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HANDBOOK OF ORE DRESSING

BY

ARTHUR F. TAGGART

Professor of Ore Dressing, School of Mines, Columbia University

CONTRIBUTORS

FREDERICK E. BEACH — R. C. CANBY
HENRY A. BEHRE — W. RAYMOND LONGLEY
JOHN M. CALLOW — CHARLES T. PORTER
PERCEY F. SMITH

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produce the "Star-brand" ingots. Antimonial or HARD LEAD containing 10 to 20 per cent. Sb is obtained as a by-product in smelting and refining antimonial-lead concentrate.

5. Arsenic, As

Properties. Metal: steel-gray, lustrous and crystalline, or black, dull and amorphous; brittle. (See also Table 1.) AT. WGT., 75.0. Unaltered in dry air, becomes tarnished in moist air, burns at 180° C. in air or oxygen with bluish flame forming arsenic trioxide. Not attacked by water. Does not dissolve in hydrochloric or sulphuric acid or bases, but is slowly oxidised and dissolved by nitric acid. Combines directly with most elements. Arsenic is tri- and quinque-valent and both base- and acid-forming. It alloys with many metals, almost invariably forming a brittle alloy.

Uses. The principal uses are for insecticides such as Paris green and lead arsenate for plant sprays and calcium arsenate for boll-weevil extermination. Sodium arsenite is used in considerable quantities on railroads and highways for a liquid weed killer. The white oxide is used in glass making to mask the coloring effect of metallic oxides and impart brilliancy. It is also used in making sheep and cattle dips. The red and yellow sulphides are used for pigments in paints, calico printing, dyeing and tanning. Small amounts of the element are used for certain alloys, principally lead shot.

Ores. Arsenic occurs as a constituent of 30 or more minerals (Hess, *MR. 1914 p. 957*), but the principal sources are arsenopyrite, arsenides and sulph-arsenides associated with ores of lead, copper and the precious metals, the arsenic being a by-product. Arsenopyrite is mined for the arsenic content in a few places. Realgar and orpiment occur as vein minerals associated with barite, stibnite, quartz, pyrite, and precious metals, but there is little or no mining of such deposits for arsenic content.

Production. See Table 8.

Table 8. World's production of white arsenic (in metric tons) (*MR and MI*)

Country	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923
United States	[illegible]	[illegible]	[illegible]	5430	[illegible]	5738	5409	10,4[illegible]	4112	9096	12,947
Canada	1535	1770	2174	1953	2063	3230	3075	2,251	1353	2337	3,307
France	...	132	324	574	677	993	735	[illegible]	. . .	. . .	......
Germany	1892	[illegible]	[illegible]	[illegible]	2051	3302	1475	2,0[illegible]	[illegible]	2060	......
Japan	21	15	13	....	....	245	833	[illegible]	1365	2041	......
Mexico	...	...	...	...	1255	1881	2246	2,15[illegible]	755	271	......
Portugal	[illegible]	[illegible]	[illegible]	...	...	.....	536	[illegible]	[illegible]	.	......
United Kingdom	1722	[illegible]	[illegible]	[illegible]	[illegible]	2387	2765	2,0[illegible]	1019	994	......
Others (a)	600	[illegible]	[illegible]	560	820	425	1120	2,1[illegible]	1910	2365	......

a Includes Belgium, China, Greece, Queensland, Rhodesia, Spain, Union of South Africa.

Table 9. Price range of arsenic [illegible]. (*MR, MI, J*)

Year	Cents per lb.
1916	3.5 to 8
1917	8.2 to 15
1918	9
1919	6 to 10.5
1920	9.1 to 11.5
1921	7 to 12
1922	6.6 to 14.5
1923	9 to 15.5
1924	6 to 15.5

Selling. The commercial form is the trioxide, 99 per cent. or better purity, white and finely powdered. A small amount of lower-grade off-color material is sold. The price has increased in recent years due to the growing use of calcium arsenate in controlling boll-weevil damage to cotton. Production facilities have increased greatly as a result until now they are probably in excess of normal demand. Range of 5-yearly average prices of trioxide

from 1901 to 1915 was 2.74 to 3.15 cents per lb. Range since 1915 is given in Table 9.

