material and the product itself must be known and often this must be reported in parts per million or finer. CFR 29, Part 1200 gives this for many types of packaging materials and containers.

Package testing is manditory for chemical products which are deemed as hazardous, as set forth in CFR 49, Part 172.101. A package for hazardous material being offered by a supplier must be tested by them or by a qualified third party. The tester must certify that the package complies with the DOT regulations and the design has been tested satisfactorily for a given packing group. The purchaser does not have to be concerned with the testing itself but only that it has been done and that the supplier can certify that the package has passed the required tests.

A second type of tests are those which shippers require when using a new package never before used for a given product, or an improved existing one. This type of testing is done in a simulated distribution environment using the actual package and often the product which is involved. The expected shock, vibration, compression, and impact shock which might be encountered in a distribution environment can be simulated in the laboratory, and a fair assessment made of the ability of the package to withstand or exceed expected conditions. One test protocol which accomplishes this is that published by the American Society for Testing Materials (ASTM) No. D4169. This protocol allows the user to define the shipping environment in minute detail, to carry out tests which simulate shock, vibration, compression, etc., and then to appraise the results of these tests. Copies of this test protocol may be obtained from ASTM, 1916 Race Street, Philadelphia, PA 19102.

Another test protocol is that specified by the International Safe Transit Association (ISTA), East Lansing, Michigan. This also simulates transportation and handling conditions. Transportation companies—truck, rail—accept ISTA test results and will transport packages bearing the ISTA marks.

Competent testing laboratories which can provide tests according to the ASTM D1469, ISTA, DOT, UN, and other protocols are located strategically throughout the United States and in most of the developed nations. The yellow pages of the telephone directory are useful to find such laboratories.

LIQUID PACKAGING

Containers Containers for liquids consist principally of drums, pails, and cans made of steel or plastic and of bottles and vials made of plastic or glass. The chemical industry is often involved with all these containers, but the most frequently used packages for industrial chemicals are steel drums and pails. For exotic products, stainless-steel drums and pails are available. The most common types used are 208-L (55-gal) drums and 19-L (5-gal) pails.

Once the appropriate package has been determined by consulting governmental and carrier regulations, the type of material compatible with the product needs to be determined. A wide variety of coatings is available for lining carbon steel drums and pails. Suppliers are often able on the basis of experience to assist in determining a lining which will be compatible with the product. When prior information is unavailable, laboratory tests can determine compatibility. Laboratory tests are often desirable before field trials. In some instances, a product may not be compatible with metal. This circumstance has led to an important container, the **all-plastic 208-L (55-gal) drum.** Made from blow-molded high-density polyethylene, this container is especially useful for products which might react with carbon steel or whose value does not warrant stainless steel. Special treatments are available to make the inner surface of the plastic drum impervious to penetration of many products. Sulfonation and fluorination are prominent among these processes.

Two basic designs of steel drums and pails exist: the tight-head and the open-head. Tight-head drums have both top and bottom members permanently fastened to the drum body. Open-head drums have only the bottom permanently attached. As the term "open-head" implies, the top of the drum does not have a permanently fixed cover; rather, a removable head is used. This head is designed so that a locking ring secures it to the drum body. Open-head drums and pails are usually employed for viscous products or for mixtures and slurries which are difficult to pump through lines 50 mm (2 in) or smaller. Tight-head drums and pails are used for low-viscosity products. No set rule can be given for the viscosities above which an open-head drum or pail must be used.

Reconditioned and remanufactured drums are authorized by the U.S. DOT for certain hazardous materials. CFR 49 paragraph 173.28 provides details of the reconditioning process. This consists essentially of rinsing the inside of the drum, removing any dents which deform the chime, grit blasting the exterior to remove all previous labels and paint, and then recoating with a new outer finish paint. The reconditioner must put their company mark on the drum. Reconditioned drums costs 50 to 70 percent of the price of a new drum and as such are useful for packaging marginally profitable products. The regulations set forth by the U.S. DOT must be complied with in complete detail.

Remanufactured drums are also permitted. Remanufacturing involves the dismantling of the drum, usually involving removal of the top and bottom head. All dents, rust, and other corrosion are removed by the grit blasting. New heads are then flanged onto the drum. An interior coating is given the drum when required, and the outside is painted. The drum remanufacturer must put their company mark on the drum. Remanufactured drums must withstand the same tests as a new drum. Details of DOT requirements for remanufactured drums are contained in CFR 49 paragraph 178.16. For products which are not classified as hazardous, the DOT and UN regulations do not apply but they are useful in setting a minimum performance standard for the packaging of any nonhazardous material.

Closures for drums and pails need to be determined together with the gasket material to be used. Consideration must be given to compatibility with the product and to the vibration which the container will encounter during transportation. The torque required to produce closure integrity is thus a significant factor. The typical closure sizes used in United States practice for tight-head drums are a 2-in national pipe thread (NPT) and a ¾-in NPT in the top head. For open-head drums, market considerations determine whether or not these fittings are used.

Steel drums are an ideal package because they can be stored out-of-doors and are generally impervious to weather conditions. Because of the drum's top head being recessed into the drum body, water can accumulate following a rain storm. While rusting of the drum head is undesirable a greater problem is the obliteration of whatever printing and labeling is on the drum head. To overcome this problem a patented wicking device "Drumwic" is available from Lee Technology Inc., Huntington, West Virginia. It is a low-cost way for quick removal of any accumulated water. The device is reusable. An illustration is contained in Fig. 21-40(*o*).

Tamper-evident seals and closures are commonly added to all packages. For certain products, child resistant closures are also added. There are several types of tamper-evident closures of which three are most common to liquid chemical products. First is a metal enclosure which covers the drum bung and which is crimped to it. The pulling of a tab breaks the tampered-evident enclosure which cannot be used again. It is customary to have the tamper-evident seal on both drum bungs. This holds also for pails. For small glass or plastic packages a seal is fitted into the cap which is then heat sealed to the bottle by means of an induction sealer. The construction of this seal consists of an outer layer of a thermoplastic material such as polyethylene, followed by aluminum foil, followed by a bleached kraft paper. The induction sealer induces eddy currents in the aluminum foil which raises its temperature to above the melting point of the polyethylene. The polyethylene melt then fuses the seal to the bottle. Another type also used for plastic and glass bottles is an external sleeve of shrinkable PVC (polyvinylchloride). This is usually applied by machine as the bottles move down the packaging line after being capped. They pass through a heated tunnel which raises the temperature of the seal to where it shrinks tightly around the closure, thereby providing tamper evidence. Child-resistant closures are those which are designed to be sufficiently complicated that the hand-eye coordination of the child is inadequate to open the package.

Filling Line Among filling-line considerations are filling and weighing equipment, mechanical handling of empty and filled drums, loading of filled drums onto transportation vehicles, workstation design for the safe and efficient use of personnel, and conformance to Occupational Safety and Health Administration (OSHA) and other codes. A typical drum-filling line, capable of handling two drums per minute, is shown in Fig. 21-38.

Filling and Weighing of Drums This procedure is divided into two parts: delivery of the liquid to the drum and weighing out the desired amount. Pumping the liquid product through a series of delivery pipes to the drum-filling point should follow good practice whereby reasonable velocities and pressure losses are maintained. The terminal point of the filling line is a control valve which is activated by a signal from a weight-sensing unit or scale. Valves may be pneumatically, hydraulically, or electrically operated, their operation being actuated either by an electric or pneumatic system or manually. The filling nozzle may be either top-fill or bottom-fill. Top filling is usually employed for most products, especially viscous materials or slurries. Bottom filling is used for low-viscosity products, for those having flash points under 37.8°C (100°F), or for places where static electricity is a concern. Also, products which tend to foam are bottom-filled. With a bottom-fill installation sufficient headroom is needed to permit the filling nozzle to be withdrawn from the drum. With both types of filling nozzles, a provision must be made for collecting product which dribbles from the end of the nozzle after filling is complete.

Weighing The weighing apparatus can be as simple as a platform scale in which the operator shuts off the filling nozzle when the desired weight has been reached. Automatic weighing can employ a load-cell system activating the flow-cutoff mechanism through a microprocessor. The same principles of filling and weighing as were described in the subsection "Weighing of Bulk Solids" hold for liquids. The advent of the microprocessor, image recognition, and stepper motor controls together with precision weight sensing has led to a custom-made system which can fill any drum or pail from 5 gal (19 L) to 55 gal (208 L) in sequence without the operator having to insert the fill nozzle into each container. (See Fig. 21-39.)

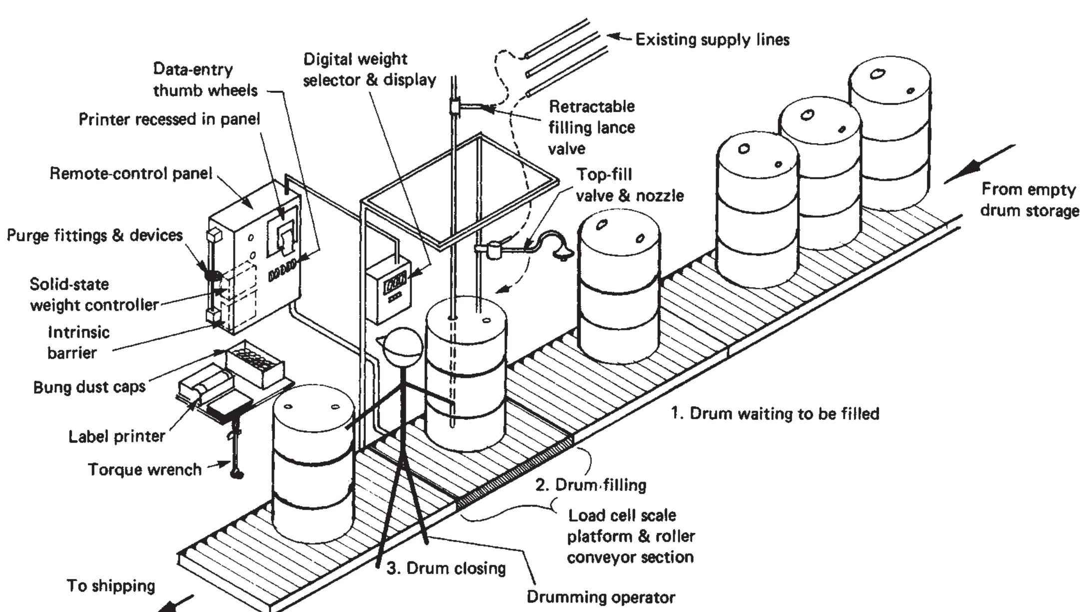


FIG. 21-38 Typical high-precision liquid filling and weighing system for packaging 208-L (55-gal) steel drums and similar smaller containers. (*Courtesy of H. F. Henderson Industries, Inc., Caldwell, NJ.*)

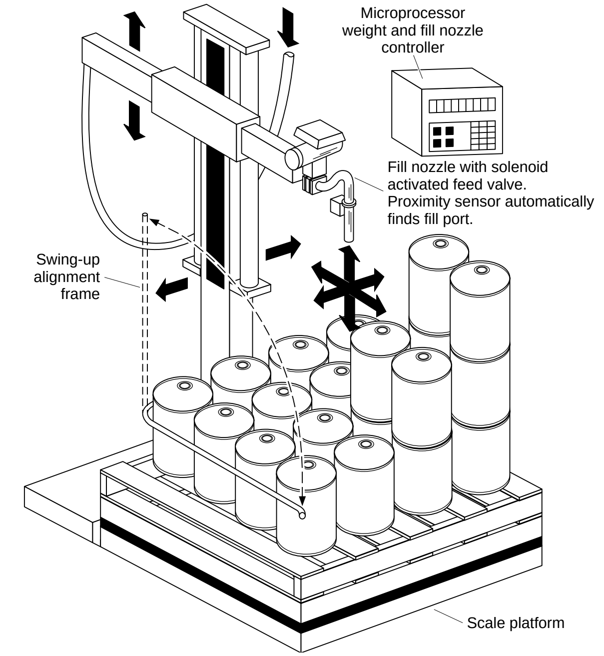


FIG. 21-39 Microprocessor-controlled drum and pail filling and weighing machine. Will fill drums or pails on one tier without operator intervention. (*Courtesy of Kg Systems, Inc., Bloomfield, NJ.*)

Work-Station Design Critical consideration must be given to the design of work stations so that filling operators work in a safe environment and are used productively. Methods design, time studies, and predetermined work-element data are helpful in determining the amount of work involved and the proper sequence of operations to permit good productivity. Of special importance (and often overlooked) is having the operator perform service functions on a drum while another drum is being filled. This is especially significant with an automatic system which does not require operator attention. The following activities can often be undertaken while a drum is being filled: removing closure plugs from the empty drum which will be filled next; replacing and tightening the closures in the drum which preceded the drum being filled; labeling and marking code numbers on the drum; and starting the filled, sealed, and labeled drum down the handling system leading to storage or transportation.

Safety Regulations Consideration must be given to safety regulations for the electrical grounding of the drum during filling, the handling of product vapors, the handling of possible inadvertent spills and splashes of product, and the design of the work station to conform to OSHA and state and local codes. Operators must be protected from contact with the product, and their physical movements must not be such as could cause potential injury. Work-station design benefits from consultation with governmental bodies and with equipment vendors and consultants.

Small Liquid Packages The packaging of small packages of liquids is a specialized field. High-speed bottle and can fillers typically are of volumetric rather than weigh design. Up to a size of 3.8 L (1 gal) volumetric fillers are used almost universally when the filling rate exceeds 10 containers per minute. Below this rate, filling is controlled by weight or even volumetrically by an operator activating manual controls.

SOLIDS PACKAGING

Containers for solids include bags, bulk boxes, cartons, and drums. While the intermediate flexible bulk container (IBC) has become an important package of world commerce, the most used package remains the multiwall paper bag, supplemented by bags of similar design made of plastic film or plastic woven mesh.

Multiwall Paper Bags These bags (Fig. 21-40), made from plies of kraft paper or from combinations of kraft and special-purpose papers and plastics, are the most common packages for almost any pelleted or powdered material as well as for briquettes or bats of such solids as synthetic rubber, waxes, and insulation.

Empty bags are ordinarily shipped compressed (to obtain high load density) and on pallets, the most common of which measure 1220 by 1065 mm (48 by 42 in), 1220 by 1015 mm (48 by 40 in), and 1270 by 1115 mm (50 by 44 in). The number of empty bags per pallet varies with size, 1500 to 2000 being common. A typical filled pallet weighs about 907 kg (2000 lb). Pallet loads are often triple-tiered in warehouses.

Two bag designs are common: the **valve** and the **open-mouth** types. The **valve** bag has both ends closed during fabrication, filling being accomplished through a small opening (valve) in one corner of the bag. The open-mouth bag has one end closed at the factory and the other after filling.

Most **open-mouth bags** are closed by sewing, whereas adhesive is used for the pinch type. The pinch bag has been the subject of inten-

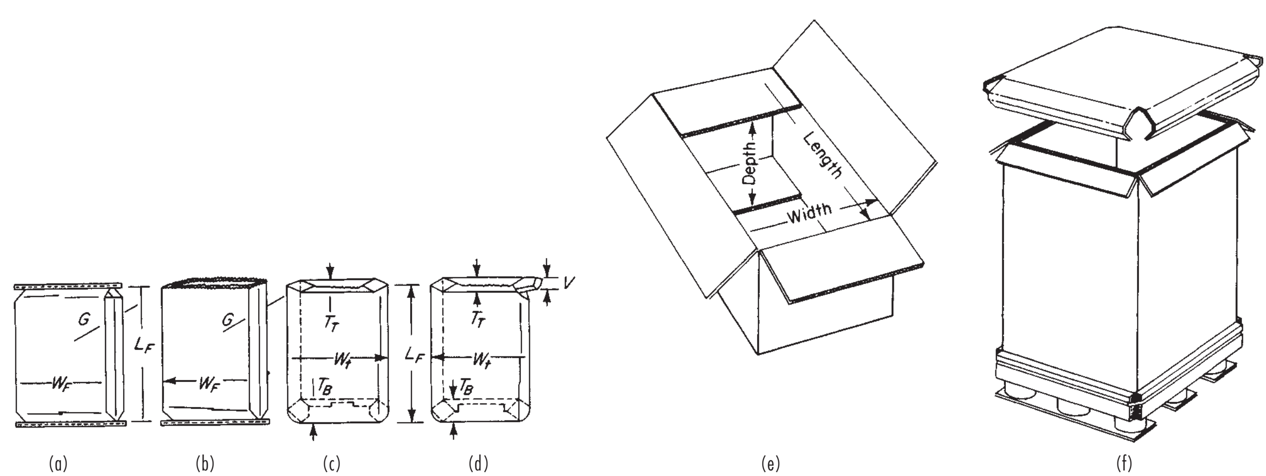


FIG. 21-40 Typical packages used for chemical products. (*a*) Sewn valve bag. (*b*) Sewn open-mouth bag; pinch-bottom-type open-mouth bag. (*c*) Pasted valve bag. (*d*) Pasted valve tuck-in-sleeve bag. (*e*) Principal (inside) dimensions of a regular slotted carton (RSC). (*f*) Bulk box of corrugated fiberboard for product weighing 450 kg (990 lb).

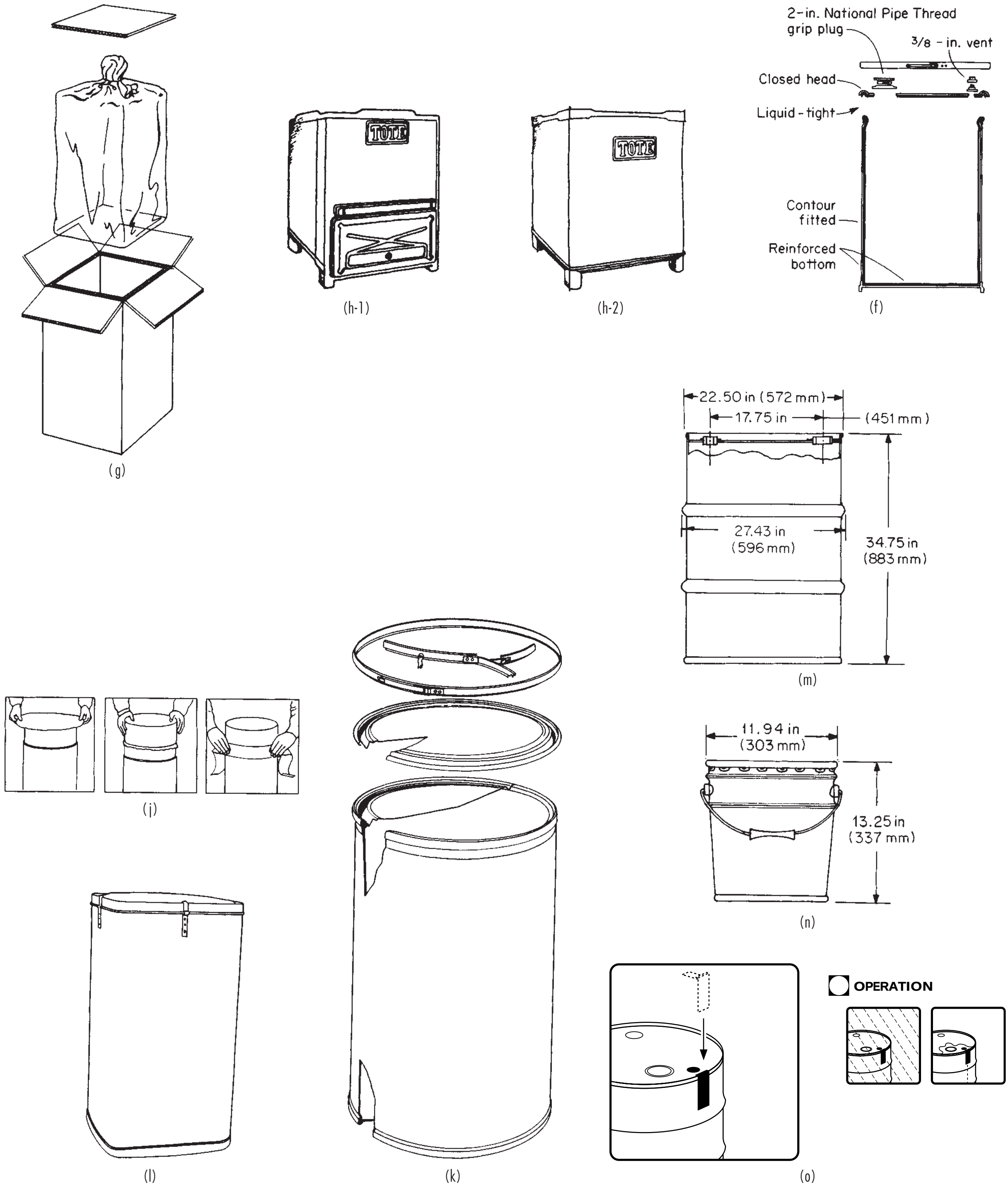


FIG. 21-40 (*Continued*) Typical packages used for chemical products. (*g*) Bag in box. (*h*) Tote-bin rigid intermediate bulk container: 1—for solids, 2—for liquids. (*Courtesy of Hoover Universal, Inc., Materials Handling Division.*) (*i*) Liquid-type polyethylene drum with fiber overpack. (*j*) All-fiber drum with removal top. (*k*) Lever-locking fiber drum. (*l*) Ro-Con rectangular fiber drum; clip-mounted top. (*Courtesy of Greif Bros. Corp.*) (*m*) 208-L (55-gal) DOT Packing Group II closed-head steel drum. (*n*) 19-L (5-gal) DOT Packing Group III open-head universal steel pail with lug-type cover. (*o*) DRUMWIC™ device for removal of water from drum heads stored out-of-doors. U.S. Patent No. 5,373,962. (From *Lee Technologies, Inc. Huntington, WV.*)

sive development by the bag industry, and as a result it has substantially displaced the sewn open-mouth bag and to some extent, valve bags. Reasons for this change include the ease, reliability, and repeatability of closing (sealing) equipment as well as the close control of the sealing adhesive applied by the bagmaker. The preapplied adhesive is activated by the closing machine in the user's plant. The positive closure of the pinch bag produces a container which completely seals in the product. Valve bags can also be sealed if they are provided with sealable sleeves. An advantage of valve bags over the open-mouth type is the availability of highly productive filling machines that not only require less labor than open-mouth filling equipment but also are capable of higher packing rates. In addition, the sealed valve bag permits the greatest pallet-load density. Bags may be fabricated from a variety of readily available flexible materials. In addition to kraft paper, barrier materials are available to prevent moisture or gases from entering or leaving the bag. These range in permeability from polyethylenes to aluminum foil. Table 21-16 presents some of the more prominent moisture barriers and their typical properties.

In the interest of standardization, the Institute of Packaging Professionals Chemical Packaging Committee (formerly the Chemical Manufacturers Association Packaging Committee) recommends four sizes of expendable four-way-entry pallets for bagged chemicals given in Table 21-22. The most common pattern consists of five bags on a 1220- by 1065-mm (48- by 42-in) pallet. This pallet size permits maximum trailer loading.

TABLE 21-22 Preferred Bag-Pallet Sizes*

Pallet size		Filled-bag face width		Filled-bag face length		Bags per tier (pattern)
in	mm	in	mm	in	mm	
48 × 40	1220 × 1015†	16	405	24	610	5
48 × 42	1220 × 1065	16	405	24	610	5
52 × 44	1320 × 1115	17.25	440	26	660	5
52 × 36	1320 × 915	16	405	36	915	3

*From Institute of Packaging Professionals Chemical Packaging Committee.
†Also GMA (Grocery Manufacturers Association) and ISO standard.

Sewn valve bags and sewn open-mouth bags are less important, except possibly for products with densities over 960 kg/m^3 (60 lb/ft^3) or for individual or small-lot shipments. These bag designs have the advantage of providing an easy grasp of the bag at the end of the sewing line without allowing fine powders to sift through the closure.

Valve bags usually rely on a labyrinth of paper or plastic film to seal off the valve. The automatic internal valve, while adequately protecting the contents of the bag, does allow a small amount of sifting of fine powders.

