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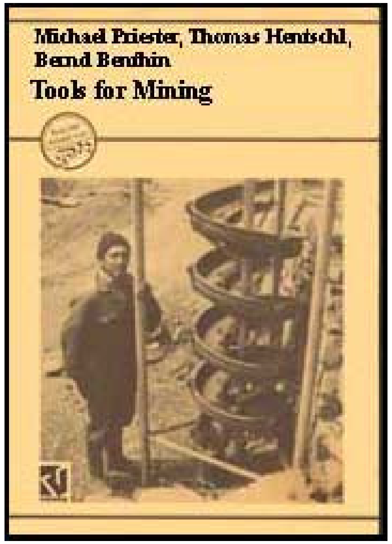


Tools for Mining: Techniques and Processes for Small Scale Mining (GTZ, 1993, 538 p.)

Technical Chapter 14: Sorting

Tools for Mining: Techniques and Processes for Small Scale Mining (GTZ, 1993, 538 p.)

Technical Chapter 14: Sorting

14.1 Jig screen, hand-jigging

Metal Mining, Gem Mining
Beneficiation, Sorting

germ.: Handsetzen im engen Sieb, Setzsieb

span.: concentracion gravimetrica manual en cribas pequenas, criba pequena pare concentracion

TECHNICAL DATA:	
Dimensions:	15 × 30 × 20 cm HWD
Weight:	approx. 0.5 -1 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	manual
Mode of Operation:	intermittent
Throughput/Capacity:	0.5 - 1.5 kg/M × min
Operating Materials:	
Type:	water
Quantity:	small
ECONOMIC DATA:	

ECONOMIC DATA:	
Investment Costs:	< 10 DM
Operating Costs:	low, only labor costs

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |—————|—————| high
Maintenance Expenditures:	low |—————|—————| high
Personnel Requirements:	low
Grain Size of Feed:	(50) 200 ym · 2 mm
Special Feed Requirements:	high density difference between valuable mineral and host material
Recovery:	relatively high, since process can be precisely regulated
Replaces other Equipment:	sluice
Regional Distribution:	Bolivia
Operating Experience:	very good |—————|—————| bad
Difficulties:	very low efficiency
Environmental Impact:	low |—————|—————| very high
Suitability for Local Production:	very good |—————|—————| bad
Under What Conditions:	screen material has to be available
Lifespan:	very long |—————|—————| very short

Bibliography, Source: Priester, Agricola, Lohneyss

OPERATING PRINCIPLE:

Manual Jigging operation achieved through up-and-down movements of the screen in water. Separation occurs through the oscillating movements of the Jigged material: concentrate on the bottom, then the middlings, and on top, the waste material. The valuable mineral is concentrated through repeated jigging of the feed material with simultaneous removal of the waste with a spatula

AREAS OF APPLICATION:

Refining/secondary cleaning of fine and medium-grained products.

REMARKS:

Very work-intensive technique with very low efficiency.

SUITABILITY FOR SMALL-SCALE MINING:

This manual Jigging technique using Jig screens is only suitable for special application such as prospecting and exploration, or for processing small quantities of feed requiring a very precise separation cut-off, due to the high level of strenuous physical work involved and the low specific output.

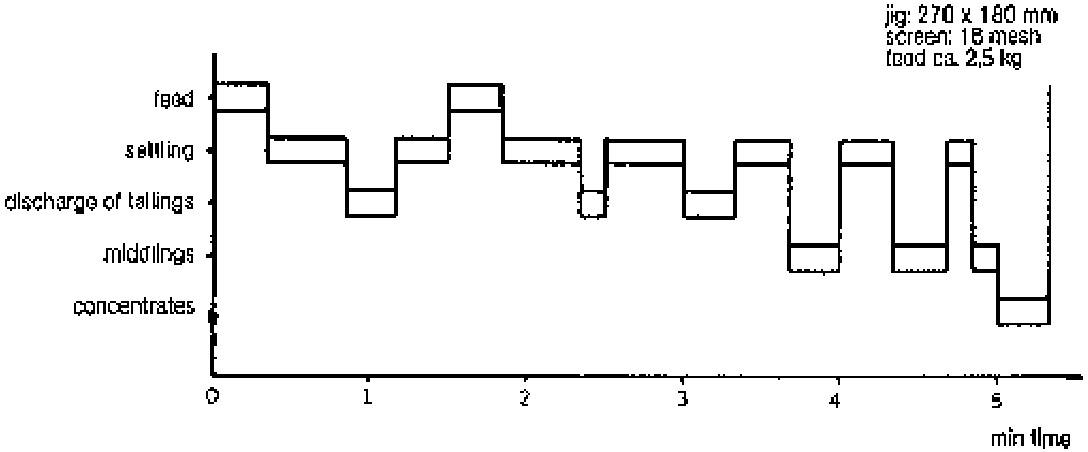


Fig.: Work-chronogram of manual jigging operation with jig screen. Source: Priester.

14.2 Simple hand jig, moving bed(percussion) jig

Metal Mining, Coal Mining
Beneficiation, Sorting

germ.: Einfache Handsetzmaschine, Stauchsetzmaschine
span.: maritate

TECHNICAL DATA:	
Height of Jig:	5 cm to max. 10 cm, jig dilluing depth 2" for coarser feed, < 1" for finer feed, frequency 80 min-1 (coarse feed) up to 120 min-1 (fine feed material)
Dimensions:	approx. 2 × 1 × 3 m HWD
Weight:	approx. 100 kg
Extent of	non mechanized

Extent of Mechanization:	non mechanized
Form of Driving Energy:	manual
Alternative Forms:	pedal-drive, hydromechanical
Mode of Operation:	intermittent
Throughput/Capacity:	5 - 10 kg/M × min
Operating Materials:	
Type:	water
Quantity:	small
ECONOMIC DATA:	
Investment Costs:	approx. 250 DM, lower when self-constructed
Operating Costs:	very low, practically only labor costs
Related Costs:	none

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |————|————| high
Maintenance Expenditures:		low |————|————| high
Personnel Requirements:	low	
Location	none	

Requirements:	
Grain Size of Feed:	500 ym - 10 mm (30 mm)
Special Feed Requirements:	high density difference between valuable mineral and host material
Output:	concentrate approx. 30 %, middlings approx. 50 %; secondary separation leads to higher total recovery
Replaces other Equipment:	mechanized types of jigs
Regional Distribution:	Bolivia
Operating Experience:	very good |—————|—————| bad
	when employed for production of pre-concentrates or coarse-grain separation
Environmental Impact:	low |—————|—————| very high
Suitability for Local Production:	very good |—————|—————| bad
Under What Conditions:	wood manufacturer, good screen quality is a prerequisite
Lifespan:	very long |—————|—————| short

Bibliography, Source: Priester, Taggert, Stewart, Treptow, Schennen, Bernewitz, Liwehr, German Museum, Cancrinus, Callon, Stifft, Rittinger

OPERATING PRINCIPLE:

In manual moving-bed (percussion) jigs, the feed material undergoes pulsating movements in water which produces a vertical differentiation according to density; the heaviest material lies on the bottom, the medium-weight material in between, and the light material on top. Concentration of the valuable mineral is achieved through repeated feeding of the jigged material and removal of the light material.

AREAS OF APPLICATION:

for - production of pre-concentrates
- sorting of coarse grains

SPECIAL AREAS OF APPLICATION:

For wet classification, whereby the undersized-pre-concentrate is removed from the Jig box.

REMARKS:

In the Harz mining region of Germany, mechanized moving-bed (percussion) Jigs were employed up until the 19th century.

Jigs suspended from spring-mounted wooden beams anchored at one end; with guides.

Percussion Jigs are characterized, contrary to all other types of jigs, by their

extreme low consumption of processing-water, which is an Important advantage. A shortage of water at beneficiation-plant locations in Latin American small-mining operations often restricts the possibilities to employ wet mechanical settling processes or wet classification in moving-bed (percussion) jigs.

Additionally, moving-bed Jigs can handle larger throughput quantities than piston Jigs.

A further advantage is the minimal loss of valuable minerals through the fines, since they are removed from the Jig box.

For all types of jigs, it is absolutely necessary that the screens are of the highest quality. Even surface-tempered screen material remains abrasion and corrosion resistant only for a short period before rusting, which leads to clogging especially of the fine-meshed screens. Especially during processing of sulfide ores, or through the use of mine water in beneficiation, the screens are subject to such strong corrosion from acidic water that screens of inferior quality can become useless after Just one application.

SUITABILITY FOR SMALL-SCALE MINING:

Due to its simple operating principle and suitability for local production, the hand Jig is knowngood traditional ore-beneficiation tool which has become widely distributed throughout the small-scale mining industry. The manual extraction of the product provides a high degree of separation precision, which, however, is offset by the disadvantages ofintermittent operation and low throughput. Use of the hand jig is suitable where water availabilily is limited.

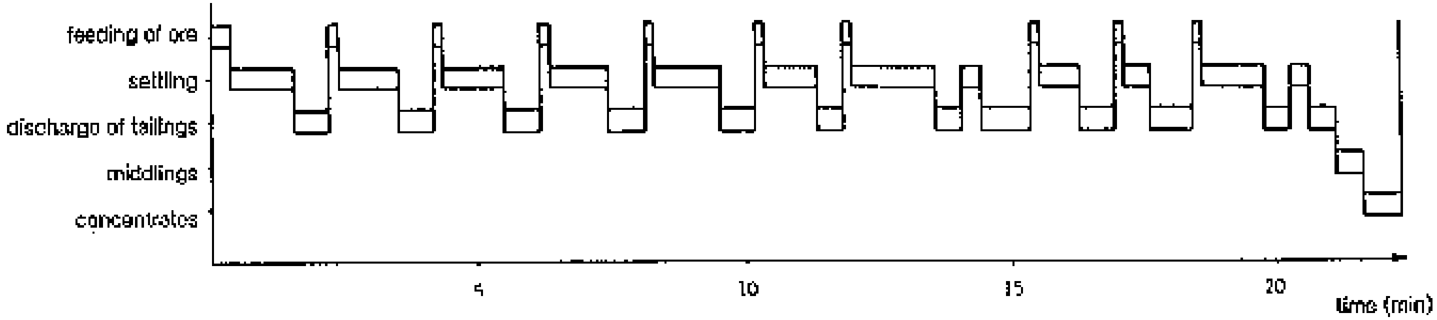


Fig.: Work-chronogram of a simple hand jig, or "maritate" to produce pre-concentrate from feed material of low valuable-mineral content. Source: Priester.

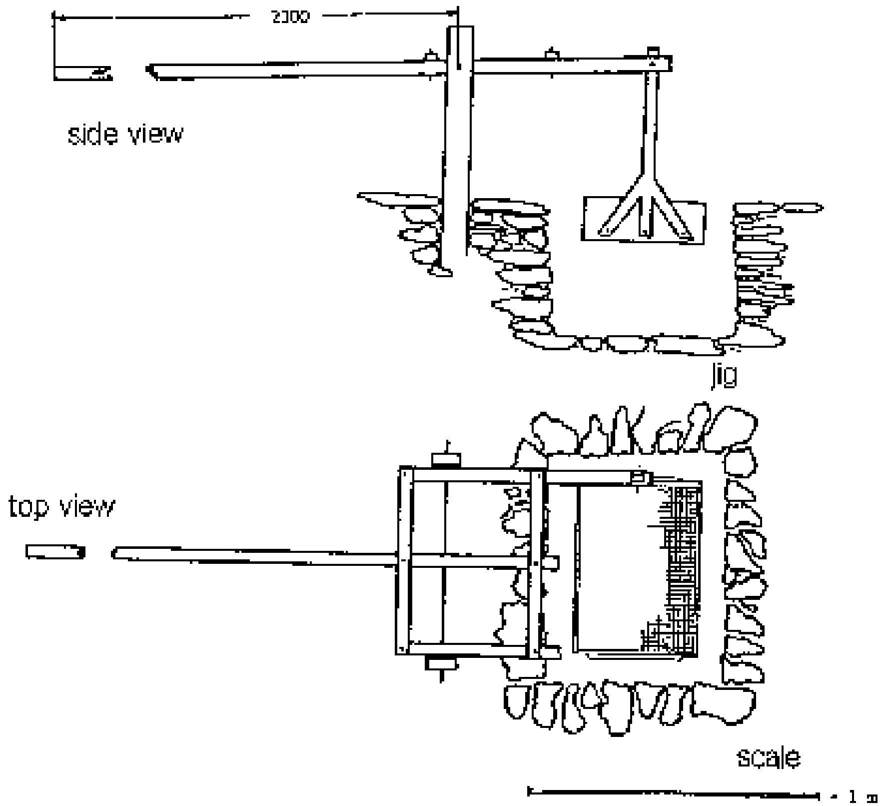


Fig.: Sketch of a simple hand jig (see above). Source: Priester.

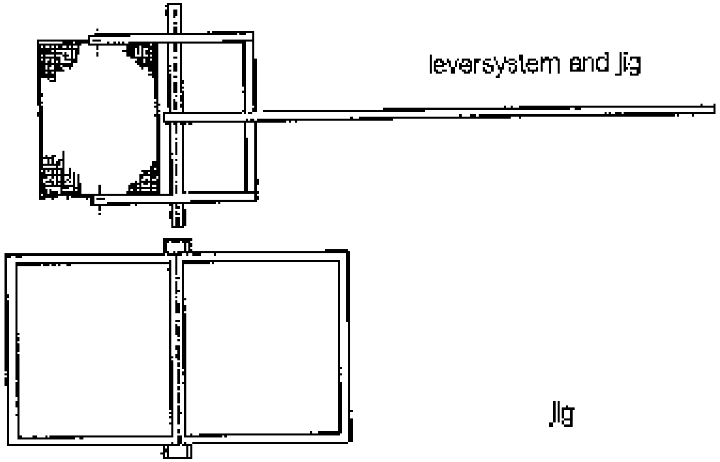


Fig.: Plan view of double-chambered hand jig. Source: Priester.

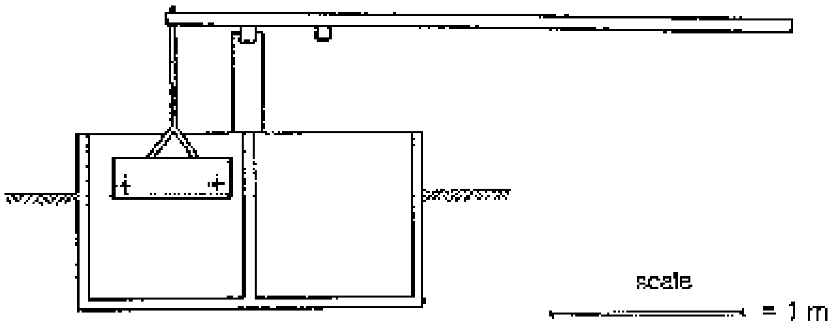


Fig.: Cross-sectional view of double-chambered hand. Source: Priester.

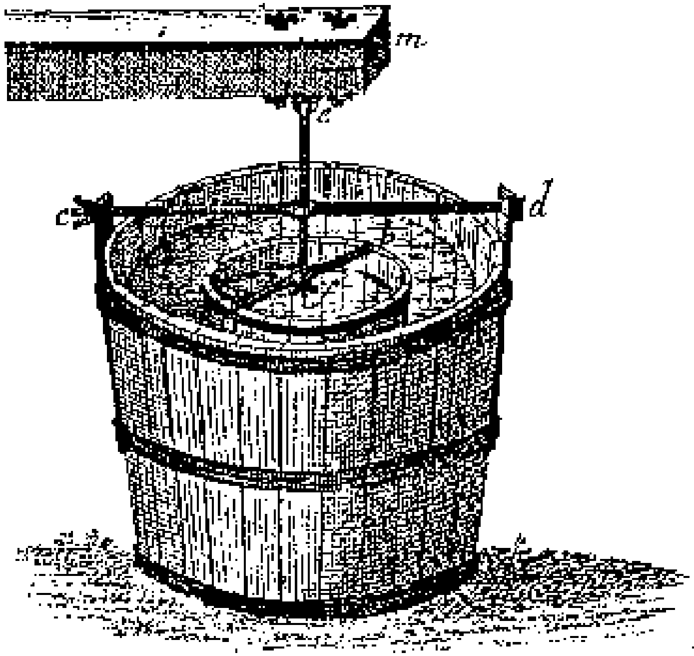


Fig.: Hand jing attached to a spring-mouned wooden beam. Source: Cancrinus.

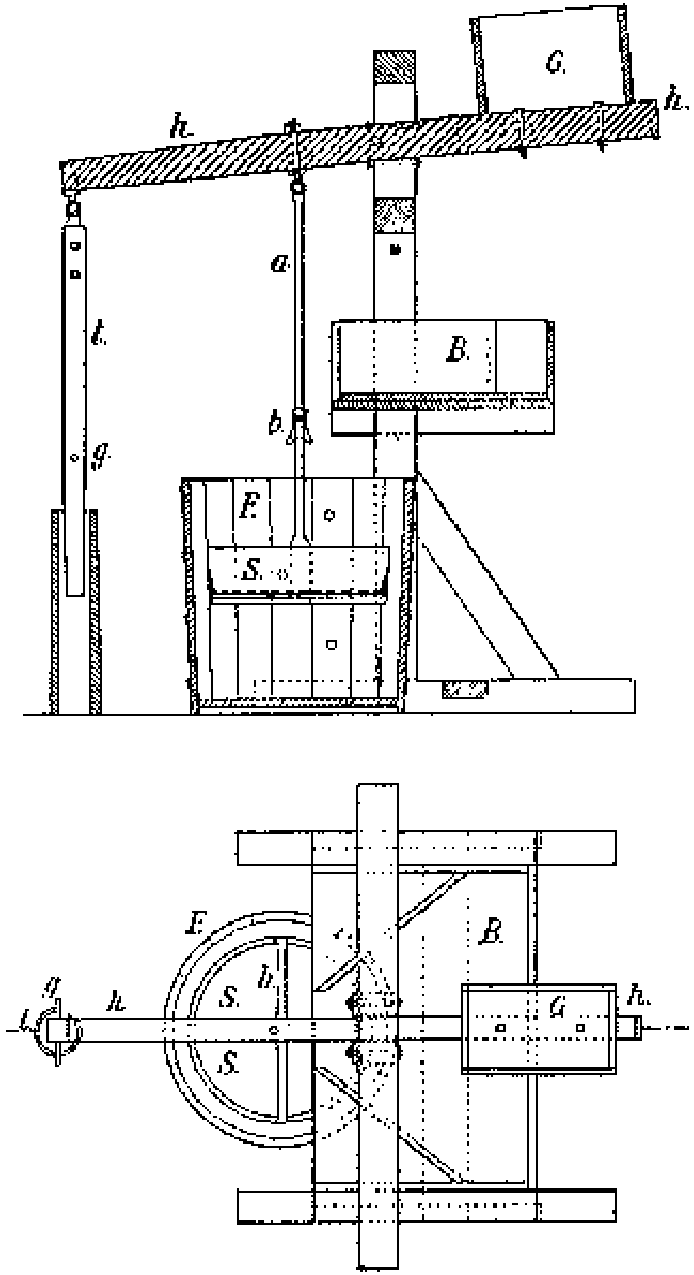


Fig.: Hand jig from the Harz mining region (Germany) design. Source: Treptow.

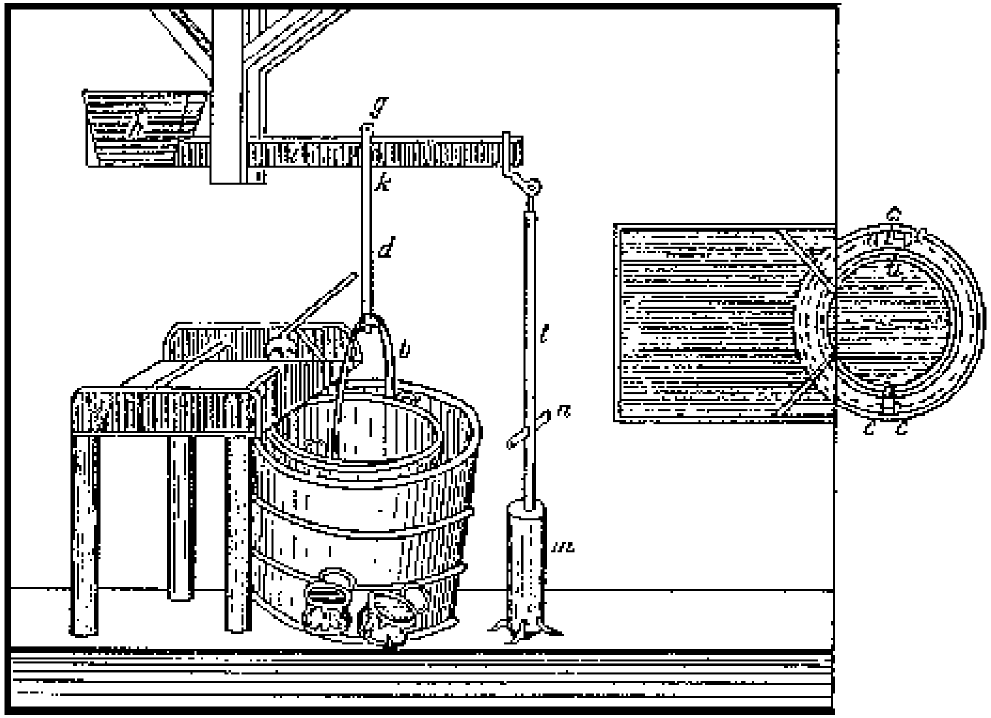


Fig.: Simple hand jig. Source: Schennen

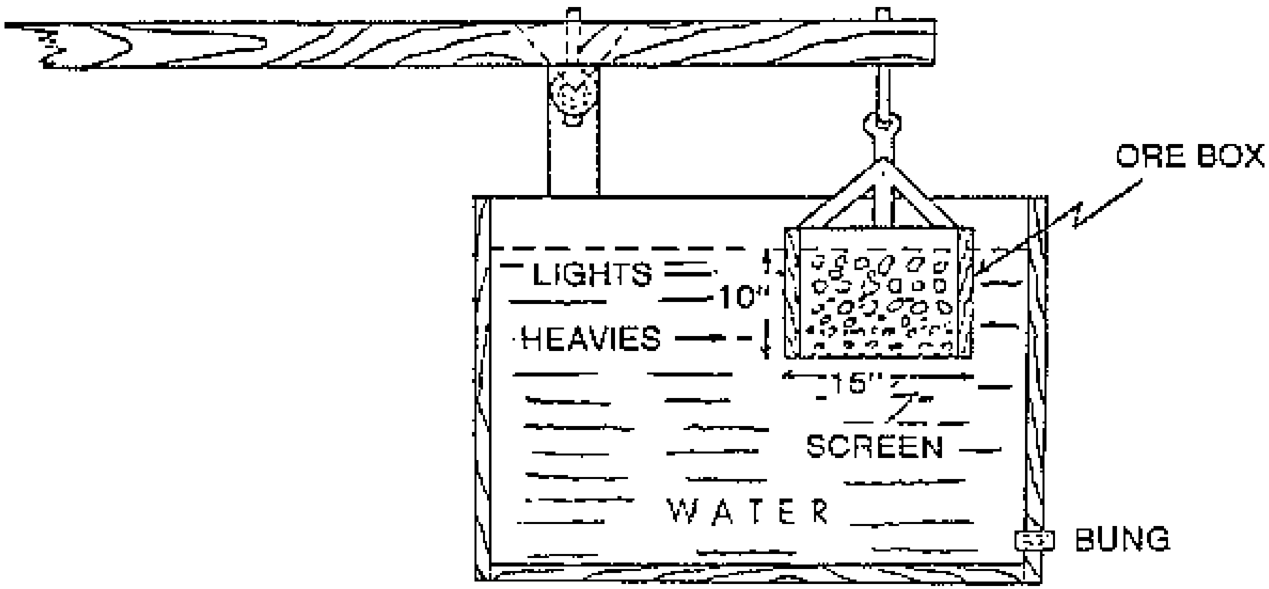


Fig.: Hand jig. Source: Stewart

14.3 Hand piston jig

Metal Mining, Coal Mining
Beneficiation, Sorting

engl.:	manual diaphragm jig, pedal diaphragm jig
germ.:	Kolbenhandsetzmaschine, Membran-Handsetzmaschine, Membran Pedalsetzmaschine
span.:	maritate de embolo, maritate con diafragma, maritate a pedal con diafragma
Manufacturer:	manual diaphragm jig: Taller Metal Mecanico, Campo Nuevo, both Bolivia

TECHNICAL DATA:	
Dimensions:	hand piston jig: approx. 1.5 × 1 × 2 m HWD; manual diaphragm jig: approx. 1.5 × 1 × 1 m HWD
Weight:	hand piston jig: approx. 100 - 150 kg; manual diaphragm Jig: 50 - 100 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	hand piston jig: manual; manual diaphragm jig: manual or pedal-drive
Mode of Operation:	hand piston jig: semi-continuous; manual diaphragm jig: intermittent
Throughput/Capacity:	hand piston jig: 0.5 - 1 t/Mh

Operating Materials:	
Type:	water
Quantity:	hand piston jig: approx. 100 I/min; manual diaphragm jig: small quantities
ECONOMIC DATA:	
Investment Costs:	hand piston jig: approx. 350 DM, lower if self- made; manual diaphragm jig: 300 - 550 DM
Operating Costs:	low, practically only labor costs
Related Costs:	none

CONDITIONS OF APPLICATION:

	hand piston Jig
Operating Expenditures:	low |—————————| high
	manual diaphragm jig
Maintenance Expenditures:	low |————|————|high
Personnel Requirements:	low
Location Requirements:	hand piston jig: flowing water necessary; manual diaphragm jig: none
Grain Size of Feed:	hand piston jig: 1 mm - 30 mm; manual diaphragm jig: (50) 200 µm - 2 mm
Special Feed	high density difference between valuable mineral and host material

Special Feed Requirements:	high density difference between valuable mineral and host material
Output:	hand piston jig: approx.concentrate 30 %
	middlings 50 %
	waste: 20 °/0
Replaces other Equipment:	hand piston jig: mechanized jigs; manual diaphragm jig: jig screen, washing sluice
Regional Distribution:	hand piston jig: Bolivia and worldwide; manual diaphragm jig: in Potosi, Bolivia as proto-type
	hand piston jig
Operating Experience:	very good |————|————| bad
	however often replaced by simple hand jigs;
	manual diaphragm jig: information not yet available
	hand piston jig
Environmental Impact:	low |—————————| very high
	manual diaphragm jig
	manual piston jig: environmentally detrimental due to sludge/silt load; can be solved through use of a thickener or clarifying basin
	hand piston jig
Suitability for Local Production:	very good |———|————| bad
	manual diaphragm Jig
Under What	hand piston jig: wood manufacturer; manual diaphragm jig: wood and

Under What Conditions:	hand piston jig: wood manufacturer; manual diaphragm jig: wood and metal-manufacturing shops
Lifespan:	hand piston jig very long |—————————| very short manual diaphragm jig

Bibliography, Source: Priester, Treptow, Callon, de Hennezel, Rittinger, Hunter, Stewart

<u>OPERATING PRINCIPLE:</u>

Hand piston jig:

Manually-operated pulsating Jig with double jig box. Operating principle is analogous to that of a hand Jig, with the addition of a lateral component generated by the longitudinal flow of the slurry through the jig. Thus the purely up-and-down motion with various vibrational amplitudes is overlaid by a longitudinal motion, which creates density-dependent particle flow-paths of varying vibrational amplitudes and wavelengths. This results in a faster transport of lighter (lower specific weight) particles and slower transport of heavier particles (higher specific weight). Consequently, in the semi-continuous operation, the heavier concentrate grains remain in Screen 1 due to their lower vibrational amplitude, while the middlings and tailings land in Screen 2, with the tailings subsequently being carried out of the jig with the slurry flow.

Manual diaphragm jig:

Manual pulsating jig or pulsating jig with pedal drive. An oscillating motion is

induced in the process water flow by means of a car-tire pulsator. The jig feed moves up and down and is sorted via vertical density differentiation.

AREAS OF APPLICATION:

Hand piston jig:

The sorting process is interruped to allow removal of the products. Employed for pre-concentration of coarser material.

Manual diaphragm jig:

Used to perform simplified jigging of fine and medium-sized grain fractions as an improvement over manual screen Jigging.

REMARKS:

Hand piston jig:

Wet classification: relatively low recovery of finer grain fractions due to the high velocity of slurry flow which also carries valuable-mineral particles out with the discharge. To achieve high recovery values, a wet classification in pulsating Jigs should be avoided. Alternatively, the fines should be caught in sedimentation basins and reprocessed (secondary separation).

A small bucket elevator (conveyor) - manual or mechanized - can be used to extract the product from the settling basin.

The density distribution of the feed must be regarded as the most important parameter in controlling the jigging process. The higher the density difference between the valuable mineral and host rock or waste material, the more successful the material can be separated in a jig. Schubert (1978) offers the following formula for estimating the sortability of the feed:

$$q = \frac{\delta_s - \delta}{\delta_1 - \delta}$$

δ_S= specific density of the heavy mineral, or density of the ore or valuable mineral in beneficiation

δ_1= specific density of the light mineral, or density of the gangue (waste material or host rock) in beneficiation

δ= density of the medium, usually water, density = 1

For determining the suitability of jigging in water, the value of q indicates the following:

q over 2.5:	separation by jigging is possible up to a lower grain- size limit of 100 ym
q over 1.75:	separation by jigging is possible up to a lower grain-size limit of 200 ym
q over 1.5:	separation up to 1.5 mm is possible, but difficult
q over 1.25:	separation by jigging is not possible

Manual diaphragm jig:

Proto-types exist, but results of operation are not yet known.

Difficulties can arise during operation concerning the homogeneity of the water flow over the jig bed; inhomogeneities must be minimized through the use of metal chutes to prevent disruption of the processing. Further need for research and development efforts.

Additional problems: sealing between the tire and the housing as well as between the tire and the reflecting plate. The use of counter-weights can minimize the leverage forces.

SUITABILITY FOR SMALL-SCALE MINING:

Hand piston jig:

As a purely manually-operated machine, the hand piston jig is suitable only under special circumstances. Since large quantities of water are needed to operate the hand jig, it should be investigated whether a hydromechanization as a "Harzer" Jig would be possible. Advantages of the hand Jig are its simple design and suitability for local construction.

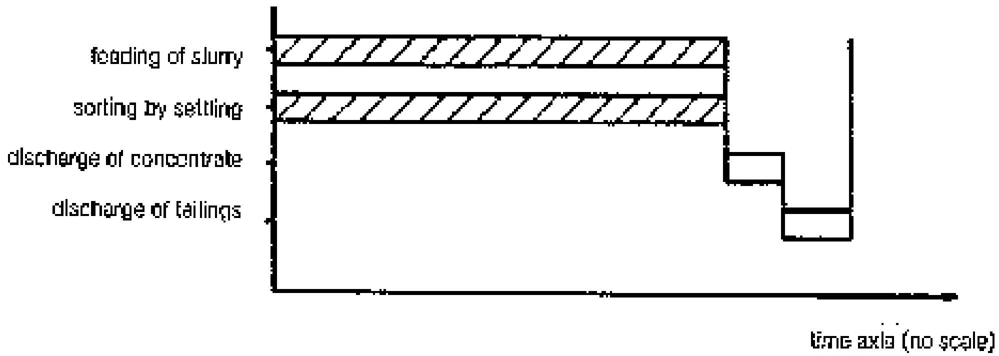


Fig.: Work-chronogram of jigging in a piston jig. Source: Priester.

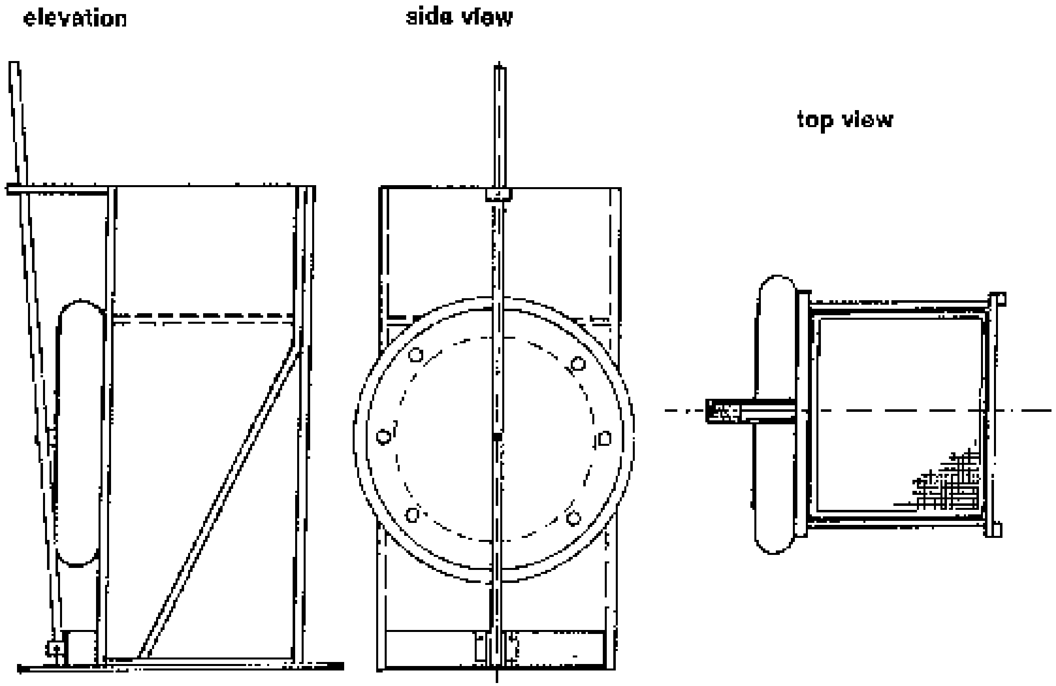


Fig.: Front view, side view and plan view of pulsating hand jig with car-tire pulsator. Source: Priester.

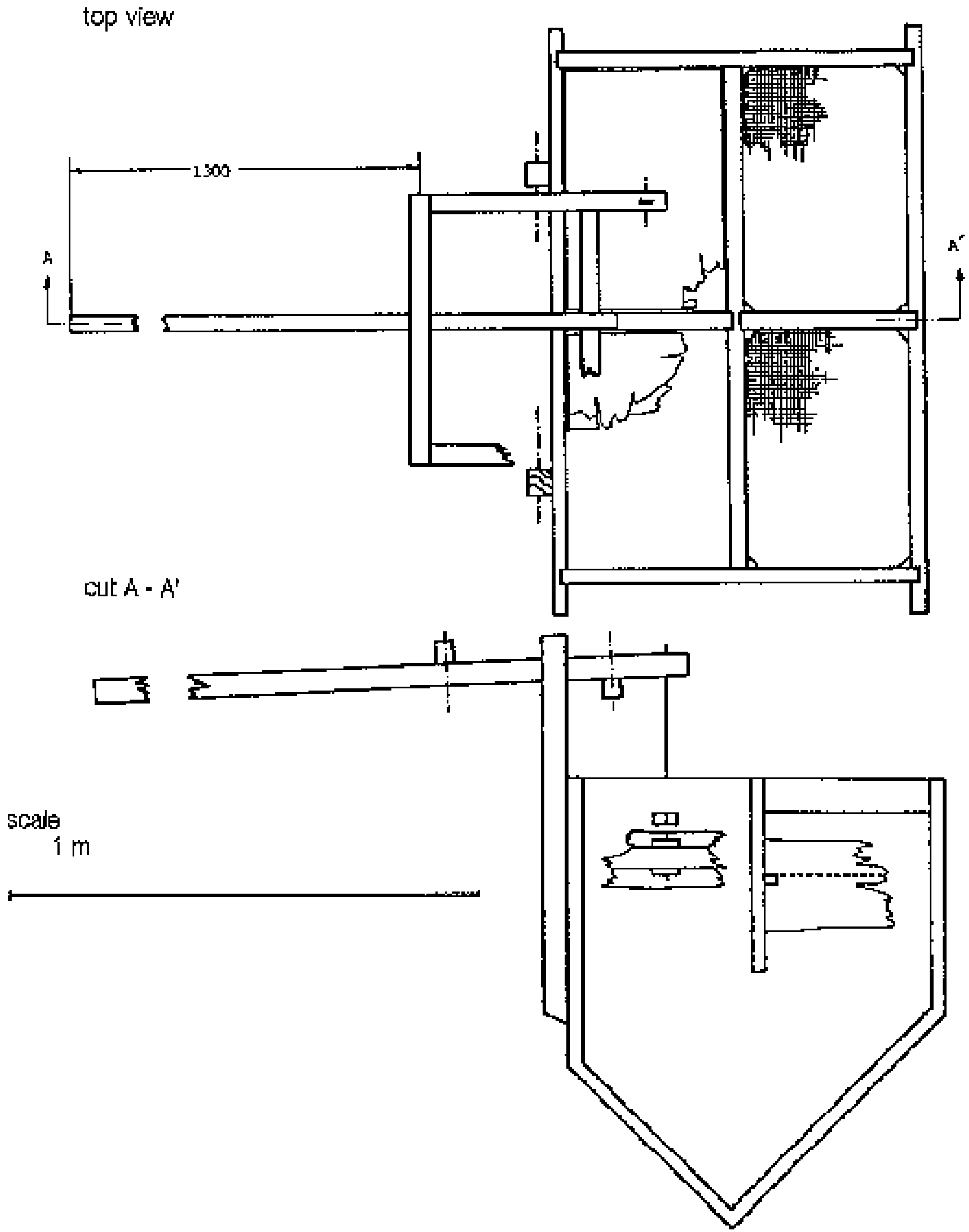

top view
1300
A
A'
cut A - A'
scale
1 m

Fig.: Plan view and cross-section of a hand piston jig. Source: Priester.

14.4 Piston jig, ''harzer'' jig

Metal Mining, Coal Mining
Beneficiation, Sorting

germ.:	Kolbensetzmaschine, Harzer Setzmaschine
span.:	jig de embolo, jig tipo Harz, maritate tipo Harz, jigger
Manufacturer:	Millan. Met. Lacha, Eq. Ind. Astecnia, Buena Fortuna, COMESA, FAHENA, FIMA, Famia, MAGENSA

TECHNICAL DATA:	
Dimensions:	approx. 2 × 2 × 2 m
Weight:	starting at 200 kg
Extent of Mechanization:	semi-mechanized
Power Required:	starting at 3 - 5 kW
Form of Driving Energy:	mostly electric or with internal combustion engine via transmission
	(mechanical)
Alternative Forms:	hydromechanical
Mode of Operation:	semi-continuous
Throughput/Capacity:	> 1 t/h

Operating Materials:	
Type:	water
Quantity:	> 100 1/min
ECONOMIC DATA:	
Investment Costs:	starting at 500 DM without drive-system
Operating Costs:	depends on type of mechanization and primary energy source
Related Costs:	handling of sludge

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |—————|—————| high
Maintenance Expenditures:	low |——————————| high
Personnel Requirements:	low
Location Requirements:	flowing water required
Grain Size of Feed:	1 - 30 mm
Special Feed Requirements:	high density difference between valuable mineral and host material
Output:	approx. 30 % as concentrate 50 % as middlings

	30 % as middlings
	20 % as waste
Replaces other Equipment:	all other types of jigs
Regional Distribution:	Bolivia, Peru, historically worldwide
Operating Experience:	very good |————|————| bad
Environmental Impact:	low |—————————| very high
	environmental pollution through sludge/silt loading; solved by using thickeners or sedimentation basins
Suitability for Local Production:	very good |————|————| bad
Under What Conditions:	wood manufacturer; high quality screens necessary
Lifespan:	very long |————|————| very short

Bibliography, Source: Fischer, Liwehr, Treptow, Callon, Kirschner

<u>OPERATING PRINCIPLE:</u>

Mechanized pulsating jig which works analogous to a hand piston jig, but is equipped with a mechanized drive-system via an eccentric shaft. Mechanized Jigs operate efficiently only when the extraction of concentrate and middlings occurs so as to ensure a continuous operation.