Treatment. Arsenical fumes and dust from bag houses and Cottrell precipitators in lead and copper smelters are calcined or roasted in reverberatory or special furnaces and the fume condensed in an ordinary flue system. This fume is known as black dust and contains about 90 per cent. As_2O_3. It is refined in a coke-fired furnace connected to a special flue system in which the refined (+ 99 per cent.) As_2O_3 collects.

6. Asbestos

Properties. Asbestos is a name describing a fibrous form of several different minerals rather than the name of one definite mineral. The usual minerals that occur in fibrous form and are classed as asbestos are chrysotile, $3\,MgO \cdot 2\,SiO_2 \cdot 2\,H_2O$, a variety of serpentine; tremolite, $CaO \cdot 3\,MgO \cdot 4\,SiO_2$; actinolite, $CaO \cdot 3(Mg,Fe)O \cdot 4\,SiO_2$; crocidolite, $NaFe(SiO_3)_2 \cdot FeSiO_3$; and anthophyllite $(MgFe)O \cdot SiO_2$, all varieties of amphibole. Another variety of amphibole recently discovered in South Africa and there mined is called amosite. Its ANALYSIS, compared with average analyses of chrysotile, crocidolite and anthophyllite is given in Table 10. SP. GR. of chrysotile is 2.2 to 2.65 and of the amphibole varieties, 2.9 to 3.2. LENGTH OF FIBER ranges ordinarily from ½ in. or less to 1½ or 2 in.; exceptionally fiber as long as 24 in. has been found. Amosite fiber is longer than the average. Fiber strength and flexibility, fineness of fiber, and resistance to heat and acids are important elements in judging the value of asbestos. Chrysotile has high flexibility and medium strength and resistance to heat and acids. Crocidolite has higher tensile strength than chrysotile but less resistance to heat. Anthophyllite has low strength and flexibility but high resistance to heat and acids. Amosite has less strength and flexibility than chrysotile, but is similar in its resistance to heat and acids.

Table 10. Analyses of asbestos minerals [illegible]

	Chrysotile *a*	Crocidolite *b*	Amosite *c*	Anthophyllite *e*
SiO_2	40.49	51.64	50.24	57.12
Al_2O_3	1.27	....	....	0.75
FeO	.....	....	7.60	6.30
Fe_2O_3	2.53	34.38	32.09	
MgO	41.41	2.64	3.96	29.44
CaO	....	0.05	Tr.	....
Na_2O	.....	7.11	2.12	.....
Water	14.05	4.01 *d*	3 (*d*)	5.47

a Cirkel, F. Chrysotile asbestos, its occurrence, exploitation, milling and uses, 2nd ed. Mines Branch, Canada Dept. of Mines, 1910. *b* Dana, System of Mineralogy. *c* Private analysis. *d* Ignition. *e* Asbestos, 1913–1919, Imperial Mineral Resources Bureau (Great Britain), 1921, p. [illegible].

Uses. Asbestos is used widely for purposes involving resistance to acids and to relatively low degrees of heat. Long-fiber material is consumed principally in making automobile brake bands; other uses are for fireproof curtains and articles of clothing, packings and gaskets, thread and wicking, electrical insulation, chemical laboratory apparatus and supplies, etc. Short-fiber grades are used in making shingles and asphaltic roofings, pipe coverings, paper and millboard, and asbestos cements that are used for heat insulation on hot and cold pipes, stoves and furnaces, fireproof safes and the like.

