CHAPTER 3

Screening

THE separation of materials on the basis of size is frequently important as a means of preparing a product for sale or for a subsequent operation. It is also a widely used means of analysis, either to control or gage the effectiveness of another operation, such as crushing or grinding, or to determine the value of a product for some specific application.

In the marketing of coal, for example, the size of the particles is the basis of its classification for sale. Certain equipment such as stokers require definite limits of size for successful operation. In the case of sand and gravel for concrete, on the other hand, only a properly blended series of sizes will insure the most dense packing, requiring the minimum of cement and securing the greatest strength and freedom from voids.

It has frequently been observed that the rate of a chemical reaction between a solid and a fluid is roughly proportional to the surface involved. Since the surface areas may be computed from a knowledge of the sizes of the particles, a sizing operation is of particular value in controlling the rates of reactions involving solids. The combustion of powdered coal illustrates the desirability of controlling the grinding operation to produce material of definite size limits in order to control the rate of combustion. Since the setting of Portland cement must take place within a specified time, it has been necessary to specify certain size limits. The hiding power of a paint pigment is indicated by size since it depends upon the projected area of the particles.

Screening is accomplished by passing the material over a surface provided with openings of the desired size. The equipment may take the form of stationary or moving bars, punched metal plate, or woven wire mesh. Screening consists in separating a mixture of various sizes of particles into two or more portions, each of which is more uniform in size of particle than is the original mixture.

Dry screening refers to the treatment of a material containing a natural amount of moisture or a material that has been dried before screening. Wet screening refers to an operation in which water is added to the material being treated for the purpose of washing the fine material through the screen.

The material that fails to pass through the screen is referred to as oversize or plus material, and that which passes through the screen openings is referred to as undersize or minus material. When more than one screen is used and more than two sizes are produced, the various fractions may be designated according to the openings employed in making the separations. For example, Table 2 shows three different ways of indicating sizes.

TABLE 2. THREE METHODS OF INDICATING SIZE FRACTIONS

First	Second	Third
Oversize $\frac{1}{4}$ in.	$+\frac{1}{4}$ in.	$+\frac{1}{4}$ in.
Through $\frac{1}{4}$ in. on $\frac{1}{8}$ in.	$-\frac{1}{4} + \frac{1}{8}$ in.	$\frac{1}{4}/\frac{1}{8}$ in.
Through $\frac{1}{8}$ in. on $\frac{1}{16}$ in.	$-\frac{1}{8} + \frac{1}{16}$ in.	$\frac{1}{8}/\frac{1}{16}$ in.
Undersize	$-\frac{1}{16}$ in.	$\frac{1}{16}/0$ in.

INDUSTRIAL SCREENING EQUIPMENT

Grizzlies are widely used for screening large sizes, particularly of 1 in. and over. They consist simply of a set of parallel bars separated by spacers at the ends. The bars may be laid horizontally or inclined longitudinally 20 to 50 degrees from the horizontal, depending upon the nature of the material treated.

as well as to furnish data for estimating the power or energy required.

Ores of metals consist of varying amounts of valuable minerals associated with undesired gangue minerals. The first step in processing ores for the recovery of metal values is the separation of the values from the gangue, since the ore as taken from the mine contains both types of minerals together in solid masses. Unless the valuable mineral exists in great enough concentration to permit the ore to be reduced to the metal without previous treatment, in which case the gangue is usually separated in the molten state, it is necessary to break up the ore mass mechanically, thus freeing the valuable minerals from the gangue. The minerals are then separated by gravity or flotation methods resulting in concentration of the valuable minerals.

The purposes of size reductions are therefore twofold: (1) To produce solids with desired size ranges or specific surfaces. (2) To break apart minerals or crystals of chemical compounds which are intimately associated in the solid state.

STAGES OF REDUCTION

For successful size reduction, it is necessary that every lump or particle must be broken by contact with other particles or by direct contact with the moving parts of the machine. As the breaking action proceeds, the number of particles increases, requiring more contacts per unit mass. Thus the capacity of a particular machine of fixed dimensions, as in tons per day, is much less for small sizes than for the larger sizes, since it is necessary for the smaller particles to remain in the machine for longer periods of time to sustain the required number of contacts. No device has been developed capable of automatically adjusting itself to the varying requirements of contact. In commercial operations, sufficient capacity in the intermediate and fine ranges of size reduction is obtained either by operating several similar units in parallel or, better, by employing machines which furnish greater numbers of contacts per unit of time.

Machines providing the required large number of contacts, particularly for smaller-size material, have been developed, primarily for the last stages of size reduction.

For commercial reduction in size of masses of solids 1 ft or more in diameter to 200-mesh size, usually at least three stages or steps are followed which are divided according to the types of machines best adapted to each stage. The three steps are:

1. Coarse size reduction: feeds from 2 to 96 in. or more.
2. Intermediate size reduction: feeds from 1 to 3 in.
3. Fine size reduction: feeds from 0.25 to 0.5 in.