AREAS OF APPLICATION:

Production of pre-concentrate. Sorting of coarse grain fractions.

SPECIAL AREAS OF APPLICATION:

In addition to hydromechanical-gravimetric sorting also for wet classification.

REMARKS:

In wet classification, relatively low recovery of fines.

Various constructions for discharge of products which also offer continuous operation are of great advantage:

- **pipe and bell, installed in the center of the screen bottom, convey the product out of the water- filled jig box. Adjustment of slot width and height of pipe supports allows the proportion of concentrate to be regulated;**

- **side slits and discharge devices in retained water**

- **side-mounted sliding plug in conjunction with an inclined jig bottom which functions as a discharge in retained water.**

Kirschner gives the following design data for the piston stroke relative to the grain-size of the feed:

Grain Size	Frequency	Grain Size	Amplitude	Grain Size	Amplitude

(mm)	(min^{-1})	(mm)	(mm)	(mm)	(mm)
		20 - 30	75	3 - 5	35
1.5 - 3	140	13 - 20	60	2 - 3	25
3 - 8	130	8 - 13	50	1.5 - 2	15
8 - 30	110 - 120	5 - 8	40		

SUITABILITY FOR SMALL-SCALE MINING:

The high throughput quantities achievable in conjunction with a continuous mode of operation, as well as the ability to easily regulate product quality, make "Harzer" Jigs very suitable even for use in larger small-scale mining operations. In combination with a hydromechanical waterwheel drive, they present an ideal classifying method.

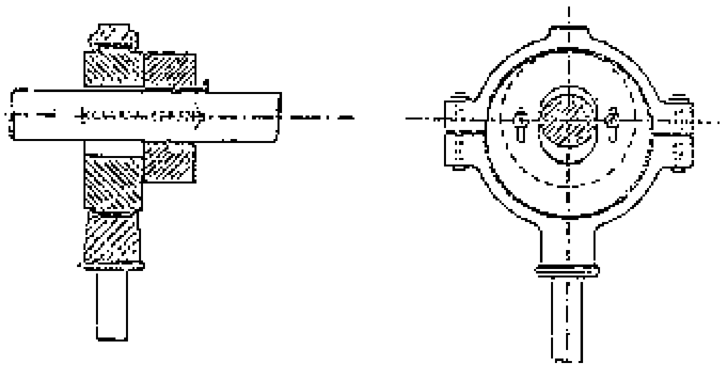


Fig.: Sliding drive transmission for the jig piston. Source: Treptow.

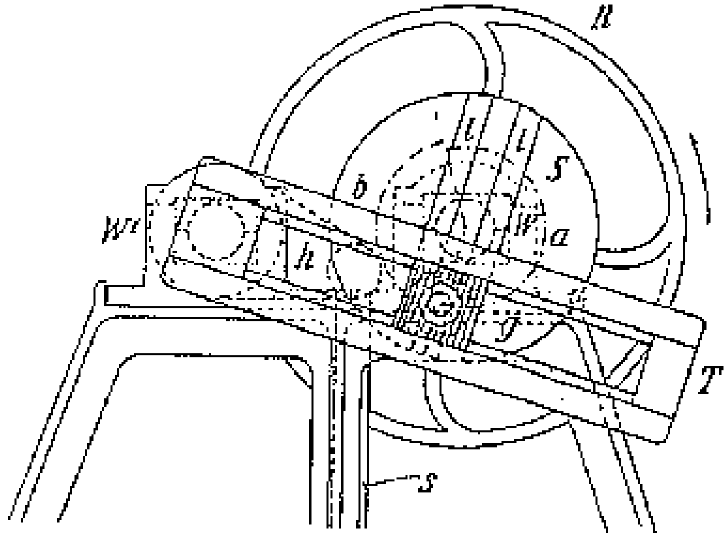


Fig.: Adjustable eccentric (cam) of "Harzer" jig. Source: Treptow.

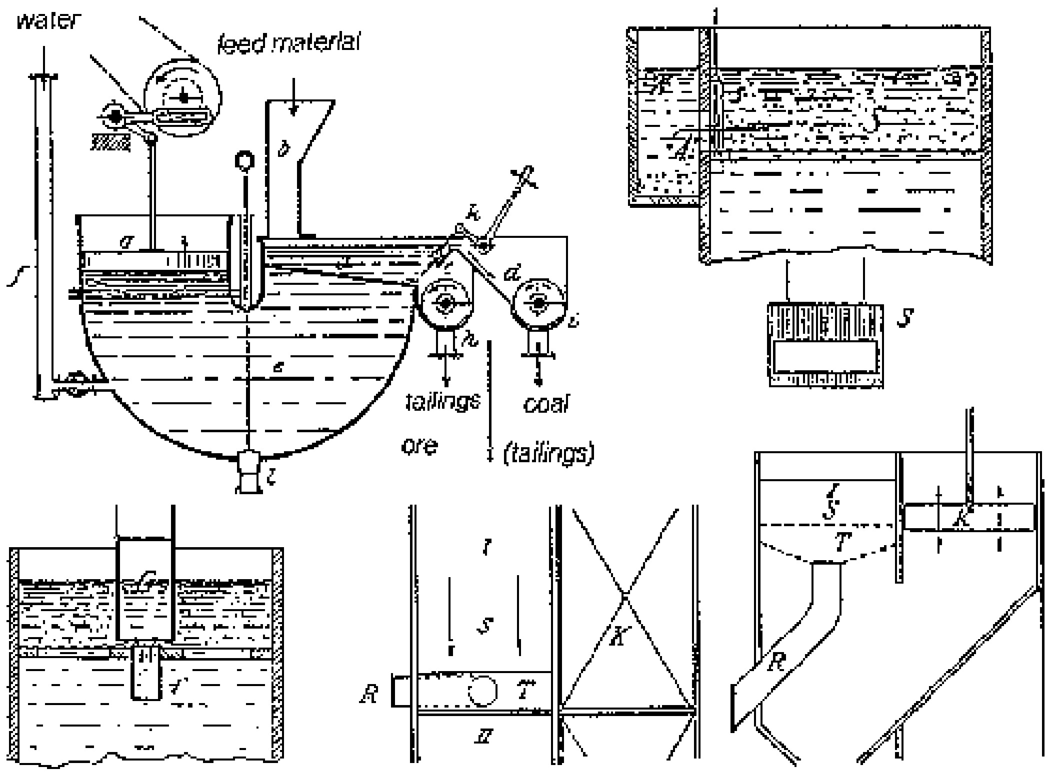


Fig.: Various forms of discharge devices for "Harzer" kigs. Above left: weirs in a jig with inclined jig bed (Source: Fischer), side-slots in retained water (Treptow), pipe and bell (Treptow) and funnel and pipe (Treptow).

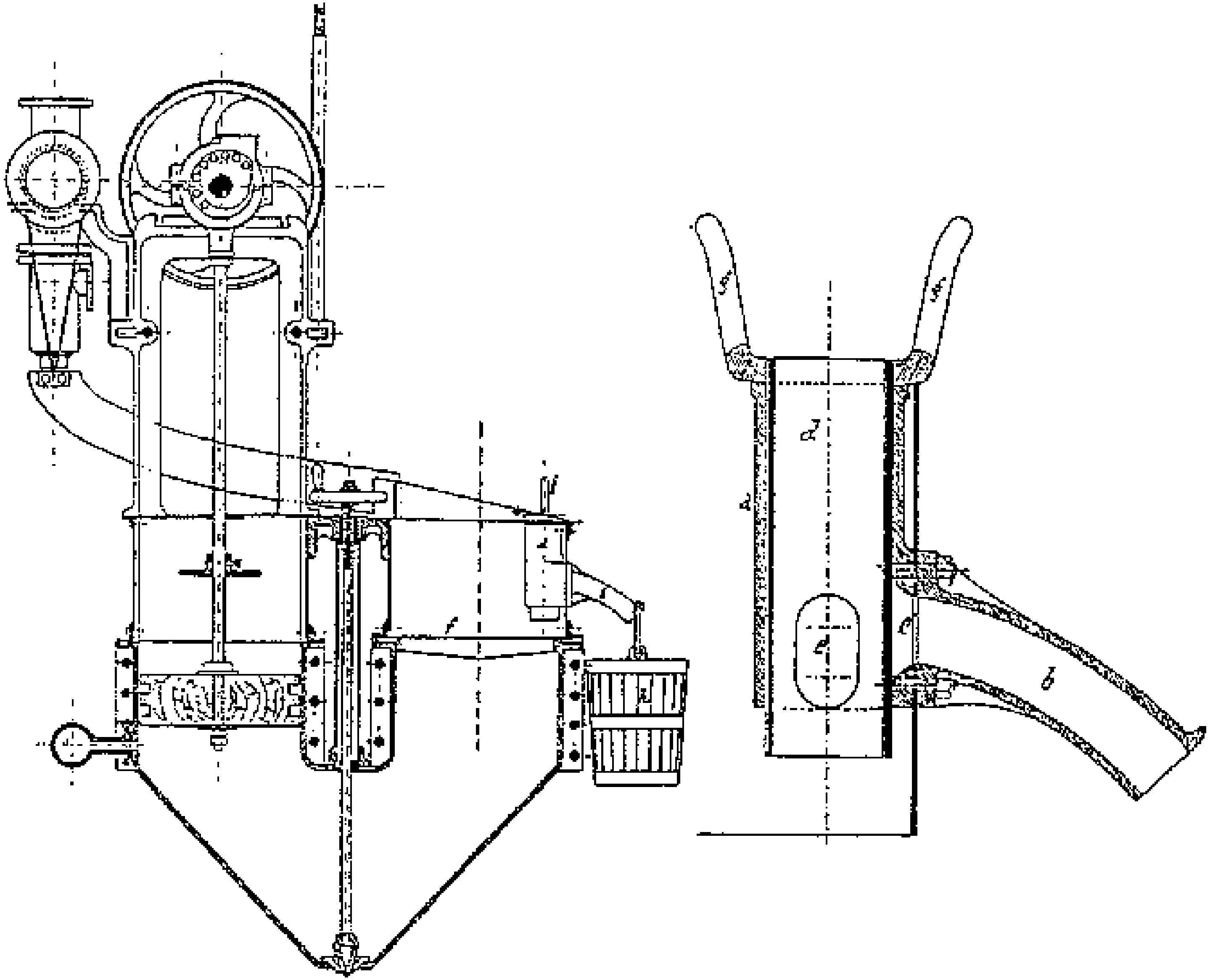
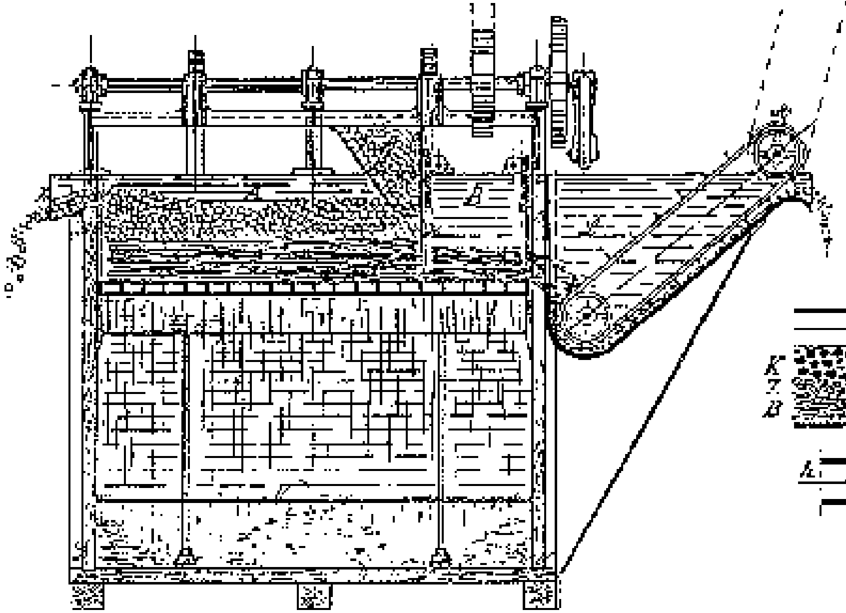
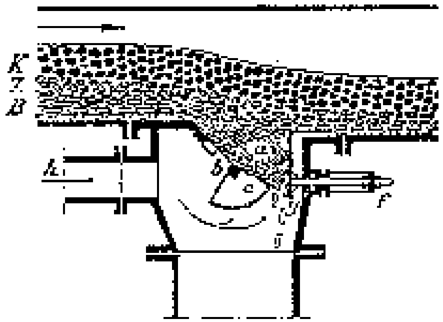


Fig.: "Harzer" jig with discharge through a pipe out the side; discarge outlet in

detail. Source: Liwehr.





Figure

Fig.: "Harzer" jig with hoisting device for discharge of the heavy component. Source: Liwehr.

Fig.: Detail of coal jig discharge. Source: Treptow.

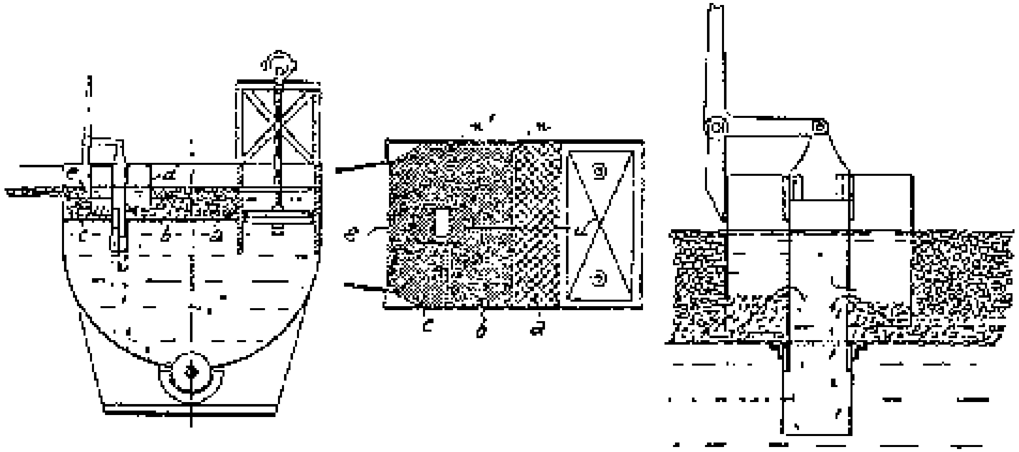


Fig.: Detail of central discharge throught pipe and bell from "Harzer" jig. Source: Liwehr.

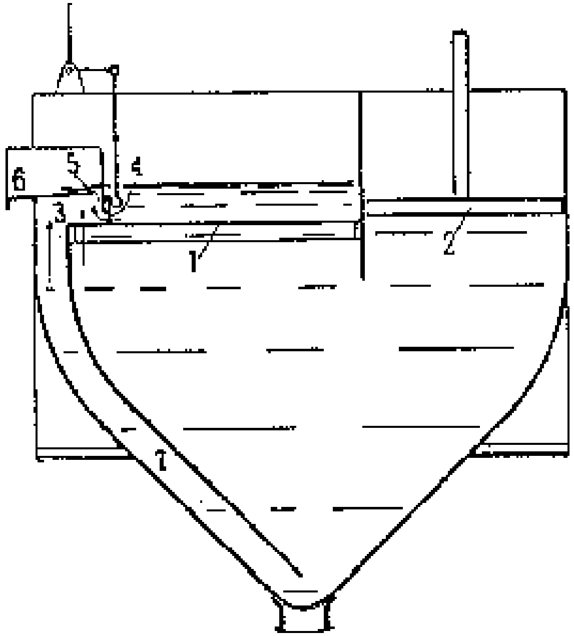


Fig.: Discharge with slotted weir and counter-current water. Source: Liwehr.

14.5 Pulsator classifier pan american jig

Metal Mining, Coal Mining
Beneficiation, Sorting

engl.: diaphragm jig
germ.: Pulsatorsetzmaschine, Membransetzmaschine
span.: jig de diafragma, jig de ague, jig con pulsador
Manufacturer: Denver, Svalcor

TECHNICAL DATA:	
Dimensions:	approx. 1 × 1 × 1 m HWD
Weight:	starting at around 150 kg
Extent of Mechanization:	semi-mechanized
Form of Driving Energy:	water pressure
Alternative Forms:	pneumatic jigs
Throughput/Capacity:	approx. 20 t/h × m² jig bed
Operating Materials:	
Type:	water
Quantity:	420 - 6601/min × m^2 pg bed
ECONOMIC DATA:	
Investment Costs:	minimum 500 to 1000 DM when self-constructed
Operating Costs:	low, mainly labor costs

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |————|————| high
Maintenance Expenditures:		low |————|————| high
Location Requirements:	water and elevation gradient necessary	
Grain Size of Feed:	approx. 0.5 - 10 mm	
Special Feed Requirements:	high density difference between valuable mineral and host material	
Output:	analogous to other coarse-grain jigging processes	
Replaces other Equipment:	under certain conditions, the mechanized jig	
Operating Experience:		very good |—————————| bad
	mostly unknown	
Environmental Impact:		low |————|————| very high
Suitability for Local Production:		very good |————|————| bad
Under What Conditions:	welding and metal workshops	
Lifespan:		very long |————|————| very short

Bibliography, Source: Priester, Schubert

<u>OPERATING PRINCIPLE:</u>

Hydromechanic pulsating jig, whereby the water flow is induced by a diaphragm-spring system. Analogous to "Harzer" Jig. Continuous-drive, semi-continuous operation. Pan-American jigs are operated with a jig bed and the screen throughput of the concentrate.

AREAS OF APPLICATION:

Sorting and pre-concentrating coarse-grained feed material.

REMARKS:

- other forms of discharge devices may be possible

- pulsators can be simply constructed of rubber diaphragms (car tires)

- a buffer of air at the charging side underneath the pulsator elastically suppresses the water movements.

SUITABILITY FOR SMALL-SCALE MINING:

Given sufficient water and vertical elevation gradient, and when the construction permits continual operation, this type of jig appears to be suitable for the sorting of coarse and medium-grained feed in small-scale mining operations.

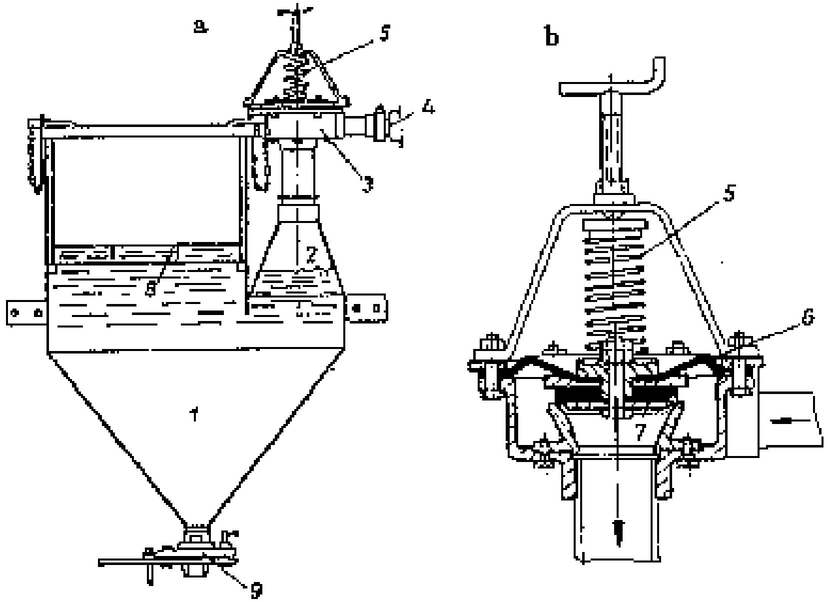


Fig.: Pulsating jig (Pan-American jig): a) jig, b) pulsator; 1) jig box, 2) funnel, 3) pulsator, 4) water supply line, 5) spring, 6) diaphragm, 7) flutwater valve, 8) brake sieve 9) concentrate dis-charge. Source: Schubert.

14.6 Sluices with or without linings/insets, long tom

Metal Mining, Alluvial Gold Mining
Beneficiation, Sorting

germ.:	Rinnenwasche mit und ohne Einsatze
span.:	canaleta para la concentracion , canal eta, chap a lavadora, canalon prefabricado, mesas rayadas, canoe
Manufacturer:	Keene

TECHNICAL DATA:

Dimensions:	inclination of sluice depends on mode of operation and grain-size of feed: 2° - 8° for semi-continuous pre-concentration of heavy mineral feed; 14.8° in Bolivia for reprocessing of narrowly classified concentrates in intermittent operation. Depending on the individual situation, sluices ranging from 2 × 0.5 × 0.5 m (Bolivia) to > 100 × 2 × 2 m (Thailand) are in use.	
Weight:	depends on type of construction, either as masonry built into the ground, or as wooden construction	
Extent of Mechanization:	not mechanized	
Form of Driving Energy:	only processing water	
Alternative Forms:	possibly mechanical vibrators/shakers	
Mode of Operation:	intermittent/semi-continuous	
Throughput/Capacity:	between 10 - 100 kg/in in a discontinuous operation; around 20 - 50 t/h in a semi-continuous operation	
Operating Materials:		
Type:	water	water
	in intermittent operation	in semi-continuous operation
Quantity:	up to 351/min	6-10: 1 ratio of fluid volume: solids volume

ECONOMIC DATA:

Investment Costs:	up to 10 DM/m
Operating Costs:	labor costs only; with turf lining higher costs due to frequent replacement

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |————|————| high
Maintenance Expenditures:	low |————|————| high
Personnel Requirements:	experience is necessary
Location Requirements:	flowing water necessary, minimum elevation gradient Dh of 0.5 m
Grain Size of Feed:	(100) 500 - 2000 ym (3 mm)
Special Feed Requirements:	high density difference between valuable mineral and host material
Output: .	approx. 60 % as concentrate, 40 % as waste in re-concentration of tin concentrates. Recovery is increased by re-sorting. Gold-sluices yield around 90 % in optical operation; the major problem is the loss of fines and of the flat, flour-like (float) gold particles, which can reduce the recovery to less than 50 % of the valuable mineral in some instances.
Replaces other Equipment:	fine-grain jigs, jig screens, flotation cells

Regional Distribution:	Bolivia; in gold mining worldwide
Operating Experience:	very good |————|————| bad
Environmental Impact:	low |————|———()—| very high
	when accompanied by flotation in the sluice, high contamination of receiving stream through acids, diesel oil and reagents
Suitability for Local Production:	very good |————|————| bad
Under What Conditions:	depending on construction, simple wood working, tin-smithing (sheet metal) or masonry work
Lifespan:	very long |————|————| very short
	when using sluices with turf lining, these have to be replaced every 2 - 6 weeks, depending on throughput quantities.

Bibliography, Source: Pirester, Stout, Treptow, Schanbel, Kirschner, Ambio, manufacturer infromation, Silva.

OPERATING PRINCIPLE:

Sluices of different longitudinal profiles (e.g. straight, bent, inclined to varying degrees, concave, etc.) with water flowing through in which, at the location of separation, the flow conditions are so regulated as to allow further conveyance of the light material but sedimentation of the heavier valuable-mineral particles.

AREAS OF APPLICATION:

For sorting of medium-sized grain fraction; for secondary processing of concentrates.

SPECIAL AREAS OF APPLICATION:

Flotation in sluice washers to eliminate sulfide impurities (e.g. pyrite, arsenopyrite, etc.) from oxidic concentrates (e.g. tin ore (cassiterite) or wolframite) .

Reagents: sulfuric acid, diesel oil, xanthate.

Feed: coarser than in hydromechanic-gravimetric sorting.

In gold mining, amalgamation is also frequently performed in sluices, whereby mercury is placed in the riffle channels. This technique leads to high Hg-losses (5 - 30 % of the Hg used per round) as a result of the mercury being broken down into small perls that are then flushed out with the slurry. In Brazilian mining, pieces of soap are packed into the riffle channels along with the mercury in an attempt to minimize the Hg losses. In any event, the practice of conducting amalgamation in sluices is extremely detrimental to the environment.

REMARKS:

Turf lining improves the separation precision in sluices (Bolivian name for this type is "Champalvadora") by increasing adhesive forces at the bottom. The following plant varieties are used in Bolivia for vegetative linings:

- Plantago tubulosa Decne
- Distichia muscoides

Both are proliferous ground-covering plants indigenous to the Andean moor ecosystem (bofedales).

Besides vegetative linings, other riffles and inserts are also being used to enhance the sorting characteristics of sluices by altering the bottom-surface and flow conditions. Known methods include:

- wooden cross-riffles
- stone packing
- rubber matting (car footmats)
- sisal (hemp) mats
- fine and coarse textiles (e.g. corduroy)
- Venetian window-blind arrangement of split bamboo rods
- structural metal/iron grid
- expanded metal mesh (biscocho, malla rombica)
- nets/mesh made from knotted ropes (e.g. hemp or grass), coarse screen mesh, or a combination of these.

Such sluices already characterize the transition to blanket sluices (corduroy tables) especially since such sluices mostly operate semi-continuously.

The higher the proportion of heavy minerals in the feed, the larger the sluice must be. In tin-ore mining in Thailand, sluices (palong) with lengths up to 120 m are in

use, whereby the length also serves to homogenize the slurry flow.

The higher the proportion of heavy minerals in the feed, the larger the volume of the sedimentation chambers behind the riffles needs to be in order to permit a sufficiently long operating period without interruption for removal of concentrate.

The finer the grain-size of the valuable minerals in the feed, the smaller the sluice inclination must be to prevent the slurry velocity from becoming too high. In mining of alluvial deposits in Southeast Asia, sluice inclinations of 3°- 6 can be observed (slurry speed: 0.7 to 3.0 m/s).

The latest state of technology for sluice sorting is the use of artificially-induced vibrations in sluice-bed proximity, generated through electric or pneumatic vibrators. The high-frequency motions contribute toward improving the separation precision and allow reduction of the sluice length. To minimize the required energy consumption, only the sluice bottom, mounted with flexible rubber seals, is vibrated.

In gold beneficiation, the successful sorting in sluice washers with riffles or stone packing requires an exact setting of the sluice inclination. If the sluice is installed too flat (a common error), the riffle channels or spaces between the packed stones become filled up with sediment, preventing flow turbulence behind the riffles, and consequently sedimentation of gold, from occurring. On the other hand, if the sluices are set too steep, gold is flushed out of the sedimentation chambers, leading to increased losses and decreased recovery.

Also of importance is the avoidance of fluctuations in the feed quantity. Whenever

only pure water flows through the sluice following separation, already-sedimented gold is partially carried back out.

Long wooden riffle sluices (about 4 m) are found frequently in gold mining, succeeding delivery chutes and washing sluices in the processing sequence. These so-called "long toms" are in use worldwide. Their average inclination is about 8%; throughput quantities total around 3.5 m gold-containing feed per day.

An interesting new development is a small tandem sluice in which the slurry feed flows over a screen (3/16") and separates into an underflow of the -450 ym grain-fraction and an overflow of the coarser grains. These two divided slurry streams then run over two riffled sluices, stacked on top of each other; the throughput (flow volume) of the fine slurry can be regulated by adjusting the slurry-feed level of the upper sluice, accomplished by restricting the cross-section of the discharge.

Another form of sluice washer was invented for processing magnetic and slightly-magnetic valuable minerals. This is a combined sluicing/magnetic separation process where magnets are placed underneath the sluice bottom near the riffle channels.

One method applied in gold ore mining involves the flow of slurry feed through a sluice with a concave depression for extracting fine gold. Mercury Iying in this cavity is stimulated by ultrasound, leading not only to a more precise density differentiation, but also to a strong activation of the Hg surface and resulting heating. The micro-sized Hg begins to evaporate and selectively precipitates onto the gold surface, a process which enhances amalgamation. Cooling is achieved by the water flowing through the sluice. The proper adjustment of the sluice incline is

complicated; it should prevent mercury from being carried out while at the same time assuring optimal surface contact for amalgamation.

Riffles for sluices used in gold mining are between 1 and 3 cm in height and installed at distances of 1 - 10 cm from the riffle grid inserted in the sluice.

Gold recovery from sluices increases if riffle grids are cleaned sufficiently often. During longer periods of operation there is a tendency for riffles to become filled or clogged with heavy minerals, causing a loss in recovery of the fine-grained material.

Studies in Brazil showed that Hg losses from amalgamation processes in sluices comprise around 40 - 50 % of the total Hg emissions in that country.

SUITABILITY FOR SMALL-SCALE MINING:

Sluices with a discontinuous charging of feed, and therefore low throughput despite very precise separation in some cases, are only suitable for processing small ore quantities, such as in secondary cleaning of concentrates. Sluices for semi-continuous operation are exceptionally well suited for producing pre-concentrates.

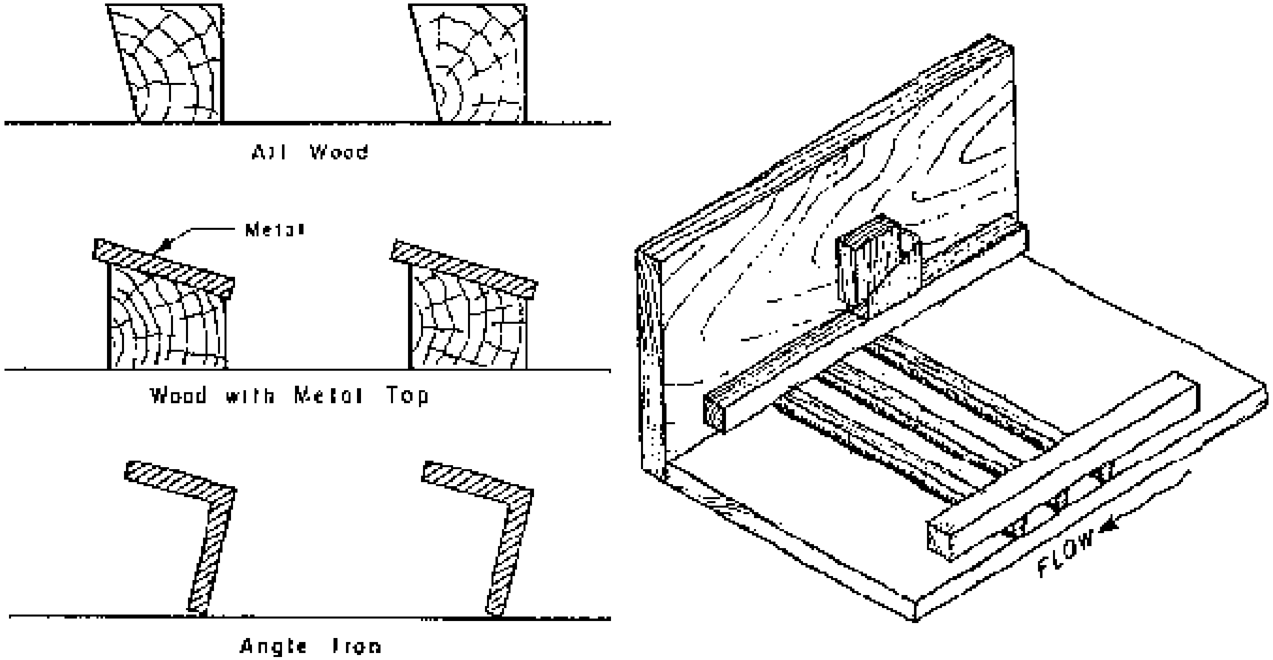


Fig.: Various forms of wood and metal or iron riffles and their installation in the source. Source: Silva.

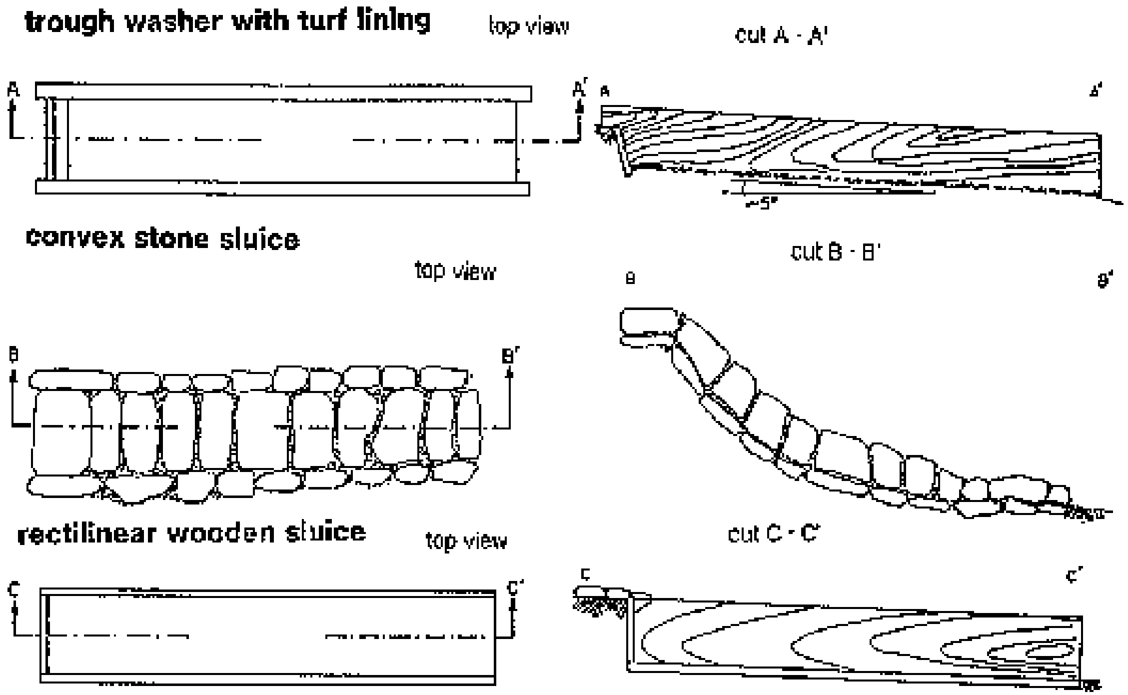
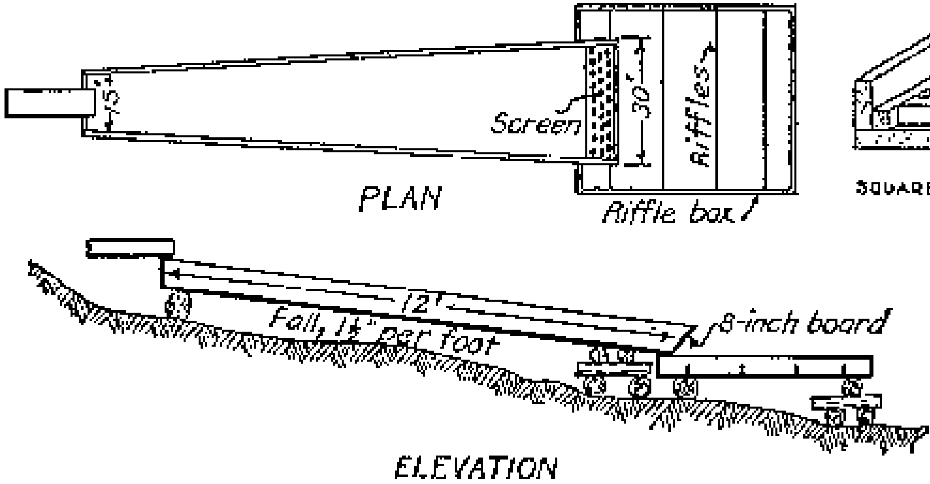
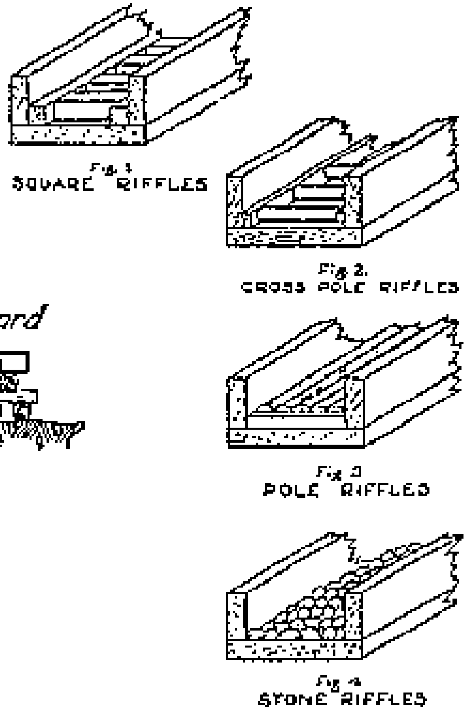


Fig.: Construction designs of sluice washers for intermittent operation; tin and tungsten mining in Bolivia. Source: Priester.





Figures

Fig.: Sluice for semi-continuous operation. Source: Bernewitz.
Fig.: Various types of wooden of stone riffles. Source: Stout.

14.7 Ground sluice

Metal Mining, Alluvial Gold Mining
Beneficiation, Sorting

germ.: Erdrinne
span.: canaletas naturales, suceo in Potosi, canalon natural

TECHNICAL DATA:

Dimensions:	approx. 1.5 × 1.5 × 200 - 300 m, up to 100 m elevation drop
Weight:	built into the ground
Extent of Mechanization:	not mechanized
Form of Driving Energy:	water and slurry flow
Mode of Operation:	intermittent
Throughput/Capacity:	approx. 10 t/min (ground sluices in Potosi)
Operating Materials:	
Type:	water
Quantity:	large quantities
ECONOMIC DATA:	
Investment Costs:	high construction costs
Operating Costs:	possibly high water costs

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |—————|—————| high
Maintenance Expenditures:		low |—————|—————| high
Personnel Requirements:	low	
Location Requirements:	large elevation difference (vertical drop) and water necessary	
Grain Size of Feed:	unclassified waste-dump material	
Special Feed Requirements:	high density difference between valuable mineral and host material	

Recovery:	very low, estimated value: < 10 % in Potosi, < 50 % in Colombia
Regional Distribution:	Potosi,Bolivia; alluvial-gold mining in Colombia
Operating Experience:	very good |—————|—————| bad locally good
Environmental Impact:	low |——————————| very high relatively high quantities of waste sludge, very large space requirements
Suitability for Local Production:	very good |—————|—————| bad
Under What Conditions:	masonry work only
Lifespan:	very long |—————|—————| very short

Bibliography, Source: Priester

<u>OPERATING PRINCIPLE:</u>

Sluice washing with fluctuating ground and elevation characteristics in which unclassified feed flows torrentially downward as sludge. The material which settles out onto the ground serves as a pre-concentrate for further processing.

<u>AREAS OF APPLICATION:</u>

For production of pre-concentrate from unclassified waste-dump material at Cerro Rico de Potosi, Bolivia.

For production of pre-concentrate in alluvial gold mining In Colombia.

REMARKS:

Due to the low degree of liberation of the sluiced material, it can only be expected that this process yields to a very low recovery of valuable minerals. In addition, processing activities in ground sluices burden the receiving stream with high sludge loading. Only a few topographical conditions allow the construction of ground sluices, since the sluice feed-input point must lie within close proximity to the raw-material deposit. Any necessity to transport the raw-material renders this already inefficient process uneconomical.