Ores. Asbestos fiber occurs in three forms in the country rock, known respectively as cross-fiber veins, slip-fiber veins and mass fiber. In cross-fiber veins the filaments are oriented at right angles to the vein walls. Filaments in slip-fiber veins are not so regularly oriented as the cross-fiber, but such orientation as exists is generally parallel to the vein walls. Mass fiber is in unoriented masses disseminated through the country rock. Cross-

fiber is much the best from the point of view of fiber length. The veins of asbestos occur in association with serpentine in limestone and dolomite and in altered peridotites.

Production. The United States is the principal consumer of asbestos but a negligible producer. Imports of unmanufactured asbestos have increased from 64,000 long tons in 1914 to nearly 190,000 in 1923, while production since 1918 has ranged between 67 tons minimum in 1922 and 1650 tons maximum in 1920. Canada is the principal world producer, with a record volume of 233,000 short tons in 1923. In the same year Rhodesia produced about 20,000 tons; Union of South Africa, 8400 tons; and scattered small amounts were mined in Australia, Corsica, Cyprus, Madagascar, New Zealand and Russia. The latter country exported about 11,000 tons annually before the revolution.

Selling. Fiber is graded differently by different producers, but in general, the grading corresponds approximately to that shown in Table 11 (*113 J 877*). The average price of all grades sold in Canada ranged between $10 and $20 per ton from 1912 until 1916, when it began to climb, reaching $80 in 1919. The peak was reached in 1921. In that year No. 1 crude sold at $3000 per ton compared to $350 in 1913.

Table 11. Grades and prices of Canadian asbestos

Trade name	Fiber length	Price (Oct., 1925), dollars per short ton
No. 1 crude	+ ¾-in.	400–450
No. 2 crude	− ¾, + ¼-in.	250–300
Long spinning fiber	2-8-4-2*a*	110–175
Magnesia and compressed-sheet fiber	0-8-6-2*a*	75–110
Pipe-covering fibers	0-5-8-3*a*	100
Shingle stock	0-1½-9½-5*a*	50–75
Paper and mill-board stock	0-0-10-6-*a*	35–45
Cement stock	0-0-5-11*a*	8–12
Floats or shorts (*b*)		8–12
Sand		6–8

a Mill fiber is tested in a standard machine consisting of three nested shaking screens, respectively 2-mesh 11-gage, 4-mesh 17-gage and 10-mesh 20-gage, and a bottom box. Screen frames and box are of wood, rectangular, 16 × 26 in. × 3 in. deep. A 1-lb. sample is placed on the top (coarsest) screen and the nest is mechanically shaken for two minutes at 300 r.p.m. Oversizes and final undersize are weighed in ounces and the weights in order from coarse to fine are recorded, as in the table. Thus 2-8-4-2 means 2 oz. on 2-mesh, 8 oz. on 4-mesh, 4 oz. on 10-mesh, and 2 oz. through 10-mesh. *b* This is material finer than any of the preceding and containing much dust and dirt.

Treatment of asbestos-bearing rock involves many problems not present in ordinary concentrating practice. In the first place, as may be seen by reference to Table 11, the value of long fiber is much greater than the value of the same material in shorter lengths, hence every endeavor is made to prevent fiber breakage. The valuable and gangue minerals are not of sufficiently different specific gravities to make them separable by gravity-concentration processes without close sizing, and the nature of the asbestos aggregates prevents such preparation. As a result of these facts a system of treatment has evolved that consists of coarse crushing, drying, screening, separating asbestos from screen oversize by suction, and subsequently separating rock dust from the sucked-up product by screening. This final screening is arranged to divide the asbestos into market grades (see Table 11). Crushing

is carried down as far as possible in jaw and gyratory crushers because these machines do the least injury to fiber. Rolls are unsuitable as they mat together the fiber and associated clayey material. In the fine-crushing section free fiber is separated ahead of each crusher. Treatment differs somewhat according to whether the ore is of the cross-fiber variety or slip or mass-fiber rock. Ru Keyser (*113 J 67*) gives the generalized flow-sheets shown in Figs. 1 and 3 to illustrate typical Canadian practice.

