The Recovery of Lode Gold in Jigs

Certain testing procedure for determining the jigging characteristics of an ore is proposed

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GRAVITY concentration of gold is a process that was known to primitive man and has been improved by the modern mining engineer only by its adaptation to a high rate of production. The jig is the foremost machine yet developed to use this process. It is now being used successfully in many gold mills to recover relatively coarse free gold as a high-grade concentrate. In a few operations jigs are used to produce a waste product or finished tailing, lessening the amount of ore treated in subsequent processes.

As yet, no standard method of testing the jigging characteristics of a gold ore has been proposed, and often it has been difficult to evaluate the effectiveness of a jig in a flowsheet without making a test run with a full-size jig and a large volume of ore.

The purpose of this paper is to develop a standard test method for jigging similar to those methods now used for cyanidation, amalgamation, and flotation when testing 10- to 100-lb. samples.

To develop a test, the theory of jigging action was reviewed to establish the most important physical factors acting to make a separation; and California mines were visited to gain a better understanding of mill conditions, the products desired, and the usual position of jigs in the flowsheet.

Principles of Jig Action—As now used for gold ores, the jig is a hydrodynamic concentrator which separates minerals according to density and size in a bed of ore supported on a screen in a rising, pulsating column

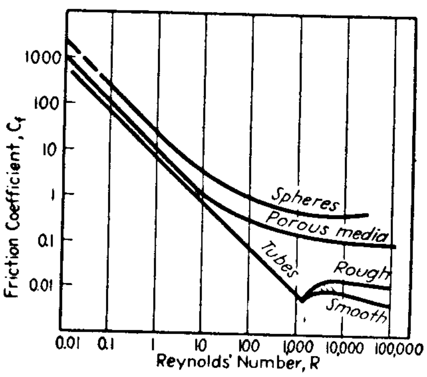


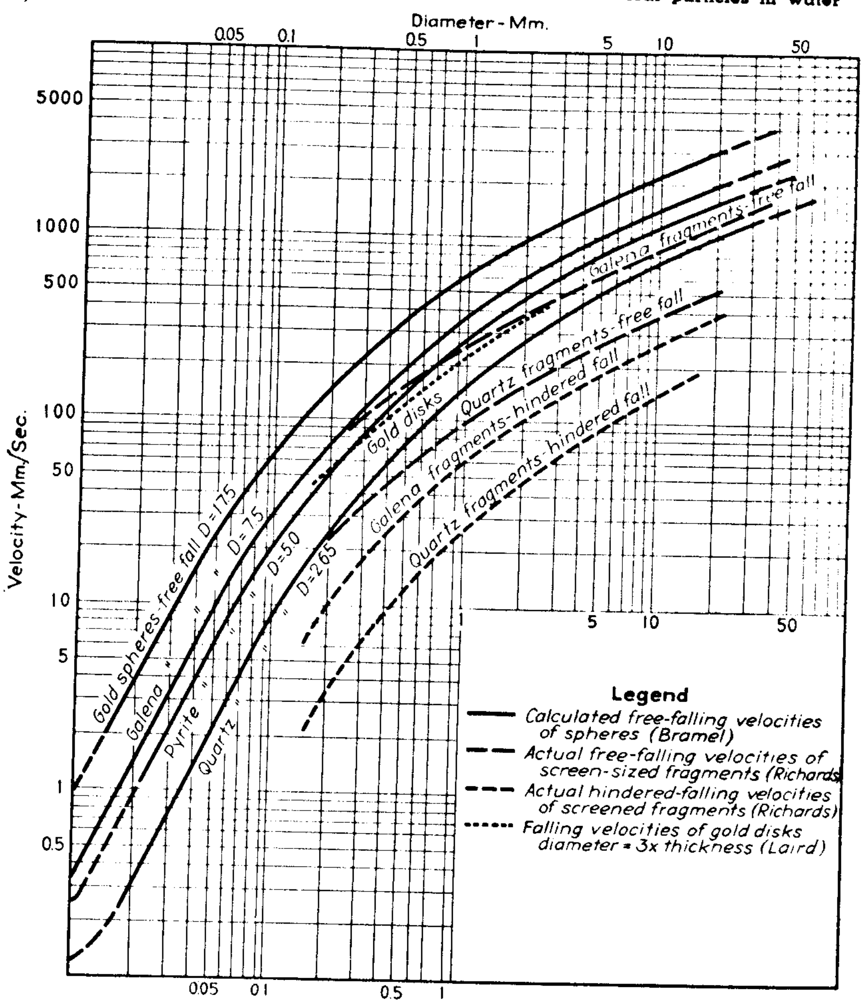
Fig. 1 . . . Characteristic curves for spheres in water, water through porous media, and water through tubes. After Bramel,* McCurdy,† and Poland §

* Bramel, H. R.: "The Hydrodynamics of Spheres and Particles in Free Motion," unpublished thesis, Stanford University, Department of Mining Engineering. 1939

† McCurdy, R. C.: "A Study of the Petroleum Drainage Problem." Unpublished thesis, Stanford University, Department of Mining Engineering. 1933.

§ Tolman, C. F. and Poland, J. F.: "Groundwater," Chapter VIII, p. 197. McGraw-Hill Book Co., New York, 1938.