The starting point in bag-size determination is the weight or volume of product to be packaged and its bulk density (aerated and settled). Also to be considered are particle size, shape, and weight; degree of aeration at time of packaging; flow characteristics; temperature and relative humidity; type of handling system up to and including the filling machine; bag-closing method; bag style; and pallet size and pattern. Three sets of dimensions are needed: (1) **tube**—outside length and width of tube before bag closures are fabricated; (2) **finished face**—length, width, and thickness of bag after fabrication; (3) **filled face**—length, width, and thickness of bag after filling. Table 21-23 and Fig. 21-40 show these dimensions and their interrelations.

A first approximation of size can be determined from Fig. 21-41, which applies to sewn valve, sewn open-mouth, pinch-type open-mouth, and pasted valve bags. The resulting tube width and length can then be converted into finished and filled dimensions, and bag samples ordered for field verification. Changing bag size to accommodate different weights, density variations, pallet patterns, etc., becomes a simple matter through the use of the graph. Correction factors for particular situations such as special plies, type of filling machine, storage system, and product characteristics are given in Table 21-24.

To use the graph, given the weight of material to be packed, follow these steps: (1) obtain the settled and loose (or aerated) bulk densities of the product (a 1-ft^3 box serves this purpose well), and then calculate the average of the two densities; (2) calculate the bag-volume requirement from the relation $V_b = [W \text{ lb (weight to be packed)} \cdot 1728]\ d \text{ lb/ft}^3$ (average density); (3) multiply V_b by the product of the correction factors (Table 21-24), which reflect product, storage, and packaging conditions; (4) from Fig. 21-41 obtain the bag-tube equivalent T_e; and (5) using the corrected V_b, determine the bag size needed for palletizing.

Example 1: Determination of Proper Bag Size 55.1 lb (25 kg) of plastic pellets having a bulk density of 38.5 lb/ft^3 (615 kg/m^3) are to be packaged in pasted valve bags constructed of three kraft plies and a free polyethylene (PE) 2-mil (0.05-mm) liner. Bags will be palletized in a 5-bag pattern, 40 bags per pallet, on 48- by 40-in (1220- by 1016-mm) pallets. Filled bags are permitted to overhang the pallet by 0.5 in (15 mm). Determine the proper bag size.

$$\text{Density} = 38.5 \text{ lb/ft}^3$$

$$V_b = (50/35) \times 1728 = 2470$$

Correction factor (from Table 21-24):	
For barrier sheet of 2-mil polyethylene film	1.05
For filling machine, fluidizing type	1.02
For ⅛-in- (3.2-mm-) particle-size pellets	1.00
For storage and handling 24 h	1.00
Overall correction factor (product of above)	1.07

$$\text{Corrected } V_b = 2470 \times 1.07 = 2650$$

$$T_e \text{ (from Fig. 21-41)} = 640$$

For first approximation let $T_T = T_B = 6$ in, and $L_f = 24 - 1 = 23$ in.

Since $$L_f = L_t - (T_T + T_B)/2 - 1$$

$$L_t = 23 + 6 + 1 = 30 \text{ in}$$

and $$T_e = W_t L_t = 640$$

$$W_t = 640/L_t = 640/30 = 21.3 \text{ in}$$

TABLE 21-23 Multiwall-Paper-Bag Dimensions

Bag type	Tube dimensions	Finished-face dimensions	Filled-face dimensions*	Valve dimensions
Sewn open-mouth	Width = $W_t = W_f + G_f$ Length = $L_t = L_f$	Width = $W_f = W_t - G_f$ Length = $L_f = L_t$ Gusset = G_f	Width = $W_F = W_f$ + ½ in. Length = $L_F = L_f - 0.67\ G_f$ Thickness = $G_F = G_f$ + ½ in.	
Sewn valve	Width = $W_t = W_f + G_f$ Length = $L_t = L_f$	Width = $W_f = W_t - G_f$ Length = $L_f = L_t$ Gusset = G_f	Width = $W_F = W_f$ + 1 in. Length = $L_F = L_f - 0.67\ G_f$ Thickness = $G_F = G_f$ + 1 in.	Width = $V = G_f$ ± ½ in. †
Pasted valve	Width = $W_t = W_f$ Length = L_t	Width = $W_f = W_t$ Length = $L_f = L_t - (T_T + T_B)/2 - 1$ Thickness at top = T_T‡ Thickness at bottom = T_B‡	Width = $W_F = W_f - T_T$ + 1 in. Length = $L_F = L_f - T_T$ + 1 in. Thickness = $T_F = T_T$ + ½ in.	Width = $V = T_T$ {+0 in. / −1 in.} §

Meaning of subscripts: B = bottom; f = finished-face; F = filled-face; t = tube; T = top.
*Formulas are based on conditions of bags after mechanical flattening.
†Valve dimension is flat width, which must not exceed ±½ in. + G to maintain good closure. Circumference of valve = twice the width.
‡T_T and T_B are usually equal; if they differ, use average. T = thickness.
§Valve dimension is flat width. Valve width can be made less than top width without affecting closure properties.

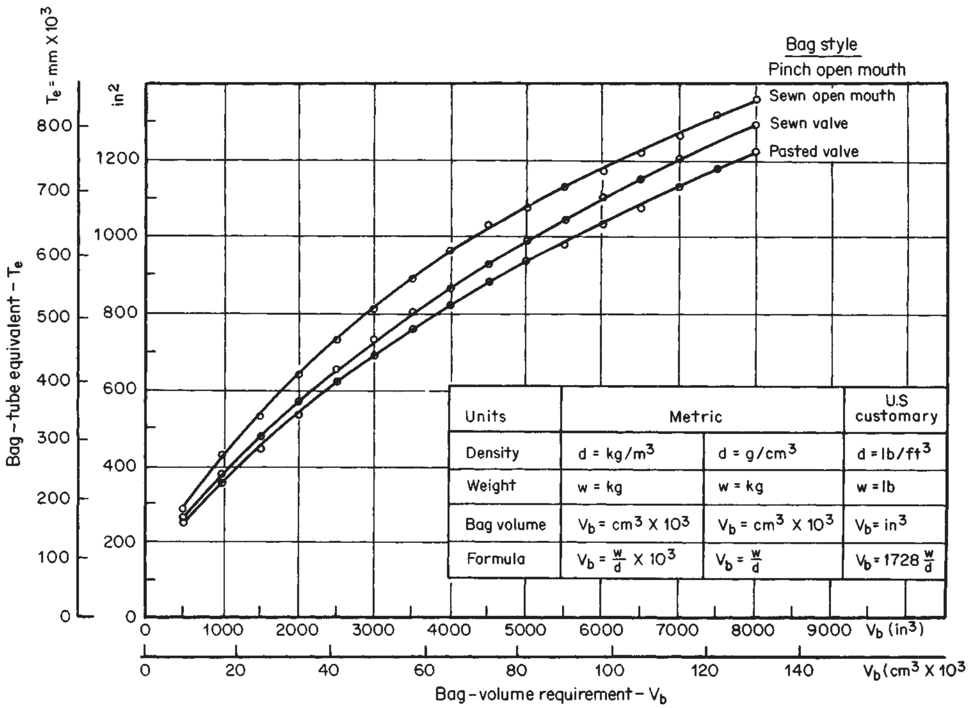
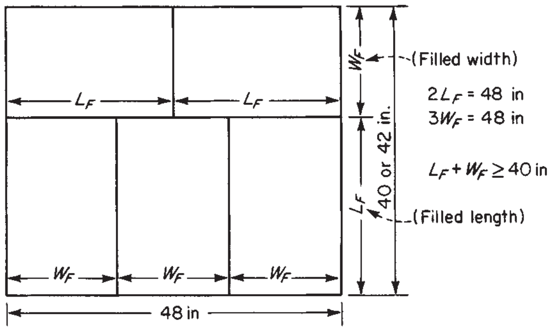


FIG. 21-41 Multiwall-bag-sizing graph. (*Raymus Associates, Inc.*)

TABLE 21-24 Bag-Volume-Equivalent (BVE) Correction Factors *f* for Specific Conditions*

Barrier and type of bag construction material		Filling-machine characteristic		Conveying, handling, and storage conditions					
				Material particle characteristic		Mechanical conveying		Pneumatic conveying	
Type of material†	*f*	Type	*f*	Size, in.	Shape	Off-product stream *f*	From storage *f*	Off-product stream *f*	From storage *f*
Asphalt-kraft laminates	1.03	Auger, gross weigh	1.00	1⁄16	Pellets, round	1.00	1.00	1.00	1.00
				1⁄8, 3⁄16	Pellets, round	1.00	1.00	1.00	1.00
Polyethylene extrusion-coated on kraft	1.05	Auger, net weigh	1.03	1⁄8, 1⁄4	Cubes	1.01	1.01	1.01	1.01
Polyethylene, extrusion-coated on kraft with random partial perforations*	1.01	Belt	1.05	+200 mesh	Granules, sharp edges	1.02	1.01	1.03	1.02
		Preweigh-belt	1.01	+200 mesh	Granules, smooth edges	1.02	1.02	1.03	1.03
Polyethylene-aluminum foil-kraft laminate	1.15	Fluidizing	1.02	−50, +200 mesh	Platelets (tiny flakes)	1.03	1.02	1.05	1.03
Wax-coated kraft	1.09	Gravity	1.15	+1⁄4, −3⁄8	Flakes	1.02		1.03	
Glassine	1.04	Preweigh open-mouth	1.00						
Free polyethylene film 1 to 4 mils thickness	1.03	Gross-weigh open-mouth	1.10	−30 to +200 mesh mix	Granules, sharp	1.01	1.01	1.03	1.02
Polyethylene-film bag (extruded tubular film with heat-sealed ends)	1.10 to 1.15			−30 to +200 mesh mix	Granules, round	1.02	1.02	1.05	1.03
				−325 mesh	Granules, platelets	1.04	1.03	1.07	1.03

NOTE: Refer to Table 21-6 for metric particle sizes.
*Approximate factors are based on many observations of each material or condition stated.
†Applies to all commercially available materials of designated type, unless noted otherwise.



Since $\qquad W_F = W_f - T_T + 1$, and $W_t = W_f$

then $\qquad W_F = 21.3 - 6 + 1 = 16.3$ in

Checking for pallet-length conformity,

$$2L_F = 48 \text{ in, or } 2(24) = 48 \text{ in}$$

$$3W_F = 48 \text{ in, or } 3(16.3) = 48.9 \text{ in}$$

Checking for pallet-width conformity,

$$W_F + L_F \geq 40 \text{ in}$$

or $\qquad 16.3 + 24 = 40.3$ in

Summary:

Bag size: 21½ in (face width) × 23 in (face length) × 6 in top and bottom (545 × 585 × 150 mm).

Pallet size: Use 48 in × 40 in (1220 × 1015 mm).

Overall filled pallet dimensions: 48.9 × 40.3 in (1242 × 1024 mm).

This example can also be carried out in the SI system by using Fig. 21-41

Liners At the time of setup of filling, many containers for bulk solids are lined with a polyethylene (PE)-film bag, the purpose being to prevent sifting of fine particles, retard moisture pickup or release, or prevent product contamination by the construction material of the container. Liner length should be sufficient to permit the top to be closed by heat sealing or wire tying. The film gauge (thickness) needed depends on the weight, bulk density, and particle roughness of the contents. Gauges of 0.05 to 0.25 mm (2 to 10 mils) are common. For ease of placing the liner in the carton, the gusseted type is preferred; and for convenience in handling, liners are usually made as continuous tubes, with heat seals and tear-off perforations at intervals equal to one bag length (see Table 21-17 for costs).

Form-Fill-Seal, Small Bags and Pouches, and Baler Bags Product weights from a few grams to 11 kg (25 lb) are often placed in packages made of plastic film, paper, or combinations of these. Groups of packages are then shipped in cartons or baler bags (see Table 21-17 for costs).

Form-fill-seal is a machine process that forms a tube from plastic-coated paper stock, heat-seals one end, fills the resultant bag, heat-seals the other end, and then cuts off the filled bag. This method has the advantage over filling small bags or pouches in that the cost of package fabrication is avoided until the package is actually needed; packaging labor is reduced to one attendant who can service a number of machines. Also, order lead time is shortened because standard, merchant plastic film or paper can be bought from local stock, often avoiding waits of 4 to 8 weeks for fabricated bags. Offsetting this is the higher investment in equipment and the service and maintenance problems associated with automatic equipment.

Small bags and pouches are made from one or more plies of paper or plastic film. The two main types of paper bags are the satchel-bottom and the pinch-bottom. Both types usually have a gusset that helps form a rectangular cross section (a useful trait when packing in cartons or baler bags). Although order lead time is longer than for form-fill-seal and operating labor is greater, capital and maintenance costs are smaller (Table 21-17), and equipment reliability is greater. These small packages require a master shipping container. Corrugated cartons are used extensively, as is the flexible baler bag.

Baler bags are pasted open-mouth bags with one or more plies and of either satchel-bottom or self-opening (gusseted) design. Pouches are loaded into the baler with their long axis parallel to that of the baler. Since the pouches must be tightly packed, mechanical-compression loading equipment is mandatory.

Rigid Intermediate Bulk Containers Rigid IBCs are made of metal or plastic suitable for the product and service intended. Sizes available range from 0.17 m^3 (6 ft^3) to 2.83 m^3 (100 ft^3). This type of container is intended for reuse and a useful life of up to 20 years. Important economic considerations are the cost of returning the empty container to the filling location and the cleaning, handling, and storage of it. Figure 21-40 (h-1, h-2) illustrates a metal container. Table 21-20 gives economic information comparing this type of container with other containers of larger or smaller volume.

Flexible Intermediate Bulk Containers These containers are an important development of the 1970s. Made from woven polyolefins or other materials, flexible IBCs are available in a wide variety of volumes and can handle up to 1800 kg (4000 lb), depending on construction. This type of container can be equipped with a thermoplastic liner when it is necessary to protect the product against moisture or other contamination. Handling is accomplished by forklift truck or by hoist. Filling and weighing of flexible IBCs can be accomplished on specially designed weigh scales or volumetrically if the container is weighed at a remote location after filling and that weight is used as a basis for invoicing. Filling is carried out through a flexible port at the top of the container, while unloading is accomplished through a similar flexible member at the bottom. Table 21-25 gives dimensional and volumetric data. Figure 21-42 shows typical container designs and types of loading and discharge spouts.

Boxes **Bulk boxes** (Fig. 21-40) of corrugated kraft paper for dry bulk products fall into two broad categories: large, for 0.5- to 2-ton loads, and small, for loads of 23 to 68 kg (50 to 150 lb). Large boxes are used extensively for resin shipment; small ones, for certain regulated materials (such as caustic soda) and for low-bulk-density products that are assessed excessive freight rates if packed in drums.

A bulk box, sometimes called *bag in box,* consists of a box within a box plus other elements such as end pads, PE bag liners, and closing materials (tape, glue, staples). The double-wall corrugated kraft board consists of an outside liner, a corrugating medium, a center liner, another corrugating medium, and an inside liner; the single-wall board

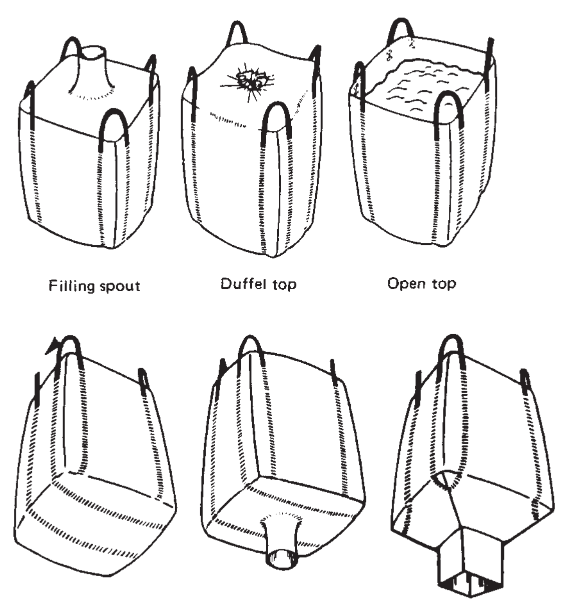


FIG. 21-42 Typical flexible-bulk-container designs and loading- and unloading-spout designs. (*Courtesy of Bonar Co., Ltd.*)

TABLE 21-25 Flexible-Type Intermediate Bulk Containers: Dimension and Capacity Data (Variable Data)*

Height		Usable volume		Maximum bulk density	
mm	in	m^3	ft^3	kg/m^3	lb/ft^3
800	31.5	0.7	24.6	1445	90
915	36.0	0.8	28.1	1250	78
1040	41.0	0.9	31.7	1120	70
1145	45.0	1.0	35.3	995	62
1270	50.0	1.1	38.3	930	58
1385	54.5	1.2	42.4	835	52
1500	59.0	1.3	45.9	770	48
1600	63.0	1.4	49.4	720	45

*From Bonar Co., Ltd.

NOTE: Maximum weight, 1 metric ton (2205 lb); cross-section dimensions, 890 by 890 mm (35 by 35 in); tare weight, 3 kg (7 lb); material of construction, woven polypropylene body and polyester lifting straps.

consists of an inner and outer liner with a corrugating medium center. The specifications for each depend on service requirements; 4100 kPa (600 lbf/in^2) burst strength is common for 454-kg (1000-lb) loads; 1900 kPa (275 lbf/in^2), for 68-kg (150-lb) loads. Materials of construction that resist high humidity and wetting with water are available.

Advantages of this container are its reclosing feature and its efficient use of storage and shipping space. Disadvantages are the space required to store box components before assembly and the limited reuse market. The lead time for ordering made-to-order boxes ranges from 3 to 6 weeks. Filling equipment is similar to that for drums. Setting up the box can require two persons because of the unwieldiness of the components. Table 21-26 gives an idea of filling speeds for several types of filling arrangements and box styles.

Wire-bound wood boxes (typical loads, 1 to 2 tons) have limited use for chemical products. The box body, consisting of thin wooden slats held in place by steel wire twisted around each slat, is fastened to a solid-deck wood pallet. The top also consists of wire-bound wooden pieces. A PE liner protects the product and prevents it from falling through the slats. Disadvantages of the container are the labor needed for setup and the space required for knocked-down boxes. Since manufacturers are usually near sources of hardwood, shipping costs to users may be high; lead times of 3 to 4 weeks are common.

Folding boxes made from chipboard are used for consumer-size units [from a few grams or ounces to about 11 kg (25 lb)] of such products as insecticides, snow-melting compounds, salt, and food additives. PE liners are often included to protect the product from moisture or to prevent it from sifting through minute openings in the top and bottom folds. Order lead time is 6 to 8 weeks. Knocked-down folding boxes are dense and store efficiently when palletized. A typical pallet measures 760 by 915 mm (30 by 36 in) with the load 1220 mm (48 in) high. Filling equipment, which can also be used for filling pouches, small bags, and glass jars, ranges from small, manually operated units to high-production, fully automatic units. Most common is the manually operated gross-weigher type.

Shipping cartons for liquids in cans and bottles, bulk solids in jars, pouches, and folding boxes, and briquetted items with or without individual packaging are usually made of corrugated kraft paper. The most common styles are the regular slotted carton (RSC), the end-opening RSC, and the center special-full overlap slotted container (SFF). End joints may be stapled, stitched, glued, or taped.

Specifications include dimensions of length, width, and depth, in that order (Fig. 21-40*e*). When boxes are set up and closed by automatic equipment, dimensional tolerances become critical. Cartons are shipped knocked down to the user from plants located in all industrial centers. Because order lead time is 4 to 6 weeks, inventories of empty boxes require considerable space. A useful booklet describing all aspects of corrugated box designs and materials is the *Fiber Box Handbook* available from The Fiber Box Association, 2850 Gulf Road, Rolling Meadows, IL 60008.

Often, the size of items packaged in corrugated cartons either does not permit interlocking of layers of cartons, or leaves considerable void space between them. Since calculating by hand the best size of carton for maximum palletizing density requires considerable effort, computer software is available. Examples are CAPE by CAPE Systems, Inc., Plano, Texas and TOPS by TOPS Engineering Corp., Plano, Texas. An analysis of pallet and trailer loading using CAPE is given in Fig. 21-63*a,b*.

Drums Drums (Fig. 21-42), made of either **steel** or **fiber,** rank next in importance after the multiwall paper bag. For dry solids or slurries, fiber drums predominate; for liquids, the steel drum. Steel drums of the open-head design are used for dry products when the product is hazardous, is to be stored outdoors, or is of a density that will cause reasonable weights to exceed the limits for fiber drums. Although only a few sizes are common, fiber drums can be made to order in almost any size and diameter-length combinations for volumes of 2 to 285 L (0.75 to 75 gal) and for weights ranging from 25 to 250 kg (60 to 550 lb; Table 21-16).

Advantages of the drum are protection of contents, ease of reclosure, and appreciable reuse-resale value. A serious limitation is the inefficient use of space because of the cylindrical shape, which results in high storage and transportation costs. To overcome this, a fiber drum with a square cross section (Ro-Con drum) and the bulk corrugated bag in box have been developed.

Fiber drums decorated with advertising adds $.80 to $3.50 to the basic cost of the drum. The most common type is the multiple-ply kraft-paper body with a steel bottom and a reinforcing top hoop crimpled to the drum. A steel lid, secured by a locking ring tightened by a lever system, fits over the body. For **vapor protection,** barriers are incorporated among the plies, or liners are used as the first ply in contact with the product. Among barrier and liner materials are PE, aluminum and steel foil, polyesters, and silicones. When liquids are to be contained, blow-molded PE liners are used. Free-film PE liners inserted by the user yield a combination of barrier and liner properties at less cost than having the liners as part of the drum body.

Fiber drums are also made with a removable fiber top and a fiber bottom that is either removable or permanently fastened to the body. This drum has limited reuse, but it costs less than the lever-locked metal-top type. Filling equipment consists most commonly of an operator-controlled spout connected to a supply bin resting on a platform scale. Table 21-26 shows the labor productivity of several systems.

Steel drums are made from cold-rolled-steel sheet formed into a cylinder. The longitudinal seam is made by electric resistance welding. The rolling hoops are expanded into the body wall by a special hydraulic fixture, and the ends are crimped to the body to form a leakproof joint. Sealing compounds are often used to assure leakproof joints. The top head has openings to allow installation of the closures or bungs. These closures have U.S. standard-pipe-thread fittings, usually one 2-in and one ¾-in fitting, to allow connection to the loading and unloading equipment.

PACKAGING OPERATIONS

Dry-bulk-packaging operations are divided into two categories: weighing and filling a package that is itself the shipping container and weighing and filling small packages that are in turn placed in outer packages for shipment. The choice of equipment and the way in which it is combined into a system depend on such factors as the product and its chemical, physical, and rheological properties; the type of package to be filled; the total packaging output required; the instantaneous and average rates of filling; cost, attitude, and availability of labor; space available for equipment; storage, shipping, and transportation conditions; cost and availability of capital; seasonality of packaging activity; expected duration of the venture; sanitary, safety, packaging, and working conditions imposed by regulatory bodies; maintainability and reliability of equipment; changes expected in the product and in the demand for it; and nature of the product market (i.e., industrial, consumer, agricultural, or government).