In gold mining In Colombian Barbacoas, similar ground sluices (canalones naturales) are likewise being used for the production of pre-concentrates. Gold-containing sediment, rinsed with low-pressure water, flows as a muddy slurry through the ground sluice, which is subdivided by stone riffle-like barriers. The pre-concentrate which collects in front of these stone barriers is repeatedly loosened and cleaned with the help of almocafres (scraping hooks) and cachos (wooden scrapers for removing the stones).

SUITABILITY FOR SMALL-SCALE MINING:

Applicable only under the special conditions present in Potosi, Bolivia; not transferable to other beneficiation plants or local conditions.

14.8 Pinched sluice, fanned sluice

Metal Mining, Alluvial Gold Mining

Benefication, Sorting

germ.: Facherrinne

span.: canaleta en forma de abanico, canaleta abanica

Manufacturer: Taller Metal Mecanico

TECHNICAL DATA:	
Dimensions:	0.5 × 0.5 × 1.5 m HWD
Weight:	approx. 25 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	only processing water
Mode of Operation:	continuous
Technical Efficiency:	concentrates to a factor of 2 or 3 per charge (processing cycle)
Operating Materials:	
Type:	water
Quantity:	< 50 I/min; 30 - 45 % by weight
ECONOMIC DATA:	
Investment Costs:	approx. 150 DM
Operating Costs:	low

CONDITIONS OF APPLICATION:

Operating low I————I————I high

Operating Expenditures:	low |————|————| high
Maintenance Expenditures:	low |————|————| high
Personnel Requirements:	low
Location Requirements:	water and Dh (elevation gradient) required
Grain Size of Feed:	100 µm - 1 mm
Special Feed Requirements:	Proportion of clay fraction in the feed should be < 5 %; valuable mineral grains between 50 ym and 0.5 mm; high density difference between valuable mineral and host material required
Recovery:	depends on degree of concentration
Replaces other Equipment:	other sluice washers, fine-grain Jigs, settling basins or buddies
Regional Distribution:	only as proto-type in Potosi, Bolivia
Environmental Impact:	low |————|————| very high
Suitability for Local Production:	very good |————|————| bad
Under What Conditions:	wood manufacturer
Lifespan:	very long |————|————| very short

depends on abrasive hardness of feed

Bibliography, Source: Priester, Helfricht, R. Leutz (heavy mineral sand) in: Erzmetall 42, Nr. 9, peg. 383 ff, Silva

OPERATING PRINCIPLE:

Sluices with converging cross-section in which a wide, shallow slurry stream is transformed into a deep, narrow stream. In this process, the heavy material separates out towards the bottom. A dividing blade at the outflow diverts the material flow into light-particle slurry (upwards) and heavy-particle slurry (downwards).

AREAS OF APPLICATION:

For pre-concentration of medium, fine and finest grain fractions.

SPECIAL AREAS OF APPLICATION:

For homogenizing and pre-concentrating of slurry prior to sedimentation in settling basins. The use of pinched or fanned sluices can eliminate peaks in flow during classification.

REMARKS:

The small relative difference in velocity between the slurry-material and the processing water allows precise separation even of the fine-grained fractions.

The pinched sluice can be very finely adjusted by varying the inclination, slurry feed and dividing-blade (experience necessary, possibly accompanied by quality-control measures via panning during processing). Rubber or plastic wear-resistant coatings increase the sluice lifespan. Pinched or fanned sluices are in use even in the technologically modern large-scale mining facilities (Cannon, Carpo-Schneider, Reichert Konus).

Concentration with pinched sluices or cone separators is only possible up to levels of 70% heavy-mineral content, since beyond this amount they no longer operate selectively.

The "tray tester" is a system of vertically-stacked pinched sluices, connected in series, in which tailings and concentrate are multiply re-sorted.

In addition to the simple gravity-based pinched sluices described above, these gravimetric-sorting sluices can also be used In combination with other separating processes. One example is the flotation fan-separator which vertically differentiates the material into float and non-float components through the use of reagent additives (to enhance flotation selectivity) and by injecting air through a fine metal mesh in the upper portion of the sluice where the slurry-feed flow is still flat; at the end of the sluice, these two flow components are separated by a dividing blade. Another example is found in the beneficiation of magnetic iron ores, where a magnetic pinched sluice is employed which is equipped with magnets installed underneath the sluice bottom to intensify the separation of heavy and magnetic ore particles into the underflow.

SUITABILITY FOR SMALL-SCALE MINING:

Pinched or fanned sluices are well suited for various processes in small-scale mining (production of pre-concentrate, homogenizing of settling-basin feed, etc.). Continuous, drive-less operation and a simple construction which can easily be produced locally are essential characteristics of pinched sluices.

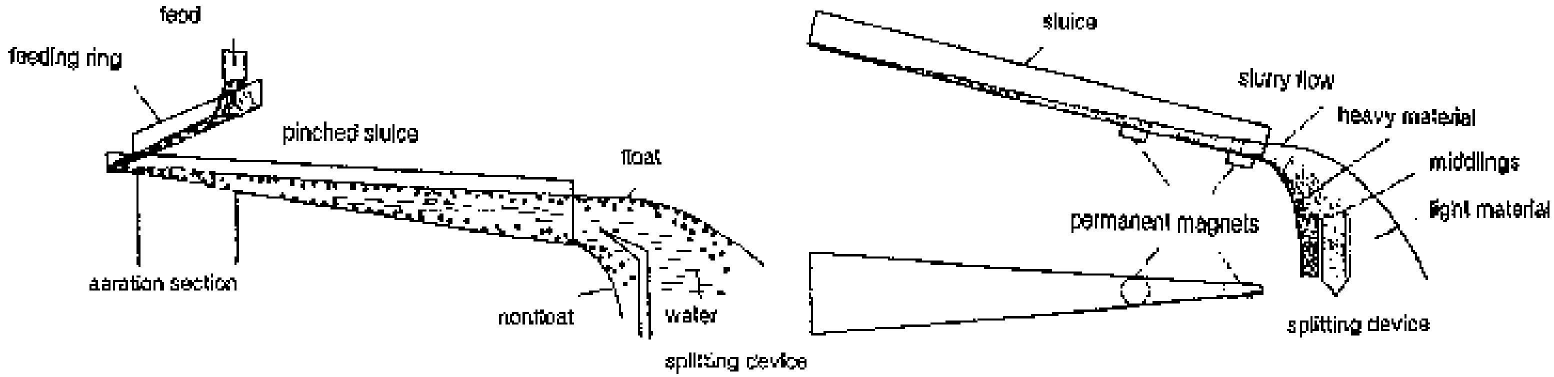


Fig.: Special types of pinched sluices: left, flotation pinched separator; right, magnetic pinched sluice. Source: Helfricht.

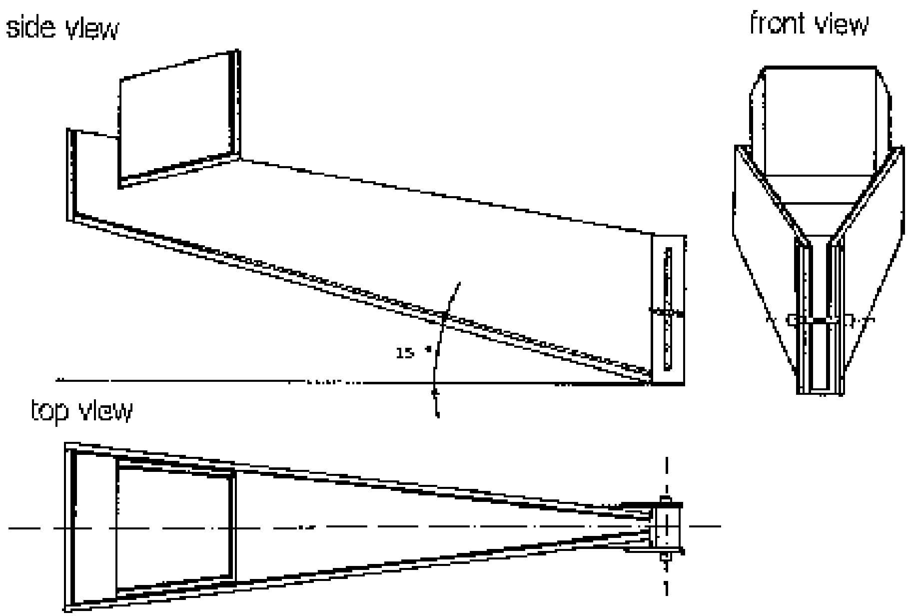


Fig.: Side view, top view, and front view of pinched sluice. Source: Priester.

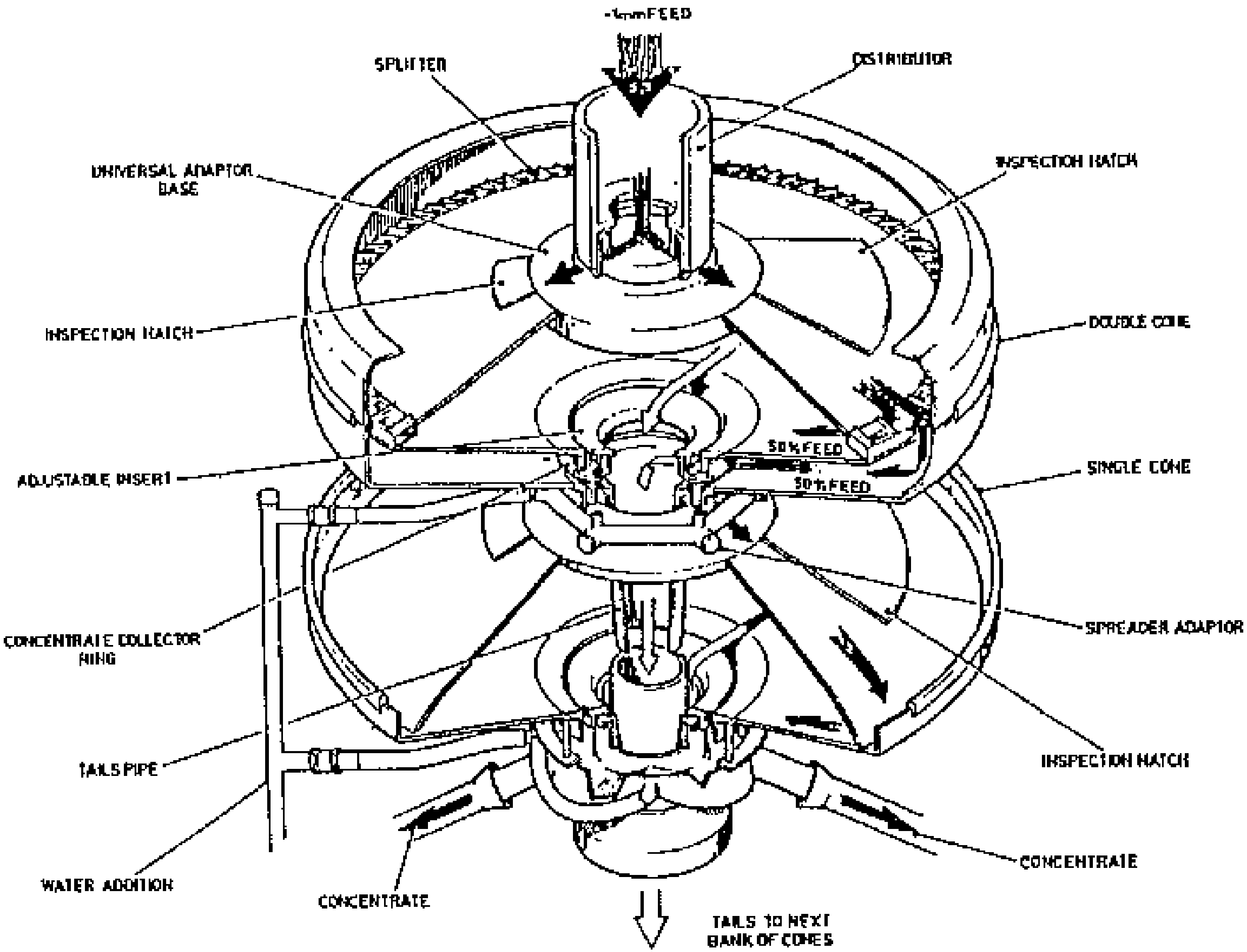


Fig.: Operating principle of a cone separator. Source: Robinson.

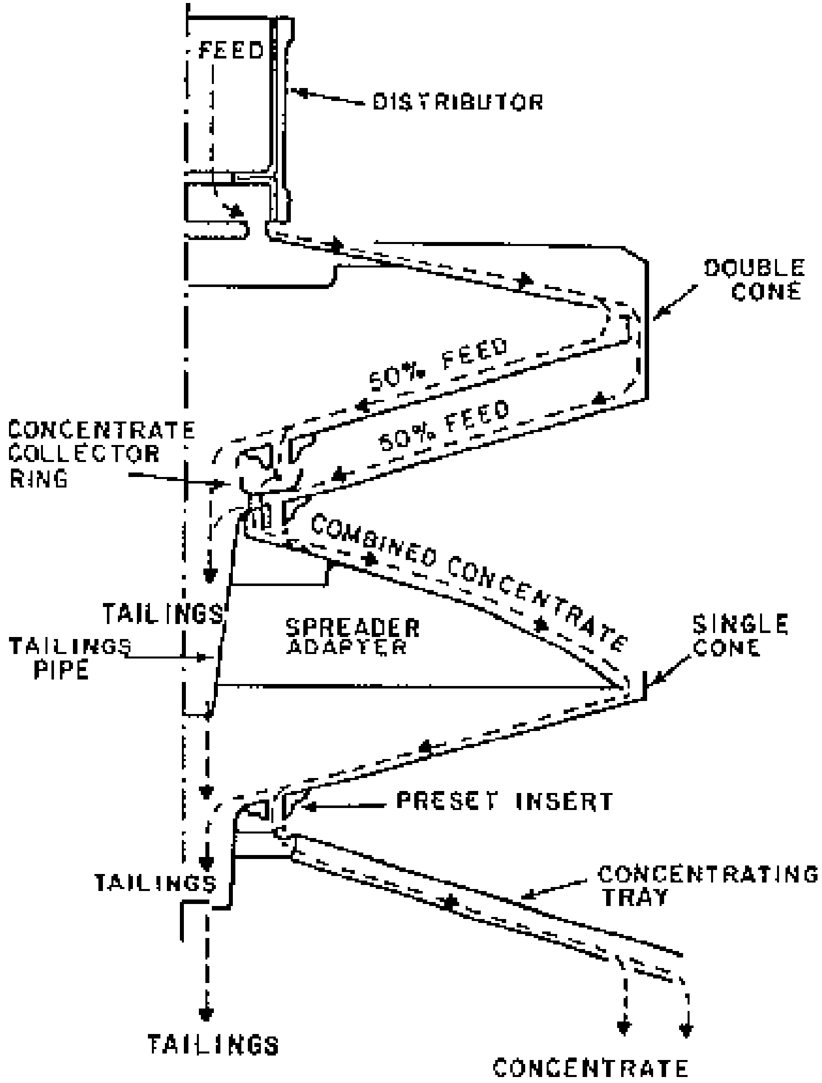


Fig.: Flow-path of material (slurry) in a cone separator. Source: Silva.

14.9 Air separator, dry blower

Metal Mining, Alluvial Gold Mining
Benefication, Sorting

engl.:	dry washer, pneumatic sluice, pneumatic table
germ.:	Aerorinnen
span.:	canaleta neumatica
Manufacturer:	Keene, Oliver Manufacturing Comp., Berry Neu

TECHNICAL DATA:	
Dimensions:	2 × 1 × 1.5 m HWD
Extent of Mechanization:	not mechanized
Form of Driving Energy:	manual drive or pedal drive, drive 250 min-1 approx. 10 cm amplitude
Alternative Forms:	mechanized with internal combustion engine
Mode of Operation:	semi-continuous

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |—————————| high
Maintenance Expenditures:		low |—————————| high
Location Requirements:	none, employable even in arid regions	
.		
Grain Size of	< 5 mm; in pneumatic tables between approx. 1 and 50 mm	

Feed:		
Special Feed Requirements:	feed must be completely dry; high density difference between valuable mineral and host material necessaryOutput: recovery in fine grain-size range is relatively low	
Regional Distribution:	Australia, USA	
Environmental Impact:		low |—————|—————| very high
	low pollution from airborne-dust	
Suitability for		
Local Production:		very good |—————|—————| bad
Under What Conditions:	wood manufacturer	
Lifespan:		very long |—————|—————| very short

Bibliography, Source: de Bernewitz, Hunter, Stout, Silva

OPERATING PRINCIPLE:

Feed is classified by screening into several fractions. The screens are inclined, and air is blown through them from underneath by means of bellows. This blown air picks up the screened oversize material lying on the screens cloth bottom and suspends it in a turbulent air layer where it is differentiated according to density. The material flow is induced by the screens inclination, whereby the heavy

fraction is caught by riffles and the lighter material is discharged over the riffles.

AREAS OF APPLICATION:

Pre-concentration of liberated (comminuted) mine ore in arid regions.

REMARKS:

By mounting the screens onto a flexible steel construction, a shaking movement can be incorporated into the system.

Besides dry blowers, dry vibrating sluices are also used in arid regions. Since a fluidized bed (turbulent air layer) is not generated in these sluices, the separation precision and recovery of valuable minerals are correspondingly lower.

Pneumatic tables:

Pneumatic tables are used for benefication of dry feed (e.g. gold sands in arid regions or coal) in high throughput quantities. Pneumatic tables consist of a screen bottom permeated by a forced-air current which suspends the feed material in a stable turbulent air-layer (fluidized bed). The inclination of the screen as well as applied impact-forces cause the suspended feed material to separate into a light-material zone and heavy-material zone. The comparably high energy consumption as well as the high proportion of airborne dust generated which characterize this process call for the use of a closed-circuit air-flow system, or an intermediary cycloning or dust removal in a dust-collecting chamber with dust collector. The fact that pneumatic gravimetric-separated concentrates do not require subsequent drying is advantageous; the low separation precision is

disadvantageous.

Air separation:

Another important pneumatic sorting technique is air classification. The material falls through an air current, whereby the lighter particles are deflected over a greater distance due to their larger surface: weight ratio than are the heavier particles. The flow components can be separated by the use of dividing blades. Air classification can be employed for separating narrowly. classified (narrow-band), totally dry, fine feed; however, the extremely large quantities of dust generated during processing pose enormous environmental problems. The use of cyclones, wet air-washing, or completely covered plants where the processing air flows in closed circuits can reduce dust pollution, but raise processing costs accordingly.

Pneumatic dry washer:

Pneumatic benefication, for example for use in arid regions, can be performed by means of pneumatic pinched sluices where air is blown through a cloth bottom creating a fluidized bed which suspends the feed material and classifies it analogous to the pinched hydro-sluice principle. High density difference and narrowly-classified feed granulation are prerequisites for successful sorting. Pneumatic pinched sluices are employed for pre-concentrating.

SUITABILITY FOR SMALL-SCALE MINING:

Well suited for application in arid regions, especially for the processing of low-grade precious-metal ores (such as the recovery of gold from laterites); simple apparatus which can be locally manufactured.

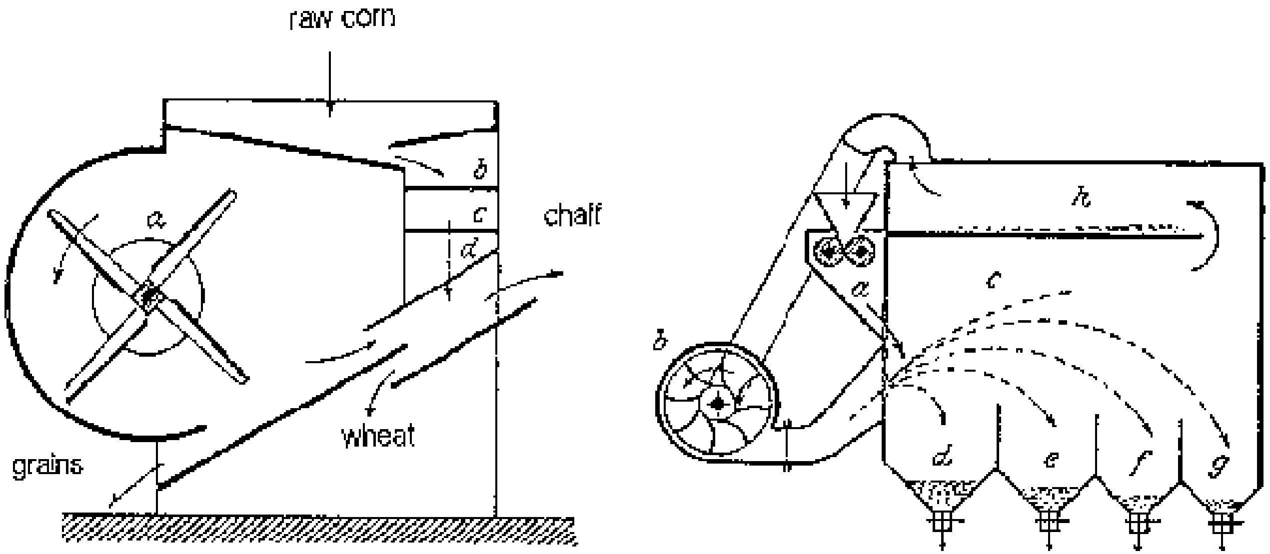


Fig.: Sorting in air current; left, air classifer for grain; right, mineral sorting in air classifer. Source: Fischer.

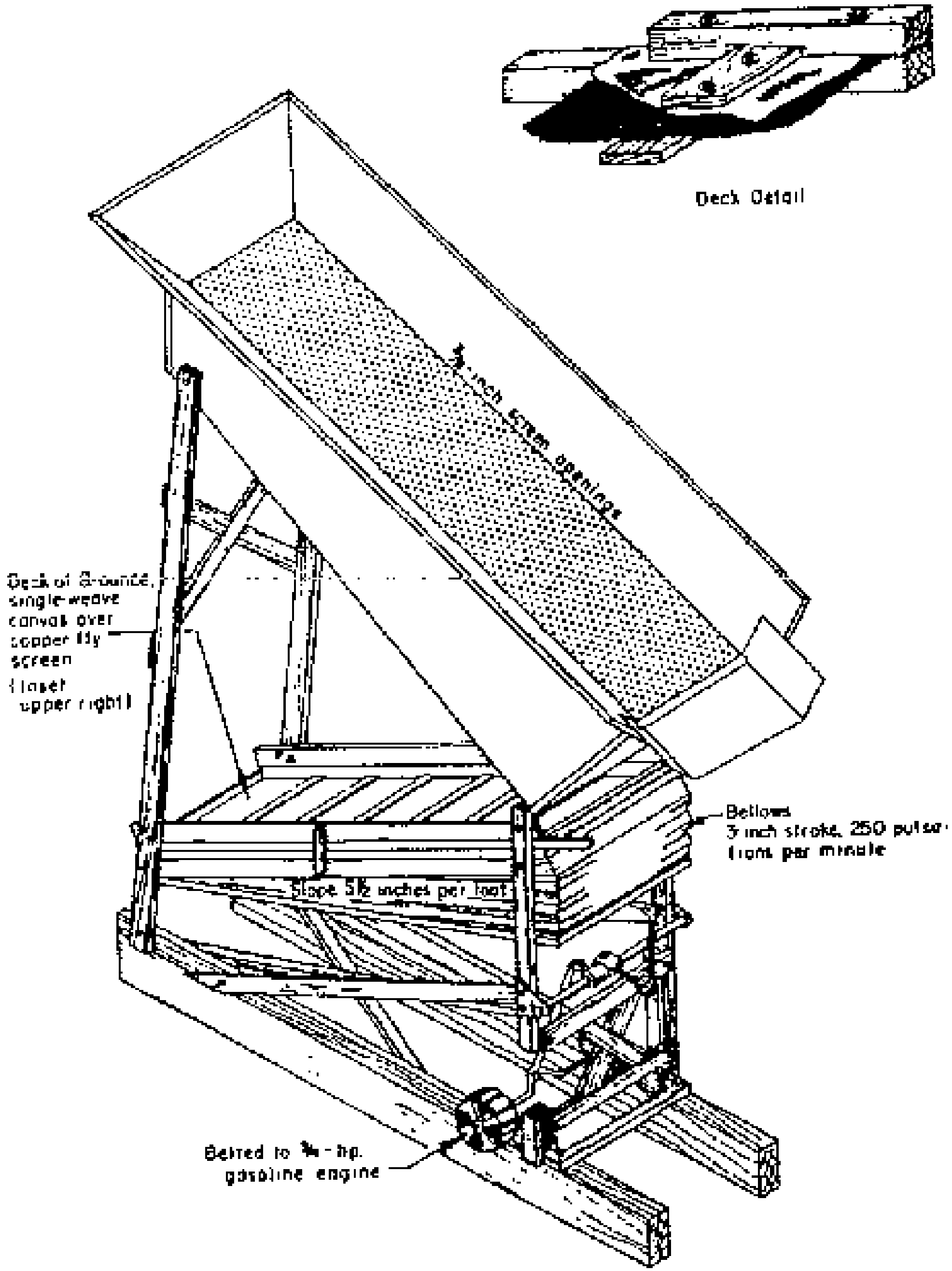


Fig.: (right) Pneumatic sluice. Source: Silva.

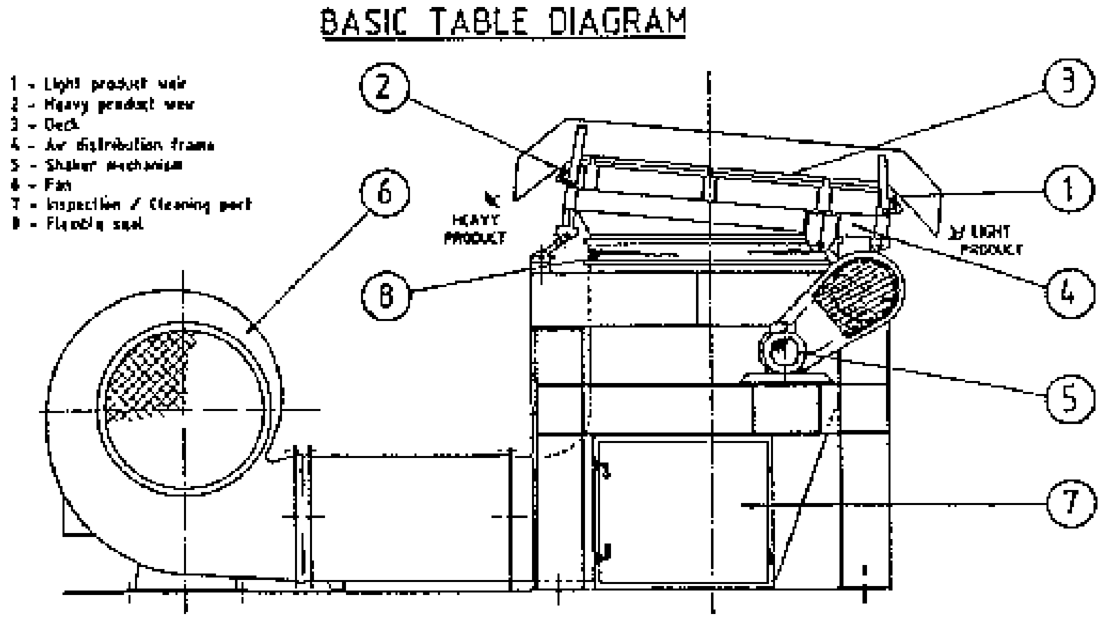


Fig.: (below) Pneumatic table. Source: Ackthun.

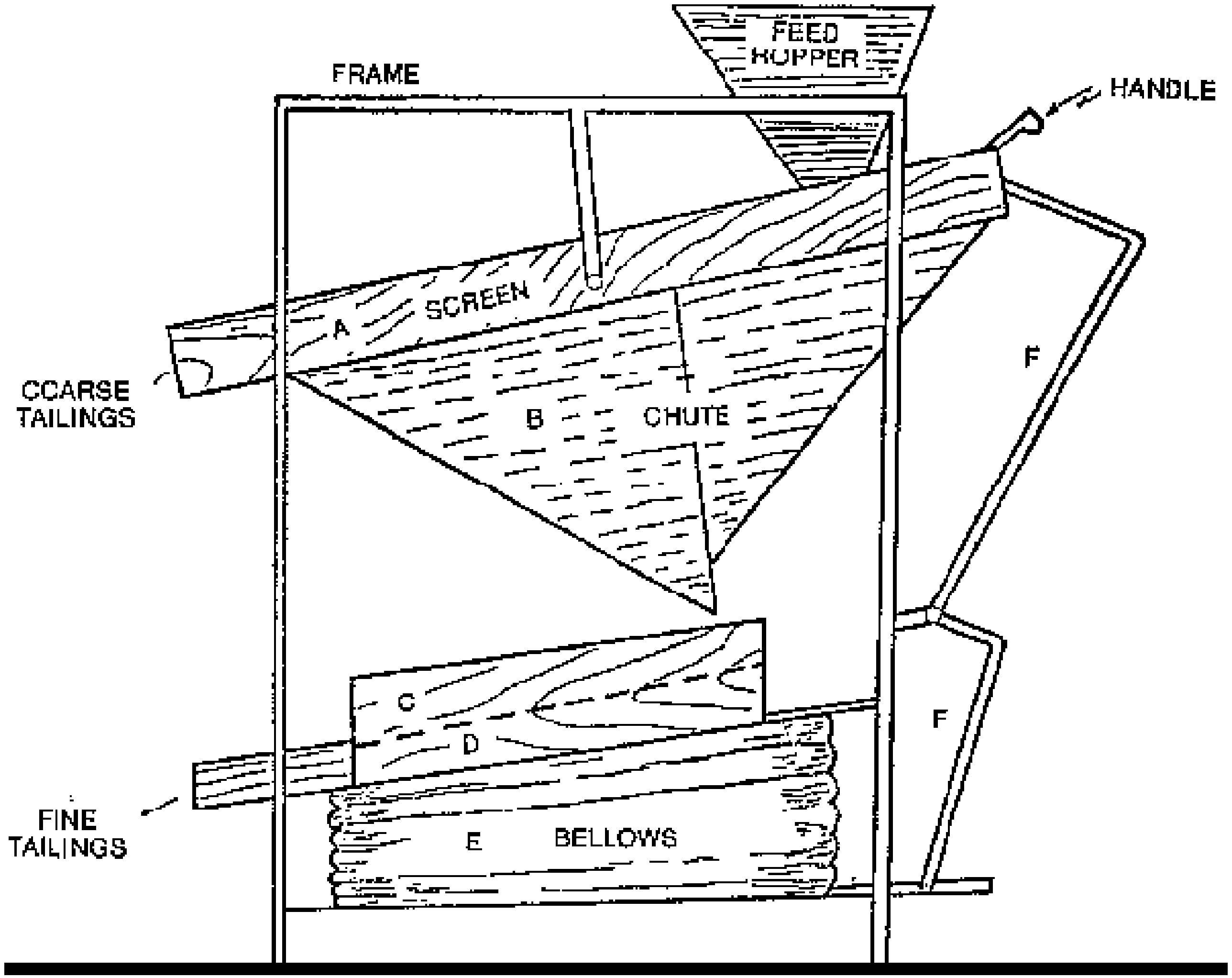


Fig.: Manual pneumatic sluice. Source: Stewart.

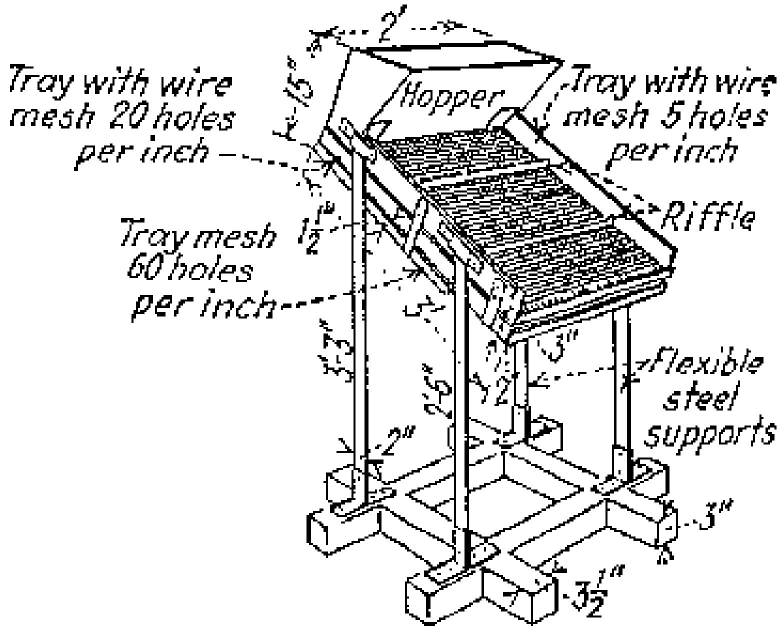


Fig.: Dry vibrating sluice. Source: Bernewitz.

14.10 Settling basin, buddle

Metal Mining, Coal Mining
Beneficiation, Sorting

engl.:	conical table
germ.:	Schlammgrube, Sandrundherd, Kegelherd, runder Liegendherd, liegender Rundherd
span.:	buddle redondo, rumbulo, rumbo, phurmuchina, plataforma conica, plataforma, redonda de concentracion

TECHNICAL DATA:	
Dimensions:	approx. 2 m 0, 1 m H, 6.3° angle of opening
Weight:	mostly built into the ground; above-ground parts approx. 20 kg

Weight:	mostly built into the ground, above ground parts approx. 20 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	only processing water
Mode of Operation:	semi-continuous
Throughput/Capacity:	up to approx. 1000 kg/h
Operating Materials:	
Type:	water
Quantity:	up to 751/min
ECONOMIC DATA:	
Investment Costs:	approx. 300 - 350 DM, less expensive if self made
Operating Costs:	insignificant, labor costs only

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |————|————| high
Maintenance Expenditures:		low |————|————| high
Personnel Requirements:	low	
Location Requirements:	water and min. Dh of approx. 1 m necessary	
Grain Size of Feed:	50 ym - 2.000 ym	
Special Feed	high density difference between valuable mineral and host material	

Special Feed Requirements:	high density difference between valuable mineral and host material
Recovery:	Averages about 50 % as concentrate, 25 % as middlings, 25 % as waste material, whereby the material is frequently recycled (reprocessed) in order to increase concentrate contents.
Replaces other Equipment:	tables, sluices
Regional Distribution:	Peru, Bolivia
Operating Experience:	very good |—————|—————| bad
	in association with flotation in settling basin
Environmental Impact:	low |—————|—————| very high
Suitability for Local Production:	very good |—————|—————| bad
Under What Conditions:	maasonry construction, wood manufacturer
Lifespan:	very long |—————|—————| very short
	extremely long

Bibliography, Source: Priester, Alfeld, Gaetzschmann, B+H.Z 1865, Linkenbach, Callon

OPERATING PRINCIPLE:

The slurry-feed is placed into the center of a flat sedimentation cone (conical table, buddle). The geometrical form of the sedimentation chamber causes a decrease in slurry velocity as it flows outward toward the table perimeter, which results in a sedimentation of the slurry material: fine heavy-material (with small surface-area exposed to the flow forces) settles in the middle, then coarser heavy-material, further out the fine light-material and at the periphery coarse light-material. The silty fines remain suspended and are carried off. Homogeneous conditions for sedimentation are achieved by damming or retaining the slurry in order to regulate the feed level. The products are extracted manually, with shovels, in concentric rings following completion of the separation process and after the material has dried.

AREAS OF APPLICATION:

Sorting of fine feed. Sorting of waste from sorting tables.

SPECIAL AREAS OF APPLICATION:

Flotation to separate sulfide impurities from oxidic concentrates using sulfuric acid, diesel oil and xanthate. Air-water interfaces occur in the centrally-located slurry feed input.

REMARKS:

- for homogenizing and slowing the slurry flow, bundled grass stalks (chorros) are place at the slurry input point,

- to simplify the damming of the slurry flow in the sedimentation chamber, weirs made from metal sheets or wood can be employed.

- throughput can be increased by simply dividing the slurry feed and processing the separate flows simultaneously in parallel-arranged buddies,

- invented about 1840 in England by Hughes/Ball (Zeitschrift fur das Berg-, Hutten- und Salinenwesen 1865, 22), 1842 by Taylor (Gurlt),

- the round buddle (Linkenbach table) is similar to the type of conical table used in Bolivia; it varies regarding feed Input and homogenization, which are performed by means of a rotating mechanism from which cloths or brooms are hung. This reduces the extent of turbulence at the feed-input point.

To assess the quality of the product, the traditional mill worker uses a shovel as a panning dish to analyze the contents of the heavy minerals at the perimeter of each respective sedimentation ring. In this way the diameter of the respective concentric rings of concentrate, middlings and waste material can be established for product extraction.

The inclination of the cone angle significantly influences the concentrate content and the recovery. Optimal values can be achieved when the inclination of the conical table (buddle) equals that of the growing sediment cone. This varies depending on grain size, distribution of minerals and throughput of slurry. The finer the feed or the smaller the density difference between valuable and non-valuable minerals, the flatter the inclination of the sediment cone becomes

towards the perimeter.

In Bolivian tin and tungsten-ore vein deposits the optimal cone angles are around 6.3°.

Regarding the processing procedure, the process flow sheets vary according to whether classification occurs before or after separation processing; i.e. whether an already-classified feed of narrow grain-size range is fed into the separation equipment (Harzer method), or whether a feed of broad-ranged granulation is processed, in which case classification is subsequently performed to remove the host or waste material (screened overs) from the concentrate (Anglo-Saxon method).

SUITABILITY FOR SMALL-SCALE MINING:

In general, the settling basin or buddle is very suitable for wet mechanical fine-grain sorting in small scale mining. It is also quite suitable for secondary separation of sorting-table tailings. The settling basin is characterized by its simple, low-cost construction which does not involve any moving parts.

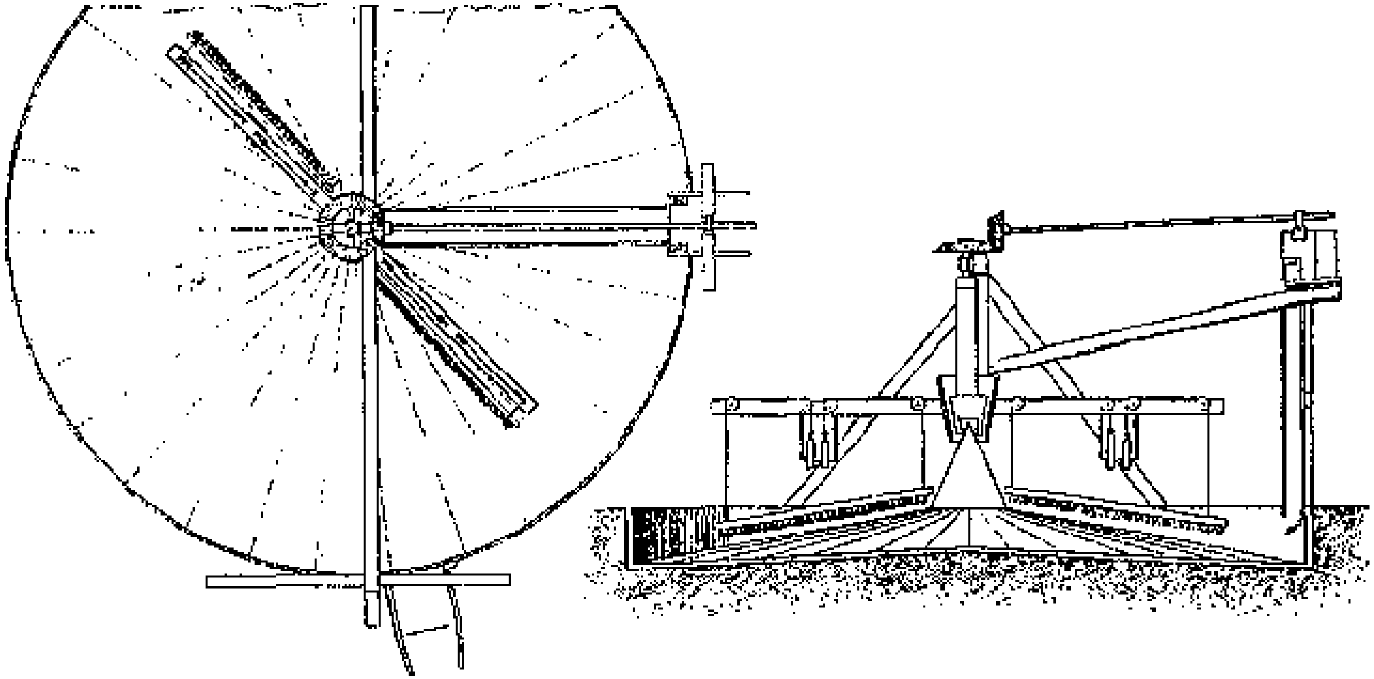


Fig.: Conical table or buddle. Source: Callon.

