Practical Stamp-Milling and Amalgamation

BY

H. W. MacFARREN

Author of

"*Textbook of Cyanide Practice*".
"*Mining Law for the Prospector, Miner, and Engineer*"

THIRD EDITION

WITH A CHAPTER ON

ARRANGEMENT AND CONSTRUCTION COSTS OF STAMP-MILLS

By

CHARLES T. HUTCHINSON

PUBLISHED BY THE
MINING AND SCIENTIFIC PRESS, SAN FRANCISCO
LONDON: THE MINING MAGAZINE
1914

(Printed in U. S. A.)

PREFACE

When I first engaged in stamp-milling and amalgamation, like many others I eagerly and unsuccessfully sought for a treatise that would tell me what to do and why — that would give the ideas and principles by which millmen were to be guided, and the methods found to be most satisfactory. Later the subject of examining ores and the adjusting of the stamp-mill to their requirements became of interest. The first edition of this book incorporated my experience and conclusions along the above lines, and the knowledge gathered from other millmen and metallurgists with whom I had associated.

Since then I have been engaged in many widely separated parts of the metal-mining regions of the United States, and have had further opportunity to observe stamp-mill practice and to discuss the subject with millmen and metallurgists. During this time I have also prepared a work on standard cyanide practice. As a result the third edition of this book is an entire revision and enlargement that has been illustrated with 77 carefully selected cuts and drawings.

This book now endeavors to set forth the principles and practice of stamp-milling and amalgamation which time and experience have indicated as correct and best. It is written directly from the standpoint of the working stamp-millman for those interested in the details of practical operation and construction. However, it gives consideration to fine-grinding and cyanidation where these are touched upon.

Mr. Charles T. Hutchinson was formerly manager of the mining machinery department of the Union Iron Works and later for the Joshua Hendy Iron Works, both of San Francisco. From the experience gathered during the construction of many mills, he has written the part on Arrangement and Construction Costs of Stamp-Mills. Mr. Hutchinson is also one of the host who have contributed many valuable ideas and much information that has been finally incorporated in the other part of the text.

H. W. MacFarren.

Salt Lake City, July 1, 1910 (First Edition).
San Francisco, October 1, 1914 (Third Edition).

TABLE OF CONTENTS

PART I—STAMP-MILLING

CHAPTER I

Page.

The Stamp-Mill 9
Location and Design 11
Rock-breaker, Grizzly, and Ore-bin 14
Battery-frame and Line-shaft 24
Mortar-block 27

CHAPTER II

Mortar and Mortar Liner 34
Shoe and Die 40
Bosshead 45
Tappet 46
Cam 50

CHAPTER III

Stem and Stem Breakage 53
Fastening the Stem 56
Adjusting Height of Drop 60
Cam Shaft and Cam-shaft Box 61
Order of Drop 65
Stem Guide 67
Finger Jack 68
Feeder 69
Screen 72

CHAPTER IV

Water Supply 84
Principles of Stamp Crushing 86
Height and Speed of Drop 87
Weight of Stamp 90
Height of Discharge 97
Feeding the Mortar 98
Power 99
Individual Stamp 101

PART II—AMALGAMATION

CHAPTER V

Properties and Care of Mercury 107
Principles of Amalgamation 109
Inside Amalgamating Plates 110

CHAPTER VI

Page.
Splash and Lip-Plates 114
Apron-Plate 116
Dressing and Care of Apron-Plate 118
Feeding Mercury 122
Dry Amalgamation 124
Outside Amalgamation 125
Amalgamation in Cyanide Solution 127
Water Required in Amalgamation 128
Temperature of Battery Water 130
Period Between Plate Dressing 131

CHAPTER VII

Construction and Arrangement of Apron Table 132
Accessories to the Apron Table 134
Plates Away from Mortar 136
Silvered or Raw Copper Plates and their Handling 137
Recovering Gold from Old Plates 139
Chemicals and their Use 140
Unsatisfactory Bare and Hard Plates 142
Cleaning Amalgam and the Clean-Up 144

CHAPTER VIII

Retorting and Percentage of Metal in Amalgam 150
Melting and Sampling Bullion 152
Recovering Gold from Slag, Old Screens, Etc. 156

PART III—GENERAL

CHAPTER IX

Loss of Gold in Amalgamation and Its Remedies 161
Sizing and Mill Tests 165
Sampling 169
Milling Systems 170

CHAPTER X

Millmen and Mill Crews 176
Mill Management 181
Handling Pulp and Tailing 185

PART IV—ARRANGEMENT AND CONSTRUCTION COSTS OF STAMP-MILLS

By CHARLES T. HUTCHINSON

CHAPTER XI

Arrangement of Stamp Battery 191
Light and Heavy Stamps 195
Sectionalized Machinery 198
Jaw and Gyratory Crushers 202
Purchasing a Mill 206
Selection of Millsite 210
Cost of Constructing Stamp-Mills 211

PART I

STAMP-MILLING

CHAPTER I

THE STAMP-MILL—LOCATION AND DESIGN—ROCK-BREAKER, GRIZZLY, AND ORE-BIN—BATTERY FRAME AND LINE SHAFT—MORTAR-BLOCK.

The Stamp-Mill.—The supremacy of the stamp-mill for crushing gold and silver ores and the reason why it has so successfully withstood the attempts of both theoretical and practical men to supersede it or limit its application, lie mainly in its simplicity, reliability, and wide range of adaptability. The modern gravity-stamp has been evolved from the mortar and pestle used by primitive man, and has remained simple in principle and construction.

At first sight it appears to be a crude machine. All is done by gravity. There is an absence of the elevating, conveying, and re-working, which give so much trouble in the other systems of milling. Its range of adaptability is far greater than that of any other crusher. It is used in Gilpin county, Colorado, in the treatment of a gold ore slow to amalgamate, with its crushing capacity subordinated in the effort to give the ore the particular treatment required to save the gold, the daily output being reduced to one ton per stamp. In South African practice amalgamation is subordinated to crushing, resulting in a daily capacity as high as ten to twenty tons per stamp. The stamp is used for disintegrating cemented gold-bearing gravel and for pulverizing the softest rock, as well as for crushing the hardest and toughest quartz. It may be fed with fine material having only sufficient grit to keep the shoes from hammering the dies, up to slabs of rock the size of a large meat-platter and 3 to 4 in. thick. Such rock is often sent through the battery during a break-down of the rock-crusher. It will crush wet or dry. It will deliver its product through a 4 or a 40-mesh screen, or through a still finer one if desired, though the modern stamp-battery is not adapted to crushing to advantage through a screen finer than 40-mesh. No machine can compare with it in amalgamating, or in preparing an ore for concentration, except where the extremely friable nature of the material requires stage-crushing; yet it has made an enviable record in crushing and preparing pyritic copper ore for the concentration of its sulphide. In the hands of a metallurgist who has made a study of the stamp-mill, a great diversity of treatment can be given an ore in an experimental way, to ascertain the best for adoption in that particular case.

The stamp-mill stands in a class by itself by reason of the variety of ores that may be treated, the widely varying methods that may be employed or the products obtained, and the control over operations to effect any reasonable end, all without reconstruction, remodeling, or material delay or change, but mainly by adjustments which are a part of the daily routine.

Estimates of the tonnage and costs with a stamp-mill can be made in advance with a close approximation to exactness. So thoroughly can it be depended upon that it has passed into an axiom that a standard stamp-mill has never caused the closing of a property by failing to do good work where good work was possible, and that it has replaced to advantage, at some time or other, practically every other kind of crushing machine. It is true that there are stamp-mills that are incapable of good work, due to careless manufacture, to incompetent mill-wrighting, and to imprudent economizing on the part of the mining company; but despite this the average millman manages to treat a fair tonnage and to make a good extraction with them, so that the president of the company in his city office is often unaware that his mill is not up to the standard.

The opponents of the stamp-mill present elaborate statements showing that the cost of installation and the power consumed exceeds that of other processes. This is true in certain cases, but they are only theoretical statements and when tested out in actual practice too often show the balance to be in favor of the stamp-mill. But where the cost of installation and the power consumed by the stamp-mill are greater, it is found, almost without exception, that the stamp-mill has other points of superiority that outweigh these disadvantages. The principal stock argument against the stamp-mill is the abnormal amount of power it is reputed to require. A careful examination and comparison of individual cases in actual practice show this increase to be small or trifling in cost per ton of ore crushed, and that the other advantages of the stamp-mill are so great that any increased power cost sinks into insignificance.

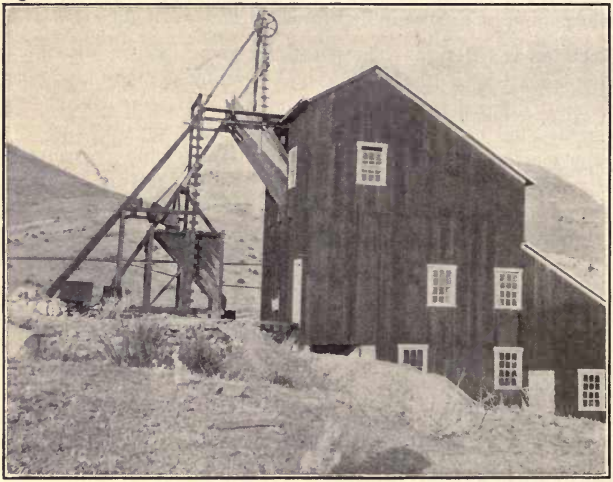
It must be remembered that exact and correct data of what a stamp-mill will do can be compiled, but that the advance estimates of what other processes and devices will attain is seldom realized under normal conditions. It is in the lower cost of operating and repairing, less loss of operating time, and wider range of treatment at command, that the stamp-mill overshadows all other crushing machines and processes.

It is an object lesson to go into some of the large and small mills that stud the Mother Lode of California so closely that he who travels through the counties of Amador, Calaveras, and Tuolumne, is seldom out of hearing of their roar; to note the ease with which the ore by gravity runs through the mill, the little labor necessary, the cleanliness of the place, and the smallness of the scrap pile, consisting mainly of worn-out shoes, dies, and screens; and then to go to a wet-roll or dry-process mill with sloppy, muddy floors, or dust-covered machinery, jammed rolls, elevators out of order, a small army of mechanics and helpers on construction and repairs, and a mountainous scrap-pile of broken and worn-out machinery.

Location and Design.—The selection of a mill-site is in some cases a simple matter, in others it is complicated by so many factors as to be a most difficult problem. Erecting the mill some distance away when it could have been built to advantage near the mine, is one of the most common mistakes. Operations should be centralized and concentrated as much as possible. Two operating points, with much of their equipment in duplicate, increases the working costs. The great cost of installing and repairing transportation lines and systems is often overlooked in making estimates of working costs. Another common mistake is the hauling of ore a long distance to water, when water could be obtained close at hand by a little development, or by further sinking in the mine if the mine water is suited to amalgamation—in a few cases it has not been. Three observations may be made: first, that it is easier to transport water to ore, than ore to water. Second, that usually more water is developed in a mine by sinking than is generally anticipated before the workings have attained much distance from the surface. Third, that the increasing perfection of machinery and systems for dewatering and conveying mill tailing has made it less and less advisable to separate the mill from the mine on account of small water supply at the mine.

Where ore is supplied to a large mill by an aerial tramway, an attempt should be made to place the mill so that the cable may run lengthwise over the bin, enabling the buckets to be tripped at any point, thus dispensing with a belt-conveyor. It can be arranged to have the buckets dump directly onto a gyratory breaker. In some cases the aerial tramway has supplied the power to run the breaker. With a mill adjacent to a working adit, straight tracks and heavy, well-ballasted rails will enable large cars—three tons—to be used with ease. At a shaft-mine it is well to place the mill near the hoist when possible. Hoisting may then be done by self-dumping skips into an ore-bin from which the ore may run by gravity to one breaker for a 20-stamp mill, to two breakers, one on each side of the bin, for a 40-stamp mill, or through one rock-breaking system connected by belt-conveyor to more than 40 stamps. The objection to putting the mill and hoist together is that in event of fire, both will probably be burned, and the fire communicated to the shaft timbers.

Efforts should be made to dispense with elevators of any nature for both wet and dry material, and to a lesser extent with belt-con-



INCLINE SHAFT WITH SELF-DUMPING SKIP HOISTING ORE DIRECTLY INTO MILL AND WASTE INTO BIN FOR TRAMMING TO DUMP.

veyors. A large part of the advantage from using the stamp-battery is due to the absence of elevating and conveying machinery. Extra expense to secure greater simplicity is money well spent. The stamp-battery is an ideal illustration of the 'unit idea' in construction as well as in operation, and a mill should be so situated that it can be added to, though the proportion of mills that are increased in size is small.

The roof of the mill should not be in one solid sheet, but should be broken by drops at the different floors, that the various floors may be well lighted by windows set in these drops.

There are several excellent reasons for painting the interior of the mill white. It causes the employees to keep the mill neater and cleaner. It greatly increases the light, perhaps nearly doubling it, and tends to eliminate dark corners. The coating of paint is to some extent a protection against fire.

It should be possible to reach the head and foot of the mill by wagon; also to unload shoes and dies at the plate-floor, and stems and other parts at the cam-floor. Likewise, the location of the machine shop in its relationship to the mill should be carefully planned.

Where it is necessary to set a water-wheel so low that it may be in danger during high water, in the effort to secure higher head, the mill may be set higher up, out of the danger zone, and connected with the water-wheel by a rope-drive.

The disposal of the tailing should be carefully considered, and the title or irrevocable right to ground on which it can be dumped should be secured, even if it does not appear that this ground will be needed, for a trespassing tailing, like smelter-fume, can be made a basis for damage suits. It is not necessary to build the mill adjoining a good site for impounding the tailing, or an existing cyanide plant. The tailing can be ditched, piped, or flumed a long distance. Concentrate has been conducted in pipes as small as one inch in diameter down mountain sides and across rivers to reduction works and storage bins.

The mining laws of the United States allow non-mineral land to be located and patented as millsite claims of five acres each, for milling purposes or any uses connected with the development of mining claims, without the necessity of annual labor or development work upon the millsite—though necessary upon the lode claim to which the millsite is attached. This is an excellent method of obtaining land for mills, camp sites, pumping plants, dumping tailing, storing ore, etc. Work or care on or in a mill will not answer for annual labor or assessment work or for the development work required for patent purposes. As mining locations can easily be lost or forfeited if unpatented, mills should never be placed upon unpatented land. There is a separate and distinct law which permits the owner of a mill or reduction works to secure patent on his millsite without the necessity of development work and without the millsite being associated with a lode claim; this law is especially applicable to custom mills.*

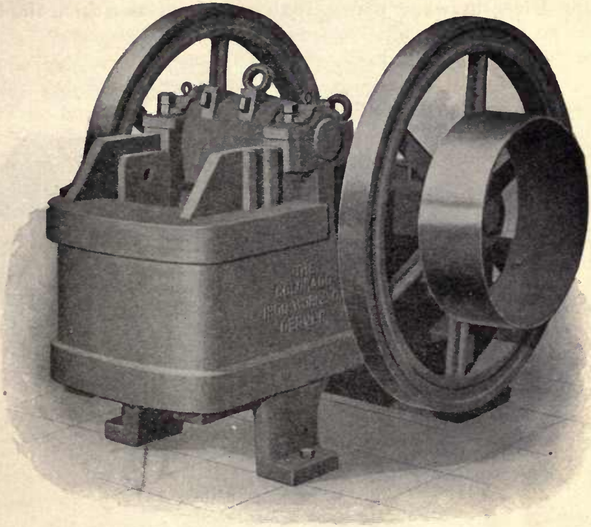
---

*The mining laws of the United States relative to millsites, to water rights for mining and milling purposes, and to the use of timber from government land for mining and milling purposes are fully explained in Chapters 12, 26, and 28 of 'Mining Law for the Prospector, Miner, and Engineer,' by the Author.

Rock-Breaker, Grizzly, and Ore-Bin.—Rock-breakers for stamp-mill work are of two types, the Blake jaw-crusher and the gyratory crusher. Each of these breakers has characteristics which fit it for certain conditions, but both types give satisfactory service under widely varying conditions. The Blake jaw-crusher requires much less mill height and less overhead space for repairing. It requires less repairing, and it is more easily performed. For these reasons the Blake crusher is suited to small installations, especially those where first cost is to be kept low, also where good mechanics may not be available. The cost of the Blake is less for capacities under 20 tons per hour, while the gyratory is cheaper in first cost for greater capacities. The jaw-crushers have rectangular openings which are well proportioned to enable them to receive very coarse rock or boulders. The openings of the gyratory are comparatively narrow, so that a great deal of sledging or hand-breaking of the coarse rock and boulders must be done. Gyratory breakers with large openings for big boulders can be built, but they are of such enormous size and capacity that they are only suited to mills of tremendous tonnage. This is the reason that so many large two-stage breaking plants are using jaw-crushers for the preliminary breaking. The gyratory produces a more even product, also a larger amount of fine material through its grinding effect. For the latter reason, jaw-crushers are preferable for preliminary breaking where ore-sorting is to follow. The jaw-crusher is superior for breaking wet ore. The gyratory requires less care in feeding and the ore may be dumped directly upon it. This fits it for certain places, such as where tramway buckets or mine cars empty upon it, and also makes feeding by automatic feeders easier than with the Blake type. The gyratory is used almost exclusively as the secondary or final fine-crushing breaker in two-stage breaking. Under conditions favorable to it, the gyratory is cheaper in first cost, power, repairs, and labor. In selecting the breaker and breaking system to be used, the size of the ore that the mine will supply should be considered, in addition to a multitude of other things.

The common practice in rock-breaking is to use a Blake jaw-crusher for 10 stamps, a Blake or gyratory for 20 stamps, or two for 40 stamps when the breakers are located over the mill bins, as one breaker cannot readily spread ore to more than 20 stamps. A single rock-breaking unit, with means for conveying the broken ore, is frequently used for 40 stamps. Such a unit may consist of one large gyratory, which should be preceded by a grizzly to screen out the fine ore if the gyratory is to be run at its utmost capacity.

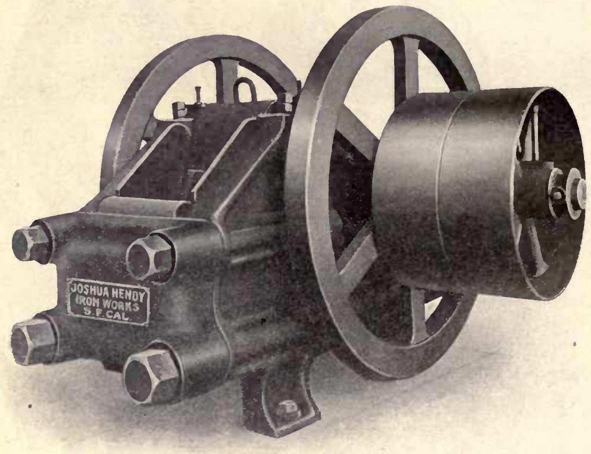
If a large gyratory is used so that the wider openings may receive the larger lumps of ore without sledging, the capacity will be so large that the grizzly may be dispensed with. A grizzly must be used if the ore comes wet from the mine, as no breaker works well when jammed with fine wet material. It may be advisable with 40



BLAKE JAW-CRUSHER WITH SOLID FRAME.
(Colorado Iron Works Co., Denver, Colo.)

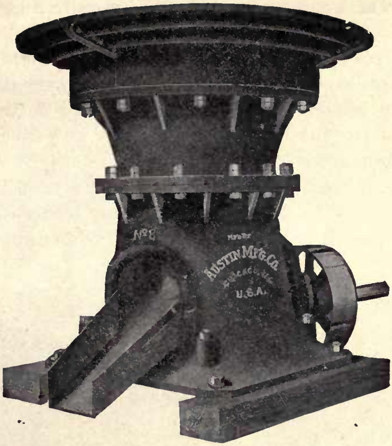
stamps, and always with more, to practise two-stage rock-breaking by breaking coarsely in a preliminary breaker, followed by screening and re-breaking the oversize in smaller breakers. This is because of the difficulty of reducing a large amount of coarse ore to a fine product in one breaker, even though the breaker is large in size; the point being that the larger parts of the large breakers must necessarily have a greater movement, which results in the openings being much wider when at a maximum and the passing of much coarsely broken rock. The preliminary breaking is performed in a Blake or gyratory—often a large gyratory without a grizzly—the ore thence passing through a revolving screen or trommel which delivers the oversize to one or two small fine-breaking gyratories. The product is delivered to a belt-conveyor, if the crusher building is adjacent to the mill, for distribution to the mill bins, or it is dropped into a storage bin for conveyance by other means.

The breaker should be driven by separate power that it may in no way interfere with the running of the stamps, especially with stamps driven by water power. It should be enclosed from the bal-

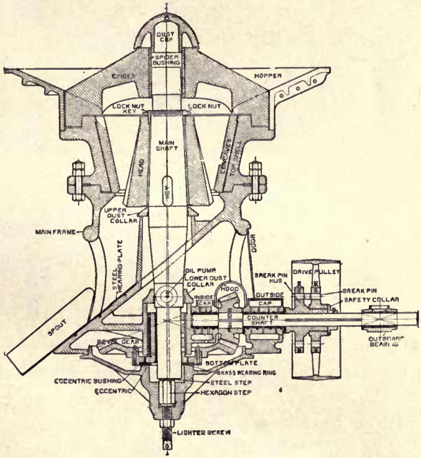


BLAKE JAW-CRUSHER WITH SECTIONAL FRAME TIED TOGETHER WITH STEEL RODS.
(Joshua Hendy Iron Works, San Francisco.)

ance of the mill that the dust may be kept out of the bearings and machinery below. A grizzly should always precede jaw-crushers. It is generally best to have a grizzly precede a gyratory crusher that it may operate to its full capacity, also that it may not become jammed through an excess of fine material and thereby break a pinion. Some consider that dispensing with the grizzly decreases the wear on the crushing faces of the gyratory. Short grizzlies of 6 or 8 ft. length will do where the ore passes over them in a thin, constant stream, as from the bin to the breaker. Where the ore is dumped intermittently upon the grizzly in large quantities, the grizzly should be quite long. Trommels screen more accurately than grizzlies, especially in finer screening, but require power, are



GYRATORY CRUSHER.
(Austin Mfg. Co., Chicago.)

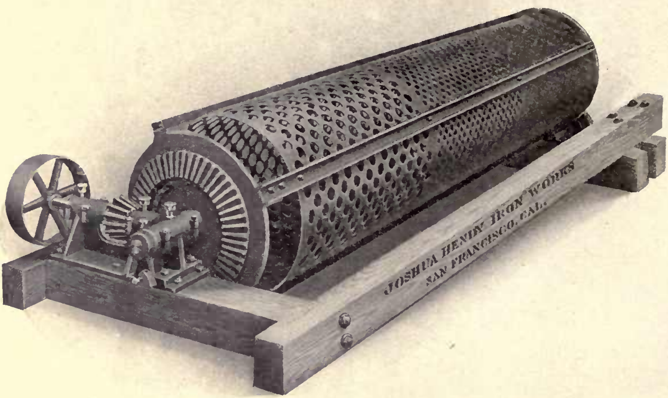


SECTION OF GYRATORY CRUSHER.
(Austin Mfg. Co., Chicago.)

more costly in first cost and repairs, and require a light, continuous feed.

Belt-driven plunger or metal belt-conveyor feeders of a size able to handle coarse rock are in use in concentrating mills for feeding breakers, even breakers of the jaw type; and as they enable the breakers to be fed automatically, they may be expected to become a detail of stamp-mill equipment.

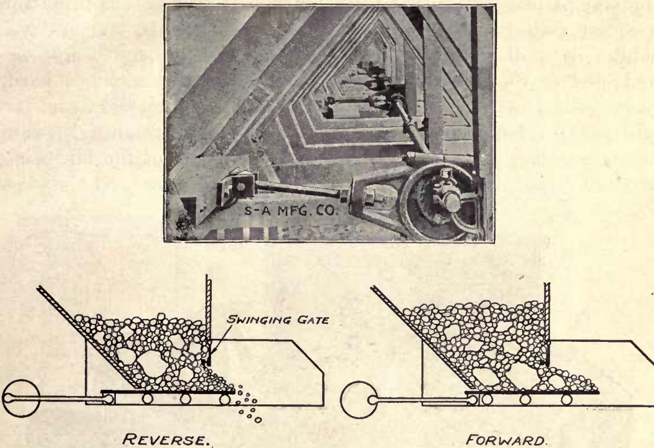
Electro-magnets are suspended over conveyor belts to pick up hammer heads, broken drill steel, and other iron and steel, so that they may not pass into the breaker and crushing apparatus.



REVOLVING ROCK SCREEN OR TROMMEL.
(Joshua Hendy Iron Works, San Francisco.)

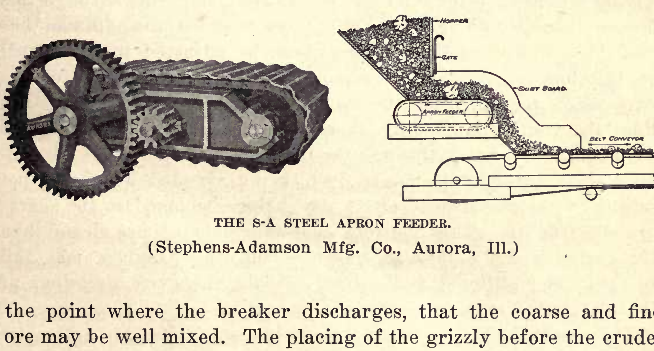
Many small mills are built in which it is necessary for the breakerman to shovel or scrape into the breaker every pound of ore that passes through it. If sufficient height be not available for placing a crude-ore bin above the breaker, then a gyratory breaker preceded by a grizzly should be used, and the ore should be dumped directly upon the breaker. This method of dumping directly and dispensing with a breakerman will not be successful with a wet, sticky ore that 'balls up' in the breaker, nor where the ore-supply does not come in small lots, although the breaker may be buried with a dry, brittle ore having no lumps too large to enter the jaws.

Where it is not desired to dump directly upon the breaker, a crude-ore bin should be used. This need not have a sloping bottom, for should the supply run low, the breakerman can enter the bin



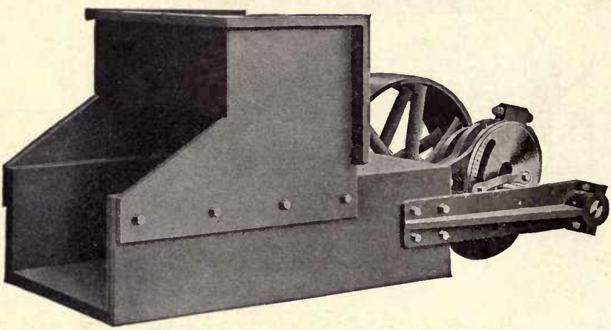
RECIPROCATING PLATE FEEDER.
(Stephens-Adamson Mfg. Co., Aurora, Ill.)

and shovel the ore forward. The grizzly should follow this bin, emptying directly into the crusher. An apron underneath the grizzly should carry the fine ore that has passed the grizzly bars to



THE S-A STEEL APRON FEEDER.
(Stephens-Adamson Mfg. Co., Aurora, Ill.)

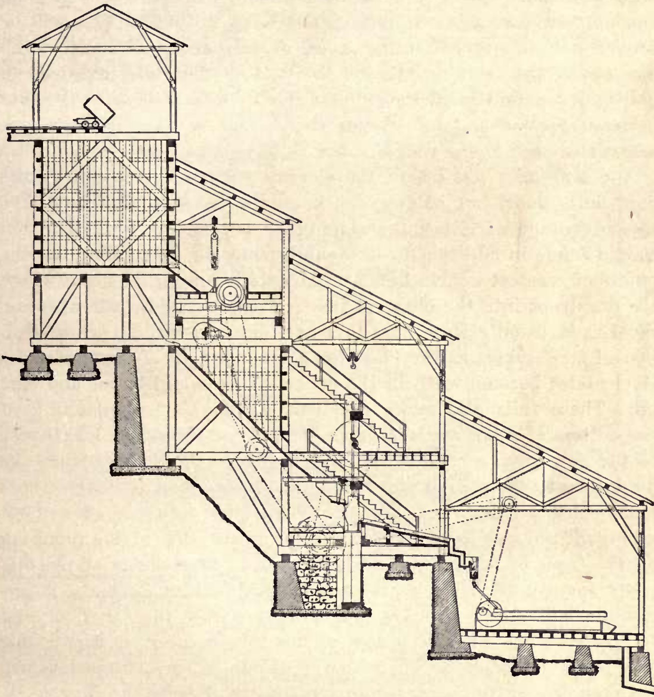
the point where the breaker discharges, that the coarse and fine ore may be well mixed. The placing of the grizzly before the crude-ore bin where the ore from the mine is dumped directly upon it, and the fine ore shunted by the crude-ore bin, or any construction that tends to keep the ore in the crushed-ore bin from being homogeneous, is bad and must be condemned. The height of drop of the stamps in a battery, and the other adjustments, are made for each ore mainly according to its character, hardness, and fineness. Where the mill arrangement is such that the fine and coarse ore delivered to the mill during the day become segregated, a hard, coarse rock from the breaker is at first fed to the mortars, and the mill works splendidly during the day and early evening; but late in the evening, the coarse rock in the front part of the bin being exhausted, the fine from the grizzly begins to come. The stamps



PLUNGER ORE FEEDER FOR CRUSHERS, ETC.
(Chalmers & Williams, Chicago Heights, Ill.)

having a long drop for the hard, coarse rock, now sink through this fine ore and strike the dies, and from then on the millman has trouble. While the stamp-battery can be adjusted to work well on this fine material, it is obvious that such adjustments for the two classes of ore cannot be made economically twice daily. Besides the trouble in feeding, there is danger in the 'camming' of the stamps that break through the bed of pulp to the die—the falling stamp, through its longer drop, being arrested by the tappet falling on the cam instead of the shoe being cushioned on the coarse ore over the die. This fine rock is usually many times richer than the coarse, and the millman, engrossed in other troubles, may fail to feed the additional quicksilver or make the extra dressings of the plates that may be required.

The crushed-ore bin, in fact any bin supplying an automatic feeder, should have a sloping bottom of from 40 to 50°. The only real argument in favor of the flat-bottom bin is that it gives a reserve ore-supply, but this reserve might as well be outside the mill, except in the case of accident to the breaker, for it will all have to be shoveled. It has been said that this extra ore by its weight anchors the bin and adjacent parts of the mill. The reply to this is that a well-constructed mill does not require such anchoring.

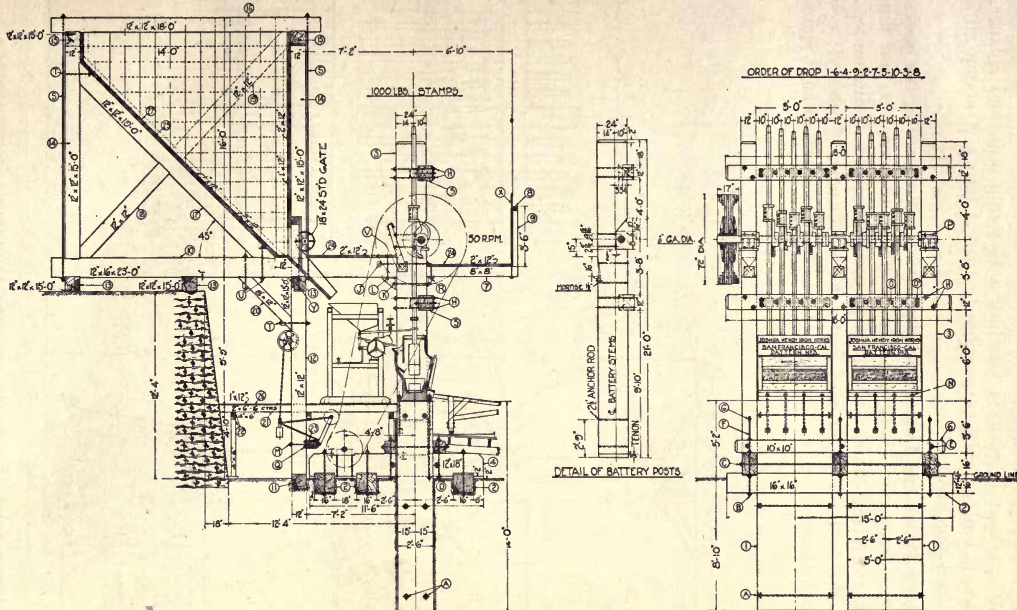


SIDE ELEVATION OF STAMP-MILL.
(Traylor Engineering & Manufacturing Co., Allentown, Pa.)

Many arguments and sophistries are advanced that these flat-bottom bins will be kept full and that no shoveling will be required; but actual observation shows that they are not kept full, and that occasional shoveling must be done. This requires an extra man or extra men, and the charges for this item soon amount to 15 to 30c. per ton. If a millman has to go into the bin, he gets surly, and voluntarily or involuntarily neglects his other work. A sloping bottom is advantageous where a wet, fine ore that will neither roll nor run is being milled, such as 'old filling' from the mine-stopes. By introducing a few pails of water at the top and back of the bin, the whole mass can be started moving slowly into the feed-chutes; care must be exercised in the amount of water used, or the whole mass will move down into the mortars regardless of the feeders, and unless the stamps are immediately hung up, the screens will be broken out; in either case the excess of pulp or ore will have to be dug out of the mortars. In some mills 1-in. pipes are arranged to deliver a constant small stream of water upon such ore at the chute between the bin and the hopper of the feeder. A water spray is sometimes used at the rock-breaker to lessen the dust.

A compromise bin where the sloping bottom begins not at the feed-chute door, but halfway back on the bin-sills, does not give the advantage of either the sloping or flat-bottom bin. The bin should have, in addition to its double planking, steel plates at the points of greatest wear, which are the grizzly apron, the point where the ore drops into the bin, and just above each feed-chute opening. Steel rails, usually worn ones that have been discarded, are used in lieu of steel plates as they last for a great length of time, whereas steel plates become worn in the course of time and break and curl up. These rails also make excellent grizzlies. The planking of the bottom of a bin and the grain of its wood should be lengthwise to the flow or movement of the ore to lessen the wear, reduce the hindrance to the sliding and rolling of the ore, and to enable those parts subject to excessive wear to be repaired or replaced without removing the less worn planking. The lower 3 ft. of the planking on the front of the bin should be placed on the outside of the bin-posts, instead of inside, as the remaining planking. This will permit the millman to insert a bar or shovel from the cam-floor and to start the ore when it is low or has 'bridged,' or it will enable him easily to enter the bin; a cover of canvas, or a hinged board, between the outside and inside planking will keep the dust back. With bins as ordinarily constructed, it is well to bore a large hole or cut a small square opening to be covered with a secure metal slide cover, at a point a few feet above each feed-chute; this will enable a steel bar to be inserted from the cam-floor for starting the ore when it has 'bridged.'

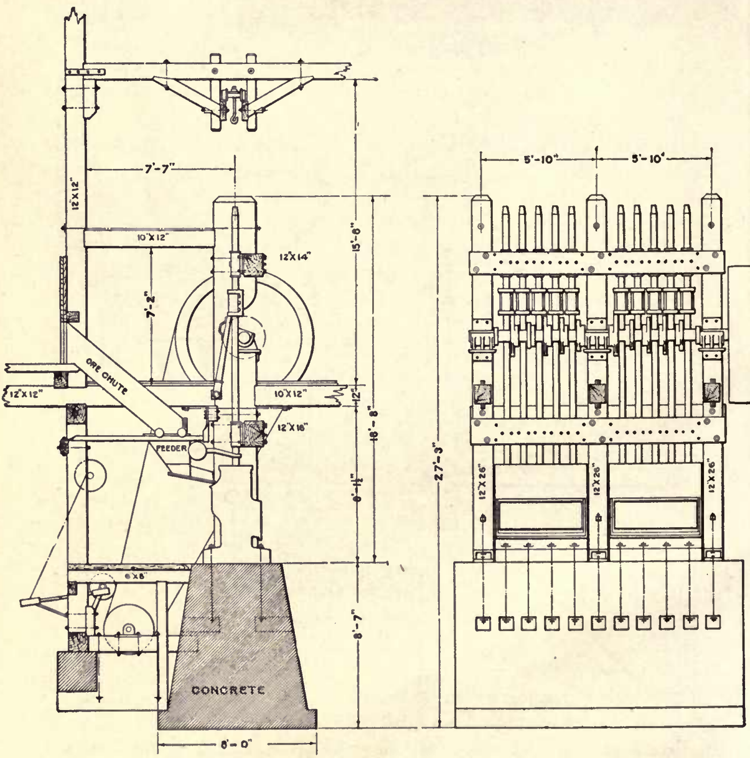
It is possible to increase the size of the mill by taking a feed-chute out of the corner of the bin and at an angle to it, to another 5-stamp battery in line with the original batteries. One side of the



TEN-STAMP, THREE-POST, BACK-KNEE FRAME, SINGLE END-DRIVE BATTERY WITH WOOD MORTAR-BLOCKS AND ANGLE-BOTTOM ORE-BIN.
(Joshua Hendy Iron Works, San Francisco.)

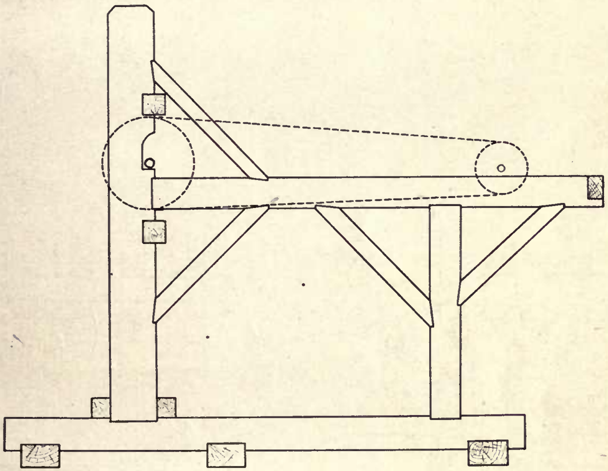
mill is always free to make such an addition, while the other will usually require some change in the driving arrangements. Where this idea is kept in view in building a 10-stamp mill, and a large high bin is built, it will be possible to turn it into a 20-stamp mill easily and cheaply.

Battery-Frame and Line-Shaft.—In battery construction, the back-knee type, where the battery-posts are tied to the ore-bin, and the line-shaft driving the cam-shafts is placed on the streak-sills underneath the feeder-floor, is now given the preference. This style requires the least amount of timber. It is the strongest and most rigid



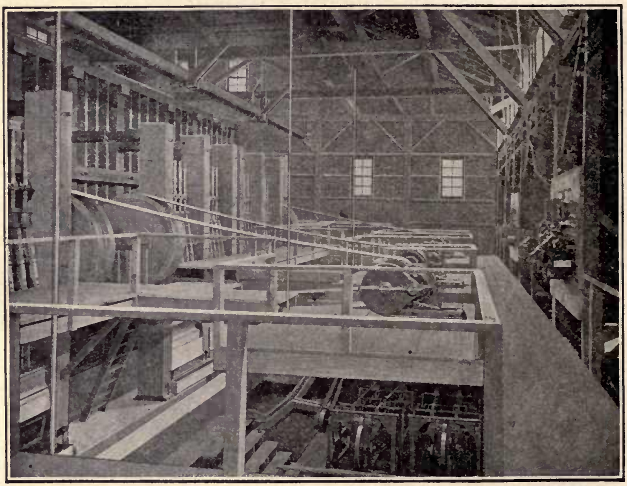
STAMP-BATTERY WITH BACK-KNEE FRAME AND CONCRETE MORTAR-BLOCK.
(Denver Engineering Works Co., Denver, Colo.)

construction, especially in view of the belt pull. It gives a clean-cut and well-lighted mill, with the upper part of the battery and mill in sight from the plate-floor. The objections are that a belt-tightener must be used on the battery belts, but this answers for the friction-clutch with which the pulleys of all horizontal battery belts should be provided. However, the wear and tear on these belts is much greater than on belts not requiring tighteners. It has been feared that tying the battery-posts and framing to the ore-bin would cause them to be thrown out of line by settling of the bin;



FRONT-KNEE TYPE OF BATTERY-FRAME.

this can only occur with bins set on a loose, poor foundation, and has seldom given any trouble. Placing the line-shaft on the streak-sills has been criticized as putting it in a place hard to get at and subject to dirt and water. Plenty of head-room should be allowed between the streak-sills and the feeder-floor, that the shaft may be easily reached for repair. Drainage should likewise be provided. Ring oilers should be used and dust-caps of canvas provided. In a well-constructed mill, no water will reach the shaft. The placing of the line-shaft on the bin-sills in the rear of a sloping-bottom ore-bin gives all the advantages of the style previously described, with the additional one that the belt is horizontal and requires no tightener. This style is limited to 20 stamps as the battery belts must pass on the outside of the bin, and it is advisable to make the bins continuous. The back-knee type is now used almost exclusively in modern mills. In a mill of 40 stamps or more there should be at least one stairway leading from the foot of the plates on the plate-floor to the front of the cam-floor, that millmen need not go to end of mill or behind mortars to ascend to the cam-floor. A raised edge of 1¾ in. should surround all openings on the cam-floor that tools, spilled ore, etc., may not be jarred off the floor. Removable

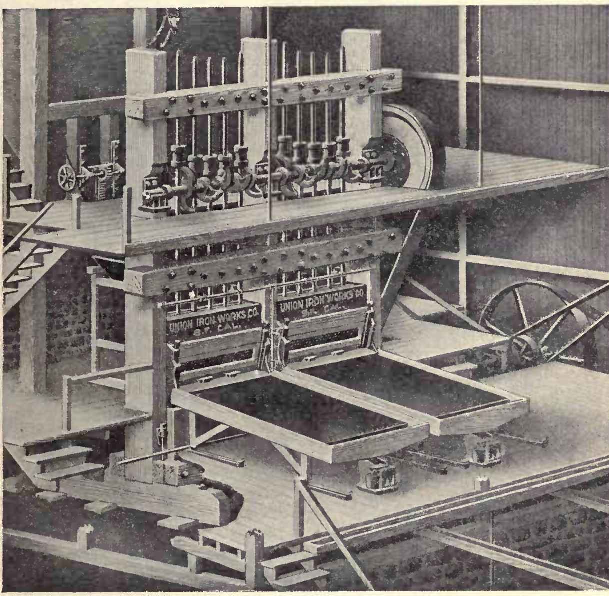


UPPER PLATFORM OR CAM-FLOOR OF FRONT-KNEE TYPE OF BATTERY-FRAME.
Cam-shaft pulleys are belted direct to back-geared electric motors without use of line-shafts.
(Stearns-Roger Mfg. Co., Denver, Colo.)

hand railings should surround the cam-pulleys, belts, and all openings for the safety of the millmen.

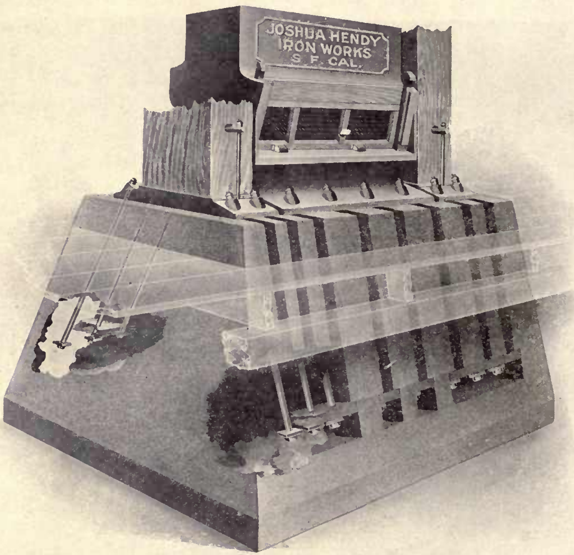
In the front-knee type, the line-shaft is placed on a level with the cam-shaft and in front of it on heavy timbers that form a part of the battery framing and brace it independently of the ore-bin, though it can be tied to the bin. It requires more timber and is neither as strong nor as steady as the back-knee type, while the upper platform darkens the mill and does not allow the upper part of the mill and battery to be seen from the plate-floor. It is not suitable for 10 stamps unless tied to the bin, as the tendency of the battery is to sway endwise on account of its comparatively small area of longitudinal anchorage.

Mortar Block.—The battery foundation or mortar block is one of the most important parts of a stamp-mill. These blocks were of wood until recent years, when concrete mortar-blocks have come into favor to such an extent that wooden blocks are no longer placed



STANDARD TEN-STAMP CALIFORNIA STAMP-MILL OF BACK-KNEE TYPE WITH WOOD MORTAR-BLOCKS.
(Union Iron Works Co., San Francisco.)

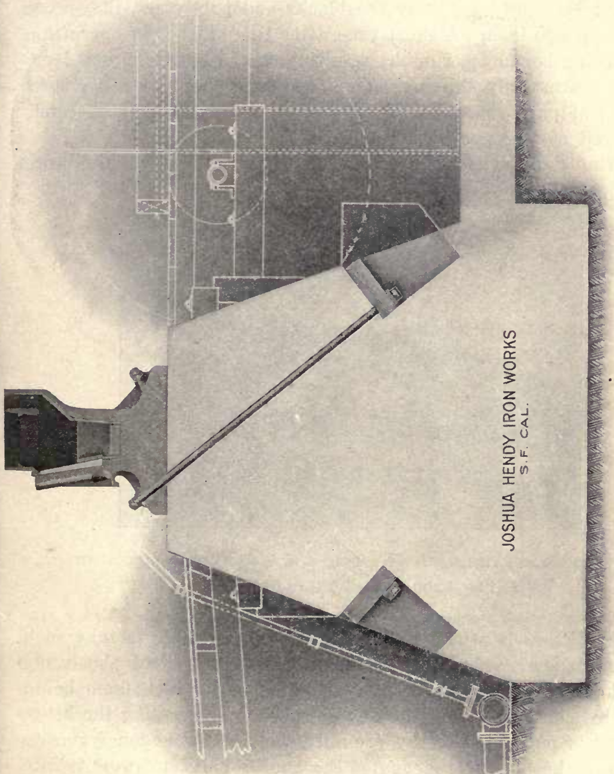
in elaborately designed mills. It was at first thought that the concrete blocks caused stems and cam-shafts to break faster than with wood blocks because there was no cushioning of the impact and jar, but with more experience it has been positively established that where the block has been built and the battery-posts assembled in such manner that everything is bolted tightly and securely together, and kept so, and the jar and vibration reduced to a minimum, the breakage of parts is less than with the wood block. The experience with concrete blocks has dispelled the former erroneous belief that battery parts required to be cushioned, and has indicated that all parts should be as rigid, as solid, and as inelastic as a line-shaft in its bearings. The concrete block costs less to build under average conditions than the wood block. It gives a cleaner looking mill, and does not decay. By its solidity and non-cushioning effect, it



CONCRETE MORTAR-BLOCK WITH POCKETS FOR ANCHOR BOLTS AND CAST-IRON BED-PLATES FOR SECURING BATTERY POSTS.
(Joshua Hendy Iron Works, San Francisco.)

increases the capacity of a stamp as much as 33⅓% over the wooden block, and herein is the reason for using concrete blocks.

It must be admitted that concrete blocks have been unsatisfactory in a number of cases, while the wooden block has given satisfaction in practically every instance. This has been due to defective construction or failure to appreciate the nature of block required. A high narrow pedestal having the same dimensions and small base area as the wooden block is liable to crack and crumble under the tremendous strain and vibration from the constantly recurring blows of heavy stamps. What is required is a block of broad area receiving the strain and shock from a broad mortar base and transmitting it into the earth with as small a strain per square inch of horizontal area as possible.

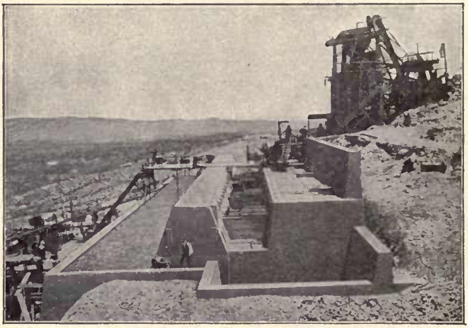


CONCRETE MORTAR-BLOCK WITH ANCHOR BOLTS SET IN PIPES TO ALLOW EASY REPLACEMENT.
(Joshua Hendy Iron Works, San Francisco.)

The principal troubles with concrete blocks have been: A rocking of the block, due to imperfect setting on bedrock or to too small a base area when set on loose ground. A disintegration of the block due to not tamping the concrete sufficiently during construction, to the use of poor material, or to the use of too small a base area and too narrow a block. A crumbling of the top-dressing or grouting, improperly put on for the purpose of leveling it after the block had partly set.

An instance may be given as a good illustration of concrete mortar-block troubles. After the blocks had partly set, they were grouted up one inch. A short time after the mill began operating, the grouting began to crumble, resulting in the battery-posts dancing and the mortars shifting. Then, within a short time, occurred breaking of parts, such as driving-pulley plates, cam-shafts, cams, stems, and mortar anchor bolts.

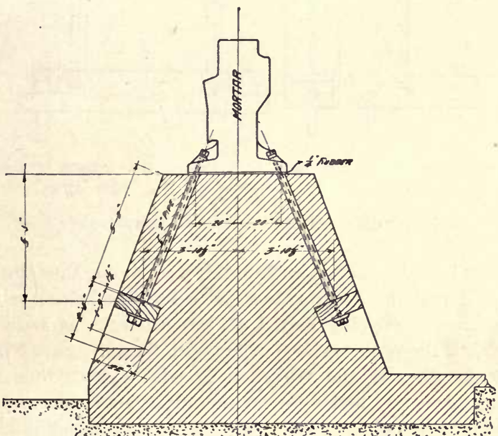
Grouting the blocks has been successful, but in view of the large



ERECTING STAMP-BATTERY FOUNDATIONS AT GOLDFIELD CONSOLIDATED MILL.
(Allis-Chalmers Co., Milwaukee, Wis.)

number of cases in which it has not, it is inadvisable to take such chances. It is necessary to make the surface of the block absolutely true, though it may vary a small fraction of an inch from being level; this can be accomplished by chiseling and scraping the block after it has partly set, or by promptly bolting a wooden frame to the top of the block by means of the anchor bolts, to press it into shape, before it has had time to set.

Anchor bolts are set solidly in the concrete, or are placed in pipes embedded in the concrete or in recesses so that they may be readily replaced if sheared and broken. The shearing and breaking of anchor bolts seems to be due to the bolts being too small in diameter and too few in number, and more so to a neglect to keep the mortar securely bolted down. When bolts embedded in concrete are broken they cannot be repaired or replaced, except by blasting the block to pieces and rebuilding it. It is considered that by using eight bolts of good material and 2½ in. diameter to each mortar and by keeping the mortar bolted tightly down, no trouble will be experienced unless the top of the block crumbles so that the mortar does not rest firmly and securely. Half this number of bolts is ordinarily sufficient. This is the rational method of building the blocks, but at present the designs allowing the bolts to be easily renewed are preferred, and will continue to be preferred until it is fully demonstrated that concrete blocks can be built with solid anchor

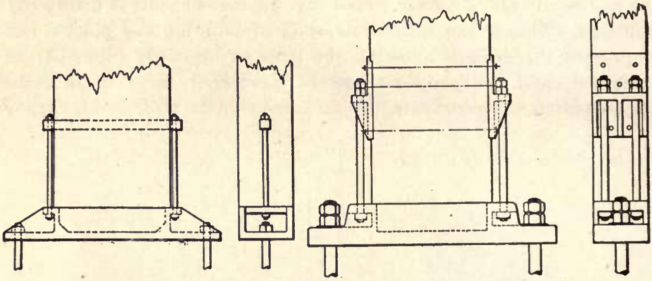


SECTION OF BATTERY FOUNDATION.

MORTAR-BLOCK AT GOLDFIELD CONSOLIDATED MILL.

bolts that will not break. The objection to the designs allowing the bolts to be removed are that there is a reduction of the large horizontal cross-section so desirable in a block, and that the blocks are more difficult to build.

Iron anvil-blocks between the mortar and the concrete are superfluous and seldom used, except beneath mortars having narrow bases and intended for wooden blocks, the mortars for concrete blocks having bases especially wide and thick. A sheet of ¼-in. rubber is placed between the mortar and the block, not with the idea of cushioning the force of the stamp blows, but to make an even bearing which will equalize any slight irregularities of the concrete surface and one into which water cannot enter, for a combination of moisture and a slight jar or working of the mortar would tend to disintegrate the block. Likewise, a sheet of rubber should be placed between the concrete block and the iron bed-plates into which the bottoms of the battery-posts are bolted, or the bed-plates will wear down into the concrete under jar.



STANDARD TYPE OF BATTERY-POST SHOE.

EXTRA HEAVY TYPE OF BATTERY-POST SHOE.

(Denver Engineering Works Co., Denver, Colo.)

There has been a question with builders as to whether the battery-posts should rest in cast-iron foot or bed-plates bolted to the concrete, or in wooden sills bolted to the concrete as with wooden blocks. With the posts resting on timbers, these timbers will absorb and minimize the jar and vibration to some extent, thus relieving the battery-posts and lessening the pounding between the cam-shaft and its boxes; but given good, wide surfaces in both the block and the mortar, with the mortar and battery-posts bolted securely to the block, there will be a minimum of jar and vibration, and to just the extent that this is reduced will the breakages and wear and tear be reduced. The bolting of the battery-posts into wide, heavy bed-plates securely anchored to the concrete is much to be favored.