Weighing and Proportioning These are terms used in the packaging industry to describe methods of measuring out an amount of product—into the packaged weight unit which is offered for sale. It could also be done as a process step where a given amount of material must be added to a process on a continuous or a regular basis. With

TABLE 21-26 Performance Data for Packaging Systems

Type of filling and weighing machine	No. of filling spouts	Package detail: Type	Size, in	Size, mm	Construction	Closure	Product detail: Material	Bulk density lb/ft³	Bulk density kg/m³	Particle size, U.S. standard§
Fluidizing, SFW‡	4	Pasted valve bag	20 × 25 5 top width	510 × 635 125	4-170 (= 4-ply, 170 lb)	Inner sleeve	PVC‡	38	609	–60 mesh
PWS, open-mouth filler	1	Pinch bag	16 × 5 × 30	405 × 125 × 760	4-170 PE barrier	Adhesive	PE	30	481	⅛-in pellets
Fluidizing, SFW‡	2	Pasted valve bag	20 × 25—5¼ top	510 × 635 135	4-170	Tuck-in sleeve	PVC	36	577	–60 mesh
Fluidizing, SFW	3	Pasted valve bag	21 × 25	535 × 635	4-170	Tuck-in sleeve	PE	30	481	⅛-in pellets
Impeller, SFW	4	Pasted valve bag	18½ × 27½ (face)	470 × 700	3-170	Insert sleeve	Portland cement	94	1506	–325 mesh
Auger, SFW, net-weigh	1	Sewn valve bag	16 × 5 × 28	405 × 125 × 710	4-190	Tuck-in sleeve	PE	32	513	5⁄32-in cubes
Centrifugal belt, SFW	2	Sewn valve bag	15 × 5 × 36	380 × 125 × 915	3-150 PE barrier	Insert sleeve	Fertilizer	55	881	⅛-in pellets
PWS, open-mouth filler,	1	Pinch bag	17 × 4 × 36	431 × 100 × 915	3-150 PE barrier	Adhesive	Fertilizer	55	881	⅛-in pellets
Fluidizing, SFW	4	Pasted valve bag	18½ × 26 5¼ top	470 × 660 135	3-150 PE barrier	PE inner sleeve	Fertilizer	55	881	⅛-in pellets
PWS, open-mouth, heat sealer	1	PE flat-tube bag	16 × 30½	405 × 775	10-mil PE	Heat-sealed	Fertilizer	55	881	⅛-in pellets
PWS, form-fill-seal	1	F/F/S gusseted bag	16 × 5 × 30	405 × 125 × 760	6 mil PE	Heat-sealed	LDPE	30	480	⅛ in
SFW, liquid fill and weigh	1	Steel drum U.S. DOT 1A1 PG Y	55 gal (208 L)—23.5 in dia. × 34.75 in high	596 × 883	18-ga (0.0428-in) ends, 20-ga (0.0324-in) body	2-in, ¾-in NPT bungs	Lacquer solvent		0.839	sp. gr.
Gravity, SFW	1	Sewn valve bag	16 × 5 × 28	405 × 125 × 710	4-190	Tuck-in sleeve	Polystyrene	32	513	5⁄32-in cubes
Platform scale, autofill cutoff, SFW	1	Drum	55 gal	208L	6-ply fiber (300 lb)	Lever-locked steel cover	PE master batch	30	481	⅛-in pellets
Platform scale, manual cutoff	1	Drum	55 gal	208L	6-ply fiber (300 lb)	Lever-locked steel cover	Cleaning compound	45	721	–20 to +80 mesh
Platform scale, autofill cutoff, SFW	1	Bulk box, 3-mil PE liner	15 × 15 × 24	380 × 380 × 610	Outer 275-lb test DW‡ liner 600-lb test, DW	Staples	Insecticide, technical grade	40	640	–200 mesh
Platform scale, autofill cutoff, SFW, automatic staple closer	1	Bulk box	41 × 34 × 36	1040 × 860 × 915	Inner, outer boxes: 600-lb test, DW kraft board	Staples	PE	30	481	⅛-in pellets
Vertical auger, SFW	1	Small bag Pouch	10 × 4 × 25 14 × 27	255 × 100 × 635 355 × 685	3-120 paper, 2- to 4-mil PE	Glued, heat-sealed	Insecticide powder	20	320	–325 mesh
Vertical auger, SFW	1	Folding box	6½ × 3½ × 9	165 × 90 × 230	12-point reprocessed board with 2-mil PE liner	Glued, tied PE liner	Sprayable insecticide powder	20	320	–10 μm
Form-fill pouch maker, PWS	2	Pouch	8½ × 15	215 × 380	1- to 3-mil PE film	Heat-seal, hot-wire cutoff	Detergent, spray-dried	39	625	–30 to +60 mesh
Baler, manual package in feed, mechanized closing	—	Baler bag	23 × 30	585 × 760	2-140	Glued	12, 5-lb (2.3 kg) bags herbicide	45	721	–325 mesh
Corrugated case, manual package in feed, mechanized closing	—	Regular slotted carton	24 × 16 × 7	610 × 405 × 180	275 DW	Glued	12, 5-lb (2.3 kg) bags herbicide	45	721	–325 mesh
Carousel liquid filler	18	Round jug	4.8d × 9.7h	96d × 223h	Plastic 100 gr.	38 mm cap plastic	Laundry bleach	—	—	1.1 sp. gr
In line liquid filler	6	'Boston Round' bottle	3.8d × 8.7h	123 × 245	Glass	33 mm cap plastic	Isopropyl alcohol USP	—	—	0.9 sp. gr

*Fractions indicate the portion of a person's time required to perform activity; these are additive to compute the number of people needed.
†Includes equipment and installation but not building or services needed.
‡Definition of abbreviations: SFW = simultaneous fill-and-weigh; PWS = preweigh scale; SMC = sewing-machine closer; DW = double wall; SOM = sewn open-mouth; PE = polyethylene; PVC = polyvinyl chloride.
§Metric equivalent of particle sizes given elsewhere.
[1]For existing equipment, remanufactured to new machine standards and guarantees, multiply the above investment values by 0.5.
[2]Where [2] is shown after the system investment, add $181,000 for an automated inspection system comprising an X-ray metal detection machine, and 3 machine vision units to verify closure in place and label and bar code are correct and in place.
[3]Investment data courtesy of In Plant Packaging Systems, Inc., Metuchen, NJ.
[4]The above data is useful in comparing alternative systems and for order of magnitude investment values. However, for capital and other budgets, recent actual quotations from manufacturers should always be used.

Weight of contents		Packaging rate, packages/min		Weight variation from average		Packaging personnel needed*				Package handling		Approximate 1996 investment ($ × 1000)	
lb	kg	Avg	Instant	oz	gr	Package setup, supply	Filling-machine operators	Package closers	Palletizers, loaders, attendants	Package conveyorized	Automatic palletizing	Filling machine[1]	System[2]
50	22.7	12	17	4	114	1	1	0	2	Yes	No	110	437
50	22.7	8	12	0.5	14	1	1	1	2	Yes	No	45	200[2]
50	22.7	6	8	4	114	1	1	0	1	Yes	No	78	330[2]
50	22.7	16	24	3	85	1	1	0	1	Yes	Yes	96	550[2]
94	42.7	22	28	8	227	1.5	1	0	0.5	Yes	Yes	110	655
50	22.7	1	2	3	85	0.25	0.25	0	0.5	No	No	27	52
80	36.4	12	16	8	227	1	1	0	2	Yes	No	66	330
80	36.4	16	22	4	114	1	1	2	2	Yes	No	44	240
80	36.4	18	24	16	455	1	1	0	2	Yes	No	119	350
50	22.7	18	24	4	114	1	1	1	2	Yes	No	66	285
50	25	8	12	1	28	1	0	0	0	Yes	Yes	1,075	3,300[2]
385	175	2	3	6	170	0.25	0.5	0.5	1.75	Yes	No	116	178
50	22.7	0.2	0.4	16	455	0.25	0.5	0	0.25	No	No	7	13
250	113.6	1	4	2	57	1	0.5	0.5	1	Yes	No	27	110
300	136.4	0.5	1	0.5	14	0.25	0.25	0.25	0.25	Yes	No	7	28
100	45.5	0.5	1	4	114	1	1	1	1	No	No	45	87
900	409.1	0.33	0.50	8	227	2	0.75	0.25	—	Yes		45	218
10	4.5	5	10	1	28	1	1	1	3	Yes	No	21	110
1.5	0.682	8	12	0.5	14	1	1	1	3	Yes	No	21	45
2.5	1.136	10	12	0.5	14	1	—	—	2	Yes	No	110	153
60	27.3	1.5	3	—	—	0.5	0.5	0.5	0.5	Yes	No	45	66
60	27.3	1	2	—	—	0.5	0.5	0	1	Yes	No	30	45
64 fl.oz.	1.81	40	50	±0.1 fl.oz.	3cc	0.5	0.5	0.5	0.5	Yes	Yes	175	750
32 fl.oz.	0.941	14	18	±0.1 fl.oz.	3cc	0.5	0.5	0.5	0.5	Yes	No	55	256

each, certain degrees of precision are required. There are several terms which are used by the scale industry. A **net weigher** (Fig. 21-43) is a device with a scale system for weighing bulk solid materials. The analog of the weight being measured is sensed by a mechanical or an electrical sensor system. Sensor output is interpreted by a control system, either electrically or mechanically or by a combination of both, which controls the flow of product into the scale and hence the weight. Net weighers are rarely used for liquids. The term **gross weigher** applies to a type of device which is becoming obsolete in the packaging industry. This type of device has a relatively large equipment mass holding the package into which the product is being weighed, with the result that high weight accuracy is not possible. The term **proportioning** is used to describe a system where a given volume of material is moved in a given period of time into a weigh vessel—often the package itself—without the weight actually being sensed. Proportioners operate under the assumption that product density is constant. For liquids, this is usually true at any given temperature. For solids this is rarely true. As a result, proportioning devices rely heavily on either having constant density or relatively uniform density which varies only slightly over time. An example of a volumetric filler is given in Fig. 21-44. This device is a vertical auger designed for filling powdered materials into glass jars. The assumption of constant density is applied. The machine is set for the required time to fill the desired weight into the package. This type of device has benefited from the microprocessor era in that downstream check weighers are used to determine the net weight packaged in each container. Using a software to calculate trends, the check weigher sends a signal to the proportioning device to increase or decrease the filling time because the weight being filled now shows a trend to drift as a result of density change. As the density increases, for the same constant period of time the filled weight will increase. The converse is true when the density decreases.

There are two principal types of package-weighing and -filling equipment: **simultaneous fill-and-weigh,** with which the material is weighed as it is poured into the container; and **preweigh,** with which the material is weighed prior to being poured into the package. The former applies mainly to valve bags, pouches, bulk boxes, and bags in boxes; the latter, to open-mouth bags, small bags, and cartons, to form-fill-seal, and, at times, to valve bags.

There is a further distinction between net weighers and gross weighers. **Net weighers** are defined by the ratio (0.3 to 0.5) of weight of charged material to weight of weighing vessel and associated parts. Preweigh scales are examples of net weighers. With **gross weighers,** of which simultaneous fill-and-weigh is an example, the ratio is usually greater than unity. Net weighers are accurate within ± 0.125 to ± 0.25 percent; gross weighers, from ± 0.5 to 1.0 percent. Maintaining certain scale-feed conditions is critical in obtaining accuracy and sustaining a given production rate; appropriate feeding devices and surge bins are of great importance. If desired, weight accuracy can be increased, at greater cost, by special modifications and accessories such as load cells and microprocessor controls, bulk and dribble devices, and feeders and bulk density tracking software.

The **weight accuracy** of a dynamic weighing device is expressed as a plus or minus percentage deviation from a given *set weight,* which can only approximate the desired *actual weight.* The dynamic nature of weighing requires that the scale respond to changing static conditions as well as to a series of constant dynamic conditions. Minor variations in product density can cause the set weight to drift, the result being unacceptable packaged weight. Scale sensitivity is often suspected to be at fault, when in fact it is the set weight that has drifted. This is easily verified by check-weighing a series of weighings and determining their standard deviation.

Check Weighing Because of drifting set weight and the influence of federal and state legislation on allowable deviation from

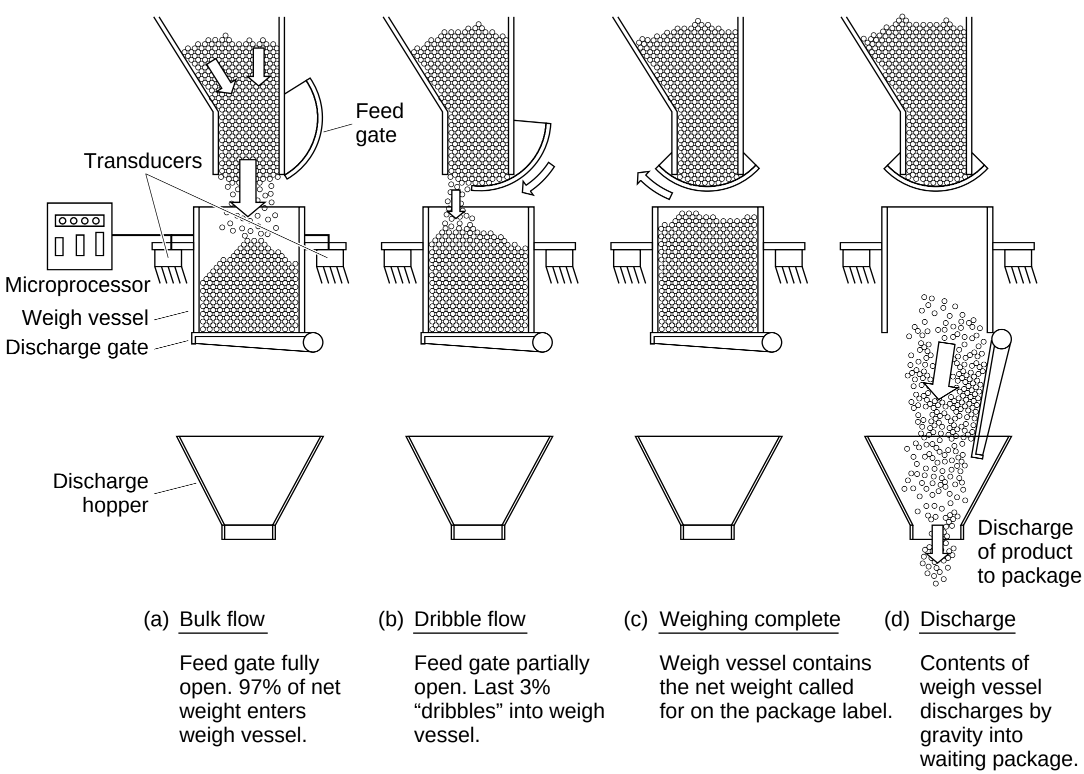


FIG. 21-43 Netweigh scale operating concept.

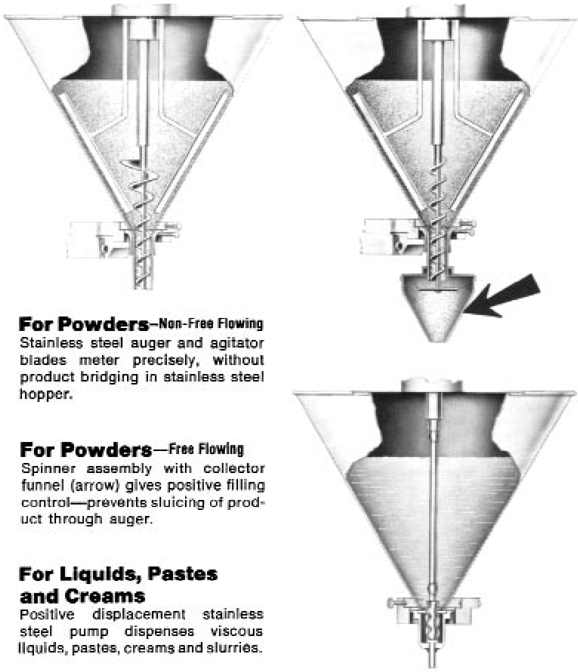


FIG. 21-44 Volumetric proportioner designs for various product types and consistencies. (*Courtesy of Mateer-Burt Co., Inc., Wayne, PA 19087.*)

advertised weights, a major new phase of package filling and weighing is that of check weighing. This can be done manually with a platform scale and then following a simple statistical procedure and control chart. There are devices applicable to preweigh scales which perform and record a static weighing just prior to discharging to the filling machine. There are in-line check weighers that weigh each package and pass or reject it depending on its weight, and keep a log of the results. One development permits continuous automatic readjustment of the scale set weight by means of a microprocessor that records each weighing and then, from a series of these, computes whether or not the set weight is drifting. An automatic adjustment is then made. The use of high-accuracy transducers aids this process.

Filling and Weighing Equipment Of special interest in the selection of filling equipment from the wide variety available (Table 21-26) and combining it into the total system is the equipment's relation to instantaneous output, average output, and personnel. Methodizing, subdividing into work elements, and prediction of the time required for each job function by means of standardized data such as methods-time measurement (MTM) and general-purpose data (GPD) permit accurate identification of jobs and work content. Actual average output can thus be calculated and, from this, the instantaneous output.

Instantaneous rate, which is the rate that equipment manufacturers imply in their guarantees of performance, is defined as the number of packages produced per minute with the equipment operating under steady-state conditions. **Average rate,** the measure that the user needs to plan production and output commitments, can be defined as the arithmetic average (packages per minute) produced over a production shift (usually 8 h). Equipment reliability must be taken into consideration in determining average rates because malfunction downtime can have a significant effect on rate values. Also, the effect of production scheduling on equipment idle time and changeover from one product to another needs to be considered.

Valve-Bag-Filling Equipment Although multiwall paper bags and plastic bags can be filled by a wide variety of equipment, the simultaneous fill-and-weigh (gross-weigher) type predominates. Net-weigher-type equipment using a preweigh scale which discharges into a valve-bag filler is finding increased favor when greater weight accuracy is required. The most widely used category is the gross weigher of the pressure-fluidizing type, for which these parameters and ranges hold:

Parameter	Capability range*
Particle size	⅜-in (9.5-mm) pellets to submicrometer
Bulk density	0.5 to 200 lb/ft^3 (8 to 3200 kg/m^3)
Filling spout	1 to 4
Bagged weight	20 to 150 lb (10 to 70 kg)
Bagged volume	1 to 6 ft^3 (0.03 to 0.17 m^3)
Material of construction in contact with product	Carbon steel, stainless steel, plastic-coated steel, aluminum
Output capability	1 to 30 bags per minute
Bag-valve size	3 to 5½ in (75 to 140 mm)
Weight error: simultaneous fill-and-weigh scale	+2 to ±4 oz (60 to 120 g)
Weight error: preweigh scale	±1 oz (30 g)

*SI equivalents are rounded off.

Fluidizing Bag Fillers These fillers can meet any production requirements, ranging from pilot-plant scale through heavy-duty, conveyorized high-tonnage installations. A chamber is provided with an air pad at the bottom, adjacent to a filling spout. A column of product over this section, which is what causes flow, may be opened to the atmosphere or enclosed and pressurized. When the desired bag weight is reached, a system is activated by the integral weigh scale to close the valve through which material flows to the bag. Fluidizing and pressurizing air is best provided by a positive-displacement blower at 1.5 kW (3 hp) per filling spout.

Of special interest on multiple-spout conveyor-equipped fluidizers and on certain types of screw and belt filling machines is a combination operator's seat, bag rest, and tuck-in-sleeve work aid. This device places the operator in an optimum work position after filling, to allow easy and positive tucking of the sleeve. Extensive use of the polyethylene film internal sleeve, however, has reduced the significance of the tuck-in-sleeve feature. Several types of heat-sealable valve-bag sleeves are available, as is equipment for closing them automatically. These are used when even slight leakage of product from an internal sleeve bag is unacceptable.

Bags can be automatically placed on valve-bag packers by means of an **automatic bag-placing device,** which consists of a magazine holding approximately 100 empty pasted valve bags and of a mechanism for removing the bag from the magazine, opening the valve and placing it on the filling spout, and initiating the filling-discharge cycle. The device's installed cost can be recovered in about 1 year's operation, based on typical wage rates paid in the United States for packaging-line labor.

Auger or Screw-Type Bag Fillers These fillers are usually applied to tuck-in-sleeve-type valve bags, for which production rates of one to two bags per minute and weight error limits of ±1 percent are required. Single-screw filling-spout designs (ordinarily of the net-weigh type) with simultaneous fill-and-weigh features are most common.

Gross-weight fillers need a feeding device such as a screw, vibrator, or belt, depending on the product. Particle size from 12.7-mm (½-in) pellets to 44-micrometer (325-mesh) powders can be handled, as can bulk densities ranging from 80 to 3200 kg/m^3 (5 to 200 lb/ft^3). Power requirements range from 373 W to 5.6 kW (0.5 to 7.5 hp). Weight accuracy is obtained by braking the motor to a rapid stop once the correct weight has been reached and the scale system has actuated the electrical or mechanical control system. Although fluidizing packers have diminished the importance of the screw type, the latter will always find application when space is a problem and investment must be low.

Centrifugal Belt-Type Packers This packer is used to a limited extent for granular or pelleted products whose bulk densities range from 400 to 1600 kg/m^3 (25 to 100 lb/ft^3). Single-spout, simultaneous fill-and-weigh fillers, which consist basically of a short-belt conveyor, handle one to three bags per minute at weight accuracies within ±1 percent; the two-spout design is most common in high-speed conveyor-equipped installations, with which preweigh scales are used. Up to 30 bags per minute can be handled, with weight accuracy within ±0.1 percent or better.

Impeller-Type Fillers Used extensively for finely divided materials such as portland cement, plaster, lime, and talc, these fillers contain an impeller that turns in a casing (similar to a centrifugal pump) to move the product into the bag. Most impeller machines are installed with conveyors, although single-spout machines have been used when bag handling is done manually. Bulk densities are limited to 800 kg/m^3 (50 lb/ft^3) and higher. Portland-cement filling rates of up to thirty 43-kg (94-lb) bags per minute are possible with weight accuracies within about ±2 percent. Power requirements range from 3.7 to 7.4 kW (5 to 10 hp) per filling spout. Impeller fillers are being superseded by the fluidizing type because of the latter's better weight accuracy, cleanliness, and reduced investment and operating cost.

Gravity-Type Fillers These fillers are available in either the gross-weigher type or the net-weight type using a preweigh scale. Gross-weigher types are used in marginal operations for which investment must be limited and performance is not critical. Packing rates of 0.5 bag per minute and weight accuracies within ±5 percent are possible. Only free-flowing pellets and granules can be handled practically. The net-weight type utilizes a highly accurate preweigh scale which is placed 3 to 5 m (10 to 15 ft) over the bag-filling spout. Gravitational energy of the falling charge of product is used to force the product into the bag. Rates of up to six 25-kg (50-lb) bags per minute per scale-fill spout unit are possible. This type of equipment requires a free-flowing material and can handle the range of 250-micrometer through 4.8-mm (60-mesh through 4-mesh) pellets. Bulk densities as low as 400 kg/m^3 (25 lb/ft^3) can be handled.

Open-Mouth-Bag-Filling Equipment Two considerations in choosing this type of equipment (Table 21-26) and in deciding between open-mouth and valve-bag systems are the labor required for a given output and the capacity limitation of the closing system. With open-mouth bags, weighing and filling are usually done by a net-weight preweigh scale; gross weighers are sometimes used on low outputs. Operating principles and installation practice for automatic scales have been described earlier in this subsection.

Preweigh scales discharge to a chute system to which a bag is attached. The kinetic energy of the charge as it reaches the bottom permits the bag to stand without lateral support on a closing-machine conveyor. The filled bag is then dropped to a short-belt conveyor that passes the bag through a closing machine. Empty bags are held onto the chute system by hand or by a bag-clamp arrangement. These scales handle from 8 to 35 charges per minute. Weight accuracies are commensurate with product value and weight laws.

Bag Closures Conventional multiwall paper open-mouth bags are closed by sewing; the pinch-bottom type, by hot-melt adhesive. Three styles of sewn closure are used. The simplest and fastest consists of sewing with cotton or polyester thread, with needle and looper threads entwined in a chain-fashion stitch. This is adequate for low-cost products, for which sifting through the sewing is not objectionable. An improved method consists of adding a flat tape over the open mouth and sewing through it with the needle and looper threads. An additional thread, called filter cord, can be added between the needle thread and the tape to increase siftproofness, but this reduces closing rates.

Complete **siftproofness** can be had by the "tape-over-sewn" procedure, whereby the tape is glued onto the finished sewn closure by a device downstream from the sewing head. For siftproofness at high production rates, the pinch-style glued closure is used. The pinch-bag closure has the adhesive preapplied to the open end by the bagmaker. After the bag has been filled, the closing machine reactivates the adhesive by heat prior to sealing.

Polyethylene film bags are closed by heat-sealing together the face and back of the bag. The closing unit consists of a pair of belts that support the top of the bag and guide it through a heated section that fuses the face and back. This is followed by a cooling section.

Drum and Bulk-Box Filling This process consists of three operations: setting up, filling and weighing, and closing. Because setting up bulk boxes is cumbersome, a well-methodized workplace, equipped with work aids, is recommended. Weighing and filling can be done manually or automatically. There is enough similarity between the two ways for manual systems to be mechanized later.