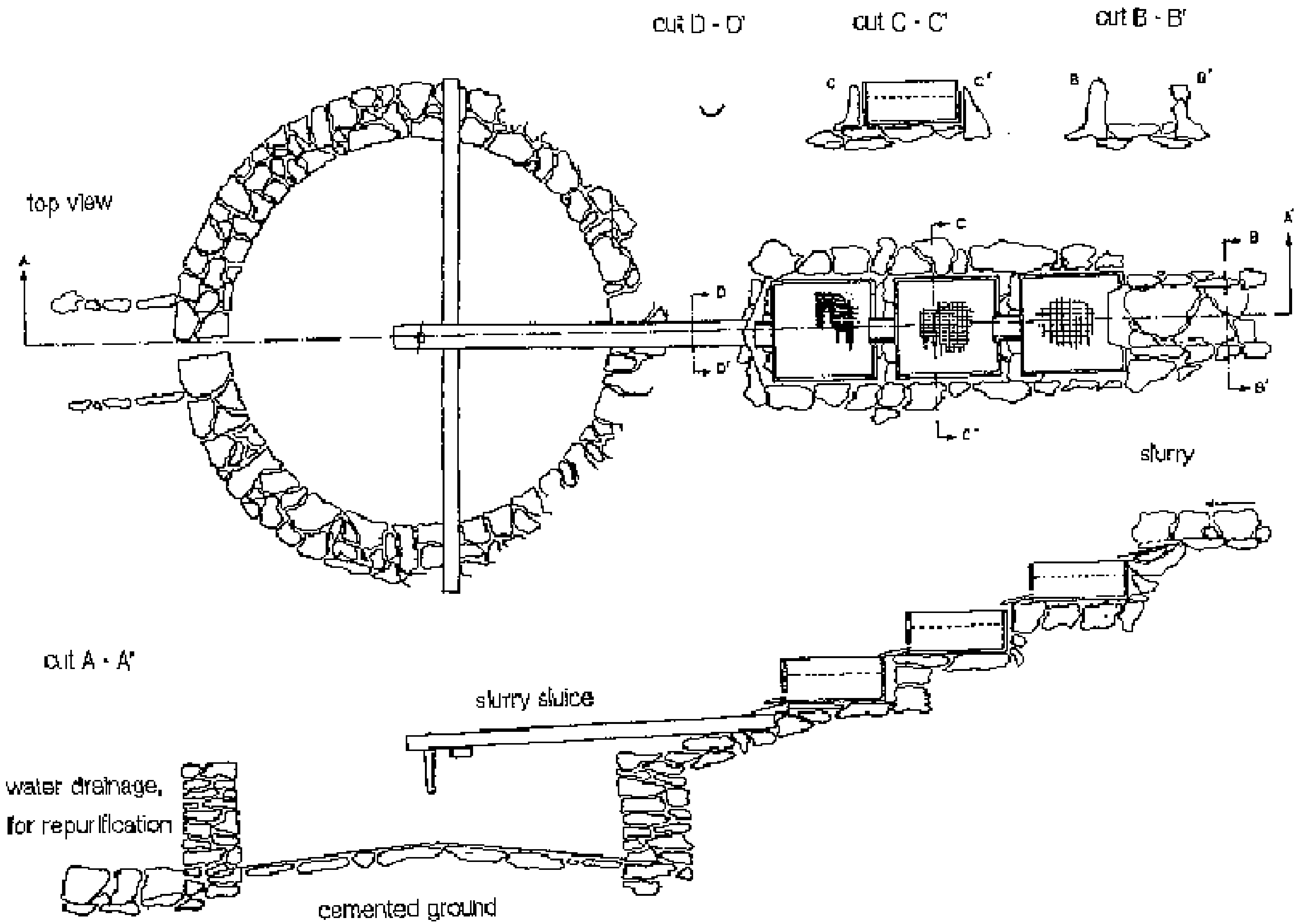


Fig.: Top view and cross-section of a Bolivian setting basin. Source: Priester.

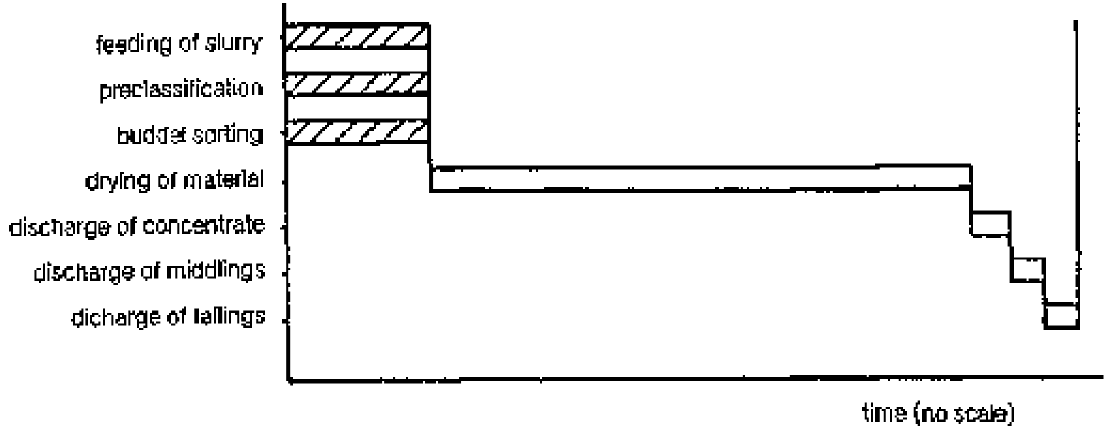
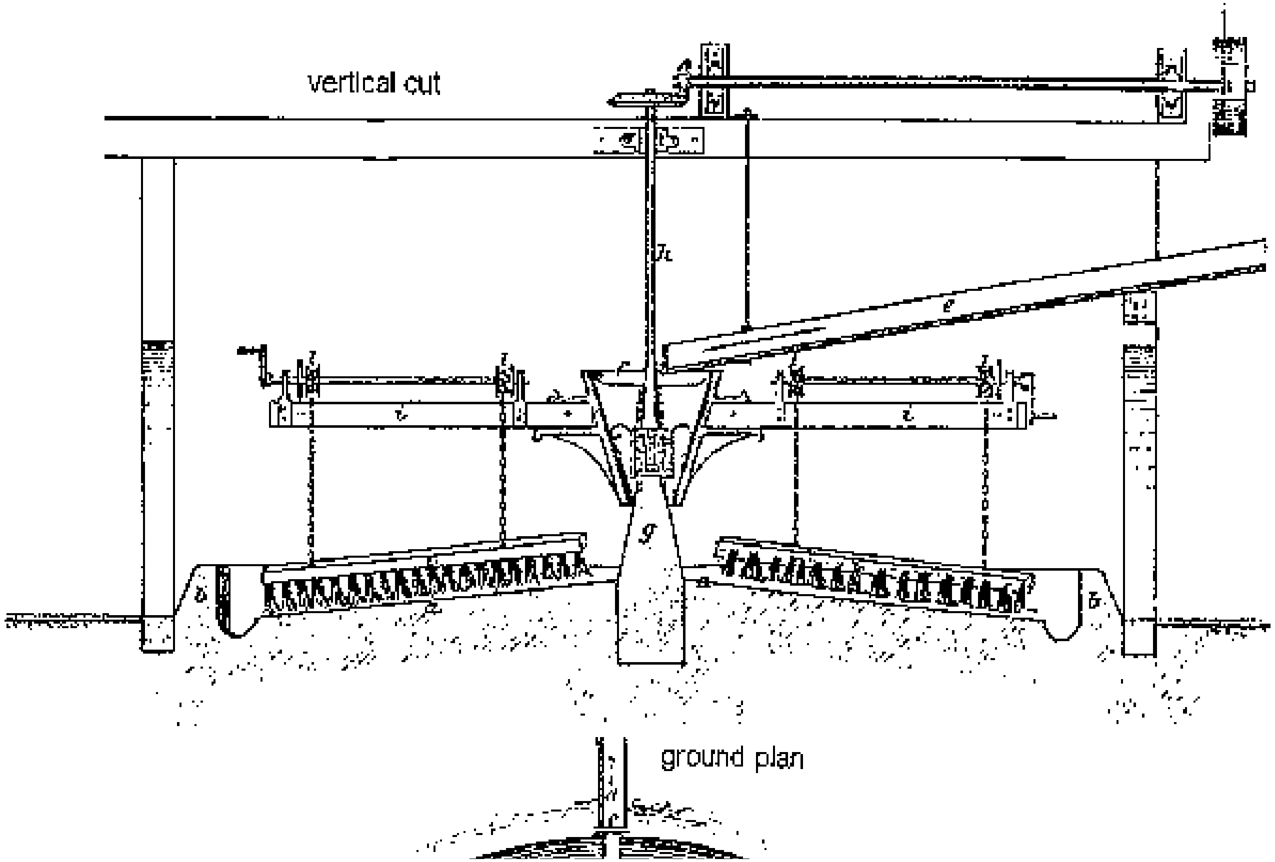


Fig.: Work-chronogram of sorting process in Bolivian setting basin. Source: Priester.



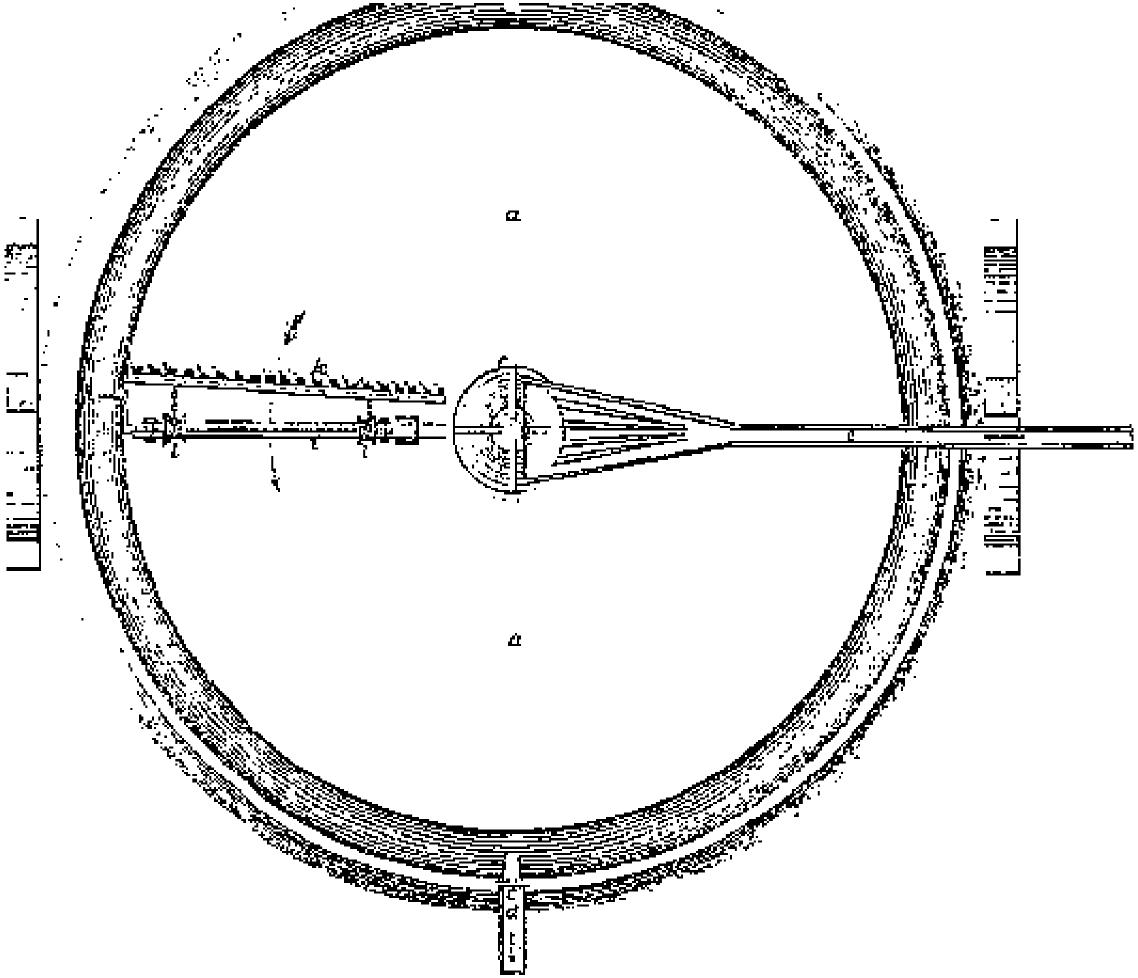


Fig.: Mechanized buddle. Source: Linkenbach.

14.11 Circular buddle

Metal Mining
Beneficiation , Sorting

germ.: Hundt'scher Trichterherd, mechanisierte Schlammgrube
span.: buddle conico de Hundt, buddle conico, buddle circular

Span.: buddle conico de Hundt, buddle conico, buddle circular

TECHNICAL DATA:	
Dimensions:	star-form with four or six channels/cloths, approx. 4 m in diameter, 2 m in height, 3.2° inclination, volumetric capacity approx. 7 - 14 m^3
Weight:	mainly built into ground, above-ground components approx. 300 kg
Extent of Mechanization:	semi-mechanized
Power:	approx. 0.5 - 1 PS, 11 min^{-1}
Form of Driving Energy:	mechanical via transmission from electric motor
Alternative Forms:	hydromechanic
Mode of Operation:	semi-continuous
Throughput/Capacity:	300 - 1000 kg/in at relatively low concentration factors
Operating Materials:	
Type:	water
Quantity:	up to 100 I/min.
ECONOMIC DATA:	
Investment Costs:	minimum of 1000 DM without drive unit if self-constructed
Operating Costs:	energy costs, labor costs, very low wear

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |—————|—————| high
Maintenance Expenditures:	low |—————|—————| high
Personnel Requirements:	low
Location Requirements:	running water and min Dh of approx. 1.5 m necessary
Grain Size of Feed:	10 ym - 200 ym
Special Feed Requirements:	high density difference between valuable mineral and host material
Recovery:	probably lower than in settling basin due to small grain sizes
Replaces other Equipment:	settling basin, buddle
Regional Distribution:	currently only rarely found in Bolivia
Operating Experience:	very good |—————|—————| ad
Environmental Impact:	low |—————|—————| very high
	large space requirement
Suitability for Local Production:	very good |—————|—————| bad
Under What Conditions:	metal and wood workshops, masonry construction
Lifespan:	very long |—————|—————| very short

Bibliography, Source: Priester, Gurlt, Liwehr, Hundt, Pieler, Koecke, Rittinger

OPERATING PRINCIPLE:

Buddle with peripheral input of slurry feed by means of a star-shaped, slowly-rotating hub with radial channels. The slurry flows down the outer wall into the funnel-shaped sedimentation chamber. The very low slurry velocity allows

sedimentation and sorting of the finest-grained feeds. In mechanized buddies the heavy material sediments at the outer perimeter, with light material and water discharging at the center.

<u>AREAS OF APPLICATION:</u>

Sorting of finest feed. Secondary separation of tailings from sorting tables.

<u>REMARKS:</u>

Long work-cycles are possible due to the large volumetric capacity. Parallel-connected mechanized buddies increase the plant throughput Extremely well suited for gravimetric-hydrodynamic beneficiation of the finest fractions, which especially In tin and tungsten ore processing contain high proportions of the valuable mineral.
Invented by Hundt in 1858 in Siegerland (Germany) and tested in Ramsbek. Results indicated higher throughput quantities than with non-mechanized buddies (settling basins) as well as significantly higher valuable-mineral content In the concentrate, but only slightly higher total recovery. Apart from a few minor details (slurry feed input, non-linear separation-chamber profile), the mechanized buddies in Bolivia have exhibited the same design for 130 years!!

According to Hundt, only one person is required to operate 3 to 4 circular buddies. Advantages compared to non-mechanized buddies are:

+ low water requirements
+ low motive power required
+ low cost for masonry construction

Driven by 2-meter high water-wheel with a very low quantity of propelling water (Pieler).
The selectivity of buddies sinks in direct proportion to the solid feed content of the slurry, which makes circular buddies more suitable for pre-concentrating purposes than for final sorting. To achieve concentrate with high valuable-mineral contents, the feed has to be reprocessed as much as six times.

SUITABILITY FOR SMALL-SCALE MINING:

Mechanized buddies represent the only known wet-milling, fine-grain sorting processincluded in traditional small-scale mining beneficiation techniques. A drive system is necessary for mechanization.

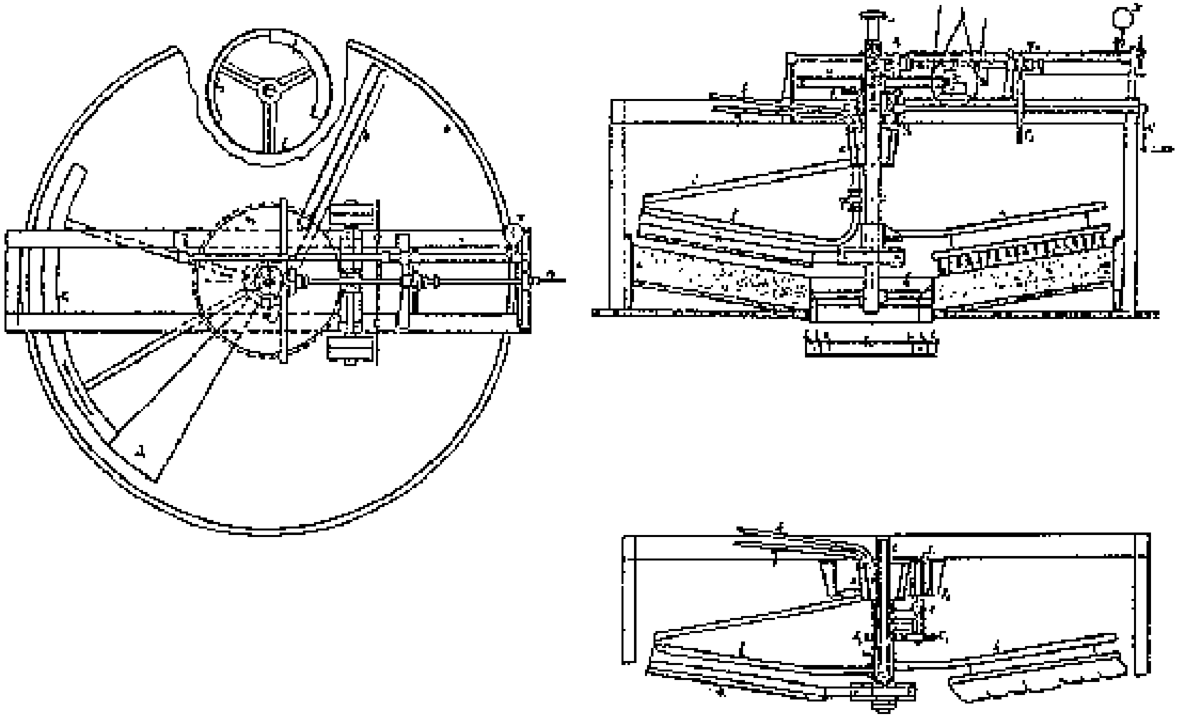
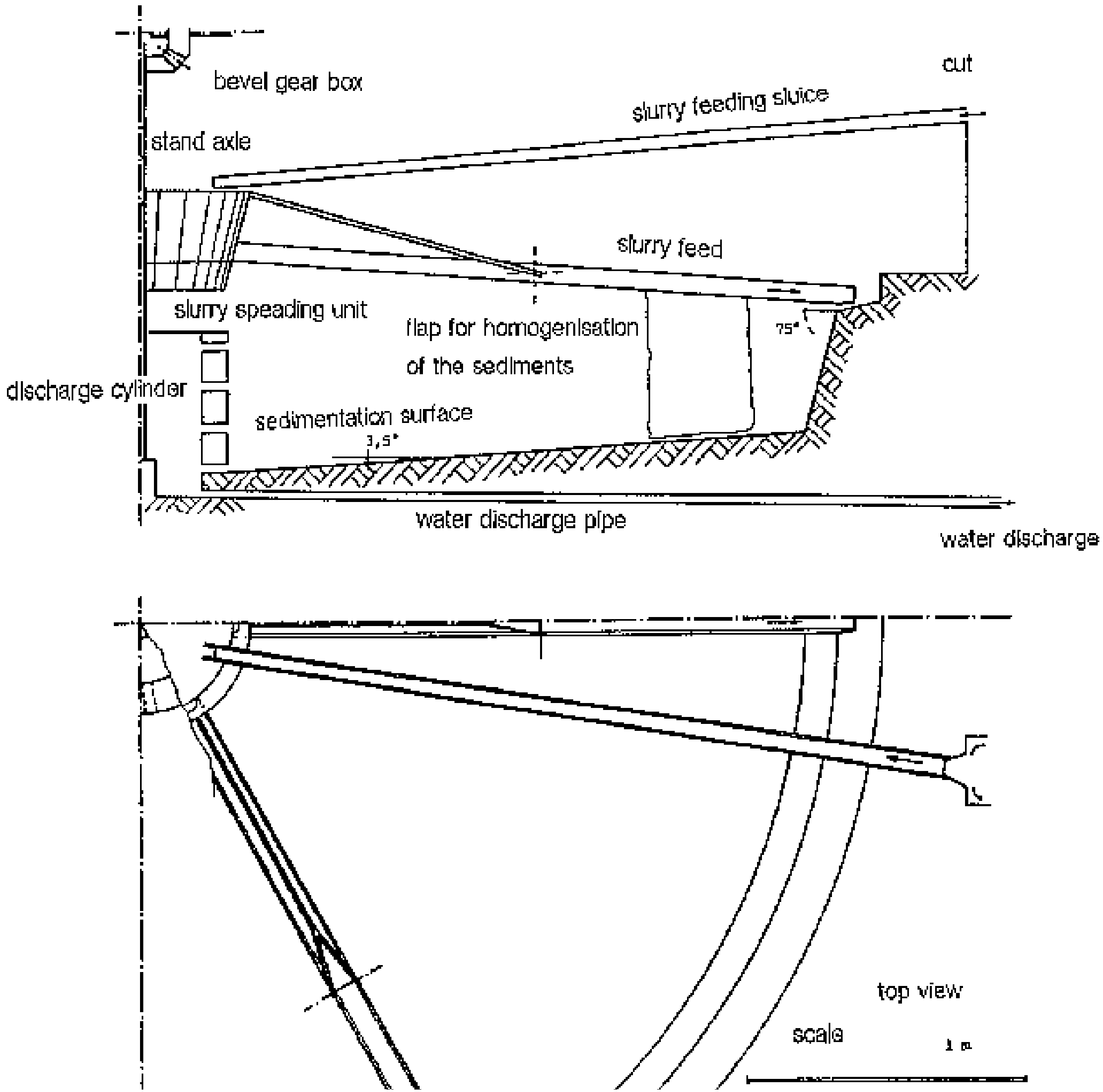


Fig.: Mechanized buddle. Source: Liwehr.



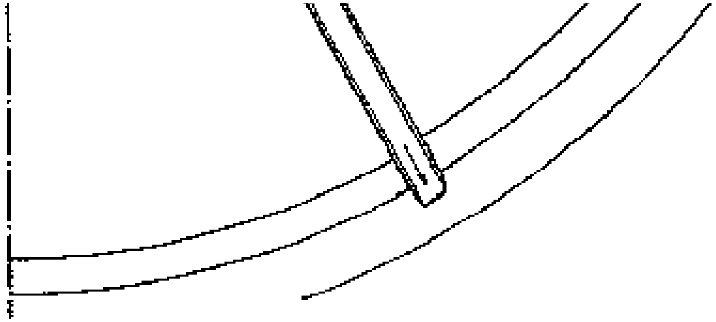


Fig.: Buddle from Bolivian tin mining. Source: Priester.

14.12 Dolly tub

Metal Mining
Beneficiation, Sorting

engl.: tossing tub, kieve, agitator

germ.: Raffinationstonne nach dem Schanzverfahren, Schlammfa, Engl. Ruhrfa, Ruhrwerk, Stauchkasten

span.: tine de refinacion, tine de levante, tine de refinacion segun el proceso de Schanz, tine de deslame, cajon de asentamiento

TECHNICAL DATA:	
Dimensions:	metal barrel or tub, 50 - 150 lifers in volume
Weight:	approx. 10 - 30 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	manual
Alternative Forms:	possibly hydromechanic ?

Throughput/Capacity:	1 - 6 kg/min
Operating Materials:	
Type:	water
Quantity:	< 51/min
ECONOMIC DATA:	
Investment Costs:	nominal Operating Costs: labor costs only

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |————|————| high
Maintenance Expenditures:		low |————|————| high
Personnel Requirements:	low	
Location Requirements:	none	
Grain Size of Feed:	20 - 2,000 µm	
Special Feed Requirements:	density difference between valuable mineral and host material	
Output:	an average of 60 % as concentrate, tailings are reprocessed	
Replaces other	sluices, buddies	

Equipment:

Regional Distribution:	Bolivia, formerly widespread throughout Central Europe, initally as sorting apparatus, later used only for drainage purposes
Operating Experience:	very good |————|————| bad
Environmental Impact:	low |————|————| very high
Suitability for Local Production:	very good |————|————| bad
Lifespan:	very long |————|————| very short

Bibliography, Source: Priester, Schennen, Treptow, Villefosse, Althaus, Zirkel

OPERATING PRINCIPLE:

Feed is mixed with water (at a ratio of 1: 1 by weight) and homogenized by agitating. Through impact pounding on the barrel the sediment becomes thixotrope and begins to flow. A sink-float process then begins in the high-density slurry, with lighter material floating upward and heavier material sinking downward. After several minutes, the water is decanted. The consolidated sediment is vertically differentiated according to density' end is selectivly removed by means of a spatula.

AREAS OF APPLICATION:

Secondary cleaning of concentrates from sluices and settling basins or buddies.

REMARKS:

As a result of the very minimal motion of the water, the finest grains can also be selectively separated with a high degree of precision. Even materials exhibiting a low density difference between valuable and waste material can successfully be processed with this technique.
Results can be improved if a suitable bottom material, such as rubber matting, is used (less wave adsorption as when directly on the ground).

In mechanized form, the dolly tub by Villefosse (from England) is known. The impact forces were induced by means of a camshaft, initially driven hydromechanically, later via steam engines.
Shock-absorbing devices appropriate for vibrating presses can be made from car springs (need for research and development).

Establishing the boundary between middlings amd tailings and between concentrate and middlings is determined by product control with a batea (panning principle).

SUITABILITY FOR SMALL-SCALE MINING:

The "Schanz-method" dolly tub is suitable for use in non-mechanized mines as a secondary-cleaning or dewatering apparatus for processing valuable concentrates (e.g. tin, wolframite, or silver concentrates). Investment costs are extremely low and the separation precision very high even for fine grained material.

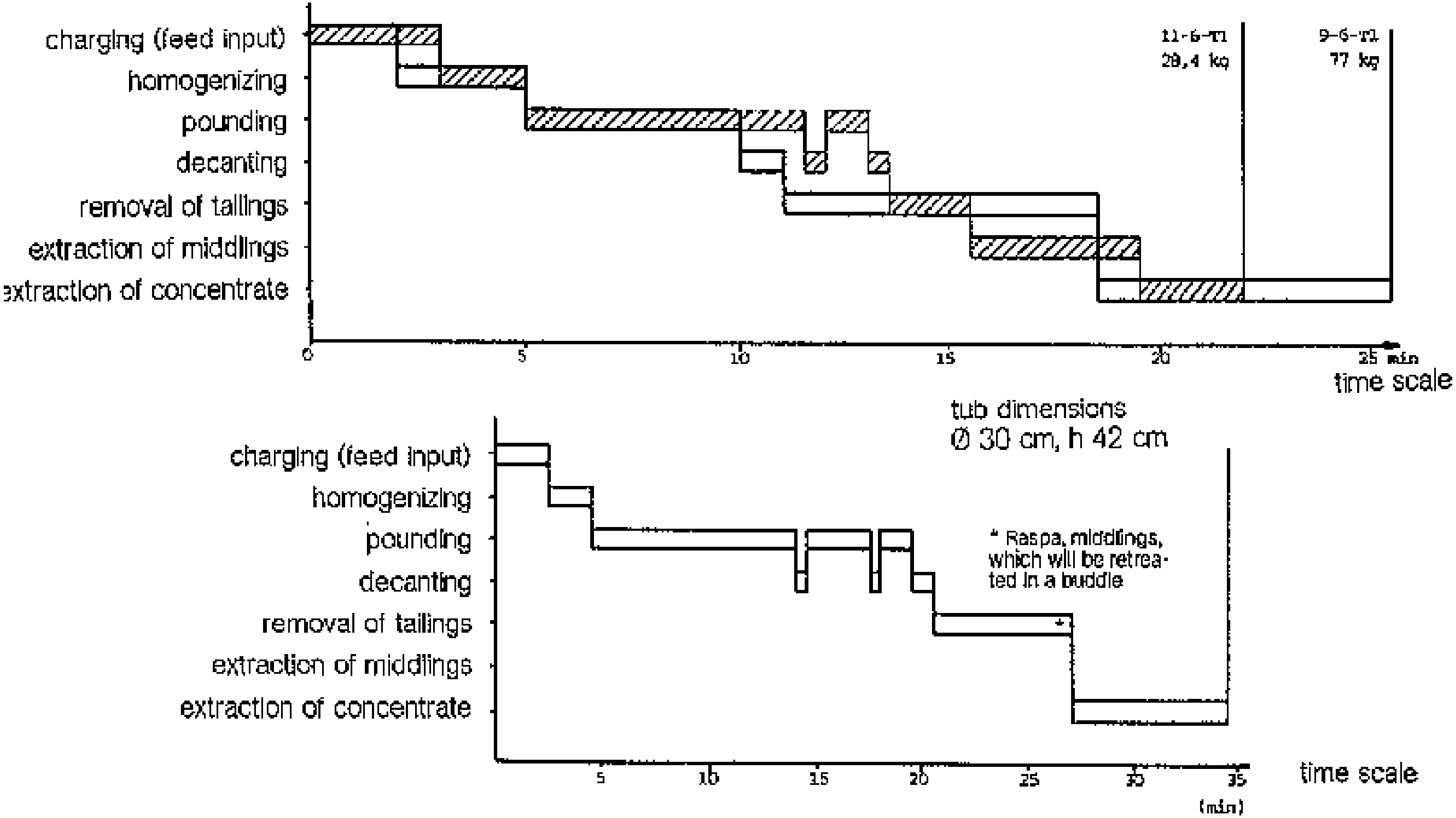


Fig.: Work-chronogram of sorting steps in tossing tub with "Schanz" method. Source: Priester.

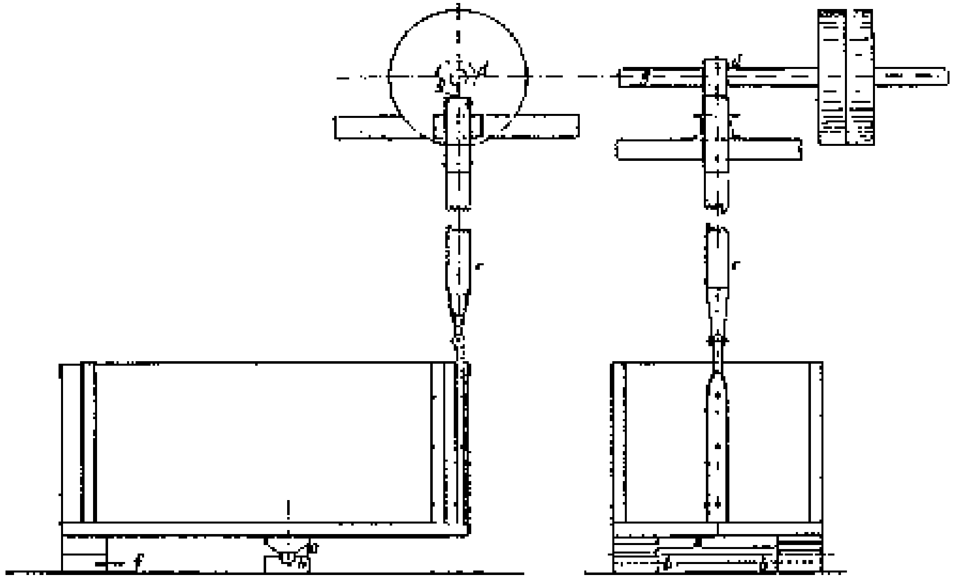


Fig.: Tossing tub. Source: Schennen.

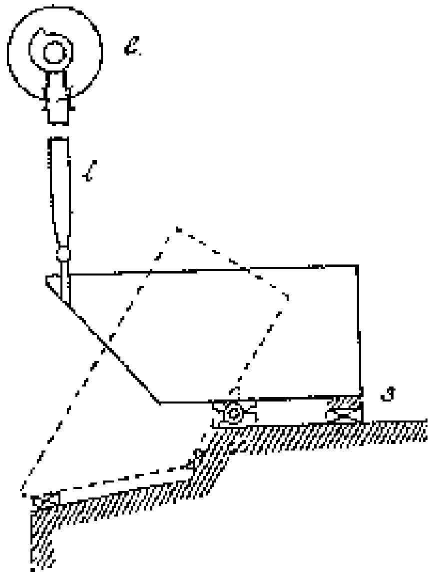


Fig.: Tossing tub. Source: Treptow.

14.13 Bumping table, concussion table

Metal Mining
Beneficiation, Sorting

engl.:	concussion table, percussion frame
germ.:	Stoherd
span.:	mesa de concentracion a golpes, mesa de sacudimientos, mesa de concentracion, mesa de golpe

TECHNICAL DATA:

Dimensions:	3 m in length, 1.2 m in width
Form of Driving Energy:	hydromechanical drive most appropriate due to the relatively low rated speed of the shaking table
Alternative Forms:	electromechanical drive, mechanical drive via internal combustion engine, manual drive, pedal drive
Throughput/Capacity:	approx. 250 kg/Mh (including charging of feed and drawing of products)
Technical Efficiency:	higher than in vanners (belt table); very fine heavy materials, for example < 20 µm gold-ore grains, are also recovered in the concentrate.
Operating Materials:	
Type:	water
Quantity:	approx. 50 - 80 % by weight

ECONOMIC DATA:

Investment Costs:	bumping tables can be produced locally at very low cost. For

example, in a Colombian pilot-plant, a bumping table with 0,65 × 1,5 m table-size could be constructed for 250 DM without camshaft or drive-unit.

Operating Costs: energy costs; labor costs

Related Costs: possibly thickener

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |—————|—————| high
	lower in comparison to vanners (belt tables)
Maintenance Expenditures:	low |—————|—————| high
Personnel Requirements:	one man can operate three bumping tables; table adjustment requires experience.
Grain Size of Feed:	between around < 10 µm and 1,000 µm - 2,000 µm
Output:	According to test results by Althaus, the concentrate-contents, recovery and throughput quantities are higher than with vanners: 3 bumping tables: 3300 kg ore, 48 h, 552 kg Pb-concentrate with 53.0 % Pb (296 kg Pb) 1 M/3 h 3 vanners: 3300 kg ore, 60 h, 643 kg Pb-concentrate with 45.5 % Pb (292 kg Pb) 2 M/3 h
Replaces other Equipment:	shaking tables, buddies, some sluices
Regional	earlier widely known

Distribution:		
Operating Experience:		very |—————|—————| good bad
Environmental Impact:		low |—————|—————| very high
Suitability for Local Production:		very good |—————|—————| bad
Under What Conditions:	good wood manufacturer	
Lifespan:		very long |—————|—————| very short

Bibliography, Source: Gurlt, Schennen, Treptow, Wagenbreth, Fisher, Villefosse, Althaus

OPERATING PRINCIPLE:

A bumping table (percussion frame) is a flat rectangular sedimentation basin. At the feed-input side, the slurry is homogeneously distributed onto the table with the help of a knubbed wooden board. The slurry then flows over the longitudinally-inclined table. Heavy material settles out in proximity of the feed input-point whereas lighter material remains suspended and is carried out with the float. To increase the precision of separation, the material is loosened by pounding on the table surface in the longitudinal direction. In so doing, the suspended table is deflected by a camshaft and swings back under its own weight against a buffer. The impact forces are transmitted with varying intensity to the feed material on the table. Consequently,the horizontally density-differentiated

material comprises separate counter-current flow components: the heavy material Iying directly on the table surface receives the strongest impulse and is set into upward motion against the slurry flow. The overlying lighter material receives a dampened impulse, which combined with its closer proximity to the overlying water current, causes it to be moved in a downstream direction with the flow. From time to time, the entire material on the table should be swept upstream toward the feed-input end to avoid possible undesired loss of valuable mineral.

After a sufficiently long sorting duration, the input of slurry feed is interrupted so that the concentrate can be extracted by shovels, spatulas or brooms and stockpiled for reprocessing.

AREAS OF APPLICATION:

Bumping tables are used for sorting of medium and fine-grained feed containing heavy minerals such as galena, wolframite, tin ore, gold, etc.

REMARKS:

Bumping tables were developed from enlarged bateas (panning dishes) and originate from Bohemia, having expanded to Hungary by 1770; also known in Germany by 1772 through the mining engineer Schmidt in Freiberg silver mining.

Bumping tables were employed until the beginning of this century in Central Europe, primarily in the German mining regions of the Harz Mountains and Saxony.

A very significant design detail of the bumping table is the installation of a wooden board at the feed input point in an attempt to achieve a homogeneous

distribution of slurry over the entire width of the table. Typical historic designs for these boards are shown on the following page.

The great advantage of bumping tables are their easy regulation of the processing conditions through the very quickly adjustable table inclination, through the frequency and intensity of impacts, and the quantity of feed slurry.

Of importance for high separation precision is to maintain a homogeneity in the slurry-feed quantity and particularly in the density, since fluctuations in these parameters cause variations in transport conditions of the discharge flow.

Bumping tables are differentiated according to those with solid buffers and those with elastic buffers. The bumping tables equipped with solid buffers operate with comparably greater separation precision when density differences In the feed (valuable mineral vs. host material) are sufficiently high; however, they consume more energy with lower throughput quantities.