Fig. 2 . . . A chart for obtaining terminal velocities of mineral particles in water



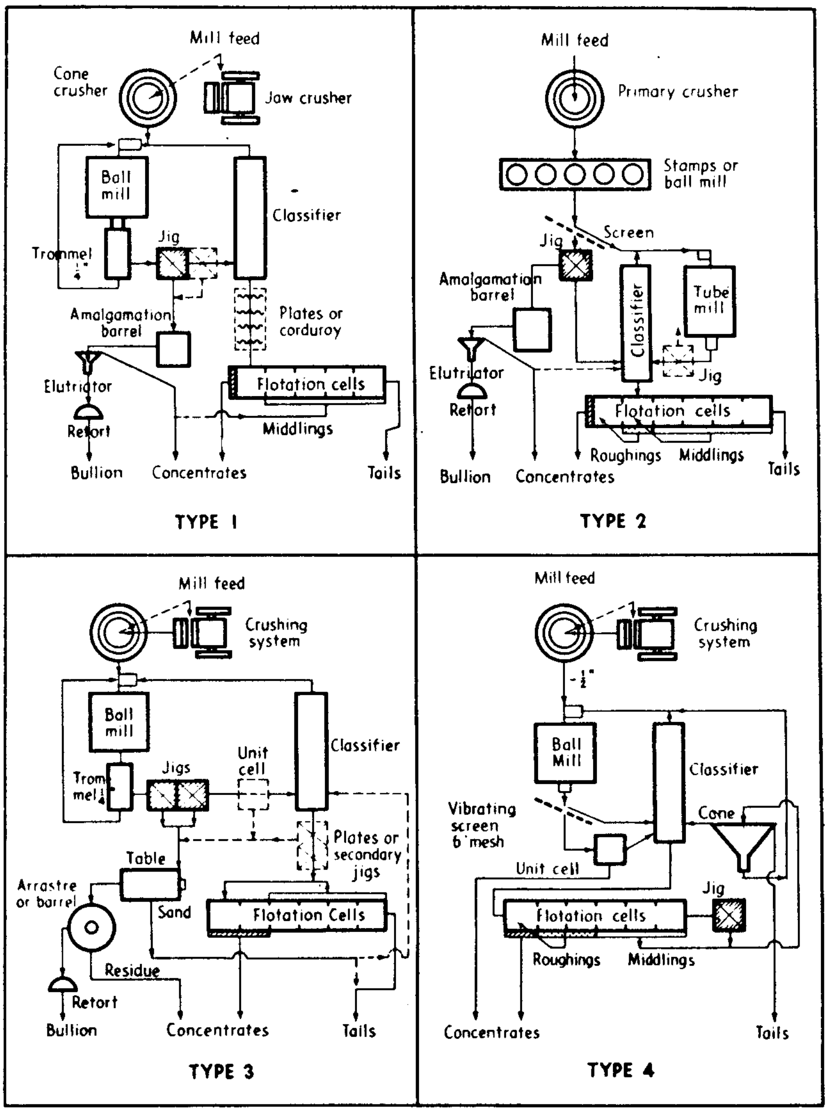


Fig. 3 . . . Typical flowsheets showing the use of jigs in connection with types of concentration equipment

of water. The mineral particles in the ore are separated by the screening action of the bed.

Heretofore five types of particle action have been studied to explain the separation taking place in a jig: (1) Free fall, (2) Interstitial fall, (3) Hindered fall, (4) Initial acceleration, (5) Stratification.[1,2,3,4,5] Of these hindered fall has come to be considered the most important. But the best key to understanding the behavior of particles in water is the concept of mechanical similarity.

Reynolds criterion,[6] $R = \rho DV/\mu$ is a dimensionless ratio which may be considered as expressing the geometric distribution of normal and tangential forces existing in the neighborhood of a solid-liquid surface. It may be plotted against various quantities. The drag or fluid resistance effective on the surface of a particle is the most important quantity. It is compared to the drag force on some arbitrary surface used as a standard of comparison to give another dimensionless ratio, friction coefficient, $C_f = \frac{F_f}{\frac{1}{2}\rho A V^2}$. The term C_f indicates the change in fluid resistance as the Reynolds number, R, is changed. Plotting Reynolds number against friction coefficient gives a curve characteristic for a particular geometrical shape and type of motion.

The characteristic curves for spheres in water, water through porous media, and water through tubes are indicated in Fig. 1. All three curves start with a slope of -1 in the zone of viscous flow, but turbulence starts at different points on each curve. The beginning of turbulent flow is indicated by the departure from the -1 slope. Different densities of particle and different kinematic viscosities of fluid $\left(\nu = \frac{\mu}{\rho}\right)$ give the same characteristic curve for a particular type of motion. We would therefore expect curves expressing relation of size to terminal velocity to be similar for all densities and viscosities and to show incipient turbulence at a point indicated by the Reynolds number curve. Fig. 2 shows curves for obtaining terminal velocities in water.

These curves have the same shape regardless of density, shape of particle, and free or hindered state of fall. Hindered fall appears to increase the kinematic viscosity slightly and the irregular shape of mineral fragments seems to increase the effect of turbulence in decreasing terminal velocity in the larger sizes.