The most common installation consists of a conveyor line with a platform scale at a central location. This scale may be a simple dial type, which the operator watches to stop flow. The first mechanization step is to add a cutoff switch to the scale. Filling rates of 5 to 10 kg/s (10 to 20 lb/s), with weight accuracies within ±1 percent, are possible. Check weighing is easily accomplished by observing the net weight on the dial. A skilled worker can operate a manual system to within a few grams or ounces of the desired weight. Preweigh scales are occasionally used for free-flowing products, when the net weight is 100 kg (200 lb) or less or is a multiple of a weight that can be set on the scale and repeated to get the desired total weight. The main advantage of preweighing is higher accuracy.

Maintenance This is an important consideration in the operation of a packaging line. It is especially true with the advent of microprocessor control and the sophisticated devices for sensing of packaging-process variables. Two requirements for successful maintenance are needed. First is skilled technicians capable of handling the electronics as well as the mechanical parts of the packaging line. The community colleges are a source of skilled maintenance technicians. The second is the availability of repair parts. In the present industrial environment these are usually minimized and confined to those which are known to fail or which are prone to premature wear. Such parts are usually maintained in inventory. However, other parts are usually available on an overnight basis from equipment suppliers regardless of location. This is true whether the equipment is made outside the United States or the country of use. The overnight-shipping services such as Federal Express make minimum stocking a practical reality. With the use of microprocessors the trend is to have duplicates of all of the circuit boards in the plant inventory. Should there be a failure, the board can be replaced immediately and the old board returned to the maker for remanufacturing.

Small Packages These are of importance in the consumer chemical and the reagent chemical businesses and for shipping samples of products. Bulk solids, liquids, and gel-type products are involved. For bulk solids such as powders, granules, and pellets, the most often used packages are folding cartons, multiwall paper pockets (bags), or form-fill-seal plastic bags. For liquids, glass or plastic bottles and jars are used. Weight units are typical up to 20 lbs, or 10 kg. Volume units are typical up to 1 gallon or 4 liters. Where the product is a gel or a thixotrope, jars are used, with weight unit to 1 lb, or 0.5 kg.

Low-speed operations for these packages use in-line-type equipment in which transfer in, filling, and transfer out are sequential. Rates of production are typically 10 to 20 packages per minute. For high-speed packaging, the in-line equipment is usually too slow or requires a high investment for multiple lines. High-speed filling is typically 40 to 100 packages per minute, but it is not unusual to find certain products packaged at over 100 units per minute. To obtain such production rates, the packaging machinery industry has developed a carousel type of equipment wherein the filling operation is continuous. The package enters at one end of the carousel, is filled as it moves around the carousel, and is discharged having the required weight or volume of product. From that point it moves to a capping or closing machine. Figure 21-45 shows a carousel unit for liquids in bottles or jars. An example of an in-line liquid filler is shown in Fig. 21-46. Figure 21-47*a* shows a carousel-filling unit for bulk solids. Small-package operations for bulk solids involve two main procedures: filling and closing.

Weighing and filling may involve either preweighing scales, proportioners, or simultaneous fill-and-weigh. Preweigh scales are preferred when high weight accuracy is required. With appropriate package-handling equipment, these weighing devices can be used to fill cartons, bags, jars, or bottles. Preweigh scales of the multiple or "gang" arrangement are used to obtain both high accuracy and rates of production on dry products. One design uses 17 separate preweigh scales. Each weighs a charge equal to one quarter of the desired weight. A process-control computer monitors all weigh vessels and selects the four whose sum of weights is nearest to the desired weight and directs the weigh vessels to discharge to the waiting package. Accuracies of 1 gram in 1 kg are typical, and production rates of 150 weighings per

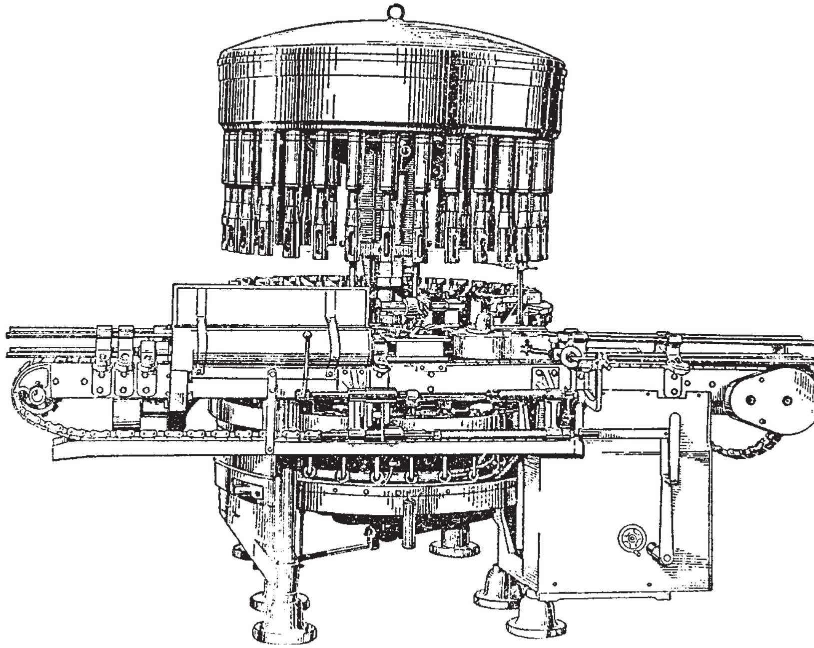


FIG. 21-45 HORIX 32 station carousel-type liquid filler for glass and plastic bottles and metal cans.

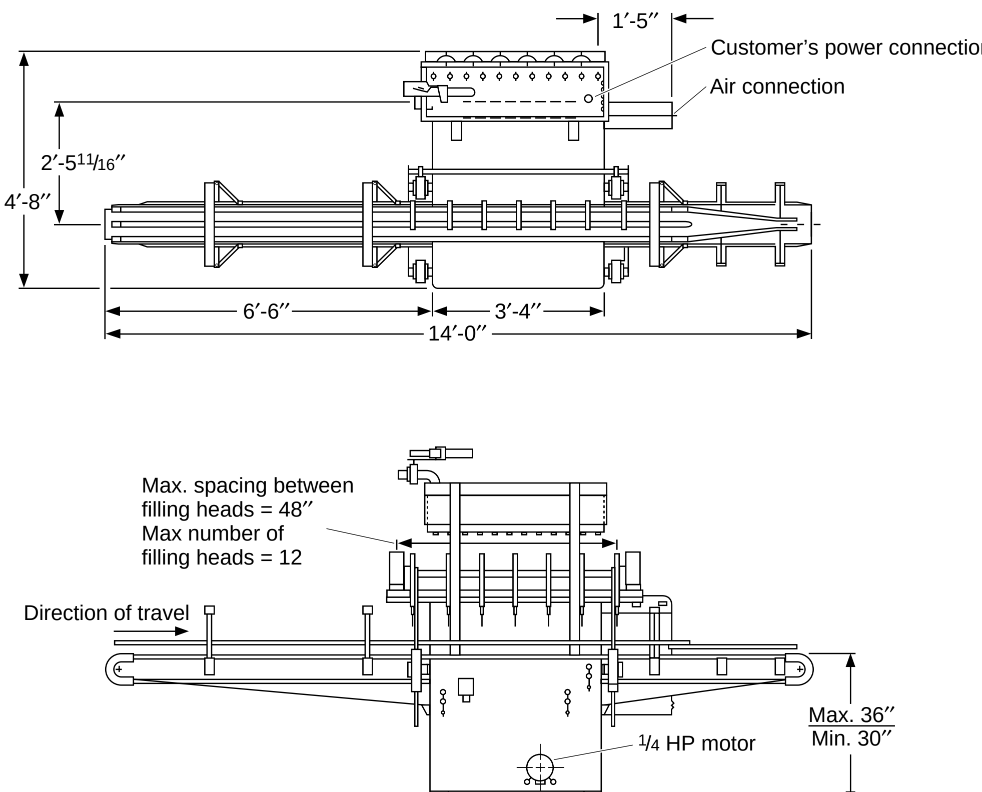


FIG. 21-46 In-line, 6-head, 2-lane filler for liquids in glass and plastic bottles and jars. (*Courtesy of National Controls, Inc., Baltimore, MD.*)

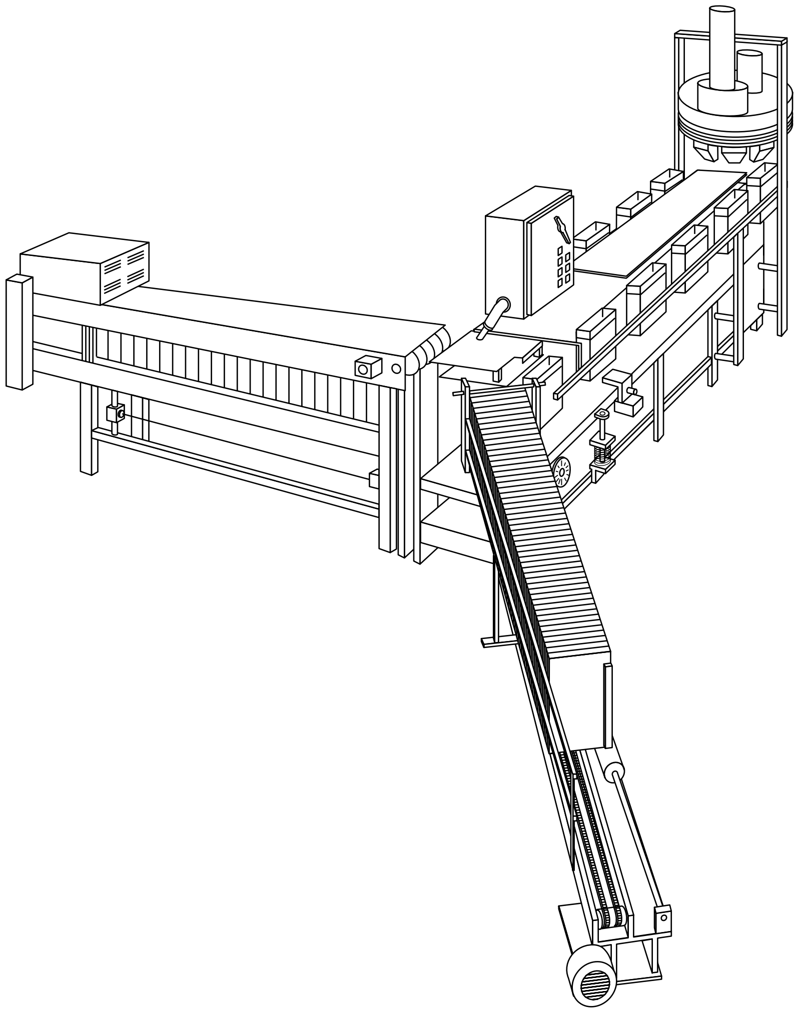


FIG. 21-47*a* Clybourn carousel-type folding carton set-filler-closer for bulk solids such as powders and granules. (*Courtesy of Clybourn Machine Co., A Division of PAXALL, Inc., Skokie, IL 60076.*)

minute are possible. Figure 21-47*b* illustrates a "gang"-type scale system. Figure 21-47*c* shows how such a weighing system can be integrated into a business record-keeping system.

Where folding cartons are to contain a product which is sensitive to moisture pickup, barriers are available which can be incorporated into the carton construction. An example of this is polyethylene laminated to paperboard. In some cases an insert bag is used instead, but this requires an additional operation and is usually accomplished by a form-fill-seal machine that makes a bag which is then inserted by another machine into the folding carton.

Form-Fill-Seal Premade small packages, when filled at high rates, present a problem because of the need to handle and store empty packages. To cope with this requirement the form-fill-seal type of packaging, which not only simplifies the supply problem but produces a superior package, has evolved. This method involves two main functions: a weigh cycle and a package make-fill cycle. Rates of up to 50 packages per minute are possible, with multiples of this rate on machines with two or more stations. Preweigh scales are of the same type used for small-package filling. Figure 21-47*d* illustrates the principles of a form-fill-seal (F/F/S) machine.

At present, form-fill-seal is limited to products having reasonably free-flowing particles with low dust concentrations. Because heat sealing to form the pouch has been largely responsible for the success of this system, thermoplastic films or other plastics and papers with a thermoplastic coating are required. The choice of form-fill-seal versus premade packages depends on economics but usually applies to materials that are nonseasonal.

Large-size form-fill-seal equipment for industrial packages has been introduced. Capable of packaging 25-kg (50-lb) bags, such units use PE sheeting or tubing in roll form. A bag is made just prior to being filled. An advantage of this system is lower labor and material costs, but this is offset by the increased complexity of the equipment. Rates of eight to twenty 25-kg (50-lb) bags are possible. Since preweigh scales are used, high accuracy can be attained.

Carton and Baler-Bag Loading, Wrapping, and Sealing Corrugated boxes may be used for shipping flexible or rigid small containers; baler bags, for flexible ones. Corrugated boxes are loaded manually, semiautomatically (manual loading of the carton set up by machine), or fully automatically. Manual setup and loading are practical for up to 3 cases per minute, semiautomatic up to 10, and automatic up to 40. Associated with each are conveyors that bring packages to the carton loader and remove filled cartons from the sealer.

Carton sealing is carried out automatically by adhesives, tape, or staples or manually by tape or staples. Carton closer-sealers have

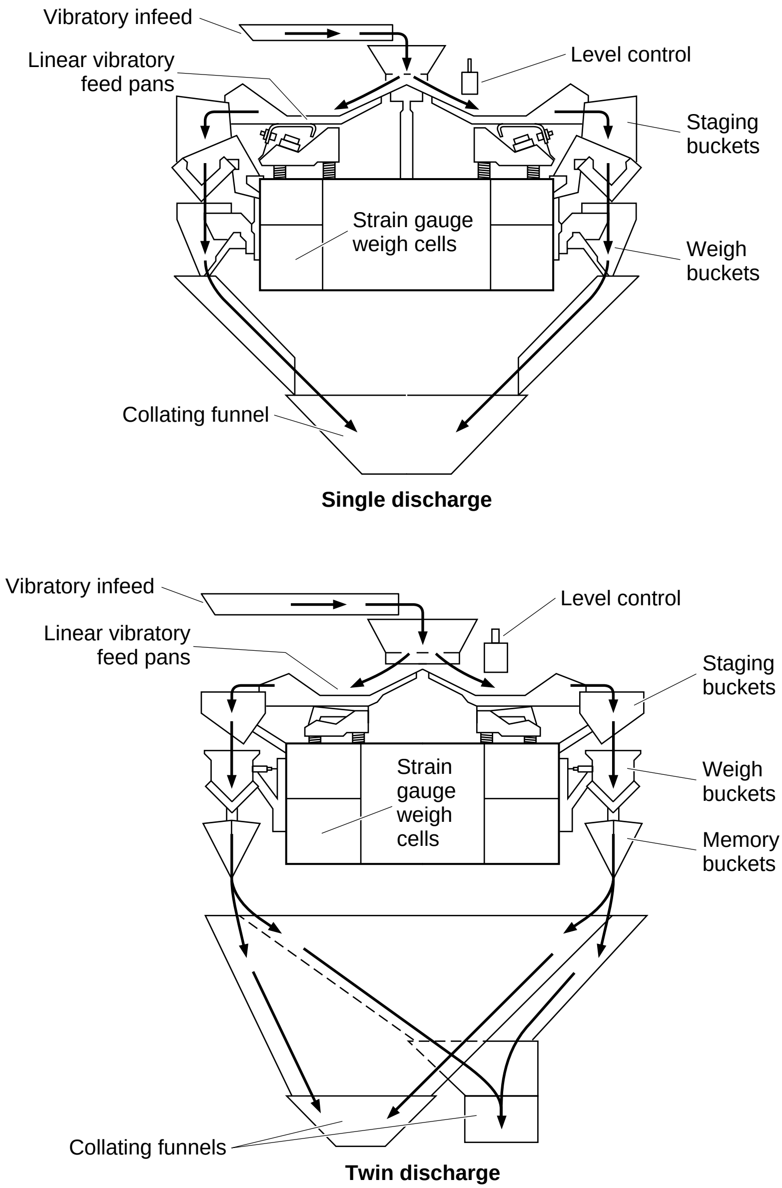


FIG. 21-47*b* Hayssen Yamato "Dataweigh" gang-type scale system. (*Courtesy of Hayssen Mfg. Co., Duncan, SC 29334.*)

become so attractively priced that small operations can justify their use even when the balance of the line is manually operated. Case closer-sealers that take different package sizes in random order are available.

Baler bags can be manually loaded, but the preferred practice involves specifically designed compression units. Their use permits making an integral load in which all package parts share the forces imposed by shipping. A manually loaded compression unit handles 2 to 4 balers per minute; semiautomatic units, with a mechanical package feed and a manual baler-bag application unit, can handle 15 to 20. Baler bags are automatically closed with tape or adhesive, the latter being preferred especially for automated operations.

Wrapping, Bundling, and Shrink Packaging These techniques have limited applications for chemical products. Wrapping and bundling are substitutes for cartons and baler bags, their advantage being that the package is made from roll stock.

Shrink packaging is a significant development. The most important application in the chemical industry is in unitizing packages for palletized shipment. A cover of shrinkable PE film serves to bind a pallet load and permit it to absorb considerably higher transportation forces than it would if packed by any other method. Palletizing, adhesives, and strapping are eliminated, which offsets the cost of the shrink wrap. But it is the reduced damage in shipment that makes shrink wrap so economically attractive.

The hand-applied shroud of shrinkable PE usually consists of a premade bag large enough to envelop the load. Equipment to shrink the wrap ranges from small propane-fired hand-held units, which take

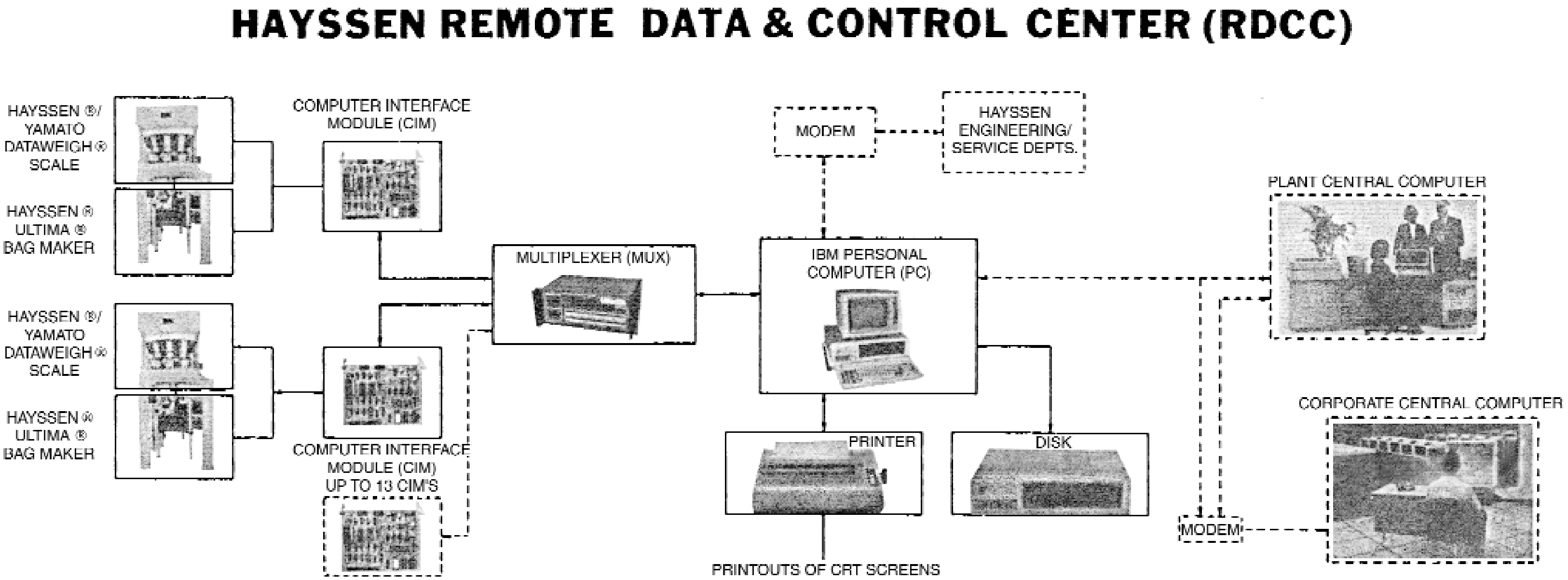


FIG. 21-47c Business data and report system using output of Hayssen Yamato "Dataweigh" scale as input to computers. (*Courtesy of Hayssen Mfg. Co., Duncan, SC 29334.*)

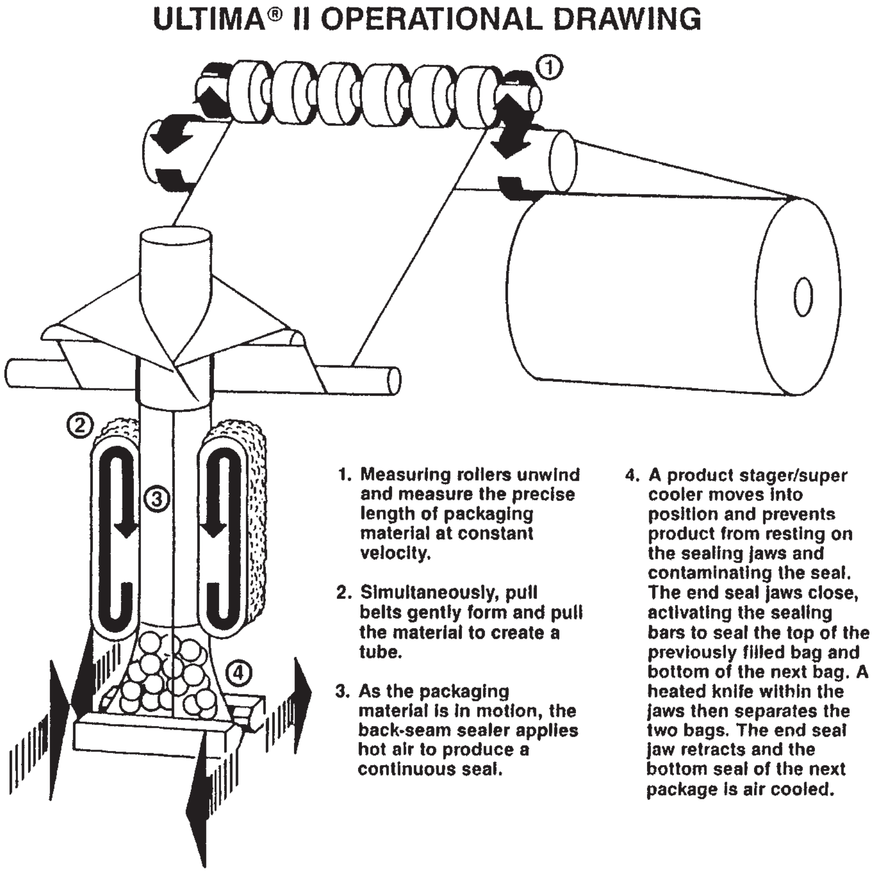


FIG. 21-47*d* Hayssen patent no. 4,288,965 form/fill/seal bag-making system. (*Courtesy of Hayssen Mfg. Co., Duncan, SC 29334, 864-486-4000.*)

about 5 min to shrink a 1-ton load, to fully automatic conveyor lines handling up to 30 pallets per minute.

Stretch-Wrap Packaging This type of packaging is an alternative to shrink packaging. It consists of wrapping a pallet load of product with a thermoplastic film which is applied under tension and which envelops the sides of the entire load. Special machinery accomplishes this procedure correctly. An advantage of stretch wrap is that it does not require the precise fit and shrinkage properties of a shrink-wrap bag to ensure tight binding of the load to the pallet. As long as the stretch film meets tensile and elongation properties and the stretch-wrap machine is in proper adjustment, a satisfactory result will be obtained. Material cost for stretch wrap is 75 to 100 percent of that of shrink wrap. An economic advantage is that stretch wrap is less energy-intensive than shrink wrap by a factor of 100 or more. Labor requirements are also less, in that one operator can start the stretch-wrap process by attaching the film to the pallet and the machine completes the operation automatically. With shrink-wrap, two operators are usually needed because of the unwieldiness of the shrink bag.