Recent experiment has indicated a good possibility that coarse fiber may be separated by jigging and fine fiber by tabling, the fiber discharging, irrespective of specific gravity, from the tailing outlets of the respective machines. The principle involved is the same as that which acts in the present screening practice, i.e., the fiber works to the top (more properly, the granular material works to the bottom) of a mass of rock and asbestos when it is sufficiently agitated to give the particles partial relative mobility, due to the fact that the elongated and somewhat fluffy asbestos bridges over the interstices in the mass while the granular rock particles enter these interstices and work toward the bottom. If further experiment proves wet separation effective, milling plants should be much improved. Dust with its evil mechanical and physiological effects will be largely eliminated, drying will be confined to a small proportion of the mill tonnage, and it should be possible to substitute cylinder mills for the relatively inefficient jumbos, cyclones, and the like.

Typical slip-fiber asbestos mill. Fig. 1. (*113 J 67*)

Location: East Broughton, Que., Canada.
Ore: Chrysotile in serpentite associated with basic igneous rocks. Slip-fiber occurrences.

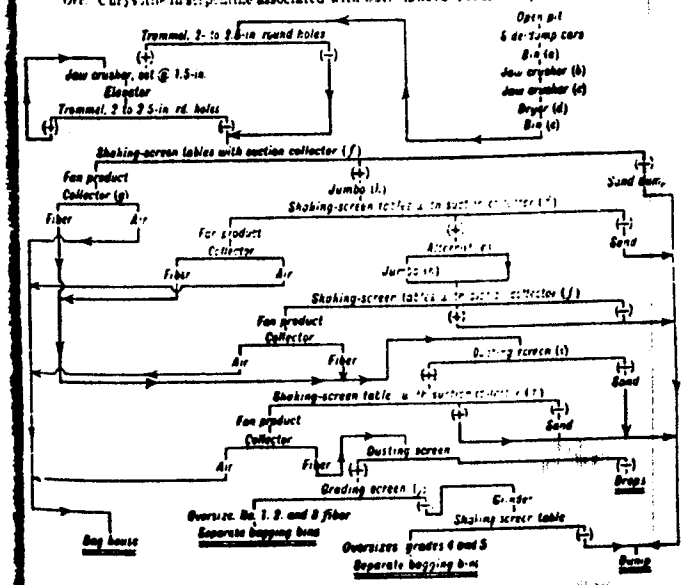


FIG. 1.—Typical slip-fiber asbestos mill.

a, Usually not more than 1-day capacity. Great difficulty is encountered in moving material through this bin in winter on account of freezing. At the JOHNS-MANVILLE

plant the ore dump directly into the primary crusher (see note *b*). *b*, At Kyle mine, 2 @ 32 × 72-in. At Johns-Manville 1 @ 60 × 84-in. set 10 in. Capacity 3000 tons per 8 hr. Nip angle 18° on account of slippery nature of rock. *c*, At Kyle mine, 3 @ 15 × 30-in. set 2.5-in. Usual practice in 2 or 3 stages of jaw or gyratory crushing from run-of-mine to 2- or 2.5-in. *d*, In all but one mill rotary cylindrical dryers of either the direct- or indirect-heat type are used, 4½ to 6 ft. diam. × 30 to 50 ft. long. One mill uses a tower dryer 40 ft. high. Extent of drying is important. Too little makes subsequent separation difficult, too much causes partial dehydration and injury of fiber. *e*, Bulk of storage capacity is usually placed at this point. At two of the mines dry-rock bin capacity is 25,000 tons. With such storage it is possible to keep the mill running and shut down the quarry and coarse crushers in the worst weather. *f*, These average about 6 ft. wide × 20 ft. long, frequently stepped into 2 or 3 decks, and are covered with screen having about ⅜-in. openings. Speed @ 300 r.p.m. The suction pipe of a rotary fan, suitably shaped (see Fig. 2), is suspended above the screen near the end of each deck. *g*, Usual conical type. *h*, Or other type of disintegrator, e.g., cyclone, swing-hammer pulverizer or the like. (See Sec. 4, Art. 21.) *i*, Usually a rotary or hexagonal trommel with about 1-in. screen. Vibrating screens are now coming into use. *j*, Screen apertures corresponding to those on asbestos-testing sieves, viz., 2-mesh, 4-mesh and 10-mesh. (See note *a* Table 11.)