Separation takes place in a jig while the minerals are submerged and hence must be governed by the principles of hydrodynamics suggested graphically in Fig. 2. Hindered settling is the condition of that stratum of the jig bed in which most of the separation takes place. The sifting action of the screen and bed (stratification) allows the capture of the heavy minerals and the exclusion of coarse gangue minerals after these two have been separated. Flow of hutch water and speed of operation may be proportioned to give greatest advantage to these two processes in the desired range of particle sizes. Therefore any test method should try to approximate the effect of hindered settling and sifting combined; or should make use of some physical process which makes a similar separation by size and density.

Performance of Jigs in California Mills—Only a few years ago jigs were a curiosity in gold mills, but now (1939) at least 30 mills in California use them in lode operations. The theory that gold occurs in only two ways—as native gold and in tellurides, and never in solid solutions—is becoming well accepted.[7,8,9,10] This would explain why a closed-circuit installation will produce a high-grade concentrate in which gold occurs as free particles; or why it is sometimes possible to use a jig as a primary separa-

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[1] Rittinger, P. R.: "Lehrbuch der Aufbereitungskunde." Ernst and Korn, Berlin, 1867.

[2] Munroe, H. S.: "The English versus the Continental System of Jigging." Trans. A.I.M.E., Vol. 17, p. 637. 1889.

[3] Richards, R. H.: "Close Sizing Before Jigging." Trans. A.I.M.E., Vol. 24, p. 433. 1894.

[4] Simons, Theodore.: "Basic Principles of Gravity Concentration." Trans. A.I.M.E., Vol. 68, p. 431. 1923.

[5] Fahrenwald, A. W.: "The Theory of Stratification and Its Application in Ore Dressing." *Mining and Metallurgy*, Vol. 7, p. 437. Oct. 1926.

[6] R = Reynolds number
ρ = density of fluid
D = diameter of tube or body
V = velocity of fluid or body
υ = viscosity of fluid
C_f = drag coefficient
F_f = force of drag
A = area of cross section
ν = kinematic viscosity

[7] Warren, H. V. and Cummings, J. M.: "Textural Relations in Gold Ores of British Columbia." Mining Technology, March 1937, p. 1., A.I.M.E.

[8] Haycock, M. H.: Investigations in Ore Dressing and Metallurgy, Mines Branch, Dept. of Mines, Canada. 1934, 1935, 1936.

[9] Head, R. E.: "Form and Occurrence of Gold in Pyrite." U.S.B.M., R. I. 3226, p. 27. March 1934.

[10] Knopf, A.: "The Mother Lode System of California." U.S.G.S. Prof. Paper 157, p. 37. Washington.

tion process to produce low-grade tailings from either a closed or open circuit. Table I will indicate characteristic performances.

Only rarely can jigs be used as the only concentrators. They are usually followed by flotation, cyanidation, blankets, amalgamating plates, cones or any combination of these to recover a part of the remaining values. But the jig increases the efficiency of other processes and adds to net profit in several ways. Typical flowsheets are shown in Fig. 3.

In mills using flotation, the chief advantage of producing and treating a jig concentrate is the easy recovery of gold as amalgam or bullion rather than in a concentrate which must bear the cost of smelting and shipping charges. The effective price at the mine for gold in a concentrate may be as low as $28 an ounce. An average effective value at the mine for bullion is $34.80 an ounce. Most of the difference is profit on that gold recovered in the jig.

The jig also tends to improve the feed to the flotation circuit. Great fluctuation in the mill heads will produce only mild fluctuation in the value of the classifier overflow. Surges of gold and sulphide particles over the classifier lip will be practically eliminated. Consequently, reagents may be fed at a constant and more economical rate, and less attendance is required on flotation units. The time and reagent concentration required to obtain a certain recovery depends on the grade of ore fed to the circuit. Hence the previous removal of a considerable amount of the gold reduces the necessary size of plant and its cost of operation. A study of cyanidation and flotation tailings has shown that surface contamination on gold particles is often responsible for a big tailing loss.[11] The surface characteristics of the gold do not affect its recovery by gravity concentration. It may be recovered from the concentrate by treating with acid or alkaline solution to dissolve the coating, or by grinding to scratch the surface, previous to amalgamation. Most operators report a reduction in average tailings assay after the installation of jigs.

In cyanidation plants, most of the advantages mentioned for flotation plants also apply. Grinding in cyanide solution is permissible with jigs in the circuit; it is not when using plate amalgamation or unit cell flotation to recover the coarse gold. If there is a possibility of cyaniding only concentrates, then carbonaceous matter, clay gangue, and other non-metallic substances deleterious to cyanidation will be eliminated from the concentrate.

There are, of course, several factors which sometimes preclude the use of jigs. With coarse ore it may be necessary to introduce more water into the hutch than can be successfully handled by the classifier or other units following the jig. The installation of dewatering cones is expensive because it usually requires operation of pumps to overcome loss of head in the cones. It may be difficult to secure a large supply of water at a steady head. When practically all of the gold occurs as particles finer than 200 mesh it would be extremely difficult to make a successful recovery of these in a jig. In such cases, blankets, a unit cell, or amalgamation plates should be used to recover fine free gold.