Batch Inclusion Packaging This has been the result of the environmental consciousness of the chemical industry worldwide. The meaning of this term is that the product contained in the package and the package itself are added to a process and the packaging material actually becomes part of the product being made. By way of example, an antioxidant in a batch inclusion package is added to a polyolefin compounding operation. Not only is the antioxidant incorporated into the product but so is the package. The package material is chosen such that it is compatible with the end product and usually represents a minute fraction of that end product. A second advantage is that many companies offering this type package will offer a specific weight requested by the customer, which simplifies their formulating operations. The development of strain gauge-microprocessor-controlled weighing equipment allows packagers to offer custom package weights at little additional costs over offering a single size. A marketing advantage can come from this type of customer service. A wide variety of film-type materials are available to packagers. These include polyethylene, polypropylene, nylon, polycarbonate, partially polymerized rubber, fluoro-chloro-ethylene polymers and others. Predictions have been made that in a matter of a few years most industrial chemicals will be packaged in batch inclusion packages. The reason is there is no costly disposal of empty packages which, depending on the contained material, may be subject to government disposal regulations.

Fine-Particle Packaging This term is applied to powders and similar finely divided materials. These present significant flow problems in material handling and packaging. Surface chemistry, particle shape, and electrostatic forces have a great effect on flowability. Weighing and filling of fine powders in plastic packages is a difficult and sometimes impossible task because of these characteristics. While much work has been done in the characterization of fine particles the development of packaging machinery to handle such difficult products remains more art than science and engineering. A notable effort in packaging such materials is that by William J. Runo of Allentown, Pennsylvania, who has developed a process which uses compressive shock to orient particles and drive them into the package so that they occupy minimum volume and consequently have maximum possible density. This process is proprietary and is licensed by Dr. Runo. An example of the ability to increase bulk density is a product having an average particle size of eight microns and a loose bulk density of 8 pounds per cubic foot (0.128 grams per cc) which was increased to 24 pounds per cubic foot (0.385 grams per cc). The principle of operation of the Runo system is that it is independent of the package type and can be used on all types of packages used for chemical products—drums, bags, batch inclusion bags, bulk bags, and others—by having the appropriate holder for the package.

Chopped-Fiber Packaging This type of packaging is complicated by a geometry of the fiber. The ratio of fiber length to diameter can be several thousand with the result that it is impossible to obtain any degree of uniform flow of the fiber into packaging machinery, into the package itself, or when the fiber is being handled, as during incorporation into a product such as a composite. A proprietary process for accomplishing uniform feeding of chopped or milled fibers is described by U.S. Patents numbers 4,669,887 and 4,953,135. This technology can be licensed and apparatus purchased from Lee Technologies, Inc., Huntington, West Virginia.

Labeling This has become a very complex issue. Labeling requirements for the products of the chemical industry are regulated by the U.S. Department of Transportation, the Occupational Safety and Health Agency, the Environmental Protection Agency, and other government organizations. Customers may also require special labeling. Requirements mandated by government must be strictly adhered to. In many states, the right-to-know laws impose additional requirements. Products of the pharmaceutical industry have additional requirements imposed by the Food and Drug Administration (FDA).

While the foregoing refers principally to the information the label must contain, there is the further consideration of how the label is to be printed, the inks which are to be used, the method of adhering the label to the package, and the method of applying the label. Application methods can range from hand to automatic machinery applications. Influencing label production and strongly benefiting it is the advent of the personal computer. Labeling systems are available in which the information is entered through a terminal, it is displayed on a CRT, and when complete, the microprocessor directs a laser type or a dot matrix printer which prints the complete label which must be attached to the package. Figure 21-48 illustrates such a label. Another system actually sprays information onto the package as it passes by the labeler which is adjacent to the package conveyor. Figure 21-49 illustrates this type of noncontact system.

Label information may be divided into two classes, that fixed for each container and that which varies from package to package or from batch to batch. Examples of fixed information are name and address, net weight, name of product, and warnings about product hazards. Variable information includes batch, blend, or lot number, consecutive package number, coded information, and possibly date of manufacture. Export packages require outside-package dimensions and the gross, tare, and net weights in U.S. customary and SI units. When there is uncertainty as to label requirements, experienced legal advice should be sought. Fixed information is usually printed by the package maker. Variable information can be applied manually with rubber stamps or stencils or by automatic in-line marking equipment.

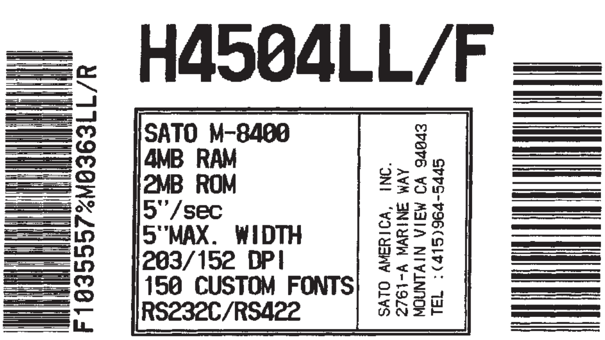


FIG. 21-48 Label example printed by a high density dot matrix printer. (*Courtesy of SATO AMERICA, Inc., 2761-A Marine Way, Mountain View, CA 94043.*)

Bar Coding Bar coding represents a major advance in being able to track identities and inventories of products on a real-time basis. The impetus for the development of bar coding was the Universal Product Code (UPC) developed under the auspices of the American grocery industry for the purpose of allowing automatic reading of product and price information at the checkout counters of supermarkets and mass merchandisers. It has since grown into a widely used system to track an inventory item or group of items. It has facilitated the use of automatic storage and retrieval systems (ASRS) described later in this section. There are currently five types of bar codes in use worldwide, illustrated in Fig. 21-50, (*a*)–(*e*).

Universal Product Code (UPC) See Fig. 21-50(*a*).

- Incorporates numeric characters only.
- Usually includes 12 digits and allows bidirectional scanning.
- Zero-suppressed version is printed using seven digits.
- Check digit is incorporated into code.
- Quiet zone is nine times the narrow bar width on both the left and the right.
- At 100 percent magnification, required size for a 12-digit UPC with the quiet zone is approximately 1.5″ horizontally and 1.0″ vertically.
- EAN variations are used in Europe.
- Common applications include retail, packaging, counting, and data processing.

When scanned, the UPC will be decoded as a 12-digit number. These 12 digits represent the following: digit 1 is the number system character; digits 2, 3, 4, 5, and 6 make up the manufacturer's ID number; digits 7, 8, 9, 10, and 11 are the vendor's item number(s); digit 12 is the check digit.

When scanned, the UPC zero-suppressed will be decoded as a 12-digit number. These 12 digits represent the following: digit 1 is the number system character, which is always zero when printing zero-suppressed UPCs; digits 2, 3, 4, 5, and 6 make up the manufacturer's ID number; digits 7, 8, 9, 10, and 11 are the vendor's item number(s); digit 12 is the check digit. However, only seven human-readable numbers appear when printing zero-suppressed UPCs.

Interleaved 2-of-5 (I 2 of 5) See Fig. 21-50(*b*).

- Incorporates numeric characters only.
- Can be of variable length, but must have an even number of characters.
- Common applications include warehousing, product/container identification, general industrial, and automotive.
- Often used in UPC Shipping Container Code formats.
- Quiet zone is ten times the width of the narrow bar.

The Interleaved 2-of-5 bar code is a bidirectional, continuous, self-checking numeric bar code. It uses a series of wide and narrow bars or spaces to represent each character, and each symbol employs unique Start and Stop elements.

The symbology requires an even number of characters to be interleaved together. The bars represent data characters occupying the odd positions, and the spaces represent characters in the even positions. Additionally, each data character must be composed of five elements, two wide and three narrow. Character pairing begins with the most significant digit (left-most digit) and continues two at a time until all characters are used. The Start element consist of two narrow bars while the Stop element combines a wide and narrow bar.

Code 128 See Fig. 21-50(*c*).

- Employs alphanumeric characters.
- Can be of variable length.
- Common applications include general industrial, inventory control, and retail container marking.
- Often used in UCC/EAN Serial Shipping Container Code formats.
- Quiet zone is ten times the width of the narrow bar.

This code has 128 characters. Like Code 39, Code 128 offers variable-length symbols. But at the same time, Code 128 is more compact.

Code 128 allows the user to encode any character found on a CRT keyboard, including the control characters. This gives the user more encoding versatility than previously possible in an industrial bar code.

Code 39 (3 of 9) See Fig. 21-50(*d*)

- Incorporates alphanumeric characters.
- Can be of variable length.

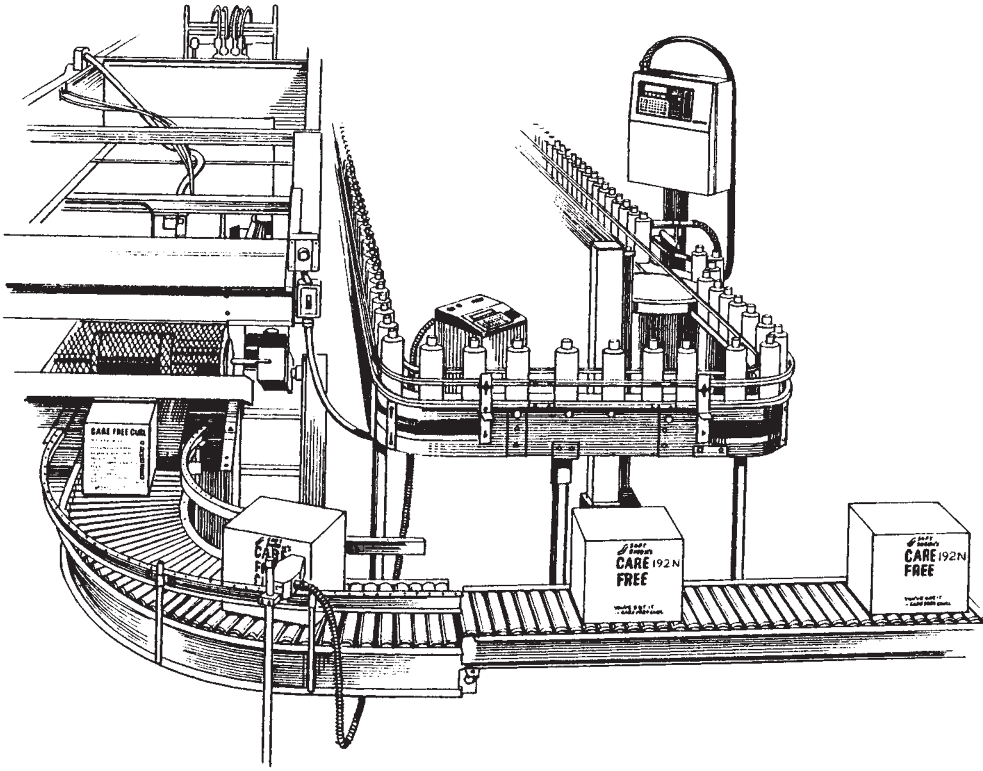


FIG. 21-49 Application of a noncontact ink jet printing system used for coding plastic bottles and corrugated fiberboard cartons. (*VIDEOJET™ shown, courtesy of VIDEOJET Systems International, Inc., 1500 Mittal Blvd., Wood Dale, IL 60191-1073.*)

- Check digit is optional but normally not used.
- Common applications include LOGMARS (Department of Defense), GSA, AIAG (automotive), general industrial, and HIBCC (health industry).
- Quiet zone is 10 times the width of the narrow bar.

The 3 of 9 bar code is a variable-length, bidirectional, discrete, self-checking, alphanumeric bar code. Its data character set contains 43 characters: 0–9, A–Z, -, ., $, /, +, %, and space. Three of the nine elements are wide and six are narrow. A common character (*) is used exclusively for both a Start and Stop character. The Start/Stop characters must be included in every bar code. It's the Start/Stop pattern that allows symbols to be scanned bidirectionally.

Code 39's flexibility to encode both text and numbers has contributed to its widespread use.

PDF417 See Fig. 21-50(*e*)

- Self-checking, two-dimensional bar code.
- Encodes up to 810,900 different character sets and/or interpretations, plus 256 international characters and binary data.
- Allows for bidirectional scanning.
- Symbology includes a Start/Stop pattern, left/right row indicators, and data codewords.
- Quiet zones are two times the *X*-dimension.

PDF417 is a multirow, continuous symbology capable of encoding large quantities of information. It's just what its name suggests—a Portable Data File.

Being one of the first two-dimensional bar codes, the symbology has not yet been standardized by any industry. However, it is being considered for coding shipping manifest information.

The symbology can vary in height and width because any number of rows of information (from 3–90) can be stacked vertically, plus a varying amount of data codewords (from 1–30) can make up the length.

Each PDF417 bar code also incorporates two parity-check codewords, which act as the symbol's error-correction code. The codewords carry out the same functions as check digits in other bar codes.

PDF417 is able to condense so much information into such a small space that it could soon prove to be one of the most flexible bar code symbologies around.

Where products are sold at retail to consumers it is necessary to have a Universal Product Code (UPC) printed on its label. The Universal Product Codes are assigned by the Uniform Code Counsel, 8163 Old Yankee Road, Suite J, Dayton, Ohio 45458. With the bar coding system, the information which is most meaningful to its user can be represented. This can include numeric and alpha (word) representations.

The economic incentive behind the development of the universal product code to allow for automated checkout, has resulted in the development of a whole industry infrastructure which supports bar coding. Automatic reading of bar codes can be done with fully automated systems with the reader as part of a conveyor line, where it reads the bar code from packages as they pass by on a conveyor. Simple systems consist of a handheld "wand" which a person points at the bar code and the code is read. Once read, the bar code analog is then processed by computer which then translates the bar code into the desired information. Such information can include product identity, package size, date of manufacture, manufacturing site, manufacturing process unit, and any special information that applies to the product, such as whether it needs specialized storage conditions, whether it is a hazardous material, and whether it has a shelf life. In Fig. 21-50, (*e*) is a schematic for a bar code system which shows both automatic and manual reading, the translation into useful information, the printing of reports, and the activation of sorting machinery. Two texts having detailed information are: *A Guide to Bar Coding* published by Bar-

FIG. 21-50 Bar code designs. (*Courtesy of Weber Marking Systems, Inc.*)

coding Systems, Inc., and *Handbook of Bar Coding Systems* by Harry E. Burke. Both are available from the Packaging Book-Store, Institute of Packaging Professional, Herndon, VA 22070. A very good summary of bar codes is the booklet "How to Stay on Top of Bar Codes," by Weber Marking Systems, Inc., 711 W. Algonquin Rd., Arlington Heights, IL 60005-4457, 708-364-8500.

Package Inspection A more critical part of packaging operations is package inspection. In the past this was largely carried out by people, under the heading of "quality control." With the increases in output of typical packaging lines the inspection task becomes greater than the human person is able to accomplish. Several important electronic techniques have been developed which allow for graphic inspection of a number of packaging variables and the rapid rejection of those which do not meet an established standard, and with the passing of those which do. One notable variable is the accuracy of weight or fill volume. Automatic check-weight systems handle all of these. In the case of a product sold by volume a machine-vision system can determine whether the liquid level, in a bottle for example, is at the proper level. Labeling is another variable which has assumed critical importance, especially for products which are regulated by the U.S. DOT or the FDA. Again, machine-vision systems are able to scan each label to be sure that it is correctly applied and that the text is correct for the product being packaged. Metal detection in a product and/or package can be accomplished with several techniques with an x-ray able to detect particles as small as 0.01 mm at high line outputs. Leaking packages can be detected at high speed with helium leak detectors. Figure 21-51*a* shows the installation of machine-vision inspection systems on a typical integrated-packaging line packing tableted products in glass bottles. Figure 21-51*b* shows an X-ray inspection system designed specifically for packaging line use.

Packaging-Line Integration The matching and balancing of all components in a given line so that the line will perform as designed is known as **packaging-line integration.** Computer simulation aids in this integration by allowing test cases of "what if" to run. By defining all conditions under which a line may be expected to function, simulation allows rapid determination of those conditions it can handle, those it cannot, and the quantitative degree to which it can. An example of an integrated line for packaging a tableted pharmaceutical is shown in Fig. 21-51*c*. This line includes inspection by machine vision at critical points and is computer directed and controlled.

Robotics The introduction of **robotics** has given a new dimension to packaging in that it is now possible to do repetitive tasks with speed and accuracy at notably lower cost than if done by people. The manufacture of robots is well established with corporations of substantial resources providing a quality product with continuity of service, supply, and software support. There is also a specialty industry which is available to supply both accessory hardware and software which are custom designed to handle specific user situations. Economic analysis needs to be done before making the decision as to whether to automate using robots, fixed automation, or the labor of people aided by work aids.

There are two principal classes of robots. One type involves a **fixed position** for a central control and manipulator unit, illustrated by Fig. 21-52. This type of device is particularly useful where a repetitive motion is required, such as taking a package component from one position and then rapidly and accurately placing it in another position. The value of the robot increases when there are more than one downstream positions and when sorting must be done. The capability of this type of robot can be further expanded by having a manipulator at its pickup point which also can function in an X-Y-Z axis basis. This permits the device to perform relatively crude tasks such as picking up a component, orienting it, and then moving it to the desired place and precisely positioning it in the X, Y, or Z planes. The term **package components** can mean any part of the package itself or the product which is to be packaged.

A second type, generally regarded as being more versatile than the fixed-point robot, is the **gantry robot.** This device also offers capability of the X, Y, and Z directions. Programming is usually more simple for the gantry than for the fixed-position robot. The gantry robot can also use a manipulator at its pickup and discharge points. This often is as simple as a clamp or a device that has its own X-Y-Z degrees of freedom. Figure 21-53 gives an example of the gantry-type robot that is used for a wide variety of packaging activities, such as palletizing.

A robot often can be economically justified when the task of doing a certain packaging operation is analyzed in detail. For example, the palletizing of the fiber drums can be accomplished by human labor but work aids would be necessary in order to have acceptable production rates, reasonable operator fatigue, and a safe working environment. When the work aids are considered and their cost determined, the additional cost for providing robot capability is often of a small magnitude, which justifies its use to replace human labor.

Another reason for considering the use of robots is the availability of people who are willing to do the hard, manual, repetitive tasks which go with much of the packaging in the chemical industry. In the United States, the cost of such labor—if at all available—can often justify the use of robotic equipment. There are many examples where a single operator controls an entire production and packaging operation where robotics do all of the manual tasks. The robots are under the direction of their software. The operator is often a person who has at least an associate in science degree from a county college. Programming language used for robots is becoming more standardized. This allows robotic equipment to be reused many times after the original operation has been abandoned. It is not unusual to see either a gantry or a fixed-position robot reprogrammed and reequipped with new pickup members, doing an entirely different task than the one it was originally purchased for. One example is a system of a tabletop gantry-type robot used originally in an assembly operation for placing spots of adhesive at precise places on a matrix. After that project was completed the robot was reprogrammed and reused on a packaging line where it places large capsules in blister packs. The investment required for reuse of this robotic system was approximately 25 percent of the cost of a new system. There is much to recommend considering the use of robotics for the packaging activities of the chemical and pharmaceutical industries.

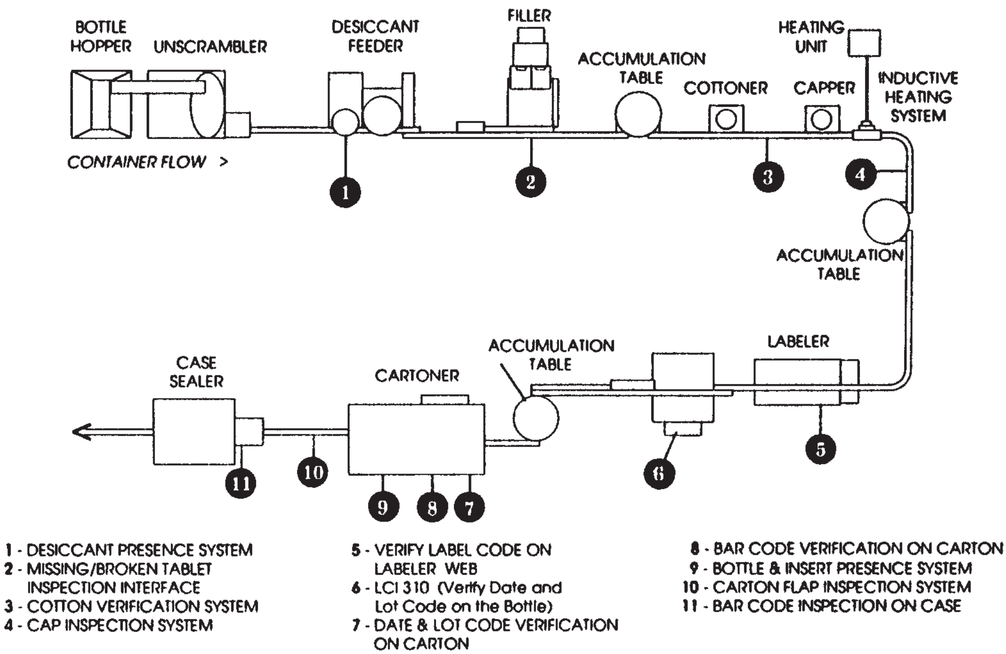


FIG. 21-51*a* Inspection system for an integrated-packaging line packing tablets into glass bottles. Machine vision, bar code technology, and sensor technology are linked together by a supervisory system. (*Courtesy of AGR International, Inc., Butler, PA 16003.*)

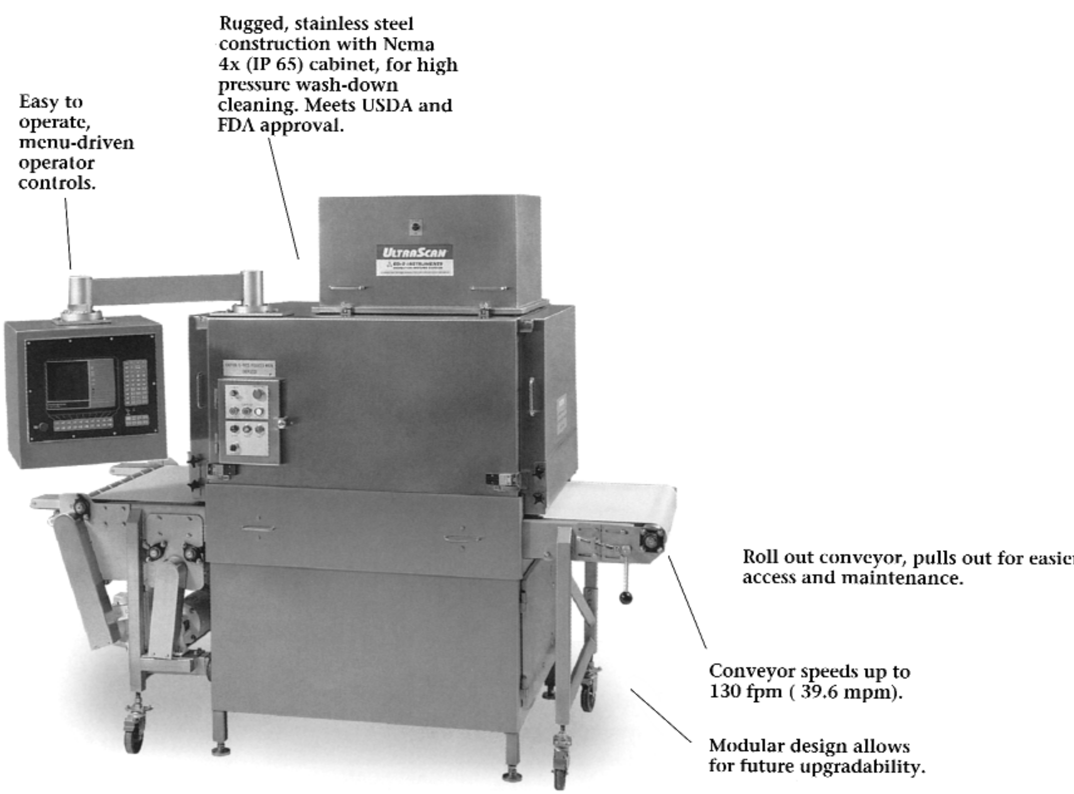


FIG. 21-51*b* An X-ray system for detecting foreign matter in packages. (*Courtesy of EG&G Instruments, Inspection System Division, Oak Ridge, TN 37830.*)