OPERATING VARIABLES

The *moisture content* of solids to be reduced in size is important. If it is below 3 or 4 per cent by weight, no particular difficulties are encountered; indeed, it appears that the presence of this amount of moisture is of real benefit in size reduction if for no other reason than for dust control. When moisture content exceeds about 4 per cent, most materials become sticky or pasty with a tendency to clog the machine. This is particularly true in the coarse and intermediate stages.

A large excess of water (50 per cent or more) facilitates the operation by washing the feed into and the product out of the zone of action and by furnishing a means for transporting the solids about the plant as a suspension or slurry. *Wet grinding* is mostly confined to the fine stage of reduction.

The *reduction ratio* is the ratio of the average diameter of the feed to the average diameter of the product. Most machines in the coarser ranges of crushing have a reduction ratio from about 3 to 7. Fine grinders may have a reduction ratio as high as 100.

In *free crushing*, the crushed product with whatever fines have been formed is quickly removed after a relatively short sojourn in the crushing zone. The product may flow out by gravity, be blown out with compressed air, be washed out with water, or be thrown out by centrifugal force. This method of operation prevents the formation of an excessive amount of fines by limiting the number of contacts.

In *choke feeding* (the antithesis of free crushing), the crusher is equipped with a feed hopper and kept filled (or choked) so that it does not freely discharge the crushed product. This increases greatly the proportion of fines produced and decreases the capacity. In some instances choke feeding may result in economy of operation, eliminating one or more reducing stages because of the large quantity of fines produced.

Each stage in size reduction may, and frequently does, have a size-separating unit following it. If the

The mechanical energy supplied to the crusher is always greater than that indicated by Rittinger's number, as friction losses and inertia effects in the equipment require more energy than the actual production of new surface. Also, fracture is accomplished, not by static loading, but by exceeding the minimum rate of loading or deformation. Even brittle substances adjust themselves to slowly applied loads, and fracture does not occur the instant the load is applied but only when the rate of loading exceeds a certain minimum.

The total energy supplied to the crusher, therefore, depends upon the rate of load application, which differs with the type of machine and conditions of operation. Table 10 gives values for the new surface produced per unit of energy supplied to the material being crushed in a laboratory ball mill operated at the same speed but with varying weights of similar balls in the machine while grinding equal weights of quartz.

TABLE 10. EXPERIMENTAL VALUES OF NEW SURFACE PRODUCED PER UNIT OF ENERGY FOR QUARTZ

Calculated by subtracting the energy required to drive the mill containing balls but no material from the total energy required to drive the operating mill for the same length of time.

Total Weight of Balls in Ball Mill, lb	sq in./ft-lb	sq cm/ft-lb	sq cm/kg-cm
36	5.6	36	2.6
71	10.1	65	4.6
142	12.7	82	5.9
178	14.6	94	6.8
249	12.1	78	5.6
Drop weight method	37.6	243	17.56

The new surface produced per unit of energy supplied to the material being crushed in a ball mill is much less than for the drop weight crusher. This may be explained by the high percentage of ineffective blows and other losses in the ball mill. The important practical point is the variation in effectiveness of size reduction with the total weight of balls charged, showing a maximum value at about 175 lb of balls in this particular mill.

Values of the Rittinger number as determined in the drop weight crusher represent maximum effectiveness in size reduction and may be used in calculating the *crushing effectiveness* for any such operation. In the ball mill with 178 lb of balls, the crushing effectiveness is 94/243 = 0.387. In this manner the performance of various machines, and variations in the same machine, can be compared.

The overall energy effectiveness (or efficiency) of a crusher is always much less than the crushing effectiveness, as the latter does not include the mechanical losses such as friction and inertia. The capacity of ball mills cannot be accurately calculated because of the effects of variables such as the relative grindability of the material and the range in size reduction. An approximate idea of the capacity and power requirements of ball mills, both cylindrical and conical, may be gained by reference to Table 11.

TABLE 11. CAPACITY AND POWER REQUIREMENTS OF BALL MILLS

Size, ft, diameter × length	Approximate Ball Load, lb	Approximate Rpm	Approximate Average Capacity, tons/24 hr: ½ in. to 48 mesh	½ in. to 65 mesh	⅛ in. to 100 mesh	Motor Horsepower
3 × 2	1,000	35	[illegible]	9	5	6-8
3 × 4	2,000	35	24	18	10	12-15
4 × 4	3,300	30	42	30	20	20-25
5 × 4	5,000	29	80	55	30	30-40
5 × 6	7,500	29	120	85	50	40-50
6 × 3	6,000	25	125	85	50	50-60
6 × 5	10,000	25	210	150	90	75-100
6 × 6	12,000	25	250	175	100	90-120
6 × 12	24,000	25	500	340	200	150-200
7 × 6	21,600	23	500	350	200	110-160
8 × 6	28,000	22	620	450	260	150-225
10 × 9	74,000	17	1500	1100	650	550-600
Cylindroconical Mills						
2 × 3⅓	600	40	4	3	2	2
3 × 3⅓	1,100	35	12	10	9	5-8
3 × 2	2,000	35	17	15	13	10
5 × 3	9,500	28	100	80	60	40-50
6 × 3	15,000	24	180	120	90	60-75
7 × 4	27,000	23	300	220	150	125
8 × 4	38,000	21	480	350	270	175-200
12 × 6	110,000	16	1800	1400	1000	700-800

Illustrative Example. A ball mill operating in closed circuit with a 100-mesh screen gives the screen analyses below. The ratio of the oversize to the undersize (product) stream is 1.0705 when 200 tons of galena are handled per day.