Proposed Laboratory Test for Jigging—Since hindered settling and sifting seem to produce jig action, one would expect a test method using these features to predict jig results better than others. A method of panning using a continuous flow of water over the ore was found to give the best results, but heavy liquid separations, making an almost perfect specific gravity separation, were also found helpful. Most

Table I—Performance of Jigs in California Gold Mills

Column — **Legend**

(1) O Operating P Planned I Idle (as of 1939)

(2) V Free gold in quartz
S Gold associated with mixed sulphides
Py Gold associated with pyrite
Ga Gold associated with galena
Ox Oxidized or clayey ore
T Tailings or old dumps

(3) B Bendelari diaphragm jig (F.N. Bendelari)
D Denver mineral jig (Denver Equipment Co.)
H Pan American hydraulic pulsator jig (Pan American Engineering Co.)
L Jig of local manufacture (usually Harz type)
M Miners Foundry diaphragm jig (Nevada City Foundry)
P Pan American placer type jig (Pan American Engineering Co.)
S Southwestern hydraulic diaphragm jig. (Southwestern Engineering Co.)

(4) Recovery as bullion from jig hutch product except as noted.

(5) and (8) Ratio and capacity are based on New Feed. Circulating load varies from 100% to 700% in Types 1 and 3.

(6) See Figs. 3 and 4

Mill No.	(1) Present Activity	(2) Type of Ore	(3) Name of Jig	(4) Recovery as Bullion, %	(5) Ratio of Concentration (New Feed)	(6) Type of Flow-sheet	(7) Mill Capacity Tons/Day	(8) Jig Capacity Tons/ft. Day
1	O	S	P	50–70	137:1	1	25	25
2	O	S	L	5–10	......	2	220	100
3	O	Ox	M	69.8 (*a*)	50:1	1	75	30
4	O	S	M	50	500:1	1	120	36
5	I	T	L	......	......	2	100	......
6	O	S	3P	70	100:1	1	900	36
7	O	S	L	7.7 (*a*) (*b*)	730:1	1 (*m*)	90	45
8	O	S	B	0.5–1.0 (*c*)	8:1	4	290	24
9	O	Py	M	50–70	400:1	1	100	25
10	O	Py	M	60	430:1	2	75	20
11	O	S	B	75	120:1	1	150 (*d*)	6 (*d*)
12	O	S	M	5–8	330:1	3	125	31
13	O	Py	B	60–85	100:1	1	100	24
14	O	V	D	90	250:1	1	25	19
15	O	Py	M	60–70	960:1	1	60	27
16	O	Py	B	54	200:1 (*f*)	3	288	16
17	I	Ox	B	......	......	3	300	33
18	O	S	B, H	(*b*)	1,500:1 (*f*)	3	200	25
19	O	S	B	66.9 (*a*)	200:1 (*a*) (*f*)	3	145	24
20	I	Ga	L	......	......	1	30	39
21	I	Ox	4P	(*l*)	......	3 (*m*)	1,000	25
22	I	Ox	H	20–30	4,000:1 (*f*)	3	150	38
23	P	S	H, S	30 (*g*)	100:1	3	220	55
24	I	S	B	(*l*)	......	3 (*m*)	120	26
25	O	Py	B	85	75:1 250:1 (*f*)	3	75	16
26	O	S	D	10–20	500:1	1	25	9
27	O	V	P	85–90	130:1	1	24 (*h*)	24
28	O	S	P	60–75	40:1	1	24 (*h*)	24
29	O	S	L	10	750:1	1	150	100
30	O	S	H	46 (*a*) (*b*)	1,000:1	1	150	38
31	O	Ox, T	2P	10–30	20:1 2,200:1 (*f*)	2, 3 (*m*)	1,100	92
32	I	D		......	......	......	......	......
33	O	T	B	19:1 (*a*) (*k*)	200:1 (*f*)	3 (*j*)	200	21
34	I	Ox	B	......	......	......	......	......
35	P	S	D	......	......	......	......	......
36	P	S (*i*)	L	......	......	3 (*m*)	150	......
37	I	Py	L	(*b*)	100:1	2	......	......

Notes

(*a*) Average for month preceding visit.
(*b*) Jig concentrates are shipped to a smelter.
(*c*) Per cent of heads value recovered from flotation tailings.
(*d*) Capacity to be increased to 300 tons a day.
(*e*) Gravel conglomerate is mined from an open pit, treated similarly to lode ore.
(*f*) Ratio for jig and table in combination.
(*g*) Table concentrate melted to form matte and shipped to a smelter.
(*h*) Mine usually operated only one or two shifts (8 to 16 tons).
(*i*) Major value of ore is in silver.
(*j*) Flowsheet includes flotation of primary slimes, cyanidation of sands, table middlings, and secondary slimes.
(*k*) Amalgamation residue is cyanided. 10.4% of bullion is amalgamation sponge.
(*l*) Jig concentrates treated by both amalgamation and cyanidation.
(*m*) Cyanidation replaces or assists flotation.