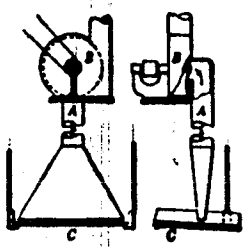


FIG. 2.—Suction fan for asbestos table.

Capacity: 50 to 1000 tons per 24 hr.

Assays: Feed and products are not capable of ordinary chemical assay, and an actual run is necessary in order to determine the amount of recoverable fiber present.

Recovery is stated as the percentage of total rock mined (or milled) that is shipped as asbestos. This method, of course, gives no measure of the efficiency of the concentrating process. Average per cent. of fiber extraction at the Quebec mines has been between 6 and 7.

Cost: Ru Keyser gives the following as typical of an 800-ton plant in 1919: Total expense per ton mined and milled, $1.65; value of ore per ton milled, $2.60; recovery of fiber, 4.61 per cent.; average selling price of fiber, $65 per ton; average operating cost of producing fiber, $15 per ton.

Typical cross-fiber asbestos treatment (*113 J 62*). Fig. 3.

Location: Thetford district, Que., Canada.

Ore: Chrysotile in serpentine.

Capacity: 900 to 1000 tons per 24 hr.

Assays: See corresponding note on slip-fiber mills.

Recovery: See corresponding note on slip-fiber mills. Recovery of No. 1 crude ranged downward from 0.1 per cent. in 1910 to 0.033 per cent. in 1920. Recovery of No. 2 crude has increased in the same time but total recovery of crude is not, in general, over 0.75 per cent.

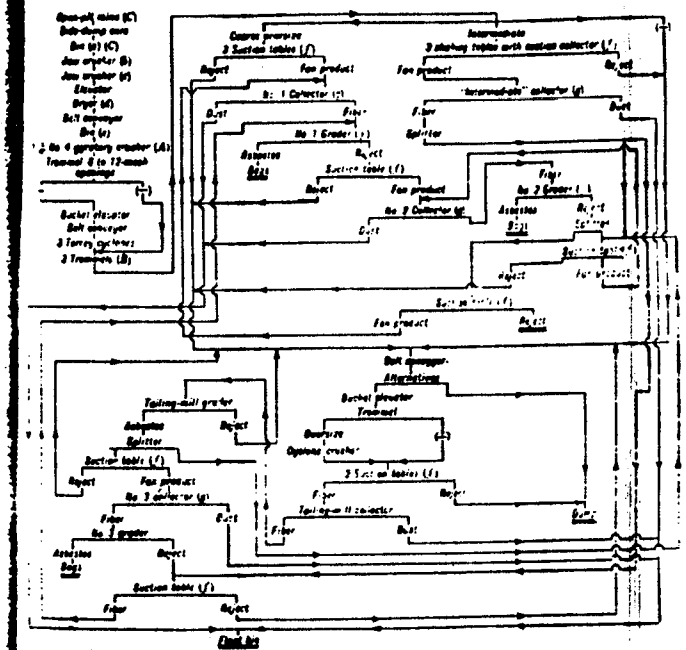
Cost: Ru Keyser gives the following as typical of 1911 operation. Value of fiber per ton of rock mined, $2.51; value of crude and fiber per ton mined, $3.43; total expense per ton mined and milled, $1.48; average value of fiber, $329.75 per ton; average total expense per ton of fiber, $147.25. Cost of milling, bagging, loading and mine (and mill) overhead is about 45 to 50 cents per ton milled. About two-thirds of the rock mined goes to the mill.