SUITABILITY FOR SMALL-SCALE MINING:

Bumping tables are very suitable for filling the technical gap between buddies and shaking tables. The simple and stable construction combined with simple (but inefficient) drive systems permits local manufacture of the apparatus at low investment costs compatable with small-scale mining budgets.

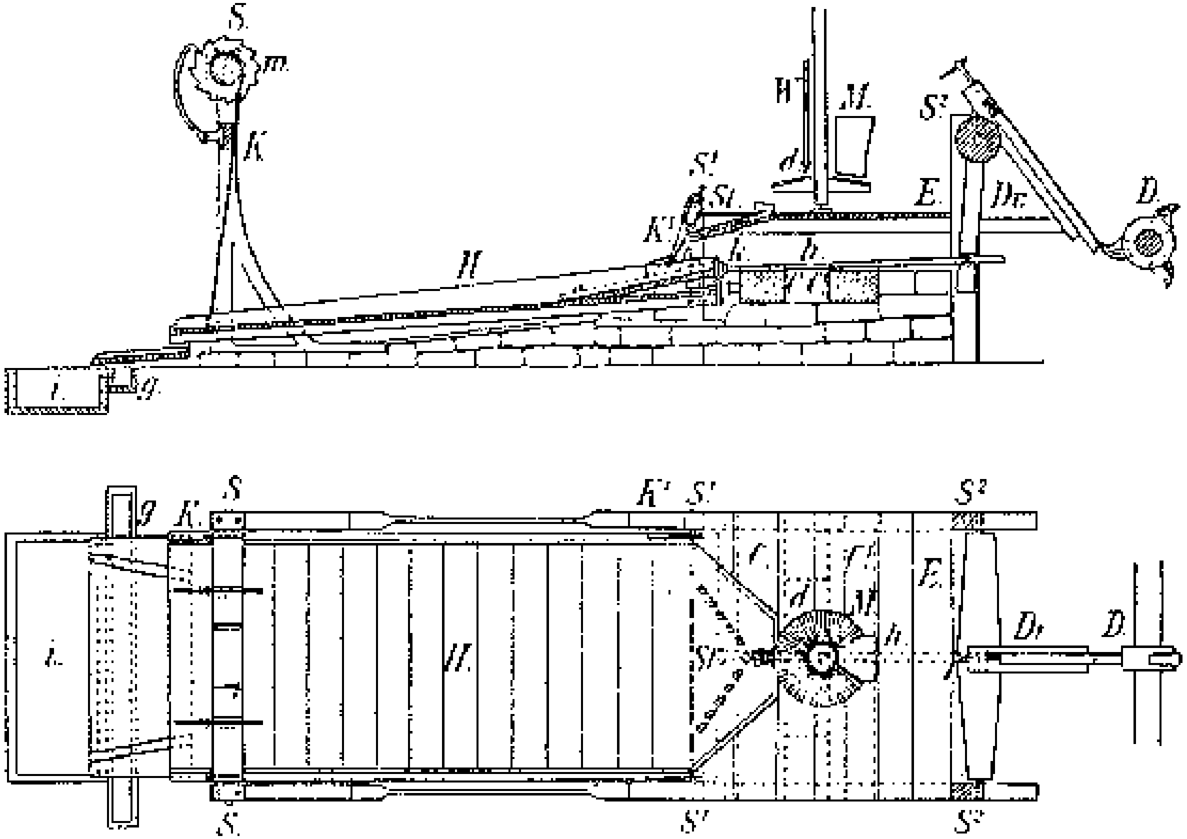


Fig.: Bumping table (Freiberger Langstoherd or "long bumping table"). Source: Treptow.

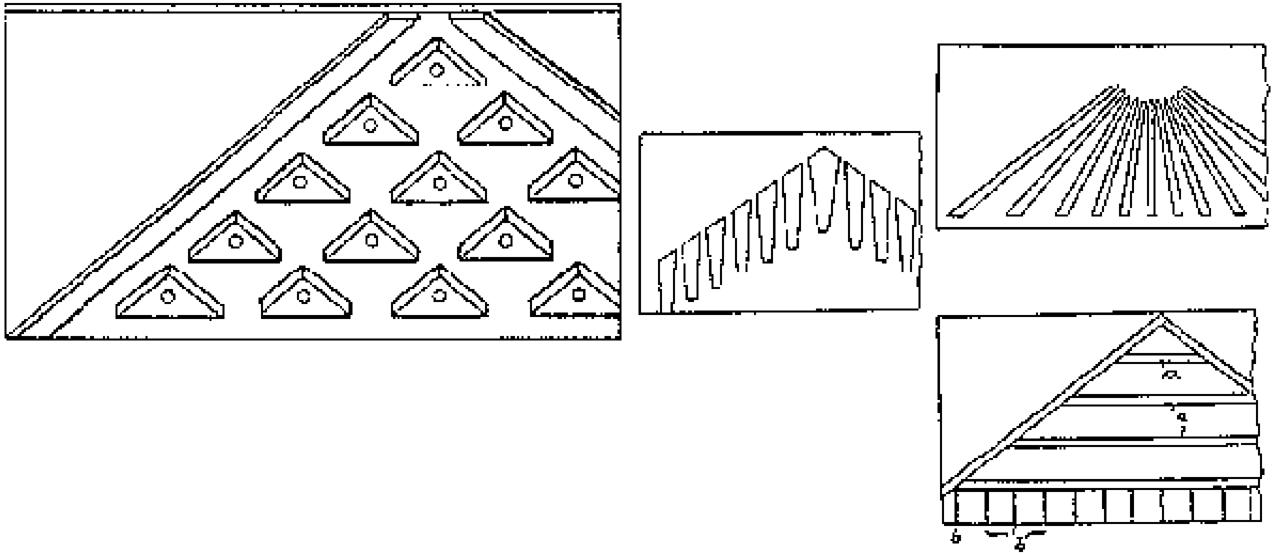


Fig.: Various designs of boards for homogenizing and distributing the feed. Source: Schennen (left); Liwerhr (right).

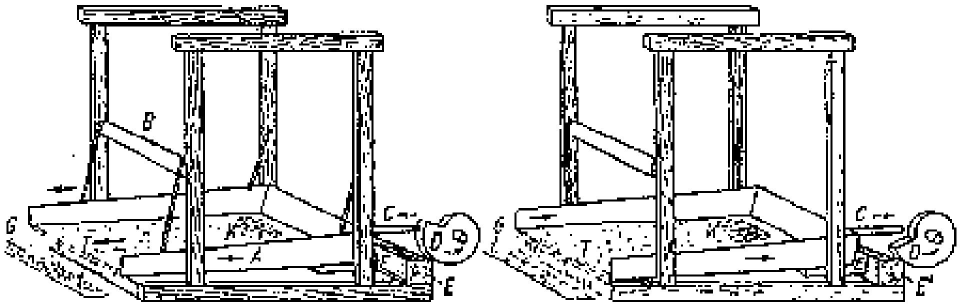


Fig.: Bumping (concussion) table. A: table; B: roller to adjust table inclination; C: rod that is moved by spiral disc D; E and E': buffer, E on table and E' on frame, G: sluice (washing trough), K: ore concentrate, shoved to right side when table rebounds and when E and E' strike; T: barren material flushed our by water into G. Source: Wagenbreth.

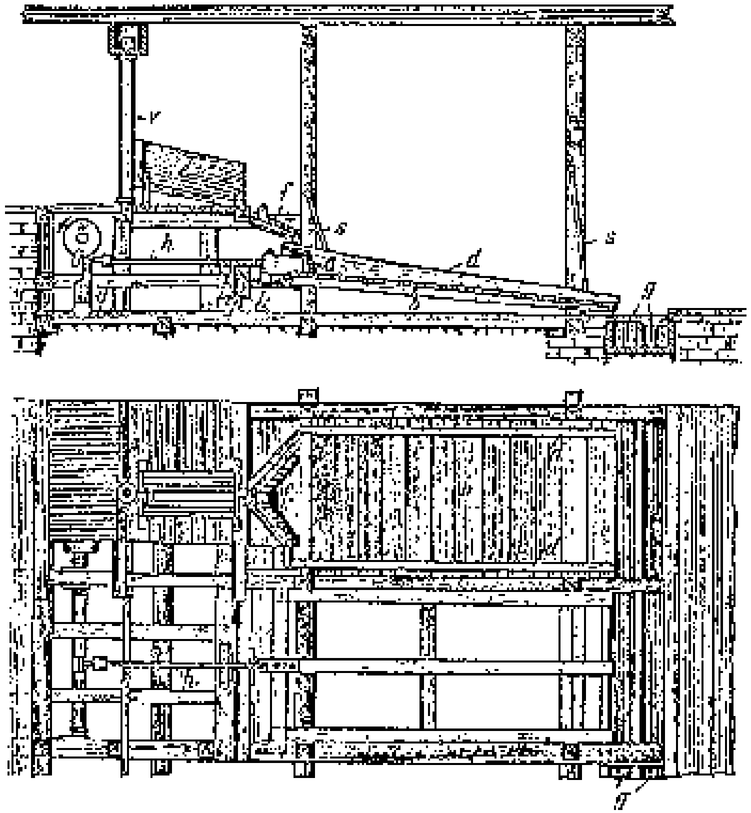


Fig.: Bumping (concussion) table. Source: Schennen.

14.14 Racking table, tilting frame

Metal Mining
Beneficiation, Sorting

germ.: Kippherd
span.: mesa de concentracion inclinable

TECHNICAL DATA:

Dimensions:	similar to vanner (belt table), approx. 2 - 6 m in length, 1 - 2 m in width
Extent of Mechanization:	not mechanized
Form of Driving Energy:	only processing water or slurry
Mode of Operation:	semi-continuous
Throughput/Capacity:	low, can be increased with multiple-deck table
Operating Materials:	
Type:	water for flushing
ECONOMIC DATA:	
Investment Costs:	approx. 1500 DM if self-made
Operating Costs:	labor costs only

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |————|————| high
Maintenance Expenditures		low |————|————| high
Personnel Requirements:	operating experience required	
Location	large quantities of water must be available	

Requirements:	
Grain Size of Feed:	0.1 - 2 mm
Special Feed Requirements:	high density difference between valuable mineral and host material
Recovery:	comparable to that of vanners (belt tables); throughput is higher due to ease of extracting products
Replaces other Equipment:	vanner (belt table), mechanized buddle
Regional Distribution:	historic technique
Operating Experience:	very good |————|————| bad
Environmental Impact:	low |————|————| very high
Suitability for Local Production:	very good |————|————| bad
Under What Conditions:	wood manufacturer
Lifespan:	very long |————|————| very short

Bibliography, Source: Zirkel

<u>OPERATING PRINCIPLE:</u>

Racking tables or tilting frames function similar to vanners (belt tables): the feed material settles out onto a slightly-inclined (longitudinally) sedimentation surface,

with grains of higher specific density sedimenting closer to the feed-input point and grains of lower specific density settling out further downstream, the distance being proportional to the density. When the table-surface capacity is reached, the charging cycle is interrupted and the table tipped along its longitudinal axis. Supplementary water rinses the surface free of material, whereby the grains are separated by dividing plates into various catching compartments. Upon completion of the rinsing step, the table is tipped back into the original horizontal position and the process continues with renewed input of feed.

AREAS OF APPLICATION:

Tables of this type were widely used in tin mining in Cornwall (England) in the last century.

REMARKS:

Zirkel describes a design in which the table is connected to a water channel by a chain, so that the tipping action automatically releases the supplementary water used to flush the products from the table.

Modern racking tables with multiple-deck (vertically stacked) and possibly a swinging system (Bartles-Mozley table) are employed for sorting the very finest heavy-mineral feeds (5 - 100 ym).

SUITABILITY FOR SMALL-SCALE MINING:

Racking tables (tilting frames) in the form of multiple-deck tables are appropriate for small-scale mining for extraction of valuable minerals from the finest grain

fractions.

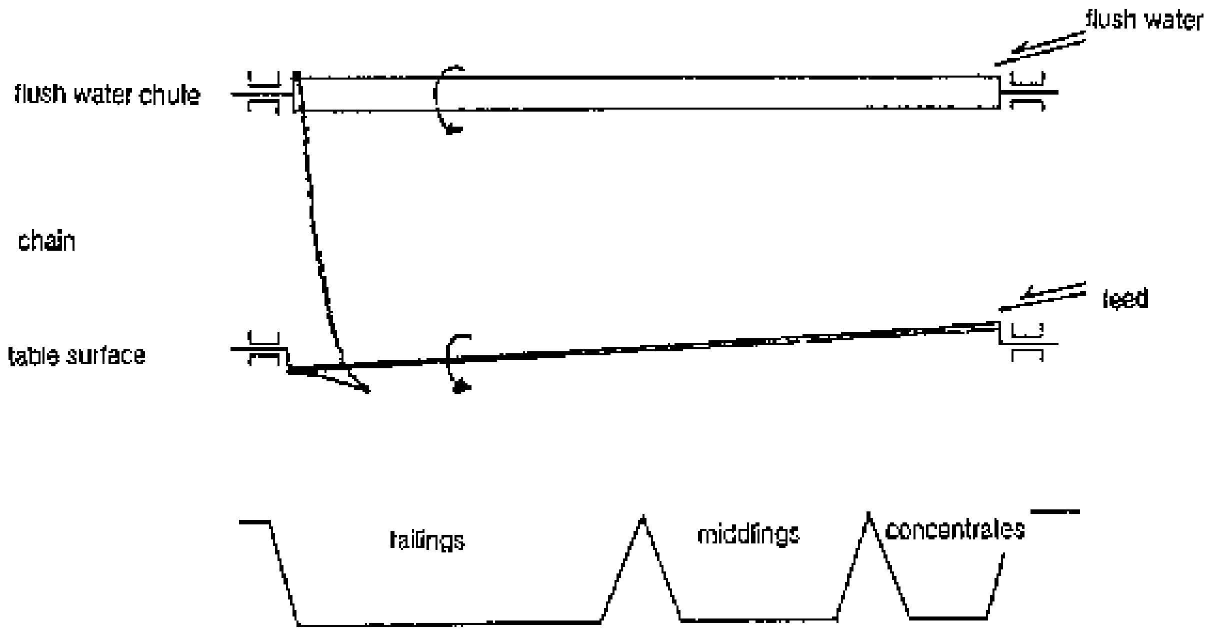


Fig.: Operating principle of a simple racking table. Source: Priester, according to Zirkel.

14.15 Sweeping table, belt table

Metal Mining, Gold Mining
Beneficiation, Sorting

engl.:	vanner, blanket (corduroy) table, Brunton table, animal pelts
germ.:	Kehrherd, Planenherd, Bruntonherd, Tierfelle
span.:	mesa de concentracion de limpieza manual, bayetas, pangs, tableros, mesas rayadas, mesa de concentracion con pano, mesa de concentracion brunton, pieles

de animal

TECHNICAL DATA:

Dimensions:	7 m in length, 1.2 m in width, Brunton table 3 × 1 m
Extent of Mechanization:	not mechanized/semi-mechanized/fully-mechanized
Form of Driving Energy:	only slurry flow, Brunton table by electric or mechanical drive, with or without vibrator
Mode of Operation:	intermittent/semi-continuous
Throughput/Capacity:	according to Althaus: approx. 100 kg/Mh Including feed input, product extraction, etc.; 3 m corduroy table: approx. 100 t/24 h
Operating Materials:	
Type:	water

ECONOMIC DATA:

Investment Costs:	approx. 200 DM when self-made
Operating Costs:	labor costs only (excluding powered Brunton table)

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |—————————| high
Maintenance Expenditures:	low |————|————| high
Personnel Requirements:	experience in adjusting tables is necessary

Location Requirements:	water and sufficient elevation difference required
Grain Size of Feed:	approx. 0.05 - 2 mm
Special Feed Requirements:	high density difference between valuable mineral and host rock
Output:	the recovery from rigid tables is significantly less than that achieved with vibrating or shaking tables. The geometry of the sedimentation chamber creates practically constant settling conditions in the longitudinal direction. As a result, the separation precision of this sorting apparatus is highly limited; comparison can be made with the bumping (concussion) table (research results from H. Althaus).
Replaces other Equipment:	sluices, tables, amalgamation tables
Regional Distribution:	corduroy (blanket) tables widely distributed in gold mining in Ecuador and Colombia; historically distributed worldwide
Operating Experience:	very good |—————|—————| bad
Environmental Impact:	low |—————|—————| very high
Suitability for Local Production:	very good |—————|—————| bad
Under What	simple carpentry or masonry construction

Conditions:

Lifespan: very long |————|————| very short

Bibliography, Source: Schubert, Treptow, Reitemeier, Villefosse, Althaus, Ullmann, Crennell, Plinius en Moesta, Agricola, Priester, v. Bernewitz, Libro de Inventos 1890, Medina/Peru

OPERATING PRINCIPLE:

A separating table, slightly inclined along the longitudinal axis, serves as a sedimentation surface for valuable-mineral grains of high specific density and for those grains in the feed which exhibit mineral-waste intergrowths. Table inclination and slurry volume are the parameters influencing the cut-off density of the separation process. After completion of sedimentation, charging of feed is interrupted and the concentrate near the feed-input point is swept together and removed. Middlings settle out further downstream from the feed intake.

For sorting of the very finest fractions, the table surface is covered with coarse cloth towels which enhance the sedimentation of heavy material. The towels are washed following sedimentation and spread out again so that the entire table surface is covered. Corduroy was the commonly-used material for lining the corduroy or blanket table. Later, riffled rubber linings (thickness 10 mm, riffle depth 3 mm, riffle interval 6 mm) were widely used.

Mechanized processing plants employ endless rotating belts in the so-called Bruton tables, in which the sorting surface is inclined 11 and the belts move at around 0.4 m/min in the opposite direction to slurry flow. Above the slurry feed, the concentrate is continually rinsed. Continuous-operating belt tables have also

been constructed as slow-rotating drums (e.g. 3.6 m length, 0.9 m 0, 3.75° inclination) with riffled rubber linings.

Cow hides are used for the winning of cassiterite (tin ore), analogous to the "Golden Fleece" of the Kolchier for winning gold, they are employed during beneficiation of very fine sludge or silt to recover the valuable minerals. The heavy ,-trains are trapped between the hairs of the hide and are recovered during subsequent washing of the hide. After several applications, the hide is then burned and the ashes further processed to extract any remaining valuable-mineral fines.

Sludge trough, German square buddle (in Bolivia: buddle quadrado)

Sluice-type buddle with square or trapezoidal cross-section measuring approx. 2 × 1 × 1 m and a preceeding sedimentation chamber. Coarse concentrate settles out in the first sedimentation chamber, and sedimentation and classified sorting of fine. grained feed (100 - 2000 ym) occur In the second sedimentation chamber, analogous to settling basins (round buddies). Due to the geometry of the grains in the slurry feed, there is only a nominal change in the slurry velocity, resulting in poor separation precision.

AREAS OF APPLICATION:

For sorting of fine and finest grains from heavy-mineral slurries, e.g. tin, tungsten or gold mining. For extraction of heavy minerals from the finest mud or silt.

REMARKS:

Already at the time of the early Egyptians belt tables were employed for sorting

silver, gold and copper ores.

The "buddle quadrado" that is applied in Bolivia represents a simple construction of a belt table.

Belt tables should be constructed in such a way that a simple mechanism allows the adjustment of table Inclination, for example by a one-sided suspension. This allows the inclination to be adjusted according to feed parameters or the desired separation cut-off size. Inclination angles range between about 1: 10 (approx. 6°) and 1: 120 (approx. 0.5°). The finer the grain-size of the feed or the lower the separation density, the smaller the sedimentation inclination angle needs to be.

In place of animal hides, industrially-produced textiles such as corduroy or similar material are suitable. This technique was widely distributed in North American gold mining for a while. Animal hide or corduroy sluices or tables are independent of the pH-value of mine water, contrary to amalgamation tables.

Cow hides were used for winning gold from alluvial deposits in Brazil up until the beginning of this century.

Reports of artisan gold mining in Peru mention the extraction of pre-concentrate from "empedrados", which are simple artificial gold traps built by packing stones together in the river bed during periods of low water level. These "chacras de oro" are then collected following the rainy season, and this pre-concentrate then further concentrated with the help of sheepskins spread on sorting tables. In this way, as much as 4 9 of gold could be won from each m² of "empedrados" or stone barrier.

SUITABILITY FOR SMALL-SCALE MINING:

Fixed, rigid tables are suitable especially for processing low-grade ores with high-density valuable minerals (e.g. in the beneficiation of tin-ore, tungsten or gold). For the processing of high-grade ore feed or pre-concentrates, the discontinuous operation which is characteristic of this techniques offers only limited throughput.

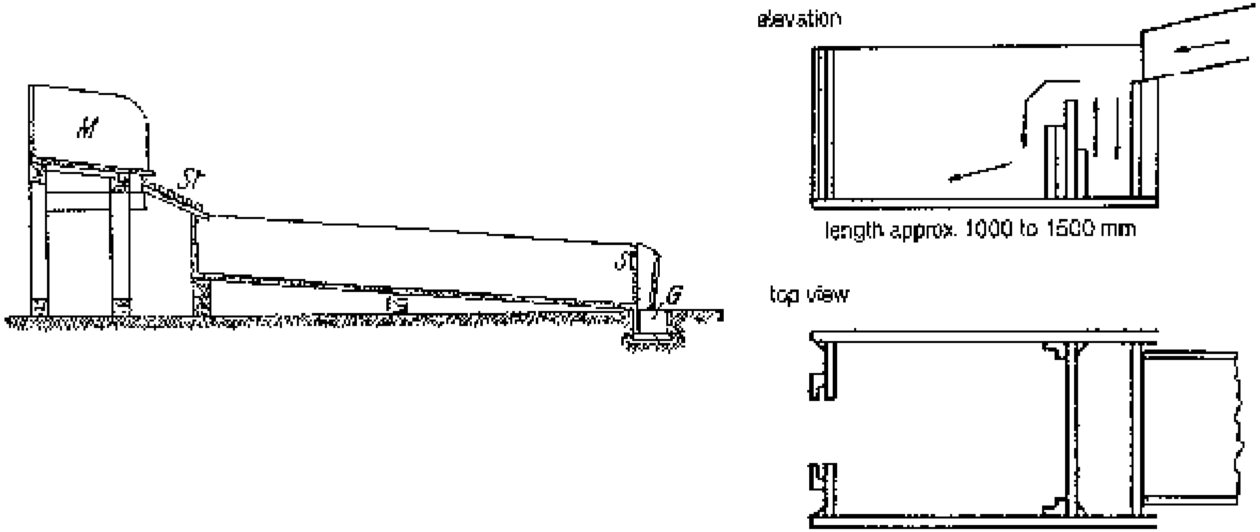


Fig.: Sluice-type buddle, simple belt table. left: from Treptow; right: from Priester.

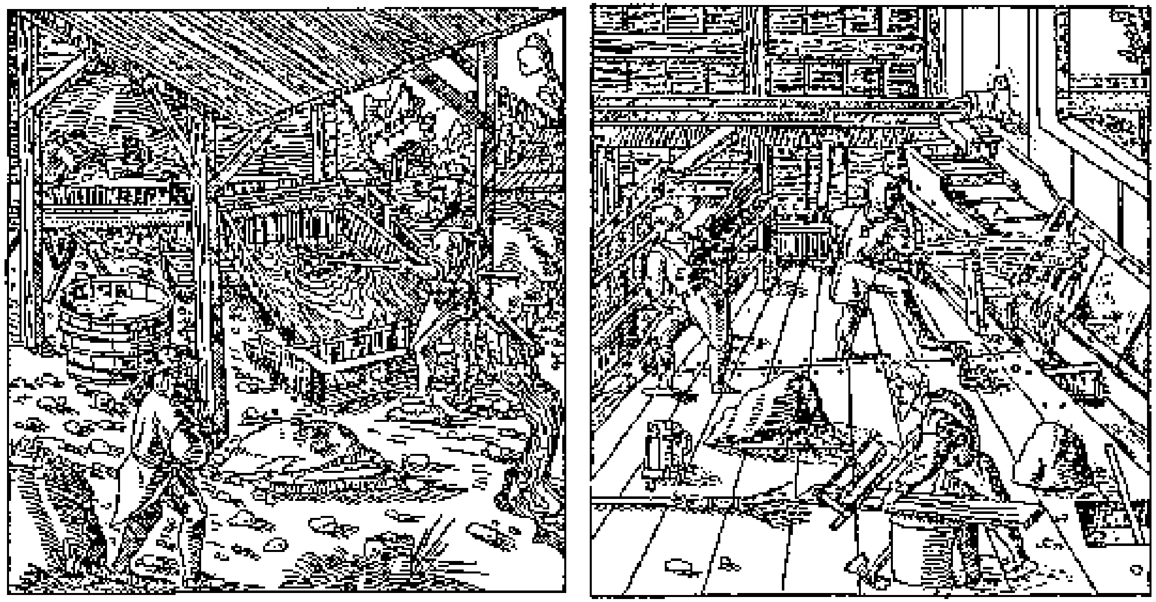
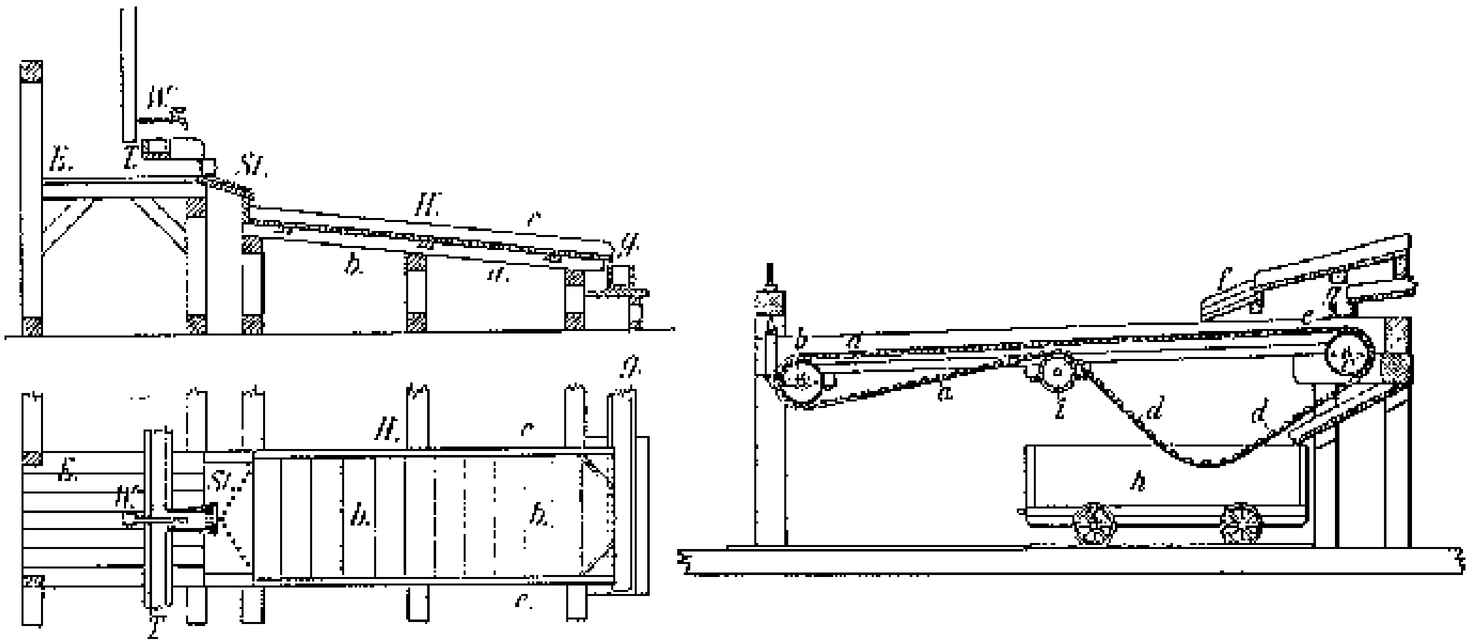


Fig.: Belt table (left) and corduroy table (right). Source: Agricola.



Figures

Fig.: Concentrating table. Source: Treptow

Fig.: Endless-belt table, Bruton table. Source: Schennen

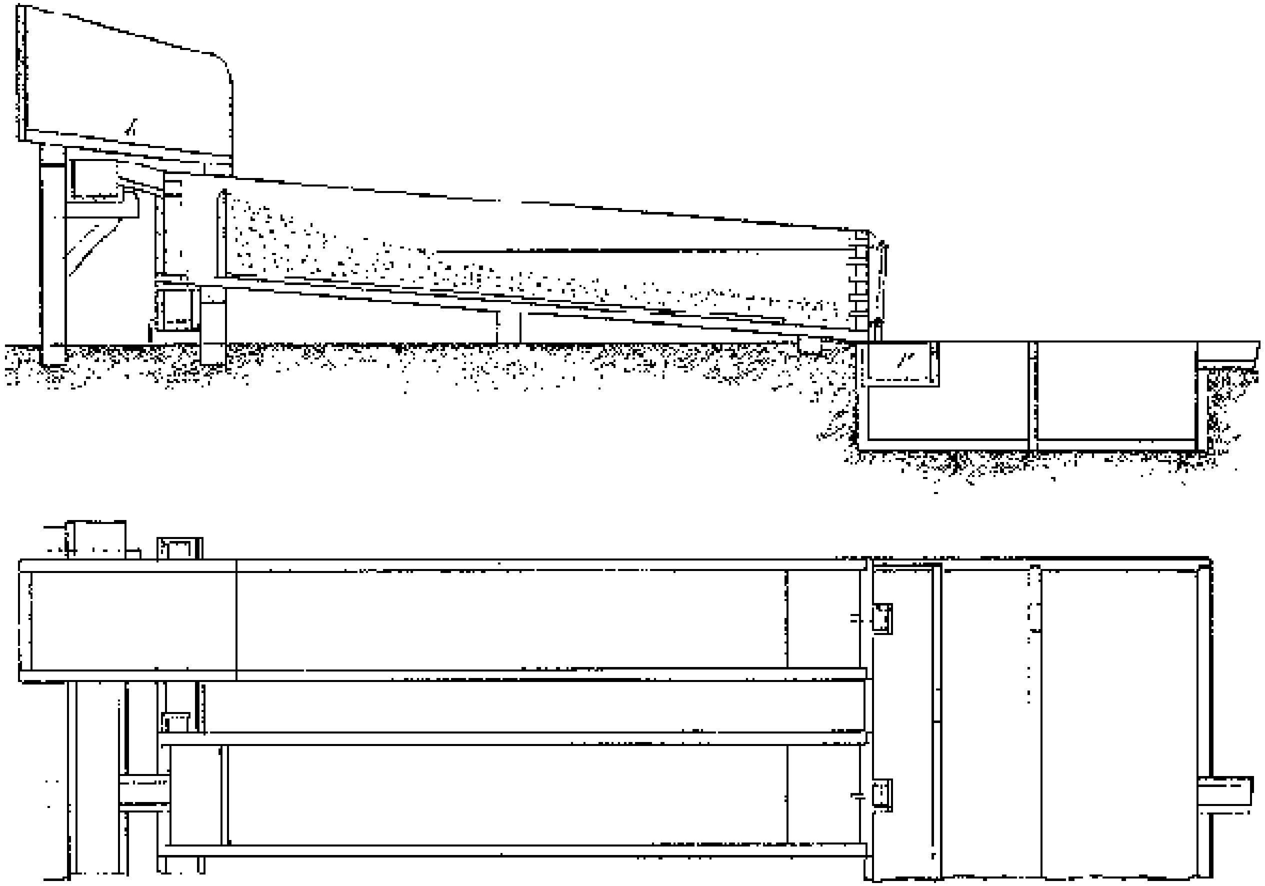


Fig.: Concentrating table. Source: Callon.

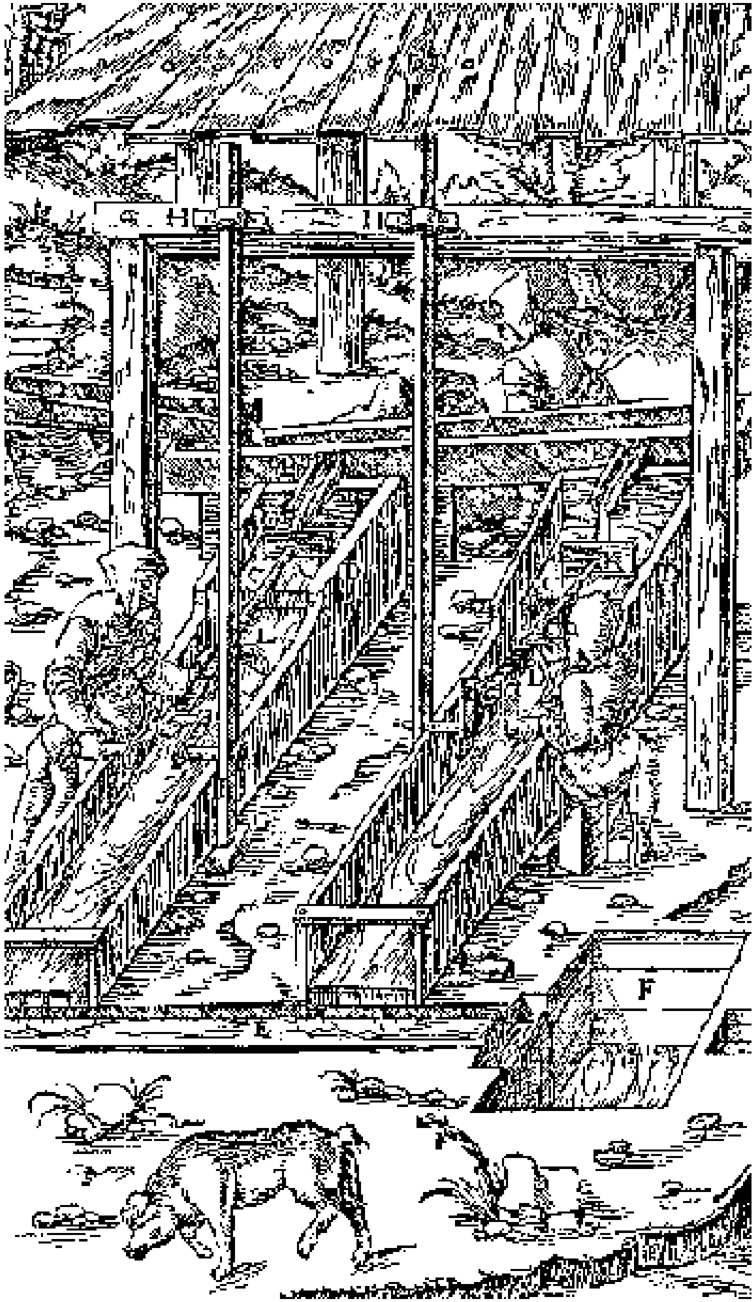


Fig.: Sweeping table. Source: Agricola.

14.16 Vibrating table

Metal Mining, Gold Mining Beneficiation, Sorting

engl.:	shaking table, wifley table
germ.:	Schwingherd, Wilfleyherd, Schuttelherd
span.:	mesa de concentracion vibradora, mesa concentradora, mesa de concentracion de Wilfley
Manufacturers:	Millan, Denver, Keene, Mineral Deposits, Wedag, Wilfley Mining, Mozley,Svalcor, Talleres J.G, Eq. Ind. Astecnia, Buena Fortuna, COMESA, FAHENA, FIMA, Magensa, SOTEEL

TECHNICAL DATA:

Optimal technological characteristics and operating parameters of vibrating tables for the processing of tin, tungsten and similar ores (by Isaev):

Characteristics	**Sand table**	**Fine sand table**	**Slime table**
	(1 - 3 mm)	**(0.2 - 1 mm)**	**(<0.2mm)**
	(shaking or bumping table)	(bumping table)	(bumping table)
Ratio of length to width of table	approx. 2.5	approx. 1.8	< 1.5
Lift in mm	16 to 26	12 to 18	6 to 12
	200 to 270	270 to 320	320 to 420
Number of strokes in min^{-1}	4 to 10	2 to 4	1 to 2.5

Lateral inclination of table surface in degrees	4 to 10	2 to 4	1 to 2.5
Longitudinal inclination of table surface in mm	20 to 30 (incline)	10 to 20 (incline)	1 to 10 (decline)
Fluid-solid ratio (vol) of feed	3.5:1 to 5:1	3.5:1 to 4:1	3.5:1 to 4:1
Cross-flow water quantity (fluid-solid volumetric ratio)	1:1 to 1.5:1	1.5:1	2:1
Height of riffles at drive-side in mm	26 to 18	18 to 12	12 to 8
Interval between riffles in mm	30 to 45	25 to 40	30 to 45
Throughput in t/h	4 to 2	2 to 0.9	0.8 to 0.2
Dimensions:	approx. 4.3 × 1.9 × 1 m LWH, also smaller as bench-scale, laboratory scale, or special tables		
Weight:	approx. 500 - 1000 kg for large concentration tables		
Extent of Mecanization:	fully mechanized Driving Energy Required: 0.2 - 2 Kw		
Form of Driving Energy:	electrical		
Alternative Forms:	turbine, internal combustion engine		
Mode of Operation:	continuous		
Operating Materials:			
Type:	water		
Quantity:	80 - 85 % by volume		
ECONOMIC DATA:			
Investment Costs:	9600 US$ (Denver cif La Paz), 2000 US$ (Millan,		

	somewhat smaller)
Operating Costs:	labor costs, energy costs
Related Costs:	milling necessary, hydraulic classification

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |————|————| high
Maintenance Expenditures:		low |————|————| high
Personnel Requirements:	trained personnel	
Location Requirements:	water and elevation difference Dh	
Srain Size of Feed:	150 µm - 1.5 mm	
Special Feed Requirements:	High density difference between valuable mineral and host material is necessary; preliminary hydro-classification of the feed, for example with a cyclone, counter-current classifier, pyramidal cone classifier, etc. is recommended.	
Recovery:	only high if tailings are re-sorted by finest-grain sorting equipment such as buddies or mechanized buddies	
Replaces other Equipment:	sluices, buddies, spiral separators	
Regional	worldwide, the most widely distributed sorting system for hydromechanic-	

Distribution:	gravimetric processing of medium and fine grainded feed; manual tables are rare
Operating Experience:	very good |—————|—————| bad
Environmental Impact:	low |—————|—————| very high
Suitability for Local Production:	very good |——————————| bad
Under What Conditions:	good carpentry or metal workshops, welding shop, knowledge of vulcanizing, etc. possibly including the use of components made of plastic, rubber, fiberglass, etc.
Lifespan:	very long |—————|—————| very short

Bibliography, Source: Taggert, Schubert, Manufacturer information, Hunter, Stewart,

OPERATING PRINCIPLE:

Vibrating tables consist of a rectangular or parallelogram-shaped separating surface that is slightly inclined both laterally and in the direction of vibrational movement. The table surface is equipped with riffles which decrease in size with increasing distance in the direction of movement (away from feed input, which occurs at the highest point on the table surface). Supplementary water is applied across the table in a lateral direction along the entire length. Explained simply, the heavy material is less subject to cross-flow forces than the lighter material, so

that the feed is differentiated into strips according to density with the heavy material discharging as concentrate over the end, middlings near the lower corner and tailings over the long side.

AREAS OF APPLICATION:

Medium and fine-grain sorting of heavy-mineral feed in solid-rock and alluvial mining of:

- **gold**
- **tin**
- **tungsten**
- **antimony**
- **lead-silver**
- **zircon**

and for separation of industrial-minerals (sand and gravel) pre-concentrates in monacite (cryptolite) and xenotime products.