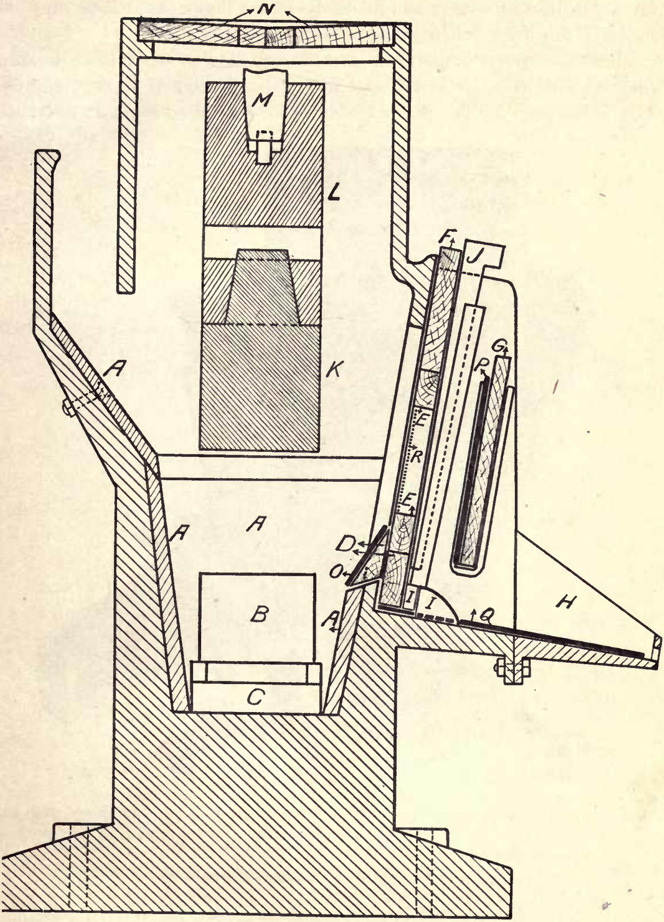
Mortar-blocks for small mills are usually of wood, consisting of pitch pine of such size that two pieces bolted together make a block, down through various sizes to ordinary planking spiked into a solid block of the desired dimensions. They should be coated with a preservative paint to lessen the tendency to rot. In length they vary from 8 to 25 ft. Where solid rock cannot be secured, a bed of concrete 2 or 3 ft. thick and as wide as 4 ft., is made as a foundation. Even where bedrock is found, a bed of concrete 1 ft. thick is advisable to give a level surface for the block to rest on, and to fill crevices or weak spots in the rock. After the block is set in place, sand is filled around it and tamped down. Pouring in concrete has been tried, but is not recommended on account of its shrinking. The nuts of the anchor bolts, tie rods, and all others about the battery should be frequently tightened after the mill goes into operation.

CHAPTER II

MORTAR AND MORTAR LINER—SHOE AND DIE—BOSSHEAD—TAPPET—CAM.

Mortar and Mortar Liner.—The mortar is made of cast iron, and is approximately six or more times heavier than the weight of the stamp to be used in it. The mortar has been made heavier since the introduction of concrete mortar-blocks, not alone in accordance with the increased weight of stamps, but also heavier in proportion to the other parts; the trend now being in the direction of a wide and extra thick base. This is to secure exceptional rigidity and strength for the same reasons that concrete mortar-blocks are made massive and heavy.

In selecting a mortar for rapid crushing, it is advisable to get a narrow one, the best known type being the 'Homestake.' All manufacturers make a mortar of this kind. By a narrow, rapid-crushing mortar is meant one having as little spare room in its crushing area as possible. Such a mortar is usually about 12 in. wide at the discharge-lip, and there is no surplus space at the ends. The inside back of many of these mortars is vertical, or practically so, which has given rise to the term 'straight-back' mortars. It may be urged that but little inside amalgamation can be done with such a mortar. This idea is erroneous, for inside amalgamation ordinarily increases with the height of the discharge, which is the vertical distance between the tops of the dies and the bottom of the screen. A chuck-block plate—the term applied to the front inside-amalgamating plate—and in some cases a back-plate, can be used in these mortars, though it will require some care and extra trouble. Inside amalgamation, as referring to the catching of a large part of the gold inside the mortar, is going out of use. Capacity is being called for, and the tendency toward outside amalgamation, or at least toward not requiring so large a proportion of the gold to be caught inside the mortar at the expense of capacity, is increasing. It has been suggested that by using a wide mortar it may be lined and thus converted into a narrow one if desired. It is hard, however, to get special liners made that will not give trouble by coming loose. It would be almost impossible to decrease the horizontal distance between the die and the screen. However, the idea has some merit and can be applied to wide mortars now in use. The

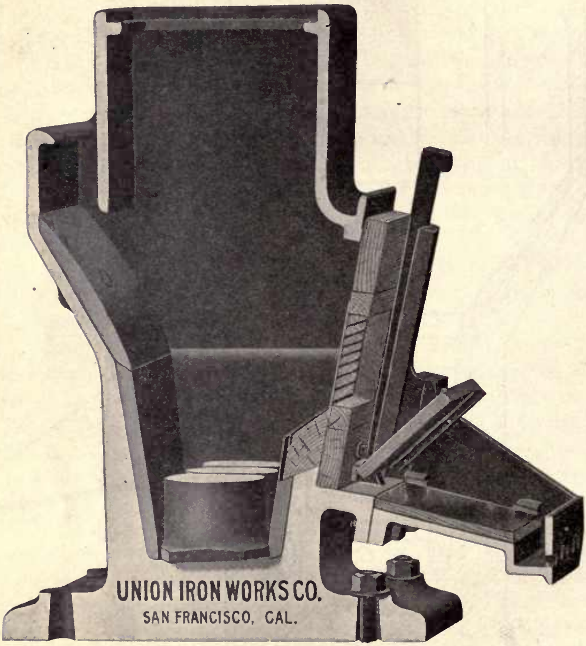


RAPID CRUSHING MORTAR OF HOMESTAKE TYPE.

A—Liners. *B*—Die. *C*—False die. *D*—Chuck-block. *E*—Screen frame. *F*—Closing board. *G*—Splash-board. *H*—Extension mortar lip or distributing box. *I*—Lug and key holding chuck-block. *J*—Key holding screen frame. *K*—Shoe. *L*—Bosshead. *M*—Stem. *N*—Cover boards. *O*—Copper chuck-block plate. *P*—Copper splash-plate. *Q*—Copper lip-plate. *R*—Screen.

feed-mouths of mortars should be wide, so that coarse rock may be fed to them during break-downs of the rock-crusher.

The 'open-front' mortar is one of the newer designs to enable easy handling of the long and heavy bossheads of heavy stamps. The front part of the mortar above the screen-opening is not cast

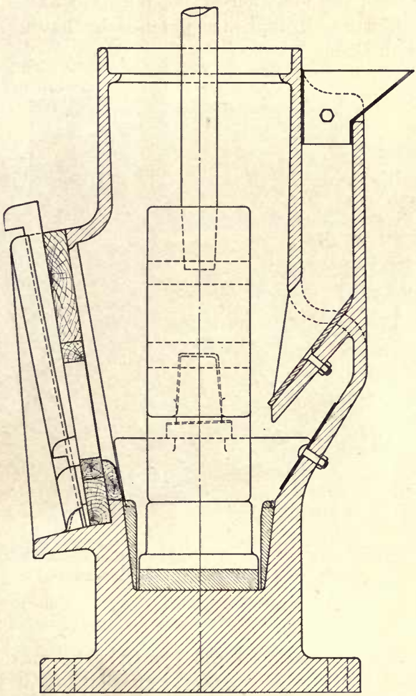


STRAIGHT-BACK RAPID-CRUSHING MORTAR WITH NARROW BASE FOR WOOD MORTAR-BLOCKS. FITTED WITH LINERS, CHUCK-BLOCK, AND DISTRIBUTING BOX BOLTED TO MORTAR LIP.

(Union Iron Works Co., San Francisco.)

solid, but is a separate piece which is bolted in place and is easily removed.

Double-discharge mortars, with a screen opening in front and behind, have been tried, but are not considered successful. The back-screen is hard to get at, and to hold in place without coming loose. There appears to be so much motion to the pulp that it does not settle on the dies, and in consequence the mortars frequently fill up with ore and pulp, especially when feeding fine material. So much water is required to get a proper action of the pulp along the screen that the outside plates cannot do good amalgamating with the dilute pulp that results. The single-discharge mortar can be made to discharge the pulp about as fast as made when treating ordinary rock. In view of this and of the inconvenience in working with a

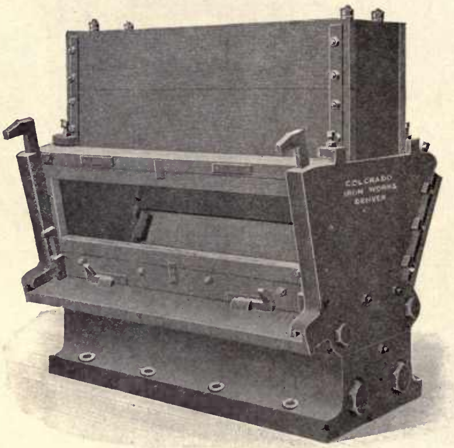


NARROW MORTAR SPECIALLY DESIGNED FOR THE USE OF A BACK AMALGAMATING PLATE AS WELL AS A CHUCK-BLOCK PLATE.

(Chalmers & Williams, Chicago Heights, Ill.)

double-discharge, these mortars are usually found with the backs closed, except with such easily disintegrated material as gravel, where the problem becomes one of screening rather than crushing.

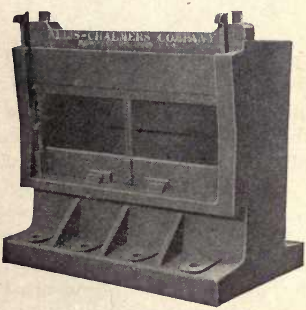
Mortars are ruined or worn out in two ways, by being cracked or by being worn through by the attrition of the pulp. Cracking is due to imperfections in the mortar as manufactured, and to loose and shifting dies without a cemented layer of sand underneath to absorb and spread the shock or impact of the stamp. This is in connection with poor feeding whereby the stamp shoe strikes the die destructively, instead of being properly cushioned on a bed of ore and pulp over the die. With mortars that are suitably lined the wear through the attrition of the pulp is small. Mortars that are cracked or worn through are patched by having steel or iron plates bolted to them.



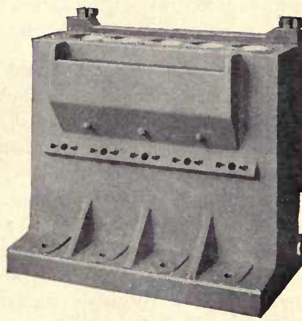
STANDARD SIZE FIVE-STAMP MORTAR IN SECTIONS OF NOT EXCEEDING 332 POUNDS FOR EASY TRANSPORTATION BY MULEBACK.

(Colorado Iron Works Co., Denver, Colo.)

Mortars should be lined in the front, back, ends, bottom, and where the feed strikes the mortar at the bottom of the feed slot. The front, back, and end-liner should dovetail; though liners having bevel ends, so as to lock themselves in position by bevel joints, have given satisfaction. The back-liner may or may not be finally bolted into place. Attention should be given to securing liners so that they will not come loose. A bottom-liner of one piece is usually a nuisance; sand and pieces of iron creep under the ends, causing the liner to sag in the middle, when a general movement begins which may result in displacing the dies when they become worn down. Two-piece liners act in a similar way. Individual plates or 'false dies' are what is required. Old dies worn smooth and down to a thickness of two inches answer well. An inch of sand should be placed between them and the mortar below, likewise between them and the 'true dies' above. This has been condemned on the ground that it cushions and consequently lessens the efficiency of the stamp blows, but its use will reduce the chances of cracking the mortar or the dies. The dies should be plumbed exactly under each stamp, and should fit snugly in the mortar, with just enough space intervening that they may be pried out without too much trouble from locking each other. Should there be any surplus room



Front view.
The part of mortar above screen opening can be removed for easy replacement of stems and bossheads.



Back view.
Showing water connections to introduce battery water under pressure to the face of each die.

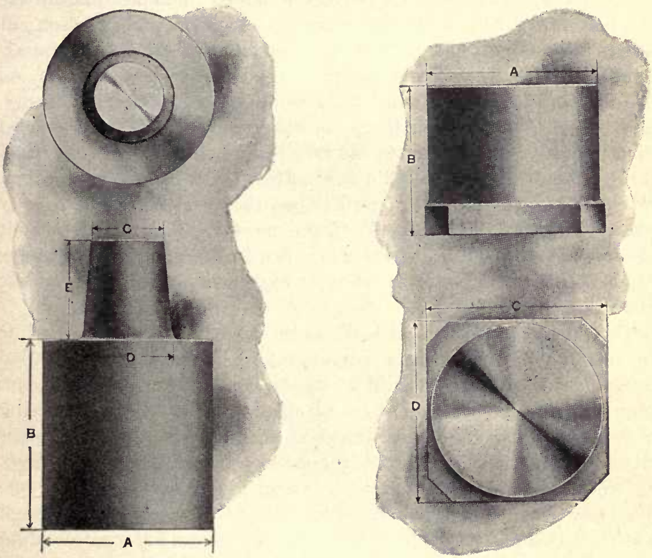
OPEN-FRONT MORTAR WITH STRONG BASE FOR HEAVY STAMPS.
(Allis-Chalmers Co., Milwaukee, Wis.)

at the ends or sides, the dies should be wedged with a piece of iron or steel. This wedging is likely not to hold when the dies become worn, consequently steps should be taken to secure liners that will completely take up this surplus space, thus enabling the dies to hold themselves securely in place. There is nothing more annoying than a mortar so large that the dies shift from their proper position under the stamps. In putting in a new set of dies, it is advised to pack coarse rock around them and to run with a heavy feed, that is, with a thick bed of pulp on the dies, for a few hours until the dies have been solidly cemented in place.

A shallow mortar should be ordered if it is expected to use a low discharge in crushing. Use a high chuck-block—a long piece of wood filling the front of the mortar at the bottom of the screen-frame—when starting a new set of dies. And decrease the screen-height an inch at a time, as the dies wear down, by chuck-blocks and wooden strips of various thicknesses, until at the last lowering of the screen, just before discarding the worn-out dies, there is nothing placed underneath the screen-frame. In short, keep the height of discharge as nearly constant as possible by lowering the screen an inch at a time, as the dies wear, and, if possible, do not move the dies until worn out. It may be necessary, with a deep mortar, to build up the old or partly worn dies by false dies. Where the dies are removed in the monthly clean-up, start the new dies without the false ones, and insert the false dies at the next clean-up after these new dies have been worn down.

Shoe and Die.—The shoe and die are made of iron and steel of several kinds, going under such names as cast and chilled iron, hammered, forged, cast, chilled, chrome, and manganese steel, and semi-steel. The millman will decide for himself when choosing from these, keeping in mind the local conditions affecting the nature of the ore and the cost of supplies. It is usually cheaper to use steel than iron, despite its increased cost, on account of the smaller consumption of steel per ton of ore crushed and the less time lost in renewals and setting of the tappets. For the latter reason steel shoes and dies are much preferred by millmen. The life of a set of steel shoes and dies may roughly be estimated at four months or less, as against half that length of time for iron, though the life of steel parts has shown on different ores such wide variations as from 2½ to 9 months, and four times that of iron. A material having the maximum hardness and the minimum brittleness is desired. The limit of hardness is passed when the shoes and dies chip, crack, or break. The remedy in this case, presuming that the feed has not been kept too low or the drop too long for the nature of the ore fed, is to use a softer die; if the trouble continues, keep trying a softer material for the die until the proper limit is reached. However, it should be remembered that a shoe or die of steel or other material of one maker may be as unsatisfactory as those of another maker may be satisfactory, due to a variation in composition and method of manufacture. It may be that the shoe in use is too hard and brittle, when a softer one or another kind should be tried, but not one as soft as the die. The wear is greater on the shoe, and it should have the harder metal. With a die softer than the shoe, the two wearing faces adjust themselves well to each other. The variation of life between a steel and iron shoe is much greater than between a steel and iron die. For these various reasons many mills are found using steel shoes and iron dies with great satisfaction. The use of a steel shoe with a semi-steel die is recommended as the combination that will probably prove the most satisfactory in the majority of cases, though the softer the ore, and to some extent the finer the ore, the softer the material that may be successfully and economically used in the shoes and dies.

With steel shoes and dies the amount of metal used or consumed in



STAMP SHOE AND DIE.
(Chrome Steel Works, Chrome, N. J.)

crushing will vary from one-half to one pound per ton of ore crushed, 60 to 66⅔% of which will be from the shoe. Under exceptional conditions the amount may be greater or less than this approximation. With iron shoes and dies the consumption may reach double this amount. With steel shoes and iron dies the consumption of each will tend toward being equal. As the ore fed to the mortar becomes coarser or harder, and the bed of ore over the die becomes thinner than normal or the feeding is poorly done, the consumption of metal increases. As the ore is crushed and discharged coarser from the mortar and the tonnage thus increased, and generally as the tonnage is increased in any manner, the consumption of metal per ton of ore crushed becomes correspondingly less, for the life of the parts in days of wear will not vary greatly.

Should the die be found to wear unevenly on one side, it may be due to a soft spot in the metal, which, once started, increases, or it may be due to some inexplicable trouble in the feeding of the mortar. The die should be turned half-way around in the effort to make it wear evenly. At some mills the dies removed when cleaning up the mortars are returned to the same exact place and position, at others they are turned half-way around, and in other mills no attempt is made to return them to any particular position. If, on examination before removing, the dies appear to be wearing evenly, and do not exhibit a tendency to wear unevenly in some general direction, it is unnecessary to use care to return them to any particular position, as a shoe and die soon adjust themselves to each other. When dies wear unevenly on one edge, the greater wear is usually on the side toward the back of the mortar, and consequently it should be made a rule in returning dies to the mortar in ordinary cases, to place the less worn edge or higher side to the back of the mortar.

The shoe generally wears to an even, slightly concave face, while the die wears convex in a corresponding manner, this is called 'cupping;' the parts are said to 'cup.' The evenness of this cupping is due to the rotation of the stamps in falling, to the dies being plumbed exactly underneath the shoes, and to closely fitting guides which enable the shoe to strike the die exactly central at each drop.

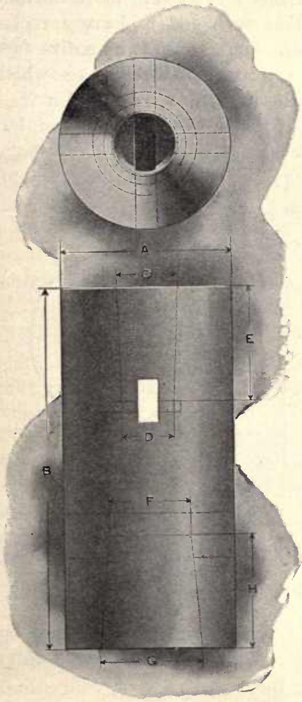
No die should be permitted to stand higher or lower than the others or it will cause that stamp to 'pound' or to 'cushion' through having too thin or too thick a bed of pulp over its corresponding die. In the effort to economize by saving 'steel'—the general term for shoes and dies,—the die is usually worn to a thickness of 1 or 1½ in.; at less than this thickness it is liable to break at any time. When a die breaks in a set that is only partly worn out, another of the same height must be put in its place. If no die of this height is available, a new set should be put in, though it is possible to replace the broken die with a shorter one built up by a false or old die. All mills have on hand an assortment of partly worn shoes and dies of various heights for this purpose, or for replacing a die that should be removed from a set because of some abnormality in its wear. Worn-out dies and discarded mortar liners and plates of jaw-crushers can be used in lining ore-chutes. The die should be of exactly the same diameter as the shoe or ¼ in. larger, as the shoe, through the looseness of the guides, strikes over an area slightly greater than its face.

For securing shoes in the bosshead, hardwood wedges made from staves of nail kegs or barrels are tied around the shanks of the shoes. Soft wood can be used if it is of a tough, pliable nature, but the shoes come off so easily that its use is not advised. Thick wedges can be used where the space calls for thin ones, by spacing them some distance apart about the shank, and allowing them to be crushed into shape when the shoe is put on. With the old style of iron bosses, having a ring on the lower end, the shoulder of the shoe should not come in contact with the boss or it will tend to loosen the ring. In bosses without these rings, the shoe may be wedged so that it will be driven up flush with the boss, for the shoe can then be worn to almost the thinness of cardboard before breaking. However, there is then no room for the shoe to be driven further into the socket and thus wedged tighter if the shoe should tend to come loose. Therefore many millmen aim to wedge the shoe so that one-third inch will intervene between its shoulder and that of the bosshead.

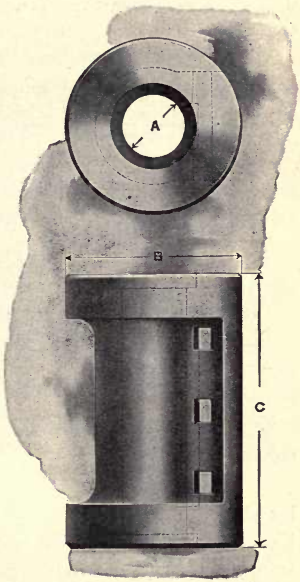
For removing the worn-out shoes, a 'drift' of tough steel is inserted in the key-way in the centre of the bosshead and pounded in, the wedging tension causing the shoe-shank to be forced out of the socket. Where the shank does not extend into the field of the key-way, a 'dutchman,' that is, a piece of metal 2 in. long, usually a broken tappet-key, is slipped in on top of the shank, and the 'drift' is carefully inserted to make a tight fit before driving. The edges of the 'drift' should be greased to make it drive easier. Shoes are also removed by blowing them out with small charges of dynamite. Should the ring of wooden wedges remain 'frozen' to the socket without dropping out with the shank, it should be allowed to remain, and in putting on a new shoe, a square piece of canvas is laid on the shank or a few new thin wedges tied about it.

In putting on a new set of shoes, the stems are first cleaned of the grease below the tappets by passing a long strip of burlap or cloth wet with kerosene or gasoline about the stem and alternately pulling each end of the cloth until the stem is clean. This is necessary as the tappet will now be set in the cleaned part—it would be impossible to make two slippery, greasy metal surfaces hold together. The tappet-keys are loosened and the stem pulled up through the tappet by means of the overhead chain-blocks until the boss is raised sufficiently to allow a new shoe to be set underneath, when the tappet keys are driven in sufficiently tight for security, and the chain-blocks removed. The new shoes are now rolled on a plank up to the mouth of the mortar; they are stood on the mortar lip and the wooden wedges tied about the shanks; then they are slipped in upon the dies underneath the bosses. The stem is now dropped, using a thick cam-stick to increase the height of drop. As the stem drops, the millman places his hand on the tappet that he may be able to tell by the jar if the shoe has been picked up by the boss. He keeps the cam-stick between the tappet and the cam at each lift of the stamp, so as to give the stamp a higher drop, and consequently a greater driving effect. It also causes the stamp to revolve more, insuring a straighter driving of the shoe-shank into the boss. As the shoe is lifted the first time, the man at the mortar below throws underneath it a shovelful of fine rock or pulp to cushion the blow and prevent cracking or chipping of the shoe or die. The operation is spoken of as 'driving on shoes,' and is followed by setting each stamp to drop the exact height desired. Some millmen, instead of driving the tappet-keys in lightly the first time, set the tappets permanently and do not re-set them after the shoes are on. This results in the height of drop being a little irregular, but some men are able to calculate so closely just how far the shoe will be driven into the boss that the plan is often a good one. When tying wedges around a shoe resting under a boss, it should be made a habit to pull the shoe out sufficiently so that, should the stamp accidentally or otherwise drop off the finger-jack—the prop upon which the tappet is supported when the stamp is 'hung up'—it will fall on top of the shank instead of encircling it, as many men have had fingers cut off in this way. A safer and more expeditious method is to tack the wooden wedges to a strip of drilling, making a ring that can be quickly slipped over the shank of the shoe before placing the shoe beneath the boss. A useful aid to putting on the wedges is to make five or ten smooth cylinders of wood, each having a diameter equal to the average diameter of the shoe-shank and a slightly tapered length equal to the height of the wedges. The wedges are tied about these cylinders so that when a shoe is to be put on, it is only necessary to set the cylinder on top of the shoe-shank and slip the circlet of wedges down over the shank. Care should be exercised that the mortar is not overfed for some time after shoes are put on, since running mortars choked tends to cause the shoes to come off.

Should a shoe come off, and the boss continue to drop encircling the shank, the socket of the boss will soon be worn so large that a shoe cannot again be fastened in it. Should the shoe turn partly or completely over on its side, the shoulder of the boss may be so battered that it may be considered necessary to remove it and chip out the socket. Instead of doing this, the boss should be set to drop encircling the shoe-shank with a height of 2 or 3 in., after



BOSSHEAD.



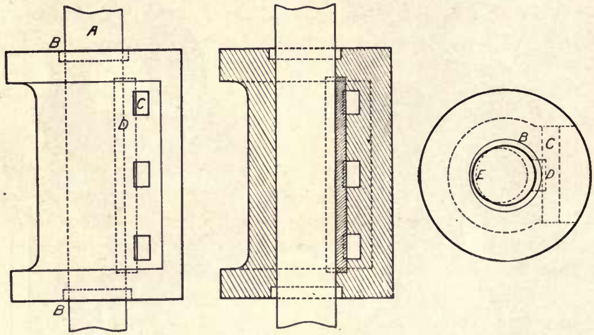
THREE-KEY TAPPET.

(Chrome Steel Works, Chrome, N. J.)

which the entire battery should be run for a half-hour, when the socket should be worn to its normal size.

Bosshead.—The bosshead, or 'boss' for short, was formerly made of iron, but now of cast steel, as steel is less liable to be split by the wedging tendency of the tapered stem or shoe-shank, or by the blowing out of shanks or broken stem-ends with dynamite. An additional reason is that there is much wear on the lower part of the boss by the attrition of the pulp when the shoes are well worn down, as can be seen by examining the bosses that have been in use for a long time. Steel is better able to resist this abrasion, as is shown by the comparative life of iron and steel shoes and dies.

Tappet.—The tappet should be of cast steel, being more durable than cast iron. It is counter-bored at each end to have a recess of ¼ to ⅛ in. wide and ½ in. or more deep, so that the entire face of the tappet exposed may come in contact with the cam which it rides, and thus wear evenly. As the cam must be placed a fraction of an inch away from the stem, if the tappet were not counter-



TAPPET.

A—Stamp Stem. *B*—End counterbores. *C*—Keyway. *D*—Gib. *E*—Longitudinal counterbore.

bored in this way a thin collar of metal would gradually form about the stem as the tappet-face wore down. This collar would interfere with the action of the cam on the tappet.

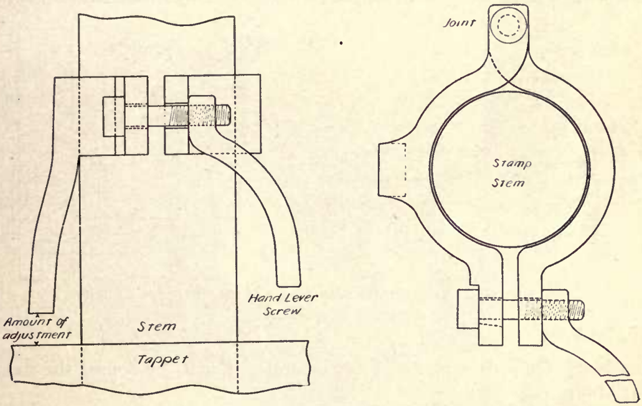
The tappet should have a slight counter-bore throughout the main bore through which the stem passes, and on the side opposite the gib or small piece of steel enclosed in the tappet which is wedged against the stem, by driving in the tappet-keys. This counter-bore should be of a smaller radius than the main bore of the tappet, and should make the main bore elliptical in form by reaming out one-third of its circumference. When the tappet is secured to the stem by driving the keys against the gib, it forces the stem into the elliptical part of the bore and gives three bearing surfaces equidistant, two where the counter-bore intersects the main bore, and one at the gib, whereas there are only two in a tappet not counterbored—one at the gib and one diametrically opposite. The use of three bearing surfaces instead of two, with the increased wedging effect, enables the tappet to be firmly fastened without driving the keys excessively tight. Slipping of tappets is one of the banes of a millman's existence, and advantage should be taken of every aid to prevent it. All manufacturers do not counter-bore the tappets in this manner, and this point should always be taken up when purchasing a mill or ordering new tappets.

Gibs that are too soft tend to cut out at the key-ways by the frequent driving of the keys. Placing a thick metal shim between gibs and keys will prevent this, though it is much more difficult to keep tappets from slipping when shims are placed between the gib and the keys than when placed between the keys and the outside of the tappet as is usually done. The use of a softer metal in the key, such as soft steel or iron, will lessen the cutting tendency. Gibs that are cut badly should be removed, that is, when they are cut so badly that the tappet keys bind on the tappet instead of against the gib. Broken gibs should also be replaced or they will mar and scratch the stems. Tappet-keys are re-shaped and re-pointed at the blacksmith-shop, or by means of a coarse file. An emery wheel is an excellent tool for this purpose and for grinding amalgam chisels, as well as for a multitude of other uses about a mill and mine, and should be included in the equipment of every mill. For driving tappet-keys, single-hand hammers with handles a little longer than usual, so that they may be used when necessary with two hands also, should be employed. When tappet-keys have to be sledged with heavy double-hand hammers to prevent the tappet from slipping, something is wrong; usually the gibs are cut out at the key-ways and the tappets are bored so large in comparison to the diameter of the stem that there is little binding surface. Where the slipping is thought to be due to grease, the tappet-keys may be loosened and a small quantity of gasoline poured into the upper counter-bore of the tappet to run down between the tappet and the stem, and thus wash out the grease. The tappet or stem has sometimes been raised and the binding surface of the stem wiped clean and chalked, with the idea that the chalk by its fine grit might increase the binding effect; powdered resin or dust has been introduced between the tappet and the stem for the same purpose. Gibs with their curves bored to a radius slightly smaller than that of the stem exert a good clamping effect. Dividing the gib into sections enables each tappet-key to clamp its own gib tight to the best advantage, and is of value with an extra long tappet.

Tappets should be bored $^1/_{32}$ in. larger in diameter than the stems. It should be possible to move and slide them easily, but no looseness should be apparent. Tappets with a bore of $^1/_{64}$ in. larger than the stem have been used, but too much trouble is experienced in slipping them over irregularities in the stem. The driving of the keys should be done evenly. If the upper or lower key be driven tight before starting the other, it may, in the case of tappets bored too large, throw the tappet out of line with reference to the stem. This may be one of the causes of stamps twirling. It may also serve to explain the lengthening of the drop of a stamp by a slipping tappet, which, however, is rarely seen; for ordinarily, when a tappet slips, it is driven upward on the stem by the repeated blows of the cam, thus lowering the stamp until the shoe touches the die, after which there can be no further lifting of the stamp. Taking the case where the upper key, or the upper part of a broken gib, is driven tight first and the tappet is slipping, the gib will be out of alignment with the stem and the upper part of the gib will be pressed tightly against the stem while the lower part is inclined from it. It is impossible for the tappet to be driven upward as usual, for the upper shoulder of the gib buries itself in the stem and prevents such movement, but the jar and rebound from the stamp striking the die causes the tappet to slip down on the stem a little, where it takes a new grip the moment the cam strikes it, causing it to drop down a little farther when the stamp strikes again. This continues until the stamp begins to 'cam,' that is, to fall on the cam from having too long a drop for the speed of revolution.

If the tappet-keys on each battery are all driven in on the same side, that is, all driven in either on the right or the left side of their respective stems, there will be less trouble from the locking or meshing of keys that project out too far, or are slipping out of the key-ways. Tappets are often made with the key-ways wider on one side than on the other, so that the keys shall be driven in from the wide side. This is imperative only when the gibs are badly worn, but in such cases the tappet should be marked by chalk or paint to denote this side, unless the manufacturers have marked it.

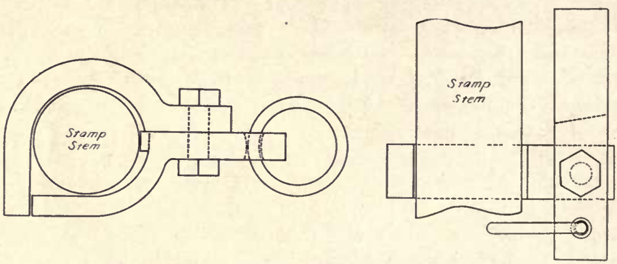
For setting the tappets, a special quick-acting clamp is placed around the stem at the required distance above the tappet, which is then resting on the finger-jack, and on loosening the keys the stem drops down this distance; the clamp is then removed after tightening the keys. Otherwise the chain-blocks are attached to the stem to raise, lower, or hold it. In setting the tappets, a man stands on each of the two opposite sides; one places a 'drift' having an eye and a wooden handle against the end of the key and loosens it with a hammer, but does not drive it out, while the man on the other side holds the tappet steady, and, with a piece of cloth to deaden the force of the blows, holds the key from being sud-



CLAMP FOR SETTING TAPPETS.

denly hurtled out of the key-way by the blow of the hammer. After the stem has been adjusted in the tappet, this second man hammers the keys back into place. Where the tappets are bored to a close fit on the stems, it is customary for one man to loosen the keys slightly, while the other makes a quick drive at one of the keys when the tappet has slipped to the mark; in this way the tappet setting proceeds rapidly. A chalk mark is placed around the stem above the tappet, so that any slipping may be readily noticed. If the tappets stick and refuse to move, a little kerosene or gasoline may be poured into the counter-bore at the top to run down between the stem and the tappet, while the tappet is struck with a hammer on the inside of the collar or on the waist. The outside or wearing face must never be roughened by being struck, or the stamp will not revolve evenly and slowly at first when that wearing face is put into use. The cam-stick may be used if desired, so that the blow of the cam may be utilized to drive the tappet upward on the stem without dropping the stamp off the finger-jack. When setting tappets, it is customary to hang up only the stamp that is being set, allowing the other four stamps to continue dropping, with the possible exception of when setting the stamp which actuates the feeder. To lessen the danger to fingers, two stamps may be hung up, the one being set, and its neighbor on the side next to the keys.

Thick tappet-keys requiring the least amount of shimming and made of a soft steel, with the ends tempered to resist the blunting

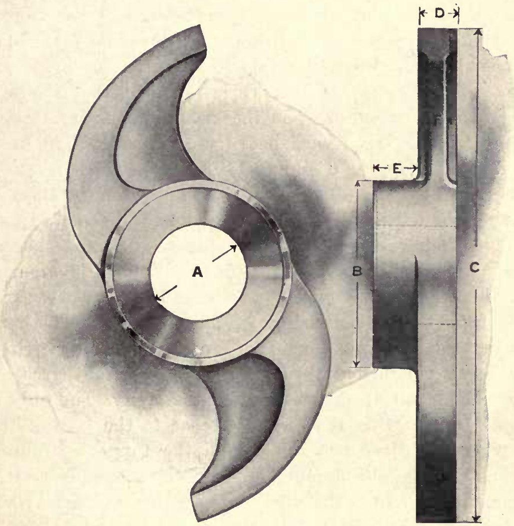


A CLAMP FOR ATTACHING CHAIN-BLOCKS TO STEM WHICH CAN BE PUT ON ANYWHERE WITHOUT SLIPPING OVER END OF STEM.

tendency from driving the keys in and out, will be found the most satisfactory.

Cam.—The cam should be of steel to insure long life and to lessen the chances of being broken, an undesirable occurrence on account of the labor involved in replacing with a new cam. They are set from $\frac{1}{8}$ to $\frac{1}{4}$ in. away from the stems, which is as close as the slight longitudinal play of the cam-shaft will allow them to be placed without occasionally striking or rubbing the stem. Cams are called 'right-hand' and 'left-hand,' and are determined by the following rule: when the hub of the cam is toward the observer and the cam rotates to the right, or clockwise, it is a 'right-hand' cam; if the rotation is to the left, or counter clockwise, it is a 'left-hand' cam. The action of the cams upon the tappets tends to cause the cams to move away from the stamps. This lateral thrust of the cams and cam-shaft is greatest at the moment when each cam leaves its tappet. It is overcome largely in the 10-stamp cam-shaft by making the cams of one battery left-hand, and those of the other right-hand, the lateral thrust of one set in one direction overcoming that of the other set in the other direction. With a five-stamp cam-shaft it is possible to use two right-hand and three left-hand cams, but generally the boss of the cam-shaft pulley is utilized as a collar in connection with other collars to prevent the lateral movement of the shaft. Even with the 10-stamp cam-shaft there is a constant undesirable longitudinal shifting of the shaft unless collars are used.

It is highly important that the cams be properly designed for the speed and length of drop to be used. The design should be



LEFT-HAND CAM.
(Chrome Steel Works, Chrome, N. J.)

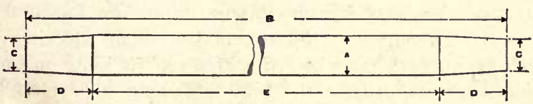
such that when the shoe strikes the die of an empty mortar the space of ¼ in. or more will intervene between the faces of the tappet and the cam, near the hub of the latter, and that when the stamp has reached the highest point of its rebound from striking the die the cam will immediately engage the tappet at a low but rapidly increasing speed as the tappet is lifted to the point where it drops off the tip of the cam. One of the greatest sources of noise, wear and tear, and broken parts, arises from a cam improperly designed and which suddenly engages or violently strikes the tappet. An examination of tappets in mills of long life usually shows that the wearing faces or shoulders of the tappets have been worn away or have been broken through inability to withstand severe strains. Makers should therefore supply tappets with extra thick wearing faces or shoulders, and the waist of the tappet should be cut out in such a manner that the projecting shoulder is weakened as little as possible.

The friction of the cam against the tappet causes the stamp to rotate while running. This is necessary that the face of the tappet may be worn smoothly all around, and also that the shoes and dies may wear or 'cup' evenly. One complete rotation of the stamp is made in from 5 to 30 drops of the present style of stamps under normal conditions. The data of two extreme cases will give some idea of the cause of this variation. In the Gilpin county practice, a stamp weighing 550 lb., dropping 17 in. thirty times per minute, rotates 1½ times per drop. In a certain mill using 1500-lb. stamps, dropping 6 in. and 110 times per minute, the stamps make one complete revolution in 30 drops. The stamps in two mills having the same weight of stamps and the same adjustments, will vary in their speed of rotation, due to different shaped cams and to the amount of lubricant on them. Where the stamps rotate too fast, there is a small loss of power and too much wear on the cams and tappets. This twirling of the stamps may be caused by the wearing parts being devoid of grease, by being gritty from dust, by being roughened through running without grease, or by the tappet being out of alignment with the stem. The only method of stopping the twirling is to apply grease to the face of the cam; if such treatment does not suffice and the tappet is found to be warm, the stamp should be hung up until the tappet is cold. Twirling is most prevalent with dusty ore, which indicates that it is due to dirt and lack of lubrication.

CHAPTER III

Stem and Stem Breakage—Fastening the Stem—Adjusting Height of Drop—Cam-Shaft and Cam-Shaft Box—Order of Drop—Stem Guide—Finger Jack—Feeder—Screen.

Stem and Stem Breakage.—The stem was formerly made of wrought iron, but now almost always, if not in every case, of mild steel. The stem does not wear out directly, but indirectly by breaking. These breakages occur mainly at the point where the stem leaves the embrace of the boss, but occasionally an old stem breaks near the tappet. Breakages at other points so seldom occur as to be phenomenal; in fact, breakages near the tappet are almost phenomenal from their infrequency, so that it is customary to con-



STAMP STEM.

(Traylor Engineering & Manufacturing Co., Allentown, Pa.)

sider that a stem will break only at the boss. When the stem breaks at the boss, it is reversed and the other tapered end is placed in the socket of the boss. When this second end breaks, the stem is sent to the blacksmith-shop to be swaged down again at each end, or to the lathe to be turned down, after which it is returned to the mill to be used again. After so many breakages have occurred that the stem will no longer run in the guides from being too short, a new piece is welded to it, or in the absence of facilities for making such a weld the stem is discarded. After welding, if bent, a stem may be straightened by laying it, while still hot, in the groove between two old stems or heavy pipes, of a diameter similar to the stem, placed parallel and an inch apart on the ground where they are firmly held by straps or bolts. In this groove the stem may be hammered and straightened.

The breaking of stamp-stems and cam-shafts has been popularly attributed to the crystallization of the metal; the theory being that the continuous jar and vibration to which these parts are subjected causes a molecular change whereby the fibrous structure of the metal is changed to a granular, crystalline form, which, not having the tenacity of the fibrous structure, finally breaks. Many arguments have been advanced for and against this theory, but nothing conclusive has been shown. It is pointed out that the break shows an apparently crystalline structure because it is across the grain of the metal in the stem, and that there is no evidence to show that any change takes place in the structure, either in the case of a broken stamp-stem or in any experiment made in a general way. It is also pointed out that should crystallization take place, the breaks would not be confined so generally to one particular point. The argument has been presented that the jar and vibration from the impact of the shoe upon the die passes into the boss, and that this vibratory motion concentrates to pass into the small cross-section of the stem at the point where the stem leaves the boss, and here is the point of greatest stress. Under the strain the particles of metal lose their power of cohesion; the metal develops 'fatigue;' minute fractures occur; there is a repeated bending stress in different directions from the stamp striking on an uneven surface, as when a piece of coarse rock is lying on the edge of the die; and eventually the minute fractures develop into a break. Conditions prevail in the stem at the tappet, where the breaks sometimes occur, somewhat similar to those at the boss. There is a jar, stress, and vibration from the impact of the cam upon the tappet which resembles that from the impact of the shoe upon the die. There is a bending strain from the cam striking the side of the tappet and away from the centre of the stem. As the tappet is continually shifted up and down the stem and its embrace is such that the vibratory motions are not communicated to the stem so constantly at one point as at the boss, the strain there is less and breakages do not frequently occur.

The breaking of stems can be prevented by annealing them, that is, by heating and slow cooling. This fact gives color to the theory that crystallization or some change in the structure of the metal does take place. Annealing is usually not feasible, except when welding or repointing the stems. It is carried out by slowly bringing the stem through a cherry red to a crimson heat, and continuing at that heat from one to six hours. The hot stem is then covered with hot dry ashes so that the cooling may be as slow as possible. The stems are sometimes cooled in chloride of lime, which is an exceptionally poor conductor of heat. The annealing process does not fuse or weld together the minute fractures in the stem, but relieves the stresses and strains in the different parts of the metal which are developed in the manufacture of the stem and greatly increased by use through the 'fatigue' of the metal. The slower the cooling, the better is the opportunity for the strains to adjust themselves. Because of tendency to warp unless carefully performed, it is generally not attempted to anneal the entire stem, unless they break elsewhere than at the boss. The breakages have been partly prevented by boring the bosses and making the ends of the stems larger. It is a question among millmen whether steel stems break less frequently than those made of iron. In general, they do break less, and experiments show that mild steel will stand a much greater strain than wrought iron before breaking, yet in some mills where both iron and steel stems are in use, the iron has been found superior. This is because the steel in the stems is of a poor quality or is too hard and brittle. Manufacturers find it difficult to secure supplies of the high quality of iron requisite for good stems and cam-shafts. The essential requirements of a good stamp-stem are a minimum of brittleness and tendency to crystallize and fracture under constant impact, jar, vibration, and bending strain. When a new mill having stems of a rather poor quality is started, the breakages will comemnce after about six months of running. With ordinarily good stems, about one year will elapse before the breakages begin. The breakages may be expected with steady frequency after the first occurrence with a set of stems. The frequency of the breakages or the life of the stems will vary with each maker, sometimes with each set from the same maker. It is interesting to note this fact when two sets of stems are being used in the same mill. In one instance in an enlarged mill, the iron stems of the old part of the mill broke with a frequency that indicated an average life for each stem of seven years between breaks, while the steel stems in the new part of the mill averaged about one year of use between breaks. In this case the trouble due to stems pulling out of their bosses was practically seven times as great in the new mill section, since when the two parts are first put together there is some doubt as to whether they will hold permanently, and the longer they have held together the less tendency there is for them to pull apart. It is a very good stem that will average three years of use between breaks.

With a view to reducing the bending strain and causing less wrenching of the stem when striking an uneven surface, stamps have been designed in which the centre of gravity is placed as low as possible. Both guides are bored to a close fit on the stem, with the lower guide placed near the boss. The stem is made short, using a long boss to make up the required weight, the result being that the stem drops straight and true, and that there is a minimum of bending and wrenching when the shoe strikes away from the centre line of the stamp. The results with these stamps appear to demonstrate the correctness of the theory upon which they are built.

Running the stamps with the feed too low or the mortar empty—'pounding steel'—shortens the life of the stems. The same may be said of poor and irregular feeding. When a piece of vagrant steel lodges on the top of a die, as is usually the case when a stamp suddenly begins to drop harder and shorter than its neighbors in the same battery, it should be removed or it may cause the stem to break. A die tipping over in the mortar will cause the stamp to act in the same way and will be productive of the same evil result. Concrete mortar-blocks were formerly supposed to be more severe on stems than wooden blocks, but the results in good installations, where everything is kept solid and tight, disprove this.

Overfeeding the motar causes the shoes to come off, and millmen popularly ascribe it to the suction of the deep body of dense pulp through which the shoe is moving. It may also be due in a narrow mortar to coarse rock wedging between the shoe and the side of the mortar, and thus forcing the shoe off. Another view when overfeeding is that the falling stamp is halted by the overthick bed of pulp, so that the cam does not come in contact with the tappet in the usual way with a light force, but strikes the tappet a severe blow as the two come in contact at a point where the peripheral speed of the cam is high. This is similar to camming, and tends to loosen the shoe from the bosshead and the bosshead from the stem. When the speed becomes dangerously high for a fraction of a minute, as when the engine governor does not act promptly, or as often happens with electric power at night, the resulting camming—and in fact camming under any condition—tends to loosen the shoes, and principally to loosen bossheads and break stems as well as cams and cam-shafts.

Fastening the Stem.—In putting stems into bosses, the boss, with or without the shoe, should rest on the die and not on a thick bed of pulp. The boss should be placed exactly underneath the stem, which should be raised just sufficiently to allow this or to give the right height of drop after the parts are fastened. Two strips of canvas, 2 in. wide by 15 in. or more long, should be placed across the socket of the boss at right angles to each other and slightly pushed in. The stem is now dropped off the finger-jack into the socket of the boss by means of the cam-stick, and is allowed to be dropped by the revolving cams until the boss is caught and the stem driven in. The stamp should be rotated while dropping so that the stem may be driven straighter into the boss. Another method of dropping the stem into the socket of the boss is to loosen the tappet and raise the stem by the chain-blocks, then tap with a hammer upon the clamp or chain by which the chain-blocks are hooked to the stem; this will jar the clamp loose, so that the stem will slip through and into the socket of the boss. Care must be exercised to have the boss placed properly and to see that the guides are tight, so that the stem may drop directly into the socket instead of striking on top of the boss. A chalk mark is placed near the end of the stem to indicate just how far it can be allowed to enter the boss, since should it enter too far, it would be impossible to insert the 'drift' for driving out the 'plug' or broken stem-end, should the stem break again. Some bosses have a hole running through the centre; by removing the shoe, a steel bar may be inserted in this hole to enable the broken stem-end to be driven out. The stem may be lowered into the socket, and should it appear that it will enter too far, more strips of canvas should be used. It is a practice with many millmen to lower the stem into the socket and drive it in by pounding with a heavy hammer on the upper end. This should never be permitted, as it is certain to spoil the tapered end so that it will not fit well in the socket when reversed, or should it be a broken end, it will 'mushroom' into a jagged end over which a tappet cannot be slipped.

When a stem pulls out of a boss and runs for some time before being seen and hung up, the tapered end is usually pounded out of shape to fit the socket, though it may not be apparent to the eye. If the stem will not catch again, it should be hoisted out of the mortar and allowed to rest on a plank across the top of the mortar, where it can be chipped and dressed with cold chisels and files. It is reported that some millmen do not turn their broken stems, but that two men dress down the broken end, using cold chisels with wooden handles and double-hand hammers; it is doubtful if a satisfactory job could be done, unless the required taper is slight.

Canvas should always be placed in the sockets, as it will lessen the number of breakages. When steel is wedged tightly against steel, it becomes as if made of one piece, and all the jar and vibratory motion is communicated to the stem at the point where it leaves the embrace of the boss. By placing canvas between the parts, the tendency is for the jar and vibration to be more generally distributed, instead of concentrated at one point. Likewise, the distribution of the bending-strain may be over a larger area. While canvas causes the parts to hold together as well or better than if not used through acting as a filler of small spaces where the stem and boss are not in a perfect wedging contact, it allows the stem or broken end to be removed more easily by the usual means of drifting, or blowing out with dynamite. Where it is not used, the parts tend to rust together so that sometimes a boss is blown to pieces in the effort to remove it from the stem. When canvas fails to make the stem stick, a shim made of tough metal should be tried, such as a thick screen plate, or thin sheet iron, bent cylindrically and set in the socket; or the metal may be cut in strips and shaped to fit in the socket in the same manner as canvas strips. If the stem still fails to stick, it may be that the taper does not fit the socket and requires dressing down; or both the stem and the socket may be too smooth to catch and bind, in which case a small stream of some fine grit, such as jasper, should be allowed to run into the socket with the stem rising and falling so that the surfaces may be roughened and eventually bind on one another, or the surfaces may be roughened by denting with chisels. Some stems will refuse to hold in the bosses, requiring the utmost patience before being finally fastened. The difficulty may generally be ascribed to the taper of the stem not corresponding to the bore of the boss, either from the way it was first fashioned or from being pounded out of shape. As a result, the binding surface between the stem and the boss is small—the stem may only shoulder against the boss with a minimum of the wedging effect. Naturally, the remedy is to shape and dress down the tapered end until it holds. The last resort, if the stem will not catch, is to turn the stem or put in another boss. Stems are fastened, whenever possible, through the top of the mortar without stopping the other stamps.

When a stem breaks, the first thing to do is to hang it up on the finger-jack, allowing the others to run until ready to change this stem; should this not be for some time, the boss with its shoe should be removed from the mortar. When ready to change the stem, the battery is 'pounded out' or 'stamped out,' which consists in shutting off the feed and allowing the stamps to run as long as may be safe, so as to remove as much pulp as possible from the mortar, the feed-water being shut off just before hanging up the stamps that the mortar may also be empty of water. The screen is removed, together with the chuck-block, and the boss is inclined outward from the mortar, the 'drift' is then inserted in the key-way and the broken stem-end driven out, after which the boss is righted into its place. Where the mortar-opening is too small vertically to allow the boss to be thus righted into its place, as is liable to be the case with a boss having a new shoe or with the long bosses of heavy stamps, a small rope-block is attached to the lower battery-girt and extended down through the top of the mortar, and the boss and shoe are pulled into position, after which the mortar is closed and the other stamps are started dropping. Open-front mortars were designed for the express purpose of obviating this trouble. Two or more turns of a stout chain are now taken about the tappet of the broken stem, and the chain-blocks hooked into this chain. The stem is raised until the tappet nearly touches the upper battery-girt. The battery is now hung up and the power thrown off from the cam-shaft. Both the upper and lower guides, which have been previously loosened, are now removed, and the stem and tappet are swung clear of the battery-girt. Raising of the stem is continued until it is possible to swing the lower end out on the cam-floor. If it is only desired to reverse the stem, it can now be done and returned to its place; but should it be desired to put in a new stem—one having a tappet held in place by one key lightly driven in usually being on hand for such cases—the old one is lowered to the floor, and the new one is picked up and swung into place. As soon as the stamp is swung into position, the other stamps of the battery are started dropping. The guides are put back and the tappet is temporarily adjusted for fastening the stem in the boss, as explained before.

Some men are able to turn or change a stem without stopping the cam-shaft and the other stamps, but it is so dangerous to limb, life, and machinery that it should not be attempted. If the plug does not easily drift out of the boss, the boss is removed to a more convenient spot for driving the 'drift,' or a new boss, together with the old shoe, is used. Blowing the plugs out with dynamite is a lazy man's refuge and may split the boss, especially when made of iron; though it is reported that even tight keys between cam-shafts and cams or cam-shaft pulleys have been blown out by dynamite. The careful millman will start with very small charges of dynamite and increase them until the parts are loosened. He will also see that the dynamite is in contact with the part to be blown out. The use of dynamite, besides breaking parts and developing minute fractures which later break, causes the mill parts to be jarred loose and jars the mill generally so that dust settles in the bearing parts. At one mill where trouble has been experienced from the plugs not readily drifting out, the boss is heated until the canvas chars, when the plug will drift out easily. In fact, heating the boss to cause it to expand, will enable a tight plug to be removed easily, even where canvas has not been used.

Adjusting Height of Drop.—It is customary to allow the stamps to increase their height of drop through the wearing away of the shoe and die, from ½ to 1 in. before re-setting. There are several ways of measuring the height of drop and the amount it must be decreased. One way is to open the mortar and measure the distance between each shoe and its die. This is an impractical way, requiring too much labor, while the measurements are unreliable if taken from a spot in the die that has cupped unevenly, or if the finger-jacks are of an uneven height.

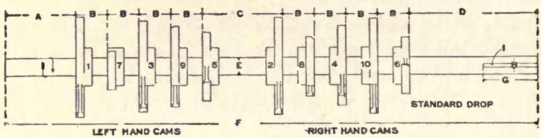
Another method of measuring the height of drop is to hold a piece of metal, such as the shims used with tappet-keys, against the stem at the guide and measure the scratch-marks on the grease with a rule while stamp is running; or chalk-marks may be quickly placed on the stem at top of the guide when the stamp strikes the die, and the lift of the stamp measured in the same as with the scratch-marks. The measurements obtained in these ways are also liable to be inexact. A better method is to hang up each stamp, rub off some of the surplus grease above the upper guide, and oil the upper guide well before dropping the stamp. After all the stamps in a battery have been treated in this way, hang up the feed-stamp or shut off the feed as long as safe. The oil-marks will now show the exact relative drop of each stamp when they are hung up. Should the finger-jacks be uneven, the oil-marks should be measured while the stamps are running. The tappets can be set by these oil-marks and re-checked after dropping again.

The best method of adjusting the height of drop is for the millman to examine the stamps once daily, and by his experienced eye single out those stamps that are dropping too long and too hard. Laying his fingers on the tappets or stems, he feels these stamps striking harder than their neighbors in the same battery, and in consequence he reduces their drop ½ in. He does not attempt to have each stamp drop the same exact distance or any exact distance in relation to the other stamps, since when using the methods first mentioned, the drop of the middle or end stamps is often varied a certain amount to get a more even stamping effect. He aims to have the individual stamps of a battery strike with an equal firmness, so that all may have an equal or maximum crushing effect, and so that he may be able to feed the battery down to a point where the greatest amount of crushing effect can be obtained. He also aims to run with the maximum of drop permissible with the speed set. These are some of the secrets of getting a large tonnage through a battery, and attention to them may result in increasing the capacity from 10 to 20%, as against a battery in which one stamp comes down hard, while its neighbor is cushioned, or where the drop is not kept as long as possible within limits of safety.