7. Barite, $BaSO_4$

Properties. Crystalline, concretionary or earthy. COLOR: white when pure; impure varieties are red, yellow, gray, blue or brown. LUSTER: vitreous to resinous or pearly. Sp. gr., 4.3 to 4.6. HARDNESS, 2.5 to 3.5. Insoluble in water and acids. Decrepitates and loses SO_3 on heating; fuses at high temperatures.

Uses. The principal uses are in the manufacture of white pigments and in making barium chemicals for various uses. Ground barite itself is used as a pigment, as a filler for paper, cardboard, rubber, linoleum, artificial ivory and in many other places where a heavy, inert filler is desired. LITHOPONE, which is the principal barium pigment, is composed of about 70 per cent. precipitated barium sulphate and 30 per cent of a mixture of 1 to 3 per cent zinc oxide and the balance zinc sulphide (see *Ledoux, Non-metallic minerals*,

p 78, for outline of method of manufacture). Various barium chemicals, including the precipitated sulphate, the nitrate, chloride, sulphide, oxides and hydroxide, chlorate and chromate are used in the manufacture of white-rubber goods, asbestos cement, ceramics, enamels, boiler compounds, insecticides, fertilizers, hydrogen peroxide, special glass, etc. (For detailed extensive list of uses see *Bul. 85, Geol. Surv. of Ga.*) Forty to 50 per cent. of the barite produced goes into lithopone manufacture, 25 per cent into manufacture of barium chemicals; the balance is ground to fine powder and used thus.



a, *b*, *c*, etc., For lower-case reference numbers read notes to Fig. 1. *A*, Probably better practice than the jaw crusher in corresponding position in slip-fiber 2-in. plant. *B*, Two screens on each, finer than 12-mesh. *C*, Ore is usually cobbled both at the mine and ahead of or following the primary breaker for the recovery of "crude" fiber.

FIG. 3.—Typical cross-fiber asbestos mill.

Ores. Barite ($BaSO_4$) and witherite ($BaCO_3$) are the principal economic minerals. United States deposits are barite in the form of particles ranging from small grains to masses containing 1 or 2 cu. ft. together with grains and masses of chert in residual, unconsolidated clays and soils. The barite particles may be either hard and crystalline or soft and granular. The latter is preferred, as it is easier to grind. Some foreign barite deposits are of vein type.

obtained in the crushing machinery used. Taking full advantage of the reduction that a given crusher can make may not always be feasible, as the power consumption may rise so high as to prove more expensive than an extra crushing and sampling operation.

Crushers of jaw or gyratory type (see Sec. 3) are used on coarse sizes down to 1- or 1½-in.; rolls (see Sec. 3) are almost universally used from this size down to ½-in..

Sampling machines. See Art. 7, 8 and 9.

Flow of material should be continuous and uniform, otherwise the scoop of a given sampler may take no material during one or more revolutions; this failure may be multiplied in succeeding machines by synchronism, or it may happen that two samplers will so synchronize for several revolutions that the scoop of the second receives all of the sample cut by first. Any one between these extremes may occur, and in any such case the correct proportion of material will not be taken and the sample will be unrepresentative. The means for avoiding such contingencies are storage hoppers, elevators, mixing drums, or feeders with some storage capacity, placed between successive sample cutters.

Feeders are usually placed ahead of the rolls preceding a sampler; they not only spread material and retard its motion sufficiently to give a continuous stream, but they feed the rolls in a thin even stream, which aids in preventing uneven wear on roll shells. The feeders are usually of the shaking type. They should be of sufficient length to accomplish the necessary retardation of material and their slope should be low enough so that the larger pieces will not move faster than the main stream. A length of 6 ft. and a slope not greater than 2 in. per ft. satisfy these requirements.