REMARKS:

Concentration tables made of fiber glass in which the riffles are preformed as negative impressions and inverted during construction are very suitable for local production.

A miniature table is being offered on the prospecting-equipment market (Keene) which operates on 12 V, weighs a total of about 15 kg, and has a throughput of 250 kg/in maximum, making it suitable for secondary sorting of Au-concentrates

(price approx. 600 US$).

The table's angle of Inclination has a crucial effect on the separation results. It could often be observed that the table inclination was set incorrectly.

Particularly for beneficiation of gold-containing ores, black rubber-lined tables have proven to be highly advantageous (good visual contrast to gold).

Concentration tables are capable of processing relatively wide-band classified feed (wide grain-size range).

The maximum grain-size of the feed must be smaller than riffle height and smaller than one-third of the interval between riffles.

A disadvantage of this technique, when large throughput quantities or feed containing high proportions of fine-grained material are being handled, is that valuable-mineral fines are carried out with the tailings. In such cases, a subsequent fine-grained separation process must be performed.

Consequently, special gold tables operate with extremely low throughput quantities (for example the Gemini 60 table with 25 $kg/m^2 \times h$).

Concentrating-table feed should always be hydro-classified prior to sorting to assure adequate separation precision.

The lowest grain-size that can still be sorted with sufficient precision ranges between 20- 100,um, depending on the feed material, whereby the grain shape of the valuable mineral and the density distribution of the minerals play an important

role.

The industry has been trying for a long time to develop table sorters that separate in the centrifugal field in order to reduce the sizes of the grains which can be processed (EP 0247 795, EP 0323 447, DE 3309 385). For this purpose, the table surface is rolled to a truncated cone with small opening angle and set into rapid rotation (160 - 240 min-1), creating 10 - 50 kg centrifugal acceleration. Finally the drum is positioned with the opening on top (0° - 5°). The entire unit is subject to a vibrating frequency of 240 - 450 min-1 parallel to the rotational axis and an oscillation amplitude of 1 - 35 cm. The only supplier (Mozley) lists a throughput of approx. 0.2 t/h with a feed grain-size range of 1 to 250 ym.

The very complicated technique for removing the tailings, which involves a rotating raking device and high investment costs of approx. 150.000 DM, render this machine unsuitable for small-scale mining purposes despite the fact that experience from Cornish tin-ore mining, where the multi-gravity separator was employed as a substitution for traditional table separating, shows that comparably high throughput, high recovery and high-grade concentrates can be achieved.

SUITABILITY FOR SMALL-SCALE MINING:

Vibrating tables, employed for mechanized sorting of medium and fine-grained heavy mineral feed, are very suitable for small-scale mining application due to their low energy requirements, high throughput, flexibity and ease of adjustment, and comparably simple operating principle.

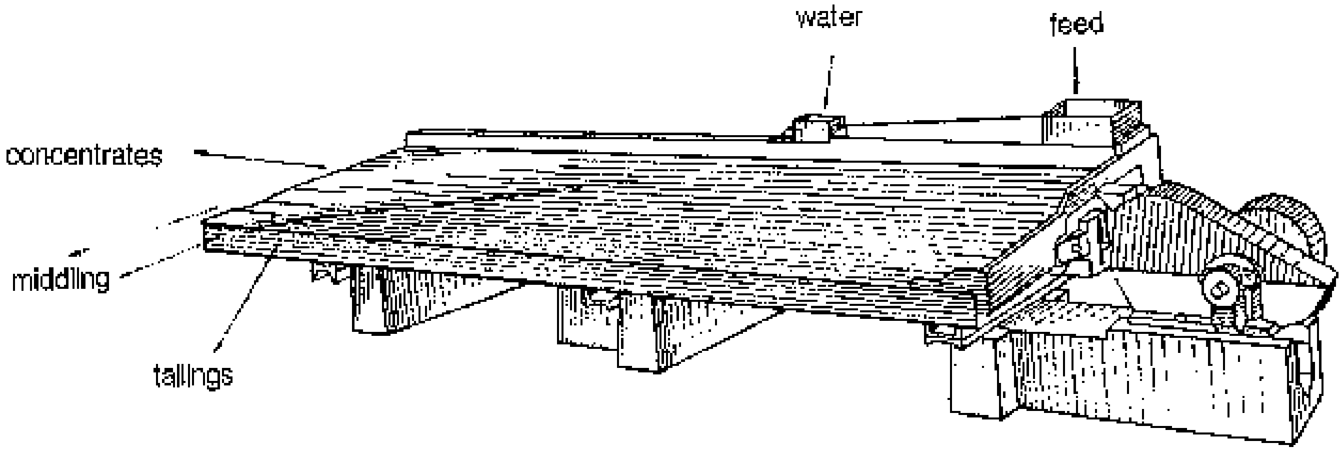


Fig.: Wilfley table. Source: Otero.

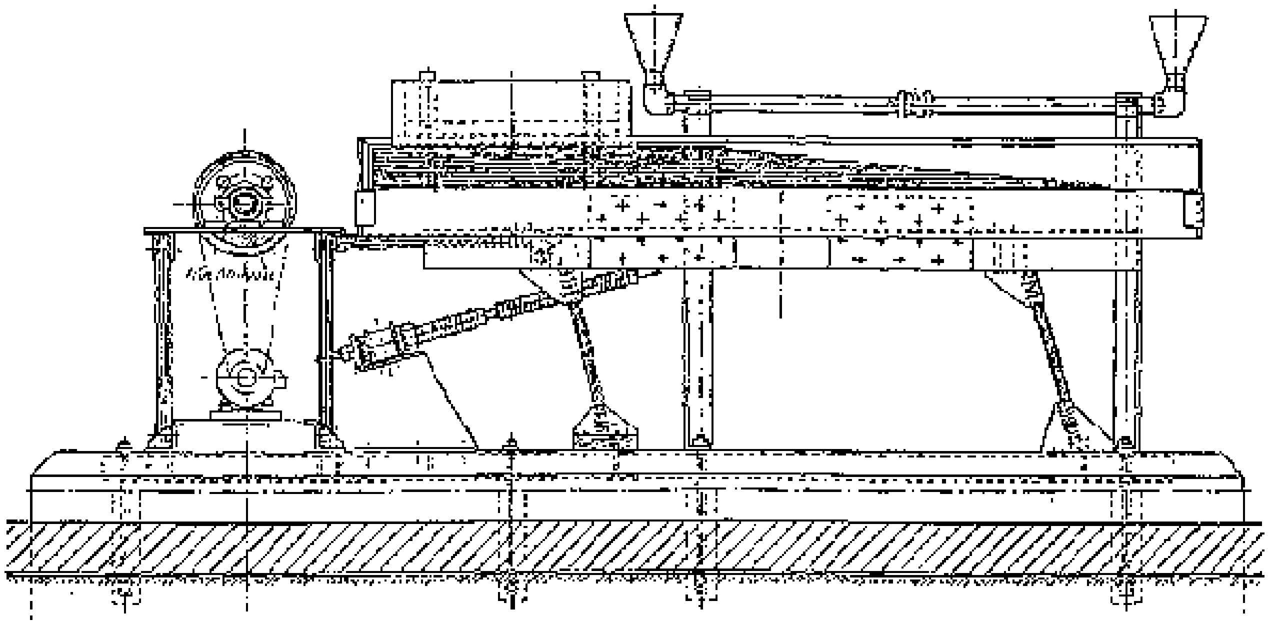


Fig.: Shaking table. By Schmiedchen.

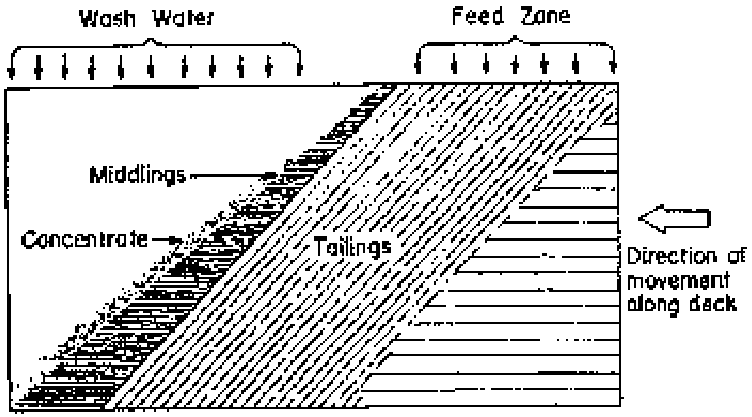
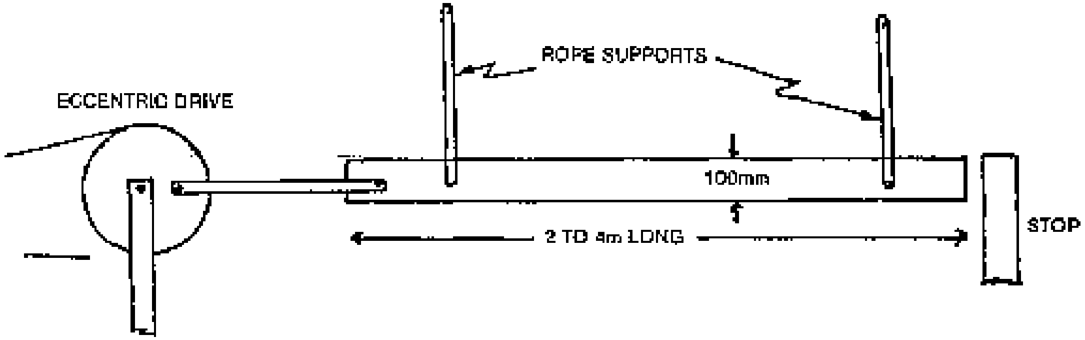


Fig.: Distribution of the products over the table. Source: Silva.



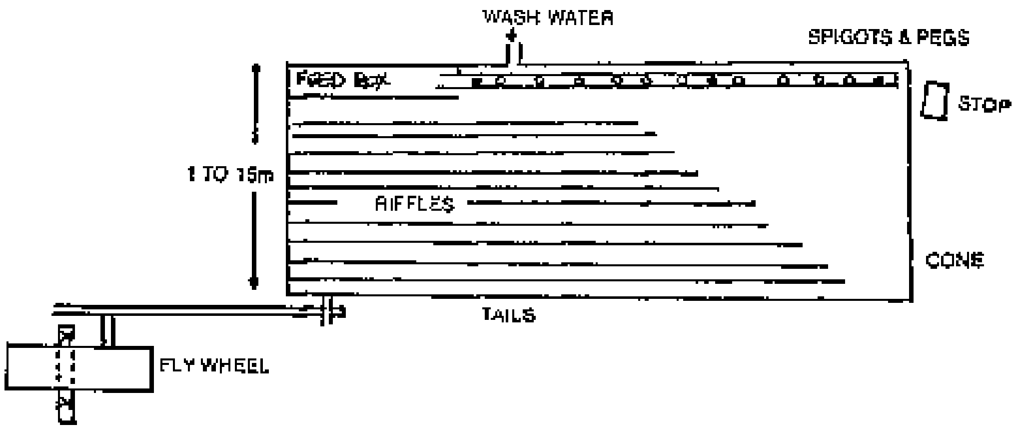


Fig.: Manual shaking table. Source: Stewart.

14.17 Humphrey's spiral, spiral separator

Metal Mining, Gold Mining
Beneficiation, Sorting

germ.: Humphreyspirale, Wendelscheider, Spiralscheider

span.: espiral de Humphrey, espiral de separacion por gravedad, separador helicoidal, espiral

TECHNICAL DATA:	
Dimensions:	approx. 1 × 1 × 3 m / 5 to 6 windings / 1 to 3 discharge outlets
Weight:	approx. 200 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	velocity of slurry/processing water
Mode of Operation:	continuous
Throughput/Capacity:	0.5 12 t/h depending on dimension of channel (launder) and grain size of feed
Operating Materials:	
Type:	processing water, slurry water
ECONOMIC DATA:	
Investment Costs:	approx. 8000 DM
Operating Costs:	low

Operating Costs:	low
Related Costs:	possibly slurry pumps

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |—————|—————| high
Maintenance Expenditures:	low |—————|—————| high
Location Requirements:	minimum Dh (without pump) of 5 m
Grain Size of Feed:	(50 ym) 100 µm - 2 mm
Special Feed Requirements:	density difference between valuable mineral and tailings
Recovery:	solids-content of the slurry: 14 - 20 % by vol.
Replaces other Equipment:	other sluice washers
Regional Distribution:	in small-scale mining in Latin America very rare; widely employed in mining in South East Asia (alluvial tin deposits) and Australia
Operating Experience:	very good |—————|—————| bad
Environmental Impact:	low |—————|—————| very high
Suitability for	very good |—————|—————| bad

Local Production:

Under What Conditions: metal foundry

Lifespan: very long |————|————| very short

when lined with wear-resistant rubber

Bibliography, Source: Kirchner, DBM

OPERATING PRINCIPLE:

Spiral separators vertically separate the feed slurry in the launder (channel) according to density differences. The heaviest feed particles fall to the bottom of the launder, where frictional forces slow their velocity. As a result, the slower, heavier grains are less subject to the centrifugal forces (generated by the flow of slurry through the spiral-formed channel) than are the lighter, faster grains higher up in the flow. This creates a horizontal density differentiation of the feed grains, with the heavy particles flowing along the inside walls of the channel, and the faster, lighter particles travelling higher up towards the outer rim. The discharge outlets are located on the inside of the channel for removal of the heavier particles (concentrate). Separation precision can be improved by adding additional water during the sorting process.

AREAS OF APPLICATION:

Production of concentrates or pre-concentrates from medium-grained Feed.

REMARKS:

The launders (channel) are made of rubberized cast-iron or cast-steel or, in more modern constructions, also of fiberglass or ceramic. The design involves numerous pipes for supplementary-water intake and discharge outlets, making the spiral separator a fairly complicated construction.

Critical construction parameters are: launder (channel) cross-section and spiral diameter, number of windings, inclination and number of discharge outlets.

Spirals of this kind were first manufactured by Humphreys in 1943.

SUITABILITY FOR SMALL-SCALE MINING:

The complicated pipe-system for input of auxiliary water and removal of concentrate makes the Humphrey's spiral less suitable for small-scale mining, although as a continual, non-powered sorting apparatus with high throughput it achieves good separation results.

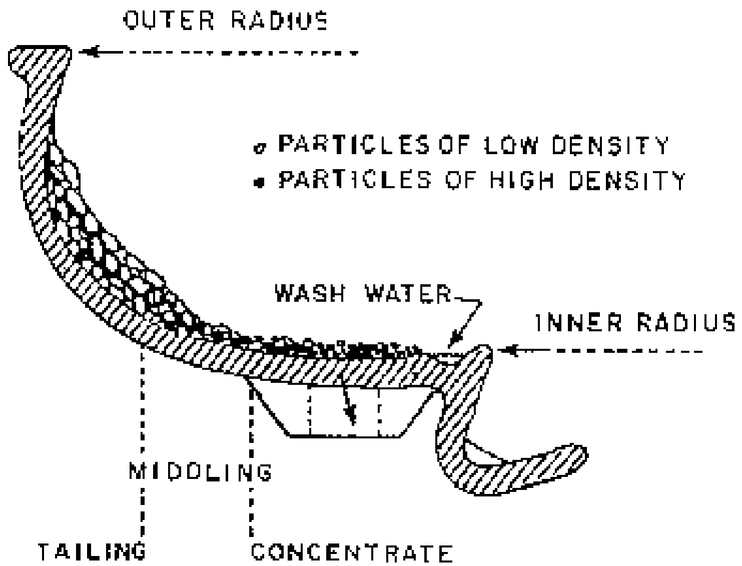


Fig.: Distribution of mineral particles in the Humphreys' spiral. Source: Silva

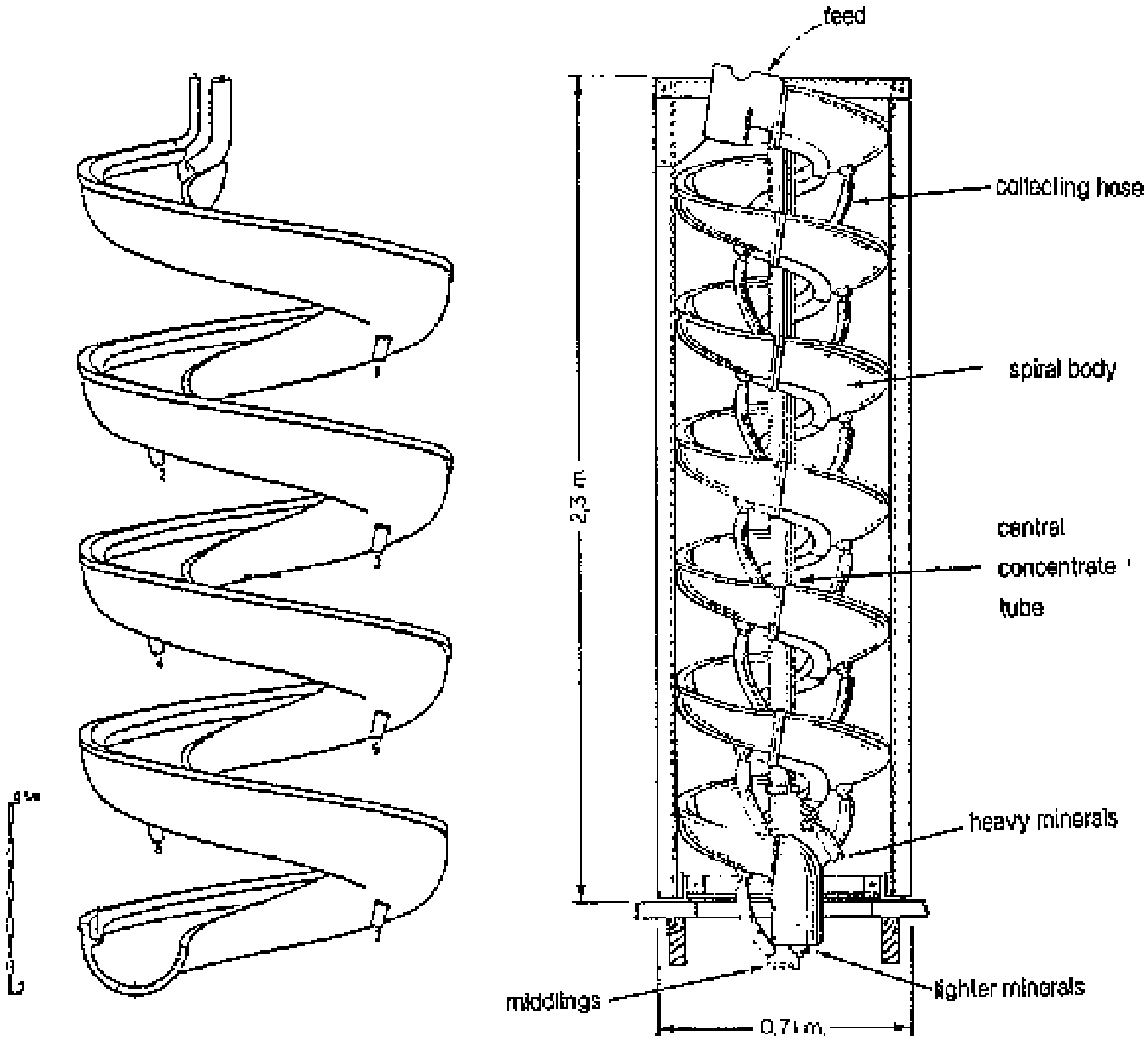


Fig.: Humphrey's spirals left, Source: Kirchner, right, Source: Silva.

14.18 Spiral concentrator

Metal Mining, Gold Mining
Beneficiation, Sorting

engl.:	centrifugal spiral classifier, Reichert cone
germ.:	Wendelscheider, Reichertspirale Mark 6+7, Zentrifugal-Fallherd
span.:	concentrador en espiral, separador helicoidal, espiral de Reichert, mesa centrifuge
Manufacturer:	Mineral Deposits, AKW, Svalcor

TECHNICAL DATA:	
Dimensions:	3.5 × 1 × 1 m HWD / Fiber glass PU coated
Weight:	43 kg (single channel) - 105 kg (triple channel)
Extent of Mechanization:	semi-mechanized
Form of Driving Energy:	hydrostatic pressure
Mode of Operation:	continuous
Throughput/Capacity:	up to 2 t/h slurry; up to 0.3 t/h concentrate
Operating Materials	
Type:	water
Quantity:	40 - 80 % by weight
ECONOMIC DATA:	
Investment Costs:	approx. 6000 DM
Operating Costs:	low

Related Costs:	possibly pumps for transport of slurry

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |—————|—————| high
Maintenance Expenditures:		low |—————|—————| high
Personnel Requirements:	low	
Location Requirements:	water and vertical elevation difference required	
Grain Size of Feed:	0.03 - 2 mm	
Special Feed Requirements:	depends on type of spiral, e.g., type LG (low grade) < 10 % heavy minerals	
Recovery:	according to the Colorado School of Mines Research Institute, concentrates contain between 75 and 98% gold	
Replaces other Equipment:	Humphrey spiral, sluices, buddies, fine grain jig	
Regional Distribution:	worldwide for mining of alluvial deposits, chromite, etc.	
Operating Experience:		very good |—————|—————| bad
Environmental Impact:		low |—————|—————| very high
Suitability for Local		very good |—————|—————| bad

Suitability for Local Production:		very good |————|————| bad
Under What Conditions:	difficult, fiber glass construction	
Lifespan:		very long |————|————| very short
	depends upon abrasiveness of the feed	

Bibliography, Source: AKW, C.N. Robinson, Cziernioch, Gaetzschmann, EP 0075563, EP 0074366, EP 0123501, EP 149518

OPERATING PRINCIPLE:

In a 6-phase spiral, density-differentiated side-streams develop as the slurry flows: the heaviest material (concentrate) collects in the deepest part (inside rim) of the channel as a result of being slowed by frictional forces due to scraping against the channel bottom, the medium-dense grain fraction collects in the middle, and the lightest particles (tailings) concentrate at the highest, outermost portion of the channel. The latter grains have the highest flow velocity are are therefore mostly affected by centrifugal force (large radius, high speed). The three stream components are split apart by dividing blades.

AREAS OF APPLICATION:

Processing of pre-concentrate from:

alluvial gold-ore deposits
tin sands and primary tin ore veins
titanous sands (ilmenite, rutile)

zirconium sands
pyrite and other sulfides for leaching
gold from gold-quartz veins
scheelite
chromite

REMARKS:

In contrast to the Humphrey's spiral, this type of spiral (Mark 7) has a much simpler design, lacking the complex pipe system for water intake and concentrate discharge. The slurry flow is first divided into concentrate, middlings and tailings at the end of the spiral channel.

Several channels (2 or 3) can be combined to form a composite of nested spirals.

Gaetzschmann describes a precursor of the spiral concentrator: The centrifugal spiral, invented by Hundt in 1863, had a spiral with a 15° - 25° inclined channel which rotated around a vertical axis whereby the products were differentiated according to density and discharged into separate concentric catchment basins for concentrate (inside), middlings (middle) and tailings (outside).

The most modern design for Reichert cones is characterized by the channel shape which is relatively flat at the deepest point (where the concentrate collects) and becomes wider as the spiral continues downward. This results in a displacement of the separation boundary further toward the outer rim, where the increased centripetal forces have a greater effect on the material being sorted. Simultaneously, the depth of the slurry flow in the region of the channel where the

concentrate flows is reduced, causing tangential waves to develop which in turn increase the separation precision by carrying lighter grains outward away from the concentrate region.

In the event that, in the deepest portion (Inner wall) of the channel, a large enough increase in slurry density occurs 60 as to disrupt the sorting process, wedge-shaped reflector or dashboards can be mounted onto the outer channel rim which cause the outer slurry flow to be sprayed evenly over the entire width of the channel (EP 123501).

<u>SUITABILITY FOR SMALL-SCALE MINING:</u>

In poorly mechanized operations, the Reichert cone provides a good opportunity for increasing the efficiency of pre-concentrate production from heavy-mineral feed. Despite comparably high investment costs, it remains suitable for small-scale mining application.

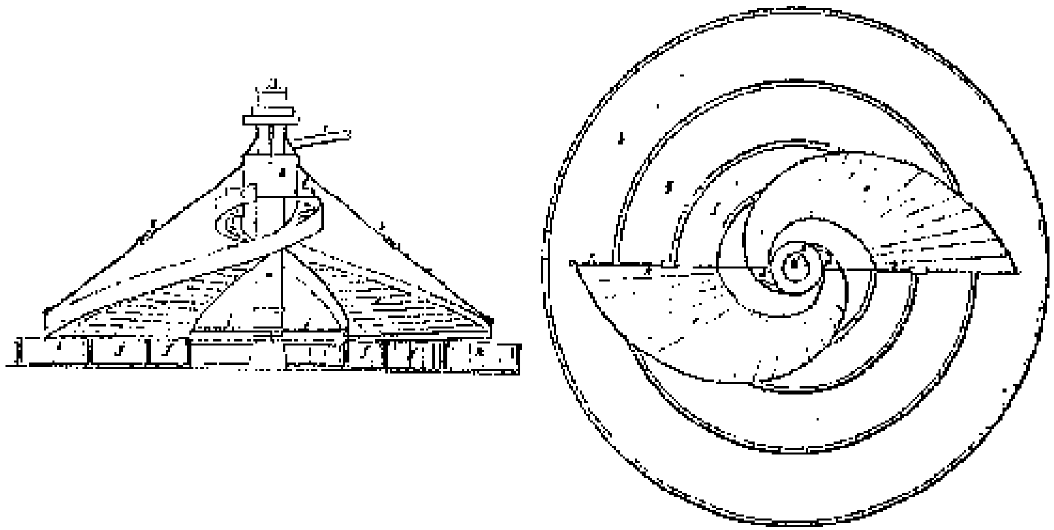
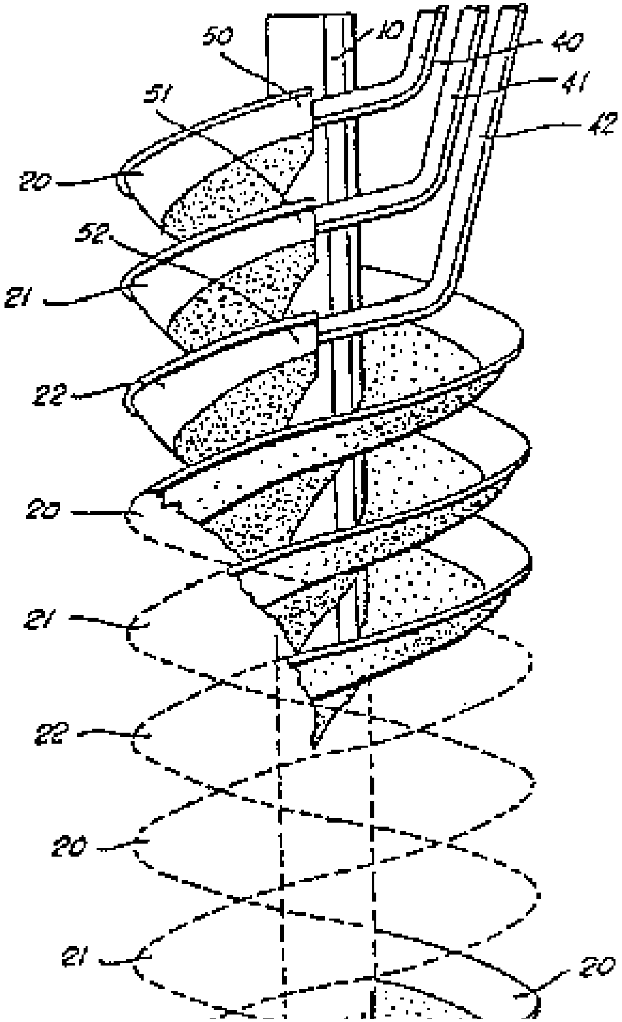
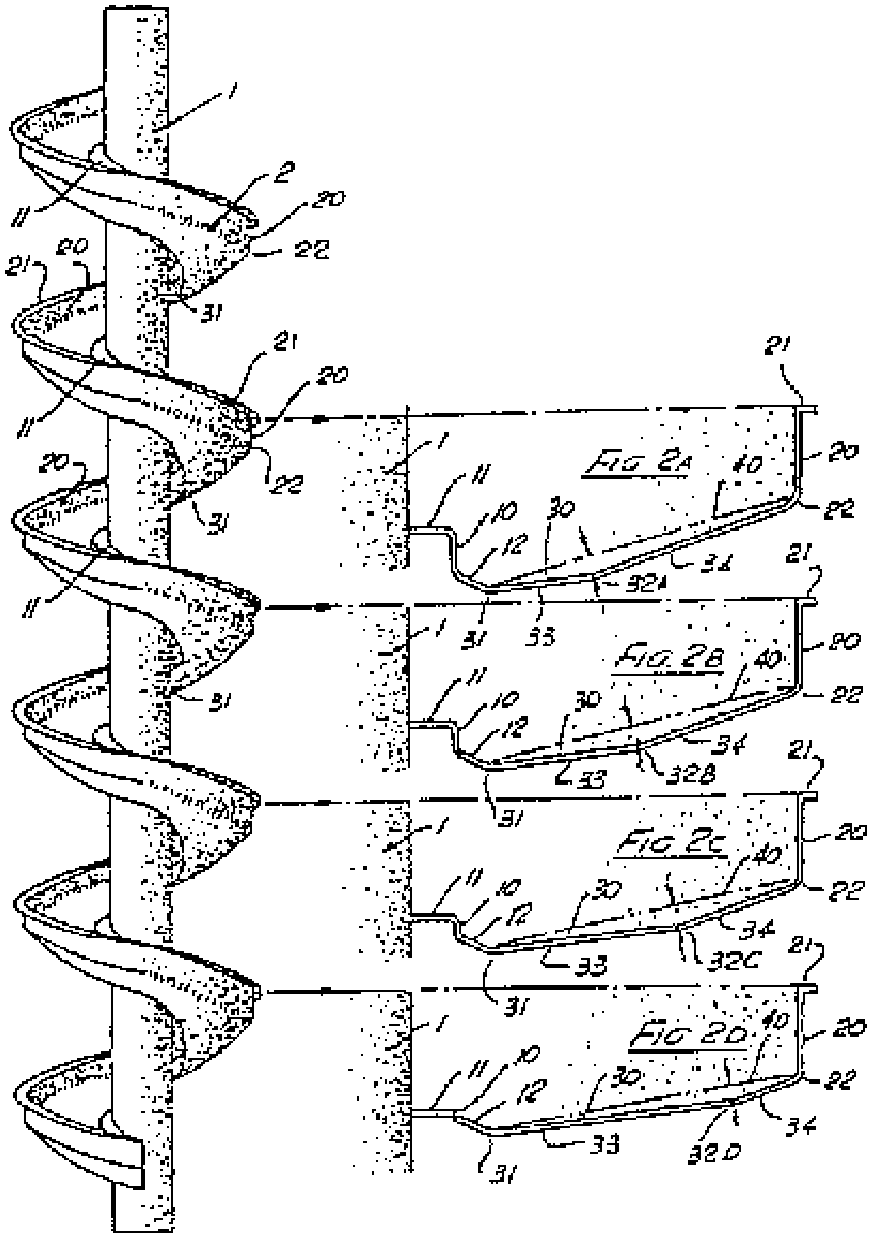
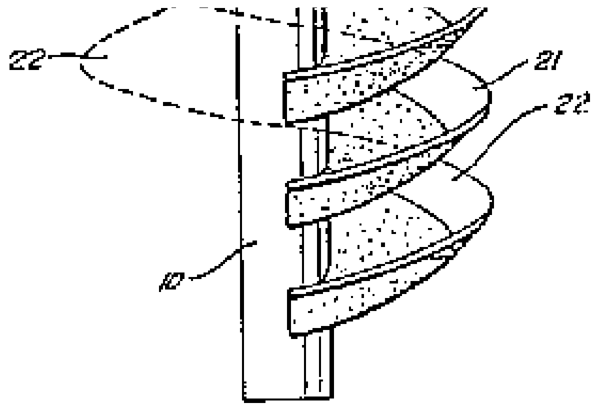


Fig.: Centrifugal spiral, a precursor of the spiral separator. Source: Gaetzschmann.







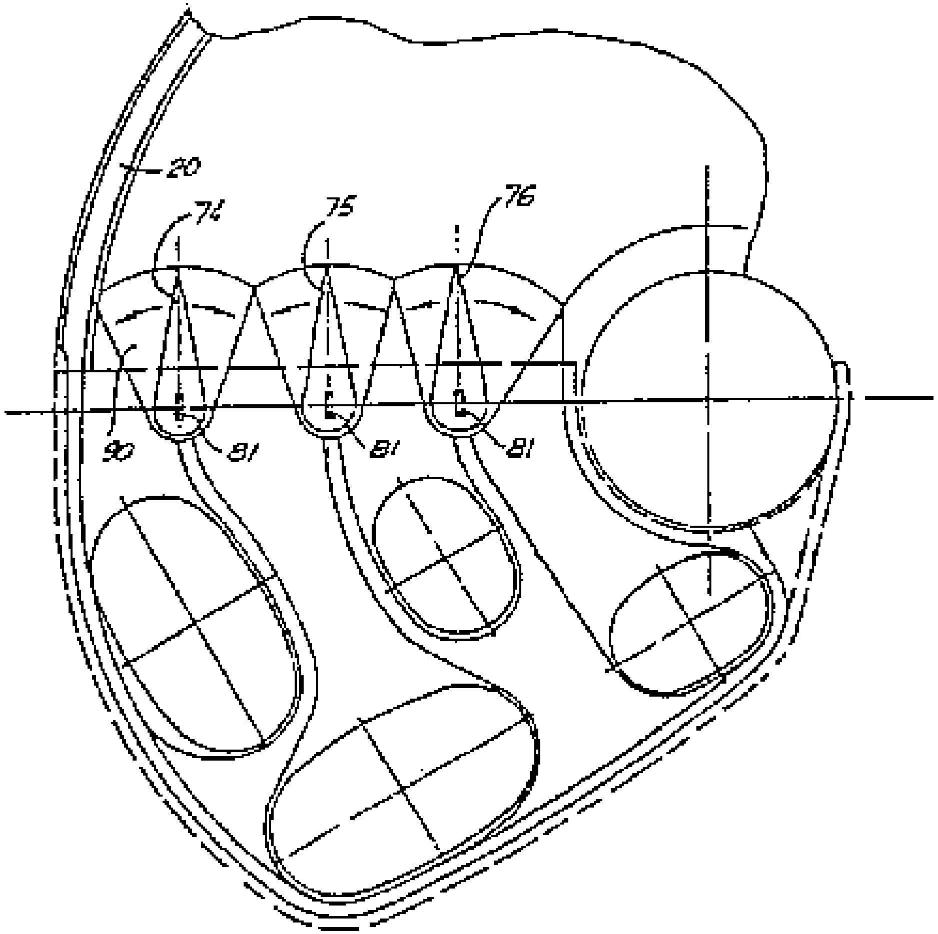


Fig.: Illustrations of spiral separators: above, left: Triple spiral; above, right: Spiral separator with varying channel channel diameter; below: Dividing plates (splitting devices) for withdrawal of products. Source: Patent No. EP 0075563 and No. EP 0074366.

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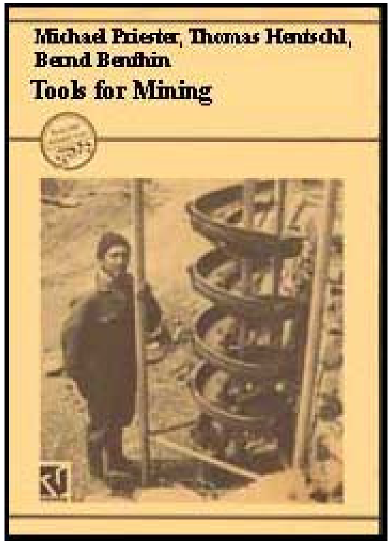


Tools for Mining: Techniques and Processes for Small Scale Mining (GTZ, 1993, 538 p.)

Technical Chapter 15: Gold Benefication

15.1 Amalgam press

Gold Mining
Beneficiation, Gold Processing

germ.: Amalgampressen

span.: prensa de amalgama

Manufacturer: ASEA, Zutta

TECHNICAL DATA:	
Dimensions:	starting at approx. 0.5 × 0.5 × 1 m
Weight:	approx. 40 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	manual
Mode of Operation:	intermittent
Throughput/Capacity:	very high, several 100 kg of Amalgam-Hg-mixture per day
Technical Efficiency:	very high degree of separation in comparison to amalgam extrusion performed in cloths without the assistance of a press; residual amalgam contains about 50 - 65 % HgOperating Materials:
Type:	possibly hot water
ECONOMIC DATA:	
Investment Costs:	when locally produced approx. 100 DM
Operating Costs:	low

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |————|————| high
Maintenance Expenditures:		low |————|————| high
Effects on Personnel:	high health hazard due to handling of toxic operating materials	
Recovery:	very high, < 0.2 % Au remains in the Hg, which is recycled back into the process with the Hg	
Replaces other Techniques:	simple extruding without auxiliary apparatuses	
Regional Distribution:	very seldom used, to date unknown in developing countries	
Operating Experience:		very good |————|————| bad
Environmental Impact:		low |—————————| very high
Suitability for Local Production:		very good |————|————| bad
Under What Conditions:	metal manufacturing	
Lifespan:		very long |————|————| very short

Bibliography, Source: Schnabel, Schennen, Villefosse

OPERATING PRINCIPLE:

The Amalgam Press takes advantage of differences in viscosity between pure metallic mercury and the gold amalgam alloy (Au_3Hg and Au_2Hg, viscous masses). The mixture is pressed through leather (chamois or deer) or dense cloth (such as linen) whereby the amalgam remains completely in the press while pure mercury, with an insignificant quantity of gold (< 0.2 %), is forced through the filter cloth/leather and collected.

AREAS OF APPLICATION:

Separation of amalgam from amalgam-mercury mixtures from amalgamating processes in order to reduce feed quantities entering the distillation retort.

REMARKS:

In small-scale mining in Latin America, the amalgam and Hg are often separated without the use of an Amalgam Press. This involves manually removing the mercury from the thick, paste-like amalgam by squeezing it out the side with the fingers. The amalgam is then wrapped in a damp cloth and wrung, whereby the Hg beads are forced out through the cloth and collected In a batea (pan). The high toxic effects of mercury, combined with the low recovery values obtained, advise against the use of this method.

In Colombian gold mining, the mixture is warmed up in hot water prior to pressing it in order to improve the separation of the amalgam from the mercury. The rise in temperature leads to a reduction in the viscosity of the compound and consequently to a better separation of the individual components as it is forced through cloth or squeezed in a press.

SUITABILITY FOR SMALL-SCALE MINING:

A simply-constructed amalgam press can be produced locally at low cost. Its use reduces health and ecological risks associated with the handling of mercury. For this reason, the small-scale mining industry should implement the use of amalgam presses in combination with distillation wherever amalgamation is being performed.