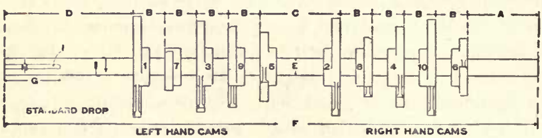
The inside of the mortar should be occasionally examined to ascertain how the shoes and dies are wearing, and also to look for any fragments of broken steel that may have fallen in, or have come in with the ore. This latter should always be attended to when changing screens.

Cam-Shaft and Cam-Shaft Box.—The cam-shaft is of hammered wrought iron or of hammered mild steel, with an increasing tendency to use iron shafts. A material is required for stems and cam-shafts that is tough rather than brittle, and is able to withstand the tendency to crystallize and break under impact; a good grade of wrought iron will answer these requirements as well or better than steel. It is the experience of most millmen that mills having iron cam-shafts have very little trouble from the breaking of the same, and that the substitution of iron shafts where steel ones break frequently will give great satisfaction; though as noted in connection with stamp stems, it is the grade of the material and its peculiar fitness for the conditions under which it is to work that determine what satisfaction it will give. Cam-shafts break from the same cause as stems, from 'fatigue' and crystallization of the metal, and from the extension of minute fractures formed coincidently with 'fatigue' and crystallization, or through defective manufacture or severe wear and tear and camming. The main cause is the impact of the cams upon the tappets, and in a poorly constructed mill, where the battery-posts jump and vibrate and are out of line, by pounding in the bearing boxes. The breaking of a cam-shaft is a serious thing as compared with the breaking of a stem, since it involves considerable time and labor, and usually a complete loss of the cam-shaft. It was customary to make the shafts for the lighter stamps from 4½ to 5 in. diam. As the weight of stamps has increased, the diameter of the cam-shafts has not always correspondingly increased, and this has been one cause of shafts breaking. A 10-cam shaft for 1000-lb. stamps should be 6 in. or more in diameter, 14 to 15 ft. long, and will weigh upward of 1400 lb. For 1250-lb. stamps a shaft 7 in. diam.

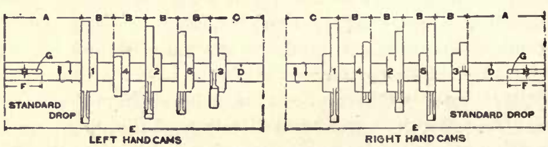
and weighing 1800 lb. or more should be used. Five-cam shafts do not require to be so large in diameter for the same weight of stamps as 10-cam shafts. With the 10-cam shafts now in use there are three bearings. These get out of alignment by the shifting of the battery-frame and the great wear and tear peculiar to a stamp-battery, which tends to throw the weight and stress on two boxes or bearings, making too great a strain for a long shaft, so that, as the shaft becomes weakened from the 'fatigue' or crystallization of the metal,



10-Stamp Shaft with Pulley on Right of Mill.



10-Stamp Shaft with Pulley on Left of Mill.



5-Stamp Shafts.

CAM-SHAFTS

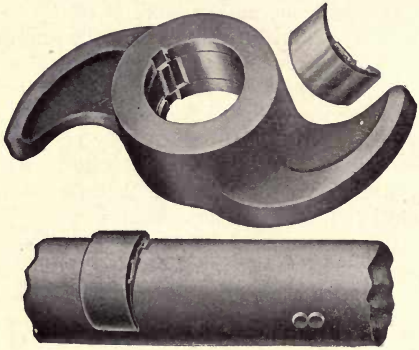
(Traylor Engineering & Manufacturing Co., Allentown, Pa.)

it is liable to break, especially when a stamp is camming on it near a non-supporting bearing. The bearing-boxes should be securely bolted to the battery-posts, and when the shaft commences to throw out puffs of air from the boxes, or to 'thrash,' pound, heat, or vibrate in them, they should be immediately babbitted that they may be in exact alignment and have three good bearings. If cast-iron boxes without babbitt are in use, the shaft should be removed and these boxes aligned. No shimming should be used under them as it will work loose from the jar about a battery. And it would appear unnecessary to state that only a most secure and solid construction that would be least liable to allow any movement, change, or wear in the cam-shaft bearings is what is necessary; that any construction giving a cushioning or spring effect must sooner or later cause serious trouble.

There is a great advantage in using 5-cam shafts in that there are few or no breakages. As there are but two bearings, even if the boxes do get out of line there is no abnormal strain at any time. These shafts enable one battery to be shut down to change a stem or for working on the interior of a mortar without interfering with the operation of another. The disadvantages are a slight increase in the length of the mill and the power required, also a doubling of the number of battery belts, pulleys, and, in some mills, the belt-tighteners. There is also the lateral thrust of the cam-shafts in one direction, but this is successfully met by the use of collars. The two-piece or sectional collar will be found superior to the single-piece collar, as it has a clamping effect in addition to that of the set-screws, and can be easily and conveniently put on or removed. A South African mill of 160 stamps was built with fourteen 10-stamp cam-shafts and four 5-stamp cam-shafts, that the 10-stamp shafts that broke might be utilized as 5-stamp shafts.

Where there is a minimum of jar in the battery-posts, and the bearing-boxes are not liable to get out of line, cast-iron cam-shaft boxes are the best, as there is no loss of time in babbitting, and little trouble from the shaft getting out of alignment or from having an abnormal strain due to the wearing and breaking away of the babbitt. Where there is much vibration of the battery-posts, babbitt, being a softer metal, is preferred for holding the shaft, while the frequent re-babbittings serve for aligning the shaft anew. Yet the truth of the matter is that if there is much vibration and pounding of the shafts, the babbitt is soon worn out or is broken and may fall into the mortar and foul the amalgamation. In such cases it is better to repair the battery and substitute iron boxes. The iron boxes are being placed in new mills and substituted in old mills when repairs are required.

To babbitt the boxes, the shaft is raised by means of screw-jacks, chain-blocks, or preferably by two long pieces of timber used as levers. The old babbitt is knocked out by means of chisels, when the shaft is let down into the position in which it shall run and is leveled. Cardboard luted with clay is placed about the shaft at the ends of the boxes, so that the molten metal may not run out. The melted babbitt is now poured in, and as soon as cold the clay is removed, and also the timber or other supports to the shaft, after which the shaft is started revolving and the stamps to dropping. Should the babbitt give trouble by breaking, especially in the box at the opposite end of shaft from the pulley where the shaft will 'thrash' about the most, it should be softened by adding some lead in the melting. It is well to have on hand a set of half-rings made of iron. These are inserted at each end of the boxes, and the shaft is lowered on them and made perfectly level, after which the supports are removed. The rings serve to hold the shaft in position while the babbitt is being poured in and to make the shell of babbitt of the right thickness. It may also be necessary to use the



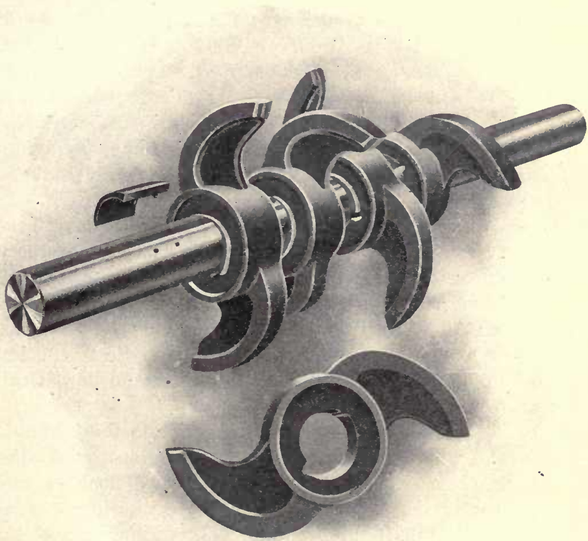
CANDA SELF-TIGHTENING CAM.

The studs upon the cam-shaft are pins driven into holes drilled 1 in. deep into the shaft.

(Chrome Steel Works, Chrome, N. J.)

clay to keep the molten babbitt from running out. After the babbitt has set, the rings are pried out. Iron caps for these bearings are universally discarded, except on the outward bearing of 5-stamp cam-shafts, but dust-caps of canvas should always be used.

When a 10-cam shaft breaks, running is continued with 5 stamps if possible, until ready to remove the shaft. The stamps are then raised by the chain-blocks until a 6-in. block can be slipped between each tappet and its finger-jack. This permits the shaft to be raised by levers, screw-jacks, or chain-blocks—first with chain-blocks removing the pulley or bull-wheel, to be rolled out on timbers away from the boxes. If self-tightening cams are used, they are removed, as it is only necessary to strike them with a hammer on the point in the reverse way to which they run. The broken shaft is taken away and a new one is brought. The cams are placed on this shaft, and it is then rolled and lowered into place. If the old-fashioned cams, fastening with keys in a slot cut in the shaft, are used, the shaft and cams are at once removed from the mill and a new shaft, having a full set of cams in position, is placed in the bearings. This method is necessitated by the fact that to remove



CAM-SHAFT WITH BLANTON SELF-TIGHTENING CAMS.
(Union Iron Works Co., San Francisco.)

and to replace a set of keyed cams is a long and laborious process. The fastening clips of self-tightening cams should be of brass, for the cams are more difficult to loosen when the clips are of a material that will rust. Heating the boss of the cam with a brazing torch assists in loosening a tight cam, either of the keyed or self-tightening type.

Order of Drop.—The order of drop of the stamps in a battery should be such that an even bed of pulp is kept over the dies, rather than an excess over one die and too little over another, and that the splashing or wave motion of the pulp be produced evenly along the screen. The first has reference to the crushing capacity of a battery, while the second refers to its screening efficiency, the two factors that make for tonnage. The academic requirement that no two adjacent stamps shall drop consecutively, or in simpler language, that no two stamps side by side shall follow each other in dropping, is fulfilled by only one order, 1-3-5-2-4, or its reverse which is usually spoken of as 1-4-2-5-3, since the custom in numbering is to face the front of the mortar and to consider the first or end-stamp on the left as dropping first. Another order of drop and the one which is most popular with practical millmen is 1-5-2-4-3. It will be noticed that the third stamp follows the fourth in dropping. The reverse of this drop as determined by counting it from the rear of the mortar and then applying it to the front is 1-4-2-3-5, in which the third stamp follows the second in dropping.

Practically every conceivable order of drop has been used, but the above two systems are the only ones that have stood the test of time. Much confusion exists in speaking or writing of the different orders of drop. Thus one man will say that 1-3-5-2-4 is a good order and has been found to be satisfactory, and that 1-4-2-5-3 has been found to be a poor order and unsatisfactory. Since the latter is the reverse of the first, it is difficult to understand how it could be better or worse.

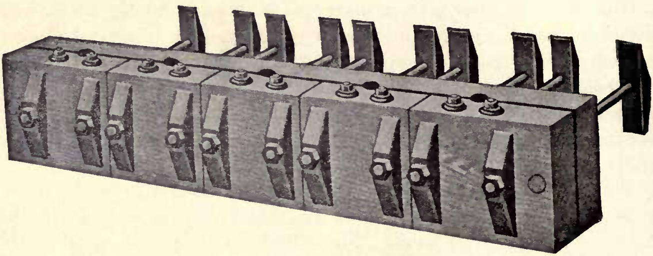
The 1-5-2-4-3 order has been found superior to the 1-3-5-2-4, both generally and where they have been tested against each other. A case under observation will illustrate the difficulties and the disadvantages of the 1-3-5-2-4 order. There was in use a narrow mortar and a 1000-lb. stamp dropping 103 times per minute through a distance of 7 to 8 in. As long as the height of discharge was kept as low as possible, and the feed perferably of coarse rock, little trouble was experienced. The tendency of the pulp to bank under the first stamp and leave the fifth pounding was marked, but in proportion as the feed was kept low and the stamps almost 'pounding steel,' this trouble was overcome. As the height of discharge was raised and finer rock was fed to the mortar, the trouble from the pulp swinging toward the first stamp became so great that when attempting to do fine crushing by the use of a high discharge and a fine screen, the results were most unsatisfactory, both as to tonnage and operation. The first stamp was set to drop 8 in. and the others evenly graded down to 4½ in. on the fifth stamp, but without getting the stamps to strike a blow of equal hardness. The pulp discharged from the third, fourth, and mainly from the fifth stamp, so that it was necessary to improvise a distributing box to get an even distribution across the plates. This difficulty with the 1-3-5-2-4 order, when running with a medium or high discharge, is generally reported, and it cannot be considered as a satisfactory order for fine screening, or a soft ore, or a high discharge.

The 1-5-2-4-3 order gives a more even splash across the screen and a better distribution in the mortar; consequently it gives a higher capacity with less trouble in operating. An increase in capacity has been reported of as high as 29% by changing to this order of drop from the other one mentioned. It scours more severely in the centre of the mortar than the other order, so that it is harder on the screen and chuck-block at this point.

While strongly recommending that the 1-5-2-4-3 order be used, it is advisable that the millman be able easily to change to the 1-3-5-2-4 and thus try both. The mills built today are all supplied with self-tightening cams, as these have been so satisfactory that no one would think of going back to the old-fashioned keyed cam; these automatically lock themselves into position according to a clip on the cam-shaft. The position of this clip is determined by two holes bored in the shaft in which the lugs of the clip are set. By drilling two extra sets of holes in the cam-shaft, making seven sets to a battery instead of the usual five, it will be possible to change from one order of drop to the other. Such a boring would give the drops 1-3-5-2-4 and 3-1-5-2-4. It will be observed that the 3-1-5-2-4 order is the 1-5-2-4-3 with the numbering commencing at the third stamp to enable a simpler comparison to be made with the other order. To change from one order to the other, it would only be necessary to reset the first two cams to the other positions; a thing that can be done easily and quickly. The millman now has at his command both of the only two orders of drop worthy of consideration.

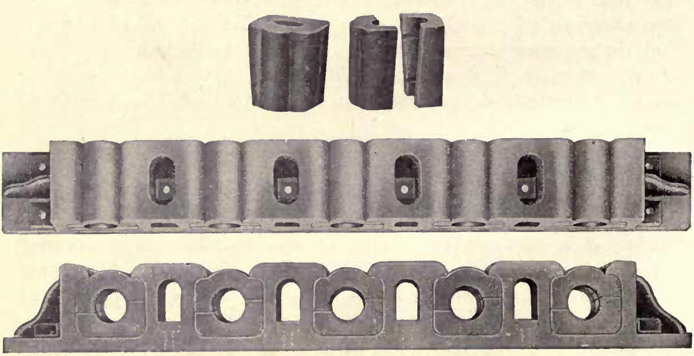
Stem Guide.—The stem guide should be of cast or malleable iron and of the individual type, though wooden guides are much used in the older mills. They should be bored to a close fit of $^1/_{32}$ to $^1/_{64}$ in. larger in diameter than the stem, carefully aligned and adjusted when first run, and supplied with a good grade of lubricating oil instead of the usual dirty oil or scrap-grease. They should be kept as tight as possible without heating or rubbing so that the stamp may move truly up and down with little side-play. The wooden guide can never give a close fit without heating, and sooner or later there will be considerable side-play from the wearing away of the wood; they are not being placed in new mills.

Finger-Jack.—The finger-jacks should raise the tappets 3/8 in. clear of the cams, so that a cam-stick of three and not to exceed four thicknesses of heavy belting may be used. Thicker cam-



INDIVIDUAL WOOD GUIDES.
(Stearns-Roger Mfg. Co., Denver.)

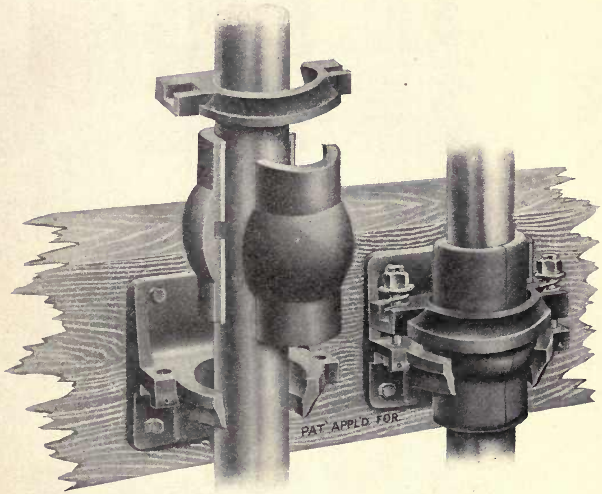
sticks are too heavy to handle with ease, and are more liable to be cut to pieces by a stamp with too long a drop. One very thick cam-stick should be kept on hand to increase the height of drop of the stamps in putting in shoes or stems and in pounding out choked mortars. A box 3 by 6 in. and 9 in. deep, and open at the top, should be fitted to the central battery-post of each cam-shaft for holding the cam-stick. Cam-sticks made of iron with handles of



IDEAL INDIVIDUAL GUIDE.
(Geo. W. Myers, San Francisco.)

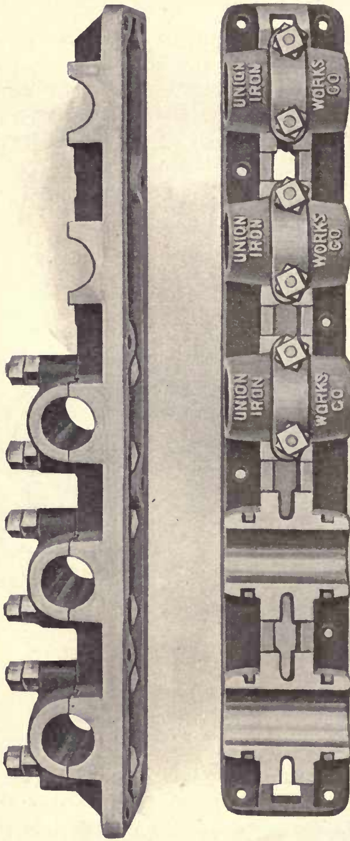
leather or belting, work well, but care must be used in placing them on the cams or they will fly back in a dangerous manner. The finger-jacks should be solid and steady; a stamp resting on a wobbly finger-jack a fraction of an inch too short, and in connection with loose guides, is a dangerous thing beneath which to examine the interior of a mortar.

Feeder.—The suspended type of the Challenge feeder, or one of the so-called 'improved' feeders of the same order, is now almost universally used, as it gives a free floor and is less in the way than the platform type. However, the standard platform type of Challenge feeder is still the strongest and most satisfactory working



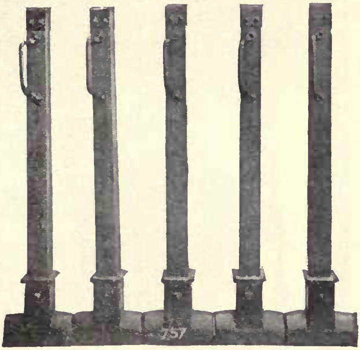
EUREKA INDIVIDUAL GUIDE.
(Joshua Hendy Iron Works, San Francisco.)

machine made. The revolving feed-plate should be set 4 in. above the mouth of the mortar, so that a platform of wood or sheet-metal may be attached to the mortar to catch and lead into the mortar as much of the drippings from the feeder as possible; and also to allow of the introduction of a long tin scoop for catching a sample of the mill-feed as it drops off the revolving plate. This revolving feed-plate should be provided with a false plate or liner that may be readily replaced when worn out. Feeders were formerly actuated by a bumper-rod struck by a cam tappet, but as these rods are liable to give trouble at times, they are not included in the design of a modern mill; a small 'feed tappet' on the middle stamp striking the arm of the feeder is now used. This tappet should be a split

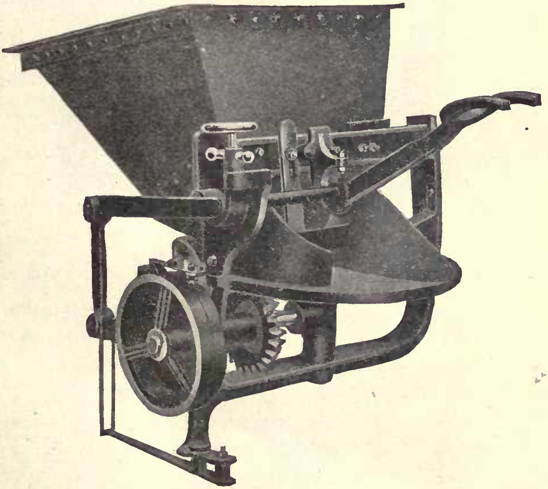


UNION INDIVIDUAL GUIDE.
(Union Iron Works Co., San Francisco.)

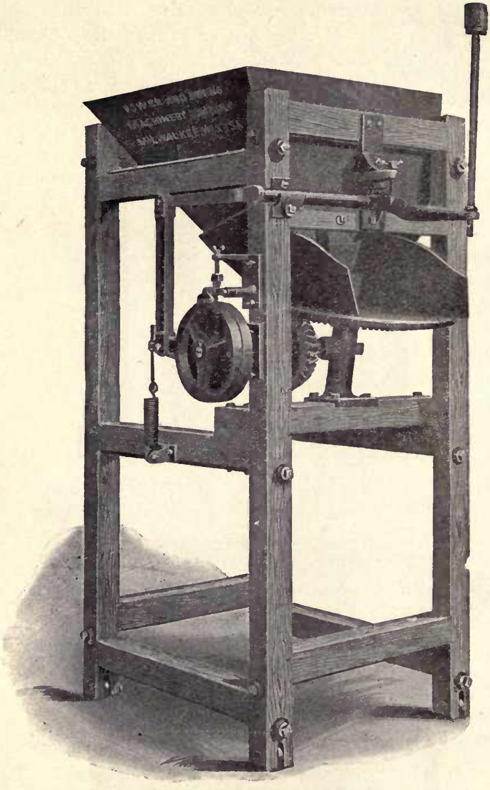
or two-piece collar, since in changing a feed stem, putting on the feed tappet is often forgotten until after the stem is stuck in the boss. These tappets, however, frequently give trouble by slipping, due to grease running down from above, or to the bearing parts being too smooth. Feeders are the only parts in a stamp-mill equipment that are of delicate construction, and they should receive careful attention. If worn out or broken, they should be renewed or rebuilt, as poor feeders cause the mill employees great annoyance, and reduce the mill capacity and increase the breakages.



FINGER-JACKS OR STAMP FINGERS.
(Denver Engineering Works Co., Denver, Colo.)



STANDARD SUSPENDED TYPE OF CHALLENGE ORE-FEEDER.
Driven by feed tappet on centre stamp.
(Traylor Engineering & Manufacturing Co., Allentown, Pa.)



PLATFORM TYPE OF CHALLENGE FEEDER WITH BUMPER ROD FOR DRIVING BY STAMP TAPPET.

(Power & Mining Machinery Co., Cudahy, Wis.)

Screen.—Screens for use in stamp-milling are divided into two general classes, the perforated or punched metal plate, and the woven wire or 'cloth' screens. Perforated screens are either plain or burr-punched. In the plain-punched a piece of the metal is punched or cut out to make the hole, while in the burr-punched the metal is bent inward instead of being removed. Burr-punched screens require to be placed with the burr or ragged edge inside the mortar so that the grains of pulp may not wedge in the orifices, and thus reduce the capacity of the screen. Even the plain-punched screens have a slight burr on one side made by the punching tool as it emerges on that side after passing through the plate; it is generally considered that this burr side should be turned inside the mortar, but some manufacturers claim the reverse, stating that the hole becomes slightly larger toward the burr side by the metal breaking ahead of the punching tool. These plate screens are generally made of Russia iron, steel, or 'tin plate,' though sometimes of brass, copper, bronze, phosphor bronze, aluminum bronze, tin bronze, aluminium, zinc, or tin. The Russia iron screen is comparatively thick so that it does not facilitate discharge, and therefore is not in high favor.

The 'tin plate' or 'tinned-iron' screen is made of a good grade of iron and coated with tin. This coating prevents its rusting before being put into use, and may prevent an acid battery-water or pulp from attacking the screen. It has been suggested that the coating of soft tin protects the screen from the impact and attrition of the pulp by presenting a yielding malleable surface. Some millmen remove the coating by heating the screen to redness over a forge or gasoline burner, which is supposed to strengthen the screen by annealing it. As it oxidizes the surface of the screen, it should not be done where the battery-water or pulp is acid. Experiments can easily be conducted on the same screen-frame to test the value of annealing. The tinned-iron screen gives the least trouble from clogging. This is because of the thinness of the metal. A grain of quartz that will lodge in a hole in a Russia iron or thick steel-plate screen, will pass the same size opening in a tinned-iron screen, or will be jarred through by the moving pulp within. The tinned-iron screen has been given the preference in many mills after being tested against the thicker perforated and woven-wire screens. The character of the rock is one of the determining factors in the choice of screen to be used. The tendency to clog with a hard, splintery quartz or a clayey, talcose ore is great, and it is sometimes possible to run a 40-mesh tinned-iron screen on an ore where it is impossible to use one of woven wire that is finer than 30-mesh on account of clogging.

The steel-plate screen is the strongest. Its life is so long that it must sometimes be removed before breaking on account of the openings becoming enlarged by wear. Theoretically, the holes should be spaced so close that the screen will break when the holes have become enlarged to an undesirable extent. Steel screens of special thinness, and of the round-punched type, have been tried against the tinned-iron with satisfactory results, but have not come into the general use they merit.

The holes in punched screens are of two kinds, the round and the slot. The slots are usually half an inch long and run

SLOT-PUNCHED PLATE SCREEN. ROUND-PUNCHED PLATE SCREEN.
(Braun-Knecht-Heimann Co., San Francisco.)

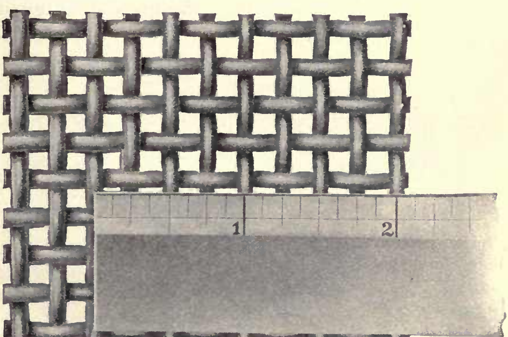
horizontally, vertically, or diagonally. The diagonal slot is given the preference over the vertical for no particular reason, except the theory that the pulp running down the screen must sooner come to an opening and by running along the opening for a short distance is better caused to pass through the screen. The diagonal and vertical slot have been found superior to the horizontal slot, for it appears that to get the best results the length of the slot should run in the same general direction as the material travels over the screen. The slot-punched screen gives a freer discharge and greater capacity with less blinding than the round-punched screen. This is partly because the slot screen has more discharge area or air space and partly because a particle of ore going through a slot will wedge on only two surfaces and will have a chance to work itself through or loose, whereas when going through a round opening it will wedge on three or four surfaces and have more friction to overcome. For the latter reason the product through the slot opening will be more inaccurately sized and will contain many flat pieces of pulp that could not possibly get through a round opening. The diagonal-slot screen is advantageous where screens blind and clog or where the product is to be reground and the uneven sizing from the stamp mortars is immaterial.

A plate screen is numbered the same as the number of the sewing needle that will just pass through its opening. This and their method of manufacture cause them to be spoken of as needle-punched screens.

SIZES OF ROUND AND SLOT-PUNCHED PLATE SCREENS

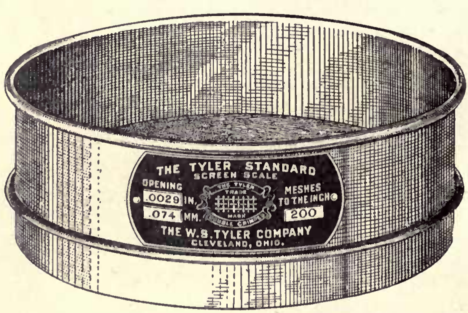
Needle number of screen.	Approximate mesh of wire cloth to which openings correspond.	Width of slot or diameter of hole in inches.	Width of slot or diameter of hole in millimeters.
1	12	0.058	1.47
2	14	0.049	1.25
3	16	0.042	1.07
4	18	0.035	0.89
5	20	0.029	0.74
6	25	0.027	0.69
7	30	0.024	0.61
8	35	0.022	0.56
9	40	0.020	0.51
10	50	0.018	0.46
11	55	0.0165	0.42
12	60	0.015	0.38
13	70	0.013	0.33

The size of woven-wire screens is designated in an inexact way by their 'mesh' and in a scientifically exact way by their 'opening.'



4-MESH, 0.105-INCH WIRE SCREEN.
(W. S. Tyler Co., Cleveland, Ohio.)

The 'mesh' of a woven-wire screen is the number of openings or air spaces per lineal or running inch, and is determined by laying a rule upon the screen and counting the number of openings embraced within the length of one inch. As screens of the same number of meshes are made from various diameters of wires, it follows that the size of the openings is not determined by the number of meshes alone, but also by the thickness of the wire. A 30-mesh screen made of heavy wire will have a larger part of the screen area taken up by the wire and consequently smaller openings than the same mesh of screen when made of lighter wire. The 'opening' or 'space' between the wires is what determines the size of the particles passing through the screen, and the width of this opening is stated in inches or millimeters. With the woven slot screens the 'opening' is the width the narrow way and has no relation to the length of the slot. The size to which the product must be screened determines the size of the openings, while the nature of the service required of the screen determines the size and kind of wires. The manufacturer in filling an order requires to know the opening, the shape of the opening, the size of the wire, and the kind of wire—unless these are included under a trade number of screen. The diameters of wires have been stated in at least six different 'gauges,' so that the simplest way to express the size of wires is by their diameters in inches. Thus it follows that the only exact way to describe the size of a screen is to give its 'opening,' or to state its mesh and the size of the wire—which will allow the 'opening' to be computed. But as decimals of an inch do not quickly give the desired impressions, practical millmen speaking in a general way will probably continue to use the term 'mesh' to express



STANDARD TESTING SCREEN.
(W. S. Tyler Co., Cleveland, Ohio.)

their ideas in a quickly grasped manner. It therefore becomes necessary to standardize in some arbitrary manner the different meshes by considering that a certain opening or width between wires constitutes a certain mesh, irrespective of the fact that with heavy wires there will be less than the stated number of meshes per lineal inch, or with light wires there may be more than the stated number. This is possible by adopting the widths of openings used in the Tyler scale or series of standard testing screens or sieves.* The base of the series is an opening of 0.0029 in. which is the opening in 200-mesh, 0.0021-in. wire cloth, and has been standardized by the U. S. Bureau of Standards. The width of the openings in each sieve increases in the ratio (as originally proposed by Rittinger) of the square root of 2, or 1.414; that is, the width of each opening in any screen is 1.414 times the width of the openings in the next finer sieve, while the area of each opening is twice as large, which allows spheres or grains of pulp of 1.414 times the diameter or twice the sectional area to pass through. If the openings of this series were adopted as arbitrarily designating these meshes, then these meshes would express both exact and easily grasped ideas.

TYLER STANDARD SCREEN SCALE

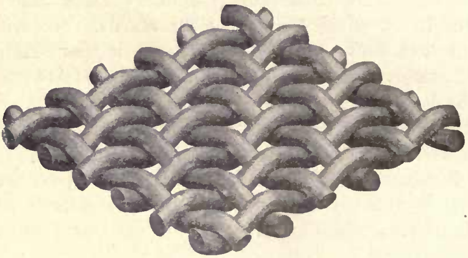
Ratio $\sqrt{2}$ or 1.414

Opening in inches.	Opening in millimeters.	Mesh	Diam. wire, dec. of an inch.
1.050	26.67	..	0.149
0.742	18.85	..	0.135
0.525	13.33	..	0.105
0.371	9.423	..	0.092
0.263	6.680	3	0.070
0.185	4.699	4	0.065
0.131	3.327	6	0.036
0.093	2.362	8	0.032
0.065	1.651	10	0.035
0.046	1.168	14	0.025
0.0328	0.833	20	0.0172
0.0232	0.589	28	0.0125
0.0164	0.417	35	0.0122
0.0116	0.295	48	0.0092
0.0082	0.208	65	0.0072
0.0058	0.147	100	0.0042
0.0041	0.104	150	0.0026
0.0029	0.074	200	0.0021

Woven-wire screens are made of iron, steel, copper, brass, phosphor bronze, and aluminum bronze. They are of two kinds, the single-crimp and the double-crimp. In the single-crimp only the wires in one direction are crimped or bent, and the result is that

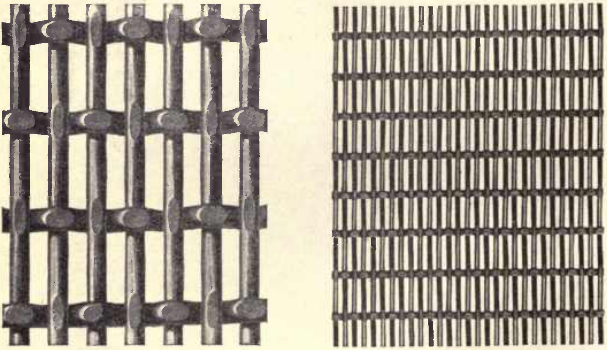
*Made by the W. S. Tyler Co., Cleveland, Ohio.

the wires of such screens tend to spread apart and make the openings of irregular size and produce much oversize in the pulp. In the double-crimp both sets of wires are bent and arched so that they are locked and prevented from spreading. The woven-wire screens are made with square openings or with slot openings, usually horizontal or vertical.



DOUBLE-CRIMPED WIRE CLOTH.
(W. S. Tyler Co., Cleveland, Ohio.)

The Ton-Cap (meaning Tonnage-Capacity) is the trade name of a special class of screen made by a prominent manufacturer.* To present the greatest possible discharging area or screening capacity



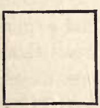
THE TON-CAP SCREEN.
(W. S. Tyler Co., Cleveland, Ohio.)

is the idea along which it is designed. It is double-crimped and then rolled, which sets the wires and keeps them from slipping

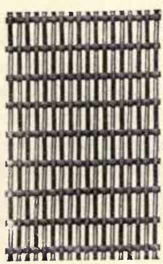
*Made by the W. S. Tyler Co., Cleveland, Ohio.

out of place or spreading, and so gives an even product. The rolling also presents a smoother surface which is more easily kept free and clean. The larger area in the woven-wire screens over the plate screens is further increased in the Ton-Cap by making the openings oblong or slotted. In this way it has the largest discharging area of any screen, and therefore is a highly efficient screen where capacity or a minimum of slime—as for concentrating—is desired. These screens are made with a different size of wire in both directions, or various diameters of wires, and of various lengths of slots. This results in several hundred kinds of screens, each of which is designated by a trade number. In this way the user can have selected for him a screen best adapted to his conditions. With small capacity he can have a screen of fairly heavy wire, and consequently of long life. He can use a screen of heavy wire for a heavy material or a low discharge, or one of light wire for a light material or a high discharge. If there is trouble from

Width of Slot, 0.027 Inch.

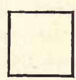


0.367 Sq. In.
Discharge Area in
1 Sq. in.

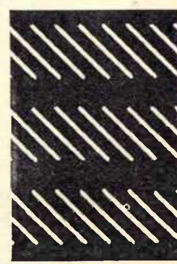


No. 93 Ton-Cap
0.367 sq. in. discharge area per sq. in.
53.000 sq. in. discharge area per sq. ft.

Width of Slot, 0.027 Inch.



0.160 Sq. In.
Discharge Area in
1 Sq. in.



No. 6 Diagonal Slot (25 mesh)
0.160 sq. in. discharge area per sq. in.
23.000 sq. in. discharge area per sq. ft.

No. 93 Ton-Cap has 129% more air space or discharging area than No. 6 Diagonal Slot to produce the same sized product.

COMPARISON OF DISCHARGE AREAS.
(W. S. Tyler Co., Cleveland, Ohio.)

blinding or choking he may obtain a screen having longer slots or smaller wires. If the wires in one direction wear out more rapidly than in the other direction, he can secure a screen in which the wires are selected to give equal life. These screens are usually made in steel wire, but are also furnished in brass, copper, bronze, and phosphor bronze wire. They are a high development in screens and, though they may not be the best suited screen in many cases, they should be thoroughly tested, especially in regard to their length of life and an increase in tonnage and a decrease in the percentage of slime produced.

Brass-wire screens have been found satisfactory for fine crushing with a high discharge, as to 30 or 40-mesh or to 60-mesh—though crushing in a stamp mortar through a 60-mesh screen has not often been performed. Brass wire is too soft for the severe wear and tear of crushing with a low discharge. It cannot be used when crushing in cyanide solution, as the screen is attacked by the solution, and soon breaks. Contrary to the usual opinion, they do not amalgamate to a prohibitive extent. After receiving the usual treatment accorded old screens for removing any adhering amalgam, they can be melted into a bar.

The brass, copper, or bronze screens—both the plate and woven cloth—are used where the battery water is acid, as from partly decomposed sulphides, and iron or steel screens tend to rust or corrode. Bronze screens have a much greater life than iron or steel screens and it would often be advantageous to use them, even at their higher cost.

The screen to be used can only be determined by extended experiments made in a comparative way under actual working conditions. Its selection is influenced by the following factors whose weight or influence in most cases is not fully understood or clear: Cost. Life. Tonnage. Effect upon extraction. Nature of product. Accuracy of sizing. Ability to screen or screening capacity. Discharging area. Nature of ore. Manner in which screen is to be used and service required. Type of screen and its structurial features. Thickness of plate or size of wire. Size and shape of opening. Nature of screen material. Attention required by screen. Trouble from clogging. Loss of time in renewals. Increase in oversize through wear.

The ideal screen from a standpoint of screening efficiency would be one of infinitely small wires separating the openings. On the other hand the ideal screen from a standpoint of service would be a screen with infinitely heavy wires between the openings. However, an excess of screening surface and discharge area is not of exceptional advantage in stamp-mill practice, or double-discharge mortars would be used. Likewise, a screen of heavy plate or thick wire is not of advantage even with an excess of discharging space, for they discharge too slowly in comparison with the thin plate or woven screens of light wire, and as a result a heavy wire or thick plate screen should not be used in obtaining a fine product.

The thick Russia-iron screen is but little used now. For crushing to 12 to 16-mesh with a low discharge, the diagonal-slot steel screen is in high favor. It produces an inaccurately sized product having large angular pieces of oversize, but such crushing is usually followed by regrinding. The tendency to blind or choke due to a hard, splintery ore or to a talcose ore is at a minimum. For crushing between 16 and 30-mesh, the tinned-iron screen has been found very satisfactory, except where the discharge is carried too low to allow these screens to have a reasonable length of life, when thin steel screens either round-punched or with diagonal slots may be substituted. It is questionable if these 16 to 30-mesh screens discharge sufficiently fast for a modern fast-crushing battery, therefore the double-crimp, rolled, slot type of woven-wire screens—the Ton-Cap—should be tried.

The woven wire should be tested against the plate screens in all cases. The plate screens are cheaper and usually stronger, but the woven wire has the advantage of more discharging space, which tends to produce greater capacity and less slime. Also, the rounding surface of the wires seems to steer the particles of pulp into and through the opening, but on the other hand this promotes clogging. The value of wire screens increases as their tendency to clog becomes less. The clogging tendency is overcome by using the slotted woven type and by using smaller wires that will make the openings less of a taper in which the grains can wedge. If clogging still continues the plate screens should be tried, and particularily those of the thinnest metal and the slotted type. Lime in the crushing solution sometimes coats wire screens so that punched plate must be substituted.

For the coarser meshes of woven wire the square opening will usually answer as well as the slot opening. The round openings of the punched screens will give the most accurate sizing—provided the screening capacity of the screen is in excess of the demands made upon it. The square openings of the woven wire will give the next most accurate sizing, but a slightly coarser product than from the round openings of the same width—because of the difference in shape of the two holes. The slot openings will give the most inaccurate sizing and the coarsest product for the same width of opening. However, the above statements must be modified by the facts that the plate screens have the smallest discharge area, that the square-opening woven-wire have a larger discharge area, and that the slot-opening woven-wire have the largest discharge area; as a result a particle of pulp splashed against a punched screen, and of the requisite size to pass through, may be thrown back and recrushed finer; whereas with the slot-opening woven-wire having a much larger discharging area and capacity, there is a much greater tendency for the particle to pass through the screen as soon as crushed to the screen size. In this way the square opening and slotted type of woven-wire may produce more accurate sizing than the punched-plate screens by reducing the amount in the slime and finer sand.

Accurate sizing and long life do not go together. The first particle of ore passing through an opening wears the wires and permits a larger piece to pass through the next time. With the heavy wires having long life, the openings must wear very coarse and the product must become materially changed—coarser—before the screen breaks. With the light wires, the openings cannot be worn very large before the screen breaks and must be replaced with a new one. Therefore the light wire screen or a screen of thin plate gives the most accurate sizing at the expense of the screen life. It is generally considered that the openings of the plate screens wear larger much more rapidly than those of wire, but the durability of the screen material is what really determines the wear. Screen tests should be made wet on the pulp issuing from new and from well-worn screens to determine if the openings wear larger and thereby deliver an appreciable amount of over-size, and if an increase in such oversize lessens the extraction to an extent warranting the removal of the screen before it is fully worn out. If it is found advisable to remove screens for this reason, a laboratory or small testing screen of such a mesh that it will retain practically no oversize from the pulp issuing through a new battery screen should be used in the mill, and when the pulp from any battery screen shows an undesirable amount of oversize, that screen should be discarded. If the discarded screen is still in good condition otherwise, it indicates the advisability of a screen of thinner plate or smaller wire, or with the holes spaced closer together.

When screens clog, they are scraped, brushed, and slapped in an effort to keep them clear. Wire screens are removed when badly clogged and left to become dry, when they are brushed and slapped. Perforated screens usually break close to the screen-frame. In such a case a piece of wood 1½ in. square, and slightly longer than the break, is covered with canvas or a piece of blanket on two sides, and attached to the frame by one or two short nails to cover the break until it is convenient to remove or turn the screen-frame. The method of tacking little blocks of wood or rubber belting over breaks in screens is followed in a variety of ways, and is one of the simple expedients by which the cost for screens is kept low.

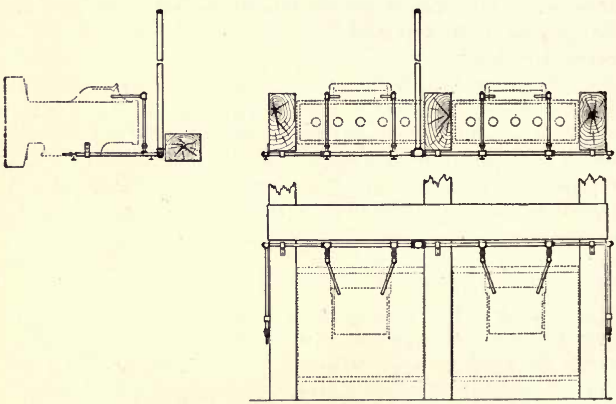
A strip of canvas or gasket-rubber between the screen and the frame will prolong the life of the screen. A good way in which to attach screens to the frame is to punch them over a template to fit small bolts in the screen-frame, bolting in place by means of strap-iron, using a hand socket wrench for the nuts. Strap-iron at the top and bottom of a screen is a good protector. Some success has been attained by having two heights of screen-frames, so that when the screen is well worn at the top and bottom through turning the screen-frame, it may be transferred to a narrower frame, the worn parts now coming in contact with the frame.

It has been found advisable to set the screen in the mortar at an angle from the vertical, in order that the pulp, besides being driven through the screen, may fall on it and run through as it flows down after the splash. An angle of 10 to 13° from the vertical has been considered sufficient.

CHAPTER IV

WATER SUPPLY—PRINCIPLES OF STAMP CRUSHING—HEIGHT AND SPEED OF DROP—WEIGHT OF STAMP—HEIGHT OF DISCHARGE—FEEDING THE MORTAR—POWER—INDIVIDUAL STAMP.

Water Supply.—The feed-water for a battery should be introduced into the top or into the feed-mouth of the mortar, using a pipe on each side because it may be thought necessary to introduce more water toward one end of the battery than the other, though this has practically no effect in the mortar. The valves should be accessible from the front of the mortar for the convenience of the



ARRANGEMENT OF PIPING ON 10-STAMP BATTERY.
(Denver Engineering Works Co., Denver, Colo.)

millman, and there should be two to each pipe; one being a gate-valve—a globe-valve cannot be so easily cleaned of trash—by which the exact quantity of water used is regulated, and the other a bibb or plug cock. When it is necessary to shut off the feed-water, the plug cock is used, and when starting again, it is thrown wide open. Thus no time is lost in adjusting the amount of water, as that is provided for by the gate-valve. The water-supply should come from a tank having a constant head, for there should be no variation in the amount of water flowing over the plates. Where the water is returned for re-use or is received in a storage tank, this tank should have large area in order to avoid a rapid reduction in the head. The main water-supply pipes entering the mill and running the length of the batteries should be of large diameter so that the amount of water passing into one mortar may not be decreased or increased by starting or stopping the flow into the other mortars.

When crushing in cyanide solution the pipes become gradually encrusted or lined with salts of lime from that added in the cyanide plant and of alumina from the clay constituents of the ore. Such pipes should be large in diameter, and have tees instead of elbows, and many unions, to enable them to be easily taken part and cleaned. Launders have been used instead of pipes to avoid this trouble.

Attempts have been made to introduce the water in the front or rear of the mortars and on a level with or just below the tops of the dies. The arguments advanced are that the finer material is thus floated up and out of the mortar, and that the pulp just below the face of the die is kept active, permitting the amalgam to sink into it and be caught. It would require a higher head of water than can ordinarily be obtained, and in fact higher than it is desirable to use, to overcome the violent pulsations imparted to the pulp by the falling stamps and to give a classifying effect in the mortar; and should it overcome these pulsations, the result would be to interfere with the even distribution of the pulp over the dies. On account of the wearing of the dies, it is impossible for the feed-water to enter at the proper point in relation to the face of the dies for any great length of time. Where the water has been introduced in the rear of the mortar, it has been found that when the dies are nearly worn out and the screen is consequently set low, the water shoots across the mortar and through the screen. Furthermore, it is almost impossible to maintain a water-tight connection between a pipe and a mortar.

Should the feed-water be shut off without warning, the stamps must be hung up with all possible speed, for they will sink down through the pulp to the die and continue falling and feeding ore until the mortar is choked with ore and pulp. Owing to the absence of water, the pulp does not run or splash back under each stamp.

The amount of feed-water used in a mortar is gauged by the flow of the pulp over the plates, the water being used in such quantities as to give ideal conditions for amalgamating on the plate-tables, rather than to supply the quantity that will give the greatest crushing and screening effect in the mortar. The amount of water used per ton of ore stamped varies from 4 to 10 tons. Where effective amalgamation takes place on a short apron-plate, $6\frac{1}{2}$ tons will be about the average amount. The crushing capacity of a battery increases with the amount of water used, up to the point where a good splash or wave motion on the screen can no longer be secured. This increase in capacity is more noticeable in a mortar with a deep discharge than with a shallow one, for such a mortar sizes and discharges hydraulically to a much greater extent than one with a low discharge. If large quantities of water are used the amalgamation is usually not so effective, long outside plates and auxiliary amalgamating devices then being required for the purpose of getting a good contact between the pulp and the amalgamated surface.

Principles of Stamp Crushing.—The stamp battery crushes in two ways, by compression as the result of the impact of the stamp falling upon the ore over the die, and by the abrasion or attrition of the particles of rock upon each other when moving from the impact of the stamp. Crushing by impact is especially the case with coarse ore, but it is not necessary that each piece and particle of rock be caught between the metal surfaces of the shoe and die, nor is the crushing by impact confined to the coarse rock. The strains of compression from the impact are communicated to all the coarse ore in the bed between the shoe and die. This strain is also communicated to the finer particles of ore caught fairly between the larger pieces. The coarse ore in responding to the compressive strain and moving from and adjusting itself to the compression of the stamp, produces an abrasive effect in all directions, which is one of the principal means by which the finer particles are still further reduced. The reduction of the finer particles by abrasion under the stamp must be very similar to that which takes place in the tube-mill. A consideration of these principles will show wherein stamp-mill crushing is radically different from all other forms of rock-reduction, will point out why the limit of economy can be passed in fine breaking in the rock-breaker, and will indicate why a fine or a soft talcose ore often requires the addition of coarse or hard ore to act as the 'grinders' before it can be satisfactorily crushed or comminuted.

The most effective method of crushing is by impact, but as a particle of ore becomes finer it becomes increasingly harder to catch it fairly between two surfaces so that it may be further crushed or comminuted. It is largely because of this that very fine crushing becomes difficult in the stamp battery. It is now recognized that the tube-mill crushes mainly by the impact of the falling pebbles, rather than through abrasion similar to that of the grinding mill; and that the pebbles of the charge should be large enough and the grains of pulp small enough that the ore particles are shattered by the falling pebbles; also that intermediate sizes of pebbles or pulp are detrimental. Time may show that the principles of stamping and tube-milling are the same to a much greater extent than is now realized.

Much has been said in regard to step or stage reduction—the removal of the ore, as soon as it has been reduced to a certain size, to another machine which will make a further reduction and pass it on to another machine which will make a still further reduction. This is more a beautiful theory than a practical reality applicable to low-cost milling, for no economically successful and satisfactory method of separating or screening the ore when it has been reduced to the proper sizes has yet been devised. The stamp-mill has, within certain limitations, the happy faculty of being able to crush both fine and coarse ore at one operation with reasonable efficiency on both, and herein is one of the features by which the stamp-mill retains its supremacy. The work of the stamp-mill would not be more satisfactory in crushing coarse ore if the medium-size ore or pulp was removed as fast as made. And it would not satisfactorily recrush coarse tailing unless some coarse rock was fed with the tailing.

Height and Speed of Drop.—The height of drop to be given the stamps depends on the size and hardness of the ore, on the weight of the stamps, and to some extent on the treatment required for the ore. Hard ore will require a heavier blow and consequently a longer drop than soft ore. Similarly a small piece of ore will not require as hard a blow or as long a drop as when coarse. Consequently a hard, tough ore should be broken finer in the breaker than soft, brittle, friable material. It would appear that the size to which the ore should be broken in the breaker would have some relation to the thickness of the bed of pulp between the shoe and die, but in actual practice the softness and nature of the ore is the determining factor. Millmen prefer to have the ore broken to what may be termed 'a medium coarse size,' rather than pulverized fine, as such ore feeds better and causes the battery to work more evenly. Also, as just noted, some ores that are soft or brittle rather than hard, tough, and close grained, appear to crush faster when containing coarse material which increases the attrition. This point should be investigated in determining the proper size for preliminary crushing in the breaker. To crush a hard rock to a size approximating

$\frac{3}{4}$ in. diam., and a soft rock to $1\frac{1}{2}$ in. would appear ideal, but in practice it is all crushed to a maximum diameter of $1\frac{1}{2}$ to $2\frac{1}{2}$ inches.

For a hard ore a drop of 7 to 10 in. is usual, for a medium ore from 6 to 8 in., and for a soft ore from $4\frac{1}{2}$ to $6\frac{1}{2}$ in. Increasing the weight of the stamps, and breaking the rock finer in the breaker permits a shorter drop to be used. As the height of drop is lessened, the stamps should be run faster on the principle that they should drop as fast as possible; the increased speed thus partly offsets the loss of crushing power through shortening the length of drop. Theoretically, a short drop and higher speed indirectly increase the capacity by keeping the finer material in better suspension and by washing it out of the mortar faster; and, consequently, is the better method where concentration is practiced or it is desired to produce a minimum of slime. Too short a drop at the maximum speed may not allow the die to become covered with pulp. The speed at which stamps can be run safely has been worked out mathematically, but the millman desirous of maintaining a high tonnage will run the stamps as fast as possible up to the point where the tappet just stops short of falling on the cam when the stamp is at its maximum height of drop. An increase of $\frac{1}{2}$ in. in the drop, without decreasing the speed, is often possible by careful work where the running speed does not vary. An increase in this way from a $7\frac{1}{2}$-in. drop to an 8-in. drop will increase the crushing capacity by $6\frac{2}{3}$ per cent.

The maximum speed possible and being used is about 115 drops per minute at 6 in., 108 drops at 7 in., 100 drops at 8 to $8\frac{1}{2}$ in., and 90 drops at 10 to $10\frac{1}{2}$ in. Instances have been reported where the speed has been decreased from the maximum limit without decreasing the tonnage crushed. This was undoubtedly due to a bad order of drop or such poor action within the mortar that the pulp was not bedded as evenly over the die or so well splashed over the screen, especially the first, when using the maximum number of drops. On an average ore a 6 to $6\frac{1}{2}$-in. drop is the usual practice where concentration is used, whether for the reason cited in the preceding paragraph or from custom is not apparent. The usual practice upon the same ore where concentration is not used, is a $7\frac{1}{2}$ to 9-in. drop.

The power required by a stamp increases directly with the height of drop, or, to be more exact, with the height through which it is lifted. This is expressed by multiplying the weight of the stamp in pounds by the distance in feet through which it is raised, and calling the result foot-pounds. This power has been spent in overcoming the resistance of gravity and represents that much potential energy stored in the stamp. When the stamp falls the same height, this amount of energy must be expended against some resistance before the stamp will come to a rest or in the impact of the shoe upon the ore and die and mortar beneath, less the friction of the guides and the atmosphere—which will be neglected herein. If a stamp weighing 1000 lb. was allowed to fall freely through a distance of one foot upon a perfect mechanism and there was no friction, the power utilized in lifting the stamp would be so restored that another 1000-lb. stamp could be lifted 1 ft., or a 100-lb. stamp lifted 10 ft. This is in accordance with the well known physical law of conservation of energy and the experience with pile drivers. Therefore the crushing power of a stamp increases directly with the height to which the stamp is lifted and through which it drops, just as the power does which is required to operate the stamp. The erroneous statement has been repeatedly made that the crushing force of a stamp varies as the square root of the height through which it falls, and that the most economical way of employing power in a stamp-mill is by making the weight of the stamp as great and the height of drop as small as is convenient. The following table has been prepared by using the common heights of drop at their highest speeds in practice:

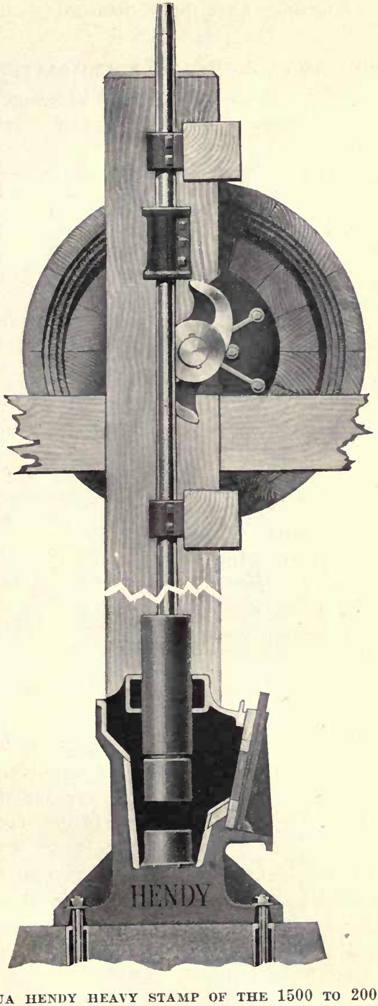
Length of drop, inches.	Number drops per min.	Number of inches drop in 1 min.	Comparative percentage power required.	Number units crushing force per drop.	Number units crushing force per min.	Comparative percentage crushing force with this speed and drop.
6	115	690	100.00	1.0000	115.00	100.00
7	108	756	109.57	1.1667	126.00	109.57
8½	100	850	123.19	1.4167	141.67	123.19
10½	90	945	136.96	1.7500	157.50	136.96

A consideration of this table indicates that the power required grows greater very rapidly as the height of drop at its maximum speed is increased, and that the crushing force increases at the same rate. It shows that the maximum crushing is effected by a stamp when using a high drop, for with a short drop the stamp is at rest or at less than the maximum speed for a greater proportion of the time. The table also shows that the heavier stamps with a shorter drop have no greater efficiency than a lighter stamp with a higher drop.