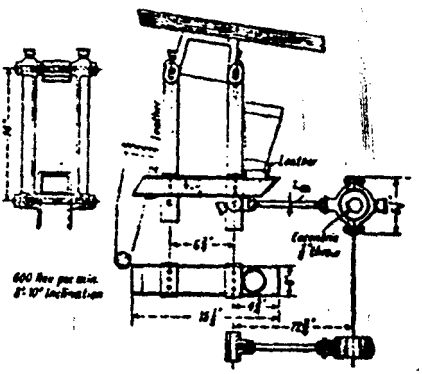


FIG. 32.—Shaking-plate feeder, Campbell and Deyell mill.

A small shaking feeder as used at Colorado (*MI 195*) is shown in Fig. 32. For other types of feeders see Sec. 20.

Drum mixers retard the stream sufficiently to make it continuous, but their ability to mix it thoroughly is questionable. Fine material rides up the side and slides back, coarse material rolls down to the top of the line of segregation rather than mixing is accomplished. Longitudinal ribs on the inside of the shell counteract this tendency; without ribs coarse material discharges mostly at one side and this causes uneven wear on the roll shell.

Drum mixers may be either cylindrical or conical; a ribbed cylindrical mixer is illustrated in Fig. 33. Drum mixers require more head room than shaking-plate feeders and are more expensive to construct. Either device requires but a small amount of power for operation.

Flexibility of plant is desirable when the size or character of ore shipments varies widely. Ordinarily a plant is designed to handle shipments of a certain size; if smaller lots arrive it may be necessary to by-pass the first sampler in order not to cut too small a sample. This can sometimes be done by stopping the sampler so that all material passes through into the sample chute; otherwise, suitable chutes should be provided to accomplish the same end. Allowance for sample variation may be made by varying the speed or cutter widths of the sample machines.

Accessibility. All parts of a sampling mill should be easily accessible for cleaning and observation. Housings on crushing and sampling machines should be detachable and easily-removable doors should be provided in all housings for elevators, chutes, launders, etc. Chutes and launders should be designed with minimum turns. Hoppers and bins should be constructed so that no

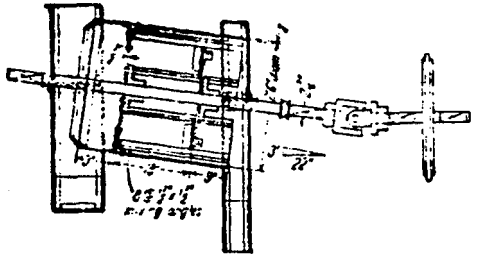


FIG. 33.—Revolving mixer.

material hangs up when they are emptied. Every precaution should be taken to avoid the possibility of clogging or leakage of material.

Cleaning between successive lots of ore is essential in order to avoid salting. Ordinarily compressed air and brushes are used for cleaning fine material from machines and spouts; floors should be swept and all material collected put with the lot just run through, or so disposed of as to preclude contamination of succeeding lots.

Dust losses. When a sampling mill has many open windows and a strong wind is blowing, the dust loss may be 5 per cent. of the total lot. As fine material is generally of higher grade than coarse, serious losses may thus occur. Further, it is hard to keep good labor in a dusty plant. Where hand sampling is employed, the ore is frequently dampened to keep down dust; this causes fine material to coat the larger pieces and thus aids in mixing. Wetting causes material to stick in automatic samplers and is, therefore, not permissible, so in sampling mills all sampling machinery and crushers should be enclosed in dust-proof housings and all chutes covered and free from leaks. If frequent observation of moving parts is necessary, small doors that can be readily closed or coverings with removable sections should be provided.

17. Custom sampling mills

These mills sample lots of ore to determine their value for sale. The charge for this service depends usually on the grade of ore and size of lot. In order to keep down the cost as much as is commensurate with accurate