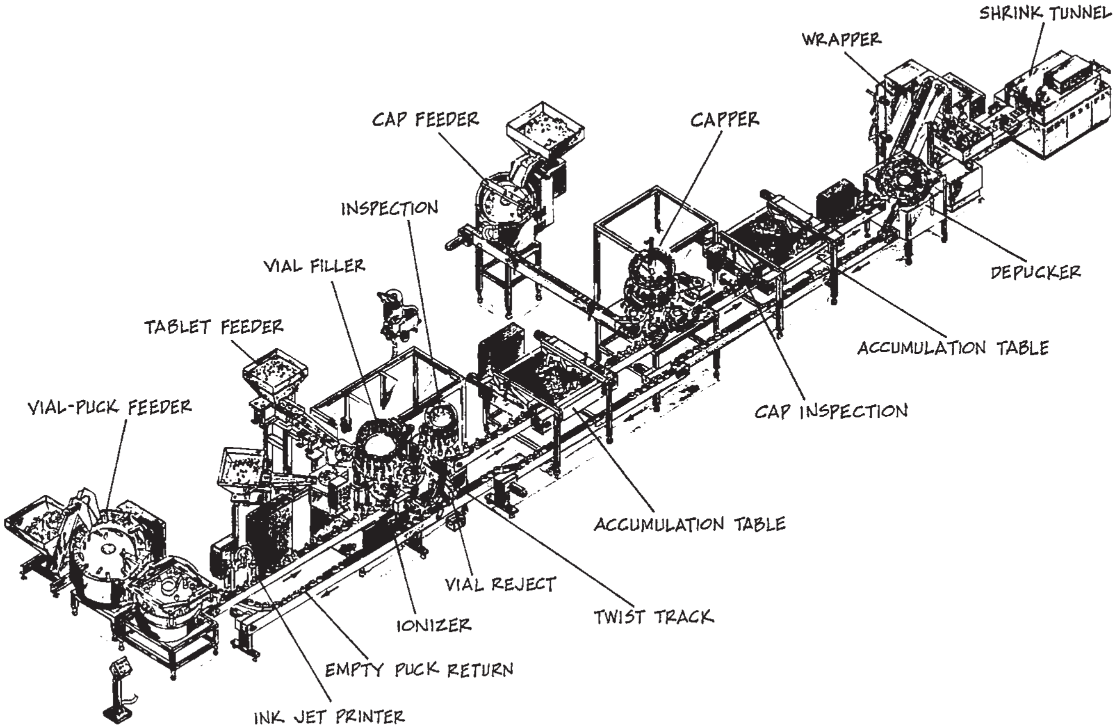


FIG. 21-51c An integrated-packaging line for a tableted product in glass vials (bottles). Machine vision inspection systems check key variables. (*Courtesy of Pharmaceutical & Medical Packaging News, Paoli, PA 19301.*)

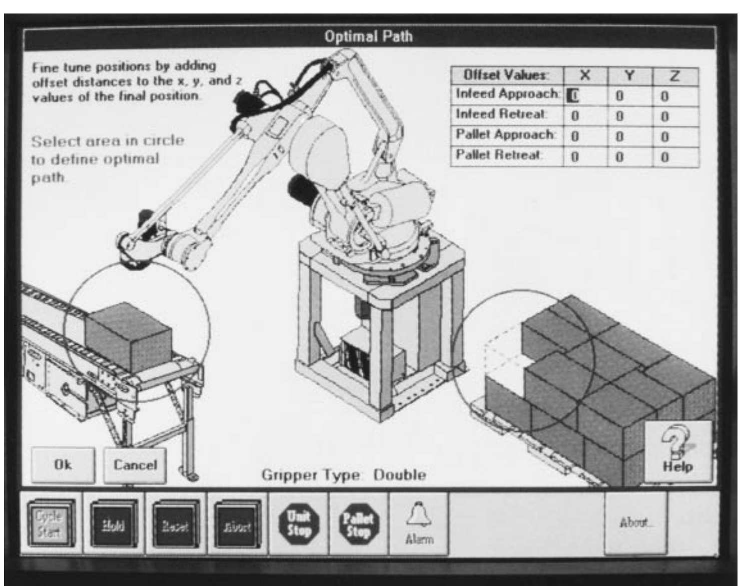


FIG. 21-52 Fixed-position robot used for palletizing of corrugated fiberboard cartons. Robot is integrated with a personal computer using WINDOWS™ graphical-user interface. (*Courtesy of FANUC Robotics North America, Auburn Hill, MI.*)

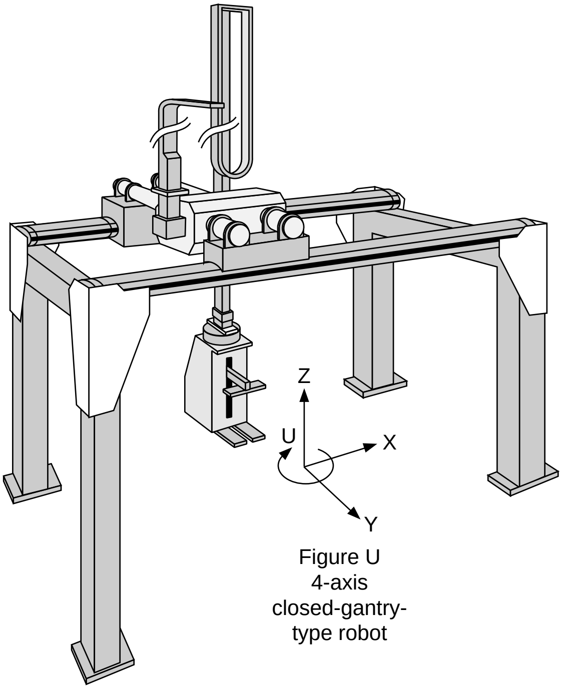


FIG. 21-53 Example of gantry-type robot having 4 axes which would be used for palletizing cartons or bags. (*Courtesy of C & D ROBOTICS, A Division of Ohmstead, Inc., Beaumont, TX 77701.*)

PACKAGE HANDLING AND STORAGE

Warehouse Requirements Finished packages of the chemical industry are usually bags, drums, pails, or cartons (the last-named containing smaller units). Equipment for package handling and storage may be grouped into three main performance categories: (1) from packaging to pallet-unit loading, (2) from pallet-unit loading to storage or shipping, and (3) from storage to shipping.

The trend has been to the use of decentralized warehouses, with less and less finished product being stored at the producing plant. A typical plant inventory consists of 2 to 3 days of production, but at stocking points the inventory may amount to as much as 15 to 30 days. Although high inventory turnover is desirable, the variety of product grades and specifications often leads to longer storage times. Because of this, storage equipment and related conveyors are available to permit either a high velocity of product movement in and out of the plant warehouse or a virtually static one.

Mechanical handling of products in warehouses began with the forklift truck and pallet combination. Since warehouses had no moving equipment, pallet loads were set on the floor or placed on top of one another. Although this procedure is still practiced, loads now move into a storage-rack system, which permits storing pallet loads in vertical columns that make fuller use of the volume or height of the warehouse. Conveyors are also used to carry the pallet loads to storage, retrieve them, and send them to shipping. Forklift trucks are usually involved in all these movements.

Package-Handling Systems The **control of package-handling systems** may depend on simple motor starters, on interlocked relays with photocell control, or on computers. Solid-state controls are finding much application in the last two systems.

A second type of control required is that of the package or pallet itself as it is handled by conveyors and other equipment. This handling may consist of right-angle transfers in a vertical lift or of a set of restrainers on the sides of a belt conveyor.

System Analysis The choice of a specific handling system must take into consideration trade-offs that can be made among different types of equipment and between people-operated and -controlled equipment and automation. A disadvantage of automation is the high cost of specialized maintenance required, which can cost annually between 5 and 10 percent of the original equipment cost and sometimes more. New technical skills are also often necessary.

Factors that enter into any economic analysis of handling-warehousing systems are (1) expected mechanical and economic life of the system; (2) annual maintenance cost; (3) capital requirements and expected return on investment; (4) building-construction cost and land value; (5) detailed analysis of each work position (to determine trade-offs of labor and equipment; expected future costs and availability of labor are important); (6) relation of system control and personnel used in system (trade-offs of people versus mechanical control); (7) type of information system (computerized or manual); and (8) expected changed in product, container, unit pallet loads, and customer preferences during the life of the system.

Forklift Trucks The backbone of most in-plant handling systems in the chemical industry is the forklift truck. Available in capacities ranging from 1 to 50 tons, the most commonly used are 1-, 1.5-, and 2-ton vehicles, with the 3-ton unit occasionally being used (Fig. 21-54). The trucks are usually powered by internal-combustion engines that consume liquefied petroleum gas (LPG) or by electricity by means of storage batteries.

With internal-combustion engines, automatic transmissions are frequently used; these are easily justified when vehicles must make many moves during the day. Smooth as is the control afforded by automatic transmissions, it is nevertheless inferior to that provided by electric trucks, especially those with solid-state controls. Gasoline and diesel power are also used, but mostly for outdoor equipment and very-heavy-duty units.

The lift-truck industry is competitive, with innovations being introduced frequently. Competent sales and service are available at low cost from most manufacturers or their dealers. Application sales engineering (a very worthwhile service) is generally supplied at no cost.

The many **options available** for lift trucks fall into two classes: vehicle specialties, which include controls, transmissions, guards, etc.; and accessories, which are devices that handle specific types of loads (Fig. 21-55). Included in this second category are high-lift masts, up to 7 m (24 ft); handling attachments for circular products, such as drums and roll goods; attachments such as carton clamps; and the fork side-to-side shifting mechanism.

Worthy of particular notice among accessories is the **side shifter** that is used to move trucks horizontally, about 100 mm (4 in) from side to side. The modest cost of this feature is returned in a few months' operation through reduced handling time, maintenance, and product damage. The driver first positions the truck approximately in front of where the load is to be set down and then makes the final horizontal adjustment by means of the side shifter. Without this mechanism, two or three maneuverings of the truck are necessary, with the load never quite being placed in the ideal spot. Correct positioning is important for pallet loads, which should be placed as tightly together as possible.

Lift trucks are available to meet a variety of **clearance restrictions.** Noteworthy is narrow-aisle equipment. Another accessory worthy of consideration is the multilift mast, which permits lifting loads over 3.7 m (12 ft). Of special importance in specifying any mast is that it will clear the various door openings it must enter, which includes those of trucks, railcars, and buildings. To meet most conditions, the collapsed height of the mast must be 2235 mm (88 in). An ideal lift truck for chemical-plant distribution warehouses would have 2000-kg (4000-lb) capacity; electric (battery) propulsion; solid-state controls; power steering; Trilift mast, up to 4.9 m (16 ft) [2235 mm (88 in) collapsed]; side shifter; operator guard; solid tires (except for outside use); and adjustable forks.

Exceptions to the preceding requirements would apply where explosionproof equipment is needed; building ceiling heights are such that the standard 3.7-m (12-ft) lift is all that will ever be needed; and loads will never exceed 1 to 1.5 tons. Safety requirements for lift trucks are mandated by OSHA, by NIOSH (National Institute of Occupational Safety and Health), by State Depts. of Labor, and often by individual company standards. Among these requirements are backup-movement signals, seat belts, overhead framework for pro-

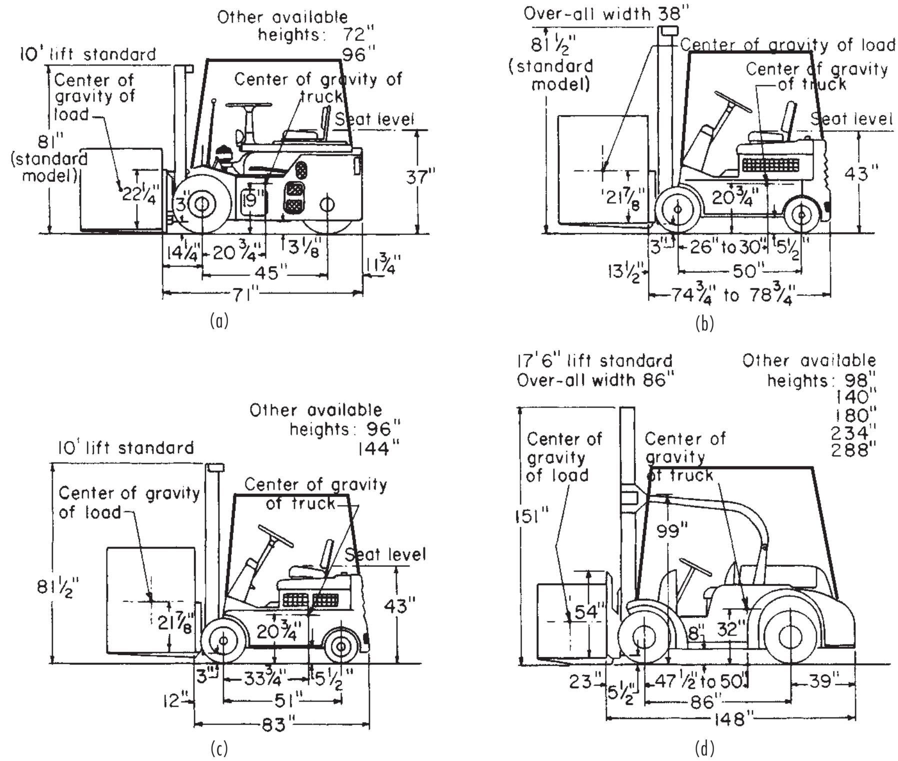


FIG. 21-54 Dimensions of representative forklift trucks. (*a*) 1000- to 2000-lb capacity. (*b*) 3000- to 4000-lb capacity. (*c*) 5000-lb capacity. (*d*) 10,000- to 12,000-lb capacity. Multiply pounds by 0.4536 to get kilograms; multiply inches by 0.0254 to get meters. (*Hyster Co.*)

tecting the operator from falling items, flashing lights, and two-way radio transmitters. Driver training is also mandated. A prominent training program is that of the National Safety Council. It includes video instruction, home workbooks, written and oral tests, and a demonstration of competency in operating an actual lift truck.

Capital investments in forklift equipment vary with specifications. Table 21-27 compares the cost of the electric-propulsion truck just described with an LPG-operated alternative. The operating cost is primarily for energy, with electric consumption being cheaper than liquid fuels.

Maintenance on gas trucks is also higher than with electric vehicles. About 5 percent annually of the initial cost applies to internal-combustion equipment, and about 2 percent annually to electric. A special feature on electric trucks with solid-state controls is the use of modules or circuit boards, which can be replaced as units and rebuilt at the factory. Typical maintenance costs for trucks operating five 8-h shifts per week are in the order of $3.15 per hour for gas vehicles and $1.78 per hour for electric ones. Under these conditions, energy costs are typically 9.3 cents per hour for gas trucks and 5.1 cents per hour for the electric units.

The **straddle truck,** designed for lifting bolsters with heavy loads or materials such as structural steel, is also finding application in handling van-type containers of packaged goods. For example, it can straddle a flatcar, pick off a van container, and deposit it directly on a truck-trailer rig. It can also be used for loading railroad flatcars and even oceangoing vessels. It is just one of many special pieces of mobile equipment available for special handling problems.

Slide Conveyors Simple gravity slides and spiral chutes, while not technically conveyors, are widely used with conveyor systems or as separate units for lowering materials from one floor to another. They are low in cost and require little floor space if slopes are held at fairly steep angles. However, they must be used only after a careful study of possible damage to containers from bumping either together or against the sides of the chutes or slides. Enclosed units are available for outside operation, and fire doors can be provided to meet requirements of local building codes. Multiple-blade chutes may be used for service to several floors, with separate inlet and outlet points. Blades may be lapped and riveted to eliminate the possibility of containers hanging up on exposed edges. Flight sections may also be flanged and bolted together.

Speed of containers sliding down a spiral may be controlled by the pitch of the spiral or by banking the outer or inner edge of the blade. Banking tends to throw the container to one side of the blade, thus varying its total travel distance. While usually fabricated of steel, blades may be specified in different materials, as required by specific applications.

Because of the steep pitch required, **slides** are limited in application. They are most commonly used to bridge the gap between roller-conveyor systems on two floors, because the roller conveyor can take the container off the slide rapidly and eliminate or reduce the chance for collisions. Slides may also be used when containers can be chuted from an upper floor to a manually loaded carrier. The use of several rollers at the feed point is recommended for easy delivery to the sloping section. If the drop is short and containers light, a roller cleanout will prevent backup of containers on the slide. The slope of gravity slides is a function of container weight, size, and friction characteristics and should be selected with care to be sure that containers do not move either too swiftly or not at all. Slides usually use flat steel sheet.

Gravity Wheel Conveyors These can be used as pusher units set horizontally or inclined for gravity flow. They are highly standardized and are usually sold in 1.5- or 3-m (5- or 10-ft) sections; special lengths are available at extra charge. Since wheel conveyors give what is essentially "point" support to containers, it is generally recommended that at least six wheels be located under the load at all times.

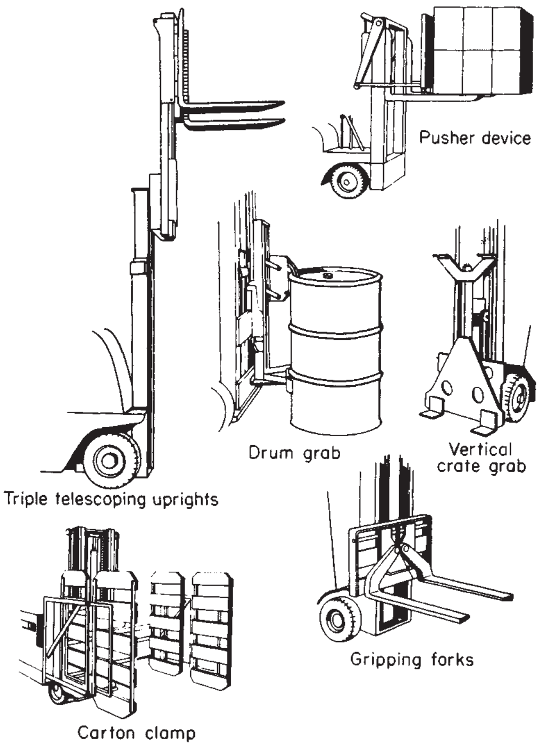


FIG. 21-55 Various types of fork-truck attachments.

Thus wheel arrangement is dictated by the smallest container that the line will handle. Only flat-bottomed containers can be handled on wheel conveyors, with the exception of fairly stiff-walled bags, which handle satisfactorily. This is due to the fact that the separate roller supports tend to pull the bag wall taut and flatten it out. Roller conveyors, on the contrary, tend to ripple the bag surface and prevent its movement. Wheel conveyors may also be specially designed for handling smooth-walled cylindrical shapes.

Wheels are available in a number of different designs, including variations in contour and material in contact with the container. Rubber or plastic tires are not uncommon. Through shafts may be used, with several wheels mounted on each shaft; stub bolts with a single wheel may be mounted to the side frame, or short shafts supported by bent bars may also be used. Wheel conveyors are generally used on lighter loads, and although manufacturers may offer widths up to 915 mm (36 in) or more, the smaller widths [up to about 457 mm (18 in)] are generally standard. Load ratings are generally given as the total uniform load which a standard section will support.

Since wheel units are relatively light, they have relatively low inertia, and loads may be started and stopped quite easily. In addition, wheel bearings are designed with loose tolerance to reduce starting friction. Metal plates or projecting hardwood slats are commonly used as stops on conveyor lines. Special hinged sections for passage of personnel through the conveyor line are available, and standard supports from floor or ceiling are recommended. Wheel-conveyor units are widely used for live storage, and special telescoping units are available for extension and retraction to meet variable conditions. Wheel conveyors are sometimes powered by a pressure belt or other methods but are most widely used as pusher or gravity lines. They are adaptable only for end discharge or side discharge by lifting, since the individual rollers tend to grip the container and prevent its sliding off the line at right angles to direction of travel.

Roller Conveyors Gravity rollers are considerably heavier than the wheels on wheel conveyors, and the weight is concentrated at a greater distance from the shaft centerline. Hence, roller conveyors have a greater inertia; they are harder to start and harder to stop, require more slope than wheel units, and on long runs tend to speed up containers at an accelerating rate.

Spiral-roller units are usually equipped with tapered rollers to compensate for the difference in distance traveled by the inner and outer edges of the container. Tapered rollers are also used on curved sections of ordinary roller-conveyor lines.

Rollers are available in a wide **variety of constructions,** with tube ends either bored or formed to take the bearing insert. Bearings may be plain, with nylon rapidly becoming the most popular material for this type. Ball bearings are probably most common and are available with a variety of seals, or the bearing may be left unprotected. Lubrication fittings may be provided on a drilled shaft, or bearings may be prelubricated and sealed for life. Roller shafts are usually nonrotating and may be cut from hexagonal stock to fit a similar opening in the side frame, or they may be round with ends milled flat to prevent turning. Rollers may be mounted in side frames in a variety of ways, above the side frames when containers are to be slid off the line or below when there is danger of the containers falling off.

Gravity roller conveyors can handle containers with protruding edges, i.e., steel drums, which is one of their advantages over wheel conveyors. However, they are not generally suitable for bags since the sides tend to sag between supports and prevent forward motion.

As with gravity wheel conveyors, roller units are highly standardized and auxiliary equipment is available for supporting the line from ceiling or floor. Many special rollers are available for retarding containers if speed becomes too great for safe handling. Switches, brakes, hinged sections, spurs, and frogs are also available.

Roller conveyors are quite frequently **powered,** the simplest method being use of a pressure belt in contact with the lower surface of the rolls. A special ripple belt with raised pads is capable of starting up the load but does not build up excessive blocked pressure if the line fills up. Other similar drives are available, with varying degrees of control over the applied power. Most expensive of the powered roller units are those in which each roll is equipped with V-belt or chain drives. Pusher bars suspended from overhead chain conveyors may also be used to move containers along a roller line.

One of the most important control devices on roller-conveyor lines is the escapement mechanism which allows containers to be released from a line individually. Powered escapement mechanisms are commonly available on highly mechanized systems. Their main function is to space out the containers so that they can be handled as discrete units.

Flat-Belt Conveyors These powered conveyors can lift containers up inclines. With the aid of special belt surfacing, grades may be quite steep. Belts also keep containers spaced out in exactly the way in which they are placed on the conveyor. However, because of the relatively high friction containers cannot be slid off belts by pushing devices.

Belt-conveyor designs use both roller and slider bed supports for the flat belt. The variety of designs available allows proper selection of flat belts for heavy or light loads and for various applications such as carton filling or emptying.

TABLE 21-27 Initial Capital Investment Comparison between Liquefied Petroleum Gas and Electric Forklift Trucks of 2-Ton Capacity*

Item	Liquefied petroleum gas	Electric
Basic truck	$40,000	$46,000
Automatic transmission	$ 1,300	
Solid-state controls (standard)		
Trilift mast, to 4800 mm (189 in)	$ 4,500	$ 4,500
Side shifter	$ 4,500	$ 4,500
Power steering (standard)		
Solid tires (standard)		
Storage battery and charger		$16,000
Total	$50,300	$71,000

*Based on 1995 prices (U.S. dollars). Initial inventory of repair parts is not included in these prices.

Chain Conveyors These devices for handling containers are available in either roller-chain designs or less costly types. There is a variety of **slat conveyors** that use both single and double strands of roller chain, as well as a slider type using cheaper chain. In general, slat chain conveyors are used only on loads which are too heavy for economical handling by belt, roller, or wheel units or which have odd shapes not suitable for roller or wheel units. They are particularly adaptable to pallet handling, as are simple open strands of chain with flat-surfaced attachments.

The most commonly used warehouse chain conveyor is the **tow chain.** Chain may be mounted overhead or in the floor, and trucks being towed can be designed for automatic detachment at a specific point. While the overhead chain is often used and is usually easy to support from structural members in the ceiling, the in-floor chain is probably most common. Automatic disengagement is possible should trucks encounter an obstruction or accidentally strike warehouse personnel. The two-chain conveyor is, of course, most economical when large tonnages are moved over a fixed path.

Chain-type **elevators,** such as arm and tray units, are commonly used for drums and barrels. Slight gravity runs at feed and discharge allow these units to roll on and off the conveyor easily and without special equipment.

Elevators Cable-type elevators are usually selected for heavy loads such as full pallets or large containers. They can be made fully automatic and are able to serve many floor levels. The use of properly designed elevator systems is often the only economical solution to multistory-plant problems.