To illustrate from the above table and the knowledge that the crushing force of a stamp is the 'height of drop' X 'speed of drop' X 'weight of stamp,' a 1000-lb. stamp with a 10½-in. drop may be assumed to give a crushing force of 136.96 units. If a 6-in. drop was used at its maximum speed it would require a stamp of 1369.6 lb. weight to give the same crushing effect, but the power to operate would remain the same.

There is another advantage in the use of the high drop. An object or a stamp falling freely increases its velocity or speed of falling with the square root of the distance through which it falls. As the height of drop is increased the stamp will impinge upon the ore at a higher speed and—disregarding the heavier weight of the blow—will strike a quicker, sharper blow. Ore tends to deform and become elastic and plastic, instead of rupturing and fracturing, to a much greater extent when struck slowly than when struck with a high velocity. This is clearly indicated by the results of swift blows of light hammers as against slow blows of heavy hammers in breaking rock, or in the running of crushing rolls at slow and at high speeds. A 1000-lb. stamp falling 12 in. should have the same energy and the power to crush the same amount of ore as a 2000-lb. stamp falling 6 inches, but because of its greater velocity due to its higher fall should be better able to fracture and crush the ore. The extent to which the length of drop can be increased to secure these advantages is limited by what is convenient and desirable in a mechanical way, for as the height of drop is increased a point is soon reached where the stamp becomes difficult to handle and breakages commence to occur.

Weight of Stamp.—In the earlier mills the stamps weighed from 500 to 750 lb.; this has been increased until in America the weight of a standard stamp with a new shoe is 1000 lb., with a tendency to increase to 1250 lb. Extended experiments made in the past in some large mills indicated 1000 lb. to be the best weight in the judgment of the experimentors. The reason given was that a heavier stamp crushed more ore than the plates could handle. In South Africa the tonnage has increased with the weight of the stamps, the favorite weight now being 1750 to 2000 lb., and in one case 2200-lb. stamps have been installed. Attempts have been made to show theoretically that this is passing beyond the economic weight for a stamp, and it may mark the maximum weight of the gravity stamp; yet much heavier gravity stamps may be tried in imitation of the steam stamp which is an effective crusher and strikes a much more powerful blow than any gravity stamp now in use. Capacities



THE JOSHUA HENDY HEAVY STAMP OF THE 1500 TO 2000-LB. TYPE.

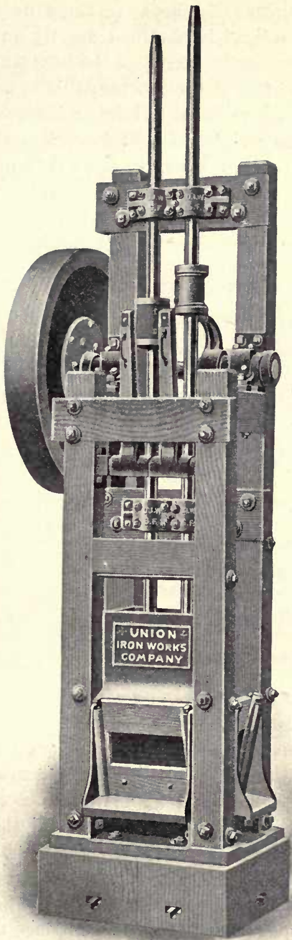
higher than 10 tons and up to 20 tons, and even more with extremely coarse crushing, have been attained with these heavier stamps.

DIMENSIONS AND WEIGHTS OF STAMP-BATTERY PARTS

	Weight of Stamp, lb.						
	850	1000	1050	1250	1500	1600	1800
Shoe, diam. of body by height, in.	8½x8	9x8	9x8	9x10	9x12	9x12	9x12
Shoe, weight, lb.	150	170	170	200	242	242	242
Die, diam. of body, in.	8¾	9¼	9¼	9¼	9¼	9¼	9¼
Die, 6 in. high, weight, lb.	106	122	122	122	122	122	122
Die, 7 in. high, weight, lb.	121	140	140	140	140	140	140
Die, 8 in. high, weight, lb.	136	157	157	157	157	157	157
Bosshead, diam. by height, in.	8½x18	9x18	9x19	9⅛x22	9¼x26½	9¼x30½	9¼x37
Bosshead, weight, lb.	232	270	285	350	420	498	621
Tappet, 3 keys, diam. by height, in.	9x12	9⅛x14	9⅛x14	9¼x15	9½x15	9½x15	9½x17
Tappet, weight, lb.	136	155	155	170	185	185	212
Cam, diam. of hub, in.	12	12	12	13½	14	14	14
Cam, weight, not less than, lb.	180	200	200	225	235	235	240
Stem, diam. by length, in.	3⅛x168	3⅜x168	3½x168	3¾x174	4x186	4x192	4x2[illegible]4
Stem, weight, lb.	365	426	455	545	661	683	725
Cam-shaft, diam. (length 14½ ft.), in.	5⅜	5¾	6	7	7	7¼	7¼
Cam-shaft, weight, lb.	1120	1280	1400	1915	1915	2050	2050
Cam-shaft Pulley, diam. by face, in.	72x14	78x16	84x16	84x18	84x20	84x22	84x24

(Denver Engineering Works Co., Denver, Colo.)

The weights of the different parts of a 1000-lb. stamp are approximately: stem, 43%; tappet, 15; boss, 26; shoe, 16. The weight of a stamp may be increased in two ways, by placing an extra tappet on the stem, either above or below the upper guide, or by using a false-shoe; this shoe is identical with the regular shoe used, with the exception that it has a socket similar to the shoe-socket of the boss. The false-shoe is first put on in the usual way after which the regular crushing shoe is put on. A variation of the plan of using an extra tappet is to clamp to the stem at any convenient point one or more heavy metal collars or discs similar to the two-piece collars used on cam-shafts. Placing weights high up on the stem has not been found entirely satisfactory, as the center of gravity of the stem is raised higher up, making the stem 'top-heavy' and thereby causing more wrenching of it and greater wear on the guides and more broken stems. The use of false shoes or the placing



TWO-STAMP MILL MUCH USED BY PROSPECTORS.
(Union Iron Works Co., San Francisco.)

of the tappets or collars on the lower end of the stem at the boss is good. With the exceptionally heavy stamps now being used in some mills, the extra weight is obtained mainly and almost wholly in some cases by increasing the length of the boss which is allowed to project up through the top of the mortar; this is good practice. It has been impossible to get millmen to take an interest in any of these ways of increasing the weight of a stamp when the shoe is worn down, though the decrease in capacity is readily noticeable, especially with the lighter stamps, the shoes of which have sometimes been removed before being worn down, solely to get the increased capacity due to the greater weight of newly-shod stamps.

WEIGHT OF STAMP PARTS

(Subject to much variation)

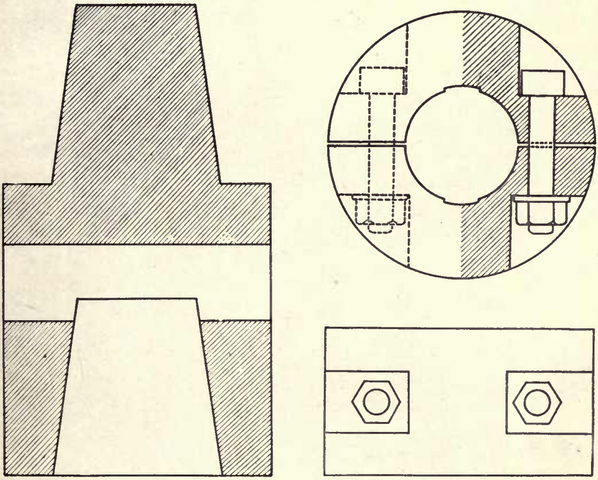
Stem.	Tappet.	Bosshead.	Shoe.	Total.
380	110	215	145	850
380	120	255	145	900
395	135	252	168	950
435	145	262	158	1000
444	169	252	185	1050
492	168	305	185	1150
575	135	364	176	1250
604	135	276	235	1250*
604	135	442	269	1450*
706	250	408	286	1650*
692	232	788	288	2000*
556	282	872	290	2000*

*South Africa.

What determines the weight of stamp to be used? Properly, the hardness of the ore and the tonnage desired, but ordinarily, custom. That custom regulates the weight is proved by the fact that though it has been fully demonstrated that the tonnage increases with the weight of the stamps, but little attempt has been made in America to increase their weight in the many installations made in the past where amalgamation is not practised. Most of these stamps have weighed 1000 lb., some 1250, and a very few 1500. Even if amalgamation is to be practised, heavy stamps should be employed, as some system of handling the pulp can always be devised. A study of the results of comparative trials of stamps of different weights and of the general results from heavy stamps in comparison with light stamps, indicates that the tonnage crushed increases directly with the weight; that is, if a 1000-lb. stamp will crush four tons per day, a 1250-lb. stamp will crush approximately five tons, and a 1500-lb. stamp will crush six tons.

Heavy stamps cost more to install as all parts must be correspondingly heavier, they also require more power, but do not appear to require much more labor, and, taken as a whole, their increased capacity tremendously outweighs their extra cost.

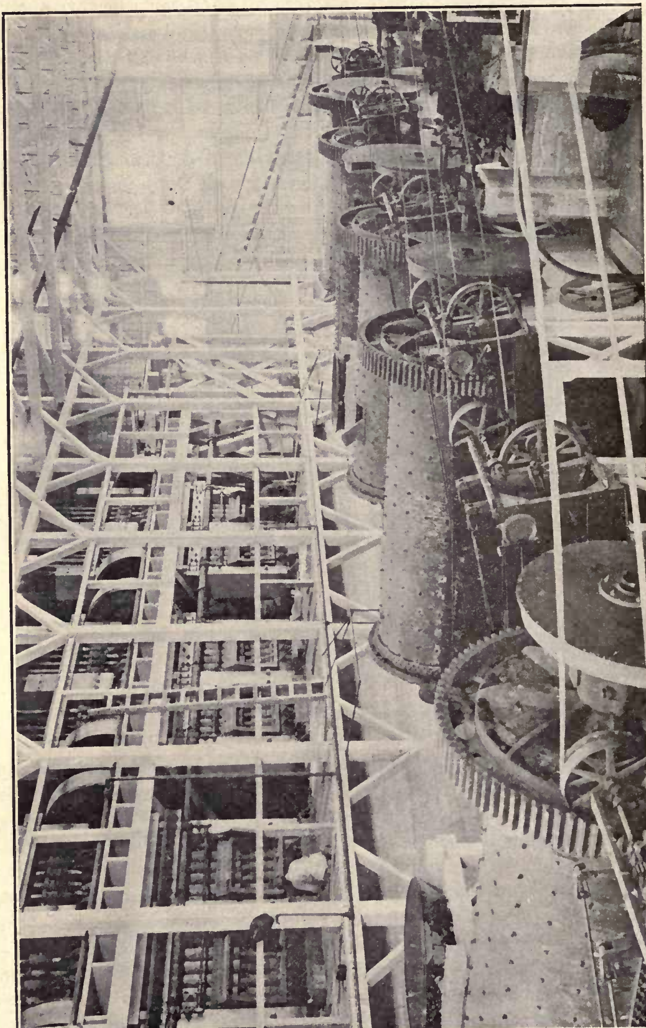
A stamp lighter than 1000 lb. should not be ordered, even for a soft ore, for should the stamp break through the bed of the pulp and strike the die, a shorter drop can be used. The heavy stamp is well adapted for coarse crushing, and with the increasing use of



FALSE SHOE AND COLLAR FOR INCREASING WEIGHT OF STAMP.

tube-mills for fine grinding it may be expected that heavier stamps will be used. There is no reason why the modern stamp-mill in America should not be equipped with 1500-lb. or 1750-lb. stamps, and arrangements made to divide the pulp between two amalgamating tables placed one in front of the other.

This can be accomplished by bolting to the mortar a distributing box having as many as sixteen holes. The pulp passes from the mortar across the extra wide lip plate, and in equal amount and a homogenous condition through each of these holes. Attach an auxiliary distributing, or rather catching box, that will catch the flow of eight alternate holes, leaving the flow from the other eight holes to pass over the plate in front of the mortar. Have the catching box empty its flow into a pipe or launder at the side and head



AURORA CONSOLIDATED MILL AT AURORA, NEVADA, HAVING 1660-LB. STAMPS.

of the table in front of the mortar. By this pipe or launder lead the flow to a table set in front of the first table and on a slightly lower bench of the mill. This method will give the thin flow of dilute pulp that is essential to good amalgamation.

The capacity of a first-class modern 1000-lb. stamp-battery in America can be estimated at 4 tons per 24 hours through a 30-mesh screen. There are so many varying factors that the tonnage ranges from 3 to 6 tons, but 4 will be found the average capacity.

Height of Discharge.—The height of discharge to be used depends upon whether coarse or fine crushing is to be done; whether or not an attempt is made to catch much of the gold in the mortar; whether it is desired to prepare the gold for amalgamation by keeping it longer in the mortar, as with 'rusty' gold requiring abrasion; also whether capacity is desired or the crushing is being done for concentration.

When the discharge is kept as low as possible without punching or wearing out the screen too fast, that is, with a 1½ to 2-in. discharge, the greatest capacity results, and the sizing is more evenly done up to the point where the screen openings are enlarged by the violence with which the pulp is forced through them. The minimum of sliming is then done, and consequently the low discharge is the best for concentrating purposes, as it affords the best opportunity for the sulphide liberated from the gangue to be discharged from the mortar as soon as crushed to the screen size, instead of being crushed and slimed still finer, as would be the case with a high discharge. The loss in concentration is mainly in the slimed sulphide.

As the height of discharge is raised, the pulp becomes finer and is slimed more in comparison to the size of the screen used. A large amount of pulp is retained in the mortar, perhaps two or three times as much as with a low discharge, so that the gold remains longer subjected to the action of the stamps, and has a more prolonged contact with the quicksilver and plates inside of the mortar. The gold also receives more abraiding and polishing by the stamps and pulp, which may or may not be an advantage, depending upon the amenability of the gold to amalgamation. As this pulp is hurled less violently through the screens, and washes over a lesser area of the screen surface, and consists of the upper, more dilute, finer portion, the capacity is reduced. The sulphide from its higher specific gravity tends to settle upon the die and is crushed finer than the gangue from which it is liberated.

This finer crushing of the sulphide increases with the height of discharge and the slowness of the drop. This is seen in the Gilpin county, Colorado, practice where a 16-in. drop, with 30 drops per minute, and a 13-in. discharge, together with a wide mortar, are used so that the sulphide may be thoroughly slimed and may thereby liberate its mechanically-held gold for amalgamation. Where concentration is to follow crushing the exact reverse of this practice is used.

About 1½ in. is the least amount of discharge height advisable, for with a lower height the pulp will usually bank against the lower edge of the screen, rendering that part inopperative and subject to excessive wear. A high discharge, 5 in. at least, is necessary when using a chuck-block plate, that scouring of the plate may not take place. Where considerable wood enters the mortar with the ore, a low discharge is sometimes used that the wood may be caught under the stamps and thoroughly reduced to pulp for passing through the screen; or a high discharge is used where the shoes are not lifted out of the water so that the wood may collect in a line along the screen and be removed by the hand or a straining spoon of wire introduced through a curtain or swinging wooden door above the screen.

A mortar having a low discharge where the faces of the shoes are raised out of the water and pulp is violently splashed over the screen surface is called a 'splash' mortar or battery; while a mortar having a high discharge where the shoes are not lifted out of the water and the pulp runs along the screen in waves is said to be a 'wave' mortar or battery.

Feeding the Mortar.—In feeding a mortar the feed should be kept 'low,' as can be ascertained by feeling the stem as the shoe strikes. Should the stamp strike a well cushioned blow, the feed has been too 'heavy,' and there is too thick a bed of pulp on the dies to get the maximum crushing effect. Should it strike with a jar or rebound, the feed has been too 'low,' and there is too thin a bed of pulp on the dies to get the maximum crushing effect, or to prevent the shoe and die from chipping, and the life of the stem from being shortened. The stamp should strike a hard, firm blow, just barely cushioned on the pulp, without jar or rebound. The beginner in feeding should first set the feeder so that it works at every drop of the feed-stamp without over-feeding the mortar, then by adjusting first one way and then another, in connection with feeling the stem, a point will be found where it is apparent to the eye that the maximum that the stamps can crush is being delivered into the mortar. By feeling the stamps now, it will be found that they are barely cushioned on the pulp from jar and rebound.

To feed 'close' is a millman's term meaning to feed very 'low.'

Power.—The power necessary for operating a stamp-battery is made up of three factors. This first is the nominal horse-power required to raise the stamps without reference to friction; this is the power directly expended in crushing. By remembering that a horse-power is the expenditure of 33,000 foot-pounds of energy per minute, the horse-power can be computed by multiplying the weight of the stamp in pounds by the length of drop in feet and this by the number of drops per minute—which will give the number of foot-pounds expended in lifting the stamp during a period of one minute,—and then dividing by 33,000.

This gives the following formula:

$$\text{Nominal horse-power per stamp} = \frac{\text{Weight of stamp in pounds} \times \text{height of drop in feet} \times \text{No. drops per minute}}{33{,}000}$$

As the stamp appears to rise slightly higher than its drop, as measured and computed when at rest, it is best to use the maximum height of drop rather than the average in computing. It should also be borne in mind that the average weight of stamps in use in a mill is not their newly-shod weight, but their newly-shod weight less one-half the difference in weight between a new and a discarded shoe, and with a further reduction due to the tapered ends broken off the stem; these two reductions may be taken as 7½% of a 1000-lb. stamp.

The second factor is the power-demand due to friction—that of the stem in the guides, which is small and is mainly due to the side-thrust of the cam striking the tappet away from the centre of the stem; the friction of the cam on the tappet; and the friction of the cam-shaft in its bearings. This power requirement is somewhat variable, but according to the generally accepted formula of Henry Louis, it amounts, in a 10-stamp battery, to 20.2% of the nominal horse-power required to raise the stamps. The sum of these two powers is the amount that must be applied to the pulley of the cam-shaft. Special attention is called to the fact that in the literature dealing with the computation of power required by stamps, reference is made to this power only, which is usually spoken of as the theoretical horse-power.

The third factor is the power consumed by the friction of the driving belt between the line-shaft and the cam-shaft, the belt-tightener, the line-shaft itself, and by the belts and intermediate shafting between the line-shaft and the source of power. The power

HORSE-POWER PER STAMP REQUIRED BY THE 5-STAMP BATTERY.

Weight of Stamp in pounds	HEIGHT OF DROP IN INCHES AND NUMBER OF DROPS PER MINUTE.																	
	A Nominal Horse-power to raise stamps without friction.						B Horse-power applied to cam-shaft pulley. (1.202 times A.)						C Approximate total horse-power. (1.35 times A.)					
	5 in. 115 Drops	6 in. 110 Drops	7 in. 105 Drops	8 in. 100 Drops	9 in. 95 Drops	10 in. 90 Drops	5 in. 115 Drops	6 in. 110 Drops	7 in. 105 Drops	8 in. 100 Drops	9 in. 95 Drops	10 in. 90 Drops	5 in. 115 Drops	6 in. 110 Drops	7 in. 105 Drops	8 in. 100 Drops	9 in. 95 Drops	10 in. 90 Drops
850	1.234	1.417	1.578	1.717	1.835	1.932	1.483	1.703	1.897	2.064	2.206	2.322	1.666	1.913	2.130	2.318	2.477	2.608
900	1.307	1.500	1.670	1.818	1.943	2.045	1.571	1.803	2.008	2.185	2.336	2.459	1.764	2.025	2.255	2.454	2.623	2.762
950	1.379	1.584	1.764	1.919	2.052	2.159	1.658	1.903	2.119	2.307	2.465	2.595	1.862	2.138	2.380	2.591	2.769	2.915
1000	1.452	1.667	1.856	2.020	2.159	2.273	1.745	2.003	2.231	2.428	2.595	2.732	1.960	2.250	2.506	2.727	2.915	3.069
1050	1.525	1.750	1.949	2.121	2.267	2.386	1.833	2.103	2.343	2.550	2.725	2.868	2.058	2.363	2.631	2.863	3.060	3.222
1100	1.597	1.833	2.042	2.222	2.375	2.500	1.920	2.204	2.454	2.671	2.855	3.005	2.156	2.475	2.756	3.000	3.206	3.375
1150	1.670	1.917	2.134	2.323	2.483	2.614	2.007	2.304	2.566	2.793	2.984	3.142	2.254	2.588	2.881	3.136	3.352	3.529
1200	1.742	2.000	2.227	2.424	2.591	2.727	2.094	2.404	2.677	2.914	3.114	3.278	2.352	2.700	3.007	3.272	3.498	3.682
1250	1.815	2.083	2.320	2.525	2.699	2.841	2.182	2.504	2.789	3.035	3.244	3.415	2.450	2.813	3.132	3.409	3.643	3.836
1300	1.888	2.167	2.413	2.626	2.807	2.955	2.269	2.604	2.900	3.157	3.374	3.551	2.548	2.925	3.257	3.545	3.789	3.989
1350	1.960	2.250	2.506	2.727	2.915	3.068	2.357	2.704	3.012	3.278	3.504	3.688	2.646	3.038	3.383	3.681	3.935	4.143
1400	2.033	2.333	2.598	2.828	3.023	3.182	2.444	2.805	3.123	3.400	3.633	3.825	2.744	3.150	3.508	3.818	4.081	4.296
1450	2.105	2.417	2.691	2.929	3.131	3.295	2.532	2.905	3.235	3.521	3.763	3.961	2.842	3.263	3.633	3.954	4.226	4.449
1500	2.178	2.500	2.784	3.030	3.239	3.409	2.619	3.005	3.347	3.642	3.893	4.098	2.940	3.375	3.758	4.091	4.372	4.603
1550	2.251	2.583	2.877	3.131	3.347	3.523	2.706	3.105	3.458	3.764	4.023	4.234	3.038	3.488	3.884	4.227	4.518	4.756
1600	2.323	2.667	2.970	3.232	3.455	3.636	2.793	3.205	3.570	3.885	4.152	4.371	3.136	3.600	4.009	4.363	4.663	4.910
1650	2.396	2.750	3.062	3.333	3.563	3.750	2.881	3.305	3.681	4.007	4.282	4.507	3.234	3.713	4.134	4.500	4.809	5.063
1700	2.468	2.833	3.155	3.434	3.670	3.864	2.968	3.406	3.793	4.128	4.412	4.644	3.332	3.825	4.260	4.636	4.955	5.217
1750	2.541	2.917	3.248	3.535	3.778	3.977	3.055	3.506	3.904	4.250	4.542	4.781	3.430	3.938	4.385	4.772	5.101	5.370
1800	2.614	3.000	3.341	3.636	3.886	4.091	3.143	3.606	4.016	4.371	4.671	4.917	3.528	4.050	4.510	4.909	5.246	5.523
1850	2.686	3.083	3.434	3.737	3.994	4.204	3.230	3.706	4.127	4.492	4.801	5.054	3.626	4.163	4.635	5.045	5.392	5.677
1900	2.759	3.167	3.527	3.838	4.102	4.318	3.317	3.806	4.239	4.614	4.931	5.190	3.724	4.275	4.761	5.181	5.538	5.830
1950	2.831	3.250	3.619	3.939	4.210	4.432	3.404	3.906	4.350	4.735	5.061	5.327	3.822	4.388	4.886	5.318	5.684	5.984
2000	2.904	3.333	3.712	4.040	4.318	4.545	3.492	4.007	4.462	4.857	5.190	5.464	3.920	4.500	5.011	5.454	5.829	6.137
2050	2.978	3.417	3.805	4.141	4.426	4.659	3.579	4.107	4.574	4.978	5.320	5.600	4.018	4.613	5.136	5.590	5.975	6.291
2100	3.050	3.500	3.898	4.242	4.533	4.772	3.667	4.207	4.685	5.099	5.450	5.737	4.116	4.725	5.262	5.727	6.121	6.444
2150	3.123	3.583	3.990	4.343	4.641	4.886	3.754	4.307	4.797	5.221	5.580	5.873	4.214	4.838	5.387	5.863	6.266	6.597
2200	3.194	3.666	4.084	4.444	4.750	5.000	3.840	4.408	4.908	5.342	5.710	6.010	4.312	4.950	5.512	6.000	6.412	6.750

If the number of drops used varies from that in the table, then multiply the horse-power taken from the table by the number of drops used, and divide by the number of drops in the table.

consumed in the driving engine or motor in overcoming its own friction, and in the conversion of one form of energy into another, may be included in this, though properly it should form a fourth part. This third part of the power is extremely variable, and may range from 10 to 40% of the entire power consumed. Consequently the greatest care should be exercised in designing and constructing a mill and in selecting the machinery, that the amount of power required may be at a minimum instead of expending a large part in uselessly racking, wearing, and tearing the machinery and building. The abnormal loss of power in this way as observed in stamp-mills, outside of that lost in the engine or motor (the type and size of which needs to be carefully looked into), may occur from a multiplicity of shafts and belts, shafts located too close together and of too small a diameter, narrow belts and pulleys of small diameter, loose and slipping belts, belt-tighteners excessively tight, insecure foundations, and unstable framework. When a bearing-box is running warm, power is being unnecessarily consumed. A change of lubricants, or a change to ring oilers or to constant-drip oil-cups, may effect a saving. Bearings having ring oilers should be used wherever possible. Where a mill is built of green timber, the boxes will need occasional readjustment, owing to the warp of the timber. Dust from the breaker and from dumping ore in the bins settles in the cam-shaft boxes and on the faces of the cams, which increases friction and the power consumed. The examination and correction of power-losses is a painstaking task and is often neglected, especially in the smaller mills, through the losses not being apparent and from failure to realize the amount that a small saving in this direction will reach in the course of a year.

It can be understood that it is impossible to give any accurate coefficient that will give the sum of these three parts of the power, or of the actual horse-power consumed by a battery having an independent source of power. It may be approximated by saying that in a good installation of say 40 stamps, this actual horse-power consumed will amount to 1.35 of the nominal horse-power required to raise the stamps, but that in a small installation, or where the efficiency of the engine or motor is low, it may amount to more than this figure.

Individual Stamp.—Various types of 'individual' stamps have been brought to the attention of the mining fraternity, but they have been generally more or less unsatisfactory, partly through inherent defects in the idea, and partly through the general mill details being poorly worked out. The first disadvantage of this type is that they are built in units of 2 or 3 stamps each, each unit requiring the same space as one standard 5-stamp battery. A summing of the extra parts and construction required to make up with individual units the equivalent of a standard 5-stamp battery will show that the cost of the finished individual-stamp mill may be nearly double that of the standard type of the same number of stamps.

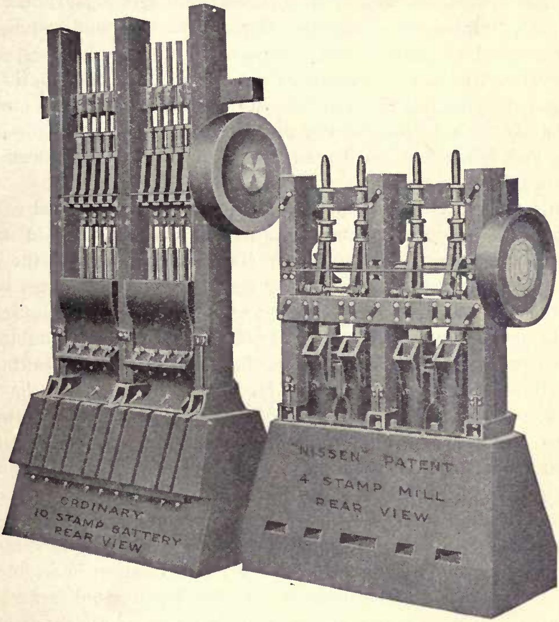
With the quadruple-discharge, there are four screens and one feeder to each stamp, or 20 screens and five feeders to be given attention for each 5 stamps, in comparison to the one large screen and feeder of a standard 5-stamp battery. It is impossible to keep an even height of discharge with the quadruple-discharge mortar, and this results in severe wear and tear on the screens before the dies are worn down. They overfeed easily, particularly when running on fine ore and using a short drop; this may be due to the large screen area, as the same trouble has been noticed in the double-discharge 5-stamp mortar, or to the fact that there are no neighboring stamps to throw the pulp back on the die. It is almost useless to feed quicksilver into the mortar without it being immediately thrown out on the plates, and it is not attempted.

The great argument has been the increased screen surface. This cannot be denied, but in answer to the question as to whether it is desirable or not, attention is called to the large number of double-discharge mortars in use with their back discharges closed up. In the 5-stamp mortar there are from 500 to 550 blows struck per minute, divided evenly all over the mortar; this results in the pulp being splashed over the screen surface all the time, the whole length of the screen being in continuous use. Whereas, in the individual mortar there is only one-fifth the number of blows and consequently the screen surface is not in continuous use. The action of the pulp within the mortar should be carefully studied in comparing the individual stamp with the standard.

Various tests have been made at different times to test the merits of double-discharge mortars and an excess of screen surface; the results of these point to one conclusion only, that the standard form of single-issue 5-stamp mortar can be made to deliver the pulp about as fast as made and that an increased screen area gives no increase in capacity.

The reports of those using individual stamps in actual practice, rather than experimental practice, is that they give little if any increased tonnage over the ordinary stamps. Where they have been run to an advantage has been with a large quantity of water and with heavy stamps, conditions that are enabling the South African millmen to obtain a capacity of ten tons per stamp and upward. The good showings in capacity and absence of slime have been made by using a minus height of discharge and with so much trouble from screen breakages that no experienced millman would attempt to run a standard battery in that way.

Until the claim of increased capacity is positively proved, it will be



STANDARD STAMP-BATTERY MOUNTED ON IRON ANVIL-BLOCKS AND THE INDIVIDUAL STAMP-BATTERY.

contended that the cost for power per ton crushed is higher rather than lower than with the standard battery, for the reason that the cam-shaft of the individual battery is identical with that of the standard, with the exception that it raises 4 or 6 stamps instead of 10. Consequently the power per stamp required to drive the shafting, independent of raising the stamps, in the individual mill is from $1\frac{2}{3}$ to $2\frac{1}{2}$ times that required for the standard battery. It is only fair to add that a material increase in the capacity would offset this slight increase in power required per stamp.

The cost of operating the individual stamp is much higher than with the standard. This is due to the extra cost and loss of time from screen troubles and to an excessive amount of general repair work. Also from the fact that they are harder to operate than the standard. In a certain large individual-stamp mill not practising amalgamation, and where the arrangement and construction was good and operations were well systematized, one batteryman with a helper attended 54 stamps—equivalent to one man running 27 stamps. Under identical conditions with the standard type, one batteryman would be running 80 or 100 stamps. At another, an amalgamating mill of the individual type having 18 stamps, one man was barely able to handle the mill on the evening and midnight shifts, and when wet ore began interfering with the operation of the small feeders, two men were required for these shifts.

While the individual stamp is a unit that can be repaired without stopping the adjoining stamps, the loss of running time in such a mill is actually greater than in the standard mill, due to the extra repairs, changing screens, and other work. There is an extra loss of time through the increased number of plate dressings required in outside amalgamation—the number of dressings being double that required when quicksilver is fed to the mortars. The advantage of the individual mortar is that the feed of each stamp can be regulated to get the greatest crushing effect, whereas with the standard battery and a lazy millman, a few stamps in a battery may be dropping hard and crushing fast while the others are being cushioned and crushing little.

The individual stamp may be advantageous in crushing an ore for concentration, the sulphides of which exhibit a tendency to slime, but in most cases, and particularly where amalgamation is to be practised, it cannot be recommended. It has been noted before that estimates of what a stamp-mill will do can be made with exactness, but not so with other crushing devices. This criticism will apply in the case of standard and individual stamps, for the latter are usually a disappointment. In the case of one very prominent installation, experimental work was carried on with a full-size working stamp over a long period of time and an estimate was made of the tonnage that should be attained. After the installation was made and the handling of the stamps was highly developed, the resulting tonnage was only 76 per cent of the estimate.

PART II

AMALGAMATION

CHAPTER V

PROPERTIES AND CARE OF MERCURY—PRINCIPLES OF AMALGAMATION—INSIDE AMALGAMATING PLATES.

Properties and Care of Mercury.—Mercury is classed as a metal, and as such is unique in that it is liquid at ordinary temperatures. It is commonly called quicksilver on account of its color and activity; in mills it is also spoken of as the 'silver' or the 'quick.' It is 13.6 times heavier than water. It freezes at -40°F. (-40°C.). It vaporizes little or not at all at ordinary temperatures, but the tendency to vaporize becomes greater with increase of temperature until at 212°F. or the boiling temperature of water there is danger of salivation in approaching it. It boils at 680°F. (360°C.). It is insoluble in water, but violent agitation causes a little of it to be taken up mechanically in a fine state of division by the water. It combines chemically with certain substances to form two series of compounds, mercurous and mercuric—as mercurous chloride (Hg_2Cl_2) and mercuric chloride ($HgCl_2$). It combines mechanically with other metals to form alloys called amalgams, which exhibit some of the characteristics of chemical compounds. Mercury is readily dissolved by strong nitric acid, and slowly by the dilute acid. It is not dissolved by hydrochloric acid. It is dissolved by hot concentrated sulphuric acid, but not by the cold acid. Metallic mercury is slowly dissolved by weak or strong solutions of potassium cyanide or of sodium cyanide; the rate of dissolution increasing with the strength of the solution; the compounds of mercury are more readily attacked by these solutions.

Mercury alloys directly with most of the metals to form amalgams. When the proportion of the mercury is small, these amalgams are hard, solid, and crystalline; as the proportion of the mercury increases the amalgam becomes pasty, and finally liquid. Gold amalgam containing 90% of mercury is liquid, with 87½% pasty, and at 85% mercury the amalgam crystallizes. Gold, silver, copper, lead, zinc, tin, cadmium, bismuth, tellurium, sodium, and potassium unite directly with mercury; the latter two requiring heat to combine actively. Iron, especially when in a fine state of division, can be caused to unite with mercury by means of sodium amalgam.

Antimony and arsenic unite with mercury when heated. Chromium, manganese, platinum, aluminum, and nickel will unite with mercury by the employment of the electric current and by other indirect means.

Pure mercury is not affected by the air at ordinary temperatures, but when impure, its surface becomes coated and tarnished with compounds of the base metals, such as oxides, sulphates, chlorides, and sulphides, and probably to some extent by mercuric oxide and sulphide. Impure mercury can readily be recognized, since its surface will appear tarnished instead of bright, and its globules will not be spherical and tend to unite quickly with one another when brought together. When rolled about, the globules will be sluggish and will elongate to a tail and leave a black film behind. Oils and organic substances also tend to render mercury impure. When it breaks up into extremely minute globules which will readily float on water, it is said to be 'floured;' and when these globules refuse to coalesce again, the mercury is said to be 'sickened.' Shaking the mercury in the presence of detrimental substances, or stamping in the mortar, promotes 'flouring,' and in the first case 'sickening' as well. Each one of the 'sickened' globules of mercury is surrounded by a film of foreign substance, quite often an oxide or other compound of a base metal.

Various methods are used to restore impure or foul mercury to its normal condition. Cyanide of potassium is beneficial through neutralizing the grease, and abstracting the oxygen from the oxides. Likewise sodium, by its attraction for oxygen, reduces the oxides of the base metals which are coating the globules of mercury; and as sodic oxide is soluble in water, it can be removed by washing, while the base metals enter the mercury forming a base amalgam. After treatment with these powerful alkalies the mercury is in condition to do good work, but owing to the tendency of the base metals to again oxidize, the relief is only temporary; consequently an attempt should be made to remove the base metals entirely. Retorting will accomplish this, if carried on at moderate heat, though probably not completely, as some of the base metals, such lead and zinc, may distill over, particularly at high heat. Purification by chemical means is easier and better. This can be accomplished to some extent by employing sulphuric acid, better by hydrochloric acid, and still better by nitric acid, the acid being dilute in each case. For this purpose the mercury should be placed in a glass or glazed vessel that will not be attacked by the acid, with a solution of one part nitric acid and from five to ten parts of water, and allowed to remain for at least 48 hours with frequent stirrings that all the base metals may be dissolved. Besides dissolving the base metals that contaminate the mercury, the acid will also dissolve some of the mercury, and should it crystallize, more water and a little acid should be added that the mercuric nitrate may be kept in solution. The mercury in solution as mercuric nitrate will be precipitated when more impure mercury is added, by base metals replacing the mercury to form nitrates of themselves. By suspending a piece of copper in the solution, the mercury in solution can be completely precipitated. The mercury should be washed to remove all traces of the acid before being used. Since impure mercury does not amalgamate gold with the facility that pure mercury does, and as it is liable to become 'floured' and 'sickened' and thereby result in loss of both gold and mercury, as well as to cause base metals to enter the bullion, the purification of the 'quick' should always be given the necessary attention.

Principles of Amalgamation.—Mercury 'wets' those substances with which it amalgamates just as water wets an ordinary substance, forming a thin film of amalgam about them by the absorption of the mercury. The surface tension of mercury is very high and its tendency is to pull within itself, or below the surface, any substance that amalgamates with it; in this way the particles of gold arrested on an amalgamating plate disappear below the surface. In the case of those substances with which it does not amalgamate, its surface tension acts negatively and it is strongly repellent to them.

In crushing an ore for amalgamation, the aim should be to crush just fine enough to liberate the gold from its matrix of quartz or other mineral, that these golden grains or flakes may be exposed to and caught by the aid of mercury. Crushing too coarse will result in the gold not being liberated, but still enclosed in the gangue rock so that the mercury is unable to reach it. Crushing too fine may result in beating the gold up into flakes so fine that it can hardly be brought into contact with mercury, or may possibly coat it with a film of slime or some constituent of the ore so that it will not readily amalgamate.

Mercury is fed into the mortar that it may come in contact with the gold as soon as liberated from the rock by crushing. The action of the stamps causes the mercury to become finely divided and to be intermingled throughout the pulp, thus 'wetting' a considerable amount of the gold. Part of this gold sinks about the dies as amalgam, part is caught upon the inside plates if any are used, and part passes out through the screen. That gold which comes in contact with the mercury while in the mortar and which passes through the screen, is, by virtue of its being encased in an envelope of mercury or amalgam, larger than the original native golden grain before being coated by the mercury; this, in connection with the coating of mercury, enables the lip or apron plate easily to catch it. Gold that is not so 'wetted' is harder to catch and may travel farther away from the mortar.

Inside Amalgamating Plates.—The part of the gold which is won from the mortar-sand is found, not in the sand resting on the dies when the mortar is opened, but in that below the level of the face of the dies. Where no mercury is fed to the mortar, this will be as coarse gold, but where mercury is fed into the mortar, it will be found as amalgam. The amount of gold retained in the mortar-sand will vary with the time the gold has been accumulating in the mortar and with the height of discharge. A wide mortar with a high discharge carries double or treble the amount of pulp a narrow mortar with a low discharge will carry. In such a 'wave' mortar it will be hard for the coarse gold and amalgam to escape as their higher specific gravity will cause them to sink down through the pulp rather than to rise and pass out through the screen, while in the 'splash' mortar they will be thrown through the screen with little regard to their specific gravity. The amount of gold retained in the mortar will also vary with the size of the particles of gold; thus, with fine gold there will be very little caught in the mortar-sand, while with coarse gold the percentage will be relatively high.

The 'chuck-block' is a piece of wood fastened to a strip of the same material, the latter resting beneath the screen in the screen-frame slots of the mortar. Its purpose is to fill a portion of the surplus space between the dies and the mortar lip and screen frame. The chuck-block is sometimes lined with a copper amalgamating plate, called a 'front inside plate' or 'chuck-block plate.' Its function is to catch and hold upon its surface as much gold in the form of a hard amalgam as possible. On account of its close proximity to the stamps, this plate is subjected to much scouring action by the pulp, which increases as the chuck-block is moved nearer the stamps, or the height of discharge is lowered, so that mortars for using inside plates were formerly designed to be from 14 to 18 inches across the inside of the mortar at the lip. Chuck-block plates are now very successfully used in narrow mortars only 12 in. wide at the lip by using a high discharge. The height of the chuck-block can be varied by inserting beneath it and in the screen-frame slots, strips of wood of varying thickness, usually 1 in., and these may be removed as the die wears down, thus maintaining the height of discharge uniformly with reference to the top of the die. Most mills have two heights of chuck-blocks on hand, the higher one being used with new dies, and the lower one substituted after the dies are worn down.

The common form of a curved chuck-block is apparently wrong, for it is this curved part or 'belly' that is in the best position to be scoured. A good method of making a chuck-block is to take a piece of 2 by 6-in. sugar pine and rip it diagonally across the ends, making two triangular sectional lengths. Attach one of these to the strip that rests in the screen-frame slot by bolts a foot apart, using a piece of strap-iron in connection with these bolts to hold the lower end of the plate in position and as a protection against its being torn loose. If the strip of iron used is from $\frac{1}{4}$ to $\frac{1}{2}$ in. thick, the amalgam will accumulate advantageously along the upper side of this iron rib and in the angle formed by it with the copper plate. Scouring can largely be prevented by protecting the plate with a heavy wire screen of quarter or half-inch mesh, spaced from the plate by a nut on each bolt that attaches this screen to the chuck-block.

A copper plate is sometimes bolted to the back of the mortar, this is called a 'back inside plate.' On account of its location it is hard to handle and to get at, and consequently is seldom used. These 'inside plates' were formerly used in nearly all mills, while today they are used very little; the tendency of modern milling is to eliminate them entirely. A chuck-block plate can be 'run' in the narrow mortar, twelve inches wide at the lip, generally used today, by employing a sufficiently high discharge and considerable care. A back plate can be used in these mortars if it can be set six inches above the dies. It should be bolted through the mortar and have two sets of bolt holes, that it may be adjusted to the wear of the dies.

These inside plates are usually of raw copper $^3/_{16}$ to $^1/_4$ in. thick, that they may not easily be dented or worked out of shape and may stand the excessive wear. As they are cleaned of the amalgam by being chiseled and are liable to be scoured, silver-plating is an unnecessary expense. They are cleaned every 10 to 30 days on low-grade ore. Where the mortar-sand is not removed at this time, an extra chuck-block is kept on hand and is merely substituted for the enriched block after being burnished and dressed with mercury. These plates must be carefully watched. They are especially hard to start and may give the amalgamator some anxiety before a film of amalgam is deposited over the whole plate. No bare spots should be allowed as they tend to spread.

The inside plates should not be kept soft or the amalgam will slough off, neither should the amalgam be kept hard to the point of being brittle, for such amalgam will not withstand the action of the moving pulp to the extent that a softer, more tenacious, slightly yielding one will, nor so readily catch the gold and amalgam. When using inside plates, mercury is fed to the mortar according to the appearance of the lip plate on the outside of the mortar and an occasional examination of the inside plates, usually that on the chuck-block. This examination of the chuck-block can be made without removing the screen, by using a canvas curtain instead of a board to close the opening in the mortar above the screen; the feed water is shut off and as soon as the water is stamped out of the mortar, the stamps are hung up; a small stream of water is run along the screen to wash off the chuck-block, when the curtain is removed and the plate inspected. Should there be a bare spot, it is burnished and a little mercury or soft amalgam is well rubbed in. After some experience the amalgamator is able roughly to judge the condition of the amalgam by reaching in with his hand and feeling the amalgam without stopping the battery. When using inside plates the greatest care should be exercised that the feed is kept just right and that no over-feeding or choking of the mortar occurs. For this purpose careful chuck-block operators remove the splash board from in front of the screen, that any change in the splash or wave of the pulp may be readily discernible; over-feeding is indicated by a line of pulp appearing, 'banking,' at the lower edge of the screen and gradually rising. The feed of quicksilver must also be watched, not alone in reference to the amalgamating in general, but also that the amalgam on the inside plates may not become too hard or too soft and thereby lost.

The use of inside plates increases the saving of gold inside the mortar, by catching and holding a large part that would otherwise pass out through the screen. This was formerly considered desirable practice, but the use of narrow mortars, heavy stamps, and low discharge have individually and collectively made good inside plate work difficult, so that the sentiment is now against their use. The two claims made in their favor are: that they should be used when running on high-grade ore with the idea that the smaller the amount of amalgam to be handled on the outside plates (referring especially to the apron plates), the smaller the loss will be; and that by their use fine or refractory gold can be caught that cannot otherwise be saved. The arguments against their use are: that they necessitate a high discharge which cuts down capacity and may cause overstamping; and that they place the gold, or rather the amalgam, where it can be easily scoured off and lost should the mortar overfeed. On opening a mortar that has been overfed, and has run choked for some time, the upper part of the chuck-block plate will usually be found to be freshly scoured, sometimes down to the copper. This scoured amalgam being hard and dry, has been found difficult to arrest on the outside plates unless they are quite wet with mercury, consequently some of the amalgam passes beyond the plates and traps and is lost.

Inside plates should only be used where it is proved that more gold can be caught by their use than without them, and such cases will be rare. In all ordinary cases, more gold will be saved per ton, a greater tonnage crushed, and more satisfaction in operating obtained without their use. When they are needed, it would appear well to employ both a front and back plate with the idea of getting all the advantage there may be in their use; usually there is no back plate on account of the trouble and inconvenience due to its position; moreover, a back plate cannot be placed in most of the mortars used today.

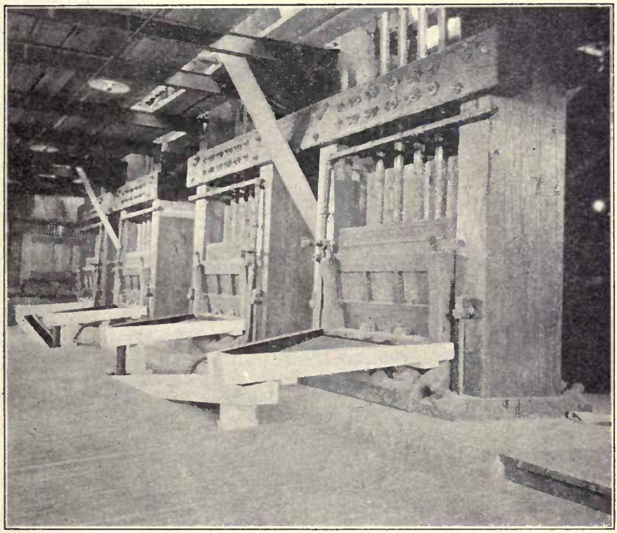
CHAPTER VI

Splash and Lip-Plates—Apron-Plate—Dressing and Care of Apron-Plate — Feeding Mercury — Dry Amalgamation — Outside Amalgamation—Amalgamation in Cyanide Solution—Water Required in Amalgamation—Temperature of Battery Water—Period Between Plate Dressing.

Splash and Lip-Plates.—The 'splash-plate' is placed in front of the screen, being fastened to the mortar or to the battery posts, so that the pulp flowing or splashing through the screen may fall or impinge upon it, run down its surface, and drop on the head of the 'lip-plate,' which is a copper plate resting on the lip of the mortar and held in place by the chuck-block, the screen frame, or otherwise. The splash-plate is attached to the 'splash-board' or answers the purpose of a splash-board, which is to catch and confine the wet pulp as it comes splattering through the screen instead of allowing it to fall promiscuously about the front of the mortar. The advisability of the splash-plate is a matter of individual opinion usually, and it is not used in all cases. The conditions under which work is largely done today are with a fine-grained gold, a low-grade ore, and a required large capacity, necessitating a narrow mortar and low discharge, which in general prohibit the successful use of inside plates, or of the catching of much gold in the mortar-sand. The amalgam on the splash and lip-plates is hard, with little tendency to run and slough off, or to granulate and break away, consequently here is a good place to hold it—a better place than on the inside plates, or on the apron plates, but not as good as in the mortar-sand. Various forms of splash-plates are in use. Besides that the pulp, after passing through the screen, shall impinge upon this plate and run down to the upper part of the lip-plate, the general requirement is that they be easily handled when necessary to remove them to open the mortar, and that in connection with the lip-plate they present a large surface.

The function of the lip-plate is the same as that of the splash-plate, to catch and hold the particles of 'wetted' gold and amalgam that have passed through the screen, and consequently their purpose, condition, and treatment is in every way similar. Due to the hardness and dryness of the amalgam on these splash and lip-plates, it is supposed that but little native gold, without any wetting of mercury, is caught here, since there is no surplus mercury to wet the particles. The amalgam on the lip and splash-plate is always found to be a little harder than that on the inside plates.

The lip-plate is as long as the mortar lip on which it rests and ordinarily six to seven inches wide, which is entirely too narrow. Every mortar should be so built that a distributing or collecting



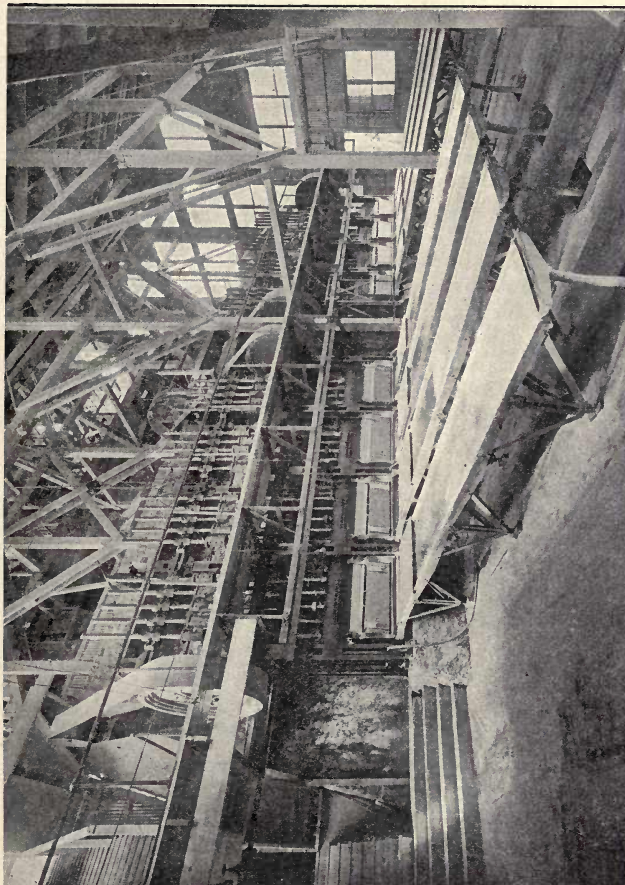
NEVADA HILLS MILL OF 1600-LB. STAMPS AT FAIRVIEW, NEVADA. (Joshua Hendy Iron Works, San Francisco.)

box can be fitted to it at the lip. This is an iron box bolted to the mortar to extend the lip. It gives a firm backing to the lip-plate which may be as much as 18 in. wide. These boxes distribute the pulp across the head of the apron plates through from 8 to 16 holes, so that by plugging up some of the holes, if necessary, an even distribution can be secured where the discharge is not uniform across the full length of the screen. They form a projection over the apron-plates, preventing leakage; and by not requiring close contact with the mortar, prevent the apron-table from being jarred.

The lip and splash-plates are burnished and dressed with mercury when put in position after being cleaned up. They receive no further dressings unless their surfaces become fouled with some base metal such as zinc, lead, or babbitt that has accidentally fallen into the mortar, or by some constituent of the ore itself. In such case the plates will receive a stiff brushing to remove the foul film, and all loose material on the plates will be collected and saved for treatment at clean-up time. The lip and splash-plates have their amalgam chiseled off semi-monthly when running on low-grade ore. An extra lip-plate is kept on hand that the battery need not be stopped longer than to make the change. Like the inside plates, unsilvered copper is the most advisable for the lip and splash-plates. The lip-plate is subjected to considerable abuse and should be $\frac{1}{4}$ in. thick, while $\frac{1}{8}$ in. may be considered sufficient for the splash-plate.

Apron-Plate.—Following the lip-plate and independent of the mortar is the 'apron-plate,' mounted on a platform called a 'table,' usually built of wood. This plate is slightly wider than the lip-plate and from 8 to 28 ft. long and sometimes longer, in which case they are built in two or more sections in series. The apron-plate is not intended for catching the bulk of the gold, except where no mercury is fed to the mortar, but more particularly for that which has escaped being caught on the plates above. Consequently it is given the greatest care and attention to keep it in good condition to catch gold. The flow of the pulp on the apron-plate is distributed in such manner as to best enable each particle to come in contact with the plate. Sufficient mercury is kept on it to render the amalgam soft enough to wet any amalgamable gold that may come in contact with it; while the amalgam is kept bright and in an active condition by frequent dressings of the plate. The idea is that it shall be in the best condition to catch gold that has not been wetted by quicksilver, no matter if quicksilver is fed to the mortar or not.