Table II—Heavy Liquids

Range of Specific Gravity	Heavy Liquid	Diluting or Washing Reagent	Method of Recovery
1.60 to 2.85	Bromoform ($CHBr_3$)	Alcohol	Shake with water to remove alcohol
2.85 to 2.95	Acetylene tetrabromide ($C_2H_2Br_4$)	Alcohol	Shake with water to remove alcohol
3.50 to 4.95	Thallous formate-malonate ($TlCHO_2 - TlC_3H_3O_4$)	Water	Distill gently to remove water

[11] Head, R. E.: "Physical Characteristics of Gold Lost in Tailings." T. P. 674, A.I.M.E., New York, 1936.

mills produce a small high-grade concentrate, and so it was necessary to use a method which could do this and at the same time give an estimate of the cleanest tailings which could be produced.

After making many different tests on ores from three California mines (the Dutch, Zeibright, and Sheepranch mines Nos. 37, 6, and 19 respectively in Table I) the testing system proposed here was developed. It should be applicable to any gold ore.

A sample of the ore to be tested should be secured at the point in the flowsheet where the jig will be used. If no decision has been made as to where or how to use a jig, a sample may be used which has been crushed to the minimum size practicable for the crusher at hand ($\frac{1}{4}$ to $\frac{3}{8}$ in). This sample is sized by screening into several fractions. A suggested screen scale is the one employing the ratio 4, e.g. 8-, 28-, 100-, and 325-mesh screens. This separation is to facilitate testing, but results from each size will indicate the size at which best jigging results are obtained.

Two pans are used for the panning operation; they are shown in Fig. 5. As both pans have recessed bottoms similar to a dinner plate, minerals

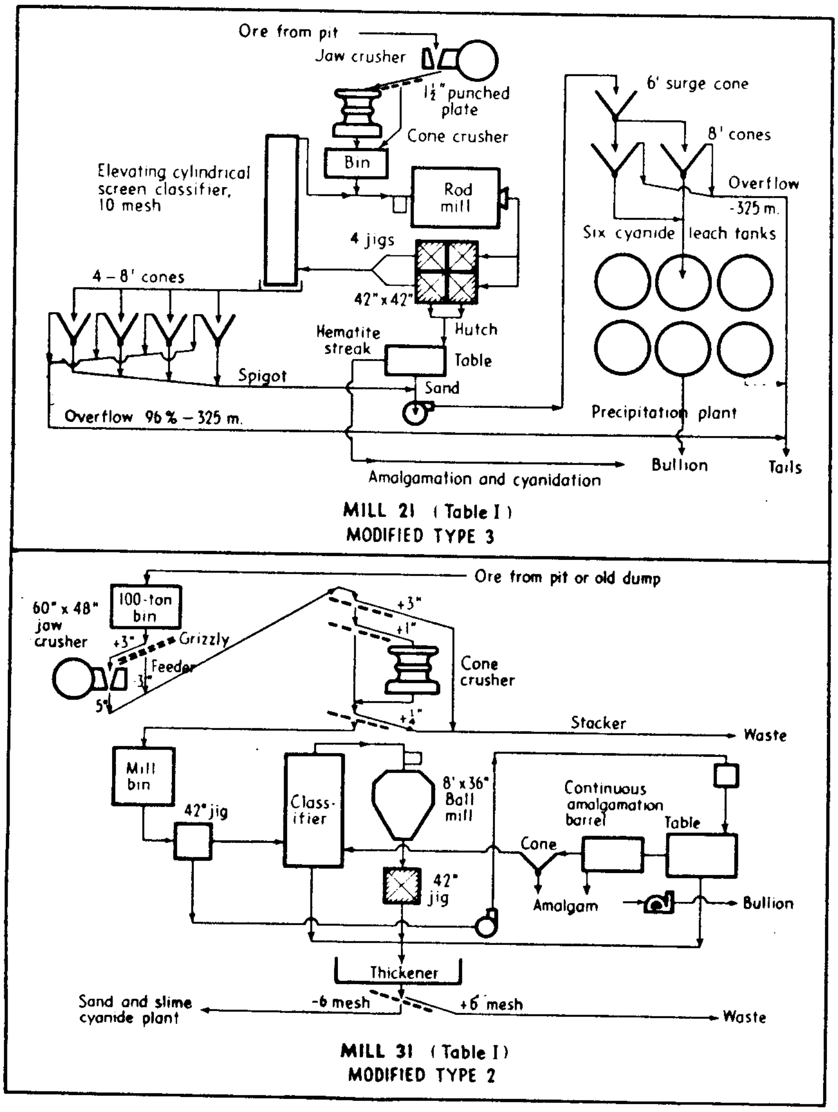
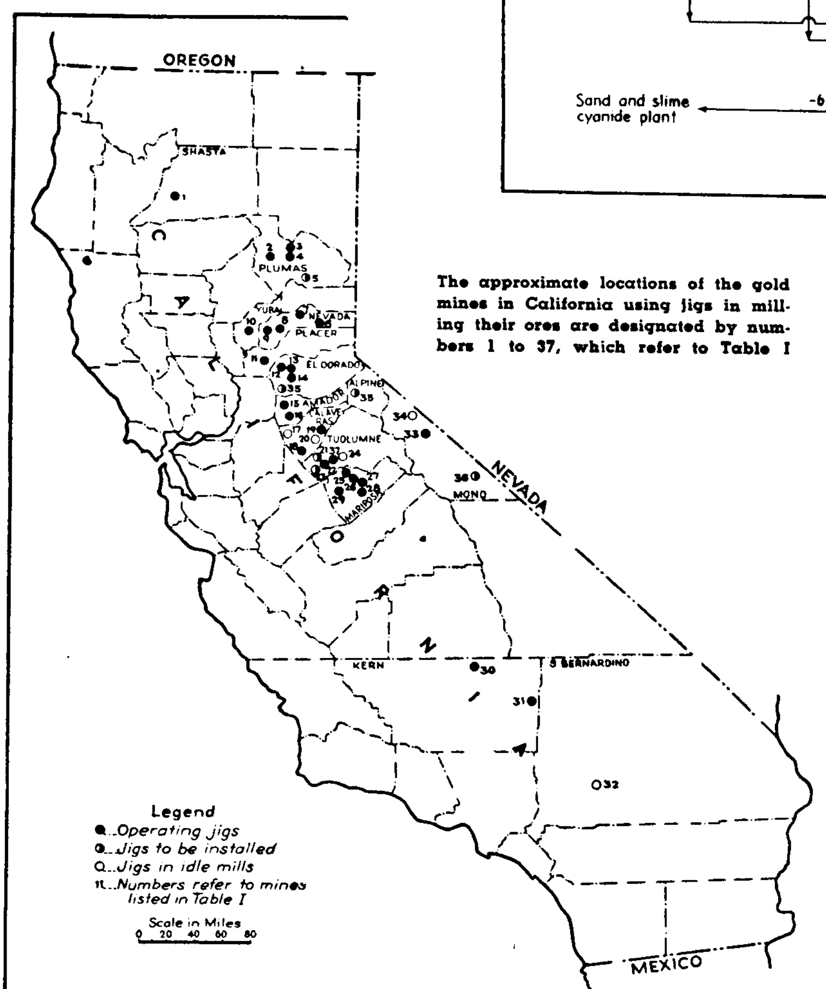