Conveyor Accessories These may be divided into two groups, those which act on the container and those which are acted on by the container. In the first group are such items as deflectors, palletizers, pushers (powered by fluid, air, or mechanical linkage), upenders, sealers, staplers, and similar devices. In the second group are such items as electric eyes for counting or identification via printed or color codes, check weighers, mechanical counters, and other devices contributing to automatic conveyor-line operation.

Automatic Palletizers These machines receive packages from production by conveyor. The packages are then arranged in tiers, and the tiers are placed on pallets. The mechanism to accomplish this consists of package-handling conveyors, package-moving stops, rams, etc.; a package-tier-pattern assembly plate; an empty-pallet-handling conveyor and elevator; a filled-pallet-handling conveyor; and electrical regulators to control the tier-pattern formation. Automatic pallet loaders can handle 40 to 80 packages per minute, or one to two pallet loads. Capital investment is about $225,000 for the basic machine, not installed. Semiautomatic operator-directed palletizers capable of handling 10 to 20 packages per minute are available; they cost approximately $95,000, not installed (1995 prices).

Package-handling systems can be designed to handle almost any situation of package type, packaging machine, and warehousing-transportation requirement. Figure 21-56 shows a typical bag-handling

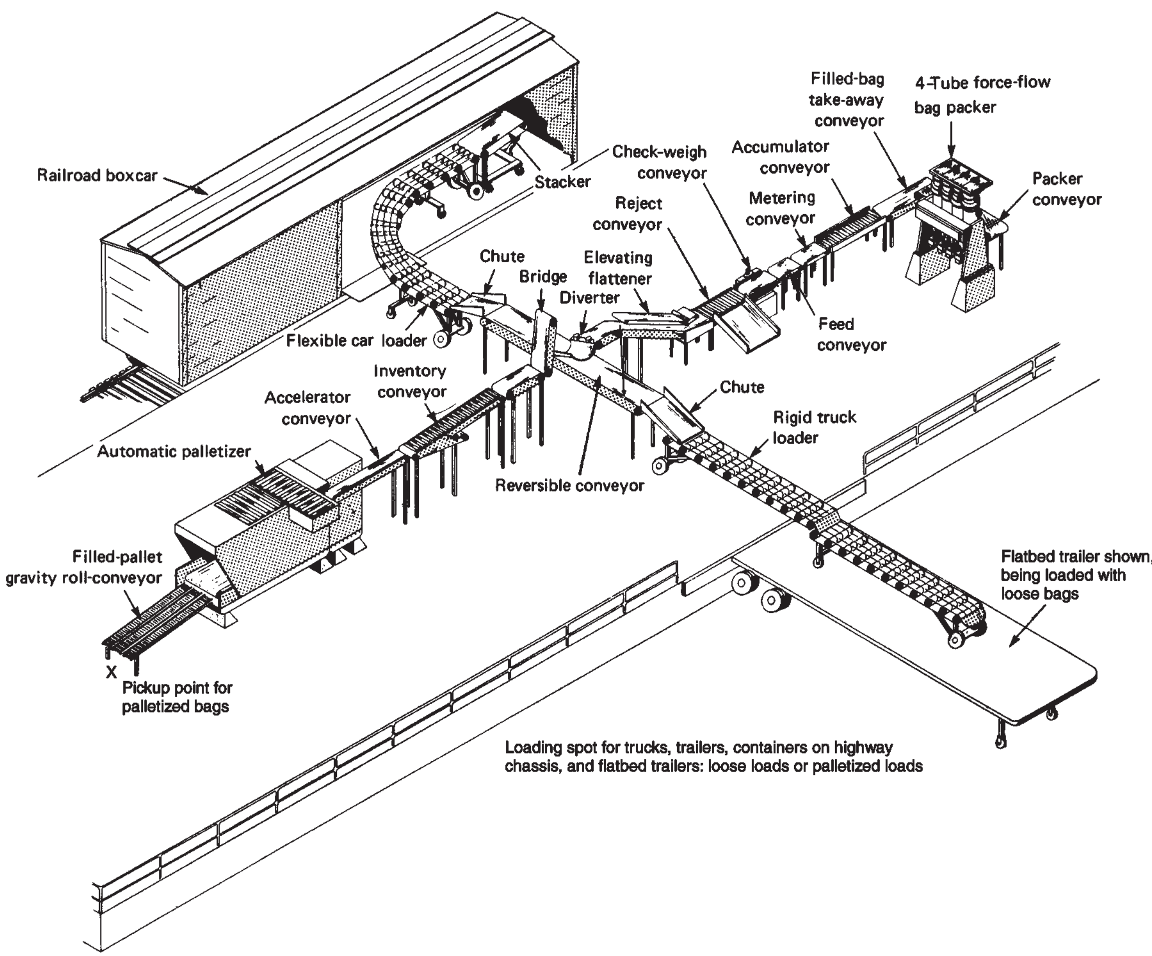


FIG. 21-56 Typical four-tube force-flow valve-bag packer with automatic palletizing and truck- and railcar-loading facilities. (*Courtesy of Stone Container Corp.*)

system in which both palletized loads and loose bags are handled. A system of this type can handle thirty 25-kg (50-lb) bags per minute. Figure 21-57 shows a system using the pinch-bottom-type open-mouth bag. Such a system can handle ten 25-kg bags per minute. Performance data for both examples can be found in Table 21-26.

Storage of Packaged Items The inventory needed to support a given sales level is increasing in quantity as well as in the number of places where inventories are maintained to provide better service. Since a major portion of the chemical-process industries is located in urban centers where space is extremely valuable, efficient ways of storing packaged inventory have become very important. A similar situation exists when inventories are maintained at production plants. Here, space may be more readily available than in urban locations, but there is the question of whether to use the space for storage or for processing. These situations have led to the development of the storage-rack concept.

Storage racks permit storing pallet loads of packages vertically as well as horizontally. Most pallet loads can be tiered two or three pallets high, with one resting on top of another (provided the packages are able to withstand the weight of the pallets above). Because the racks bear the pallet weight, stacks six to eight and even more pallets high are possible. Forklift trucks and stacker cranes are used to place and remove the pallets.

From an inventory-turnover point of view, four major rack-storage systems are possible: drive-in, drive-through, flow, and aisle.

Drive-in racks, which are practical up to a height of 10 m (30 ft), are serviced by forklift trucks. The inventory system required is last-in–first-out (LIFO), which many consider inefficient. Capital investment (installed) for a 5000-pallet rack system is about $90.00 per stored pallet, lift truck not included. Drive-in racks make good use of floor space, having a higher ratio of storage to aisle space than aisle racks.

A typical drive-in rack consists of a steel structure to support palletized goods at the pallet edge, with the center of the pallet unsupported. The space between pallet support members is sufficient to permit a lift truck to drive in to place or retrieve a load. These racks are usually made to accommodate 12 pallets, which are positioned from the service aisle to the end of the rack. Because of the rack, each pallet position has the ability to hold 6 to 8 pallets vertically.

In operation, the lift truck takes the first pallet load and drives to the end of the rack to set down the pallet. With the second pallet, the truck enters the rack with the pallet elevated to permit clearing the support member. This procedure is repeated until the rack is filled. Lift-truck productivity is low because the driver must possess agility and skill to manipulate pallets extended on the truck.

Drive-through racks are similar to the drive-in kind, differing mainly in having lift-truck access at both ends. The main advantage of drive-through racks is that they allow a first-in–first-out (FIFO) type of inventory management. Capital investment, installed, is about $100 per pallet for a 5000-pallet rack structure. In operation, the rack is loaded in the same way as a drive-in rack. The unloading is different, in that removal of pallets begins at the opposite end from the loading point.

Flow racks are similar to drive-through racks in that they are loaded from one end and unloaded from the opposite end. However, the truck does not enter the rack. Rather, each lane in the rack is equipped with a conveyor (roller, wheel, or belt, depending on pallet characteristics) which both supports the pallet and transports it (by

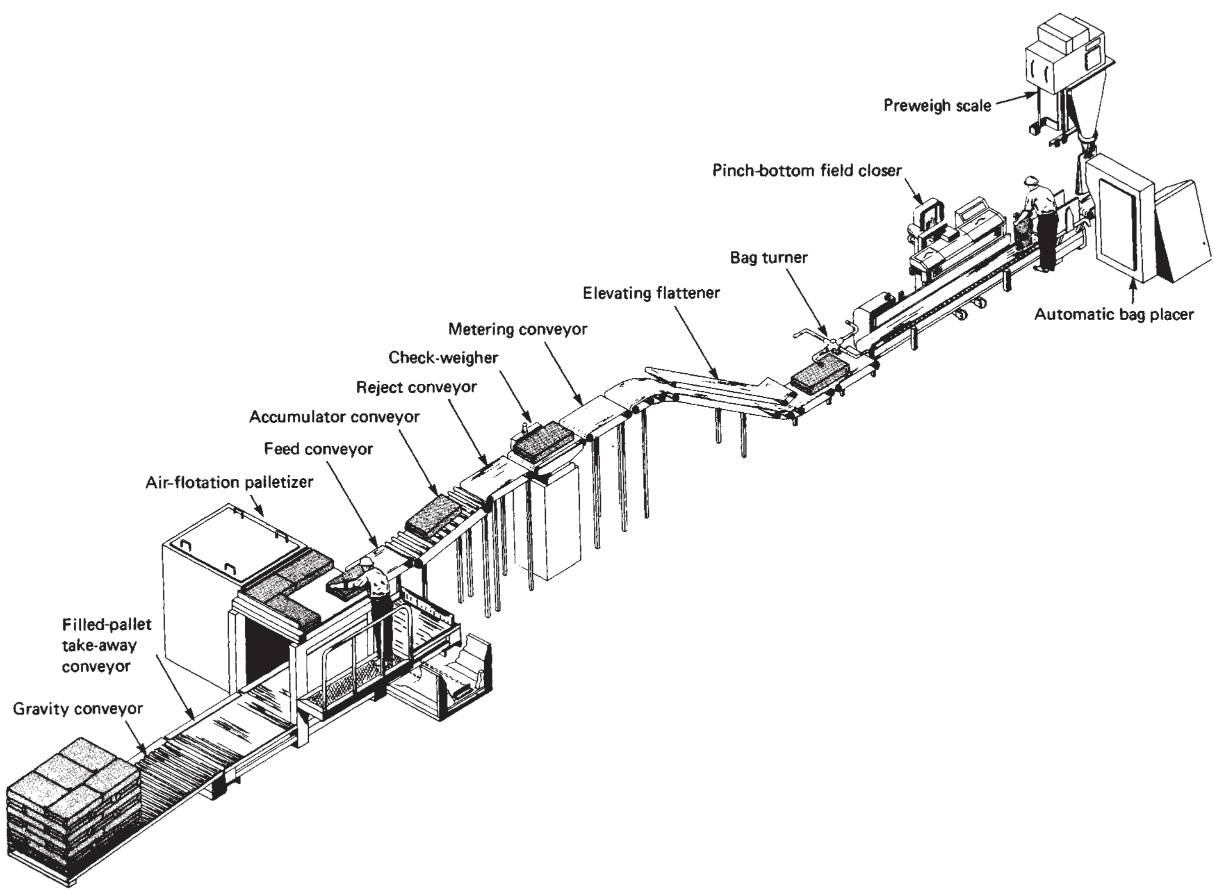


FIG. 21-57 Typical pinch-bottom system with automatic bag hanging and semiautomatic palletizing. Filled bags are handled on pallets only. (*Courtesy of Stone Container Corp.*)

gravity) from the entry point to the discharge end or to the nearest pallet. As a pallet is removed, the remaining ones flow to the removal point. This is a FIFO system of inventory.

The installed capital investment is about $375 per pallet for a 5000-pallet system. A characteristic of drive-in, drive-through, and flow racks is that, at any one point in time, only one product can occupy a given storage lane. Products are not mixed because of the complications that this practice presents in inventory management. In any event, there is seldom any need to mix products in the chemical industry because products are made in lots, blends, etc., and a storage lane is ordinarily designed to accommodate either a complete lot or some fraction of a lot. The result is that the total storage space available rarely is completely used. This is a problem that aisle racks overcome.

Aisle racks, used when there is a rapid turnover of inventory, permit a storage depth of only one or two pallet loads but offer the advantage of instant access to the stored item. Although this requires only a minimum of lift-truck time to store or retrieve a pallet, a high percentage of floor space must be devoted to aisles.

The inventory system needed is FIFO, which is desirable when inventories are subject to obsolescence or deterioration or when they consist of raw materials that fluctuate widely in value. The capital investment for a typical aisle-rack storage system having a 5000-pallet capacity (1 deep) is $65 per stored pallet (this does not include lift-truck investment).

Lift-truck operation is very simple and productive, even at 7-m (20-ft) elevations. Aisle racks can be as high as 30 m (100 ft), but above 7 m stacker cranes are favored over lift trucks because cranes allow servicing high storage at high rates. The installed investment in aisle racks, including a stacker crane, is about $500 per pallet.

Automatic Storage and Retrieval Systems These systems are of increasing importance in the warehousing of chemical products whether they are for consumer or industrial markets. They are comprised of warehouse racks which can be several stories high. These racks are serviced by stacker cranes equipped for palletized handling. Each rack is divided into storage modules. Each module is capable of holding one pallet load of product and has an address which is stored in a process control computer memory. Stacker cranes are under the direction of the process-control computer. Through use of bar codes marked on packages and pallets, products entering the warehouse are identified by such variables as nomenclature, weight, package type, and any expiration date. The entering pallet load is identified by its bar code through use of a laser scanner which picks up the information from the bar code and transmits it to the process-control computer. The computer then directs the stacker crane to an empty storage module which is available and makes a record of the product and its storage location. The stacker crane places the pallet load in the module. The computer verifies this record before the stacker crane leaves the storage module. Stacker cranes often are equipped with an enclosure for a person who can ride the crane and inspect any storage module. This is also used where an operator does order picking, as in the case when single cartons of product are ordered. The term *paperless warehouse* is a very apt description of automatic storage and retrieval systems since they rely entirely on bar code, scanning, and computers, with a minimum of personnel. Pallets for such systems must be accurately made to required dimensions and have sufficient mechanical strength to withstand the repeated handling. Often, metal pallets are used to support wood pallets and their loads. The metal pallets never leave the warehouse, and assure trouble-free operation.

TRANSPORTATION OF SOLIDS

TRANSPORT OF BULK SOLIDS

Originally confined to the shipment of crude raw materials and fuels, the term "transportation of bulk solids" now applies also to manufactured products, which often become raw materials for other industries. In recent years, increasing tonnages of highly processed, finished chemical products have moved to customers in large bulk units. A useful definition of a bulk shipment is any unit greater than 2000 kg (4000 lb) or 2 m^3 (70 ft^3). The containers available range from small portable hoppers of 2-m^3 (70-ft^3) capacity to railroad cars of 255-m^3 (9000-ft^3) capacity.

The choice of shipping in package or bulk depends on market requirements and economics. Products from different sources that tend to have the same characteristics (appearance, quality, price) are usually offered in bulk form. Those tending to be specialties, while sometimes offered in small bulk units, usually are sold in packages. Many products are sold in both ways. A comparison of the costs of typical package and bulk units is given in Table 21-17.

Bulk Containers These containers may be either open or closed. Generally, it is the effect of the weather on the product that governs the choice. High-value materials, such as certain ores, may be shipped in open containers, while relatively low-cost items, such as portland cement, require closed containers. Further influencing the choice of bulk containers is whether deliveries are made by truck, railroad, or water.

When customers maintain small inventories, **truck** delivery is often used, provided the location of the supply point is nearby, usually 550 km (300 mi) or less, and deliveries are frequent. If, however, a user maintains large inventories, deliveries are ordinarily made by **rail.** Other parameters influencing choice are transportation cost; operating costs of supplier loading facilities; customer receiving and unloading facilities; turnaround time for the container and the number of trips made per year (hence, investment write-off per trip); and container-operating cost, exclusive of transportation.

In planning for railroad-car loading or unloading facilities, many dimensional and weight factors must be dealt with. The common carriers that are to serve the facility are usually able to provide technical assistance as to clearances and weights to be handled.

An interesting new concept in planning for finished goods and bulk storage (when rail is used principally for customer delivery) is the use of hopper cars instead of fixed storage bins. Since products are eventually to be loaded into cars, there is much to be saved by avoiding double handling and capital investment. A systemwide analysis often will show this to be the least costly method, especially if there is a policy of minimum finished-goods inventory.

The most important bulk containers are railroad hopper cars, highway hopper trucks, portable bulk bins, van-type (ship) containers, barges, and ships. Factors determining the suitability of any of these containers (after establishing whether open or closed containers are to be used) depend on product physical properties, the most important of which are ease of flow, corrosiveness, and sensitivity to contamination.

Railroad Hopper Cars Hopper cars follow three basic designs: (1) covered, with bottom unloading ports; (2) open, with bottom unloading ports; and (3) open, without unloading ports. Three types of unloading systems are used: gravity, pressure-differential, and fluidized. For the open-type car without unloading ports, clamshell buckets are often used. The car is loaded through ports located on the top of the car. Figure 21-58 shows a common type of covered hopper car.

Table 21-28 gives dimensions of hopper cars and other cars typically used in the chemical industry. Vacuum-pressure systems are used most frequently for unloading covered hopper cars. For certain free-flowing materials, in both covered and open-top hopper cars, shakeout devices are useful.

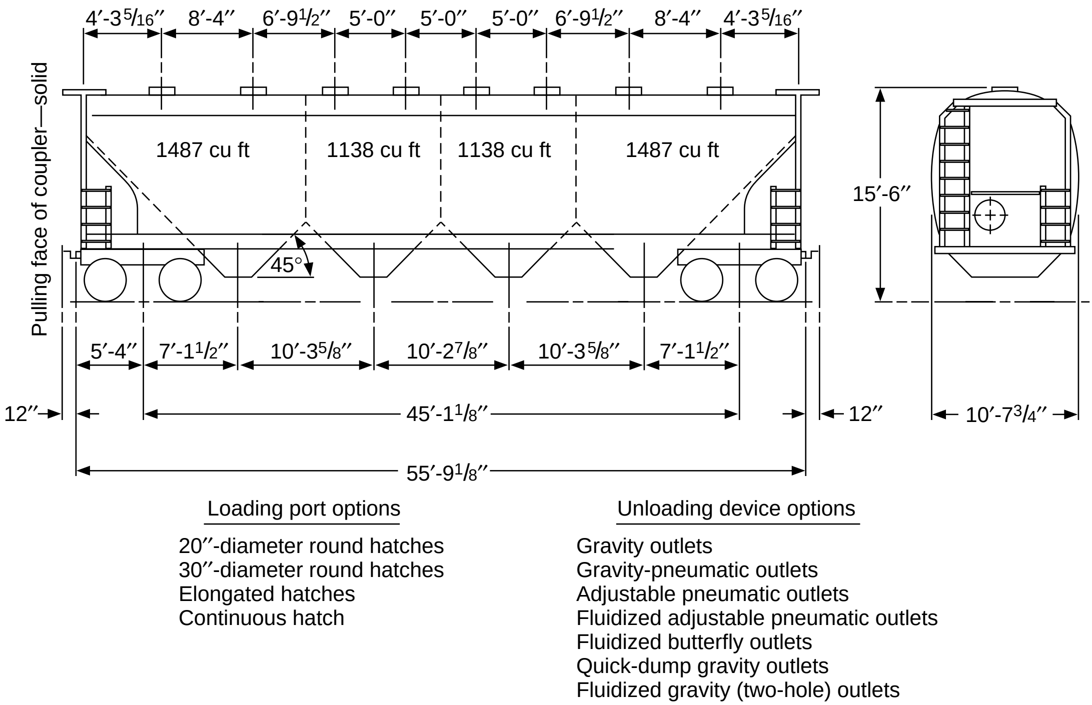


FIG. 21-58 Typical railroad covered hopper car, 5250 ft^3 (148.7 m^3) ACF Centerflow designed for ladings having a bulk density of 42 lb/ft^3 (672 kg/m^3). Load limit 200,000 lb (90,720 kg). Unloaded weight with 20 in (508 mm) loading ports and gravity pneumatic unloading devices is 66,920 lb (33,355 kg). (*Courtesy of ACF Shippers Car Line Division.*) Change dimensions to inches and multiply by 25.4 to get mm. Multiply ft^3 by .02832 to obtain m^3.

Because of the railroad-car shortage that has persisted for many years, boxcars are often used for bulk materials. Lined with suitable materials to prevent contamination and with special bulkheads at each door, these cars are acceptable substitutes for covered hopper cars even though unloading is more difficult. Vacuum conveying wands are used to pick up the material, as are front-end-loader-type vehicles.

Loading of hopper cars and trucks can be done with most types of conveyors: air, belt, screw, etc. When an extremely full loading is required, centrifugal trimmers are frequently used. Available in a range of capacities, they can be engineered for any size of unit, up to a shiphold cargo (Fig. 21-59).

Track hoppers are needed for some boxcar and bottom-dump-car shipments. Since boxcars discharge to one side, fairly light construction can be used for the hoppers, which are located to one side of the tracks. However, for bottom-dump cars, the hoppers must be located on the centerline of the tracks. This requires heavy track girders over a hopper and feeder conveyor pit, but hopper depth must be set to give sufficient angle for material to flow well. Belts or reciprocating-plate feeders commonly carry the material to the bucket elevator.

TABLE 21-28 Typical Railroad-Car Dimensions and Capacities*

Type of car	AAR* class	Nominal inside dimensions, Length	Width	Height	Nominal outside dimensions, Length	Width	Height	Cargo (lading) volume, cu. ft. × 100	Cargo (lading) weight, lb. × 1000
ACF center-flow hopper car	LO				39 ft. 8 in.	10 ft. 8 in.	14 ft. 10 in.	29.7	207
ACF center-flow hopper car	LO				54 ft. 8 in.	10 ft. 9 in.	15 ft. 1 in.	47.0	200
ACF center-flow hopper car	LO				59 ft. 2 in.	10 ft. 9 in.	15 ft. 1 in.	52.5	200
GATX	LO				42 ft. 0 in.	10 ft. 8 in.	14 ft. 4 in.	26.0	140
Airslide hopper car	LO				54 ft. 6 in.	10 ft. 7 in.	14 ft. 6 in.	41.8	192
Hopper car	HT	42 ft. 10 in.	9 ft. 8 in.		43 ft. 10 in.	10 ft. 6 in.	10 ft. 8 in.	27.5	157
Gondola car	GB	41 ft. 6 in.	9 ft. 4 in.	2 ft. 5 in.	42 ft. 9 in.	10 ft. 2 in.	6 ft. 2 in.	9.6	100
Boxcar	XM	50 ft. 7 in.	9 ft. 6 in.	10 ft. 8 in.	55 ft. 2 in.	10 ft. 6 in.	15 ft. 9 in.	51.2	100
Boxcar with DF† equipment	XL	50 ft. 6 in.	9 ft. 5 in.	10 ft. 6 in.	57 ft. 7 in.	10 ft. 6 in.	14 ft. 10 in.	49.5	100

*From Association of American Railroads. Data are given for United States railroads, which do not use SI dimensions. To convert to SI dimensions (millimeters), change dimensions shown to inches and multiply by 25.4. To convert volume to cubic meters, multiply by 0.02832. For weight, multiply by 0.4536 to obtain kilograms.
†Damage-free.

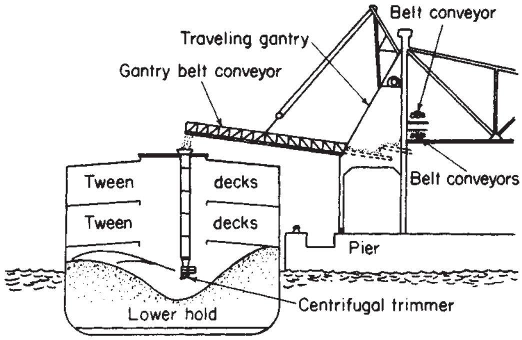


FIG. 21-59 Ship-loading system with trimmer and telescoping chute. (*Stephens-Adamson Division, Allis-Chalmers Corporation.*)

Hopper Trucks These trucks are used to transport by highway a wide variety of materials. Vehicle types range from the open-dumping kind to the closed type. Most common is the type that unloads by pressure differential into its own pneumatic-conveying system, which is temporarily connected to a storage silo. On this type of truck, the unloading of 18,100 kg (40,000 lb) of products takes about 1 h, sometimes less.