It is in the care of the apron-plate that the amalgamator takes his greatest pains and pride. Here is found a striking difference in the ideas and methods of different millmen. Some keep the apron-plate hard, even to the verge of the amalgam breaking away and the lower end of the plate becoming quite blue in appearance, for the purpose of preventing the mercury from working down the plate into the mercury trap at the foot of the plate and eventually into the creek below. These are said to be amalgamate 'dry,' as the plate is kept comparatively dry of mercury. Others keep the amalgam soft and plastic, sometimes overfeeding mercury or dressing the plate so soft that the mercury separates from the amalgam and collects in globules, 'tears,' which work down the plate carrying a

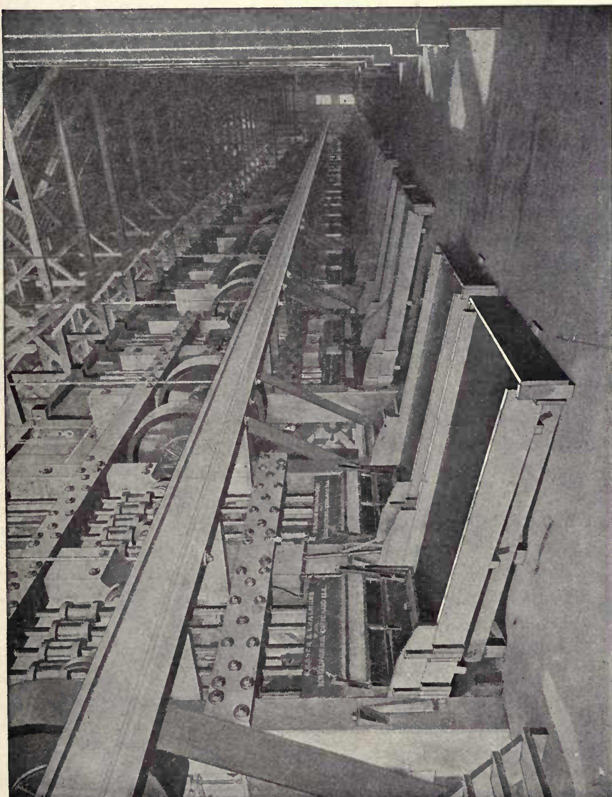


NORTH STAR MILL AT GRASS VALLEY, CALIFORNIA, WITH STEEL BATTERY-FRAME.
(Union Iron Works Co., San Francisco.)

little gold with it into the traps from which a part of it will usually be lost. This is said to be 'wet' amalgamation, as the plate is kept wet or moist with mercury.

A coarse, easily amalgamated gold will be readily caught on a hard plate, but fine gold requires a soft, plastic sheet of amalgam. A hard plate is not as active in catching gold as a soft one, since it cannot so readily wet the gold, and the surface tension in absorbing the gold into and below the surface of the amalgam is not so great on account of the amalgam being crystalline. The coarse gold, because of its greater weight, sinks through and is dragged along the bottom of the film of pulp, coming in repeated contact with the amalgamated plate beneath, so that with coarse gold this plate need not be so active in wetting and catching it. Whereas the fine gold is carried along distributed throughout the pulp and only occasionally comes in contact with the plate, consequently the plate should be in the best condition to wet the gold at the first contact. The coarse gold is more liable to be wetted in the mortar, and when in such condition should be quickly arrested, even on a hard plate. If a particle of hard amalgam or of gold is brushed over a hard, dry amalgamated surface, it will probably not be caught, but if brushed over a soft, wet spot it will quickly attach itself to the amalgamated surface. This leads to the inference that wet plates are the best amalgamators. By keeping them soft they form the best amalgamating surface, but if the narrow margin of safety is overstepped, the mercury will separate out of the amalgam and run off, carrying with it some of the gold with which it has amalgamated, and herein is the difficulty with wet amalgamation. Given an easily amalgamated ore, the amalgamator may approach dry amalgamation and save the greater time and attention required for wet amalgamation without increasing the loss in the tailing.

Dressing and Care of Apron-Plate.—In cleaning-up and dressing the apron-plate where wet amalgamation is practised or the plates are kept reasonably soft, some mercury is first sprayed on the plates where needed—usually the head of the table where considerable amalgam has collected. The mercury is well rubbed into the amalgam by means of a stiff whisk broom that is worn down or cut off. The amalgam is loosened and softened down to the silvered surface of the plate. It is usual with wet amalgamation to remove part of the amalgam once daily when treating an average ore, so that a constant amount remains to keep the plate in good working condition, taking off no more on clean-up day than on any other day. The part of the amalgam to be removed is now pushed up to one place at the head of the plate by a whisk or a 'rubber'—a piece of pure rubber or rubber belting 3 by 5½ by ½ in. thick—where it is taken up by a scoop. The plate is now well rubbed again, that the amalgam may be thoroughly softened down to the silvered surface

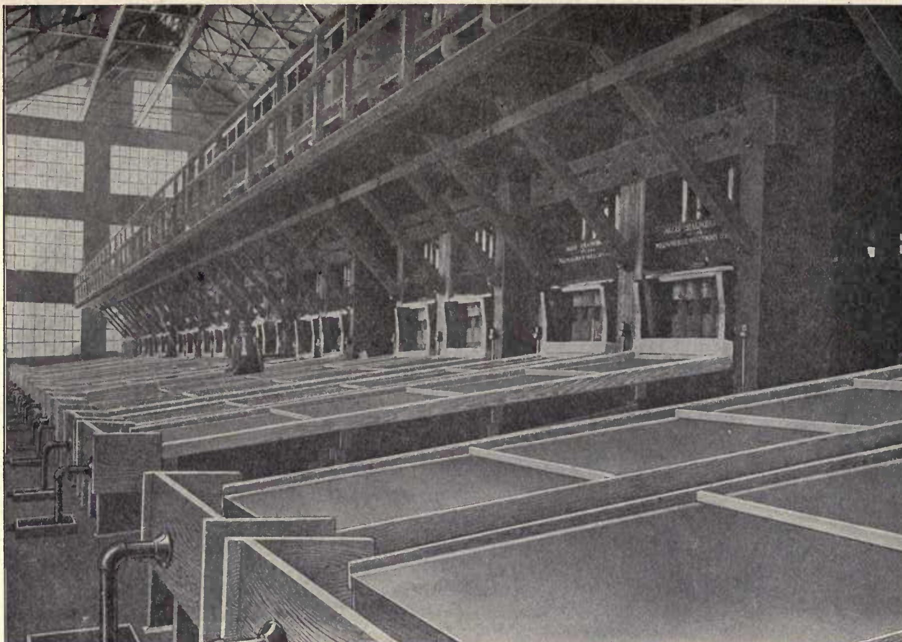


MODERN STAMP-BATTERY AT TREADWELL MINE IN ALASKA.
(Allis-Chalmers Co., Milwaukee, Wis.)

with a view to preventing the formation of a hard film or scale of amalgam; that the consistence and texture of the amalgam may be such as is desired; that the mercury in the amalgam may be more evenly distributed and more securely held by it; and that the amalgam may be worked into an active condition. The amalgam is now distributed evenly across the plate so that there is considerable soft amalgam at the head of the table, very little on the middle section of the table, and none on the foot which is kept fairly hard to catch any mercury or soft amalgam running down from above. Finally, the amalgam is smoothed or 'bedded down' across the plate and at right angles to the flow of the pulp by using a soft and long-straw whisk broom. The practice of riffling or roaching across the soft amalgam has been condemned by some as wrong for the reason that these riffles catch the fine iron and steel from the mortar and the heavier sulphide from the ore, and thus coat or foul the amalgamating surface. The fact that these tiny grooves do act thus, speaks well for their function in catching gold. However, these riffles can be avoided by smoothing the surface of the amalgam with a fine-haired paint or calcimining brush. An experiment should be conducted by brushing one side of a plate crosswise and the other side lengthwise to the flow of the pulp. Care is used that all particles of amalgam are well set, for this reason many amalgamators finally run the brush up and down on each side of the table where there is liable to be loose amalgam in the corners.

Some amalgamators use considerable refinement in their methods and claim that a whisk for rubbing and a rubber for scraping the amalgam are injurious to the silver plating. They use for these purposes a rag, often a pad of blanket cloth. A rag requires more labor to use and is harder on the hands than a brush, so that whisk brooms are commonly used. For carrying the tools used in dressing the plates and for holding the amalgam recovered, a deep iron kettle is used, or sometimes a gold-pan. For spraying the mercury on the plates, a strong bottle with a piece of canvas or a double thickness of muslin tied over the mouth is used. Suitable bottles may be made of iron by screwing a cap over one end of a 1½ or 2-in. pipe of a few inches in length. Mercury is also tied up in a canvas bag in quantity about the size of an egg; such a bag is kept in a cup to prevent loss of the mercury.

The amalgam in wet amalgamation, especially that on the first plate, should be of such consistence that it can be pushed up with the finger and remain without flattening out; that it will be soft and plastic like putty; that the brush lines do not run or disappear; that it does not run or slough down the plate, as indicated by its being caught lower down than usual and piling up at the drops between plates; and that no tears of mercury appear or hang to the edges of the individual plates. The idea is to keep the plate as wet as possible without losing any of the mercury or amalgam. The



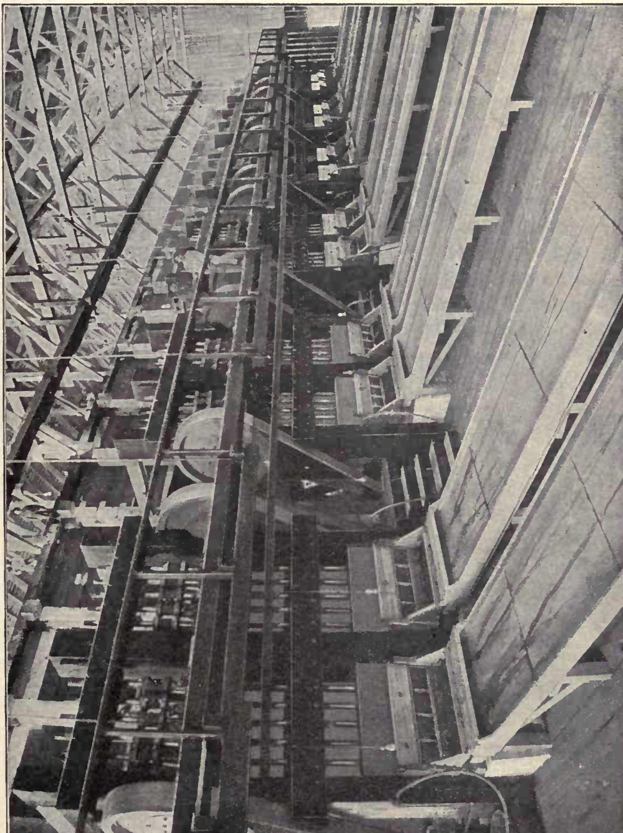
STAMP-BATTERY OF GOLDFIELD CONSOLIDATED MILL BEFORE REMOVAL OF PLATES.
(Allis-Chalmers Co., Milwaukee, Wis.)

loss of mercury carrying away gold is the main argument against wet amalgamation and the greatest care and study should be given to prevent any abnormal loss and yet keep the plate moist. In appearance this amalgam should look neither hard and dead from too little mercury, nor like a mirror from an excess, but have a white frosted appearance. It has been said that the plate should have the appearance of a silver dollar; this is correct if the kind of a dollar is stated. The peculiar whitish lustre of a newly-minted silver coin is the appearance the amalgam should have; but should the amalgam appear like the ordinary silver coin that has lost its 'youthful bloom,' it is too hard, too dead, too crystalline for the good amalgamation of gold that is in a fine state of division or that is at all difficult to catch.

Feeding Mercury.—The apron-plate is examined at its head at intervals of one-half to two hours, usually hourly, clearing it by means of a stream of water for the purpose of learning how amalgamation is progressing and how much mercury must be fed into the mortar. At first the amalgamator will press or mark the amalgam with his finger to learn its consistence, but in a short time will be able to tell by its appearance alone. After examining the plate, mercury is fed into the mortar; the amount being judged by the appearance of the plate. It should be sufficient to keep the plate in good condition until the next examination. Should the plate upon this inspection have its amalgam of the proper consistence and be wet with mercury to the proper point, a normal amount of mercury, as indicated by experience with that ore, is fed to the mortar; should the amalgam appear hard and dry, an extra amount of mercury is fed; should the plate appear too soft and wet, no mercury is added that it may harden to the right condition by the time of the next examination.

For feeding the mercury into the mortar, an amalgamator's spoon is used to measure it from a cup. This spoon is of wood, much like a mustard spoon; the bowl is bored or burned in it to hold mercury to the size of a small pea. The amalgamator throws the quicksilver into the mortar through the feed slot at the back, a half or full spoon or more, according to the amount he considers necessary from the appearance of the plates. Some head amalgamators make use of a chart having a blank space for each battery, and write on these blanks the amount of mercury to be fed to each mortar by their assistants on the different shifts. This is an unsatisfactory method and seldom found, for even an inexperienced man can learn under instruction in a short time to feed mercury properly.

The mercury is weighed each morning to ascertain the amount fed to the mortars during the previous day. After the plates have become saturated with mercury and loaded with what may be termed their constant of amalgam, the amalgamator divides the ounces of



STAMP-BATTERY AT HOMESTAKE MINE IN THE BLACK HILLS.
(Allis-Chalmers Co., Milwaukee, Wis.)

bullion recovered during a stated period by the number of ounces of mercury fed to the mortars during that time. This result becomes a factor by which he estimates the amount of gold amalgamated each day and from this what the month's run should be.

With an amalgamator who uses care in feeding mercury and a gold that does not vary greatly in the size of its particles, this is a fairly accurate factor and a satisfactory method, being equal to the haphazard methods of sampling, assaying, and estimating that obtain in many mills.

While it is well to inform the amalgamator whether low, medium, or high-grade ore is being put into the mill, he makes but little use of this information except in corroboration as it is so often unreliable, and he is also unable to know when this ore of a different nature is going to reach the mortars. At the hourly examination of the plates he is able to see how much amalgam is being deposited or built up on the plates, and this is a true index of the gold content of the ore, unless it has suddenly become base or unamalgamable. When mercury is fed in the right quantity and at the proper intervals, very little additional mercury is required in dressing the plates. Where inside plates are used, the lip is used as the outside indicator of the amount of mercury to be fed to the mortar to keep the inside plates in condition; should the apron-plate become dry, a little mercury can be sprayed on the dry spots at the head of the table from a bottle or bag without stopping the battery. If one side of the plate is dry and the mercury is fed to that end of the mortar, the larger part will come out on that side if the mortar is of the splash or low-discharge type.

Amalgam, or mercury containing gold, has a greater attraction for gold than mercury alone. Mercury that has the gold only partly strained out of it is better for amalgamating than gold-free mercury. A bed of gold amalgam is a most active catcher of gold—superior to silver amalgam—and the plates should always be covered with it. Amalgam acts tenaciously in holding the mercury on the plates. New plates dressed with mercury do not give the best results until a bed of amalgam has spread over them, as has been proved by sampling and assaying the pulp after passing over plates when in this condition. Consequently close clean-ups with chisels should be avoided unless some of the amalgam is returned to the plates. Such clean-ups, however, in connection with thoroughly rubbing and softening the amalgam, prevents the formation of hard layers of amalgam, but the close 'skinning' of the plate is detrimental to the silver-plating, and some amalgamators will not use even a rubber for removing the amalgam.

Dry Amalgamation.—Where 'dry' amalgamation is practised, the procedure does not differ materially. In dressing the plates, no efforts are made to soften the bottom part of the amalgam or to keep it soft in comparison with the silver-plated surface; the efforts being confined to putting the surface of the amalgam in good condition for catching the gold. Any soft amalgam that may be considered as surplus is removed, or only that which loosens and breaks away in the dressing, the 'crumbs,' is removed; the balance being allowed to remain and become hard until the monthly or semi-monthly clean-up, when it is removed by being chiseled and scraped off, care being used not to reach into the silver-plating. After the chiseling, mercury is rubbed in to soften the remaining amalgam, which is scraped together by a 'rubber.' At many of the mills where dry amalgamation is in vogue, the plates are 'sweated' at intervals by pouring boiling water on them, or by placing a cover of wood or blankets over them and turning steam or boiling water in underneath. This results in loosening the film of hard amalgam that will always form, especially when amalgamating dry, so that it may be scraped and scaled off if at once attacked. A large amount of gold that would be otherwise locked up on the plates is secured by 'sweating,' but it is destructive to the silver-plating and dangerous on account of the possibility of salivating the workmen. The paternal laws of Australia prohibit approaching a 'sweated' plate until after the lapse of a certain length of time, which makes the 'sweat' of little avail. A wet sponge should be worn at the nostrils when there is danger of salivation.

As to the relative merits of wet and dry amalgamation, dry amalgamation answers where the gold is coarse and easily amalgamated, and as it require less labor and attention, and usually entails a smaller loss of mercury, it may be advisable in some cases. As the gold becomes finer and more difficult to amalgamate, the necessity of amalgamating wet increases. The life and good condition of the plates is increased by amalgamating under the wet conditions described. Where amalgamation is done entirely outside, the plates should be kept wet, certainly wetter than is usual with dry amalgamation, since the gold, not being wetted in the mortar, will have a tendency to slip farther over the dry surface.

The amalgamator should make tests on each ore to determine the relative merits of wet and dry amalgamation for that particular ore, by running a 'wet' and 'dry' plate side by side. Possibly the percentage of sulphide may have some bearing on the way the amalgamation should be conducted, through the scouring effect of the heavy sulphide or the tendency of the sulphide to foul the plate.

Outside Amalgamation.—Where the mercury is fed inside the mortar with the object that the particles of gold may be wetted and that sufficient mercury may come through the screen in the form of amalgam, or in a finely divided state, to keep the 'outside' plates in proper condition, they are said to practise 'inside amalgamation,' though formerly this term had more particular reference to catching and holding the gold on the inside of the mortar. Where no mercury is fed to the mortar, but all is added on the outside plates, and the gold comes through the screens as native gold unwetted by mercury, they are said to practise 'outside amalgamation.'

Outside amalgamation involves no radical departures from the general methods of plate amalgamation when mercury is fed to the mortar. Lip and splash-plates are dispensed with, all the gold being caught on the apron-plates. A common fault, where outside amalgamation is practised, is that the plates are dressed too wet and then allowed to become too dry before dressing again. This can be avoided and the plate kept in condition by sprinkling at intervals as required a little mercury from a bag on the dry spots at the head of the table without stopping the battery, but it must be carefully done. The greater part of the coarse gold can often be caught on the first 12 in. of the plate surface if mercury is dropped on as required. When mercury is not fed as needed and the plate becomes hard and coated, as quickly happens when treating rich ore, the gold will tend to slip over the dry part and be caught lower down. As the gold is not brought into intimate contact and wetted with mercury in the mortar, longer plates covered with a greater length of the soft amalgam which is so active in catching gold may be required than with inside amalgamation. With outside amalgamation the plates will usually be dressed from two to three times as often as when the mercury is fed through the mortar. Outside amalgamation is interesting and affords excellent opportunity to study plate-work; some experience with it will cause the amalgamator to incline toward wet amalgamation.

As to whether outside or inside amalgamation should be the practice is properly dependent on the ore and the crushing machinery, as indicated by the amount of mercury lost, the increase or decrease in the amount of gold saved, and the ease with which amalgamation can be conducted; but in most cases the prevailing local custom is followed without testing the merits of the other method. Outside amalgamation is followed with individual stamps as any mercury fed to the mortars is immediately thrown out, so that the wetting of the gold and the even feed of mercury to the plates cannot be effected. The stamping of the mercury in the mortar comminutes it into fine globules; moreover, the tendency of mercury in the presence of water and agitation is to form small globules to some extent which are carried away mechanically in this finely divided condition. This natural tendency of the mercury to 'flour' is increased when it is impure, or is in association with deleterious substances in the ore, so that great loss may result from either of these causes. With a clean ore, the loss of mercury in the practice of inside amalgamation is usually about double that occurring when doing outside work, and with ores containing substances that are detrimental to the mercury, the loss may be five or six times as great. It is impossible to say how much gold is carried off by this vagrant mercury, but it should be less than that indicated by assaying the mercury caught in a newly cleaned mercury trap, as the larger part must be lost in the form of finely divided mercury that has amalgamated with but little gold. Oil and grease, talcose and clayey ores, arsenic and the compounds of arsenic and antimony are the worst enemies to amalgamation—coating the floured mercury with a film so that it becomes permanently floured, in which condition it is said to be 'sickened.' Oil and grease are particularly bad and every effort should be made to prevent them from coming in contact with the ore, or mortar, or the plates. When constituents of the ore coat the plates and foul them against amalgamation, as much amalgamation as possible should be obtained in the mortar.

Amalgamation in Cyanide Solution.—Amalgamation in cyanide solution presents no difficulties within the requirements made on it —a close saving on the plates not being essential. The loss of mercury is high as it is dissolved to be precipitated in the ore and in the zinc box. Most silver ores and some gold ores contain base elements which unite with and destroy cyanide to an undesirable extent. The mercury unites with or replaces some of these elements, in the latter case forming a compound of mercury and cyanide which is an active solvent of gold and silver.* When the solution is again brought in contact with the ore, the precious metals are dissolved and replace the mercury which is precipitated in the ore. The mercury thus plays an important and beneficial part, but only a small amount of mercury is utilized in this way, the greater part being precipitated in the zinc box. This deposition on the zinc, if not too excessive, appears to assist the precipitation of the gold and silver, due to the formation of a galvanic couple. The mercury cannot be recovered economically under ordinary conditions. The strength of the solution should be kept down to one-half pound of potassium cyanide per

*See 'Textbook of Cyanide Practice' by the Author.

ton of solution to prevent the too rapid dissolution of the plates and mercury, though a solution of two-pound strength has been successfully used. As the life of the plates is limited to from six to nine months and the amalgamation rather roughly carried on, silver-plating the plates is an inadvisable expense. No aids or methods of prolonging the life of these plates have yet come into use, notwithstanding that the item for renewals is an important one. The lower plate and lower part of each plate is eaten through first. As the amalgam is cleaned up the closest from these places, it gives weight to the natural conclusion that a thick coating of hard amalgam would prolong the life of the plates. The cyanide keeps the plates beautifully free from stains as it dissolves the copper compounds as fast as formed, and owing to its low strength does not harden the plates to the extent that might be expected. The plate tables should be built water tight that neither the mercury nor solution may run through, for the plates are eaten through irregularly and it may not be convenient to remove them when the first spot appears. In fact it is the custom to repair the first spots or bare places by tacking pieces of old plates over them.

Iron tables or those having the bed of plate-iron or steel and water tight would be excellent. Raw copper plates of extra thickness with backs covered with a thoroughly solution-proof paint, in two-foot sections with a drop between each, the sections to be easily and independently removable or changeable, are the lines along which these tables should be designed. The plates should not be allowed to project beyond their backing as the ends are gradually dissolved down to dangerous knife edges. The solution being weak does not injure the hands of the workmen, though it may make them rough at times. Rubber gloves are not required. In designing and building a mill for crushing in cyanide solution, every effort should be taken to prevent the leaking and spilling of the gold-bearing solution, while the floors should be arranged to catch and carry any such solution to a sump tank. The loss from this source is high in some mills.

Water Required in Amalgamation.—For amalgamating on the apron-plate, the feed water used in the mortar should be just sufficient to carry the pulp down the table in waves that appear retarded, almost but never stopping, rolling over and over and breaking up, that each part and particle of the pulp may be brought in contact with and dragged over the amalgamated surface of the plate as much as possible. The coarse gold sinks to the bottom of the pulp and is caught, usually on the upper section of the plate, within 2 or 3 ft. of the mortar lip, while the fine gold is carried along by the sweep and rush of the pulp, and being unable to sink through it, must wait until the turning over and breaking up of the pulp finally brings it in contact with the plate. A difference has been noticed in the proportion of the gold to the silver in amalgam caught at the head of the table as against that caught at the foot. This has been credited to the greater ease with which gold is amalgamated than silver, but a sizing of the gold particles in the ore might reveal that the fine gold caught farther away from the mortar contains a higher proportion of silver.

Where difficulty is experienced in amalgamating the gold, or where the plates appear to be too short, less water should be used in the mortar, even if the grade of the plates has to be increased, that the pulp may be dragged and rolled over the plates rather than sluiced. The fall of plates now in use varies from 1¼ to 3 in. per foot, and should not be less than 1¾ or 2¼ in. A low fall requires too much water in the mortar that the pulp may not bank on the plates to give good apron-plate amalgamation, especially if the ore contains much sulphide or other heavy material. It is better to make the grade too great than too little. There are various methods of constructing plate tables that allow the grade to be easily changed, and it is well to use such construction. Where the pulp has banked on the plate, the careful amalgamator does not hose it off with a large volume of water, thereby losing any gold caught in the pulp or only lightly attached to the plate, or any spikes of crystalline amalgam; he turns on a light stream and slowly and gently washes the deposit away. Some millmen place a stick of wood diagonally on the plate above a bank of sand, diverting the stream of pulp, and thus washing the sand away.

It was customary years ago to use a spray of clear water from a perforated pipe or distributing box at the head of the table to slightly retard the pulp and to cause the gold to settle and attach itself to the plate. The crushing capacity at that time was small, due to light stamps and wide mortars, but with the reverse of these conditions now, all the water that it is safe to use should be introduced through the mortar in the effort to pass the material through the screen as fast as possible. Wherever extraordinarily long plates are required, it will be found that an excess of water is being used, or that the gold is extremely fine. Where extra plates are needed or much amalgam is caught on the last plate due to an excess of water, the pulp should be divided between two short extra tables rather than one long extra table. This will induce the rolling of the pulp and the thinning of its layer, both so necessary to facilitate contact of the finer particles of gold with the amalgamated surface and good plate amalgamation. Where the plates are so long that the lower plate scours, and much mercury is required to keep it in condition, while it returns no amalgam, the plates may be shortened, or the use of more water in the mortar can be tried. The last should cause the gold to be caught lower down and the lower plates to keep in condition, while the amalgamator can salve his conscience for this departure from good amalgamating practice by the increased tonnage due to the use of a larger quantity of water.

A plate requires the constant addition of mercury and gold to keep it from being denuded by the pulp. Running on dumps of extremely low-grade ore, as is so often done before the final shutting down of a mill, has been unsatisfactory in many instances for the above reason. Also, coarse crushing is generally resorted to in the effort to compensate for the low value of the rock by increasing the tonnage, whereas the gold is usually finer and may require finer crushing to liberate it. Should the plates scour when running on this low-grade rock, a small amount of water should be used in the mortar to induce the gold to be amalgamated on a short length of plate, while removing the lip and splash-plates may assist in keeping the apron-plates in condition. Clear water will carry off mercury and amalgam and when allowed to run over a plate for some time, the amount should be reduced to just sufficient to keep it wet and prevent oxidation and discoloration.

Temperature of Battery Water.—Many experiments have been made with varying temperatures of battery water, and the best results have been secured when it is at a temperature between 45 and 70°F. (7 to 21°C.). Below that temperature the amalgam tends to become hard and crystalline, and poor amalgamation may result, though the heating of the feed water is seldom attempted. Above 70°F. the amalgamation of the gold upon the plates appears to be promoted, but the amalgam becomes so liquid that it is hard to retain it on the plates, much of it running down into the traps. Amalgamating in water of either an unusually high or low temperature bears a certain analogy to amalgamating wet and dry. A high temperature causes any acidity of the battery water or the ore to act more vigorously in staining the plates by the formation of various compounds with the copper. The amalgamator usually manages to do good work with water of either a high or low temperature by keeping the amalgam at the proper consistence, but where the water has a considerable variation of temperature during the twenty-four hours, it is impossible to vary the practice accordingly.

Period Between Plate Dressing.—How often shall the plates be dressed? Just as often as needed to keep them in good condition. Where the conditions are not greatly variable this will be reduced to dressing at stated periods, generally 12 hours apart. Where the ore is low grade, 'plating' $1.50 to $3 per ton, the plates are dressed once daily in the morning, though the night shift may soften and dress the upper plate of each apron if it becomes hard. This refers to a large mill, in a small mill two dressings will be made daily, even if the plates are in fair condition, on the principle of giving the night amalgamator something to do. With ore amalgamating $4 to $8, two or three dressings will usually be made during the twenty-four hours, while with rich ore they occur a few hours apart. The clean-up of the amalgam is made when the plates are dressed in the morning. At the time of other dressings only the loose crumbs of amalgam are removed unless the ore is rich. The plates should be rubbed sufficiently to secure an even texture of the amalgam, in theory stopping short of the silver-plating, while allowing as little of the hard scale to form as possible. The amalgam should be worked into its most active condition with a view to catching gold, and further rubbing is superfluous. Two men will dress a plate 16 ft. long in from 5 to 12 minutes, depending on the care and refinement used. The grade of ore is not the only factor determining the number of dressings. The appearance of stains, or the coating of the plate by galena or other sulphides, or by the semi-amalgamation of tellurium or some base metal, will at once call for a dressing to remove the fouling substance. Plates that have been treated with strong cyanide solution do not hold mercury well, and some time after the dressing the mercury may collect in drops, or tears, that work down the plate, when the plate is said to 'run,' and should be dressed at once.

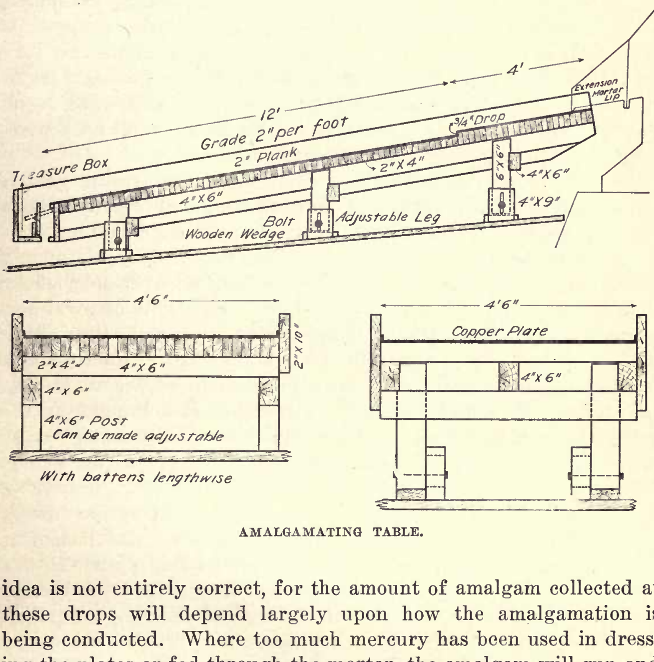
CHAPTER VII

Construction and Arrangement of Apron Table—Accessories to the Apron Table—Plates Away from Mortar—Silvered or Raw Copper Plates and Their Handling—Recovering Gold from Old Plates—Chemicals and Their Use—Unsatisfactory Bare and Hard Plates—Cleaning Amalgam and the Clean-Up.

Construction and Arrangement of Apron Table.—The plate table should be as free from jar as possible, preferably carried up from the ground independent of the flooring and framework of the mill. It has been claimed that the jar is beneficial in promoting amalgamation and attention has been called to the excellent work following the apron-plates of shaking plates mounted on vanner concentrators from which the belts have been removed, or similar mechanisms. The motion these shaking plates receive is an even, gentle, vanning motion like that which causes the gold to settle in the gold pan; while the vibration to which a plate table is subjected from coming in contact with the mortar, or from the jar of the floor, in a poorly built mill, is quite different—one that causes the mercury to exude from the amalgam in globules, and the amalgam to granulate.

Plate tables are commonly built of 1½ and 2 in. plank, laid either lengthwise or transversely, with side pieces of the same material 10 to 12 in. wide. A better method is to use 2 by 4, 4 by 4, or 3 by 5 in. planed, well-seasoned lumber, placed lengthwise of the table, either spiked together or bolted across the width of the table every three feet, and put together with a thick waterproof paint. With such a table there should be no leakage. When drops are introduced they are made shallow, the material being cut out as required. The supports beneath should be as simple as possible, except where rendered complicated by introduction of means for changing the grade. The table should be dressed down to make the center $^1/_6$ in. lower than the edges, or the pulp will riffle toward each side of the table forming washes there and leaving it too shallow in the centre.

Drops between the plates are introduced as the gold tends to collect where the pulp strikes the plate; also, the farther the pulp travels down a straight plate, the greater its speed becomes, one of the visible indications of which is the increased size of the waves at the lower end of the table. A drop serves to start the pulp off anew and prevent the acceleration of the speed of the pulp, wherefore it is preferable to decrease the grade of the lower end of the table if drops are not used. A drop also breaks the flow of the waves, thereby giving the fine float and suspended gold a better opportunity to come in contact with the plate, and also induces a more even distribution of the pulp. As the amalgam piles up at these drops, they are much in favor; the general idea being that by increasing the number of drops, the length of the plates may be diminished. This



AMALGAMATING TABLE.

idea is not entirely correct, for the amount of amalgam collected at these drops will depend largely upon how the amalgamation is being conducted. Where too much mercury has been used in dressing the plates or fed through the mortar, the amalgam will run and slough off and collect at these drops, so that the amalgamator when examining the plates, should also use the drops as an indicator. About the only objection to drops is that they interfere to a slight extent with the quick dressing of the plates. For this reason a single copper plate 12 ft. long is often used. A very nice apron plate consists of one 4-ft. length of raw or silvered copper, followed by a drop, and finally a 12-ft. length of silvered copper. A drop of one-half inch is sufficient to give the desired results, and more than three-quarters of an inch is liable to cause scouring. Where a drop scours, a strip of wood should be used as a baffle-board to ease the pulp to the plate.

Blankets can be placed underneath the plates if necessary to even up the table. The sides of the plates should be turned up and the ends slipped well under one another that neither the water nor the mercury may work through to the floor. It is preferable to have the plates held down by side strips and overlapping without the use of screws, which become loose or partly destroyed by rusting or electrolysis so that they interfere in cleaning and dressing the plate. Designing the tables so that the plate adjacent to the mortar may be rolled away from the mortar and over the remaining part of the table, or that the entire table may be moved forward, is an unnecessary expense, as advantage of this is only taken when removing a mortar or repairing a mortar block.

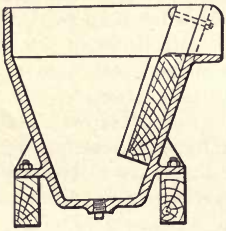
At many mills running on low-grade ore, or where the gold is largely in the sulphide, it is customary to clean and dress the plates without stopping the battery, thus saving the considerable labor involved in hanging up the stamps and the loss of duty in stopping the battery. This can be easily and satisfactorily accomplished by dividing the plate into two sections by placing a strip of wood permanently down the center, and directing the entire flow to either half of the plate by plugging the holes on one-half of the distributing box, usually also cutting down the amount of water entering the mortar. If no distributing box can be bolted to the mortar, the plate table can be built so that a wooden trough distributer can be set beneath the lip of the mortar. At the Empire mill, Grass Valley, California, the tables are so fitted to the mortars that when dressing a plate, a launder of sufficient size and length to carry the flowing pulp to the plate of an adjoining battery is inserted under the mortar lip. At first sight it would appear that overloading a plate in this manner would be bad practice, but the actual experience has been so satisfactory that experiments by sampling and assaying the tailing under the different conditions should be made before condemning this practice at any mill. Mills using these systems generally have long plates. In view of the Empire mill practice, it should be possible to deflect the pulp to a launder or pipe leading to an extra plate set over the concentrating floor or at the side of the mill, and this has been arranged for in a few mills.

Accessories to the Apron Table.—At one time 'sluice-plates' were in vogue. Following the lip-plate and mortar was one apron-plate the width of the mortar and 4 ft. long. The plate table was then narrowed down to hold three or four plates of half the width of the apron-plate. Only the heavier gold and amalgam could sink down through the flood to which the pulp was contracted while running over these plates, also the tendency of the pulp to scour the plates was increased. These sluice-plates were extensively used at one time, but have been entirely discarded.

The pulp falling from the last apron-plate is collected by a 'tail-box' delivering to a mercury trap or launder. The tail-box should be fitted with what is known as a 'treasure-box.' This is simply another or second compartment in addition to the one collecting the pulp for the launder; a swinging door, or lid, enables the pulp from the plate to be directed to either compartment. The plate is washed down with a heavy stream of water, preparatory to dressing, into this second compartment; after dressing, the plate is again washed down, this time with a light stream. The function of the treasure-box is to catch the particles of loose amalgam that might otherwise be lost, and also the rich sulphides that have attached themselves to the plate by reason of the amalgamating of an exposed face of contained gold. This box is very necessary when running on rich ore. A portable trough box that can be set beneath the lower edge of the plate is used to serve the same purpose. The treasure-box is a handy accessory when the mortar is opened, as the pulp and rock that always litter the mortar lip and upper apron-plate at such times is sluiced into the box to be returned to the mortar without getting into the traps or on the concentrators. A combination treasure-box and mercury trap can be made by simply placing a partition or baffle in a wide tail-box, so that the pulp from the table is caught in the first compartment to overflow the baffle into the second compartment leading into the launder.

A plate should be tried in the tail-box, in the launders, and on the distributing box of the concentrators, but these plates must be dressed at intervals and kept in good condition to enable them to catch anything. Riffles should be placed in the launders or made by notching the bottom plank of the tailing flume, as even with the most careful amalgamating a little amalgam escapes which can be occasionally gathered from them without expense.

Patent amalgamators placed following the apron-plate have been successful in many instances, but it does not appear wherein they are superior to plates except that they may present a larger amalgamating surface, opposed to which is the more refined manipulation that can be practised on the ordinary plate. It is better to make a trial of them rather than an outright purchase. Too often such machines do not get a fair test, due to the inexperience of the mill-man with them and to his proceeding on the theory that their



MERCURY TRAP.
(Denver Engineering Works Co., Denver, Colo.)

introduction in the mill is a reflection on his ability as an amalgamator, as, in truth, it often is.

Plates Away from Mortar.—The placing of the plates at a distance from the mortars, instead of immediately following them, has not been entirely successful. The first reason being that it is hard to distribute the pulp evenly across the width of the plates. The second is that the gold appears to become coated with slime in the short time that elapses between its leaving the mortar and reaching the plates, so that it is rendered less amalgamable. The third is that the pulp loses its homogeneity to some extent in its passage, just as in a tailing flume the coarse sand settles to the bottom. When the pulp in this condition reaches the plates, the coarser sand tends to segregate, while the finer and more dilute portion of the pulp passes on and over the plate; thus a steeper grade of plates and more water are required. The pulp flows down over the plate in a sheet, or flood, rather than with the rolling over and over wave motion so desirable, and amalgamation must necessarily be poor, especially with a gold difficult to catch. The pulp as it leaves the mortar is homogeneous, though the tendency of the coarse and fine particles to separate is noticeable toward the foot of a long plate.

Where the ore has been dry-crushed and subsequently watered and run over plates, the results have been unsatisfactory in many cases, partly for the above reasons and partly because the gold has become fouled, retarding amalgamation by being coated with dirt or air bubbles in the process of being crushed.

In placing plates at a distance from the mortars, well considered arrangements should be made for securing an even distribution of pulp to and across the width of them. Comparative tests should be conducted against a plate set in front of the mortars. Sufficient mill space should always be provided to allow plates to be placed directly in front of the mortars, if thought desirable. With a clean ore that slimes but little and a coarse gold, it should be possible to amalgamate satisfactorily at a distance from the mortar, but with a sliming ore and fine gold it is doubtful.

Silvered or Raw Copper Plates and their Handling.—The apron-plates may be of raw copper, but those plated with silver are much preferred. The amount of silver used per square foot varies from 1 to 3 oz. One ounce is sufficient for the upper plates, but the last one should have a heavier coating as the scouring action over it is much greater than above where more amalgam is deposited. These plates are from 52 to 56 in. wide—slightly wider than the discharge to them—and can be obtained in lengths of 12 ft., but are commonly used in sections of 4 ft., and such a section is usually spoken of as a plate. The usual thickness is $1/8$ in., though plates $1/16$ in. thick are in use, but such plates are easily dented by objects falling on them. The best Lake Superior or electrolytic copper is used to insure purity and softness. As these plates are rolled out, which makes the surface dense, in purchasing raw copper plates it should be stipulated that they be annealed; the annealing softens the surface of the copper that the mercury may be better absorbed. They can be softened by heating over a fire, but this, if not evenly done, is liable to buckle the plate, so that it is better not to try it, but to use the plate as it is.

Silver-plated apron-plates are used in most mills, and are preferred by amalgamators as being easier to care for. Experiments have shown that a greater saving can be made with silvered plates than with the raw copper. Still, the amalgamator who has handled both and who knows how to care for the raw copper plate, believes that he can amalgamate as well with one as with the other. It appears that the personal equation of the amalgamator's ability becomes a greater factor with raw copper than with silvered plates.

One objection to the use of raw copper plates is the trouble necessary to get them into suitable condition. It requires a few weeks before they become saturated with mercury and while there is not a large amount of gold carried into the copper, there is quite an amount on the surface of the plate which it is not desirable to remove as being prejudicial to the further good working of the plate. The silvered plate has a suitable surface already prepared. The mercury sinks slowly through this silvered surface, so that the plate on the start does not have to be dressed with additional mercury as often as the raw copper, but eventually it absorbs as much mercury as the raw copper plate. The amount of gold carried into the copper has been found to be small, assays of plates in long use showing about one-sixth ounce of fine gold per square foot, consequently the great amount of bullion coming from old plates is from the hard scale of amalgam on the surface, and the amalgamator should aim to keep this as small as possible. It has been stated that microscopical examination has shown the gold within the plate proper to be mainly in the blowholes of the copper, rather than to be truly absorbed. Once a raw copper plate is well started and in the hands of a good amalgamator it should do first-class work, but the bullion returned for the first month in operation will be less than if a silvered plate was used. The difference is not lost—the gold is held on the surface of the plate.

To prepare a raw copper plate for amalgamating, it is necessary to clean the surface of all impurities and copper compounds, and to a lesser extent, to soften the copper, after which it is amalgamated by rubbing mercury in. The cleaning is done by thorough scrubbing with fine sand, wood ashes, or slime, using wood blocks, rags, or whisk brooms. Immediately following this burnishing, a weak solution of potassium cyanide, sal-ammoniac, nitric acid, or caustic soda or potash is used with a view to softening the copper. The plate can be amalgamated without any softening in this way, but the mercury is not so readily absorbed and consequently it is a longer process. For this reason one of these chemicals is used in the initial process of amalgamating of a new raw copper plate, even by those who are prejudiced against the use of chemicals on the plates under other conditions. The plate is usually scrubbed after the burnishing with a 5% solution of nitric acid followed by another scrubbing with a 2½% solution of potassium or sodium cyanide—the acid being washed away thoroughly that it may not re-act to neutralize the cyanide; the cyanide is washed away and followed by spraying mercury (to which it is well to add a little sodium amalgam) over the plates and rubbing for a long time; mercury is added from time to time and the rubbing continued until the plate will hold no more. With the passing of time mercury is absorbed into the plate and the process of rubbing mercury is continued until the plate is saturated with mercury, which will take about two weeks, when it is ready for the dropping of the stamps. After the first amalgamating no acid should be used on the plates, though the cyanide solution may be used if the mercury does not readily amalgamate the copper. Following the first amalgamating or just before dropping the stamps, the plate should be coated with silver amalgam or the ordinary amalgam, if either can be obtained; this will cause the plate to get into condition quickly and to become a good catcher of gold almost from the start.

Silver-plated copper plates require but little preparation. They should be washed with a weak solution of lye to remove any grease on their surface, and they may be polished with a little slime or ashes, though the latter is not necessary. A long and thorough rubbing in of mercury is desirable. Silver amalgam or the ordinary amalgam should be applied, if obtainable. If amalgam is not applied, then some sodium amalgam should be added in the mercury to make the plate more active at the start. When starting new plates, a low-grade ore should be run through first, preferably one having a coarse, easily amalgamated gold, certainly never a high-grade ore as the catching power of a new plate is low. After a bed of amalgam is started, a better grade of ore can be milled.

Recovering Gold from Old Plates.—A much discussed question is how to prevent the locking up of a large amount of bullion in the plates. To melt the plates into a bar of base bullion requires a new set which is costly. While the old set will more than pay for the new, all would prefer some way by which they could 'eat their cake and still have it.' Of this locked-up gold, comparatively only a small part is absorbed in the plates, probably $^1/_6$ or $^1/_8$ oz. of fine gold per square foot, and most of it in the surface copper, as has been shown by planing plates and assaying the different sets of shavings. The major portion of the gold is in the form of a hard scale of amalgam; to remove this scale the copper must be laid bare and will thus have its amalgamating efficiency reduced for some time, which means a loss. To resilver the plate is expensive. The wet amalgamator attempts to keep the thickness of this scale at a minimum by softening the amalgam down to the silver-plating, the dry amalgamator accomplishes it by chiseling the amalgam off at intervals; but the scale is certain to accumulate unless they are willing to ruin the silver-plating and thereby lose its advantages. Certain mills use raw copper plates, with the exception of the last plate which is silvered on account of the scouring action of the pulp. These copper plates are periodically sweated and in this way there is little hard scale left on the plates. Where a part of the amalgam is spread back on the plates, the practice is a good one, but where the stamps are started up with the plates bare, it must be condemned.

Where it is considered necessary to use silvered plates, and it is still desired to secure this bullion, it is more economical to scale the plates and have them resilvered than to melt them into a bar for shipment to the bullion buyers. There is no really good method for removing this scale. Besides sweating and chiseling, the plate can be given repeated scourings with pumice stone and mercury, and it is surprising the amount of gold that can be taken from a plate in this way. It is recommended that this method be followed, and that in no case should the plates be melted down where others must be installed. 'Burning' the plate is resorted to, which consists in driving off the mercury by heating the under side of the plate, after which the gold can be scaled off. To induce the scale to more readily come off, the plate being burnt, may be subjected to a scouring with or a bath in some chemical that will form a compound with copper, thereby softening the surface copper. Burning a plate causes it to buckle and puts it in such bad condition that plates to be resilvered or re-used should not be treated in that way unless the heat applied is moderate or there are facilities for restoring the plane surface to the plate again. It would appear that a method could be devised of using heavy raw copper plates and periodically removing them and planing the enriched surface off by hand or machinery.

Chemicals and their Use.—As few chemicals as possible should be used in the treatment of plates. Their continued employment is analogous to the use of stimulants by a man. Apparently beneficial, their after effects usually more than counteract their fancied or real temporary advantages. The mercury should be 'pickled' in weak nitric acid to remove impurities, as has been explained before, but all traces of the acid should be washed out before applying the mercury to the plates. Greasy plates should be scrubbed with soap and water or a very weak solution of lye, which will dissolve and remove the grease. Potassium cyanide has been used extensively in the past, but its use must be condemned as wrong in theory and harmful in results. Cyanide of potassium solution removes grease, in which it is beneficial; it also dissolves the compounds of copper, allowing them to be washed away, in which it is also beneficial; but it goes farther, it dissolves the metallic copper itself and thereby pits the surface of the plate, especially if the coating of amalgam is thin. This pitting of the plate and the formation of compounds of copper and cyanide that are only partly removed by the water, increases the tendency of the plate to absorb mercury—is said to soften the plate. But these beneficent results are only temporary, for the plate becomes still harder and the mercury tends to ooze out of the amalgamated plate, as may be observed in plates that have been continually treated with strong cyanide solution, while the copper compounds that have been formed, oxidize to tarnish the plate at every opportunity. When the solution is used, it should be weak, that only the copper compounds may be attacked, and that the raw copper may be unacted upon, and it should be thoroughly washed away immediately after using, that none of the copper compounds or salts may remain. A 2½% solution—less than one-half ounce potassium cyanide to a pint of water—is the strength generally used, and a still weaker solution is preferable. Plates that have been long treated with strong cyanide solution are difficult to handle, especially if little amalgam is kept on them, and that in a hard condition. In general, any acid or chemical that will form a compound with copper should not be applied to the plates, while the copper should be kept well covered with amalgam that tarnishing due to oxidation by the air or indirectly by the acidity of the water or ore may be minimized.

Amalgamators have various 'dopes' and nostrums, secret and otherwise, for applying to the mercury and plates, the action of which they themselves but little understand, especially in regard to the chemical reactions from which they must derive their virtue, if they possess any. It is best to dispense with them all. There is only one 'dope' or panacea for the ills of amalgamation, and that is a thick bed of amalgam, kept in an active condition and free from foreign substances. This, together with a vigorous application of 'elbow grease,' produces the best results.

The mercury is sometimes 'loaded' by adding sodium amalgam, up to the point where the mercury just commences to amalgamate a bright or newly filed nail. Sodium amalgam is prepared by heating the mercury in a glazed dish, or better still, a quicksilver flask, the top of which has been cut off to form a deep pot. The making of sodium amalgam is attended with danger and should be conducted carefully. Heat the mercury to about 300°F. (149°C.) and cut small chips, the size of a good-size pea, from the stick of sodium, handling with a pair of tongs. Drop but one chip into the heated mercury at a time. A slight explosion should follow. If it does not, stir it gently with a wooden paddle, which will hasten the flash. Then add another chip in like manner, up to 3% of the weight of the mercury to be thus treated. This will crystallize, forming a solid amalgam when cold. Keep the face away from the flask, both on account of the flashing sodium and to avoid the mercurial vapor that is likely to arise from the heated pot. This amalgam should be kept in air-tight bottles that it may not decompose, and should be added in small quantity to the mercury as required. The effect of the sodium in making the mercury so active in amalgamating is not fully understood, but is supposed to be largely due to its reducing action. It reduces the oxides and other compounds of the base metals, causing them to amalgamate with the mercury. It is but little used by practical amalgamators as it causes the amalgam to 'freeze' to the iron and steel surfaces of the mortar through amalgamating with them, while so much fine iron and steel and sulphide are caught with the plate amalgam, that these surfaces become foul. It is productive of an increased quantity, but a lower grade of amalgam. Besides being useful in covering bare spots, it is of benefit in starting new plates—making them more active.

Silver amalgam can be prepared by dissolving silver coin or other silver in dilute nitric acid. To this solution add the mercury and a few bright nails, keeping the acid weak. The silver will be deposited on the mercury forming an amalgam. Unless the amount of copper in the silver is large, its presence is not material. This copper can be removed by precipitating the silver from the nitrate solution by adding a solution of common salt up to the point where no more precipitation occurs, then washing the precipitate until all green color of copper is gone, after which very dilute nitric or sulphuric acid, mercury, and bright nails are added. The finely divided precipitated silver may be separated by filtering, and worked up with the mercury later, if that method is preferred. A rough method of making silver amalgam is to reduce the silver to filings and amalgamate it by mixing with mercury.

Unsatisfactory Bare and Hard Plates.—The stains, the so-called 'verdigris,' which appear on the plates very much resembling bare spots and which are a source of grief to many amalgamators, are in nearly every case an oxide of copper, though they may be a carbonate in some instances. These stains are due to copper in the amalgam, which is turned into an oxidized compound by the air or water. This copper may be amalgamated from the ore together with the gold, or may have its source in the shells of detonators used in blasting, or may have contaminated the mercury. Another cause of the stains is acidity in the battery-water or ore, which may arise from decomposing sulphides producing sulphuric acid, which in turn acts upon the copper of the plate, forming the compound which is the stain. Generally the stains arise from the plate due to too thin a film of amalgam, and to the overuse of chemicals. The remedy is to use purified mercury, and dress the plates as often as the stains appear until a good film of amalgam is accumulated over the plate, and especially over the spots which most frequently tarnish. Solutions of potassium cyanide, sal-ammoniac, and of the acids are used, especially the first, to dissolve these stains that they may be washed away, but as it is impossible to prevent the chemicals from continuing to act further, they should not be employed. The use of silvered instead of raw copper plates will ordinarily obviate this trouble. However, it largely depends upon the ability of the amalgamator.

Bare spots on the plates are due to the amalgam having been removed too close to the copper by chiseling, or they may be started by a tarnishing spot. They also may appear on the lower apron-plate

IRON HAND MORTAR FOR GRINDING AMALGAM.

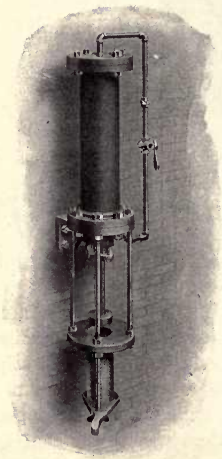
WEDGEWOOD BOWL FOR GRINDING AMALGAM.

(Braun-Knecht-Heimann Co., San Francisco.)

due to the scouring of the pulp as has been mentioned before. These spots require careful treatment for a little while. The copper should be burnished with fine grit, such as wood ashes or slime, until the pure copper is exposed, when the adjacent amalgam should be worked over it and well rubbed in. The deposition of the amalgam should be coaxed from the edges to the center. A little sodium can be used to advantage in the mercury and this compound, sodium amalgam, applied to these spots, as it will promote the attachment between the amalgam and the plate and aid in the recovery of additional amalgam. Cyanide and acid solutions should not be used on these spots.

Some amalgamators are troubled by the amalgam on the apron-plates becoming abnormally hard. The exact reason for this cannot be given, though it is often due to certain substances in the ore, but usually it is the combination of a bare plate, dry amalgamation, and the too frequent use of cyanide in dressing the plates. The amalgamator, in his effort to prevent this hardening of the plate, may dress it wet until it resembles a mirror, but in a short time the mercury begins to form in visible globules and drain off, leaving the plate hard. To correct this trouble all chemicals should be dispensed with, and the principles of wet amalgamation practised by keeping a thick layer of amalgam on the plates and dressing them often, giving the amalgam a long and hard rubbing. This amalgam should not be kept too wet or it will increase the tendency for the plate to 'run.' Unless the trouble lies in the ore or water, the plate will regain its normal condition under this treatment.

Cleaning Amalgam and the Clean-Up.—After the amalgam is removed at the daily cleaning of the plates, it is necessary to clean it by removing the sand, iron, sulphide, and base metal dross. This is done by grinding it in a wedgewood or iron bowl with enough



AMALGAM PRESS.

The amalgam is placed in a canvas bag and inserted in the perforated cylinder that the ram may descend upon it.

(Power & Mining Machinery Co., Cudahy, Wis.)