Fig. 4 . . . Two flowsheets for high capacity, in which jigs are employed with other concentrating equipment



The approximate locations of the gold mines in California using jigs in milling their ores are designated by numbers 1 to 37, which refer to Table I

must move over two edges before passing to the tailings basin. Hence the operation is called duplex panning. A nozzle is fastened to one edge of the pan and a rubber hose used to connect to some steady and adjustable water supply. The nozzle is held at the top of the pan when it is tilted down for operation. The amount of water required varies from 1 to 0.2 g.p.m., the amount being reduced as the amount of ore in the pan is reduced. During panning, the pan is shaken from side to side as in ordinary panning, and tilted so that a small amount of tailings will run over the edge into a tailings basin. Part of the water passes down and under, and then up through the ore; part merely passes over the top. If the flow of water is insufficient to remove the larger gangue minerals, the pan may be tilted back toward a level position until a small amount of water accumulates, and then let down periodically to produce a slight surge. Only one layer of minerals should be passing

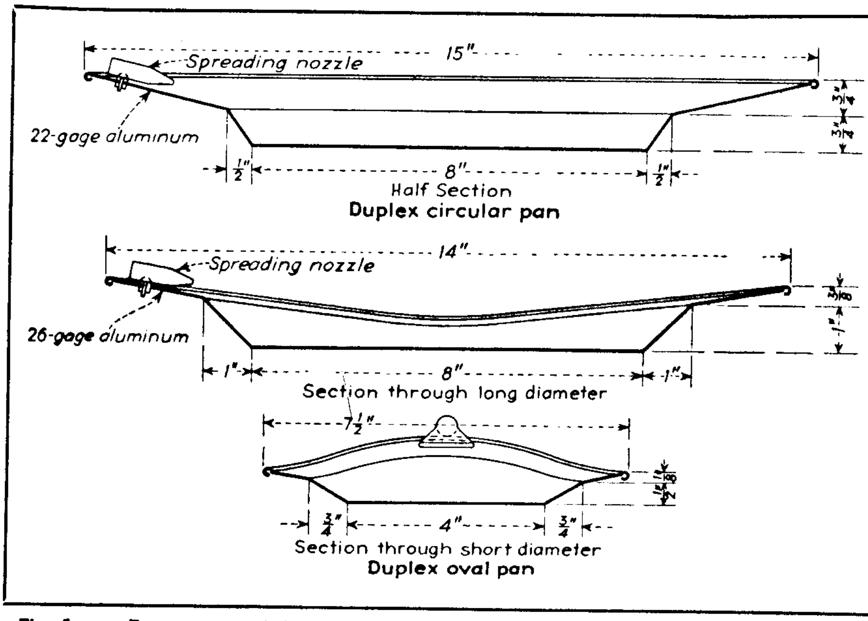


Fig. 5 . . . Two pans used for the panning operation in the laboratory test proposed by the author for jigging