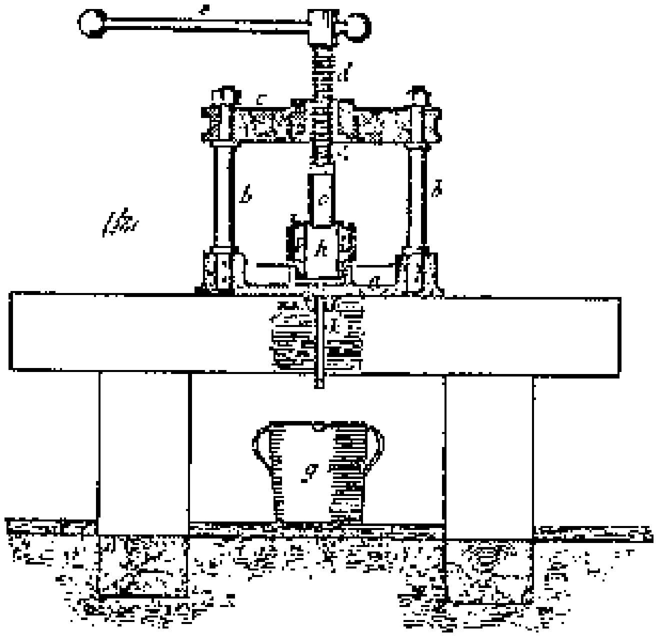


Fig.: Amalgam Press. Source: Rittinger.

15.2 Amalgamating table

Gold Mining
Beneficiation, Gold processing

engl.: copper plates

engl.: copper plates

germ.: Amalgamierherd, Amalgamiertisch

span.: place de amalgamacion, place electroplateada, mesa de amalgamacion, planca de cobre

TECHNICAL DATA:		
Dimensions:	4 × 2 × 1 m WDH and smaller; 2.5° - 12° inclination angle	
Weight:	several 100 kg as free-standing apparatus with stand, otherwise constructed on the ground	
Extent of Mechanization:	not mechanized	
Form of Driving Energy:	only processing water	
Mode of Operation:	semi-continuous	
Throughput/Capacity:	3 t/d per m², table surface area	
Operating Materials:		
Type:	water	Hg see comments below
Quantity:	slurry density 20 % solids	>= 50 g/m²
ECONOMIC DATA:		
Investment Costs:	when of imported construction with stand, high costs due to copper or muntz metal plates, approx. 10.000 DM; when locally produced with copper plates in masonry sluices built on the ground, less than 1000 DM	
Operating Costs:	relatively low, almost exclusively costs of reagents	

Operating Costs:	relatively low, almost exclusively costs of reagents
Related Costs:	subsequent hydraulic heavy-material trap for recovery of discharged amalgam and Hg; sun shade above plates to reduce mercury evaporation.

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |————|————| high
Maintenance Expenditures:	low |————|————| high
Effects on Personnel:	high health risk from handling toxic material
Location Requirements:	water necessary
Grain Size of Feed:	50 µm - 1 mm; good classification necessary to avoid mechanical wear (abrasion) of the amalgam
Special Feed Requirements:	Au must exist as liberated free gold; gold may not be encrusted, for example by limonite; a slightly basic pH-value of the slurry improves the amalgamation
Recovery:	60 - 80 % of the free gold, in the fine grain-size range generally higher than with gravimetric sorting
Replaces otherEquipment:	sluices, tables, amalgamating barrels
Regional Distribution:	earlier widely distributed especially in the USA

Operating Experience:		very good |————|————| bad
Environmental Impact:		low |—————————| very high
	possible sources of environmental contamination are: discharge of large quantities of Hg due to mechanical abrasion of the amalgam and to discharge of foreign-metal amalgams, such as antimony and arsenic amalgam; evaporation of Hg through the water film into the air; discharge of reagents during preparation of the copper plates prior to the amalgamation, e.g., cyanide and silver nitrate	
Suitability for Local Production:		very good |————|————| bad
Under What Conditions:	good copper plates must be available	
Lifespan:		very long |—————————| very short

Bibliography, Source: Schnabel, von Bernewitz, Schennen, Clennell, Treptow, Hentschel, Amalgamation ABC, Taggert. Hypolito, Escobar Alvarez and Echeverri Villa

<u>OPERATING PRINCIPLE:</u>

A slurry composed of the liberated, ground feed material flows along the flat, inclined copper plates. The angle of Inclination must be so chosen as to prevent sedimentation of the mineral particles (dependent on the specific density of the

heaviest accompanying minerals). Gold flows at the bottom of the slurry flow and is amalgamated by the mercury. The table surfaces are cleaned of the gold amalgam several times daily and prepared anew for the next amalgamation processing.

AREAS OF APPLICATION:

The amalgamation of finely stamped or ground Au ores. The recovery of Hg following amalgamation in stamp mills or Chilean mills.

REMARKS:

- **Besides copper plates, muntz metal plates (60 % Cu, 40 % Zn) are recommended.**

- **The pre-treatment of the plates is complex and time-consuming:**

  - **Polishing with fine sand**
  - **Degreasing using a 1 % Na- or K-cyanide solution**
  - **Polishing with fine sand**
  - **Use of salmiac solution to remove the oxides of non-precious metals**
  - **Coating with mercury**

- Silver amalgam is more effective than pure mercury in amalgamating gold. This is produced either by adding silver nitrate solution to the Hg or alloying with silver foil. Alternatively, the copper or muntz metal plates can be activated by plating them with a thin layer of silver. Pure copper tends to oxidize on the surface. Upon the application of Hg, the Hg surface is made inert by the partly soluble copper salts. Furthermore, these hydrated layers prevent the mercury from adhering to the surface of the plates. The application of silver on the surface prevents this.

- Acidic mine water is detrimental to the amalgamation. By grinding limestone in with the feed, this effect can be neutralized. Correspondingly, It is recommended that this be done only in deposits which have ores containing little or no sulfidic accompanying minerals.

The development of the amalgamation occurred in the 1st century AD. during the reign of Emperor Nero (54 - 68 AD.) in Bosnia.

The inclination of the table has a critical effect on Au recovery. Tables should be inclined just enough so that heavy-material grains do not settle out. The slurry should flow with small periodic waves over the table surface. Small steps improve the amalgamation. The plates comprising the table surface must, in any case, be completely smooth.

To avoid evaporation of mercury especially when the flow of slurry is turned off, the amalgamation table should always be protected from direct sunlight.

- Soluble lead minerals, arsenic (in arsenopyrite, arsenic sulfphides etc.), antimony, and bismuth react either with the mercury, forming amalgam or chemical coatings, or dissolve Hg or precious metal amalgam out of the compound, which lead to substantial losses of precious metals and mercury. Fresh pyrite and copper pyrite, to the contrary, do not affect amalgamation. Barite, talc, steatite and viscous hydrogenized magnesium and aluminum silicates also cause disruptions or losses during amalgamation.

- Oils, grease or lubricants are extremely deleterious and instantly lower the recovery achieved from the amalgamation.

- Prior to amalgamation on the amalgamation table, the feed must be thoroughly classified to ensure that no coarse grains flow over the table which could cause mechanical abrasive wear of the amalgam.

Contaminated, impure mercury is much less active than fresh mercury. While the latter forms ideal beads, almost perfectly round with a bright metallic glow, the contaminated mercury can be recognized by its dull surface, deformed shape of the beads, and the tendency of the beads to adhere somewhat and form a tail when rolled over a smooth inclined surface.

There are several methods of cleaning and reactivating contaminated mercury;

- by screening with a very fine-mesh screen (~ 200 mesh)

- by washing with wood ashes and water (whereby calcium carbonate contributes to the saponification of impurities)

- by washing the mercury with water containing tensides or with special plant-sap solutions, both of which are capable of saponifying grease and greasey substances and bringing them into solution

- by washing with reagents such as ammonia, ammonium chloride, cyanides, hydrochloric acid, nitric acid, etc.

- by distilling the mercury in the retort, which removes slightly volatile impurities

- by admixing sodium amalgam with the mercury, whereby the Na-amalgam is transformed into NaOH upon contact with water, which in turn dissolves surface components of the impure mercury. An effective solution concentration is 1 part sodium to 2000 parts mercury. (The production of Na-amalgam through electrolysis is performed as follows: A vessel is filled with mercury and brought into contact with a carbon cathode placed inside an insulated tube (e.g. glass or plastic). A sodium chloride bath (10 - 15 % solution), which is connected to a carbon anode, is poured over the mercury. Through the direct current of a car battery, Na+-ions are transferred onto the Hg surface and amalgamated as metallic sodium. After 10-15 minutes, sufficient concentrations are reached. The Na-amalgam obtained should be stored under air-tight conditions, for example under petroleum.

REPORTS OF OPERATING EXPERIENCES:

In gold mining in northern Chile, the copper plates are cleaned with urine before

being coated with the mercury.

In gold mining in Colombia, amalgamating tables are widely distributed. The amalgamating tables are cleaned of amalgam every 6 hours and newly prepared for reuse. Cleaning of the copper plate, and then the mercury surface, is performed using either a strong detergent or the sap from sisal leaves (cabulla, fique). Sisal contains tenside-like substances which dissolve grease. At the same time, sisal sap helps prevent flotation of gold particles during the amalgamation process. This is accompilshed by placing a piece of leaf in the stamp mill and grinding it in with the ore feed' thereby releasing the sap.

SUITABILITY FOR SMALL-SCALE MINING:

For the processing of finely intergrown gold ores which do not have high sulfide contents, the amalgamation table represents a sorting method which is very effective, reasonably-priced and simple to operate. The use of amalgamation tables should, however, automaticallyinclude the use of devices for the recovery of amalgam and mercury (retorts and hydraulic heavy-material traps) for protection of both health and the environment.

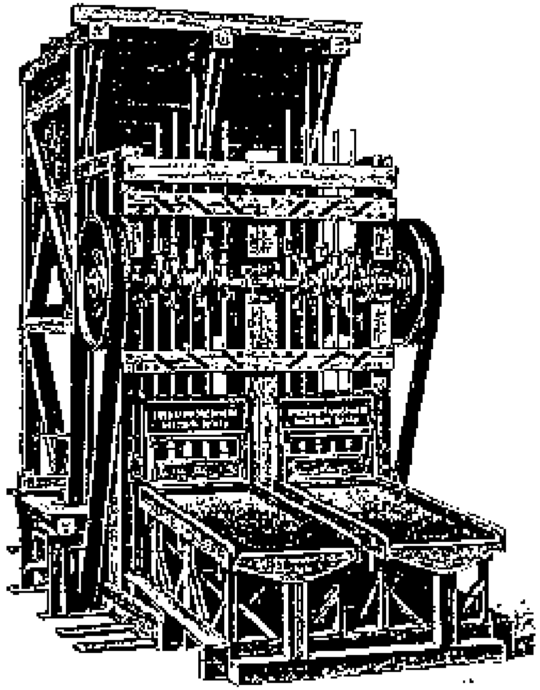


Fig.: Amalgamating table directly behund a stamp mill. Source: Uslar.

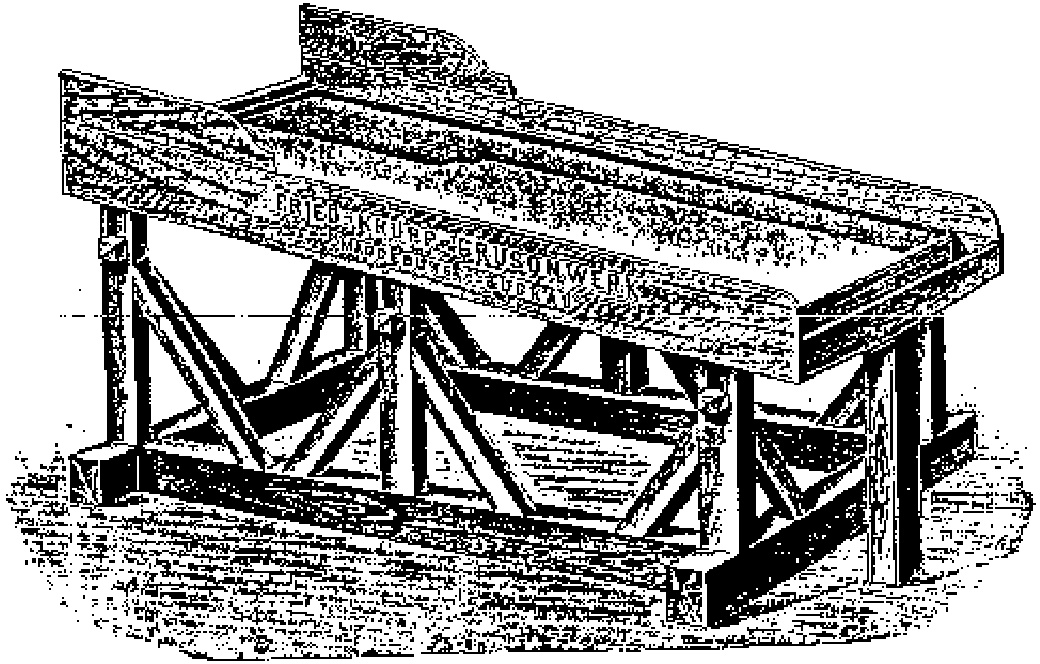


Fig.: Amalgamating table. Source: Uslar.

15.3 Amalgamating barrel

Gold Mining
Beneficiation, Gold Processing

germ.:	Amalgamiertrommel
span.:	tromel de amalgamacion, chancho, amalgamadora, barril de amalgamacion
Manufacturer:	Svalcor

TECHNICAL DATA:	
Dimensions:	Berdan pan: 1.0 × 0.6 × 0.6 m HOOD, inclination angle approx.

	15°, 20 - 30 min^{-1}			
Weight:	from approx. 50 kg up to several 1000 kg			
Extent of Mechanization:	not mechanized/semi-mechanized			
Form of Driving Energy:	electric motor or internal combustion engine, hydromechanical, manual, pedal drive			
Mode of Operation:	intermittent			
Throughput/Capacity:	depends on size			
Operating Materials:				
Type:	mercury	possibly steel balls	water	reagents to activate surface of Hg, e.g. NaOH, sodium amalgam, ammonium chloride, cyanide, nitric acid, tensides
Quantity:	approx. 1 - 3 kg/kg Au	or stone pebbles		
ECONOMIC DATA:				
Investment Costs:	dependent on extent locally produced and type of drive-system, starting at approx. 100 US$			
Operating Costs:	cost of reagents and energy			
Related Costs:	amalgamating press, distillation retort, pre-concentrating equipment			

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |————|————| high
	depends on power source
Maintenance Expenditures:	low |————|————| high
Personnel Requirements:	training in handling of Hg is necessary
Location Requirements:	very little water needed
Grain Size of Feed:	20 · 50 ym to 2 mm for Au-fraction
Special Feed Requirements:	free, liberated gold without crustations (for example by fine Fe-oxides); possibly treatment with reagents, no platy floured gold, low content of antinomy minerals, possibly prior flotation, but then problematic surface conditions (hydrocarbons)
Recovery:	very high under good working conditions; in some cases > 95 %
Grade of Concentrate:	amalgam contains up to 50 % Au, but lower concentrations of gold in the amalgam are practical, with subsequent concentration in an amalgam press
Replaces other Equipment:	manual amalgamation in batea (pan), amalgamation in combination with other processes
Regional Distribution:	worldwide in gold mining
Operating Experience:	very good |————|————| bad
	compared to amalgamation in sluices, Chilean mills, stamp mills, etc., Hg-

compared to amalgamation in sluices, Chilean mills, stamp mills, etc., Hg emissions can be kept at very low levels; in particular the addition of reagents and reduction of slurry velocity prevent the occurrence of floured mercury.

Environmental Impact:	low |————|————| very high
Suitability for Local Production:	very good |————|————| bad
Under What Conditions:	metal manufacturing involving pipe sections, sheet metal, bearings, etc.
Lifespan:	very long |————|————| very short

Bibliography, Source: Hentschel, Born, Bernewitz,

OPERATING PRINCIPLE:

The amalgamating barrel operates according to the same principle as the ball mill. The mineral feed consists of rich pre-concentrates. During rotation of the barrel, this feed material is extensively mixed with water, mercury (in a quantity about three times the amount of gold expected to be recovered), grinding bodies and the above-mentioned reagents. During the process, Au-particles come into contact with the mercury and amalgamate. Under influence of the grinding bodies, the gold is worked into the mercury; this occurs so effectively that even the finest gold-fraction, which otherwise could not be recovered In the amalgam due to the surface tension of the mercury, penetrate into the mercury. Upon completion of the rotation process, vibrations and pounding impact forces enhance the density

differentiation, whereby the amalgam-Hg mixture collects at the deepest portion of the barrel and is removed following flushing or scimming off of the tailings.

AREAS OF APPLICATION:

For amalgamation of pre-concentrates in a closed reactor.

SPECIAL AREAS OF APPLICATION:

For the simultaneous grinding and amalgamation of non-liberated pre-concentrates in a non-continuous operation, which requtres, without exception, a higher filling-gradient (more grinding bodies) in the ball mill.

REMARKS:

Instead of a ball mill, small-scale mining operations often use cement mixers for barrel amalgamation.

The feed material for barrel amalgamation should always be thoroughly washed prior to amalgamating In order to wash out soluble minerals which could cause inactivation of the Hg-surface.

During a purely amalgamating process, the rotation speed of the amalgamating barrel lies at about 50 % of the optimal rotation speed for a mill of comparable size. At this low speed, the formation of floured mercury is avoided. In simultaneous grinding and amalgamation, an intermediate rotational speed must be applied as a compromise between losses in efficiency due to sliding of the grinding bodies and unfavorable conditions for the amalgamation.

The American "berdan pan" is a slowly-running one-ball mill equipped with a circular ecliptic track, whereby the mill shell rotates and the ball remains in the deepest portion of the track where it floats on the mercury.

The advantage of amalgamating barrels is their contribution to environmental protection by eliminating or reducing losses In metallic mercury (as floured mercury) during amalgamation. During processing, the surface characteristics of the Hg in the closed barrel can be maximized according to the feed material through the addition of reagents.

SUITABILITY FOR SMALL-SCALE MINING:

Amalgamating barrels can be highly recommended for their effectiveness in preventing the release of Hg during amalgamation. They combine the advantages of easy low-cost construction, diverse mechanization possibilities, and ability to control the surface activity of mercury through the addition of reagents with the utilization of the good separating characteristics of amalgamation. Pre-concentrating of the feed material is a prerequisite.

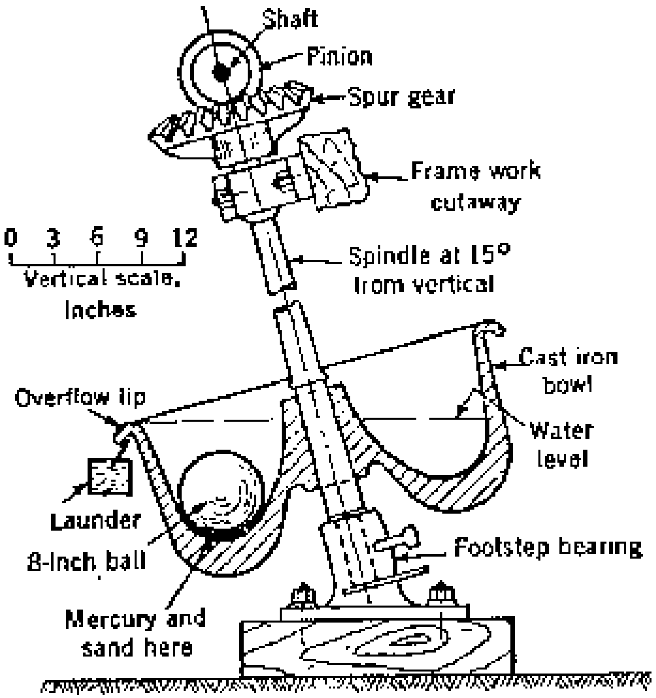


Fig.: Berdan pan, single-ball mill for amalgamation. Source: Bernewitz.

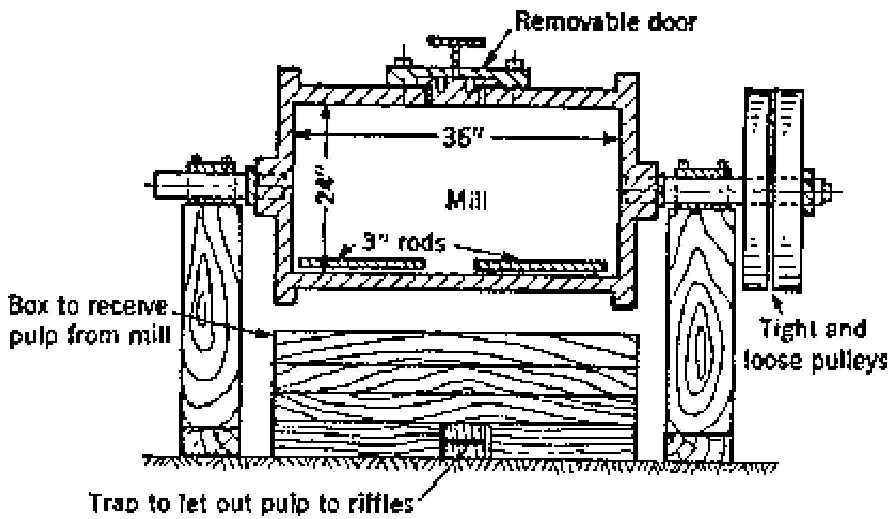


Fig.: Amalgamating barrel as rod mill. Source: Bernewitz

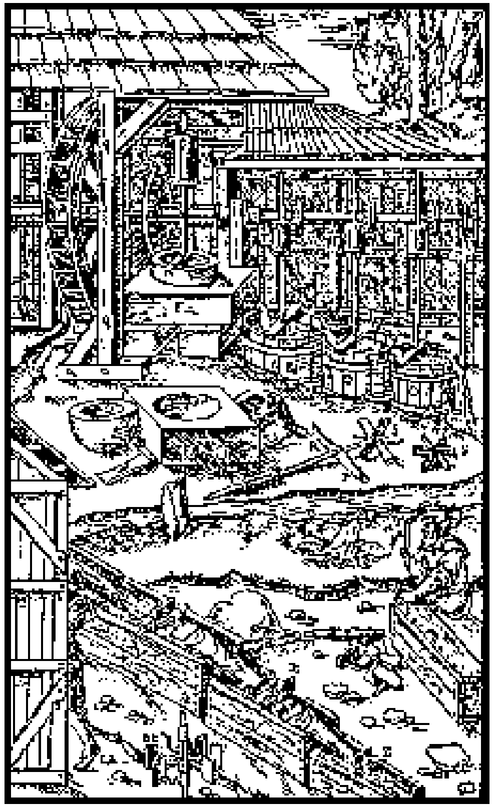


Fig.: Amalgamation in agitators, by Agricola. Source: Agricola.

15.4 Rocker, cradle

Gold Mining
Beneficiation, Gold Processing

germ.:	Rocker, Wiege, Wiegensieb
span.:	cuna, criba cuna, chinchola, cuna californiana, cuna siberiana, lavador, concentrador
Manufacturer:	Keene

TECHNICAL DATA:	
Dimensions:	up to several m in length
Weight:	20 - 50 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	manual
Mode of Operation:	semi-continuous
Throughput/Capacity:	500 - 1000 kg/MS including refining with batea (panning)
Technical Efficiency:	approx. 6 - 10 t feed with 2 persons in 10 h when solely pre-concentrating
Operating Materials:	
Type:	water
Quantity:	400 - 3000 1/10 h
ECONOMIC DATA:	
Investment Costs:	starting at approx. 200 DM if locally produced
Operating Costs:	mainly labor costs

CONDITIONS OF APPLICATION:

Operating Expenditures: low |————|————| high

Maintenance low |————|————| high

Expenditures:	
Special Feed Requirements:	lowest possible content of sticky, tenacious clays or partially consolidated sediments that cannot be crushed with the rocker during processing and therefore prevent liberation of the gold
Recovery:	somewhat low recovery in fine fractions, therefore suitable for high quantities of feed (high throughput) containing relatively coarse-grained gold (> 100 ym).
Replaces other Equipment:	sluices, batea (panning)
Regional Distribution:	Chile, Colombia
Operating Experience:	very good |—————|—————| bad
Environmental Impact:	low |—————|—————| very high
Suitability for Local Production:	very good |—————|—————| bad
Under What Conditions:	rockers can be manufactured in simple wood manufacturers using good screen material
Lifespan:	very long |—————|—————| very short

Bibliography, Source: Rittinger, Buch der Erfindungen 1890 ("Book of Inventions 1890", in German), Silva

OPERATING PRINCIPLE:

The rocker consists primarily of a classifying device and a trough washer. The classifying device has the form of a deep screen box for receiving the feed. Located underneath it is an Inclined wooden riffled trough with transverse slats. The inclination of the trough varies depending on the grain size of the feed material. For feed with high clay content, the angle of inclination is less than for material of coarse grain size. This entire unit is mounted on rockers, so that the whole upper portion can be rocked back and forth by means of a lever handle. The input and discharge of processing water for flushing is performed manually, requiring a total of four people for the mining and processing of gold using one rocker: one for mining the raw ore, one for transporting and feeding the ore into the rocker, one to do the rocking, and one for flushing with water.

AREAS OF APPLICATION:

For processing of loose or slightly-consolidated gold-containing sediments.

REMARKS:

The rocker represents the classic processing tool of North American gold miners and was used up until the present century.

In gold mining in North America, the pre-concentrates obtained from processing with the rocker (heavy-mineral sands with gold) were subsequently dried and sorted by wind-classifying.

The proper adjustment of the sluice's inclination greatly affects the recovery

achieved with the rocker. The discussion presented for sluices is applicable here as well.

Rockers are particularly well suited for arid regions due to their low water requirements.

SUITABILITY FOR SMALL-SCALE MINING:

The advantages of a rocker (light-weight construction, portable non-powered technique, highly suitabile for local production) make it appropriate as a mobile beneficiation apparatus for processing sedimentary gold ores during prospecting and mining. Especially for loose materials which do not require crushing, the rocker offers the advantage of a combined classification and sorting.

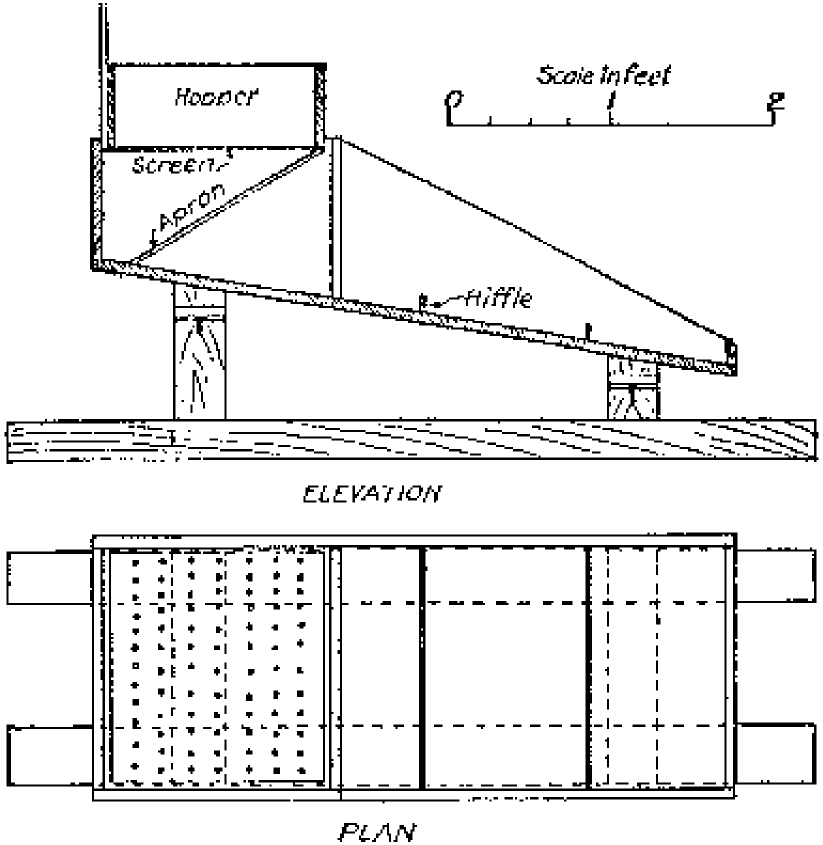
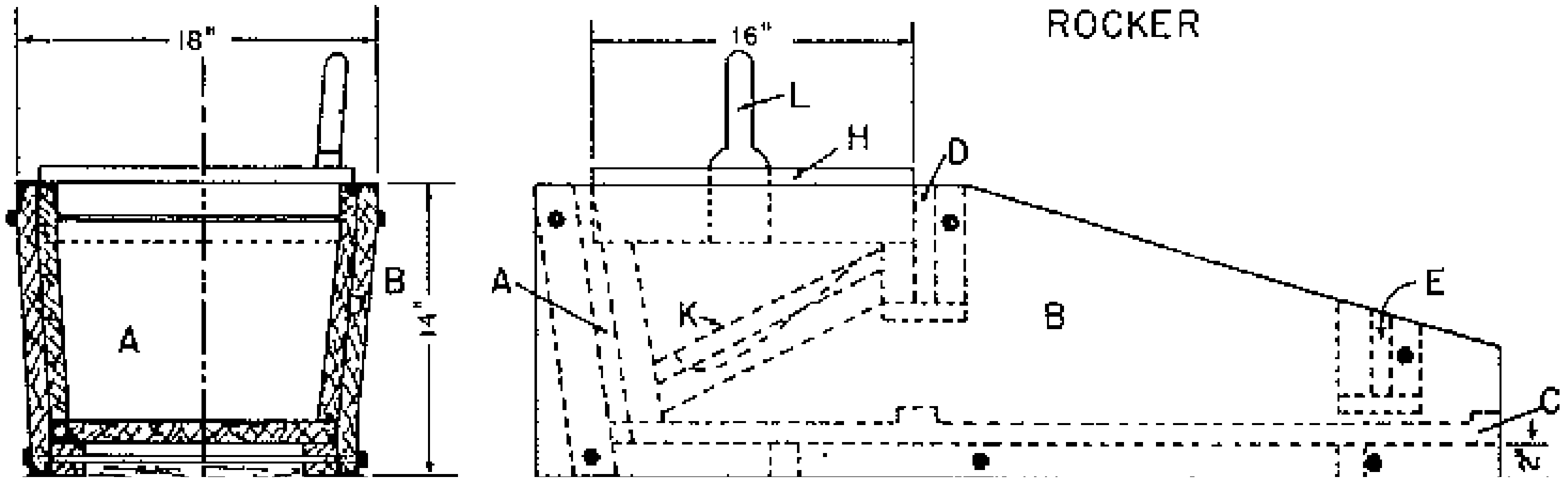
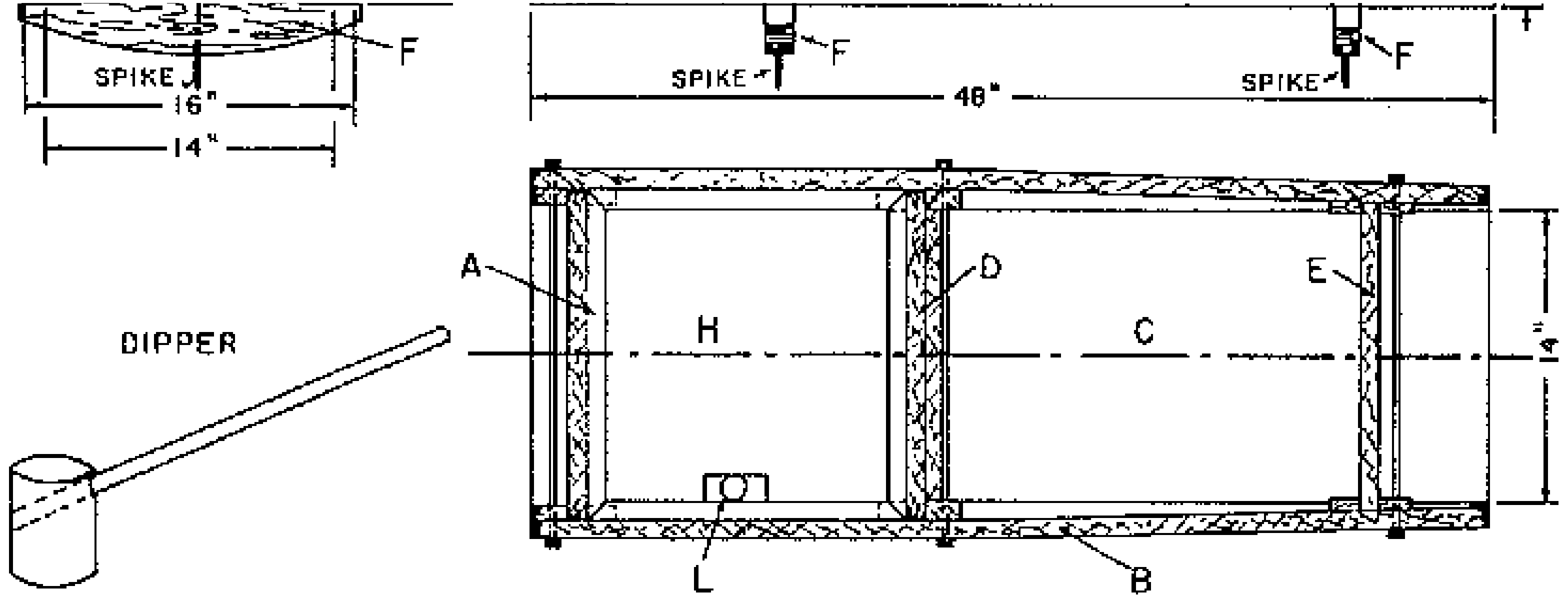
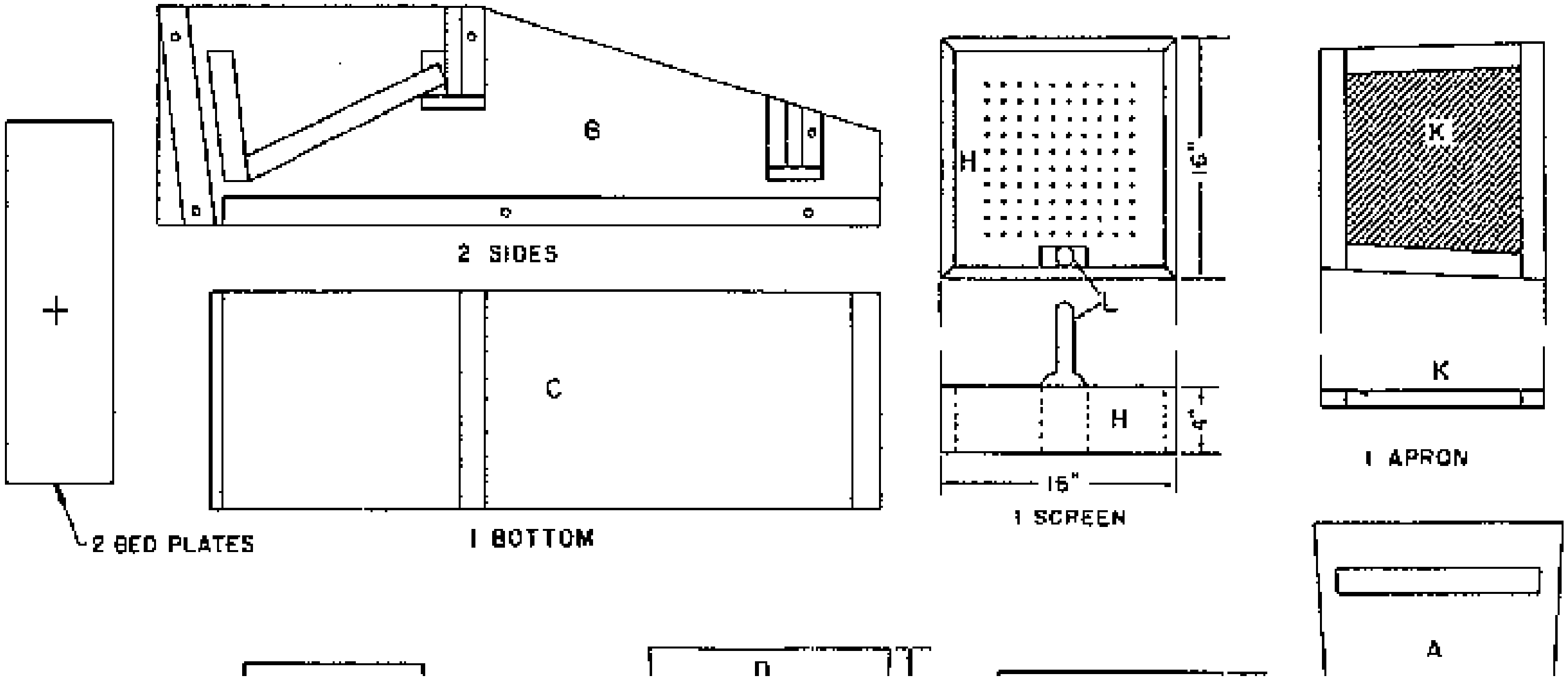


Fig.: Elevation and plan views of a rocker. Source: Bernewitz.





ROCKER PARTS



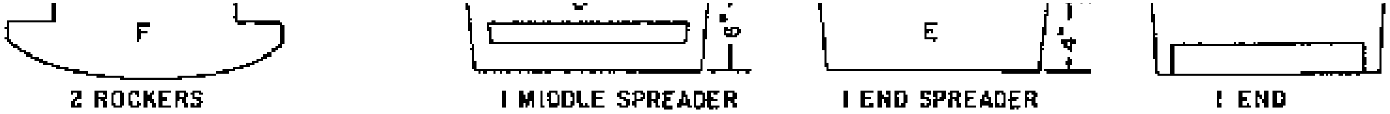


Fig.: Design plans a rocker. Source: Silva

15.5 Mechanized, compact gold processor

Gold Mining
Beneficiation, Gold Processing

engl.:	gold saver, washplants
germ.:	Mechanisierte kompakte Goldaufbereitungen, z.B. Gold Saver, Prospektor
span.:	beneficios de oro mecanizados en forma compacta, por ejemplo gold saver, prospector
Manufacturers:	Denver, Goldfield, Svalcor, Buena Fortuna, Fima, Metal Callao E.P.S., Met. Lacha

TECHNICAL DATA:	
Dimensions:	1 17x74x153 cm HWD
Weight:	270 kg
Extent of Mechanization:	fully mechanized
Driving Power:	3 PS
Form of Driving Energy:	internal combustion engine or electric motor
Alternative Forms:	hydromechanical ?
Mode of Operation:	semi-continuous

Mode of Operation:	semi-continuous		
Throughput/Capacity:	2-3 m^3/h		
Operating Materials:			
Type:	water	fuel	lubricants
Quantity:	20 - 351/min	approx. 2 - 5l/h	small quantities
ECONOMIC DATA:			
Investment Costs:	approx. 4000 us$ if locally produced; approx. 25.000 DM fob factory		

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |—————————| high
	3 people: 1 to feed, 1 to remove tailings, 1 to operate	
Maintenance Expenditures:		low |————|————| high
Grain Size of Feed:	< 100 mm	
Special Feed Requirements:	relatively coarse gold grains	
Recovery:	can be substantially increased with subsequent sluice or amalgamating table	
Replaces other Equipment:	sluices, Long Tom	
Regional Distribution:	Colombia	
Operating Experience:		very good |————|————| bad

Operating Experience:		very good |————|————| bad
Environmental Impact:		low |————|————| very high
	depending on type of feed material, high sludge loading can occur	
Suitability for Local Production:		very good |————|————| bad
	according to Degowski, a Gold Saver has already been reproduced locally in Pasto, Colombia	
Under What Conditions:	good metal and welding workshops	
Lifespan:		very long |————|————| very short

Bibliography, Source: Degowski

OPERATING PRINCIPLE:

Washplants for gold processing, for example those offered by Denver or Goldfield, consist of a classification drum with a coarse screen for separating and autogenous crushing of consolidated chunks of host rock. Fine material is subsequently processed in a vibrating sluice at a frequency of 200 - 220 min-1. The over-flow can then be further processed, for example, in a sluice or amalgamating table.