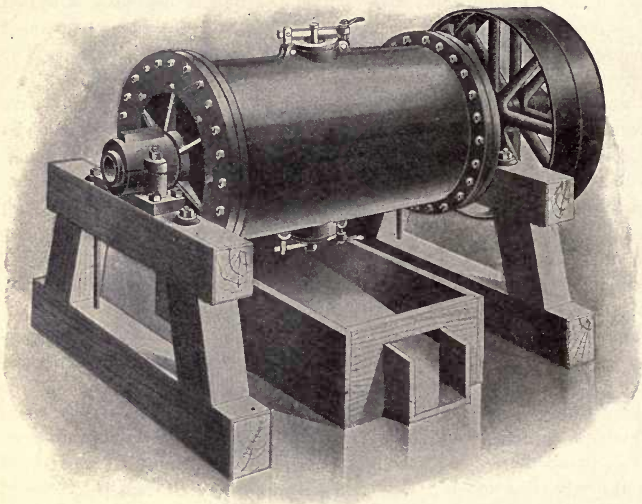
mercury to make it quite liquid. The impurities rise to the top, where they are carried over the side of the bowl into a gold pan in which the bowl sets, by a stream of water from a hose, or they are taken off by a coarse sponge. After the quartz and dirt and dross—impure and foul amalgam—has been taken off, a magnet is passed through the liquid amalgam several times to remove the fine iron and steel. It is now poured into a wet canvas or a double thickness of stout drilling lining a bowl. The cloth is gathered up by the corners and twisted tight, forcing the liquid mercury through the fabric and leaving the hard amalgam behind in the cloth. This process of squeezing or wringing the amalgam is continued, the globules of mercury being washed off by aid of water into the bowl beneath. When all the mercury has been expressed that the operator can wring from it, the cloth is spread out exposing a ball of hard amalgam within. The ball is rolled around in the cloth to pick up the loose flakes of amalgam; after which the ball is weighed, wrapped in paper on which is usually marked the date and weight, and locked up until the monthly or semi-monthly retorting and melting. The mercury passing through the cloth will carry some gold, but this is not considered undesirable as such mercury is more active in promoting amalgamation than that which is gold-free. The amount of gold so retained can be reduced by squeezing the amalgam through a less porous material, such as chamois. Mechanical amalgam squeezers are in use. Their product is not as satisfactory as that produced by hand, but as they work faster and save labor they are suitable where a large amount of amalgam is produced. Where compressed air, steam, or water pressure is available at the mill, they can be rigged up out of an old air rock drill.

Some amalgamators clean the amalgam by adding sufficient mercury to make it soft and mushy, when it is dumped upon the upper apron-plate, where it is puddled by the fingers, or a rubber, until it sticks to the plate in one mass. Water is turned on from a hose, which, in connection with the puddling, washes the amalgam clean. After using the magnet, the amalgam is scooped up and transferred to the straining cloth. This is a poor method, though the amount

GOLD PAN WITH BOTTOM OF COPPER FOR AMALGAMATION PURPOSES.
(Braun-Knecht-Heimann Co., San Francisco.)

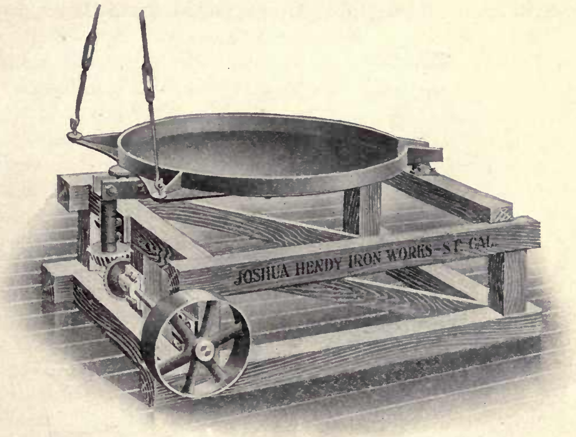
of amalgam lost is small when the treasure box is used; it causes a loss of running time and leaves a wet spot on the plate. The easiest way is to use a gold pan having an amalgamated copper bottom on the inside, when removing the amalgam from the plates. Then, when at leisure, work this amalgam up at the clean-up sink in the same manner as on an apron-plate. Grinding with an excess of mercury in a wedgewood bowl gives the cleanest amalgam. The dross or impure mercury and the rich sulphide collecting from the daily cleaning of the amalgam should be ground with mercury when a quantity has collected. All of the debris and refuse from these cleanings should finally go to the tank of the clean-up sink, to be run through the clean-up barrel or pan later, or sent through the mortars in the absence of a clean-up barrel or pan.

Where there is considerable gold in the mortar sand, this sand is removed once a month or on a general clean-up day. At this time



CLEAN-UP BARREL.
(Power & Mining Machinery Co., Cudahy, Wis.)

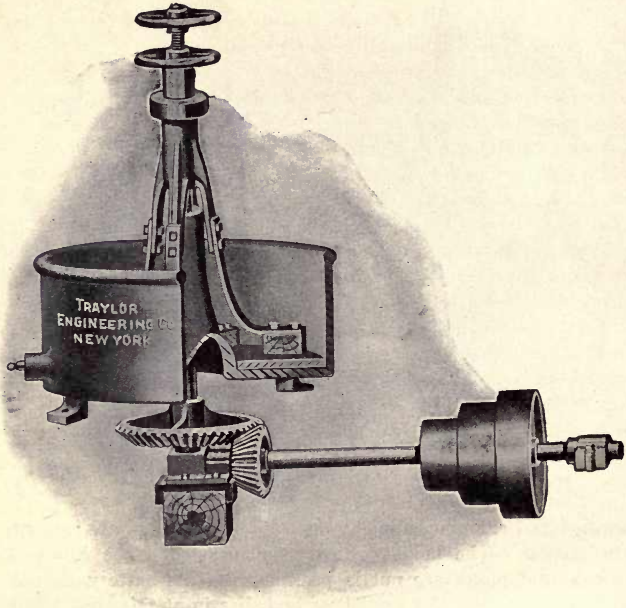
the battery is stamped out and hung up. The apron-plates are cleaned before the mortar is opened. A platform of boards with cleats to fit the apron-table is placed over the first plate to work upon without marring the plate. The screen is removed. The splash, lip, and inside plates are removed to the clean-up room to be chiseled and scraped, which is done by means of old files forged down to chisel ends and ground sharp on a grindstone or emery wheel. A putty knife is a useful tool for this purpose. The pulp lying on the dies is shoveled into boxes or tubs to be returned to the mortar, as it usually contains too little amalgam to be treated. The sand about the dies is dug out with small bars and, together with that underneath the dies, is carried in pails or tubs to the clean-up room, or to the clean-up barrel or pan. The dies are pried up and removed to get the amalgam-bearing sand around and beneath them. All the sand is removed, together with any amalgam adhering to the sides of the mortar or to the shoes and bosses. The dies, which have been



STAMP-MILL BATEA.
(Joshua Hendy Iron Works, San Francisco.)

washed and examined for any deposits of amalgam, are returned to the mortar. The height of drop is adjusted. The chuck-block, screen, and plates are put in position, and the battery started up. It is aimed to put the new shoes and dies in at this time whenever possible, and the mercury traps are also then cleaned. Where the amount of gold retained in the mortar sand is too small to make it advisable to lose the running time and the labor necessary to obtain it, the clean-up will consist in scraping the outside and inside mortar-plates and perhaps the apron-plate also; the battery sand being removed and treated only when new dies are put in. At some mills the battery sand from all the mortars, when low in amalgam, is sent through one mortar having a high discharge, and only the sand from this mortar is taken to the clean-up room, but it is not considered good practice. At the clean-up room the sand from the mortars is either panned down in an ordinary gold pan or is run through a rocker to separate and collect the amalgam, the sand tailing being fed through the mortar before the next clean-up.

If a clean-up barrel is used, the mortar and mercury-trap sands, together with that in the clean-up sink from the daily cleaning of the amalgam, are put in the barrel with 40 lb. or more of mercury—sufficient to insure the amalgam being liquid—also enough water to make a sludge or thick pulp. To this is added a little lye, usually



CLEAN-UP PAN.

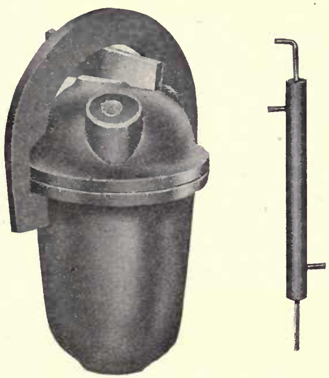
(Traylor Engineering & Manufacturing Co., Allentown, Pa.)

one small can, to 'cut' the grease and keep the mercury in condition; also many pieces of iron and steel to act as grinders or mullers, such as cannon balls, broken stem-ends, and shoe-shanks. Pieces of hard quartz or other rock answer well. The barrel is now revolved from three to eight hours, depending on the ideas of the amalgamator and the time available, at a speed not exceeding fifteen revolutions per minute—the higher the speed, the greater the tendency of the amalgam to flour. After grinding, the barrel is slowed down in order that the soft, liquid amalgam may collect; it is finally stopped with the manhole uppermost and a small plugged opening below. The manhole is opened first to give vent to any gases that may have formed, after which the plug below is removed to allow the amalgam to run into a deep receptacle or pail set underneath. The sand is slowly sluiced out of the barrel with sufficient water to make a thin pulp that will not carry away any amalgam as it overflows the pail. It is run through a coarse screen to remove nails and other small fragments of iron, to riffles and an amalgamated plate for catching any escaped amalgam, and is finally caught in a box or tank. A stamp-mill batea, a large shallow iron bowl or pan which may be characterized as a mechanically-operated gold pan that retains the amalgam and pans off the sand, is superior to riffles or a plate for catching any amalgam that has overflowed the pail. The amalgam recovered is cleaned of iron by the magnet and strained through canvas into balls in the usual manner. The sand is eventually carried back to the mortar as it always contains a little amalgam. Grinding pans are used at some mills instead of barrels for cleaning the sand and amalgam; the only variation in the general treatment being that necessitated by the difference in their construction; both are dispensed with at many mills as they are considered by some to flour the amalgam, while on the other hand some mills are equipped with both. The amalgam chiseled from the plates, or that panned out of the sand, is ground up in a large wedgewood bowl or in an iron hand-mortar with an excess of mercury. Warm water is often used in cleaning the amalgam that it may become softer and liberate more freely the impurities mechanically held or suspended in it, and that it may be squeezed drier. Some amalgamators, though not many, add the amalgam chiseled from the plates at the clean-up to the sand in the barrel and clean it in that way, but it is not good practice to thus take any chances of its being lost or stolen.

CHAPTER VIII

Retorting and Percentage of Metal in Amalgam—Melting and Sampling Bullion — Recovering Gold from Slag, Old Screens, Etc.

Retorting and Percentage of Metal in Amalgam.—The amalgam is retorted to free the gold from the mercury. This is accomplished in a closed cast-iron vessel having a tube leading from it to carry away the volatilized mercury and deliver it to a kettle re-condensed in liquid form. These vessels are called retorts, and may be either large cylinders solidly set in a foundation of brick over a fire-box, or they may be small portable affairs that are placed over a fire made in a temporary furnace of brick or stone, or even on the ground in the open air. The inside of the retort is lined with three or four thicknesses of paper, with chalk, or with a paste of wood ashes, lime, or red oxide of iron, to prevent the gold from sticking to the sides. In the retort the balls of amalgam are placed so that it will not be more than three-quarters full when the cover is placed on. If the 'sponge,' as the metal after retorting is called, is to be shipped without being melted into a bar, the amalgam is packed down tight to make a solid mass of it, and a hole is forced down through the center to enable the mercury the better to escape from within the mass. If the retorted metal is to be melted into a brick before shipping, the balls are put in loosely since that will allow the volatilized mercury to readily escape and the sponge to be easily broken up for convenience in handling in the melting. A ring of lute made of fire-clay, wood ashes, and a little salt is placed between the cover and body of the retort to insure an airtight joint. The retort is set in a furnace, on a tripod, or is carefully propped up in the open, and a slow wood fire started about it. This fire is gradually raised until the retort finally becomes cherry red; the heat being applied all about the retort, not on the bottom alone. The pipe coming out of the retort passes through an outer pipe, and in the space between them cold water is constantly circulating, which condenses the volatilized mercury to the liquid state. When using small retorts, gunnysacks wrapped about the pipe, to which cold water is continually applied, may successfully be used. A vessel filled with water is placed at the lower end of the pipe to catch the condensed mercury. A cloth should be wrapped about the end of the tube, forming an extension of it. This extension should dip beneath the surface of the water with which the pail is filled and which overflows as the mercury condenses. Care should be taken that the lower end of the pipe itself does not project into the water, as there is a tendency for the atmospheric pressure to force the water up into the pipe at times, due to the diminution of the volume of gas in the retort caused by the fire being checked or dying down; in such case the cloth will be drawn against the pipe



RETORT AND CONDENSER.
(Braun-Knecht-Heimann Co., San Francisco.)

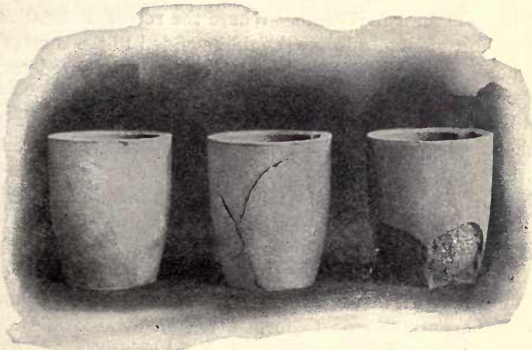
and air drawn through the pores of the cloth, whereas, if the end of the pipe were in the water, the water might ascend into the retort and an explosion result. If the end of the pipe were exposed without the cloth, some volatilized mercury might escape if the condenser was not working properly, endangering salivation.

Retorting will take from 2½ to 5 hours. The fire should be continued for 20 minutes after the mercury ceases to condense in the pipe as ascertained by tapping the pipe and watching for the mercury to drop out. When distillation is complete the fire is withdrawn and the retort allowed to cool. There is always danger of salivation if the retort is opened while hot. It is practically impossible to drive off the last of the mercury and it should not be attempted by raising the heat, as such heat may result in a partial fusion of the gold, causing it to stick to the retort, and is also destructive of the retort. Retorting with an assay furnace or on a blacksmith's forge invariably results in using too high a heat. Where the amount of amalgam to be retorted is large, the oval or cylindrical retorts of large capacity before referred to are used in specially built furnaces. The amalgam is placed in cast-iron trays or separated by partitions of plate iron in these retorts, these trays or plates being well chalked or painted with ashes, lime, or other mixture and well dried to prevent the gold from sticking to them.

If the amalgam has been properly cleaned and retorted, the sponge will show a gold color and require a minimum amount of flux in the melting. Blackness indicates that the amalgam was poorly cleaned. A pale whitish color shows that it still contains mercury, and a bluish color generally indicates the presence of lead, usually babbitt. Retorting should be done in the open, or with the windows of the retort room open, to lessen the danger of being salivated, though there is little danger if proper precautions are taken.

The percentage of metal that is obtained from the amalgam by retorting and melting it into a bar depends upon the amount of impurities in the amalgam, and to a much greater extent on the size of the particles of gold. Coarse gold does not require as much mercury to amalgamate, or cement it, as a fine-grained gold. About 30 to 40% is the usual amount of bullion obtained from the amalgam of ordinary gold. With coarse gold as high as 65% of bullion has been obtained, while with an extremely fine gold the amalgam may run as low as 20% of bullion. This principle is true with respect to the point at which the gold is caught in the amalgamation process. The amalgam taken from the mortar-sand will retort the highest percentage of gold, since only coarse gold is caught there. The amalgam from the foot of the table will retort the lowest percentage of gold, as only very fine gold will reach that point before being caught. Harder squeezing in the canvas does not materially lessen the amount of mercury. The use of sodium amalgam will increase the amount of amalgam by amalgamating the fine iron, steel, and sulphide. In one case, with a fine gold that ordinarily retorted 22% bullion, sodium amalgam was used in starting new plates, resulting in an increased yield from these plates that assayed only 12% fine bullion.

Melting and Sampling Bullion.—Before melting the retorted metal, the black-lead or graphite crucible must be annealed by driving off all the contained moisture, or the sudden heating of this moisture through its expansion and the formation of steam will burst the pot. For this purpose the pot is kept in a warm place, such as under or over a stove or boiler for a week or more, when it is placed directly in the stove or in the boiler fire for some time, being in this way slowly and gradually brought to a very high heat, after which it can be used with safety. Between melts the crucible should be kept in a dry, hot place, for when below 250°F. the crucible tends to absorb moisture, and its life is largely dependent upon the thoroughly annealed condition in which it is used. The pot is placed in the furnace fire and when sufficiently heated to melt the metal, the flux is added. After the flux has become molten, the re-



GRAPHITE CRUCIBLES WITH PINHOLE DUE TO POOR ANNEALING, OR CRACKED OR BURST FROM FAILURE TO ANNEAL.

(Joseph Dixon Crucible Co., Jersey City, N. J.)

torted metal sponge is added in pieces as fast as it melts down until the whole is melted, employing a long scoop or tongs in handling the pieces of gold sponge. The quantity of the flux and its character will depend upon the cleanness of the sponge after retorting and the nature of the impurities. The amount of flux used and the proportions vary with each melter and can be determined only in an empirical way—by knowing the theory of fluxing and then judging the amount and character of the impurities. Should the amount of flux appear too small, as melting proceeds, more can be added at any time, while an excess does no harm, nitre excepted. The pot should be provided with a cover which is kept in place during melting, except when removed for observation or for stirring the melt.

The experienced melter on a clean retorted metal will use little or no flux, while the novice may use, on a somewhat base retort, flux to the amount of 5 or 10% of the metal. The average melter employs borax-glass and bi-carbonate of soda in approximately equal proportions by bulk. The professional melter confines himself largely to borax-glass. The principal impurities to be fluxed off are oxide of iron, sand, and a little sulphur. Borax dissolves the metallic oxides forming borates of the bases; soda acts as a desulphurizer and forms sodium silicates with the sand; together they slag off the impurities and cause the metal to melt down rapidly. It is preferable to use an excess of borax-glass. For taking care of small or medium amounts of iron, in addition to the use of borax, silica may be used to form an iron silicate. Where the retorted metal contains a large amount of iron, sulphur should be added to the surface of the molten metal at the sides of the melting pot, and stirred in with a plumbago stirrer to form a matte of sulphide of iron.

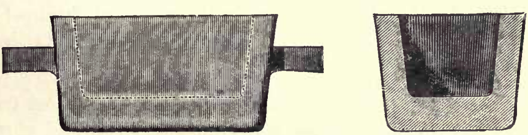
Should the amalgam have contained some sulphide, the molten metal should be 'poled' by allowing a heated iron rod to remain in the pot for a little time to slag off the sulphur as iron-matte (iron-sulphide). If the amalgam contained much metallic iron this 'poling' will not be required. If the quantity of iron sulphide formed is small, it will be dissolved by an excess of slag; if large it will form a matte between the bullion and slag. This matte should be saved and after a quantity from several melts is collected, should be fused with borax and soda to form a button of gold and a bar of clean matte, or should be cast into a bar and shipped.

Nitre (potassium-nitrate) is used to oxidize the base metals that they may pass into the slag, but it also oxidizes the carbon of the crucible while its base—potassium—combines or slags with the clay used in the manufacture of the crucible, corroding it badly, consequently nitre should only be used by the experienced melter. Silica tends to increase the grade of the bullion, but if not used in the right proportion the slag is liable to become viscous and contain shots of gold. An excess of soda makes a liquid slag and one that separates easily from the bar; a large excess can easily be detected in cold slag, especially when slacked or chilled in water, from having the characteristics of soda. An excess of soda will attack the crucible while an excess of borax will not.

A silicious slag—one containing an excess of silica—is stringy, can be pulled into long strings when cooling, and is glassy and brittle when cold. When the slag contains such an excess of silica that it becomes thick and viscous—it will still be stringy—it should be thinned by the addition of soda to unite with the silica as a sodium silicate. A basic slag—one containing less than a normal amount of silica or acid flux—is 'short,' cannot be pulled into strings when melted or cooling, and is dull and stony looking when cold. The slag made in melting retort metal is usually of a very basic nature, borax being relied upon to slag the impurities and thin the charge, but too great an excess of borax will make the slag thick. If the slag is too thick and yet is basic, and it is deemed inadvisable to add more borax, then silica should be added, which may be in the form of fine quartz tailing free from slime, since the slow-settling slime is mainly clay—silicate of alumina—rather than pure silica. The appearance of graphite in the slag indicates that the crucible is being attacked, and usually means that more silica should be added.

For melting an ordinary retort sponge, a small amount of flux consisting of two or three parts by weight of borax-glass and one of soda, and 'poling' with an iron rod, if the amalgam contained much sulphide, is all that will be required in the way of fluxing. After the metal and slag have subsided to a quiet fusion, the mass is stirred with an iron rod that has been previously heated red hot that no gold may adhere, the object being to settle any shots of metal in the slag and to render the gold homogeneous. The crucible is then lifted from the fire by means of suitable tongs and its contents are poured into an iron mould, which has previously been well coated on the inside and heated. The slag rises on top of the metal and may overflow the mould without doing any harm, if it be quite fluid, while the gold by its greater weight or specific gravity sinks down through the molten slag and is retained in the mould. It is improbable that any shots of gold that will not settle while in the furnace will do so after pouring, so all slag from gold melts should be carefully examined for shot gold.

The mould should be smooth and clean on the inside, all rust, old slag, or metal should be removed. It should be given a coating on



BULLION MOULD.
(Braun-Knecht-Heimann Co., San Francisco.)

the inside, preferably of carbon. This may consist of a mixture of lampblack and lubricating oil having the consistence of soft butter. Or it may be a coat of soot given by inverting the mould over burning pitch pine, resin, or oiled waste. Whitewash can be used. Thick oil has been used, but it sputters while pouring and afterward burns with a disagreeable smoke and odor. The purpose of this coating is to prevent the gold from sticking to the sides of the mould and to allow the bar to come out easily. The mould should be well warmed, but not excessively, before being used, that it may not be cracked by the introduction of the hot metal, and that the gold and slag may not be suddenly chilled, interfering with forming a neat smooth bar. The mould is finally leveled that the bar may be of an even thickness. Usually the mould is placed at a right angle to the flow from the melting pot, but a neater, easier pour can be made by setting the length of the mould in the line or direction of the pour. Greater homogeneity can be given the bar for the purpose of sampling by continually moving the entering stream of metal up and down the length of the mould in pouring.

After the gold and slag have cooled sufficiently to become solid, they are dumped out of the mould into a tub or sink of water, which usually causes the slag to separate easily from the gold. The bar is cleaned by knocking and scrubbing off any bits of slag, or by setting back in the melting pot until hot and then plunging it, first into dilute sulphuric acid, and then into water. Nitric acid is also used. If the bar looks very base and dirty, it may be re-melted and refluxed. Two opposite corners are chipped off for assay, or it is bored in from four to eight places with a ⅛-in. drill, rejecting the surface borings; the latter method of sampling is to be preferred. Some use graphite rods for stirring the molten bullion; these are either purchased or are made by cutting a section out of an old or condemned crucible in the shape of the lower part of a golf club. A small hole is bored in the toe of the stirrer. After stirring the bullion, the gold caught in the hole, amounting to half a gram or more, is poured into a basin of water; this is repeated three or four times and the bullion assay made from the granules obtained in this way. A dip sample taken in this way is more accurate than any bar sample.

Recovering Gold from Slag, Old Screens, Etc.—The slag from the meltings, likewise old melting crucibles, are saved and eventually run through the clean-up barrel in a separate charge to recover any shots of gold. The slag can be sent through the battery if there is no clean-up barrel available, but the crucibles should be crushed otherwise and panned, as the graphite is harmful to the plate amalgamation. After this treatment the tailing should be assayed, as it may still contain sufficient gold to warrant shipping to a smelter; it has been cyanided, but with poor extraction.

The wood removed from the mortars, together with old screen-frames, and all wood or canvas likely to contain any amalgam should be burned and the ashes put through the clean-up barrel, or the mortars in lieu of a barrel or pan. The burning is sometimes accomplished in the stove installed for the comfort of the millmen, the ashes of which are regularly emptied into the mortars. This method cannot be used where cyanidation follows because of the tendency of carbon to precipitate gold and silver. The worn-out screens should be thoroughly scrubbed and pounded after being taken from the frames, to remove any amalgam, and then placed in a heap. Shoes and dies and pieces of iron from the mortars should be scrubbed and hammered and the 'eyes' of amalgam in the blow-holes picked out by means of old round files tapered down to a point, finally being consigned to a pile. The fine iron removed from the amalgam should be placed in shallow tubs. The oxidation of these screens and coarse and fine iron and steel should be promoted by occasionally adding salt and frequently wetting with water. After being reduced to rust as far as possible, that material which will enter the clean-up barrel should be ground up in it with a small amount of mercury and finally dropped into water, puddled, and the finer iron removed by a magnet. It may be necessary to re-wash this finer material. The screens and coarse iron receive a thorough scrubbing and pounding before being finally thrown out. Roasting or burning the screens and fine iron is a quick way to loosen the adhering amalgam and to promote oxidation.

PART III

GENERAL

CHAPTER IX

Loss of Gold in Amalgamation and Its Remedies—Sizing and Mill Tests—Sampling—Milling Systems.

Loss of Gold in Amalgamation and Its Remedies.—The loss of gold in amalgamation may be due to:

1. Free gold included in or surrounded by the gangue rock.
2. Gold that is chemically combined in the tellurides or mechanically enclosed in the sulphides.
3. 'Float' gold that is carried along on top of or suspended in the pulp, and which does not come in contact with the amalgamated plate.
4. 'Rusty' or coated gold.
5. 'Overstamping.'
6. Poor amalgamation due to the methods in use.
7. Poor amalgamation due to deleterious substances in the ore.

First: If the loss is in the free gold included in or surrounded by the gangue rock, a sizing test will reveal it by the higher value of the coarser sands. In some cases the coarser sands can be crushed finer in a hand mortar and panned to show a 'prospect' of free gold. The correction for this is to crush finer, not the ore in general, but these coarser grains. This crushing is better accomplished by using a finer screen with the same or a lower height of discharge. Running two batteries with different size screens in competition with each other and comparing the tailing assays will determine in an empirical way, but sizing tests in connection with this is necessary for a true diagnosis of the conditions.

Second: Gold in association with tellurium is chemically combined and can only be saved by cyanidation along special lines, by chlorination, or by smelting, and rarely by concentration.

Gold in the sulphides is mainly in a free state, finely divided, and mechanically held by the sulphides. This gold is usually saved by concentration, and in some cases by cyanidation of the tailing without concentration. However, a part of it can be amalgamated, as in the Gilpin County practice, by the use of a wide mortar, deep discharge, long and slow drop, and an attempt to catch the gold inside the mortar. Here the sulphide because of its higher specific gravity sinks to the bottom and is held longer in the mortar than the balance of the pulp, allowing the gold to be liberated by the thorough sliming of the sulphide, and to be brought in long contact with the mercury and inside plates. This process has had slight application outside of the locality mentioned, where it was necessitated by a large proportion of the gold being contained in the sulphide that was of too low a grade to ship and smelt profitably. Part of the loss in the tailing may be due to sulphide crushed so fine (slimed) that it cannot be caught on the concentrators; this will be considered under 'Overstamping.' The amalgamation of the gold in the sulphide has been accomplished by grinding it in amalgamating pans, tube-mills, or arrastres, but the extraction has never been high, so that it is now preferable to cyanide it if it contains no interfering elements, or to ship it to the smelters. However, there are local conditions or peculiarities of the metallurgical practice under which it may be highly advisable to reduce the value of the sulphide to be shipped, smelted, or cyanided by preliminary fine grinding and amalgamation. And this question should be thoroughly investigated, both in existing plants and in designing new plants.

Third: 'Float' gold really refers to that gold which occurs in flakes so light and thin that it is floated along on the surface of the pulp, perhaps buoyed up by a bubble of air; but in most cases it will be found to be gold so fine that it is carried suspended in the pulp and gets no opportunity to come in contact with the amalgamated plate. When an ore containing visible gold is pounded up in a hand mortar and panned, the gold is found to be pounded into scales or into infinitesimal bits, depending on the nature of the gold. It is doubtful if much gold is overstamped to an extent producing scales so thin that they will float on the surface of water like gold-leaf, although such gold has been found in both mills and placers; but it can be understood that gold which is powdered fine may be carried along in the pulp clear of the plates, though it really does not float. The loss attributed in a tentative way to float gold is found by assaying the flocculent slime of the tailing. Should this show a value as high or higher than the sand, it would indicate overstamping, and adjustments calculated to prevent this should be made. A part of the value lost in the tailing and assigned to float gold is in the slimed sulphide, but only a part of the loss can be rightly ascribed to this.

Perhaps the easiest explanation is to say that the loss consists of gold, sulphide, and amalgam in microscopic particles, which is both coated with slime to an extent that prevents it from amalgamating and is held suspended in the pulp by the slime. Increasing the grade of the plates and using as little water as possible in the mortar to secure a better wave motion and contact between the pulp and the plates, together with making the plates longer and keeping them covered with a bed of soft amalgam, will aid in saving more of the fine and float gold. If the battery water is being re-used it should be well settled, for as the water or pulp becomes thicker and more slimy it will carry off more of this light gold. Patent amalgamators for catching this kind of gold should be tried. It is practically impossible to determine the form or condition of the gold in the slime where the amalgamation and concentration has been capably done, or to hope to promote any further extraction by laboratory and amalgamation tests; reliance must be placed on less sliming and on cyanidation.

Fourth: 'Rusty' gold is free gold covered with a film of some substance other than air or the gangue rock in which it is contained. This may be due to an oily or greasy mineral peculiar to the ore, like graphite; to an oxide of iron or copper, or to other compounds of the base metals; to silicates of magnesia or alumina; or to slime arising from crushing the ore. This film prevents the gold from coming in direct contact with the mercury. Gold to amalgamate must be clean, so that it may be readily wetted by the quicksilver. When gold is dirty, rusty, or coated, and the contaminating material does not amalgamate with quicksilver, then the quicksilver through its surface tension is negative and strongly repellant of the contaminating material and its more or less enclosed golden grain. Rusty gold can sometimes be detected by panning the tailing and examining the concentrate with a microscope. This gold should be caught by the concentrators, or in the cyanide plant if not too coarse, also by the use of riffles or blanket tables. To amalgamate this gold it must be made clean by being scoured. This can be done by using a high discharge, preferably with a coarser screen and a narrow mortar that the tendency to overstamp may be reduced. With a low-discharge, rapid-crushing mortar, the ore is in the mortar an average of four or five minutes, this length of time can be doubled or trebled by increasing the height of discharge, so that the particles of gold, especially the heavier ones, are subjected to the scouring and attrition of the stamp and the pulp for an increased length of time. Sodium amalgam in the mercury should be tried. If any of this gold is retained in the traps, they should be cleaned often, perhaps at each plate dressing, the sand being ground in the clean-up barrel with some additional mercury, to scour and amalgamate this gold. Theoretically, coarse crushing in the mortar followed by regrinding and amalgamating in a pan or roller mill should be successful. It is considered that the pan amalgamator will amalgamate gold that no other method of amalgamation will save.

Fifth: 'Overstamping' is holding the pulp longer in the mortar subject to the action of the stamps than is necessary, thereby pulverizing it finer than is required or is beneficial. While the capacity is reduced, the term properly has no reference to that, but to the treatment the ore receives causing it to give a reduced extraction. Experiments have shown that a hammered gold is not readily amalgamable, and further experiments tend to prove this to be due to the gold being covered with a film of dirt and grease in the process of hammering, which, in connection with its increased density, does not allow it to be so easily wetted by the mercury. As has been observed under float gold, it is improbable that much gold which can be hammered into a scale is rendered non-amalgamable by stamping in the mortar, especially in the presence of mercury; while there is no doubt that gold in the allotropic form of being brittle can be stamped so fine that it is hard to catch in the mortar or on the plates, particularly if it is covered with slime. The danger of overstamping is augmented with increase in the grade and percentage of the sulphide. The Gilpin County practice is an ideal illustration of overstamping sulphide.

As to whether the ore is being overstamped or not is judged from the sizing-test assays taken in connection with the tonnage and operating expenses. If the assays of the slime and fine sands closely approach or are higher than those of the coarser sands, adjustments should be made that will reduce the percentage of fine material in favor of a higher tonnage. If it is an actual case of overstamping, resulting in the gold being rendered less amalgamable by being hammered, broken up, or coated with a film, or the sulphide being slimed, the proper change of adjustments should reduce the assays of the slime and finer sands. The changes of adjustment have one object in view—to get the pulp out of the mortar as quickly as possible after having been crushed to the proper size to liberate the gold and sulphide from their matrix.

Sixth: Poor amalgamation, due to the methods in use, may be caused by the following: To keeping the amalgam so hard that it becomes crystalline and breaks away, or that it reduces the tendency of the gold to catch. To keeping the plates so wet that the mercury and amalgam run down into the trap. To the gold not catching due to stains, bare spots, plates cleaned too close, too much water used, or too small a plate area. To loss of amalgam by not removing or bedding down the crumbs when dressing the plates. To use of impure mercury. To grease falling into the mortar and contaminating the plates. In fact, to bad practice in any of the various details connected with amalgamating.

Seventh: Poor amalgamation due to deleterious substances in the ore does not often occur. Arsenical and antimonial ores are the worst offenders in this regard. They tend to foul the mercury and amalgam, coating it with a film of the slimed material so that the mercury does not readily amalgamate with the gold, but is sickened and a large part of it lost. This trouble is liable to occur to some extent with any base and heavily sulphureted ore. The principal remedy where the loss of mercury is great, is to practise outside amalgamation; though in cases where the outside plates become coated and fouled, it may be necessary to attempt to catch and hold the gold within the mortar. Crushing in cyanide solution may assist the amalgamation in so far as the cyanide solution will tend to keep the mercury and amalgam in better condition. Clayey, talcose, and other slimy ores sometimes give trouble in a similar way, or by coating the gold.

Sizing and Mill Tests.—In making mill tests two batteries should be selected that receive a feed as nearly identical as possible. Comparative tests should be made simultaneously with the different adjustments. Sizing of the tailing samples from these two batteries should exhibit the characteristics of the ore under the different treatments. These tests may be conducted in the following manner. Each tailing sample, understood to have been carefully taken and in every way representative, is drained of its settled water, dried, and thoroughly mixed. A quantity of from 30 to 60 oz. is removed for the sizing test, a 'head' assay sample is also taken. All assays should be made in duplicate. The sizing sample is panned and repanned until all the concentrate is removed, this concentrate to be examined for rusty gold and amalgam. The sample together with the water used in panning is now thoroughly stirred, and after settling for a moment, the slimy water is poured off, care being exercised that no sand passes over with it. More water is added to the sand and the process repeated again and again until only the granular sand remains and the water contains slime that is a true flocculent slime, one that is light and feathery, that agglomerates, that does not readily settle in water, and that makes water muddy, in contra-distinction to sharp, granular sand which readily settles and does not make water muddy. The sand is sized, either before or after drying, into a coarse, medium, and fine sand.

The testing screens should be shaken or tapped to the same extent in obtaining each size and in each test, for continued shaking results in working more ore through the screen and thus making the results more variable and of less value for comparison; also, a single set of screens should be used, for there is liable to be a marked variation in the openings of two screens labeled as of the same mesh. Where comparative tests are not being made on two batteries, a fourth size, an extra coarse sand, should be made. Thus, when crushing through a 30-mesh screen, by making an extra coarse size out of that held on a 40-mesh screen, we may be able to judge how the ore held on it will act when crushed to pass through a 40-mesh screen. The sand, slime, and concentrate are now dried, weighed, and assayed, after which the results may be tabulated. The following is taken from a note book, and is an actual test made on a small lot of tailing that was dried before being weighed for the sizing test:

MILL TEST, G—— MINE. NOV. 7, '05.

(No. 35 brass wire screen. 5-in. discharge. Head assay, $1.30. Weight taken, 600 grams.)

Size.	Weight: Grams.	Weight: Per cent.	Assay value.	Value of this size in 1 ton of tailing.
Held on 40 mesh	80	13.4	$1.40	$0.19
Held on 60 mesh	93	15.7	1.40	0.22
Held on 100 mesh	77	13.0	1.40	0.18
Passed 100 mesh	112	18.9	1.20	0.23
Flocculent slime	232	39.0	1.00	0.39
Concentrate	none found			
	594	100.0		$1.21

The deductions from the above test are that the concentration is perfect, but that the ore is being crushed too fine for the purpose of economic amalgamation, since the assay of the slime is comparatively high and the quantity abnormally large, while the coarse sand, that held on '40-mesh,' assays no more than the finer sand.

The results of a single sizing test should not be taken as conclusive, but a series made. The capacity may be obtained by catching the pulp in a tub or barrel for a certain length of time and weighing the dry pulp. Where cyanidation follows amalgamation and concentration, the adjustments of the battery will be determined by the sizing tests of the cyanided tailing, which indicate how fine the ore should be crushed to get the maximum extraction by the cyanide solution.

Generally too little attention is given to testing and studying an ore before erecting a mill, though the stamp-battery, thanks to its wide range of adaptability, can invariably be made to do satisfactory work, consequently the change, if any, usually takes place in the concentrating and cyaniding departments. The usual procedure is to take a sample of the ore which is seldom representative of the run-of-mine ore. This ore will probably come from a dump, or near the surface, and be an oxidized ore, while the assay value will be high. After making a trial run at a testing works, a mill will be ordered by the directors of the company, the details of the mill being left to the machinery supply house. The mill-site may be selected and the mill designed by a man who has had little or no experience in milling. Finally, the mill is completed and turned over to the millman who must then spend considerable time in changing and rearranging. It is incomprehensible why mining companies so seldom employ competent metallurgists, independent of machinery supply houses and special process companies, to examine the ores of their mines and to design and build a mill suited to those particular ores and conditions. The cost and loss of time in changing, rearranging, and providing for those things that have been overlooked would pay for the metallurgist, to say nothing of the daily saving that may be effected in a properly designed mill. Such a man should more than save the expense of his fee by knowing what, how, and where to buy.

The metallurgist should himself take representative samples of the different ores and make laboratory tests in amalgamation, concentration, and cyanidation, together with sizing tests, that he may thoroughly understand the ore.* For making amalgamation tests two methods can be followed. The first is to place six or eigh assay tons of the ore crushed to the desired mesh in a large glass bottle with sufficient water to make a thin pulp, adding ½ oz. of mercury. The pulp is rolled around in the bottle, is lightly shaken, and is given a panning motion for some time, that all the free gold may be amalgamated. The contents are finally washed out of the bottle, panned, and repanned until the amalgam is separated from the pulp, when the tailing is dried and assayed; the difference between the head and tailing assay representing the amount amalgamated. If mercury that contains no gold has been used in this test, the gold in the amalgam can be determined and the amount amalgamated ascertained in this way. The amount of gold is found by boiling the amalgam in dilute nitric acid until only the pure gold remains, when it can be washed, dried, annealed, and weighed as

*Testing ore by cyanidation is fully described in the chapter on 'Ore Testing and Physical Determinations in the Author's 'Textbook of Cyanide Practice.'

usual in the gold assay; or the amalgam may have the mercury driven off by heating it in the open where there is no danger of salivation, and cupelling the resulting sponge. Mercury entirely free from gold can seldom be obtained, but can easily be prepared by dissolving it in dilute nitric acid, when the gold remains undissolved and can be filtered off, while the mercury can be precipitated by suspending a piece of copper in the solution.

A better method of making an amalgamation test is to work the ore as a thin pulp in a gold pan having an amalgamated bottom, assaying before and after treatment; the pan being used at the same time to separate any sulphide present. Laboratory amalgamation tests, as a rule, will not give as high an extraction as will be obtained in actual mill practice. This may be due to the fact that in preparing ore for such a test, it is screened frequently, resulting in an evenly sized material, whereas in actual practice a large proportion is crushed much finer and should give a higher extraction. It is also possible that the dry crushing may coat the gold with dirt or slime so that to some extent it resists amalgamation.

In cyanide practice it is possible in nearly every case to determine by laboratory tests the extent to which the gold can be dissolved, and the metallurgist can be required to closely approximate this in the actual work. But in amalgamation by small tests it is impossible to determine with any close approximation the maximum amount of gold that can be amalgamated. Therefore the ability of the millman and the thoroughness with which the amalgamation is being accomplished must be judged from the results attained in actual practice.

The points it will be necessary for the metallurgist to know are: What percentage of the gold will amalgamate under ordinary crushing, and what increased extraction can be obtained by regrinding and amalgamating a second time. What percentage of concentrate there is in the ore, its nature, value per ton, and amenability to cyanide or other treatment. What extraction can be secured from the ore on the plates, on the concentrators, and from the tailing by cyaniding with coarse, medium, and sliming crushing. Also the nature, occurrence, and condition of the gold in the ore. Making tests with a few pounds of ore has been decried, but while such small tests are not conclusive, they are a reliable guide when the sample represents the ore fairly and the tests are conducted by a metallurgist experienced in the processes. They will enable a system of treatment to be outlined that should be tried out by treating a few tons of the different classes of ore at a testing works under the personal direction of the metallurgist, and with the same devices as those to be installed.

One of the main reasons why a 'mill run' should be made with the same devices as those to be installed in the mill, is that no laboratory crushing can exactly duplicate the product obtained from various kinds of mills. For instance, the comparatively clean, angular, unslimed particle of gold or sulphide liberated by the stamp, and the slimed, ragged, flaky product of the tube-mill when operated for the purpose of sliming—the first so essential in amalgamation and concentration, the other so desirable in the cyanidation of certain material. Chemical laboratory tests, such as by cyanidation, may be relied upon to quite an extent, even when made on a small scale. But where the process is mainly a mechanical one, mill tests are necessary to furnish the essential mechanical hints and to indicate if a difference in the crushing will make any difference in the final results. Yet small scale mechanical tests will furnish many valuable ideas to one whose familiarity with the process is both in the mill and the laboratory.

The extent to which the testing should be carried varies with the nature of the ore and largely with the degree to which the metallurgy of similar ores in that locality has been worked out. There are some districts where it seems hardly necessary to test the ore for a process, such as the Mother Lode of California. There are other districts, however, where the working out of a successful treatment system seems to almost require a full-size mill operating under the actual working conditions, such as was seen in the case of the silver ores of the Tonopah district of Nevada.

Sampling.—The taking of mill samples should be done as automatically as possible. A sample of the battery feed taken by picking it by hand from the revolving plate of the feeder is unreliable on account of taking too large a proportion of the coarse ore. The sizing of a battery-feed sample through a quarter or half-inch-mesh screen will usually show that the fine material assays three or four times as much as the coarse, and may, in some rare instances, show the reverse. A long tin trough or scoop that can be placed beneath the revolving plate and catch all of the ore as it drops from the feeder will give a very good sample when taken hourly or half-hourly, especially if the fine and coarse ore are well mixed in the bin. Where outside amalgamation is practised, the sample of the battery feed is obtained in front of the mortar just before the pulp strikes the plate.

The tailing sample should be taken automatically by a device for that purpose, and the millman should be under instructions not to put it out of use during the period of dressing the plates. The millman fears that loose amalgam will be washed away to 'salt' the sample; but if amalgam to this extent is being lost, immediate steps to prevent it should be taken. Where the samples are taken by hand they are liable to become 'picked' samples, as, for instance, where the concentrator man carefully adjusts each machine before taking the tailing sample. For catching the tailing sample from an automatic sampler, the usual gasoline can may be used with a light tin pipe 3 or 4 inches in diameter, fastened to a few pieces of wood which allow it to rest on the can with its bottom end projecting into the can. The pulp flows into the can through this pipe, and when the can is full the clear water commences to overflow without any attention from the man in charge, who finds the pulp well settled when he comes to remove the sample.

Milling Systems.—Where gold will amalgamate to the extent of 20% or more, amalgamation, preferably in water, may be practised. If the ore will not amalgamate to this extent and requires cyanide treatment, amalgamation had better be dispensed with unless some of the amalgamable gold is coarse and escapes the cyanide plant through the inability of cyanide solution to dissolve coarse gold. The coarse gold in an ore that is finely ground in cyanide solution by a tube-mill can be expected to be ground so fine that none will escape the cyanide plant without being dissolved.

Crushing in cyanide solution is a great aid to cyaniding, as the ore is brought promptly into contact with the solution, and under conditions that cause the precious metals to go into solution quickly, thus requiring less tankage for dissolving the gold. It also permits using a certain amount of water in washing the dissolved gold and silver out of the pulp to compensate for the moisture discharged in the tailing. This makes a saving in the amount of cyanide mechanically lost, and in practice also effects a saving in the amount of dissolved gold mechanically lost. Crushing in solution has its disadvantages in that the solution throughout the mill is carrying quite an amount of gold; and a little of this solution is constantly being lost, even in well designed mills, by the leakages, overflows, accidents, and otherwise. There is an abnormally large volume of solution to be cared for, pumped, and precipitated, which makes a material increase in the costs per ton of ore treated. Another disadvantage of crushing in cyanide solution in a mill where amalgamation is being practised, is that a part of the gold goes into solution which would be amalgamated if the crushing was done in water. If this gold was amalgamated, practically all of it would be returned, but by going into solution the proportion returned is lessened, both through the losses above referred to, and through the indifferent washings of the filtering devices used. The amount of gold going into solution that could otherwise be obtained by amalgamating in water will vary with the size of the particles of gold; thus with an extremely fine gold crushed in strong cyanide solution as much as one-third or one-half of the amalgamable gold may be dissolved so quickly that it cannot be amalgamated. In such a case it is inadvisable to crush in cyanide solution. Where the gold is coarse and but little of the amalgamable gold enters the solution, crushing in solution may be advisable, depending on the character of the cyanide plant and the perfection of its operation in gathering all of the dissolvable precious metal into the clean-up.

Where the sulphide is amenable to cyanide treatment and is small in amount or low in value, it may be expedient to cyanide it with the sand without concentration, offsetting the decreased extraction from this sulphide by the lessened cost of treatment. At one prominent property operating along this line, a high discharge is used to retain the sulphide longer in the mortar, that it may give a higher extraction in the cyanide plant through being crushed fine, while a large amount of water is used in the mortar to increase the tonnage and thus compensate for the decrease due to the high discharge.

Economic problems must be studied when considering amalgamation and cyanidation. With a small mill of 10 or 20 stamps obtaining a good extraction by amalgamation and concentration, it may not be advisable to put in a cyanide plant taking the pulp directly, on account of the high cost per ton of capacity for installing and operating a small plant of this type. It may be better to run the tailing into a pond and later put in, at less tonnage expense, a leaching plant of large capacity. With a pulp crushed through a 30 or 40-mesh screen and properly impounded, it is possible to extract practically all of the dissolvable gold and silver. In a country of average working costs, an impounded tailing having a value of 80c. per ton and giving an extraction of 80% will return a good margin of profit. As the plate or concentrator tailing becomes higher, the necessity for a plant to treat it directly increases, since the tailing pond will hold a large amount of money that is not available, and there is a loss from the sand blown away and an occasional breaking of the dam. A tailing pond is sometimes a desirable thing to a manager, or promoter, as when it figures prominently—too prominently usually—in the report of the assets and possibilities of the company's property. Regrinding of the pulp followed by amalgamation (secondary amalgamation) may reduce the value of the tailing to a point so low that it may not be profitable to cyanide it, and this point should be looked into when making the tests preliminary to designing the mill. For this purpose some form of grinding pan, a Chilean mill, or the slow-speed roller mill, that will admit of amalgamation within the mill, may be recommended. The tube-mill has been found the most satisfactory machine for fine-grinding for cyanidation. It was formerly considered a poor machine for amalgamating purposes, since any mercury fed to it, as well as the gold which is liberated, is supposed to come out thoroughly slimed. But this idea is passing away, for excellent outside amalgamation can be effected after the tube-mill, as due to the fineness of the pulp, a beautifully thin flow can be had over the plates. When crushing in cyanide solution the grinding and sliming action within the mill causes so much of the gold to go into solution that it is usually not worth while to try amalgamation afterward.

From a theoretical standpoint it would appear that where amalgamation or concentration is to follow the tube-mill, the mill should be run at a speed that will cause the balls to be carried part way around and to crush by their falling impact, rather than the slower rate of speed whereby comminution is effected by the attrition or rolling and grinding of the pebbles alone. The first is a case of cracking open the grains and liberating the gold or sulphide as a relatively large angular particle susceptible of easy amalgamation or concentration, whereas the second results in the scaly, impalpable, unmanageable slime produced by attrition. The first is illustrative of the principle of the stamp, the second that of the grinding mill. An appreciation of these principles will lead to a better understanding of the reason for the supremacy of the stamp-mill.

Within recent years fine-grinding and 'all-sliming,' invariably connected with crushing in solution, have rapidly come into vogue. In most cases it has been advisable, but in many instances these methods have been employed because it has been the fad, or because filtering devices were installed that required them. This is clearly wrong. Fine-grinding should not be carried beyond the economic point. The cost of finer comminution increases rapidly, whether by stamp, Chilean mill, tube-mill, or other device. The degree of fineness that will give the highest extraction in the laboratory is not necessarily the one that will give the most profit. The milling and cyaniding machinery should be susceptible of adaptation to the economic requirements, and the millman or metallurgist should possess the ability to find them.

It may be given as a rule of broad application that the higher the grade of the ore and the baser it is toward amalgamation, the better adapted it is for all-sliming and crushing in solution; while the lower the grade and the less base it is toward amalgamation, the less adapted it will be to those methods. For as the grade of ore increases the percentage of extraction will also increase somewhat, but the value of the tailing in dollars and cents will likewise increase. Finer grinding will reduce the amount in the tailing, at least when cyanidation is used; but as the ore becomes lower in grade the additional amount won from the ore by finer grinding rapidly grows less until it is overbalanced by the increased cost of finer grinding. It is an open question as to whether crushing in solution decreases the working costs per ton, but we will suppose a case in which it does and in which cyanidation is necessary. At first sight it would appear best to dispense with amalgamation and catch the gold by one process only—that of cyanidation—but the cost of amalgamating and the almost negligible loss of gold in amalgamating varies but slightly with the amount of gold amalgamated per ton; whereas the working costs per ton by cyanidation increase as more gold is dissolved per ton, because of the more elaborate equipment required in the attempt to obtain all the dissolved gold, also because the mechanical loss of gold grows greater as the amount dissolved per ton of ore increases. Thus it follows that as the amount that can be amalgamated increases, the advisability of crushing in solution decreases. The correctness of this principle is indicated by the reversion from attempting to remove the dissolved gold from the ore solely by filter washing, to the method of separating as much gold as possible from the ore by preliminary decantations before sending the pulp to the filter for final washing. What better method than amalgamation is there for reducing the value of the pulp going to the filter, and lessening the mechanical loss and perhaps the working costs throughout the whole process of cyanidation?

It is a fact that crushing in solution has been generally unsatisfactory on low-grade ore, and there do not appear to be any plants operating under such conditions today—or at least any that are widely known outside of the Black Hills, yet there are many plants employing final cyanidation on low-grade ore. The question now comes, if crushing in solution has to give way to other methods on low-grade ore, why are not these other methods more economical on higher grade ore? Various factors enter into the consideration of this matter, but the principal reason why no satisfactory answer has yet been made appears to be that the metallurgists who should give us the answer are too busy boosting special processes in which they are interested.

There have been a number of mills built to employ these methods which have not proved successful. These have usually been small mills, either not elaborately and carefully designed or embodying some rather new and untried devices. The best way to handle these 'novelty mills' is to go back to proved methods. Crush in water and amalgamate, following with regrinding and secondary amalgamation. Get all that can possibly be obtained by amalgamation, for that will be 'absolute,' at least in so far that loss of amalgamable gold cannot be detected after the careful amalgamator, except by the 'eyes' of amalgam appearing in the tailing flume. Then take the tailing to the cyanide plant and do the best that can be done with the machinery available.

The idea should be borne in mind in designing and erecting and in starting a new mill; the arrangements should be such that the crushing may be done either in water or solution, and it is generally wise to start crushing in water and effect the change to crushing in solution after the metallurgical system and the mill equipment have been tried out.

In general, mills should be designed and built along tried and proved lines, for then it can be foretold with confidence just what the mill will accomplish, especially in a mechanical way. Thus the successful experience of others can be utilized, and should some unlooked for difficulty arise, precedents will be at hand for solving it. Such a mill can be started without a long and costly siege of loss of time, worry, experiments, and alterations, and new employees will require little coaching. Science is the accumulated knowledge of the ages from which the errors have been removed, the rough places straightened out, the shoals marked, and the principles made clear. He who follows in its footsteps can expect a fair measure of success, but he who throws his fortunes with what science and practice have not yet indicated as safe, has left the lighted way and may expect a hard path and usually disaster. Scientific mill designing consists in following the lighted way, and if this does not promise a sufficient measure of success, then surely the untried way is one of danger. To be more concrete, scientific mill designing and operation consists in three things: First, thoroughly testing the ore until all necessary information is obtained. Second, designing and building a mill which embodies those ideas and those particular devices which practice linked with science have indicated to be the most reliable and advantageous for each particular part and purpose. Third, after the mill has been placed in successful operation along conservative lines, experimenting and testing with various machines, devices, and expedients—the original design of the mill to include the idea of facilitating this—to increase tonnage and extraction and to decrease costs. The first two will insure a successful mill. The last will greatly prolong the life of the mine, for a consideration of the mines famous for long and continuous production will show that they are operating on low-grade ore with a remarkably small margin of profit per ton, and a margin due to a scientific reduction of costs and increase of extraction begun while the mine was in good ore.

One of the later ideas in stamp-milling has been to employ Chilean mills as intermediate grinders following stamps. This is with the viewpoint that the tube-mill finds its greatest efficiency in reducing 30 or 40-mesh material to 200-mesh, the Chilean mill in medium grinding, and the stamp in coarse crushing. With this idea it has been proposed to use heavy stamps crushing through a 4 to 12-mesh screen, delivering to Chilean mills grinding through a 30 or 40-mesh screen to tube-mills sliming to the desired fineness. However, there has come contemporaneously with this idea a rapid increase in the weight of stamps and a development of tube-milling to cover a wider range. As a result it is recognized that stamps harnessed to tube-mills make a combination crushing by impact that is so efficient that the introduction of intermediate grinding mills is inadvisable. The Chilean mill has been used in this way to increase or double the capacity of existing mills without erecting more ore-bins and stamps, by being placed after the stamps or between them and the tube-mills. The same result can be effected by adding more tube-mills.

CHAPTER X

Millmen and Mill Crews—Mill Management—Handling Pulp and Tailing.