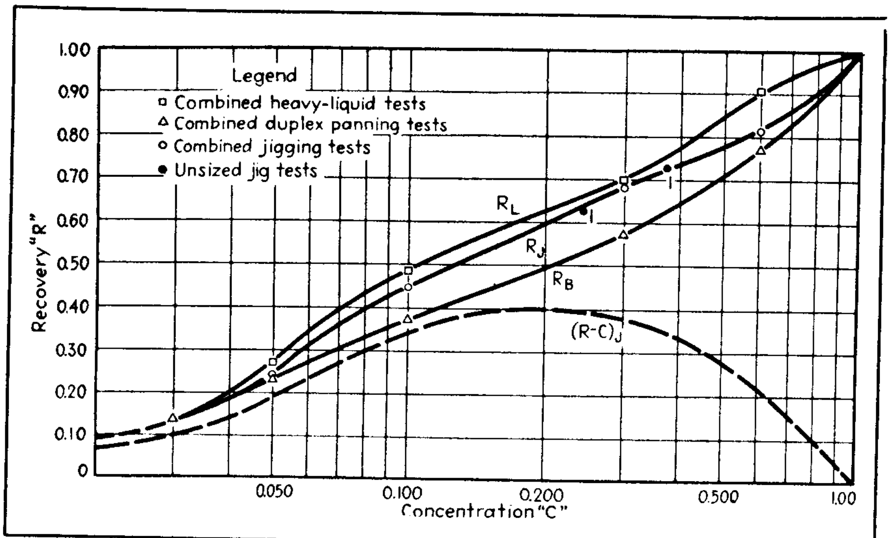


Fig. 6 . . . The curves above, representing combined tests on ore of Mill 37 (Table I), together with those given in Figs. 7 and 8, furnish examples of the best results obtained on three California ores

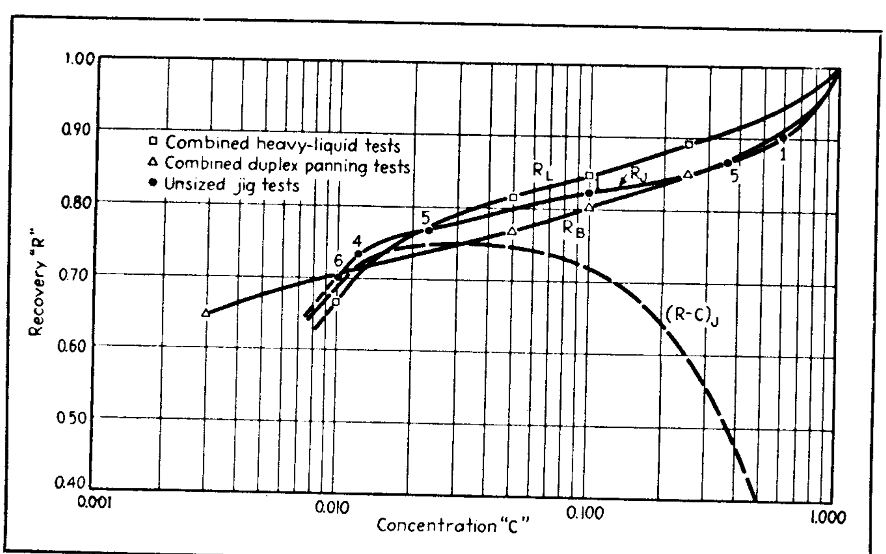


Fig. 7 . . . Results of combined tests on ore of Mill 6 (Table I)

over the edge at any moment. In this way, the operator has a chance to give all particles a cursory examination. If sulphides or other heavy minerals start coming over the edge, the pan is tilted back and shaken more thoroughly until only gangue is washed over when the pan is tilted down.

From 200 to 1,000 grams is taken from each size except the finest, and is panned in the duplex circular pan. When sulphides or ore minerals start passing over the edge of the pan despite careful shaking, the operation is temporarily stopped and the tailings are repanned; the second concentrate is added to the first. If this combined concentrate is small—less than 50 grams—it can be transferred to the smaller duplex oval pan. If not, another fraction should be removed until only 20 to 30 grams remain. The final concentrate is produced in the oval pan using only 0.3 to 0.2 g.p.m. of water and using as much care and time as patience allows. Tailings from these second and third operations are kept separate. The concentrate may be reduced until it appears that further panning might lose some gold. Each of the three or four products separated is dried and weighed and a sample of each assayed. If the amount of free gold which can be recovered from the concentrate is an important factor, the final product is given an amalgamation test. A concentrate of small weight (1 to 10 grams) is agitated in a flask or a larger concentrate is rolled in a bottle with 1 to 4 grams of mercury.

The value of each tailing removed determines a certain decimal recovery (R) in the remaining concentrate.

$$\left(R = \frac{\text{Total heads value} - \text{total tails value}}{\text{Total heads value}}\right)$$

The weight of the concentrate determines the decimal concentration (C).

$$\left(C = \frac{\text{Wt. of concentrate}}{\text{Wt. of sample}}\right)$$

From four products three pairs of values for R and C are obtained. These values are plotted to form an R_B curve for panning. Semi-logarithmic coordinates are used to separate the low range for C.

If possible, two or three heavy liquid separations should be made on each size to give values of R and C for plotting an R_L curve which will set an upper limit for jigging. Table II shows recommended reagents.

The bromoform and acetylene-tetrabromide may be used at room temperature but the thallous formate malonate, a mixture of equal parts by weight of the formate and malonate salts, must be used between 60 and 90 deg. C., unless it is used as a water solution of less specific gravity.