The actual weight that the truck can carry in the United States depends on state-highway load limits, which in turn depend on the net vehicle weight and the number of axles on the truck (and tractor, when a trailer arrangement is used). The accepted maximum combined total weight of vehicle and cargo is 36,200 kg (80,000 lb). In some states, this is reduced slightly, while in others it is exceeded.

Of significance is the rapidly developing containerization system used for package cargo. SeaLand Corp. has developed a patented liner device which can be used to convert a cargo container into a bulk carrier. Figure 21-60*a* provides dimensions of typical bulk hopper-truck equipment.

Important in the planning for an installation that is to handle rail and highway equipment are the width, length, height, and turning radius of vehicles that will serve the facility. These dimensions can be easily obtained from carriers as well as from equipment manufacturers. Adequate clearances must be provided for railroad and other work crews. The clearances are often specified in state labor-practice codes.

Movement of railcars and trucks within plants is frequently done by carrier crews. Since, however, plant production schedules and availability of railroad switch crews are often not compatible, many plants provide their own switching service. Specially built prime movers that can operate on both roads or rails are available. Front-end loaders can be equipped with couplers to permit car movement. Cable-operated car pullers are now generally in disfavor because of lack of control of cars being moved. Trailers are often moved by tractors especially equipped with an adjustable "fifth-wheel" coupling, which will couple to any trailer regardless of the height of its coupling.

TRANSPORT OF PACKAGED ITEMS

Vehicle Choice Small units such as **bags, boxes, cartons, carboys, cans, and drums** are usually transported in closed van-type highway vehicles, which may range from small pickup and delivery vehicles of 1400-kg (3000-lb) capacity to trailers capable of holding 23,600 kg (52,000 lb). There has been a trend to higher and wider vehicles, but loading and unloading facilities should be designed to handle not only the newest and largest vehicles but also the older, smaller versions. Figure 21-60*b* shows a typical trailer with principal dimensions.

Ship containers are now predominant for ocean transport of freight in specially designed containerships. They fall into three categories: package-freight containers, tank containers for liquids, and open containers for handling unwieldy items of large size, such as chemical-processing machinery, which are mounted on wood skids. The dominant container sizes are the 20, 40, and 35 foot length. Table 21-29 gives the principal inside dimensions for a variety of package-freight-type containers.

The use of closed railroad cars has declined somewhat in the handling of packaged chemical products in favor of trailers hauled pig-

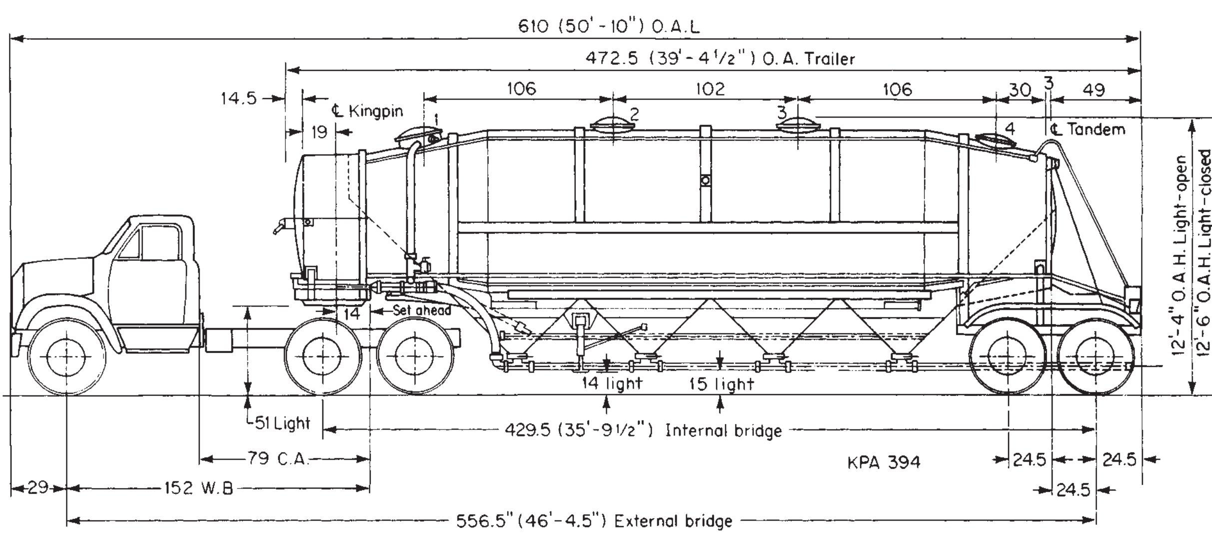
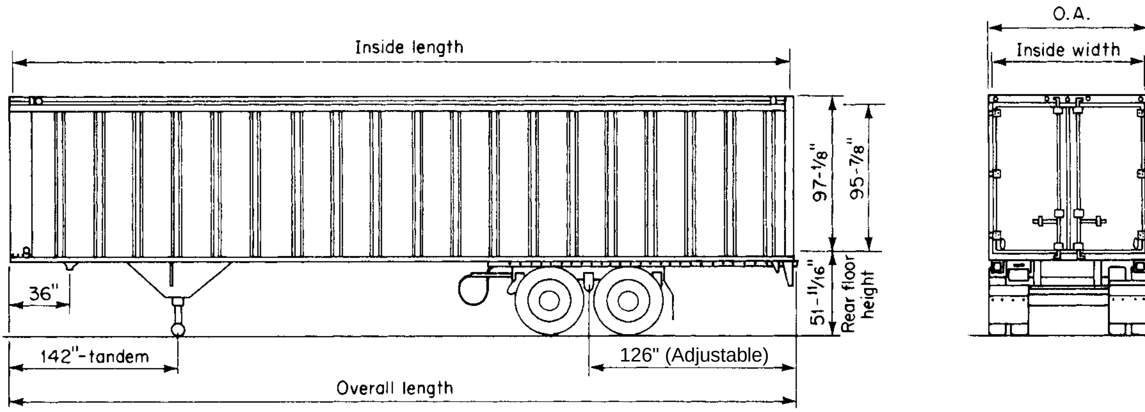


FIG. 21-60*a* Bulk hopper truck. Tractor trailer used for plastics. (*Butler Mfg. Co.*). To convert data to the SI system, change the dimensions shown to inches and multiply by 25.4. To convert volume to cubic meters, multiply cubic feet by 0.02832.



Typical inside dimensions for trailers used in North America.

Width: 92 1/2 in, 2350 mm

Height: 96 in, 2438 mm min; 111 in, 2820 mm

Lengths: 28 ft, 8534 mm
45 ft, 13716 mm
55 ft, 16764 mm

FIG. 21-60*b* Typical inside dimensions for trailers used in North America. Dimensions shown are for an inside height of 96 in. (2438 mm).

gyback fashion by the railroads. This trailer-on-flatcar approach combines the convenience and flexibility of trucks with the low cost and high speed offered by the railroads. Covered railroad cars for hauling packaged freight include not only standard boxcars but much special equipment offering heating, insulation, refrigeration, high volume for low-density products, and special protection for fragile items. Table 21-28 shows principal dimensions for some of this equipment. Of special note is the so-called damage-free (DF) equipment that provides bulkheads with the car. These form modules within the car to keep the freight from shifting during car movement, thus reducing damage.

Pallets These portable platforms, on which packaged materials can be handled and stored (Fig. 21-61 shows several designs), can be had in a variety of standard sizes and in almost any custom-made size. The dimensions, however, tend to be set by the transportation vehicle in which they will move. The older and most common 2235-mm (88-in) truck width and the 2743-mm (108-in) boxcar width have resulted in a "standard" pallet size of 1065 by 1220 mm (42 by 48 in), which fits two across in a truck (the 1065-mm side) and two across in a boxcar (the 1220-mm side), with adequate clearance for maneuvering the lift truck handling them.

There are several variations of this basic size, including the well-used Grocery Manufacturers of America size of 1220 by 1015 mm (48 by 40 in). The choice of the exact size depends on the truck and boxcar width normally available, the size of the package load, and the customer's receiving and handling facilities. Ideally, the sum of the

TABLE 21-29 Typical-Ship-Container Data*

									Capacity			
	Length		Width		Height		Volume		Maximum load†		Tare weight	
Type	ft	mm	ft	mm	ft	mm	ft^3	m^3	lb	kg	lb	kg
20-ft standard‡												
Out	20	6,096	8	2438	8	2438	1,123	31.8	52,913	24,000	4410	2000
In	19.479	5,935	7.771	2370	7.406	2258						
20-ft high§												
Out	20	6,096	8	2438	8.5	2591	1,197	33.9	52,913	24,000	4585	2080
In	19.479	5,935	7.771	2370	7.813	2383						
40-ft standard												
Out	40	12,192	8	2438	8.5	2591	2,430	68.8	59,500	26,990	7700	3490
In	39.594	12,069	7.781	2373	7.896	2405						
40-ft high												
Out	40	12,192	8	2438	9.5	2895	2,684	76.0	60,400	27,400	6800	3080
In	39.563	12,059	7.688	2344	8.823	2689						

*From Hapag Lloyd.

†This is the maximum load that the container will safely carry. The actual load will usually be less because of road weight limits, which vary from country to country and among states and other political subdivisions. In planning, these limits need to be determined with governmental authorities.

‡Liquid tank containers having these outside dimensions and holding 5055 U.S. gal (19,140 L) are available.

§This type of container is also available for dry bulk cargo.

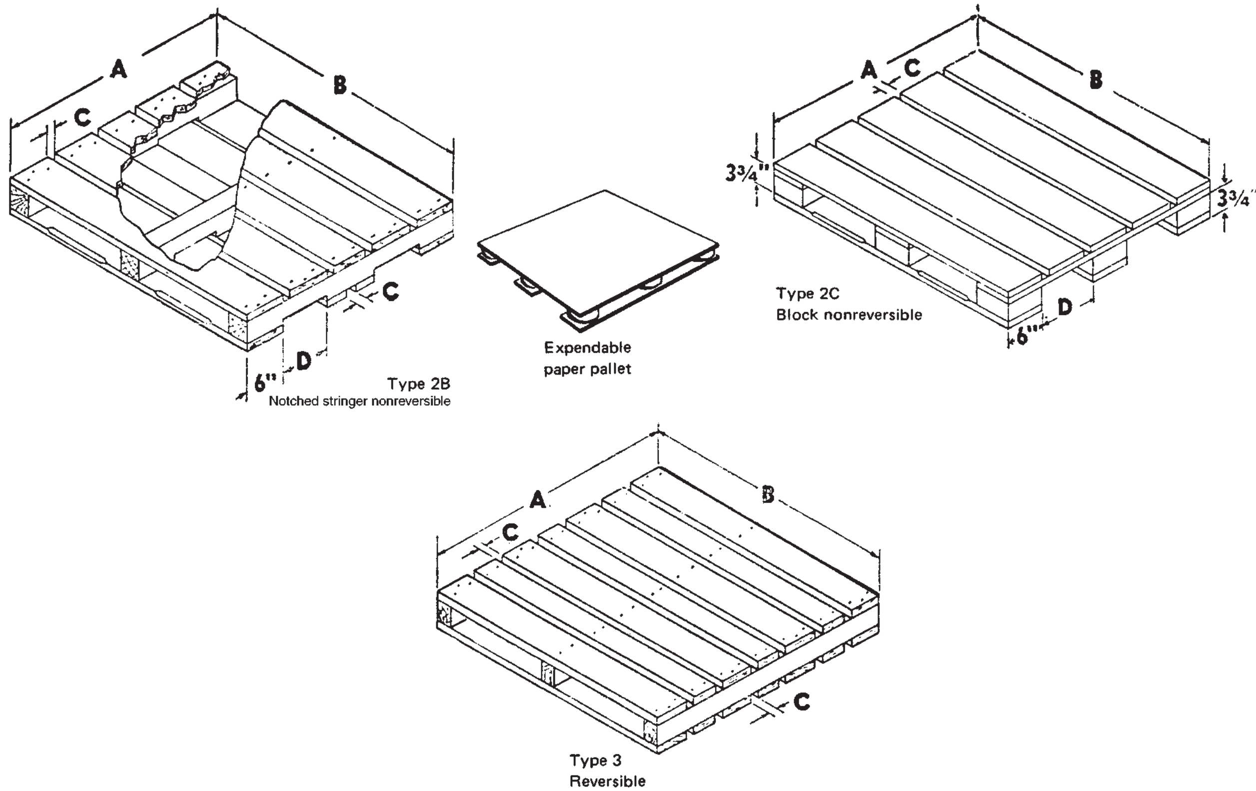


FIG. 21-61 Types of pallets. Designations are standard designs based on nomenclature of the National Wooden Pallet and Container Association, Washington, D.C. Types 2B and 2C are used for bags and corrugated cartons. Type 3 is used for drums and pails.

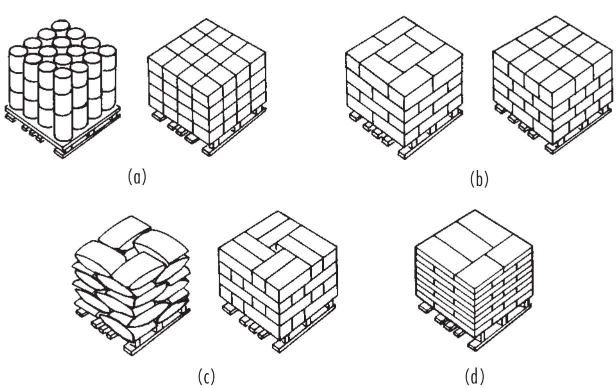


FIG. 21-62 Typical pallet patterns. (*a*) Block pattern is commonly used, although it is often unstable. It may be made more secure by encircling the top tier of containers with wire or strapping. (*b*) Brick pattern is the most commonly used. Containers are interlocked to make a relatively stable load by placing alternate tiers at a 90° position to each other. (*c*) Pinwheel pattern is used when the brick pattern is found to be unstable. Alternate tiers can be interlocked. (*d*) Three-to-two interlocking pattern is used extensively for bagged products. All pallet loads benefit from load-securing systems such as stretch wrap, shrink wrap, or palletizing adhesive.

package dimensions should exactly fit the pallet, but in practice this is virtually impossible. The following rules of thumb are helpful:

For bags: exact pallet dimensions, or up to 13-mm (½-in) overhang on each side

For cartons: pallet dimensions or underhang by 13 mm on each dimension

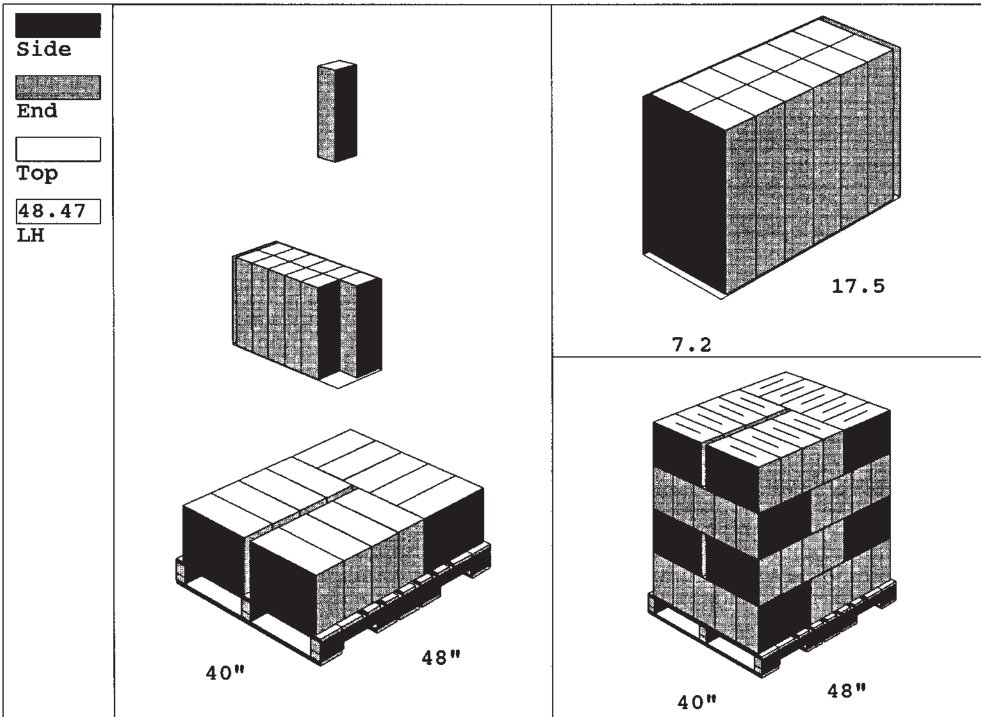
For drums, cylinders, etc.: pallet dimensions or underhang by as much as 25 mm (1 in)

Pallet patterns to achieve these conditions are numerous. Figure 21-62 shows common patterns used in the chemical-process industries.

The traditional material for pallet construction has been hardwood such as oak, ash, and maple. Yellow pine is also often used. Nails and adhesives are used to join component pieces.

The growing shortage of hardwood has increased the cost of wooden pallets to a point at which plastic pallets and composites of wood, paper, and plastics are economically feasible. Much development work is being done on plastic-pallet design to handle typical loadings. Because of the cost of disposing of expendable pallets, returnable ones are often justified.

Blocking and Bracing of Packaged Loads All transportation vehicles impart significant forces to the packages they contain. Forces of up to 2 G are regularly encountered in rail and ocean shipments, and of up to 1 G in trucks. Some forces are caused by vibration of the vehicle in the vertical plane; vibration frequencies are in the 20- to 40-Hz range. Longitudinal forces caused by starting or braking are of similar magnitude under normal conditions, but



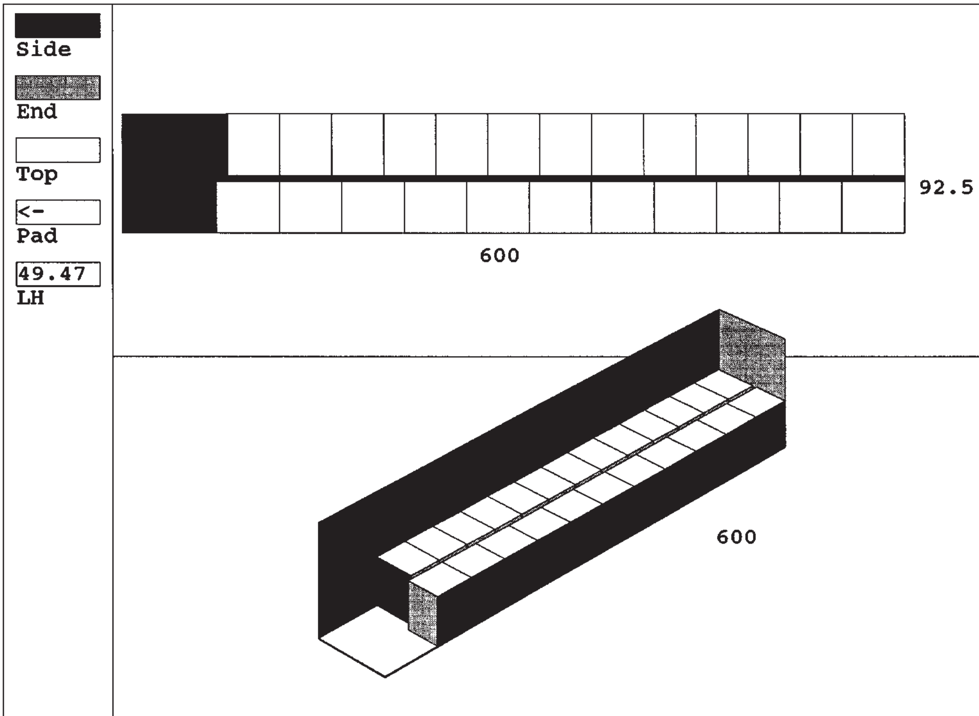
Product Name	Laundry Detergent, SPGR=1		
Product Code	LD		
Datafile Name	RUTGERS (04-04-96)	12	Bottle / Case
Solution Ref.	1 I	624	Bottle / Load
Volume Used	80.2 %	13	Case / Tier
Area Used	88.5 %	4	Tier / Load
Pallet type	48X40B	52	Case / Load

	Outside Dimension				Weight			
	Length	Width	Height		Net	Gross		Cube
Bottle	3.500	2.750	10.500	in	2.500	2.800	lb	0.06 cuft
Case	17.675	7.395	10.900	in	33.600	34.357	lb	0.82 cuft
Load	47.255	36.975	48.475	in	1747.200	1851.585	lb	53.86 cuft

FIG. 21-63*a* Use of CAPE software system for determining carton, shipping case, and pallet load dimensions and patterns for defined conditions. Shipping cases must fit within the pallet dimensions. (*Courtesy of CAPE Systems, Inc., Plano, TX, 800-229-3434.*)

severe coupling action or the starting of a long train, through slack action, can cause these forces to reach 6 to 8 G. To protect packaged freight from damage restraining systems have been developed. There are **energy-absorbing blocking and bracing systems** which can absorb these forces with little damage to the packages. Readily available at low cost, these systems are economically justified by reducing or eliminating repackaging cost and by lowering product loss due to package failure. This subject is treated in detail by J. J. Dempsey in *Methods for Loading, Bracing and Blocking of Packaged Goods in Transportation Equipment* (E. I. du Pont de Nemours & Co., Applied Technology Division, Wilmington, DE 19898), which may be purchased from Du Pont at nominal cost. **Simulation of transportation systems** on a laboratory scale is used to predict the effectiveness of freight-restraining systems before actual tryout. The effect of a system on controlling damage at various levels of impact and vibration can be determined quickly and at low cost. As a result, the risk of substantial product loss during initial trials of a new system is reduced significantly. This service is offered by several firms and by the Center for Packaging Science and Engineering, Shock and Vibration Laboratory, Rutgers, The State University of New Jersey, Piscataway, New Jersey.

Distribution packaging design applies primarily to small packages such as found in the household-chemical industry. The competitive nature of household chemicals sold in supermarkets and by mass merchandisers involves frequent change in the design of the primary package—that which is on the supermarket shelf—with a consequent redesign of the secondary protective package in which the point-of-sale packages are shipped. This further influences pallet pattern and loading. Redesign using manual methods can be time consuming, and finding an optimum package is difficult. The era of the personal computer has changed all this. Software which can be run on most 486 personal computers can rapidly evaluate alternative designs and a near optimum established. The CAPE software mentioned previously provides a real-time ability to not only rapidly design the primary and



Product Name	Laundry Detergent, SPGR=1		
Product Code	LD		
Datafile Name	RUTGERS (04-04-96)		
Solution Ref.	1 C		
Volume Used	35.6 %	24	Case / Tier
Area Used	83.0 %	1	Tier / Load
Pallet type	50FTTRCK	24	Case / Load

	Outside Dimension				Weight			
	Length	Width	Height		Net	Gross		Cube
Case	48.000	40.000	48.475	in	1881.600	1924.014	lb	53.86 cuft
Load	527.912	92.480	49.475	in	45158.4	46177.3	lb	1589.04 cuft

FIG. 21-63*b* Use of CAPE for determining trailer loading for conditions of Fig. 21-63*a*, where the maximum cargo weight cannot exceed 46,800 lbs (21,228 kg). Note: CAPE can also give SI units. For Fig. 21-63*a* and *b*, multiply in × 25.4 for mm; cu ft × .02832 for m^3, and lbs × 0.4538 for kg. (*Courtesy of CAPE Systems, Inc., Plano, TX, 800-229-3434.*)

secondary packages and pallet loading, but also determine truck-loading patterns based on highway and road-limit restrictions. Figures 21-63, *a* and *b,* show the design for a one-liter bottle of laundry detergent whose basic dimensions of width, thickness, and height were determined by the industrial designer responsible for the artistic design of the bottle. The CAPE software rapidly evaluates this and in the example given has the restrictions that there can be no overhang of shipping containers over the pallet edges, and that the number of point-of-sale packages in a shipping container is twelve but it can be in any pattern or combination so long as there are twelve bottles in a shipping container. The highway-load restriction is 46,800 pounds. The operation of the CAPE program including loading it into the PC, setting up the case study given, and obtaining results took less than five minutes.