Millmen and Mill Crews.—The men who are in charge of stamp-mills are almost invariably good mill mechanics, a large part have graduated out of machine shops, and even the least of them are first-class 'monkey-wrench' machinists, but only a small part are metallurgists. The methods of many of them are those that they were taught, and these methods they apply to all conditions with but little variation. This lack of ability to initiate experiments, to test, to devise new methods, and to progress, has hampered the advancement of the stamp-mill process. It is seen in the tenacity with which they cling to the old-time idea of saving the maximum amount of gold in the mortar, when the same and in some cases a higher saving could be obtained by giving the stamp-battery a chance to perform its proper function—to prepare the ore for amalgamation, rather than to amalgamate it. Wherever the millmen have forsaken the well-beaten path of trying to save all the gold possible in the mortar, the tonnage has increased and ease of operation has been promoted. "Catch the gold as soon as you can—catch it inside the mortar," is a good old maxim, but the slogan of the millman should be, "Down with the tailing and up with the tonnage," and not, "Increase the inside catchment—keep it up to 60 or 80 or 95%." The millman should understand adjusting the mill to the peculiar requirements of the ore, that he may be able intelligently to put his slogan into actual practice. He should also be able to determine the point where a higher tonnage ceases to be desirable by reason of resulting in too high a tailing, the economic limit having been reached.

The millman should have, in addition to training in large and small mills in various localities, and in mechanical work dealing in a general way with the setting up, operating, and repairing of machinery, with carpentering, pipe fitting, and construction work, a short training in assaying and ore-testing, and some study—home study if nothing more—in chemistry and mechanical and constructive drawing. In view of the wide application of electricity as the motive power for mills, the millman should understand the use and care of alternating-current machinery. While it is not expected that he should be able to set up transformers or connect the windings of motors, he should understand more than merely to start the motor according to the printed directions.

Much has been written and said about the honesty of mill employees. One of the principal arguments advanced for dispensing with amalgamation and centralizing the recovery of gold in the cyanide plant, is that it will prevent loss of amalgam by theft. It has been the fortune of the writer to have worked and associated with many millmen in various parts of the country, and to have come in contact with them on an equal footing and under conditions whereby their character could be best studied, and he has not known of a case of amalgam theft or a suspicion of such, except by report.

There are two reasons why so little thieving occurs, despite the fact that amalgam stealing appears easy and safe. The first is the *esprit de corps,* or loyalty to the profession, which is as strong in the millman as in any other calling. The second is that the amalgam or bullion is viewed by the millman as so much merchandise which he is accumulating for his employer, just as he is saving the sulphide in the concentrating department. It is an actual fact that millmen who may 'high grade' when working in the mine, or on the rock-breaker, will take no amalgam from the mill and nothing more than a specimen from the feeders.

The danger of amalgam theft lies in putting a green man of unknown character in a mill as helper, or temporarily on clean-up day. Also in the employment of a so-called millman who is only following milling until he can find an easier way for getting the living that 'the world owes him.' Outside of the above two, the danger does not lie mainly with the professional mill employee, but with the dishonest manager, superintendent, or confidential man who does the melting, and who may have a private ingot mold of his own to fill.

In late years a new class of stamp-mill superintendents has arisen; these are the cyanide metallurgists, who, as milling and cyaniding operations are becoming more closely linked together, are taking both operations in charge. Where the work is carried out in conjunction, this is a step in the right direction, but one in advance of the supply, for it is difficult to find men who have a thorough experience in stamp-milling, amalgamation, and cyanidation, mechanically as well as metallurgically. In the extended acquaintanceship of the writer there is only one past master of stamp-milling, amalgamation, and cyanidation, who is able to direct and instruct his subordinates in every detail.

The tendency of these new mill superintendents who have little or no training in stamp-milling and amalgamation, is to put too much stress on the cyanide branch. These are the men who would grind all the ore so that the precious metal would be extracted by cyanide solution, disregarding the fact that if a grain of gold is caught on the plates, practically 100% of it is recovered; whereas, if it goes to the cyanide plant, a little of it is lost through the various wastes of solution, the cleaning up, and through the imperfect washings of the filters used.

The stamp-battery, to do good work, requires to be in the hands of a man who is in immediate charge of it, one who is a good millman and a strict disciplinarian, a crank on having everything done right and kept in condition, stopping just short of the point where the details to be carried out become idealistic rather than practical and beneficial. The average competent mill employee prefers to work under these conditions, rather than where no system prevails and everything is racked to pieces so that he must constantly keep a sharp outlook for trouble and be continually repairing. The placing of a stamp-battery in charge of a master mechanic who is not an experienced millman and whose attention is elsewhere most of the time, is just as serious a mistake as to consign it to the mercy of the different shifts of employees, all of whom are equally responsible and acting without a directing head. A man may be a first-class millwright and machinist and still be unsuited by lack of experience to take charge of a mill. A mistake is made in placing a man in charge of a stamp-battery whose experience has been superficial, no matter how competent he may appear; the result of such error is that the mill gradually wrecks itself until it becomes so badly racked and worn and generally broken down that it is a nightmare for a millman of long experience to work in it. The stamp-battery is such a simple machine that an observing man can learn to operate it under instruction in a short time, but being ponderous machinery subjected constantly to jar, tremendous vibration, and high tension, to insure long life and good health it must have a man in charge who can promptly recognize its symptoms of trouble and at once apply the proper remedies. From experience and observation it can be stated positively that it is a wise procedure to employ only the highest class of millmen, even if highly priced, for such men increase tonnage and extraction, lessen the cost for repairs, and prolong the life of the mill far more than is generally known.

A few words may be added for the novice just entering stamp-mill work. Owing to the noise that forbids all conversation except that absolutely necessary, the apprentice must learn largely from observation rather than by direct instruction. Careful, minute, and concentrated observation is the first step, for stamp-milling has become a highly developed craft in which some construction can be placed or some fact read in details so small that they can hardly be observed by the inexperienced man. By close observation and thoughtful consideration the apprentice is able to observe these details and interpret their meaning, so that in a short time his attention becomes subconscious and therefore no longer forced. He learns to wear engineer's coats or 'jumpers' worn as a shirt, or other tight-fitting clothes that offer no loose ends to be caught by belts and machinery; to use methods that are not unnecessarily dangerous to life and limb in putting belts off and on, hanging up stamps, setting tappets, and working on the stamps; to never drop a stamp until he is sure that no one at the mortar below will be caught or injured by it, etc. The millman operates his mill largely by sight and sound. As he walks by the stamps, even though at some distance and with his attention preoccupied, he notes any stamp that is dropping too hard or that is too much cushioned; a stem that has pulled out of its boss, or has lost its shoe, or is dropping on a piece of steel that has inadvertently fallen into the mortar; a motar that is running empty; the coarse oversize due to a break in a screen; or any of the details that may need remedying. Amid the awful roar he is able to differentiate the sound of improperly working parts from those working properly. If, while he is in a distant part of the mill shoveling ore in an almost empty bin, working in the clean-up room, or talking to a friend outside the mill door, a stamp breaks, pulls out, or commences to fall on a piece of vagrant steel, a tappet begins to cam, or a mortar to run empty, his trained subconscious mind recognizes the peculiar jangle, or steady clap-clap, or muffled hollow roar, and before he realizes it he is started and perhaps half way across the mill on his way to the seat of trouble, though as a mill becomes racked and worn from poor condition and ill use it becomes more difficult to run by sound. As the steam engineer judges the condition his engine is in by its movement and sound, so does the millman judge his mill; but unfortunately, the fact that the stamp-mill will stand ill use and abuse as well as answer to the refined control of a master hand has led many to consider the stamp-battery as a relic of medievalism, fit only to be presided over by a low-browed, strong-armed giant equipped with a sledge-hammer and an inexhaustible stock of profanity and endurance.

The crew of a 10-stamp mill having concentrators will be composed of one man per shift. The man on the day shift will be in charge and assisted by the man who tends the rock-breaker. A

20-stamp mill with concentrators has been run by the same size crew, but the work is so strenuous that men will not long remain and the company suffers a direct loss during their stay from poor work, especially in the concentration. One batteryman per shift with a head millman can run 40 stamps and do the amalgamating; and for this reason it is an economical size of mill to build. One man per shift has run up to 60 stamps and done the amalgamating, but the work is entirely too arduous for one. The crew of a 100-stamp mill will consist of an amalgamator in charge of the shift, one batteryman who attends to the feeding, and one helper. On the day shift there may be a repair man in addition to the head millman. Should the ore be low grade, requiring only one or two dressings of the plates in 24 hours, and the mill be in first-class condition, the helper on each shift may be dispensed with. Should amalgamation not be practised, the amalgamator may be dispensed with, leaving one man—the batteryman—in charge of the 100 stamps; but a first-class mill kept in splendid condition is required if one batteryman per shift with a head millman and a repair man on the day shift are to operate and keep in repair 100 stamps. The mill wood work, such as making screen-frames, chuck-blocks, and other small matters of this kind, is done in the mine carpenter shop.

It is always advisable to place the mine air compressor in the mill of a small or moderate size property—unless there are urgent reasons for placing it elsewhere—preferably on the plate floor if there is no steam engineer to take charge of it, since for some inherent reason not readily explainable or through custom the batteryman rather than the concentrator man seems to be the proper individual to care for it. The mistake of isolating the air compressor, which requires a constant but small amount of attention, at a point where a compressor man is required to watch it when it could just as well be cared for by one of the mill employees, is often observed. Cases have been noted where the compressor has been located under the same roof as the mill, but in a room so distant from the mill machinery that neither the millman or the compressor man could assist each other. If the compressor is placed on the plate floor, a separate room should be provided to reduce the tendency for dust to settle on the compressor and in the moving parts. If located on the concentrator floor it is generally not necessary to house it off, as usually very little dust reaches the concentrator floor.

Mill Management.—Each 5-stamp battery is commonly designated by a number, but it is better to use letters for the batteries, reserving the numbers for the stamps of each battery. Thus B4 is a short way of designating in writing, or orally, the fourth stamp of the second battery.

It is an excellent plan to paint with black paint a space upon a battery-post of each battery for use as a blackboard. Above the board is painted the letter or number of the battery. Upon the board is painted in white the words, "Shoe," "Die," "Screen," and "Exam." A piece of chalk is kept in a small tin box nailed at the side of the board, and the day and month on which the shoe, die, or screen is renewed, or the interior of the mortar is examined, is written down. Other notes or instructions are placed on the bottom of the blackboard. Millmen find this of great assistance in keeping track of mill conditions.

For recording the loss of running time the 'stamp-hour' system is the simplest and best. In this system the length of time any number of stamps is hung up is multiplied by the number of these stamps, the result being called 'stamp-hours.' The idea is to show the time lost as measured on one stamp only, and to simplify the recording of lost time. Thus, on one shift a single battery is shut down for 20 minutes, which is equivalent to one stamp being shut down for 100 minutes or 1⅔ stamp-hours; later on 10 stamps may be shut down for 30 minutes, making a loss of 5 stamp-hours, or a total of 6⅔ for the shift. At the end of the day, or month, the millman divides the total number of stamp-hours lost by the number of stamps in the mill, and the result is equivalent to the number of hours of running time lost by the entire mill.

To record mill work various report systems and blanks are in use. These should be simple and cover the details desired without requiring questions from the management. At some mills a tin holder carrying a small sheet of paper is nailed to the post of each battery, upon which all hang-ups, breakages, and other causes of stoppage occurring to the battery are noted. These papers are collected each morning by the mill foreman and turned into the superintendent's office. An excellent method, especially in a small or medium-size mill, is to post a form covering a month near the change room of the mill. This form is on heavy detail paper and has a line for each shift, with large space under the caption, 'Remarks.' Just before going off duty, the millman whose shift is ending fills out his line, and under 'Remarks' notes down what stems have broken, where new steel has been put in, what boxes are running hot, and any other details, so that the oncoming millman, by glancing over the sheet, will note at once what has been done on the other shifts and know what parts of the mill require special watching. At the end of the month the columns are totalled for the monthly report of operations and the sheet filed away as a summary of the work for the month. Where there is irregularity in the hours worked, or the crew is large, the time-slip method, whereby each man turns in his own time, should be used. A ruled form in a book, or posted on the wall, should be provided in which to record supplies received, used, and remaining on hand at the end of the month. The mill-foreman should be provided with a blank form in which he should enter daily the following data, if it can be consistently done: Number of tons crushed. Ounces of mercury fed inside the batteries, on outside plates, and ounces amalgam collected from outside plates; these data relating to feeding of silver and collection of amalgam should be entered for each unit of 5 stamps, if accurate information is desired. Also number of pounds (wet weight) of sulphide collected from concentrators each 24 hours. To this sheet may properly be added the various stoppages and their cause, such as dressing plates, broken belts, babbitting shafts, changing screens, broken stems, replacing shoes or dies, power off, and the numerous other affairs that interfere with the steady operation of the mill. This sheet is not posted for general inspection, but goes promptly each morning to the office of the superintendent, where it is entered on a book kept for the purpose, and the millsheet placed on file.

Another sheet should show the supplies consumed, including shoes, dies, screens, quicksilver, lubricants, light, belting, chemicals, lumber, water, power (read by meter), concentrator belts, and all other items going to make up the cost of milling, including labor.

Whether a daily mill report is made or not for the superintendent at the property, or the manager at the general office, a monthly summary of operations should always be required of the mill superintendent, which should include a cost-sheet, and also a description of all tests and experiments made. This summary should be exhaustive, giving all the data of any practical value it is possible to obtain, and these should become a part of the permanent records at the property, with a duplicate at the general office. In the preparation of this report the millman will observe many things of interest and value that may result in further study and increased efficiency. It would require too great a length to speak of the invaluable uses these reports are put to. A concrete illustration will suffice. A small mill having a somewhat complicated treatment system was operated for an extended period by different metallurgists of repute. The mill finally shut down pending negotiations for equipping the property with a larger plant, and the blocking out of ore. When it was decided to begin metallurgical operations on an increased scale, the company in attempting to decide whether to increase the small plant, build a larger mill, or use some other system for treating the ore, found itself with only a lot of scattered incomplete information of the most vague nature, much of which was hearsay. In this extremity they were obliged to send out a metallurgist to start up the small plant and by a series of experiments determine what could be done—in short, to get the data that a proper report system should have given.

The general superintendent, or manager, can materially assist milling operations by impressing on the mine foreman the necessity for keeping the mill bins full; by keeping the mine foreman, the mill foreman, the cyanide man, and the assayer in harmonious relation instead of antagonistic to each other, as is too often the case; and by urging the mill foreman to take advantage of the help of the assayer in his testing.

Directly in front of the middle of the batteries a floor should be erected overhanging the concentrator floor. A good stove should be placed here, that the batteryman on the night shift may be able to warm himself at a point where he has everything in plain sight, instead of going out to the boilers, or down to the cyanide plant. In a cold climate these floors have been boarded up to form a clean and cozy change-room with a glass front. The clean-up room can be situated to advantage at this point. It is preferable, where not too cold, to surround it with wire netting instead of boarding it up, that there may be more light. It is a wise expenditure to build a commodious and well-equipped clean-up room. Floors should be built tight and drain into a launder running the length of the mill to a box from which the amalgam, sulphide, and sand that has been flushed into it can be recovered to go into the clean-up barrel or through the mortars. Concrete floors make a neat looking mill, but are cordially detested by mill employees as they produce leg-weariness, calloused feet, and 'draw the cold and dampness.' A mill-man experiences a great relief in changing from a mill having concrete floors to one having wood. The use of rubber heels, overshoes, or thickly soled shoes affords some relief. Where concrete floors are put down, a walk of plank or grating should be run between the concentrators and along in front of the plates and at other convenient places for the benefit of the employees.

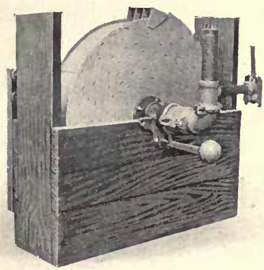
A work-bench should be provided together with a full set of the tools such as are required in a stamp-mill, including the more common carpenter and machinist tools. These tools should be stamped, but not kept under lock and key, with the exception of the extras. Each tool should have a place and the name of the tool should be printed at that place. During shut-downs on account of lack of power, or other external causes, the belts should be gone over and those parts of the mill repaired and cleaned that cannot be conveniently gotten at while in operation.

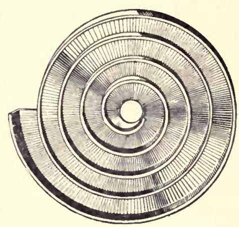
The millman who wishes to make a name for himself will keep his mill scrupulously clean and neat in appearance. He will first stop the running out and splattering about of oil and grease, likewise of the water and pulp, then of the ore that falls out of the chutes, and about the feeders. Finally he will remove the rust, grease, and mud from the stems and shafts, and the mortars. Once the mill is burnished up and the splattering about and leakage stopped the mill can easily be kept in this condition. A clean mill and a good millman go together. There is a great difference in millmen, some are so careless and inexpert in making repairs and so unsystematic in the daily routine work that the duties become trying to the employees. Other millmen are able to keep their mills in such good condition and to plan the routine of daily work so well that the mill work is no longer odious but is accompanied with a considerable degree of gratification. Besides an able millman, a well constructed and properly designed mill is necessary. With these factors the stamp-mill becomes the most satisfactory metallurgical machine in use, to those both directly and indirectly interested. There are 40-stamp mills operating without a machine shop or even a lathe, all repairs necessary being made by the millman sometimes assisted by the blacksmith. There are 10-stamp mills that, figuratively speaking, are in the machine-shop all the time, due to the absence of one of these factors, usually to defects in the installation.

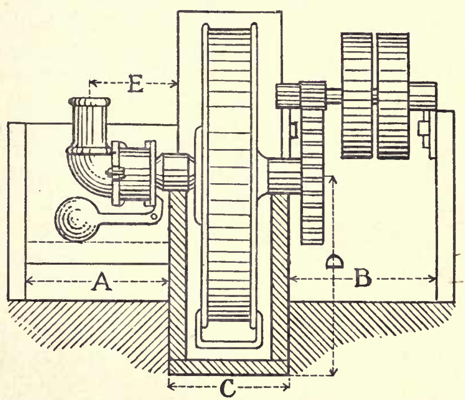
No whistling or shouting should be allowed in a mill, except as a danger signal. To call attention a hissing noise should be made; as such a noise is keyed in a different pitch from that of the stamps, it can be heard across a large mill. Similarly, in talking no attempt should be made to talk above the roar, but in a moderate tone keyed in a different pitch, which can only be learned by experimenting. Sign language should be developed as far as possible. Where it is desired to call a man at a distance, as at the rock-breaker or the cyanide plant, a triangle, such as is in common use at mine boarding-houses, should be used. In some mills the foreman carries a police whistle for the purpose of calling men. Colored signal lights are used for telephones.

There is a serious part of stamp-milling—the loss of hearing. A 10 or 20-stamp mill is not hard on the hearing, but the larger mills cause the majority of men to become deaf in time. To save the ear drums as much as possible and reduce the distress of the continuous noise, wads of cotton, wool, or waste are worn in the ears. These should be softened with clean oil such as olive oil or vaseline, that they may not inflame the ears. Further relief can be obtained by sealing the ears up, after the cotton, with a soft pliable wax or stiff salve that can be moulded into place.

Handling Pulp and Tailing.—For elevating pulp where necessary the tailing wheel is used in large installations, though other methods







Sectional Elevation of 8 by 48-inch Pump.

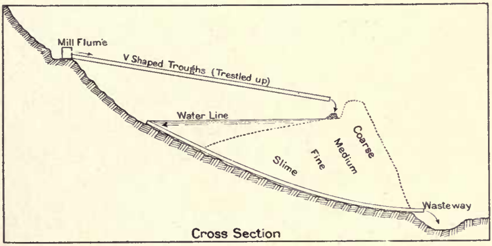
FRENIER SPIRAL PUMP.

(Frenier & Son, Rutland, Vt.)

are considered preferable. As these wheels are costly to install and the cost of operating remains practically the same whether a large or small quantity of pulp is to be elevated, some other machine is used in small plants. The centrifugal pump is too costly and troublesome from the shell, liners, and stuffing-box of the pump becoming rapidly worn by the grit. The Frenier sand-pump has been found very satisfactory. Its maximum lift is about 20 ft. in a practical way, and for a higher lift two or more of them should be placed tandem. The wear on these pumps is mainly in the bearings, the grit of the pulp giving no trouble. They have to be stopped for a period of 10 minutes every 2 to 4 weeks to allow replacing the gland with one that has been re-packed. Experiments have been made with an air-lift pump. These cost little to install and to keep in repair, but their efficiency is low. The air-displacement pump is now being used in pumping slimy and gritty liquids and slush, and has been introduced for pumping thickened pulp into filter-presses against a high head. This pump would appear to solve the problem of a cheap and efficient installation for elevating wet pulp as they cost but slightly more than a centrifugal pump, require little attention, are compact, have high efficiency, and the cost for wearing parts or repairs is nominal. The hydraulic lift, or elevator, is being used for elevating pulp where the extra amount of water necessary to their operation is not considered undesirable, as in a canvas-plant.

Stamp-mill launders within the mill should be set with a grade of one foot in twelve. Discharge launders or flumes leading away from the mill should have a grade of not less than one foot in sixteen. A grade of one foot in twenty will work under favorable conditions without giving trouble, but is generally too small, particularly in a cold country. In one case the finely crushed tailing of a 40-stamp mill was transported in a flume having a grade of one foot in thirty-two, but considerable trouble was experienced.

Where it is necessary to impound the tailing, it is usually done to prevent it from reaching sites or water courses where it is not wanted, or for the purpose of subsequent treatment, such as by the cyanide process. A hillside can usually be had to form a wall on from one to three sides, while the pond is laid out in two or more sections that the walls of one section may be raised by shoveling or scraping while the other is filling. Where the tailing is not being banked for future treatment, the tailing flume is carried over the pond just inside of the wall that has to be raised by shoveling. The tailing is discharged along this wall through several small gates. The coarser sand of the tailing settles at this point, damming the slime back against the hillside where a box flume laid on the ground and passing underneath the pond, carries off the clearer water. The depth of the slime is increased by extending the bedrock flume as needed. The mill flume can run along the contour of the hill and small V-shaped troughs can be lightly trestled up to carry the tailing to the outer bank of the pond. This method of filling results in the slime being separated from the sand, and should not be used where the tailing is to be eventually cyanided, as it is impossible to treat this caked slime without a highly expensive equipment. In this case four sets of inlets and outlets should be spaced about each section of the pond and a change made from one set to another daily or semi-daily. This will result in throwing a layer of sand upon a stratum of slime through which it will sink to some extent, and will enable the cyanide man to put a homogeneous and leachable charge into his vats without leaving any material behind as unleachable.



BUILDING UP A TAILING POND.

These ponds have been used to return some of the water to the mill for re-use, but a settling plant is much better. This may be of the well known cone settlers purchased outright or home-made of wood at a small plant. A simple and efficient water-saving plant consists of deep pulp-thickening tanks ending in cones with 60° sides and large gate-valve discharges. The pulp is introduced into the centre of the tank some distance below the surface of the overflowing water that its introduction may not be violent and that the settling effect of a slowly ascending column of water may be obtained. The valves are opened at intervals of a few hours to withdraw a part of the thickened pulp, which comes out as a thick and solid sludge requiring a launder set at heavy grade. The wooden-box settlers so common around small mills in desert regions and so unsatisfactory in operation, should be divided into compartments fitted with these cone bottoms and gate-valves.

Novel instances of mill-tailing put to agricultural purposes are found in California. Some 30 years ago, the tailing from a large mill crushing a quartz ore containing much of the slate in which the orebody lay, after running in a creek for three miles, was diverted by an earth dam and impounded to form a fill. The flat bottom of the creek had been cleaned bare years before by placer miners. A stone wall, 6 to 15 ft. high, was roughly laid at the side of the creek, to raise the proposed surface above high water. This wall was about 2200 ft. long, and inclosed a strip of ground of that length and from 125 to 250 ft. wide, to be filled by the tailing. This filling was done in sections and required several years to complete. The surface was well manured, and the tailing was found to make an excellent soil for growing vegetables and fruits, being preferred to the natural soil. It is still actively worked and is considered the best garden in the county. There are many gardens of this character along the Mother Lode of California.

PART IV

Arrangement and Construction Costs of Stamp-Mills

By Charles T. Hutchinson

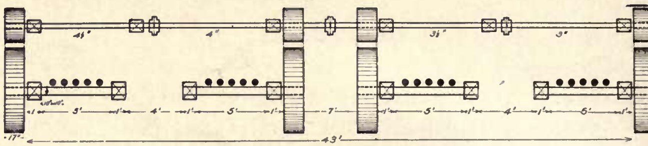
CHAPTER XI

Arrangement of Stamp Battery—Light and Heavy Stamps—Sectionalized Machinery—Jaw and Gyratory Crushers—Purchasing a Mill—Selection of Millsite—Cost of Constructing Stamp-Mills.

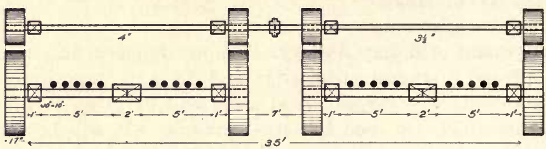
Arrangement of Stamp Battery.—The arrangement of stamp batteries affects first cost primarily, and to a certain extent the operating cost. Five hypothetical cases will be given to illustrate this, all of which are used in actual practice. It will be assumed that 5-stamp mortars will be used; that the battery-frame will be of the back-knee type; that the drive is accomplished by means of a belt-tightener and countershaft set on the line sills below the feeder floor; that the speed of the countershaft is 100 r.p.m., and that of camshaft is 50 r.p.m.; that the section of the countershaft with pulley for receiving power from the prime mover is omitted; and that no battery-frames are included. Figures and other comparisons are made on the basis of 20-stamp mills having 1000-lb. stamps.

Case No. 1.—This arrangement includes four 5-stamp batteries individually driven. Each battery is placed in a 2-post frame, and each frame is set 4 ft. apart. As shown, a floor space 43 ft. wide is required for this setting. Easy access to the feeders from any part of the plate floor is possible through the passageways. This design enables the mill bins to be of large capacity.

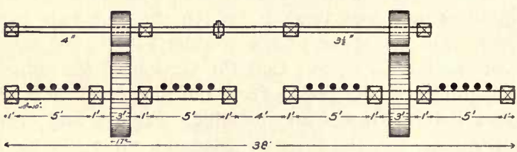
Case No. 2.—This is similar to Case No. 1 in that the batteries are still arranged in individually driven 5-stamp units, but each 10 stamps is set in a 3-post frame. For this arrangement, the ends of the 5-stamp camshafts butt together at a double-bearing placed on the centre post. The accessibility of Case No. 1 is practically preserved, while a floor space only 35 ft. long is required as compared with 43 ft. in Case No. 1. The shortening of the floor space brings about a corresponding decrease in the cost of machinery, foundations, and the mill building. This is a very practical arrangement. The illustration of the Aurora Consolidated mill on page 96 shows a battery arranged in this manner.



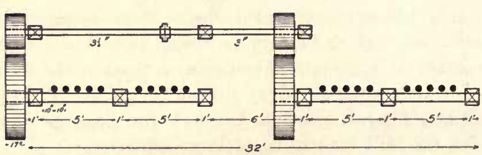
CASE NO. 1



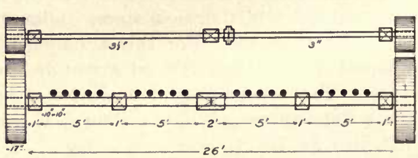
CASE NO. 2



CASE NO. 3



CASE NO. 4



CASE NO. 5

STAMP-BATTERY ARRANGEMENT.

Case No. 3.—This arrangement contemplates the erection of the mill in two 10-stamp units. Each unit of 10 stamps is set in a 4-post frame, and is operated with a single camshaft, the battery pulley being placed at the centre of the camshaft. The floor space occupied is 38 ft. long, or slightly in excess of that required for Case No. 2. The battery countershaft, however, is shorter, and as there are two less drives than required for either Cases No. 1 or 2, the cost of machinery is correspondingly less. This form of construction will insure a rigid camshaft, whose ends will not jump and pound in the bearing boxes. But serious difficulty is encountered, as the shaft must sometimes be removed from its boxes, when the battery pulley is to be repaired or it has become loose. However, battery pulleys give little trouble from coming loose when self-tightening clips, similar to those for cams, are in use. The Nevada Hills mill, illustrated on page 115, is arranged in this manner.

Case No. 4.—This arrangement embodies 10-stamp units, having 10 stamps operated by each camshaft, similar to Case No. 3. But each 10-stamp battery or unit is erected in a 3-post frame with a space of approximately 4 ft. 6 in. in the clear between the units. Also, the battery pulley is placed at the end of the camshaft. This arrangement requires a floor space 32 ft. long, which is considerably less than in any of the first three cases. While the same number of drives is required as for Case No. 3, the battery countershaft is shorter, thereby decreasing the first cost of machinery, as well as that of foundations and mill building. The Goldfield Consolidated mill, as illustrated on page 121, is arranged in this manner.

Case No. 5.—For a 20-stamp mill this is the cheapest possible arrangement from a standpoint of first cost. The entire 20 stamps are erected in a 5-post frame, and in two 10-stamp units whereby 10 stamps are driven from each camshaft. The ends of the two camshafts butt together at the centre post in a double-bearing. A floor space only 26 ft. wide is required. This type of battery arrangement is shown in the illustration of the North Star mill on page 117.

The following tabulation shows the relative floor spaces, weights of machinery, and approximate costs at factory of each of these five cases.

Case No.	Floor space, ft.	Weight, lb.	Cost.
1	43	82,672	$5482.00
2	35	81,667	5384.00
3	38	75,162	4943.00
4	32	73,415	4791.00
5	26	73,640	4823.00

It will be noted that Case No. 4, although taking up more floor space, is cheaper, as far as the first cost of machinery is concerned, than Case No. 5. The reason for this lies in the position of the drives, which makes possible a cheaper counter-shaft. On the other hand, this difference will be more than counteracted by the increased cost of the mill building. The cost of foundation and mill building will vary directly as the floor space increases.

There are many points in favor of Case No. 2 from the standpoint of operating costs because of the nature of camshafts. The most frequent cause of prolonged breakdowns in stamp-mills is breakages of camshafts. It is, of course, perfectly feasible to devise a camshaft of such size and quality of material as will make it wear indefinitely. The obstacle in the way of this is the purchase of mills on purely a price-competition basis. The stock mill of 1000-lb. stamps, as ordinarily put out by manufacturers, has a camshaft 5⅞ in. diameter and about 14 ft. 2 in long where 10 cams are mounted on a single shaft, and 8 ft. long where 5 cams are mounted on a single shaft. The material used in most cases is a so-called mild steel that has preferably been drawn under the hammer from a bloom about 8 in. square. This forging process has two objects. The heating helps to anneal the material and relieves internal stresses. The hammering has the effect of compacting the material and making it more homogeneous in general. On the other hand, in order to save money in the cost of manufacture, some of the so-called hammered shafts are merely rolled shafts that come to the manufacturer 6 inches in diameter direct from the mill. They are not intended for camshafts, and are totally unsuited to the severe duty that is exacted. To turn such a rolled shaft to the required diameter, only $\frac{1}{16}$ in. of stock has to be turned off all around. This, in some cases, is barely sufficient to clean up the shaft and present a bright surface, especially if the shaft has not been carefully straightened before being put into the lathe. Again, manufacturers frequently draw a 5⅞-in. shaft from a 6 or 6½-in. square bloom, the object being to reduce the cost of forging. It is obvious that a reduction in the amount of hammering required gives a correspondingly less chance to secure a camshaft that is homogeneous throughout. These matters, of course, are not apparent upon inspection of the finished shaft, and buyers seldom appreciate the significance of these details until after the mill is placed in operation.

Breakages of camshafts are due primarily to crystallization induced by what steel makers call 'fatigue.' It is analogous to the fatigue and physical breakdown of the human body, for the shaft under continual hammering while in use gradually changes from its fibrous structure to a crystalline one that finally succumbs to the jar and vibration and impact to which the camshaft is subjected. Manufacturers and millmen concede that broken camshafts are bound to occur, and so the object of the mill designer is to make these breakages as few as possible, and to arrange the mill so that when a breakage does occur, as small a portion of the mill as possible will have to be shut down.

This is one of the principal reasons for advocating that each 5-stamp battery should be driven by its own camshaft. If a camshaft breaks, but 5 stamps are out of commission instead of 10 when using 10-stamp camshafts, while the cost of a new shaft will be much less for 5 stamps than for 10 stamps. It must be admitted that the load on a 10-stamp shaft from a standpoint of flexure is better distributed than on a 5-stamp shaft, for the reason that the intervals in revolution are one-twentieth of the complete circles instead of one-tenth. It must also be admitted that the 5-stamp shaft is not as well anchored in the bearings as the 10-stamp shaft, because of the downward pull of the driving belt, which, for so short a shaft, causes the shaft to jump more at the farther end. To reduce this tendency, which is a material cause of shafts crystallizing and breaking, it is advisable to confine the outer end of the shaft by means of a capped box instead of the usual open-pattern box. On the other hand, the torsional strain increases directly with the length of the shaft and the power to be transmitted, while the 10-stamp shaft is subject to twice the jar and vibration due to cam impact. Not only that, but the 10-stamp shaft is under a much heavier strain where, through defective construction or abnormal wear or lack of care, the bearing boxes do not truly and rigidly support the camshaft or one of the three boxes does not support the shaft at all. Crystallization is rapidly induced by these conditions and under heavy strain the shaft may break.

Light and Heavy Stamps.—The four important questions in comparing light and heavy stamps are: (1) will the heavy stamp work as satisfactorily as the light stamp, particularly in crushing ore to a fine mesh; (2) what economy in the operating costs will be effected by heavy stamps; (3) what reduction will be effected by heavy stamps in the costs of installation, referring to excavations, grading, foundations, and building; (4) what are the comparative costs of the machinery of light and heavy stamps. Only the last question will be discussed herein. The subject may best be treated by the following three hypothetical cases of reduction works crushing quartz ore to pass a 30-mesh screen, and having a capacity of 200 tons daily: Case A, a 40-stamp mill of 1000-lb. stamps, preceded by the usual breaking plant. Case B, a 10-stamp mill of 2000-lb. stamps, preceded by the usual breaking plant, and followed by a Dorr mechanical classifier from which the oversize or coarse sand is fed into two Chilean mills for regrinding. Case C, a 20-stamp mill of 2000-lb. stamps, preceded by a breaking plant as in B.

CASE A.—FORTY 1000-LB. STAMPS.

	Weight, lb.	Cost.
One breaking plant, including grizzly; 12 by 20-in. Blake crusher; 16-in. troughing belt-conveyor, 60-ft. centres, with automatic tripper. (Power required, 20 hp.).....	30,000	$ 2,750
One 40-stamp mill, including four 10-stamp batteries having 1000-lb. stamps; eight ore-bin gates; eight automatic feeders; one battery trolley, including a 2-ton chain-block and 70 ft. of 6-in. I-beam track............	185,000	11,000
One battery countershaft, including belting, pulleys, bearings, and four battery-belt tighteners. (Power required, 100 hp. Floor space, 77 ft. wide)................	12,500	1,250
Total	227,500	$15,000

CASE B.—TWENTY 2000-LB. STAMPS AND TWO CHILEAN MILLS.

	Weight, lb.	Cost.
One breaking plant same as for Case A, except that belt conveyor and automatic tripper are omitted..........	21,000	1,500
One 10-stamp mill, including two 5-stamp batteries having 2000-lb. stamps; two ore-bin gates; two automatic feeders; one 5-ton chain hoist with trolley and 30 ft. of 18-in. I-beam track; one Dorr duplex mechanical classifier; two 6-ft. Chilean mills.........................	190,000	14,750
One set transmission machinery, including battery and Chilean mill countershafting, with belting, pulleys, tighteners, and boxes complete. (Power required, 120 hp. Floor space, 20 ft. wide and two benches.).......	12,000	1,450
Total	223,000	$17,700

CASE C.—TWENTY 2000-LB. STAMPS.

	Weight, lb.	Cost.
One breaking plant, same as for Case A, except that belt conveyor and automatic tripper are omitted..........	21,000	1,500
One 20-stamp mill, including four 5-stamp batteries having 2000-lb. stamps; four ore-bin gates; four automatic feeders; one 5-ton chain hoist with trolley and 50 ft. of 18-in. I-beam track	160,000	9,500
One battery countershaft, including belting, pulleys, bearings, and four battery-belt tighteners. (Power required, 100 hp. Floor space, 40 ft. wide.)................	13,500	1,350
Total	194,500	$12,350

The question will be asked, why does the cost of twenty 2000-lb. stamps so closely approach that of forty 1000-lb. stamps? It is because the heavier pieces must be made of larger forgings composed of better material, which costs more per pound. Also, the cost of the machine work on the larger pieces is sufficiently greater to make the cost of the machine work per pound equal to that upon lighter parts. A further reason for the increased cost of heavy stamps in the above cases is that the diameter of the shoes has been increased from the usual 9-in. diameter with 1000-lb. stamps to 12 in., and the length of the mortars and camshafts has been increased accordingly. It will be noted that this is an increase of three-fourths in crushing area to keep pace with the doubling of the weight of the stamp, though the South African practice with 1800 to 2000-lb. stamps is to use a shoe of 9¼-in. diameter. It will be observed that the cost of the 'stamp-mill' parts in both the light and heavy stamps is about six cents per pound.

The cost of the heavy-stamp and Chilean-mill plant is about 18 per cent greater than that of the light-stamp (1000-lb.) plant, notwithstanding that the weight is 2 per cent less. This is due in part to the higher cost of heavy stamps, the addition of a mechanical classifier, and the use of more belts, which is a costly item.

It is apparent that so far as the cost of machinery is concerned, Case A (forty 1000-lb. stamps) will cost 21½ per cent more than Case C (twenty 2000-lb. stamps), while Case B (stamps and Chilean mills) will cost 43⅓ per cent more than Case C. The weight of machinery in Case A is 17 per cent greater, and in Case B is 14⅔ per cent greater, than in Case C. Therefore, in the matter of the cost of machinery and freight charges, the advantage is decidedly with Case C (twenty 2000-lb. stamps), while Case A (forty 1000-lb. stamps) has an advantage over Case B.

Viewing the subject from the cost of excavations, foundations, and mill buildings, the difference in the three cases becomes very pronounced. The forty 1000-lb. stamps will occupy a floor space 77 ft. in width. The twenty 2000-lb. stamps will occupy a floor space 40 ft. in width. This would indicate that the cost of the excavation, foundation, and mill building for the light stamps would approach twice that for the heavy stamps. The combination of ten stamps and two Chilean mills would occupy a floor space only 20 ft. wide, but would require two benches, which would make the building costs approach that of the twenty 2000-lb. stamps.

The power consumption would be the same for the forty 1000-lb.

stamps or the twenty 2000-lb. stamps, but would increase 20 per cent for the stamp-Chilean mill combination.

Sectionalized Machinery.—Mill equipment must be made in sections when destined for use at mines in remote localities where road conditions are such that mule-back transportation is necessary. The weight of these sections is necessarily determined by the carrying capacity of the average mule, and is ordinarily fixed at 300 pounds. Wherever possible the weight limit should be placed at half this amount, as it greatly simplifies proper balancing of the load to be able to put a 150-lb. section on each side of the mule's back, rather than to load a single piece weighing 300 pounds.

The necessity for sectionalizing affects three essential items: first cost, construction or assembling cost, and design. Of the several parts of a stamp battery, the following, as ordinarily furnished, must be sectionalized:

Mortar
Stamp stem
Camshaft
Battery pulley

All of the other parts of the iron work come within the sectionalized weight limit.

MORTAR.—The mortar is perhaps the most important part of the battery, therefore design and quality of material, rather than first cost, should govern its selection. Badly fitting joints soon give way under the continuous hammering to which the mortar is subjected; crushed ore and water leak out carrying with them particles of quicksilver and amalgam; while an unstable anvil upon which the stamps pound promotes breakage of stems and other parts and diminishes crushing capacity. Though cast iron is ordinarily satisfactory for solid mortars, a combination of cast and plate steel for sectional mortars possesses many advantages. Strength and durability are obviously essential. The ideal material for a sectionalized stamp mortar (see page 38) combines these qualities with lightness.

A sectional mortar suitable for 1000-lb. stamps and made with a cast iron base and $\frac{3}{16}$-in. steel plate sides had the following dimensions:

Height over all	4 ft. 6 in.
Length over all	4 ft. 8¼ in.
Thickness under dies	7 in.
Weight finished	5000 lb.

A similar mortar using a cast steel base as a substitute for the cast iron would only require a thickness of 6 in. under the dies.

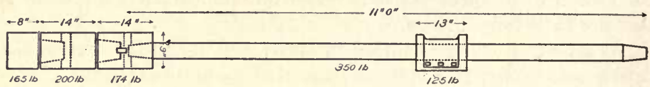
The difference in weight would be about 480 lb., a point not to be lightly considered when the high cost of mountain mule packing is taken into account.

In a properly designed sectional mortar, the base sections are carefully machined, grooved, and tenoned in order to secure tight joints. The tenons are the weakest points, being subject to both shearing and bending stresses. Cast iron has low tensile and shearing strengths, and practically no elasticity. The comparative strength of cast steel may be taken at from three to five times that of cast iron in these respects. The mechanical advantages in its use are therefore obvious.

As an additional precaution to insure rigidity in the mortar base after assembling, two bolts are inserted longitudinally through all sections. The bolts are generally made $1\frac{1}{2}$ in. diameter, and the holes are drilled $\frac{1}{16}$ in. larger through all the sections after they are fitted and bolted together. When assembling the mortar on the ground, these bolts should be heated to a dull cherry red and inserted. The nuts should be tightened with a monkey-wrench and not by two men on the end of a long-handle wrench. The latter method will result in either stripping the threads or stretching the hot bolts to such an extent that in cooling the mortar may crack.

In addition to the through-bolts, the mortar sections have the usual flanged joints that are held together by turned bolts carefully fitted into the drilled and reamed holes. These bolts should have a moderate drive fit. The nuts also should be faced. Careful workmanship, accurate fitting of all joints, and thorough rigidity in use should characterize the well designed and properly built sectionalized mortar. Gasket joints for this purpose are an abomination and predestined to failure. Flush-joint mortar-base sections, unstiffened by grooves and tenons, place all the strain of continuous pounding upon the bolt threads. It is impossible to keep the flange bolts tight, even by riveting over the nuts. Small leaks mean large losses, and a dancing mortar is not conducive to rapid crushing or long life for the battery parts. The difference in first cost varies with the types of construction, but is so small an item as to be negligible to the intelligent buyer when the interests involved are considered. A sectional mortar having a cast steel base and constructed in general along the lines described above would cost about $450, or $75 more than if the cast iron base was used. The difference in weight, however, is about 480 lb., so it will be seen, when the cost of freight is taken into consideration, that the higher cost of the steel base mortar is more apparent than real.

STAMP STEM.—The stem for a battery of 1000 lb. stamps is ordinarily $3\frac{7}{16}$ in. diameter, 15 ft. long, and weighs 480 pounds. This presents a most awkward problem to the designer of sectionalized machinery. The excess weight is 180 lb., and the length is such that transportation over mountain trails is both difficult and costly. The duty of the stem in use precludes the possibility of its being cut in pieces. This situation has been met, without impairing the crushing and mechanical efficiency of the 1000-lb. stamp, by making an extra long stamp-head or boss in two pieces, and shortening the stem to



STAMP FOR SECTIONALIZED MILL.

provide for the increased weight of the boss. The lower half of the sectional boss has the usual taper recess cored to receive the neck of the shoe. At the upper end is a taper shank the same as a shoe neck. This shank is wedged into a taper recess in the upper half of the boss in precisely the same manner as the shoe is fastened to the boss in a standard battery. The upper end of the top section of the boss is bored as usual for the taper end of the stem. The following schedule of weights shows the advantage in the new method over the old:

	Old method.		New method.	
	Size, in. ft.	Weight, lb.	Size. in. ft.	Weight, lb.
Stem	$3\frac{7}{16}$ by 15	480	$3\frac{7}{16}$ by 11	350
Tappet	9 by 13	125	9 by 13	125
Boss (solid)	9 by 17	234		
Boss (sectional, upper).......			$8\frac{1}{2}$ by 14	174
Boss (sectional, lower).......			$8\frac{1}{2}$ by 14	200
Shoe	9 by 8	166	9 by 8	166
Total		1005		1015

It is obvious that the sectional boss should under no circumstances be made of cast iron. Chrome cast steel makes breakages practically a negligible feature, except in the remote possibility of a casting proving defective.

CAMSHAFT.—This portion of the stamp battery has thus far defied the efforts of the designer at successful sectionalizing. The camshaft for a battery having 1000-lb. stamps would, if made of hammered iron or so-called mild steel, be not less than $5\frac{7}{8}$ in. diameter, although some builders make them $5\frac{7}{16}$ in. diameter for batteries in 5-stamp units. For a unit of this size, which is the maximum for a sectionalized mill, the length may be taken as 8 ft. 2 in., assuming 12-in. posts 5 ft. apart. A shaft $5\frac{7}{8}$ in. by 8 ft. 2 in. weighs about 760 lb., or more than double the sectional weight limit.

An expedient that has been used with some degree of success has been to split the shaft in halves longitudinally and dovetail them together, using countersunk head machine screws to hold the pieces together. This is effective in reducing the weight of the pieces, but is also open to several objections, principal of which is the danger of springing the pieces in handling en route, and the difficulty in keeping the screws tight when the shaft is in use. The jointed shaft is less strong to a degree corresponding to the tightness of the joint, than a solid shaft of the same diameter. A sectional shaft of this size costs $75 more than a one-piece shaft, and it is questionable whether the extra cost is justified by the results achieved.

A far superior method is to use a hollow shaft. In order to keep the overall dimensions and consequently the weight down these hollow shafts must be made of the very best materials obtainable. A number of shafts were made to the following specifications, and after several years of service are still unbroken: "Camshafts must be made of the best mild open-hearth steel, test pieces from which must exhibit a tensile strength of not less than 60,000 nor more than 70,000 lb. per sq. in., and an elongation of not less than 25% in 4 inches. A bar $\frac{1}{2}$ in. square to bend cold through an angle of 180° around a mandrel 1 in. diameter without showing any signs of fracture. The camshafts are to be hollow, $5\frac{7}{16}$ in. outside by 8 ft. long, bored cut to $3\frac{1}{4}$ in. diameter inside; to be turned full length and to be drilled for cam fastenings and camshaft pulleys." This shaft weighed 400 lb. finished, and cost about $175. While this is considerably in excess of the cost of either the solid or split shafts, it is so far superior for the purpose that there should be no question as to a choice whenever conditions demand light sectionalized construction.

BATTERY PULLEY.—The battery pulley as ordinarily furnished with a standard 5-stamp mill is 72 in. diameter and 13 in. face. It is built up of wood, fitted with cast iron sleeve flanges, and shipped completely assembled, weighing about 1300 pounds. It is not difficult to ship such a pulley knocked down. The wood segments are cut, painted, and crated in packages of any desired weight. The face of the pulley must be turned true at the mill after assembled, but this may be easily done when it has been placed in its proper position on the camshaft.

The sleeve flanges as ordinarily furnished are made in two pieces, one with a hub cast on and one without. As the combined weight of a set of 36-in. flanges is about 750 lb., it is necessary to make the flanges and hub separate in order to come within the mule-pack weight limit. Again, in this instance, steel may be substituted for the usual cast iron to great advantage. Excellent results have been obtained with steel flanges 30 in. diameter, and used on a wood pulley 66 in. diameter and 13 in. face. The specification used was as follows: "Camshaft pulleys 66 in. diameter by 13 in. face. The pulleys to be constructed of wood with cast steel sleeve flanges. The steel flanges to be secured to the shaft by a self-tightening fastening similar to that used for the cams. The wood segments composing the pulleys to be carefully fitted, assembled, and bolted together, and to be knocked down for shipment. No part of the sleeve flanges to weigh over 200 lb. All necessary bolts for securing the wood work to the flanges to be supplied."

The sleeve flanges above weighed as follows:

	Pounds.
Two flange sections	320
One hub	145
Total	465

They cost about $85, or $35 more than the ordinary cast iron. The greater facility with which they could be transported, however, more than overcame this difference.

Jaw and Gyratory Crushers.—Rock breakers as ordinarily manufactured may be broadly classed into two types, the Blake or oscillating jaw type, and the gyratory. Blake breakers may be further subdivided into two types. One is constructed with sectional frames tied together with heavy steel tie-rods which take the strain of crushing and are in tension. The other is made with a solid one-piece frame in which the sides and ends of the breaker are cast in one piece. There is a good reason, within certain limits, for the sectional-frame construction. Forged steel is obviously better adapted to withstand a tensile strain than cast iron, as the latter has no elasticity of any consequence and a comparatively low tensile strength per unit of area. In order to manufacture a solid-frame crusher that will render satisfactory service, it is necessary to use a large factor of safety in designing the frame. This results in a very heavy crusher which is difficult of transport, and which is expensive to repair in case of failure of the frame. On the other hand, the mechanical difficulties in tying the end-frame sections together and keeping them tight and rigid greatly increase in constructing a sectional-frame type of crusher beyond certain sizes. Both types of crushers are illustrated on pages 15 and 16.

With the gyratory breakers the first objection is the high first

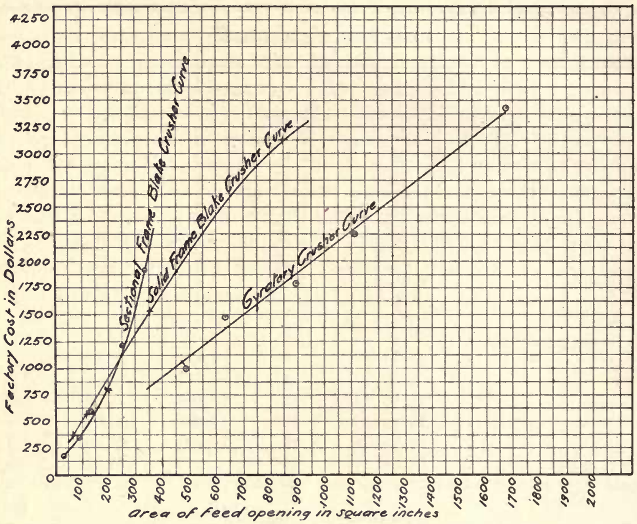
BLAKE JAW CRUSHER

No.	Receiving opening in inches.	Cap. per hour in tons to pass 1½ to 2½" ring.	Weight — Sectional-frame type.	Weight — Solid-frame type.	Horse-power.
1	6 by 8	4	2,700	4,000	4
2	7 by 10	6	4,000	8,000	7
....	8 by 12	8	5,500	.....	8
3	10 by 16	12	10,200	16,500	13
4	12 by 20	20	16,600	25,000	18
5	14 by 24	25	26,600	36,000	24
6	18 by 24	35	.....	54,000	40

GYRATORY CRUSHER

No.	Receiving openings, each, inches.	Combined openings, inches.	Cap. per hour in tons to pass 1½ to 3½" ring.	Weight.	Horse-power.
1	5 by 20	5 by 40	4 to 8	7,500	6
2	6 by 24	6 by 48	6 to 12	9,500	10
3	8 by 30	8 by 60	10 to 20	15,500	16
4	9 by 35	9 by 70	15 to 30	22,500	20
5	11 by 40	11 by 80	30 to 50	35,000	25
6	12½ by 45	12½ by 90	50 to 80	48,000	35
7½...........	15 by 55	15 by 110	70 to 120	71,500	55
8	18 by 63	18 by 126	120 to 180	100,000	85
9	21 by 76	21 by 152	140 to 220	160,000	120
10	25 by 100	25 by 200	200 to 400	180,000	150

cost for the small sizes as compared with the Blake type. The second objection is the contracted feed opening in proportion to tonnage-output rating.

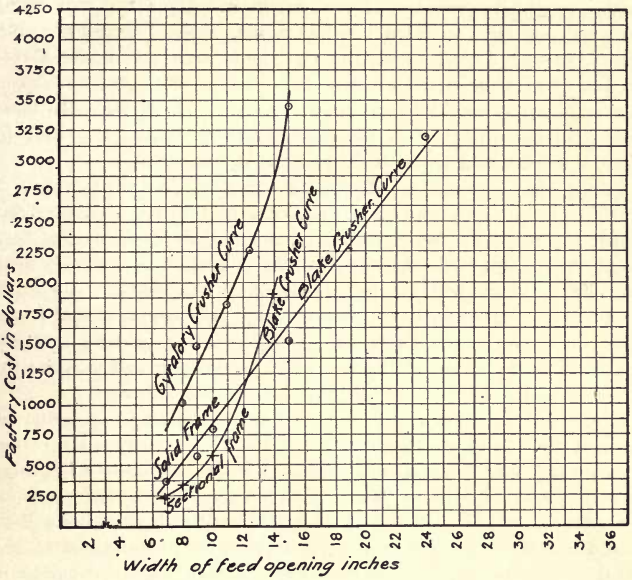


CURVE No. 1. FACTORY COST OF CRUSHERS. SIZES IN TERMS OF AREA OF FEED OPENING.

Comparisons of first cost may best be studied by means of curves. Curve No. 1 shows the first cost at the factory for all three types of machines. The ordinates represent the area of the feed opening in square inches, and the abscissae represent the first cost in dollars at the factory. In studying these curves it will be noted that the gyratory crusher is by far the cheapest in sizes down to the No. 3 machine, which has an opening of 8 by 30 in. for each of its two feed openings. The manufacturers rate this machine at 10 to 20 tons per hour, and it is conceded that as far as first cost is concerned the gyratory breaker cannot compete with the Blake below this size.

A further reference to Curve No. 1 will show the curve of the solid-frame Blake machine crossing that of the sectional-frame machine at a point which would indicate that the sectional-frame machine is cheaper in first cost in sizes of about 10 by 16 in. and smaller.

Beyond this point, however, the advantage lies with the solid-frame machine. It is admitted that the most satisfactory basis for comparison would be that of actual tonnage output, but as this varies



CURVE No. 2. FACTORY COST OF CRUSHERS. SIZES IN TERMS OF WIDTH OF OPENING.

so widely in different localities and as it is obviously most difficult or impossible to obtain examples where all three types of machines may be operated crushing the same rock under exactly the same conditions, this basis of comparison is out of question. The manufacturers' ratings also vary widely—as much as 100%. Nor can any comparison that is not misleading be made between jaw and gyratory crushers by means of area of feed opening.