The ball mill requires 15.0 hp when running empty (with the balls but without galena) and 20.0 hp when delivering 200 tons per day of galena. Find:

1. The effectiveness of crushing based on drop weight crushing as 1.00.
2. The overall energy efficiency.

TABLE 15. MAXIMUM LUMP SIZE AND SPEEDS FOR CONVEYOR BELTS

Belt Width, in.	Maximum Lump Size, in. Uniform Size	With 90% Fines	Cross-Sectional Area of Load, sq ft	Normal Speed, fpm	Maximum Belt Speeds, fpm Free-Flowing Material *	Average Material †	Abrasive Material ‡
14	2	3	0.11	200	400	300	250
16	2½	4	0.14	200	500	300	250
18	3	5	0.18	250	500	400	300
20	3½	6	0.22	300	600	400	300
24	4½	8	0.33	300	600	500	350
30	6	11	0.53	350	700	500	350
36	8	15	0.78	400	800	600	400
42	10	18	1.09	400	800	600	400
48	12	21	1.46	400	800	600	400
54	14	24	1.90	450	800	600	400
60	16	28	2.40	450	800	600	400

* Free-flowing includes such materials as grain and fine-sized anthracite coal.

† Average includes such materials as coal, crushed stone, sand, and fine ore.

‡ Abrasive includes such materials as coke, screened lump coal, gravel and coarse ore.

TABLE 16. MAXIMUM CAPACITIES * FOR CONVEYOR BELTS

Belt Width, in.	Cu Yd/Hr at 100 Fpm	Maximum Capacity with Materials of Various Bulk Densities, tons/hr at 100 fpm: 25 Lb/Ft³	50 Lb/Ft³	75 Lb/Ft³	100 Lb/Ft³	150 Lb/Ft³
14	23.6	8	16	24	32	48
16	31.1	10	21	31	42	63
18	39.6	13	27	40	54	81
20	49.3	16	33	49	66	99
24	72.4	24	49	73	98	147
30	116.7	39	79	118	158	237
36	173.3	57	115	172	230	345
42	242.2	82	165	247	330	495
48	324.4	110	220	330	440	660
54	422.2	142	285	427	570	855
60	533.3	180	360	540	720	1080

* Operating capacities of flat belt conveyors are taken at one-half of those listed. Capacities of inclined conveyors are 5 to 10 per cent less than listed. For material weights and speeds other than shown above, use direct proportion for tonnage calculations.

TABLE 16A. APPROXIMATE WEIGHTS OF CONVEYORS

Flight conveyors	
4 × 10 to 6 × 18	0.5 lb/in. of width per running foot
8 × 18 to 10 × 24	1.0 lb/in. of width per running foot
Belt conveyors	1.0 lb/in. of width per running foot

Actual dimensions and weights are available in manufacturers' catalogues.

Power requirements for trippers may be computed as follows.

$$\text{hp} = YS + ZT$$

where S = belt speed (fpm).
T = peak capacity (tons/hr).

Y and Z are constants from following table.[3]

Constant	Width of Belt, in. 14	16	18	20	24	30	36	42	48	54
Y	0.0020	0.0020	0.0026	0.0029	0.0034	0.0047	0.0060	0.0069	0.008[illegible]	0.0100
Z	0.0035	0.0035	0.0035	0.0040	0.0040	0.0050	0.0050	0.0055	0.0060	0.0070

An interesting modification of the belt conveyor is the zipper conveyor which is essentially a belt conveyor with the edges zipped together to form an endless tube (Fig. 60). In operation the tube is closed after being loaded and is zipped open at the point of discharge, remaining open until the loading point is reached. Because the tube is flexible and completely encloses the material, it may travel around corners at any angle and in any plane.

Apron conveyors are similar to belt conveyors in that solid materials are carried in a moving trough, but the trough is formed of articulating sections of wood or metal instead of a continuous flexible belt. Apron conveyors are frequently employed when the material to be conveyed is lumpy, abrasive, hot, or otherwise injurious to flexible belts. Their weight restricts apron conveyors to relatively short hauls and much lower speeds, but they are capable of carrying much heavier loads than belt conveyors. The only discharge point is at the head end of the conveyor.

Apron conveyors may appear in several types of construction, but the usual form, shown in Fig. 61, consists of two endless strands of roller chain which are connected by double-beaded steel pans. The idea of the beading is to maintain a continuous trough to prevent leakage in transit, and to prevent material from being wedged between the aprons when the load is being discharged at the head end of the conveyor. The beading also prevents material from slipping backward when the conveyor is