A 100-gram sample is sufficient for heavy liquid tests and may be used

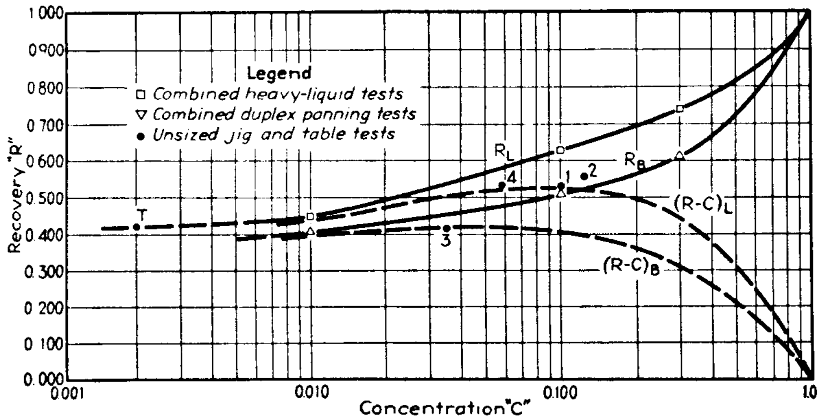


Fig. 8 . . . Results of combined tests on ore of Mill 19 (Table I)

with about 100 ml. in a 250-ml. beaker. After stirring, the ore which floats is removed with a spoon fashioned from copper screen. When all material that will float has been removed, the liquid is decanted from the concentrate remaining in the bottom of the beaker and both float and sink portions of the sample are washed several times with the washing reagent. In some cases the concentrate (sink product) from one test can be treated with a still heavier liquid, producing three products altogether to give two values for R and C.

The heavy-liquid products are treated in the same way as the products of the panning to give values of R and C which will give an R_L curve.

Jig results (R_J) in each size may be estimated to fall slightly above the R_B curve and below the R_L curve. If the jig is to be used on unsized materials, a mathematical combination of size curves may be drawn assuming little or no recovery in the size passing the last screen. Figs. 6, 7, and 8 are examples of the best results on the three California ores (Mill Nos. 37, 6, 19).

[12] Luyken, W. and Bierbrauer, E.: "Calculations in Ore Dressing." T. P. 214, A.I.M.E., New York, 1929.

An $(R-C)$ curve is drawn from the R_B curve by plotting several values of R less the C at that point. The maximum of this curve indicates the value of C which gives the greatest "absolute enrichment."[12] The possibility of producing a finished tailing is indicated by the first batch of tailings from the panning operation. If these were low enough in grade to be discarded, the jig could probably produce the same product in a large-scale operation.

In closed circuits the test results may be modified because most of the ore must be ground finer than a certain size before escaping from the circuit and only the portion of the fine gold released in the first pass through the grinding mill will be lost by the jig. The upper and lower limit of the size range is determined by the operating range of the classifier or screens. This limited size range may be tested in one batch for panning or heavy-liquid separation. The extraction indicated by the test gives an estimate of R, but a large circulating load may make it difficult to secure as low a value of C as the test indicates unless the installed jig capacity is 50 tons or less per square foot of bed area per day, based on circulating load rather than on feed.

(To be concluded)

New Course in Mineral Dressing
An Innovation in Engineering Education

Will aim at thorough grounding in mathematics, physics, and chemistry. It includes petroleum

A NEW PROGRAM of study in the field of mineral dressing, broadened to cover the preparation of all crude minerals for industrial use, including petroleum, will be introduced into the engineering curriculum of Columbia University next year under the direction of Prof. Arthur F. Taggart, according to a recent announcement. The innovation marks the first academic recognition granted to mineral dressing, hitherto concerned chiefly with the extraction of metals from metallic ores, as a profession in itself. The new curriculum will train men for the technological work which bridges the gap between the extraction of crude minerals from the earth and their preparation for consumer use.

Previously treated as a part of the training received in mining and metallurgy, mineral dressing will be made a special division of the curriculum leading to the degrees of bachelor of science and master of science in mineral dressing. In the past those who studied the subject were not given instruction in petroleum refining and it is also true that they received only a minimum amount of training in extractive metallurgy.

The new curriculum is reported to aim at a thorough grounding in mathematics, physics, and chemistry. It comprises further, as a foundation, the fundamental engineering subjects, the concepts of which are used continually by all engineers. Although established principles will be emphasized in the instruction, due consideration will be given to the empirical facts that have developed out of the recent practice of mineral dressing.

"If the course is criticized on the grounds that the scope of the subject matter is too broad for comprehension and absorption by the average student," says Professor Taggart, "encouragement can be found in comparing it with any good chemical engineering course. Here an equal range of unit processes and a greater range of materials and products are studied.

"Mineral dressing is the modern outgrowth of the ancient art of ore dressing, which comprised and was limited to the concentration of ores into smaller and more valuable bulks for metallurgical treatment. In the modern profession of mineral dressing, ore dressing is but one of three major parts, the other two being extractive metallurgy and petroleum refining. This is because the growth of modern technological science has made the mineral matter comprising the crust of the earth the source of supply for substantially all of the material demands of present-day civilization excepting only food, clothing, and a minor part of housing.

"The young graduate in mineral dressing will be equipped to enter, with substantially equal preparation, any one of the three general fields. There is a sufficient overlapping of training to make experience gained in one field useful in the others. The three divisions comprise a range of industrial activities of such breadth as to tend to absorb a part of the shock to employment that is imparted by economic depressions."