The object of installing a rock breaker is to avoid doing by hand what can be done better and more cheaply by machinery, regardless of the theoretical capacity of a breaker which cannot crush a rock that is too large to permit of its entering the feed opening. For instance, the No. 3 gyratory mentioned before has two 8 by 30 in. feed openings or feed-opening dimensions of 8 by 60 in., and is rated at from 10 to 20 tons per hour. The area of each of the two openings, therefore, is 240 square inches. To obtain an equivalent area of feed opening in the Blake type machine requires one with an opening 12 by 20 in., which is rated at 15 tons per hour. A piece of rock larger than an 8-in. cube would not be taken into a No. 3 gyratory, while the Blake with a feed opening of equivalent area would take a rock up to a 12-in. cube, or 50 per cent greater than the gyratory. From this standpoint the 12 by 20-in. Blake, rated at 15 tons per hour, would be the equivalent of the No. 6 gyratory having two 12½ by 45-in. openings and rated at 50 to 80 tons per hour.

Curve No. 2 compares the factory cost of the three types of crushing machines as in Curve No. 1, except that the ordinates represent the width of feed opening in inches instead of area of feed opening. On this basis of comparison the situation becomes changed and the gyratory will be seen as the most expensive. The solid-frame Blake crusher curve crosses that of the sectional-frame Blake machine at the 12 by 20 in. size, thus indicating that for smaller sizes the sectional-frame crusher is cheaper, and that for the larger sizes the solid-frame machine has the advantage.

The entire question of the selection of a crusher is an economic one and the true basis of comparison is one of operating costs, rather than factory and construction costs. It is the concensus of opinion of experienced operators that replacements and renewals may be more easily and more cheaply accomplished with the Blake than with the gyratory. The main reason for the installation of the gyratory in the majority of crushing plants having a capacity in excess of 20 tons per hour is in the lower first cost, and the fact that the average run of mine rock at many mines is of such a size that nearly the whole of it may be taken into a feed opening 8 in. wide. Where the breaker is fed by hand, the comparatively narrow opening of the gyratory may not greatly influence the cost of rock breaking, for the attendant can sledge the oversize if the percentage is not too great. But if the breaker is to be fed automatically and is not to receive continuous attention, it is of the utmost importance to install a breaker with a feed opening wide enough to receive the largest pieces of rock.

Purchasing a Mill.—The first requisite in purchasing a mill is that the buyer should know what he wants. Some buyers want to put up a mill for the purpose of being better able to sell stock in their mines, and so want as cheap a mill as possible, while other buyers want a mill to obtain the metals from their ores, and so want as efficient a mill as possible. The latter must comprehensively sample their orebodies and turn the samples over to a metallurgist for testing to determine the proper process. This is one of the critical stages in the development of a mine, and requires scrupulous care and study. It is essential that the samples shall represent the average of the ore to be milled. If a pay shoot or vein is but 12 in. wide, it is foolish to sample the pay shoot only, without taking into consideration the impossibility of mining a pay shoot of that width without including a certain amount of waste. And yet this is done over and over again. Ores that will 'assay' $8 to $10 are found to 'mill' but $2 to $3, so that the disappointed stockholders shake their heads and resolve to have nothing more to do with mining investments. The sampling should be performed under the direction of the superintendent or mining engineer in conjunction with the metallurgist, for the first two should know the grade of the ore and what ore it is expected to send to the mill, while the wide-awake metallurgist acquires a knowledge of the nature and characteristics of the ore and the proportions of the different kinds of ore that will be supplied to the mill, and can call attention to any mistake in selecting the samples.

After the samples have been tested by the metallurgist and the proper treatment system and machinery outlined by him, the next step is the designing of the mill and the purchase of the apparatus. The mill should be designed by a mechanical engineer who has specialized in this line, and his work should be outlined and directed by the metallurgist. The metallurgist is a man who has worked with the process in many fields, and has an up-to-date and working knowledge of the appliances that may be used. But, generally speaking, the metallurgist cannot calculate in a practical way the strength of materials, or determine what the chords of a roof truss should be, or the proper size and arrangements of the driving parts, or the proper foundations for the machinery, etc. Obviously these things are the work of the mechanical engineer, who is a specialist in them. And the closer in touch that the metallurgist and the mechanical engineer work, the better will be the results. The final work of designing consists in drawing up a complete list of specifications, giving the quantities and sizes of the different parts or devices required, and particularly specifying their material and methods of manufacture. With this list in hand the buyer knows what he wants.

However, the entire question of building a mill is so bound up with the manufacturer of mill machinery, that a correct understanding of his functions is necessary. The machinery manufacturer lives by selling machinery, and years of experience have taught him that he must proceed along certain lines. One of these is that he must keep a force of mechanical engineers and designers, and submit mill designs and give advice to prospective buyers free of charge. It is always well to seek the advice of the manufacturer, as much money may be saved by using his standard product and patterns wherever they may be found applicable. But the representatives of the buyer should be the men who draw up the plans and specifications, not the manufacturer, for the manufacturer cannot assume the responsibility for the successful operation of the plant in addition to his own responsibilities, and so it will invariably be found when it comes to signing a contract that the manufacturer will only "guarantee the workmanship and material to be free from defects when used for the purpose ordered." There will seldom be any guarantee of tonnage output, and never a guarantee of any degree or percentage of extraction; the responsibility for the mill's successful operation, outside of failure due to defective material and workmanship, rests with the buyer and his representatives.

The buyers of small plants seldom appreciate these facts, and in order to economize upon the cost of engineering services, will frequently submit their own general ideas as to the proper treatment to the machinery manufacturer in order to obtain advice for nothing. The manufacturer under such conditions does the best he can. He must, perforce, assume the buyer's statement of conditions to be correct, and devise a plant accordingly. He knows, of course, that the buyer is telling the same story to other manufacturers and that, therefore, there is no chance that all will bid upon a uniform set of specifications. Each manufacturer bids upon what in his opinion is the cheapest plant that can be put up. He keeps his bid as low as possible, partly by the use of cheap material and a scant design, and mainly by eliminating every item possible, even the most necessary accessories are often omitted. It should be clearly understood that the manufacturer indulges in no guesswork in making his bid, but does it by setting down each item of machinery and parts that he will supply and the price that he can sell it for, and then obtaining the sum total of the items. Obviously, the more items he can eliminate, the lower will be the bid. A large majority of buyers of this type will hastily turn over the pages of the specifications until they come to the last page. Then scrutinizing the final figures or lump-sum bid, will wonder why A can furnish a 'complete' mill so much more cheaply than B—and promptly proceed to give A the order. The eventual result is that it will cost the buyer from 15 to 50% additional for extra machinery and accessories, repairs and alterations, and the loss of time in getting mill fitted up and into commission is a matter of even more serious consequence.

This type of buyer is a severe tax on the conscience of the manufacturer, who has learned to recognize the type on sight and to act accordingly. He also knows that a buyer showing so little intelligence in buying is apt to have shown but little more in developing his mine, and that the mill will probably not operate more than six months, not that the machinery installed is inadequate or defective, but that the buyer has neglected to provide himself with a mine. As a rule machinery manufacturers are honest, but professional mill builders recognize that great dissatisfaction arises in putting up the mills of certain manufacturers, while workaday millmen speak of the mill put out by certain manufacturers as bunglesome and unsatisfactory of operation because of poor material and bad design. All of which tends to prove that a mill should be purchased on merit of a reputable manufacturer.

Having purchased the mill, the next step is its erection by a competent millwright or mill erector, who should work in conjunction with the metallurgist or millman who is to put the mill into commission, at least the assistance of the millman should be sought as the mill nears completion. This is for the reason that the millman has certain detailed knowledge which can hardly be expected in the erector or millwright, also because there are a great many small details of construction and arrangement which the millman requires to satisfy his own personal ideas and which he will make sooner or later.

It has been stated that a metallurgist or metallurgical engineer should test the ore and outline the treatment system and machinery. That a mechanical engineer, working under the advice of the metallurgical engineer should design the mill and draw up the specifications. That the specifications should be submitted to the manufacturers for bids upon each item of the quality specified. And finally, that the mill should be erected by a millwright or mill erector working with the advice of the millman who is to operate the mill. This applies admirably to mills of medium and large size, but by far the greater proportion of mills vary in size between 2 and 20 stamps. In building small mills embodying only standardized stamp-milling and concentration, financial and other conditions may be considered not to warrant such extensive engineering service. In such cases the mill plans will doubtlessly be furnished by the machinery manufacturer, but the plans and specifications should be checked by the experienced men who will build and operate the mill, while the mill should be purchased on merit and individual specifications and not on a lump-sum bid.

Selection of Millsite.—The first step to be taken before starting to prepare an estimate or a mill plan is the selection of a site. As the mill must be designed to suit the site, which influences the cost of milling as well as construction, a brief discussion of the necessary characteristics will be given. It is recognized that the position of the mine and the method of treating the ore are fixed, and it lies with the engineer in charge of the proposed mill construction to make the best possible use of existing conditions as far as the selection of a millsite is concerned. As the influence of the site upon milling costs is of prime importance, the characteristics of an ideal site from this standpoint will be considered first. An ideal site should be so situated that the ore from the mine may be dumped into the mill storage bin in the least possible time, without being handled by any other than mechanical means and by as little machinery as possible, and requiring little if any power. At the same time it must be kept in mind that waste must also be drawn from the mine and carried to a suitable dump, if possible by mechanical means and with little, if any, expenditure of power. An ideal situation in this respect would be one in which the ore from the tunnel or shaft could be dumped automatically from the car or skip into the mill bin, and the waste into a chute or down an incline to a canyon or gully being both steep enough to carry it away by gravity and sufficiently large to provide storage for all the waste produced during the life of the mine. Following this, the site should be situated on a hill side of sufficient incline to permit the ore and pulp to flow by gravity through each successive stage in the treatment, and thus avoid the use of pumps or elevators for handling the pulp during the course of treatment.

The ground should be solid rock in order to provide a suitable foundation for the heavy machinery, so that it may run with a minimum of vibration, thereby reducing breakages and permitting the best possible performance to be obtained from the concentrators, which, on account of the peculiar nature of their own vibratory movement, are seriously affected by insecure foundations. The last requirement is that means should be provided for the disposal of the tailing. The storage ground or runway should have a capacity equal to the life of the mine, and should have sufficient incline to allow the tailing to flow away from the mill by gravity.

The constructor or builder, however, looks upon the question in an entirely different light. The only features of interest to him are those influencing the cost of construction. He would like a site where the ground is comparatively soft, in order to have a low cost of grading, and yet hard enough so that the cost of retaining walls and foundations could be kept down. A flat spot, as close to the millsite as possible, and large enough for a framing yard and for the storage and shaping of timber and lumber, is most desirable. Proximity to the wagon road over which the freight and material is transported is also desirable, as moving heavy material and machinery by hand is costly and is to be avoided as much as possible. The site should not be too steep so that the cost of grading becomes unnecessarily high, neither should it be too flat or an expensive and heavy timber supporting structure may have to be built. A millsite on an angle of 30°, with a leeway of 5° either way, will be found to be nearly ideal for mills that include crushers, stamps, and concentrators. In view of these facts the folly of obtaining a 'stock' plan from a manufacturer and cutting up a millsite to suit it will be apparent at once. There are very few men buying a small mill of 10 stamps who have the remotest idea of the influence of the topography of their millsite, but take a set of stock plans from the manufacturer of the machinery, and, when ready to commence construction try to find a site to fit the plan instead of making plans to fit the site. When the mine owner is ready to proceed with the construction of a mill, a surveyor should be put to work making both contours and a profile of the site of the proposed mill. With this information in hand a manufacturer or engineer can design the mill to suit the site.

Cost of Constructing Stamp-Mills.—Estimating on the cost of stamp-mill construction is not an exact science. No engineer or contractor can see far enough into the future to know beforehand what unusual or unexpected conditions will arise during the progress of construction, any of which will influence the cost of the work. The following has been written primarily for those who contemplate the erection of small mills up to 20 stamps in size. It gives the average cost of the various classes of work, and the various elements entering into construction costs are briefly pointed out, with the object in view of furnishing a basis by which a man familiar with the ground on which the mill is to be erected may prepare an intelligent estimate.

There is an idea prevalent among mining men in general that stamp-mills can be built complete and turned over in running order for $1000 per stamp. This estimate may be correct in possibly one case in a hundred, and as no two sets of conditions governing the cost of mill construction are exactly alike, the use of this formula—if it may be so called—can only result in disappointment. The figures here given are based upon California conditions of labor and climate, the rate of wages being as follows per 8-hour shift: millwrights, $5; carpenters, $4; helpers, $3; masons, $5; machinists, $4.

The elements entering into the cost of stamp-mill construction will each be treated separately, and will all be found in the following summary. This affords a good form for preparing estimates, and will be of aid in itemizing the factors which make up the total cost:

MATERIAL

Machinery f.o.b. factory.
Lumber for mill building f.o.b. shipping point.
Timber for ore-bin and battery-frame f.o.b. shipping point.
Shingles or shakes for roof.
Galvanized corrugated iron for sides and roof.
Doors.
Windows.
Building hardware.
Nails.
Cement.
Sand.
Broken rock.
Building bolts and washers.
Red brick.
Fire brick.
Fire clay.
Lime.
Tools for construction.
Freight charges on all the above from shipping point to railroad station nearest mine.
Hauling charges on all the above from railroad station to millsite.

LABOR

Framing and erecting building.
Putting on siding; shingle roof; shake roof.
Iron siding and roof.
Setting doors and windows.
Erecting machinery.
Handling building material and machinery on the ground.

Framing and erecting battery-frame; ore-bin.
Grading and excavating.
Masonry retaining walls.
Concrete retaining walls.
Wood mortar-block.
Concrete mortar-block.
Concrete foundations.
Brick setting for steam-boiler.
Superintendence.
Timekeeper and office work.
Allowance for unforseen contingencies.

MACHINERY, COST AT FACTORY.—This information is the easiest of all to obtain, and an inquiry sent to any reputable machinery manufacturer will meet with a prompt response. Modern trade catalogues are so carefully prepared and enter into so much detail that they are practically text-books on machinery construction and design. Most machinery houses maintain a competent engineering department, which will co-operate with prospective customers and assist them in making proper selection of the machinery best suited for treating their ores. Much time will be saved if prospective buyers will give the manufacturer a definite idea of conditions to be met in order that an intelligent estimate may thus be prepared. In sending an inquiry to a manufacturer for prices of mill equipment it is necessary that he should be informed as to (*a*) character of the ore; (*b*) process that is to be used; (*c*) number of tons per day of 24 hours that it is desired to treat; (*d*) fineness to which it is desired to crush; (*e*) kind of power to be used; (*f*) probability of increasing the capacity and size of the plant in the future.

If conditions require gasoline-engines for power, the altitude above sea-level at the millsite must be stated, as internal-combustion engines lose about 3% efficiency for each 1000 ft. rise above sea-level. If steam-power is to be used, the kind of fuel should be stated.

If electricity is to be used, the voltage must be stated if current is continuous; phase, voltage, and frequency must be stated if the current is alternating. If transformers are required, primary voltage and phase must be stated.

If water-power is to be used, the manufacturer must know the quantity of water available in cubic feet or gallons per minute or miner's inches, and the head in feet or vertical distance between point of intake and point of outlet. If pipe-line is already in place, length and diameter must be stated; and if not already in place, the length only will suffice.

ERECTION OF MACHINERY.—This is an item which may cost from $30 per ton upward, depending upon the skill, ingenuity, and experience of the man in charge of construction. After all orders for machinery, building material, and supplies have been placed, instructions should be sent to the various concerns furnishing material, for the purpose of arranging a systematic schedule of shipping dates, so as to have the machinery and other material arrive on the ground as nearly as possible in the sequence in which it is required. There is seldom any gain in attempting to rush all shipments indiscriminately, as the confusion and chaos on the ground will result in more lost time and delay than is gained by quick though unsystematic shipments. If foundations are ready for the heavy machinery, the latter can be lifted direct from wagons and set in its proper place in the mill; otherwise it may have to be handled two or three times, and each time it is handled it costs money.

Bolts, washers, and small fittings when unpacked from shipping cases should be systematically arranged according to size; this can be attended to by a boy or laborer when not engaged on more urgent work. Often a $5-per-day man will spend an hour looking through a pile of small parts for a bolt, which should have had its place and been in it. Manufacturers generally send out a detailed statement with each shipment showing the contents of each package and case, so there is no excuse for waiting until a job is nearly ready to turn over and then find that the work must be hung up and a crew of men stand around idle, waiting for some small detail or missing part which may have been overlooked at the factory or lost by careless unpacking of material. Small parts and fittings liable to be lost or damaged by exposure to the weather should be housed. Even the crudest kind of a shed will save its cost many times over during construction of the plant. Building material, lumber, etc., should receive the same care and systematic handling as machinery and supplies. It is surprising how much time and money can be saved by a little foresight in this direction. A suitable framing yard should be prepared, as near the millsite as possible, in which all lumber can be systematically stacked on arrival according to width, thickness, and length, and where all framing can be done. Carrying lumber, heavy timbers, etc., back and forth by manual labor and trying to make a good job of framing when working on a side-hill are not compatible with low costs. When a man has spent much of his time and money in developing a prospect, and then has spent more time and hard work in financing his company, it can be readily understood why he is impatient to get started, but he should stop to consider that it nearly always costs as much money to try to force work ahead at a pace faster than circumstances will permit, as it would to go to the other extreme and delay matters.

FREIGHT AND HANDLING.—These two items are governed entirely by local conditions, and no general information on this subject can be given; therefore, calculations must necessarily be made in each case according to circumstances.

LUMBER FOR MILL BUILDING.—The first cost of lumber is governed by local conditions and by the prevailing market price existing at the time the order is placed. The labor cost is also a variable factor, depending upon local conditions and the individuality of the workman himself, but the following rates will give a fairly close average approximation:

Framing and erecting mill buildings up to 30 ft. in height, $25 per M board-feet.

Framing and erecting mill buildings 30 ft. in height and upward, including setting roof-trusses, $35 per M board-feet.

Putting on 1-in. rough siding, battened, laying wood floor, etc., $20 per M board-feet.

It has been found by actual experience that a workman can work about half as fast at a height of 30 ft. or over as he can when below that point, and for this reason roof-trusses should always be framed and put together complete on the ground, then hoisted into place and fastened, rather than be put together in position by piece-meal.

Underestimating the quantity of lumber required is a mistake frequently made. The principal cause of this is that the inexperienced estimator figures merely the superficial area to be covered and the net lengths of the timbers for the building framework, whereas lumber is always cut in mill standard lengths, breadths, and thicknesses, and will have to be ordered accordingly. A wise precaution is to obtain such a list from the lumber dealer before commencing to figure the lumber bill. The dealer, however, does not always carry in stock all of the sizes listed. Inform yourself as to exactly what sizes are carried and make your calculations accordingly. If the concentrator room, for instance, is shown 10 ft. 6 in. high on the plans, every post, piece of siding, and batten will have to be ordered 12 ft. long as there is no intermediate length made between 10 and 12 ft. Any normal surplus of lumber remaining after completion of the mill will soon be used for other purposes.

Such items as launders and lumber for concrete forms are also frequently omitted in estimates, and yet require an appreciable quantity of lumber. Another item that is a frequent source of underestimation is the cost of freight and hauling lumber. Dry pine lumber weighs about 3¼ lb. per board-foot. It is stored out in the open, exposed to all kinds of weather. It has a wonderful capacity for absorbing moisture, and while dry lumber may and does weigh about 3¼ lb. per board-foot, wet lumber often weighs 50% over this amount. A simple expedient is to ask the lumber dealer to quote, delivered at destination. This course will protect you, and perhaps save a shock when you come to compare actual cost with your estimate.

The table on the opposite page will be of assistance in figuring lumber bills and the quantity required.

ORE-BIN AND BATTERY-FRAME.—The same remarks as regards first cost of material apply in this case as in that for lumber for the mill building proper. Dressed timber need not necessarily be used, although many builders prefer it on account of appearances. Occasionally builders prefer to have the timber furnished already cut and framed where machine tools are available, on the ground of economy, but it is questionable whether this course pays in the long run, since sufficient stock must always be left to allow for trimming when lining up the frame, camshaft bearings, and guide girts, which work cannot be done until the machinery is actually in course of erection. The cost of framing and erecting a battery-frame and ore-bin, including planking, is about $35 per M board-feet.

SHINGLES FOR ROOFING.—The following schedule will apply to ordinary mill roofs, 250 shingles being 1 bundle: Using pine shingles with 4 in. exposed to the weather, 1000 shingles per square will be required, weighing approximately 245 lb. If 6 in. be exposed to the weather, 670 shingles per square will be required, weighing approximately 165 lb. Sheathing should be 4 in. wide and spaced 4 in. apart. A square equals 10 by 10 ft., or 100 sq. ft. Labor cost per square is approximately $1.50.

SHAKES FOR ROOFING.—There is quite a variation in the size of shakes as furnished by the different mills, but the ordinary shake may be considered to be 6 in. wide and from 32 to 36 in. long. With 10 in. exposed to the weather, 250 shakes per square will be required. Sheathing should be 6 in. wide and spaced 5 in. apart. Labor cost per square is approximately $1.25.

DOORS AND WINDOWS.—The ordinary 12-light, 10 by 12-in., single windows are ordinarily used, the price varying according to local conditions. Labor cost of setting windows is approximately $1.50 each. Plain doors, 2 ft. 8 in. by 6 ft. 8¾ in., will vary in cost according to local conditions. Labor cost of setting is approximately $1.50 each. Ordinary plain hardware used on windows and doors should not cost to exceed $2.50 per door or window.

Number of Feet, Board Measure, in Lumber of Various Sizes

	Length in feet.							
Size in inches.	10.	12.	14.	16.	18.	20.	22.	24.
1 by 2	1⅔	2	2⅓	2⅔	3	3⅓	3⅔	4
1 by 3	2½	3	3½	4	4½	5	5½	6
1 by 4	3⅓	4	4⅔	5⅓	6	6⅔	7⅓	8
1 by 5	4⅙	5	5⅚	6⅔	7⅓	8⅓	9⅙	10
1 by 6	5	6	7	8	9	10	11	12
1 by 7	5⅚	7	8⅙	9⅓	10⅓	11⅔	12⅚	14
1 by 8	6⅔	8	9⅓	10⅔	12	13⅓	14⅔	16
1 by 10	8⅓	10	11⅔	13⅓	15	16⅔	18⅓	20
1 by 12	10	12	14	16	18	20	22	24
1 by 14	11⅔	14	16⅓	18⅔	21	23⅓	25⅔	28
1 by 16	13⅓	16	18⅔	21⅓	24	26⅔	29⅓	32
1 by 18	15	18	21	24	27	30	33	36
1 by 20	16⅔	20	23⅓	26⅔	30	33⅓	36⅔	40
1¼ by 4	4⅙	5	5⅚	6⅔	7½	8⅔	9⅙	10
1¼ by 6	6¼	7½	8¾	10	11¼	12½	13¾	15
1¼ by 8	8⅓	10	11⅔	13⅓	15	16⅔	18⅓	20
1¼ by 10	10 5/12	12½	14 7/12	16⅔	18¾	20 5/6	22 11/12	25
1¼ by 12	12½	15	17½	20	22½	25	27½	30
1½ by 4	5	6	7	8	9	10	11	12
1½ by 6	7½	9	10½	12	13½	15	16½	18
1½ by 8	10	12	14	16	18	20	22	24
1½ by 10	12½	15	17½	20	22½	25	27½	30
1½ by 12	15	18	21	24	27	30	33	36
2 by 4	6⅔	8	9⅓	10⅔	12	13⅓	14⅔	16
2 by 6	10	12	14	16	18	20	22	24
2 by 8	13½	16	18⅔	21⅓	24	26⅔	29⅓	32
2 by 10	16⅔	20	23⅓	26⅔	30	33⅓	36⅔	40
2 by 12	20	24	28	32	36	40	44	48
2 by 14	23⅓	28	32⅔	37½	42	46⅔	51⅓	56
2 by 16	26⅔	32	37½	42⅔	48	53⅓	58⅔	64
2½ by 12	25	30	35	40	45	50	55	60
2½ by 14	29⅙	35	40⅚	46⅔	52½	58⅓	64⅙	70
2½ by 16	33½	40	46⅔	53⅓	60	66⅔	73⅓	80
3 by 6	15	18	21	24	27	30	33	36
3 by 8	20	24	28	32	36	40	44	48
3 by 10	25	30	35	40	45	50	55	60
3 by 12	30	36	42	48	54	60	66	72
3 by 14	35	42	49	56	63	70	77	84
3 by 16	40	48	56	64	72	80	88	96
4 by 4	13⅓	16	18⅔	21⅓	24	26⅔	29⅓	32
4 by 6	20	24	28	32	36	40	44	48
4 by 8	26⅔	32	37⅓	42⅔	48	53⅓	58⅔	64
4 by 10	33½	40	46⅔	53⅓	60	66⅔	73⅓	80
4 by 12	40	48	56	64	72	80	88	96
4 by 14	46⅔	56	65⅓	74⅔	64	93⅓	102⅔	112
6 by 8	30	36	42	48	54	60	66	72
6 by 8	40	48	56	64	72	80	88	96
6 by 10	50	60	70	80	90	100	110	120
6 by 12	60	72	84	96	108	120	132	144
6 by 14	70	84	98	112	126	140	154	168
6 by 16	80	96	112	128	144	160	176	192
8 by 8	53⅓	64	74⅔	85⅓	96	106⅔	117⅓	128
8 by 10	66⅔	80	93½	106⅔	120	133⅓	146⅔	160
8 by 12	80	96	112	128	144	160	176	192
8 by 14	93⅓	112	130⅔	149⅓	168	186⅔	205⅓	224
10 by 10	83⅓	100	116⅔	133½	150	166⅔	183⅓	200
10 by 12	100	120	140	160	180	200	220	240
10 by 14	116⅔	140	163⅓	186⅔	210	233⅓	256⅔	280
10 by 16	133⅓	160	186⅔	213⅓	240	266⅔	293⅓	320
12 by 12	120	144	168	192	216	240	264	288
12 by 14	140	168	196	224	252	280	308	336
12 by 16	160	192	224	256	288	320	352	384
14 by 14	163⅓	196	228⅔	261⅓	294	326⅔	359⅓	392
14 by 16	186⅔	224	261⅓	298⅔	336	373½	410⅔	448

IRON BUILDING.—In many localities, particularly the desert country, where lumber is scarce and the cost is correspondingly high, galvanized corrugated iron, and sometimes flat painted iron sheets, are used for the sides and roofs of buildings. The price of this material varies with market conditions and locality. The following table will be of assistance in making calculations as to the quantity required:

NUMBER OF CORRUGATED SHEETS PER SQUARE

Length of sheet, inches.	3-in. corrugations. Width flat, 31 in. Width after corrugating, 28 in. Net covering width, 24 inches	2½-in. corrugations. Width flat, 30 in. Width after corrugating, 27 in. Net covering width, 24 inches	1¼-in. corrugations. Width flat, 30 in. Width after corrugating, 26 in. Net covering width, 24½ inches
60	8.572	8.888	9.231
72	7.143	7.407	7.692
84	6.122	6.349	6.593
96	5.357	5.555	5.769
108	4.762	4.938	5.128
120	4.286	4.444	4.616

If material is painted, add 20 lb. per square to allow for paint. No. 26 is the gauge usually used for both roof and sides, although No. 28 sides are sometimes deemed heavy enough. The labor cost for fastening roof and sides is approximately $1.25 per square.

WEIGHT OF CORRUGATED SHEETS PER SQUARE

	Black			Galvanized		
Gauge.	3-in. cor.	2½-in. cor.	1¼-in. cor.	3-in. cor.	2½ in. cor.	1¼ in. cor.
20	166	167	170	183	184	187
21	152	153	156	170	170	173
22	138	139	142	156	156	159
23	125	125	127	142	142	145
24	111	111	113	128	128	131
25	97	97	99	114	115	117
26	83	83	85	100	101	103
27	76	76	78	93	94	96
28	69	69	71	86	87	88

NAILS.—The quantity of nails of each size required for each class of work may be fairly accurately calculated, provided that there is no excessive waste, and the following tabulation will be found to be close enough for all ordinary purposes:

For each:	Use: Pounds.	Size.
1000 shingles	4	4d
	3½	3d
1000 laths	6	3d
1000 ft. clapboarding	18	6d box nails

For each:	Use: Pounds.	Size.
1000 ft. siding	20	8d
	25	10d
10 ft. partition shedding	1	10d
1000 ft. 1 by 3 flooring	45	10d
1000 ft. 1 by 2 flooring	65	10d
1000 ft. pine finish	30	8d
250 shakes	2½	5d

STANDARD STEEL WIRE NAILS

Size.	Length.	Gauge No.	Approx. No per lb.
2	1	15	876
3	1¼	14	568
4	1½	12½	316
5	1¾	12½	271
6	2	11½	181
7	2¼	11½	161
8	2½	10¼	106
9	2¾	10¼	96
10	3	9	69
12	3¼	9	63
16	3½	8	49
20	4	6	31
30	4½	5	24
40	5	4	18
50	5½	3	14
60	6	2	11

(Note.—100 lb. equals 1 keg.)

SHINGLE NAILS

Size.	Length.	Gauge No.	Approx. No. per lb.
3	1¼	13	429
4	1½	12	274
5	1¾	12	235
6	2	12	204
7	2¼	11	139
8	2½	11	125
9	2¾	11	114
10	3	10	83

A special barbed galvanized nail is used for attaching corrugated or painted sheets to wood-frame buildings, and is driven first through a lead washer, then through the iron into the wood frame. In this work 1½ lb. of 2-in. No. 9 galvanized barbed nails are sufficient for one square; 325 lead washers, weighing 1 lb., are sufficient for about two squares.

BUILDING BOLTS.—As this item is one that is subject to great variation, depending upon the ideas of individual mill designers, it is difficult to give information that will be even approximately correct without publishing mill drawings also. In the treatment of free-milling gold ores by amalgamation only, the building bolts for a 5-stamp mill will weigh approximately 500 lb.; a 10-stamp mill, 1000 lb.; a 20-stamp mill, 2000 lb. It is quite possible to design an excellent building in which building bolts are almost entirely omitted, and it should be understood that the above information should be used for what it is worth and no more. It is a comparatively simple task to calculate the number and cost of bolts required when drawings are made and submitted by the designer.

GRADING AND EXCAVATING.—This is the most difficult of all to treat in generalities, as the following factors are commonly all vital as far as costs are concerned and vary widely in each locality: (*a*) cost of labor; (*b*) character of the ground; (*c*) cost of powder, fuse, and caps on the ground; (*d*) whether machine drills or hand drills are used. The average millsite has an overburden of earth of varying thickness which can ordinarily be moved by hand-picking and shoveling, with possibly a few shots to loosen it thoroughly. On ground of this nature one man can remove about 10 yd. in an 8-hour day, but if it must be handled in wheelbarrows for any considerable distance, the cost will probably equal $1.25 to $1.50 per yard. On solid rock, however, where the rock is hard and tough and does not shatter readily, and where hand-drilling is necessary, one yard for two men per day will be as much as could be expected; especially if the rock must be bulldozed after breaking in order to get it down to pieces small enough to be shoveled by hand and hauled away in wheelbarrows. These two cases illustrate the extremes in the cost of grading, and costs covering average conditions will be somewhere between these two. A mill grade of large size has been made as cheaply as $1.50 per yard for the shooting ground where all conditions were exceptionally favorable.

POWDER REQUIRED.—In one specific case, shooting fairly hard rock, 3420 yd. required 750 lb. of 40% giant, and 800 lb. of 60% giant for bulldozing. The fuse cost about 2c. per yard and caps 1c. per yard. When the mine-owner has carried his underground development far enough along to warrant fully his considering the purchase and construction of a mill, he will have had sufficient experience in breaking his own ground to calculate the cost of his mill grading accurately.

RETAINING WALLS AND FOUNDATIONS.—Retaining walls are not required unless the ground is of such a character that it will not stand without them. They may be built either of masonry or concrete, depending entirely upon the material available on the ground That required for concrete walls is rock (hard, sharply broken, and absolutely free from dirt, clay, or other foreign substances), clean sharp sand, first quality portland cement, and water. Another combination sometimes used is broken rock, sand, gravel, cement, and water, and while this latter will answer for retaining walls, it is not as satisfactory for machinery foundations or mortar-blocks as the first combination given.

Walls are calculated by the perch, a perch being 16½ by 1½ by 1 ft. and containing 24¾ cu. ft. To make one perch, use 2500 lb. of broken rock, 1250 lb. of sand, and 625 lb. of cement. The proportions ordinarily used are 1:2:4 for cement, sand, and broken rock and 1:2:4:8 for cement, sand, gravel, and broken rock. Lime is sometimes used instead of cement on account of its cheapness, but it does not give nearly as great strength or permanency as cement.

The following cost of retaining walls for a 40-stamp mill built in Arizona will give an idea of the cost of this type of construction

	Perch.
Concentrator-room wall contained	135
Battery-room wall contained	371
Total	506
Cost of the above was made up as follows:	
68½ bbl. of lime cost, delivered	$157
63 cu. yd. of sand cost, delivered	50
Labor: mason 59 days, helper 161 days, cost	668
Total	$875

Cost per perch, $1.72.

(Note.—Broken rock was available on the ground without charge.)

Concrete foundations ordinarily cost from $6.50 to $7.50 per cubic yard finished, when cement costs $3.50 per barrel delivered; labor, $2.25 per yard; and boxes, $0.40 per yard. A barrel of cement weighs 400 lb., and is equivalent to 4 sacks containing 1 cu. ft. each.

A man inexperienced in concrete work should not attempt to select rock, sand, or gravel for this purpose, but should obtain the advice of some one familiar with the requirements of this work. Otherwise failure is altogether likely to follow. Not all rock is suitable, by any means, and care in selecting raw material will be repaid in the superior quality of the finished product.

CONCRETE FLOORS.—Concrete floors are generally made 4 in. thick and require no forms or boxes, but are made from the regular concrete mixtures already mentioned, with a thin top-dressing of a thick cement grouting to give a smooth finish. The following case will give a fair general average idea as to what may be expected for cost of concrete floors:

Floor contained 6680 sq. ft., 4 in. thick. To make this floor required:

76 bbl. of cement costing delivered	$406
Labor: mason 40 days, helper 80 days, costing	375
Total	$781

Average cost per 100 sq. ft., $12.

(Note.—Broken rock and sand were available on the ground without charge.)

STEAM-BOILER SETTING.—Every boiler manufacturer has his own designs for boiler setting and publishes a schedule for the number of brick and fire-brick required, but the following table will answer for approximate estimates to cover the setting of single tubular boilers with half fronts:

Diameter, inches.	Length, feet.	Horse-power.	No. red brick.	No. fire-brick.
30	7	10	6,000	550
30	8	12	6,200	550
36	8	15	6,700	650
36	10	20	7,050	720
42	10	25	8,700	770
44	10	30	8,800	880
44	12	35	9,300	940
44	14	40	10,800	1020
48	14	45	12,900	1140
48	15	50	13,700	1140
54	15	60	14,200	1270
54	16	70	15,000	1270
60	16	80	21,500	1540
60	16	100	25,000	1900

In making comparisons between boilers designed for a brick setting as compared with the locomotive fire-box and the internally fired types, the latter should always be considered as requiring a covering of asbestos 2 or 3 in. thick in order to reduce the radiation losses and keep the fuel consumption down. Common red brick weigh 5 lb. each, and standard fire-brick 7 lb. each. A 4½-in. wall equals 7 brick per square foot of surface; a 9-in. wall equals 14; a 13-in., 20; 18-in., 26½; 21-in., 33; 27-in., 39½ brick. The weight of walls is 112 lb. per cubic foot in red-brick work and 150 lb. in fire-brick work. A cubic foot of red-brick work equals 17.9 in. straight brick, and 1 cu. ft. of silica-brick work weighs 130 lb. In making estimates on red-brick work, consider that 9 cu. ft. of sand and 3 bushels of lime will lay 1000 brick, and that 250 to 350 lb. of fire-clay or silica cement will lay 1000 fire-brick. A bricklayer will ordinarily lay from 1200 to 1500 brick per day of 8 hours.

CONCRETE MORTAR-BLOCKS.—As there are many different ideas as to method of construction and proportions of material to be used, there will be given three specific instances of blocks which have been built and in use for a sufficient number of years to determine their practicability. They represent what may be considered as typical cases, and will give fair average conditions between the cheaper and simpler forms of blocks and the more elaborate and expensive.

The first case to be given covers the blocks used for a 40-stamp mill, which after ten years continuous operation have proved perfectly satisfactory. The stamps weighed 1000 lb. each when new, and drop 100 times per minute. The blocks themselves were not monolithic, but were divided, the type of construction being the usual one with battery-posts going down beside the blocks and setting on short wooden streak sills. The monolithic type of block, however, in which the mortar foundation for the stamp-mill, regardless of the number of stamps, is in one piece and flush all along the top and having the battery-posts setting in cast iron shoes, is preferable. In the case cited, each block contained 6⅔ cu. yd. The concrete was mixed in nine batches, the first eight in the proportion of 12 cu. ft. of broken rock, 9 cu. ft. of sand, and 3 cu. ft. of cement. The ninth batch, forming the top, was slightly richer and was mixed in proportion of 12 cu. ft. of broken rock, 9 cu. ft. of sand, and 4 cu. ft. of cement. For reinforcing, old wire cable was used, it being wrapped around the mortar foundation bolts for each batch of concrete. Cost was made up as follows:

Cement, 55½ bbl., cost delivered	$296
Handling sand and stone	16
Labor: mason 8 days, helper 28½ days	115
Total	$427

Average cost of each block, $53.38.

(Note.—Sand and broken rock were available at the millsite without charge.)

Had wooden blocks been used, the cost under the same circumstances would have been as follows:

Lumber, 13 M. ft., cost delivered	$481
Planing and setting	200
Total	$681

Average cost of each block, $85.10.

For the second case, the data following cover mortar-blocks for a 100-stamp mill, which is considered to be one of the best, if not the best, built mills in the United States, everything being built and designed with the idea of absolute permanency.

A 2-horse team at $8.50 per day hauled 1 yd. of broken rock or sand per load. A 4-horse team at $14 per day hauled 3 yd. of broken rock or sand per load. Eight loads in either case constituted a day's work. Proportions used for concrete mixture were 1 part cement, 3.6 parts sand, 3.67 parts broken rock. The battery-blocks contained a total of 108 yd. and cost $11.82 per yard, the cost being made up as follows:

Cement	$ 5.03
Rock	1.06
Rock sand	0.67
Pit sand	0.45
Labor	1.32
Forms	2.76
Engineering and superintending	0.15
Reinforcing	0.38
Total cost per yard	$11.82

Average cost of each block, $63.83.

The third case covers South African practice, the proportions used being 22½ cu. ft. of 2-in. broken rock, 7 cu. ft. of ½-in. broken rock, 13 cu. ft. of washed sand, and 1⅛ bbl. of cement, making 1 yd. of concrete. For the last 2 ft. from the top, 1¾ bbl. of cement was used, the other proportion remaining the same.

UNFORESEEN CONTINGENCIES.—This is an item for which no arbitrary method of figuring can be given, but which, nevertheless, forms an essential point to be considered in making up an estimate. The unforeseen always happens, and, incidentally, invariably adds to construction costs. The estimator must make an allowance to cover the unexpected happening, according to the situation on the ground in each particular case. When mill construction commences late in the season, allowance should be made for increased cost of working in stormy weather. An early rainstorm plays havoc all around, holds up freight teams, damages material not under cover, keeps men from their work in the open, and in other ways increases costs. The matter of systematic handling of shipments and material has already been mentioned, and figures given for construction costs have been based upon the intelligent and systematic handling of all work.

By way of illustration of adverse conditions, take the case of figures given on framing mill buildings, $25 per M board-feet. Assume that the wagon-road terminates at the bottom of a hill and that the lumber and material has to be carried up the hill to the millsite for a distance of 500 ft.; 1000 ft. of dry lumber weighs approximately 3250 lb.; one man could handle about 100 lb. by hand and carry it up a 20° slope at the rate of 50 ft. per minute; 20 minutes would be consumed on a round trip, and counting the time lost by resting, etc., two trips per hour would be about the average for an 8-hour day. The cost, therefore, of getting the lumber to the millsite after the teams had discharged their load would be about $6 per M ft., which is about 25% increase in the total amount allowed for framing and erecting; and if such a condition as outlined should exist, 25% would have to be added to the estimated total cost of framing to cover this contingency. The same condition would obtain should the situation on the ground prevent the machinery from being hauled any closer to the millsite, and, as the figures given do not cover any such unusual contingency, it is obvious that a careful study of local conditions must be made in each individual case to arrive at a reasonably close estimate as to what the extra cost will be to cover the handling of the material on the ground as an item separate and apart from the cost of construction and erection.

On small mills up to 20 stamps in size, the amount of material to be handled would hardly justify the purchase of an elaborate outfit of construction tools and apparatus, such as power-operated derricks. Therefore appliances for lifting machinery and building material in general would consist of the usual block and tackle, gin pole, a good hand-winch, chain-block, timber dollies, and rollers. Everything would have to be man-handled from the time it is dumped off the teamster's wagon to the time when the mill is ready to start operating.

INDEX

A

Page.

Acid on mercury..107, 108, 138, 140
 plates 138, 141, 142
Aerial tramway................ 11
Air-compressor in mill.......... 180
Amalgam, amount of gold in... 152
 cleaning 144, 148
 nature and kinds of........ 107
 retorting 150
 silver 139, 142
 sodium....139, 141, 143, 152, 163
 squeezer 145
 stealing 177
Amalgamated gold pan....145, 168
Amalgamation 105
 after heavy stamps........ 95
 away from mortar......... 136
 chemicals in 140
 dry and wet...............
 ....116, 120, 124, 139, 144
 feeding mercury........112, 122
 in cyanide solution.127, 170, 173
 inside 34, 109, 110, 126, 176
 loss of gold in............. 161
 loss of gold in sulphide.... 162
 on apron-plate ....
 ....116, 118, 124, 126, 131
 on inside plates ...109, 110, 113
 on sluice-plate 134
 on splash and lip plates.114, 146
 outside 125
 principles of 109, 116
 secondary 172
 test 167
 tools for 120
 water required 128
Amalgamator, patent 135, 163
Anchor bolts of mortar....... 30
Annealing graphite crucible... 152
 stem 54
Anvil, iron, for mortar block.. 31
Apron-plate, amalgamation in
 cyanide solution on.....
 .... 127, 170, 173
 amalgamation on ....
 ...... 116, 118, 124, 126, 131
 away from mortar......... 136
 clean-up of 118, 125, 146
 construction of 132
 cyanide on....131, 138, 140, 143
 dressing the...118, 124, 126, 131
 drops in 132
 fall of 129
 hard or stained 142
 preparation for use........ 138
 scouring of 130
 shaking 132
 silvered *v.* raw copper..137, 139
Arrangement of batteries...... 191

B

Page.

Babbitting cam-shaft box...62, 63
Back-knee battery-frame 24
Barrel, clean-up 148
Batea 149
Battery-frame 24, 26
 post, bed-plate for.......... 32
 pulley, sectionalized 201
Belt-tightener 25
Bin, arrangement of........12, 19
Blake crusher 14, 202
Block, mortar. See mortar-block.
Boiler-setting, cost of......... 222
Bosshead 44
 fastening stem in.......... 56
 iron *v.* steel............... 45
 repairing 44
 sectionalized 200
Box, cam-shaft 62, 63
 distributing.....36, 95, 115, 134
Brass-wire screen 80
Breakage of stem and cam-shaft
 ....27, 32, 53-56, 61, 194
Breaker. See crusher.
Bullion, cleaning 156
 melting 153
 mold 155
 sampling 156
Buying a mill................ 206

C

Cam 50
 design of 51
 right and left-hand........ 50
 self-tightening 65, 67
 stick 68
Camming 48, 56
Cam-shaft 61
 box 62, 63
 box, babbitting 62, 63
 breakage 27, 32, 61, 194
 changing 64
 collar for 51, 63
 for 5-stamp batteries.51, 63, 194
 hollow 200
 iron *v.* steel............... 61
 manufacture 194
 sectionalized 200
Challenge feeder 69
Change-room 183
Changing cam-shaft 64
 stem 58
Chemicals on plates 140
Chilean mill 172, 175, 196
Choked mortar......44, 56, 85, 113
Chuck-block 39, 98, 110
 plate 98, 110, 113
Clamp for setting tappet....49, 50

Page.
Cleaning amalgam 144, 148
bullion bars 156
Clean-up, apron-plate..118, 125, 146
barrel 148
inside plates 111
pan 149
room 183
splash and lip-plates 146
the general 146
Collar for cam-shaft........51, 63
Concentration, crushing for ... 97
Concrete floor 183
cost of 221
Concrete mortar-block. See mortar-block.
Construction costs of stamp-mill 211
Copper plate, raw 137, 139
silvered 137, 139
Cost of boiler-setting 222
concrete floor 221
constructing stamp-mills ... 211
grading and excavating 220
hardware 216
lumber 215
machinery and its erection. 213
mortar-block 223
stamp-mill 196
walls and foundations...... 220
Counterbore of tappet........ 46
Crucible, graphite 152
treatment of discarded..... 156
Crusher, arrangement of 15
Blake *v.* gyratory 14, 202
feeder for 18
solid *v.* the sectional-frame Blake 15, 16, 202
Crushing for concentration.... 97
in cyanide solution 81, 127, 165, 171, 173
in cyanide solution, lime encrustation 81, 85
principles of stamp 86
Crystallization of stem and cam-shaft 53, 61, 195
Cupping of shoe and die....42, 52
Cyanidation, amalgamation in solution 127, 170, 173
banking tailing for 187
crushing in solution 170, 173
general 169, 171, 178
mercury in 127
Cyanide on plates.131, 138, 140, 143
mercury...107, 108, 127, 131, ... 138, 140
Cyanide solution, amalgamation in 127, 170, 173
crushing in .....81, 85, 127, ... 165, 170, 173

D

Design of cam 51
mill 167, 174, 207
tappet 46, 52
Die 40
care of 42
cupping of 42, 52
false 38
placing in mortar 39, 42
steel *v.* iron 40
Discharge, height of.34, 40, 97, 111
Distributing box ...36, 95, 115, 134
Double-discharge mortar ...36, 102
Dressing apron-plate 118, 124, 126, 131
apron-plate, the initial..... 138
inside plates 112
lip and splash-plates 115
Drop, adjusting height of..... 60
height required 87
in apron table 132
influence of higher drop on tonnage 89
order of 65
speed of 88
Dry amalgamation....116, 124, 139
Dynamite, use of 43, 59

E

Electro-magnet in rock-breaking 18
Emery wheel in mill 47
Excavating, cost of 220

F

Fall of apron-plate 129
False die 38
shoe for increasing weight. 92, 200
Farm made of tailing......... 188
Fatigue of stem and cam-shaft 54, 61, 195
Feeder for mortar 69
rock-breaker 18
Feeding mercury 112, 122
the mortar 98, 112
Fine-grinding 86, 169, 173, 175
Finger jack 68
Five-stamp cam-shaft ...51, 63, 194
Float gold 161, 162
Floor, concrete 183
concrete, cost of 221
Floured mercury 108, 127
Fluxes in bullion melting..... 153
Foundations, cost of 220
Frame of battery 24, 26
Frenier sand pump 185
Front-knee battery-frame 26

G

Gasoline engine, loss of efficiency 213
Gib, tappet 46, 47

Page.
Gilpin County, Colo., practice.. .... 9, 52, 97, 162, 164
Goldfield Consolidated mill..30, 121
Gold from old slag. screens, etc. 156
Gold in amalgamating plates.. .... 138, 139
Grade of apron-plate 129
Grading, cost of 220
Graphite crucible 152
  treatment of discarded..... 156
Grinding pan or mill..164, 172, 175
Grizzly 15, 22
Grouting concrete mortar-block 30
Guide, stem 55, 67
Gyratory crusher 14, 202

H

Hard amalgamating plate..... 142
Hearing, loss of in mill...... 185
Heavy stamp 90, 94, 195
  amalgamation after 95
Height of discharge..34, 40, 97, 111
  drop, adjusting 60
  drop, influence on tonnage. 89
  drop, required 87
Hollow cam-shaft 200
Homestake mill 123
Homestake mortar 35

I

Increasing size of mill......22, 175
  weight of stamp 92, 200
Individual stamp 101, 126
Inside amalgamation 34, 109, 110, 126, 176
  plates 109, 110
Iron for bosshead 45
  cam-shaft 61
  shoe and die 40
  stem 55
Iron mortar-block anvil 31

K

Key, tappet 46, 47, 50

L

Launder, grade of 186
Law of millsite location 13
Lime encrustation from cyanide solution 81, 85
Liner for mortar 34, 38
Line-shaft 25
Lip-plate 114, 146
Location of mill............11, 210
Loss of gold in amalgamation. 161
  hearing 185
  mercury 127
Lumber, cost of 215

M

Page.
Machinery, cost of 213
  manufacturers 207
  sectionalized 198
Management of mill 181
Matte in melting 154
Melting bullion and fluxes 153
Mercury and acid.107, 108, 138, 140
  and cyanide solution...... ...107, 108, 127, 131, 138, 140
  care of 108
  feeding 112, 122
  floured and sickened...108, 127
  impure 108
  loss of 127
  properties of 107
  salivation by 125
  trap 135
Mesh, definition of 75
  of perforated screens 75
Mill, buying a 206
  Chilean 172, 175, 196
  cost of construction 211
  design of 167, 174, 207
  grinding 164, 172, 175
  location of 11, 210
  loss of hearing in 185
  management 181
  records 181
  talking in 184
  tests 165
  sampling 69, 169
Milling systems 170
Millmen and mill crews...... 176
Millsite, law on location of... 13
Mortar 34
  anchor bolts for 30
  choked 44, 56, 85, 113
  double-discharge 36, 102
  Homestake 35
  feeding the 98, 112
  liner for 34, 38
  open-front 36, 39, 59
  rapid-crushing 34
  repairing 37
  rubber sheet beneath 31
  sectionalized 38, 198
  splash and wave 98, 110
  wood in 98, 156
Mortar-block 27
  anchor bolts of 30
  concrete 27, 56
  cost of 223
  grouting concrete 30
  iron anvil for 31
  wood 27, 32, 56
Mold for bullion melting 155

N

Nevada Hills mill 115
North Star mill 117

O

Page.
Open-front mortar 36, 39, 59
Order of drop 65
Ore-bin 12, 18-22
Outside amalgamation 125
Overstamping 161, 162, 164

P

Painting interior of mill 13
Pan, clean-up 149
grinding 164, 172
Perforated or plate screen.72-75, 81
Plate. See apron, lip, splash, and inside plates, and amalgamation.
Pond, tailing 186
Power required 88, 99
table of 100
Pulley, battery, sectionalized... 201
Pumping tailing 185
Purchasing a mill 206

Q

Quicksilver. See mercury.

R

Raw copper plate 137, 139
Records in mills 181
Retaining walls, cost of 220
Retort 150
Retorting amalgam 150
Rock-breaker. See crusher.
Room, clean-up and change.... 183
Rotation of stamp 48, 52
Round *v.* slotted-opening screens 74, 81
Rubber sheet beneath mortar. 31
Rusty gold 97, 161, 163
Russia iron screen 73, 81

S

Salivation 125
Sampling bullion 156
from feeder 69, 169
tailing 170
Scouring of apron-plate 130
chuck-block plate 111, 113
Screen 72
brass-wire 80
care of 82
frame 83
mesh of 75
perforated or plate...72-75, 81
round *v.* slotted-opening.74, 81
Russia iron 73, 81
size, table of perforated... 75
standard testing 77
tinned iron 73, 81
Ton-Cap 78, 81
Page.
test 165
treatment of discarded 156
woven-wire 75-80, 81
Secondary amalgamation 172
Sectionalized battery-pulley ... 201
bosshead 200
cam-shaft 200
machinery 198
mortar 38, 198
stem 200
Self-tightening cam 65, 67
Settler, water 187
Setting tappet 48
Shaking plate 132
Shoe 40, 42
coming loose 43, 44, 56
cupping of 42, 52
false, for increasing weight. 92, 200
putting on 43
removing 43
steel *v.* iron 40
wedges for 43, 44
Sickened mercury 108, 127
Silver amalgam 139, 142
Silvered plate 137, 139
Sizing test 164, 165
Slag in melting 154
treatment of old 156
Slime, definition of 165
Sliming 86, 169, 173, 175
Slipping tappet 47, 48, 70
Slotted *v.* round-opening screen 74, 81
Sluice-plate 134
Sodium amalgam 139, 141, 143, 152, 163
Solution, cyanide. See cyanide and cyanidation.
Speed of drop 88
Splash board 112, 114
mortar 98, 110
plate 114, 146
Squeezing amalgam 145
Stains on plate 142
Stamphead. See bosshead.
Stamp, individual 101, 126
heavy 90, 94, 195
Stealing amalgam 177
Steel for bosshead 45
cam-shaft 61
shoe and die 40
stem 55
Stem 53
annealing 54
breakage 27, 32, 53-56
changing 58
fastening in bosshead 56
guide 55, 67
sectionalized 200
steel *v.* iron 55
Sweating plate 125, 139
Systems of milling 170

T

Page.
Table, apron, construction of.. 132
of data on stamp parts...92, 94
of power required 100
of size of perforated screens 75
of testing screens 77
Tail-box 135
Tailing disposal 13
handling 185
impounding 186
made into garden 188
sampling 170
Talking in mill 184
Tappet 46, 52
clamp for setting 49, 50
counterbore 46
gib 46, 47
key 46, 47, 50
setting 48
slipping 47, 48, 70
Test, amalgamation 167
mill 165
sizing 164, 165
Testing screen, standard 77
Tinned-iron screen 73, 81
Ton-Cap screen 78, 81
Page.
Tools for amalgamation 120
Trap, mercury 135
Treadwell mill 119
Treasure-box 135, 145
Trommel 18
Tube-milling 86, 169, 172, 175
Twirling of stamp 48, 52

W

Walls, retaining, cost of...... 220
Wave mortar 98, 110
Water, amount in amalgamation 128
amount in stamping 85
temperature in amalgamation 130
settling for re-use 187
supply 84
Wedges for shoe 43, 44
Weight of stamp 90, 94
increasing 92, 200
Wet amalgamation 116, 120, 139, 144
Wood in mortar 98, 156
Wood mortar-block..27, 32, 56, 223
Woven-wire screen 75-80, 81

6 R 100-