AREAS OF APPLICATION:

Extraction of gold from non or slightly-consolidated sediments containing coarse lumps < 100 mm in size.

REMARKS:

A Gold Saver of similar construction as described above was locally produced and applied in a GTZ-project (German Technical Assistance) in Colombia.

Gold Savers may find little acceptance compared to traditional methods. Especially in the extraction of gold from fluviatile alluvial deposits' mine operators consider the following aspects as problematic: the dependency on fuels, the danger of rising water levels in the river which necessites relocation of the Gold Saver to higher ground at the end of each work day, and the very high throughput which requires a corresponding increase in production capacity.

SUITABILITY FOR SMALL-SCALE MINING:

The advantage of the Gold Saver is its compact and mobile construction, serving as a complete processinq unit for loose and slightly-consolidated sediments. For stationary application, however, or when powered hydromechanically. the employment of individual components is a more cost-effective solution.

15.6 Hydraulic gold trap

Gold Mining
Beneficiation, Gold processing

germ.:	Hydraulische Schwergutfalle
span.:	trampas hidraulicas pare material pesado
Manufacturer:	Zutta Hermanos, ASEA-Perini

TECHNICAL DATA:	
Dimensions:	up to 60 × 60 × 60 cm depending on throughput capacity
Weight:	from approx. 2 - 20 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	only processing water, no drive system
Mode of Operation:	continuous
Throughput/Capacity:	several t/d
Operating Materials:	
Type:	water for counter flow
Quantity:	10 - 50 I/min with hydrostatic pressure of 0.1 - 0.5 bar
ECONOMIC DATA:	
Investment Costs:	very low, approx. 100 - 200 DM depending on size
Operating Costs:	very low

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |————|————| high
Maintenance Expenditures:		low |————|————| high
Location Requirements:	trap is built into sluice systems, water necessary	
Grain Size of	range of grain size should have an upper limit of 1 - 3 mm	

Grain Size of Feed:	
Output::	only coarse gold grains are separated from the mass flow, for example to prevent their being subject to further grinding; no amalgamation occurs, contrary to the similarly designed Jackpot where amalgamation occurs at the deepest point
Replaces other Equipment:	sluices for coarse fractions
Operating Experience:	very good |—————|—————| bad
Environmental Impact:	low |—————|—————| very high
	since no mercury is used
Suitability for Local Production:	very good |—————|—————| bad
Under What Conditions:	metal workshop
Lifespan:	very long |—————|—————| very short

Bibliography, Source: v. Bernewitz, Schennen

OPERATING PRINCIPLE:

The hydraulic gold trap functions like a small artificial sedimentation basin which is placed in the material flow. In so doing, the flow is not interrupted, so that only

heavy particles sink down. The sedimentation chamber is kept free of light material by means of a supplementary underwater flow. Therefore, the hydraulic gold trap is comparable to a single-celled settling box with clear water countercurrent.

The concentrate can be withdrawn during processing by opening the outlet valve.

AREAS OF APPLICATION:

Separation of coarse gold and heavy-mineral sand fractions from beneficiation processing circuits, e.g. prior to further grinding, sorting, amalgamating, leaching, etc.

SPECIAL AREAS OF APPLICATION:

Also applied for separating amalgam and mercury after the amalgamating process, for example following a stamp mill to collect the amalgam.

Also appropriate for collecting jig-bed particles discharged from a Jig.

REMARKS:

Suitable only in deposits which contain coarse fractions of gold; not practical for use in deposits containing exclusively fine. grained gold fractions.

In addition to the above-described construction with cross-current flow, some hydraulic gold traps have a slurry-feed input through a centralized pipe under the slurry surface. This forces a reversal in the direction of slurry flow, allowing the

gold to settle out. This system therefore functions analogous to the continuous (rake) thickener, or Dorr-type thickener.

SUITABILITY FOR SMALL-SCALE MINING:

Hydraulic gold traps are a simple, efficient, and inexpensive alternative for preliminary separation of coarse gold grates or nuggets. Hydraulic gold traps also play an important role as amalgam or mercury traps succeeding any type of amalgamating equipment.

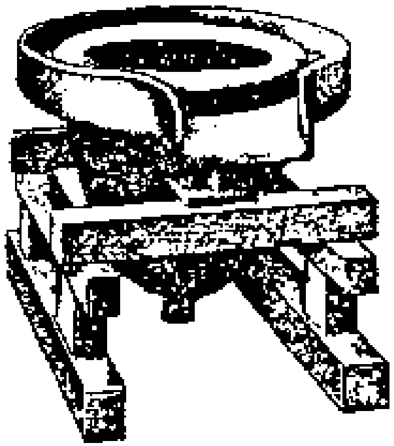


Fig.: Simple hydraulic trap. Source: Schennen.

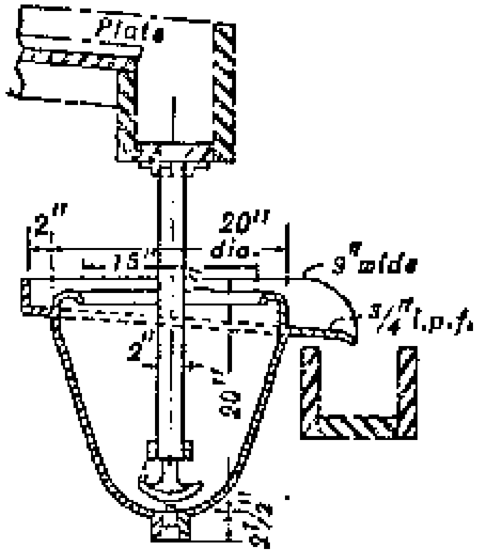


Fig.: Cross-section through a hydraulic trap. Source: Taggert.

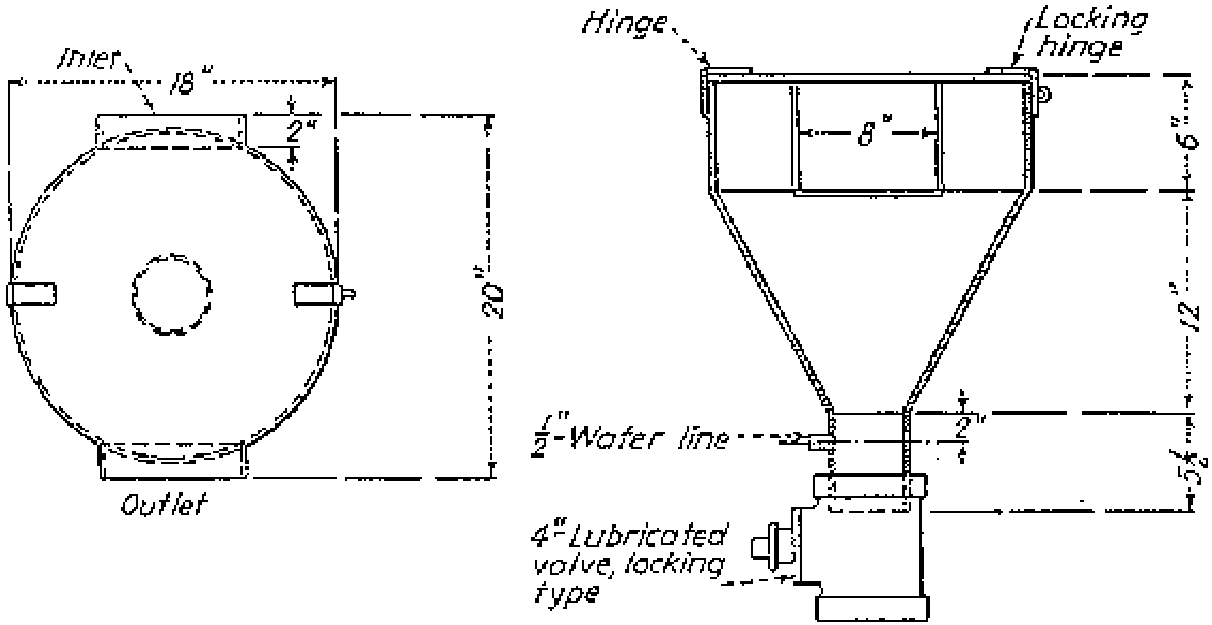


Fig.: A hydraulic gold trap. Source: Bernewitz

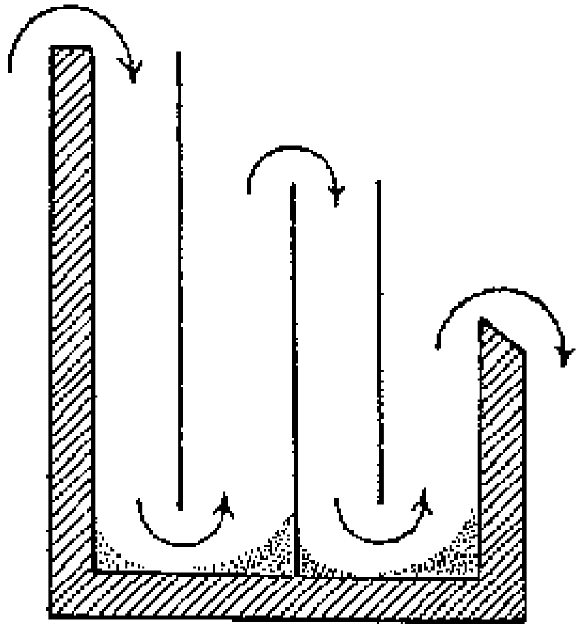


Fig.: Basic operating principle of a simple hydraulic trap for mercury and amalgam. Source: Escobar Alvarez.

15.7 Retort for, amalgam

Gold Mining
Beneficiation, Gold Processing

engl.:	still, distillation retort
germ.:	Destillierkolben
span.:	retorta de destilacion, retorta de amalgama, matraz de destilacion
Manufacturers:	Keene, Svalcor, Talleres J.G., Taller "Centro del Muchacho Trabajador", ASEA, Zutta

TECHNICAL DATA:

Dimensions:	approx. 10 × 10 × 60 - 80 cm, crucible approx. 5 cm in diameter, 5 cm deep
Weight:	approx. 10 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	thermal from biological fuels
Mode of Operation:	intermittent
Throughput/Capacity:	depending on design, between 0.5 and 70 or more kg capacity, duration of distillation approx. 15 - 25 min
Operating Materials:	
Type:	water Heat by burning wood, coal, gasoline, diesel, gas, etc
Quantity:	small quantities For cooling
ECONOMIC DATA:	
Investment Costs:	Retort: 100 to 500 DM if locally produced, serial production should be targeted to lower the cost of production, however amortization possible through recovery of Hg.
Operating Costs:	relatively high due to heating; however in open-circuit distillation, costs are also incurred for fuel
Related Costs:	blow torch approx. 30 DM

CONDITIONS OF APPLICATION:

Operating low I————I————I high

Operating Expenditures:	low |————|————| high
Maintenance Expenditures:	low |————|————| high
Location Requirements:	even the distillation of amalgam in retorts should take place in sufficiently ventilated environments, preferably in open air
Special Feed Requirements:	the amalgam should be cleaned (see 15.2)
Recovery:	heating of the gold amalgam to a temperature above the boiling point of mercury (350° C) separates the amalgam into gold (residue) and mercury (vapor). Recovery is nearly 100 %.
Replaces other Techniques:	must replace separation processes openly exposed to the atmosphere!!
Regional Distribution:	widespread in beneficiation laboratories in Latin America, seldom found in production plants
Operating Experience:	very good |————|————| bad
Environmental Impact:	low |————|————| very high
	minimal Hg-vapor pollution due to opening of the crucible or loose cover/seal
Suitability for Local Production:	very good |————|————| bad
Under What	simple metal manufacturer, produced from pipe sections (Rossi-Retort)

Conditions:

Lifespan: very long |————|————| very short

Bibliography, Source: v. Bernewitz, Stout, Albes, Villefosse, Rittinger, Ullmann, Company Information

<u>OPERATING PRINCIPLE:</u>

Through the inparting of heat to the crucible, the gold-mercury-alloy is dispersed into its components at around 600°C and mercury is vaporized. In the condenser tube, the Hg-vapor condenses as droplets (counter-current cooling with water) and flows into a catchment vessel containing water (which prevents further evaporation).

<u>AREAS OF APPLICATION:</u>

For the separation of amalgam into mercury and the valuable metal (gold or silver)

<u>REMARKS:</u>

Due to the short utilization period of distillation processes, the distillation retorts should, when possible, be cooperatively purchased and used in order to more widely distribute the investment costs.

Retort constructions which are built from steel-pipe sections are comparatively inexpensive and lend themselves to mass production without major cost or effort.

In all types of retorts, extra care must be taken that fittings, valves or closures are air-tight.

In cases where amalgamating with open Hg-circuits cannot be eliminated, then efforts should be taken to encourage the gold buyer to purchase the amalgam instead of the processed gold. The amalgam could then be distilled in the presence of the mine operator, the gold weighed, and payment made.

Before distillation, the amalgam is wrapped in paper. The ashes of the burned paper form a non-adhesive intermediate layer between gold and the bottom of the retort. It would be better to dust the lining of the retort with a thin layer of graphite, limestone, gypsum or talc prior to inserting the amalgam so that the gold does not stick to the bottom of the retort following distillation. In no case should greasy or fatty substances be used; these evaporate with the mercury and Inactivate its surface.

If a retort is not tightly sealed, the leak can be sealed prior to distillation with a mass made of fine, moist clay mixed with ash applied at the fitting between the cover and the bottom. The clay may not contain any grains, however.

It could often be observed that the acceptance of distillation devices in small-scale mining in developing countries is relatively low. Even when retorts are already present, amalgamation is still performed in open Hg-circuits, first because this proceeds faster, and secondly because the color of the gold produced after evaporating the mercury in a ceramic crucible is lighter, and therefore brings a higher price from the buyers. These disadvantages can possibly be counteracted by lining the Inner surface of the retort with a highly corrosion-resistant material.

On the other hand, impurities in the amalgam are partly responsible for the discoloration. In small-scale mining in Ecuador, for instance, the gold concentrate is washed with the juice from sugar-cane oranges or lemons in order to complex silver and thereby increase the fine-gold content. Such impurities impart a black coating during air-tight distillation. A good washing of the concentrate or amalgam can remove these substances, which cause later discoloration, from the feed prior to distillation.

Finally, there are other amalgams, for instance amalgams of arsenic, antimony or copper, which cause impurities In the gold as well as in the Hg. Depending on the boiling temperature and the vapor pressure of the metal, these evaporate With the mercury during the distillation process, or remain as a crust on the gold. These amalgam impurities can be washed out before distillation. First, the amalgam is degreased using a milk of quick lime, then freed of iron chips, and finally washed with diluted hydrochloric acid.

In order to increase acceptance of disillation retorts in small-scale mining regions, the process can be demonstrated to the miners using glass retorts made of heatproof glass. These demonstrations would make the process understandable to the miners and remove their fears of allowing their gold or amalgam to be processed in a closed reactor. This type of retort could also be produced in developing countries by technically-qualified glass-blowers.

In constructing retorts, It is important that the condensation surface for the mercury is kept as small as possible. This minimizes the loss of mercury through cohesion of the finest beads on the inner wall of the retort. Therefore the cooling pipes should be of the least possible diameter, and must be made of iron or steel

pipe sections since brass amalgamates with mercury, The inside surface of the pipe must be smooth, and seams should always face upwards to avoid losses due to dripping. Nevertheless, about 2 - 5 g mercury always remain in the device which can only be recovered by washing. For this reason it is advantageous to always collect larger quantities of amalgam for distilling together in one operation.

During operation, the distillation retort must always be heated so that the entire crucible and its lid, as well as the rising portion of the vapor tube, become hot enough to prevent a condensation of mercury in this zone. Otherwise, this liquid mercury runs down again Into the deepest part of the retort and has to be revaporized.

Instead of amalgamating in a distillation retort, the distilling process is unfortunately often conducted in an open-circuit process involving open flat clay or ceramic bowls which are heated by means of blow torches, allowing the mercury to evaporate out of the amalgam. Highly toxic Hg vapors develop.

In Ecuador, a fresh banana leaf is placed over the bowl or crucible in order to recover part of the mercury escaping as vapor from the amalgam. Hg condenses on the surface of the leaf and collects at the edges. Colombian miners use orange peels or cabbage leaves for this purpose.

Besides distillation in retorts, there are also chemical methods for separating mercury from the amalgam. Among these is the analytical method of dissolving Hg out of the amalgam with (diluted) nitric acid. The transformation reaction occurs as follows:

$HgAu + 2\ HNO_3 \rightarrow Hg(NO_3) + Au + H_2$

After the precipitated spongy gold-residue has been separated from the dissolved nitrate, the mercury can be recovered through ion exchange with copper or other non-precious metals, with the copper nitrate being discarded. In using chemical separation methods, the danger exists with silver-containing gold ores that Ag gradually concentrates in the mercury, which consequently requires a periodic cleaning by distillation. The chemical reaction for mercury separation is:

$Hg(NO3)_2 + Cu \rightarrow Cu(NO_3)_2 + Hg$

Mercury losses through distillation in retorts are very minimal (< 0,1 %).

WARNING!!!

The separation of the amalgam in the atmosphere is endangering to life and toxic to the environment (Hg-vapors).

In all distillation retorts, care must be taken that, upon completion of heating, no water is sucked in which can penetrate inside the crucible during cooling. This can lead to an explosion of the still-hot crucible due to sudden evaporation. This danger can be prevented through the use of water sacks or similar devices, or by maintaining a minimal distance between the suspended cooling pipe and the catchment bucket.

SUITABILITY FOR SMALL-SCALE MINING:

For economic and especially ecological and health reasons, every amalgamation

plant should, without exception, amalgamate in closed mercury circuits, i.e. employ distillation retorts.

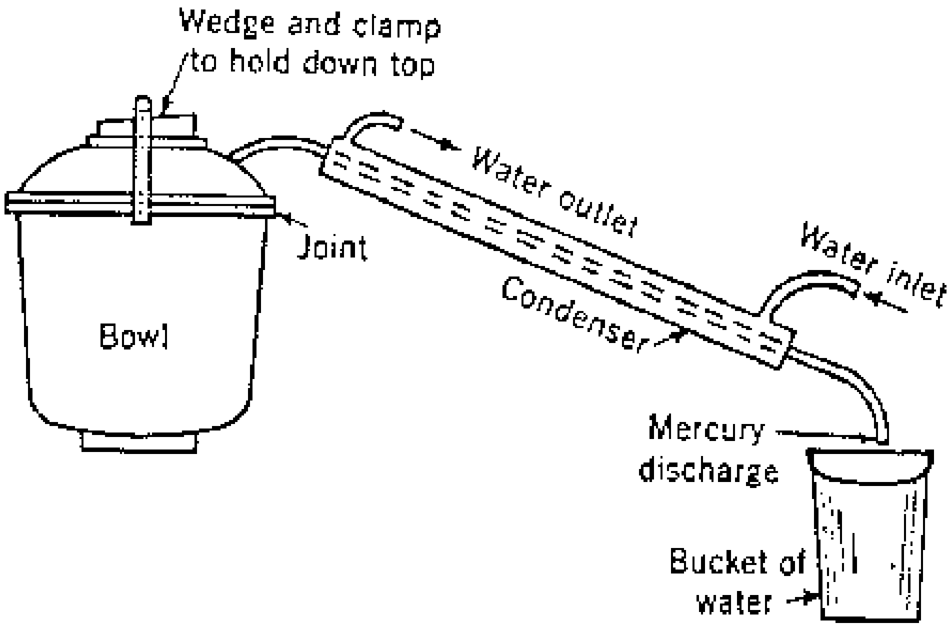


Fig.: Design drawing of distilation retort. Source: Bernewitz.

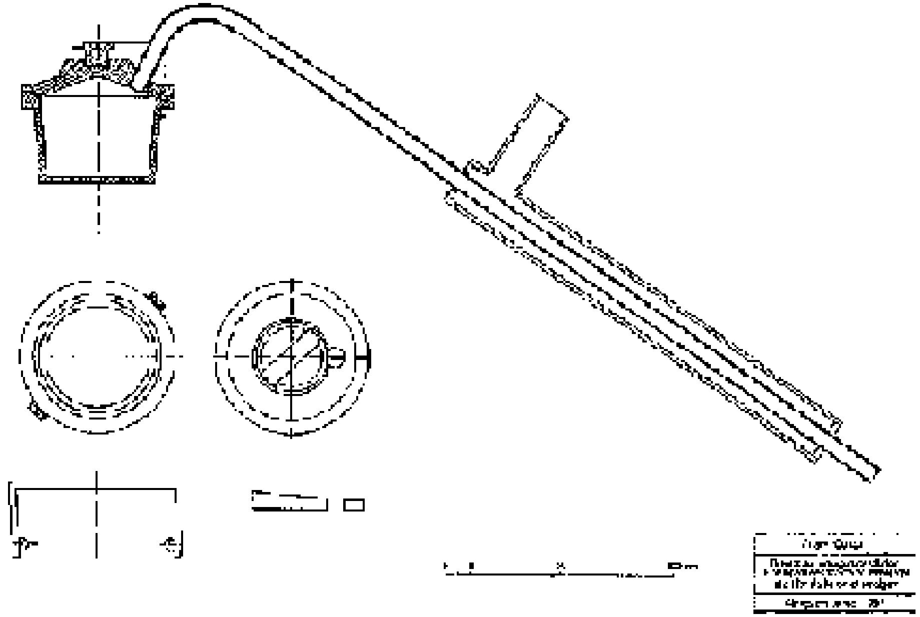


Fig.: Retort for amalgam distillation, designed by Proiekt-Consult,made in Colombia.

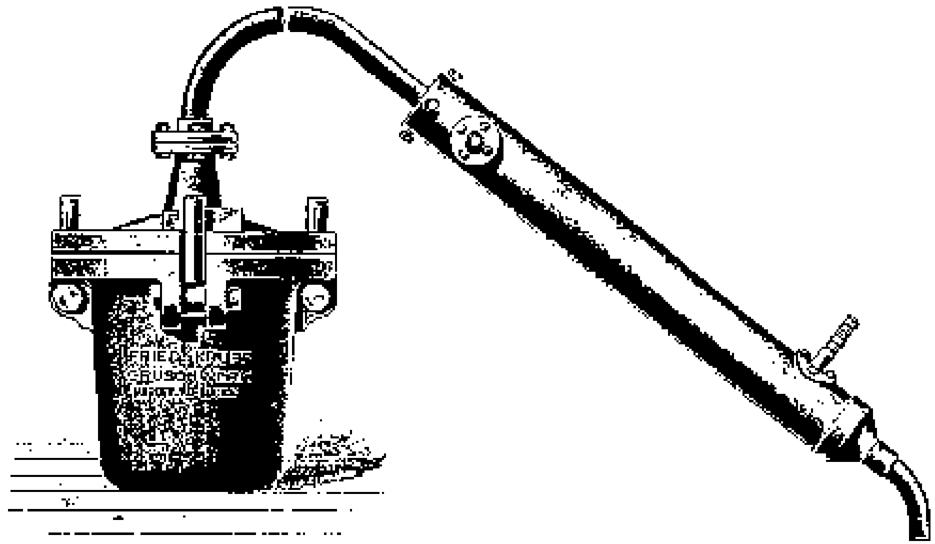
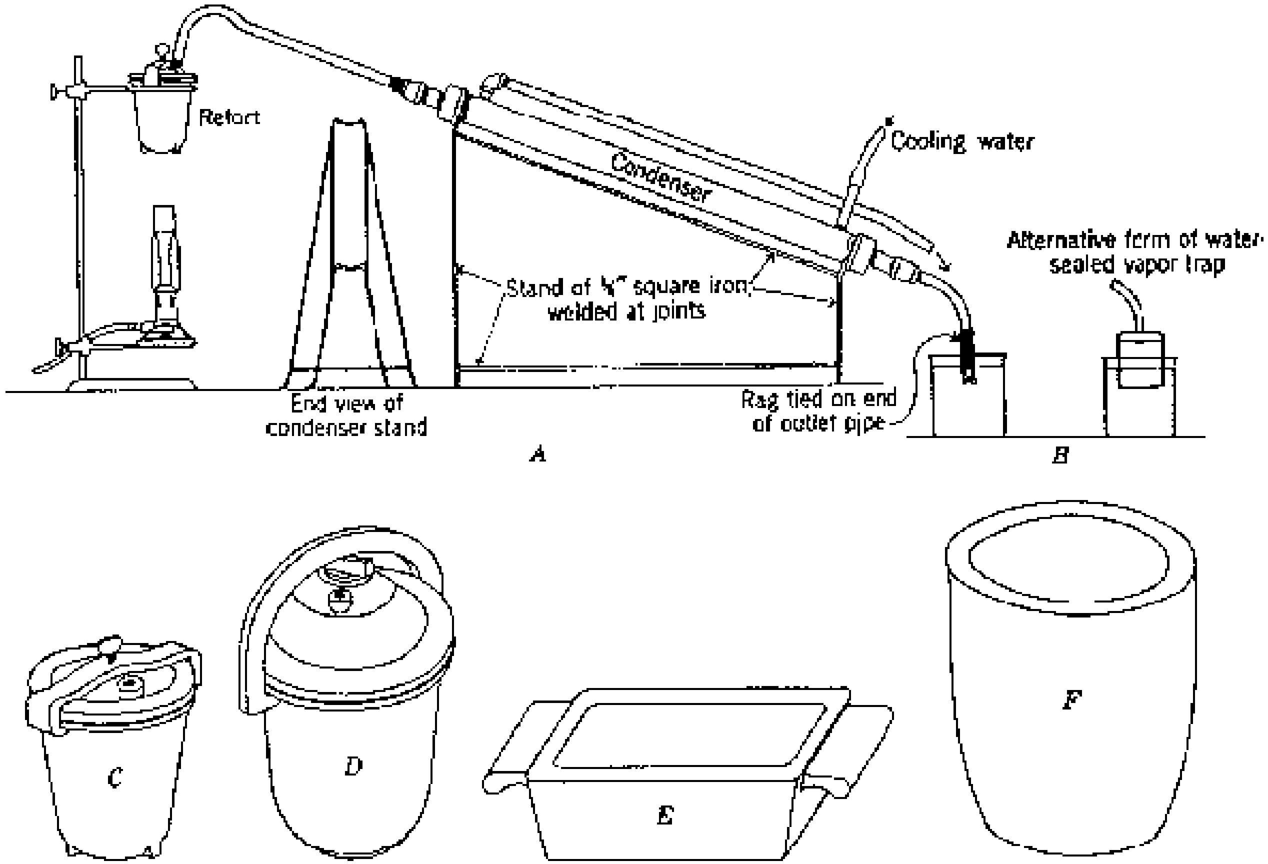


Fig.: Retort for distilation of amalgam. Source: Ulsar.



APPARATUS FOR RETORTING AMALGAM AND QUICK SILVER

Plate 6-5

Fig.: Types of retort constructions for distillation. Source: Stout.

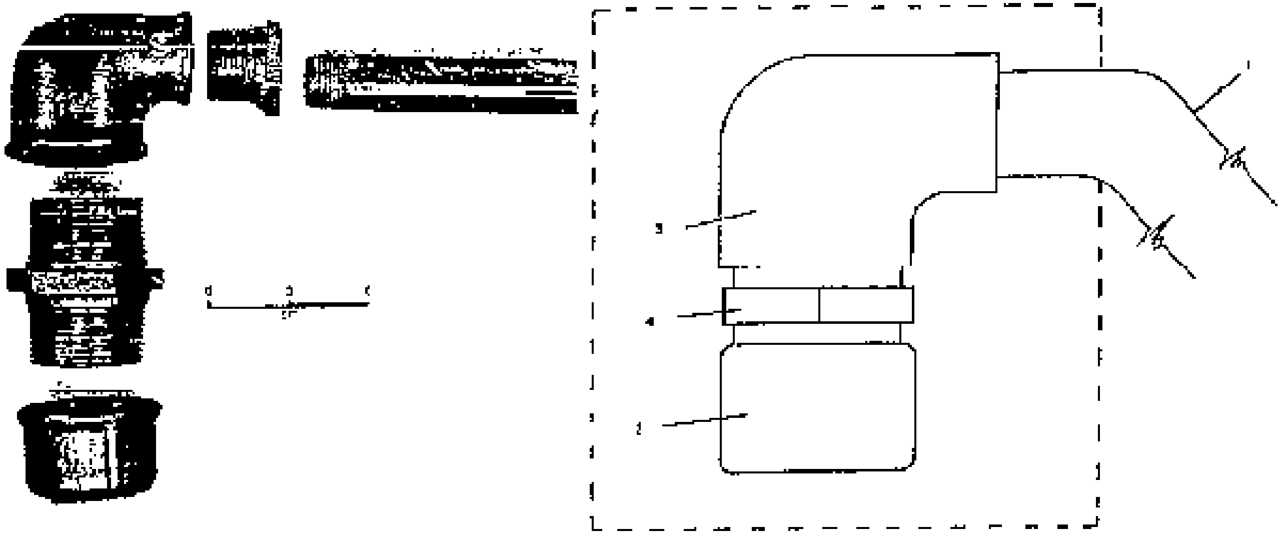


Fig.: Simplest retort made of standard pipe joints, threaded couplings and pipe sections. Source: Apropriate Technology

Figure 1. The Hypolito retort or RHYP (above)
Figure 2. The condensation tube (1), tampion (2), elbow (3), and double nipple (4), wich together make up the retort (below).

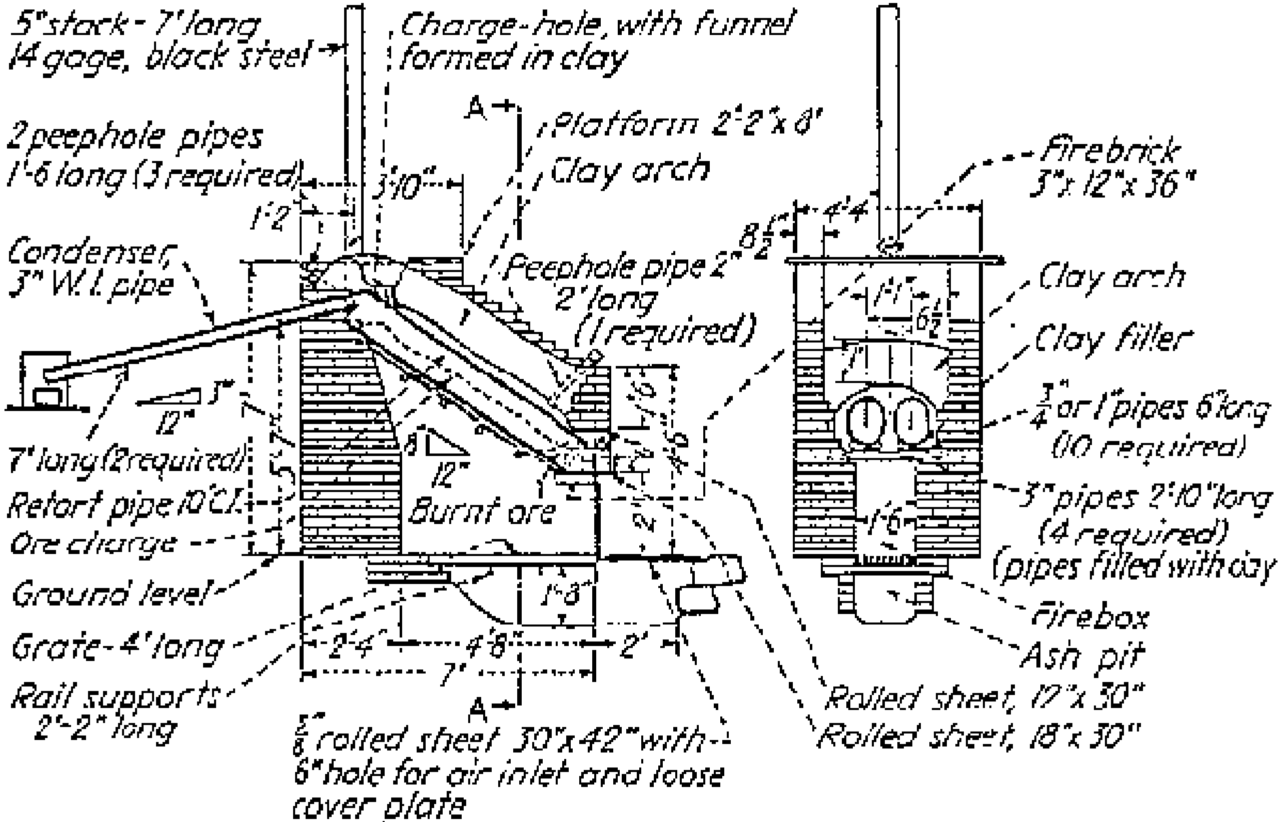


Fig.: Design sketch of a distillation retort made of pipe sections. Source: Bernewitz.

15.8 Centrifugal separator

Gold Mining
Beneficiation, Gold Beneficiation

engl.:	Knelson concentrator, Knudson bowl
germ.:	Zentrifugalscheider
span.:	concentrador centrifugo, Knelson concentrador, Knudson bowl

Manufacturers: Knelson International Sales Inc., Mineral Deposits, Steve and Duke's Manufacturing Co. or Lee-Mar Industries Ltd., Goldfield, Falcon Concentraters, FUNDEMIN, VARDAX, Met Lacha, INCOMEC

TECHNICAL DATA:

	Knelson 7.5"	**Knelson 12"**	**Knudson**
Dimensions LWH	33" × 22" × 26"	31" × 31" × 34"	~ 860 × 760 × 585 mm
Weight	117 kg	154 kg	172 kg (without motor)
Driving Capacity	3/4 PS	1 PS	7.5 PS
Throughput	650 kg/in	5 m^3/h	3 - 4 t/h
Quantity of Concentrate	1.5 kg	5 kg	
Slurry	17 gal/min	30 gal/min	
Backwater Quantity	20 gal/min	35 gal/min	-
Backwater Pressure	2 - 3 bar	aprox. 4 bar	-
Washing Water			
Maximum Grain	< 4 mm	< 4 mm	< 4 mm
Minimum Grain	> 30 µm	> 30 µm	50 - 70 µm
RPM	~ 400	100 - 400	100 - 105

Centrifugal acceleration	60 g		
Separation Cut-off			
Mode of Operation	semicont.	semicont.	discont.
	Falcon B 12	**Falcon B 6**	**Vardax 801**
Dimensions LWH	36" × 60" × 73"	19" × 20" × 32"	72" × 18" × 24"
Weight	800 kg	100 kg	110 kg with classifier
Driving Capacity	7.5 PS	1.0 PS	2 PS
Throughput	~ 6 t/h	0.5 t/h	- 2 t/h
Quantity of Concentrate	- 4.5 kg	~ 1 kg	~ 80 kg
Slurry		7 - 12 gal/min	
Backwater Quantity	-	-	
Backwater Pressure	-	-	
Washing Water		5 gal/wash	2 gal/wash
Maximum Grain	< 1.5 mm	< 0.9 mm	< 6 mm
Minimum Grain	> 30 µm	> 30 µm	
RPM			

Centrifugal acceleration	300 g	300 g	
Separation Cut-off	4 g/cm³		
Mode of Operation	discont.	discont.	discont.
Extent of Mechanization:	fully mechanized		
Form of Driving Energy:	electrical, optional internal combustion engine, possibly convertable to hydromechanical drive with difficulty		
Technical efficiency:	concentration up to more than 1: 8000; comparatively very high recovery with well-liberated free gold		

ECONOMIC DATA:				
Investment Costs:	Prices from original manufacturer fob factory:			
	Knelson 7.5":	6850 US$	Knelson 12":	12500 US$
	Knudson:	4500 US$	Falcon B 12:	34000 US$
	Falcon B 6:	7000 US$	Vardax 801:	2400 US$
	Vardax Sec.:	14500 US$		
Operating Costs:	cost of energy and minimal labor costs			
Related Costs:	possibly costs for thickener, sedimentation basin or sludge pond			

CONDITIONS OF APPLICATION:

Operating Expenditures:		low |—————|—————| high
Maintenance Expenditures:		low |—————|—————| high
Location Requirements:	water	
Grain Size of Feed:	< 6 mm	
Special Feed Requirements:	the feed may only contain a small proportion of clay minerals or partly-consolidated sediments, since these envelope the gold and, due to their consistence, prevent it from existing in a liberated state.	
Output:	According to the manufacturers, approx. 95 % free Au up to grain size > 500 mesh (approx. 30 ym). Mineral Deposits lists 50 - 70 µm as the lower grain-size limit for Knudson centrifuge. BGR in Burundi with Knelson concentrator, 95.5 % recovery, 0.63 - 0.063 mm grain size.	
Replaces other Equipment:	sluices	
Regional Distribution:	rare	
Operating Experience:		very good |—————|—————| bad
Environmental		low |—————|—————| very high

Environmental Impact:	low |————|————| very high
Suitability for Local Production:	verygood |————|————| bad
Lifespan:	very long |————|————| very short

Bibliography, Source: Beyer, Hersteller, BGR

OPERATING PRINCIPLE:

Knelson:

Centrifuge with radial acceleration up to 60 g. Slurry is fed through a pipe at the deepest point of the centrifuge and rotated in circular grooves within the drum. Counter-current water flow is forced into the circular grooves from the outside which loosens the material, similar to a fluidized bed. Light material flows over the wall into the next higher circular groove.

Knudson:

The similarly-built Knudson centrifuge operates without a counter-current flow, which greatly simplies the construction. Instead of the water, a vertical blade within the rotating drum assists in spinning the material In the circular grooves, leading to a purification of the concentrate material.

Falcon:

The Falcon centrifuge is comprised of a vertically rotating cylinder with a partially

cone-shaped inner surface. A central slurry feed-intake pipe directs the suspended solids onto the rotating feed-intake disk. Under the influence of centrifugal acceleration, the material migrates outward onto the upward-widening conically-formed centrifuge wall. This effectively results in a radial density-sorting of the slurry in which the heaviest particles remain adhered to the smooth wall. The light material flows over the top of the upper cylindrical portion of the centrifuge and is carried out. A ring-formed zone of concentrate with a wedge-shaped cross-section develops. After cessation of feed input, this concentrate is washed off with supplementary rinsing water, whereby the solid materials between the feed-intake disk and the wall of the centrifuge are flushed through the hollow axis into a receptacle for collecting the concentrate.

AREAS OF APPLICATION:

Sorting of feed material containing high proportions of fine gold, specifically alluvial gold.

SPECIAL AREAS OF APPLICATION:

In addition to its application in gold deposits, the profitable winning of by-products with the Knelson centrifuge is also possible in some cases, such as obtaining gold from gravel pits or heavy industrial minerals from kaolinite deposits. The very high throughput capacity of the Knelson centrifuge concentrator allows it to be integrated directly into the processing circuit.

Knudson centrifuges have also been used in some instances for amalgamating.

REMARKS:

In Brazil, Knelson centrifuges have already been manufactured locally. A problem encountered with local production is the centrifuge bearings; worn bearings must be taken up or replaced if necessary.

It is extremely important that the feed material to be centrifuged is completely liberated or suspended prior to processing in the centrifuge. Clay-like sediments or gold occurring in laterites require a partially expensive pre-processing before sorting by centrifuging. Mineral components in the feed which have very heavy specific densities, particularly arsenic gravel, are also recovered with the concentrate. If the proportion of these minerals is very high, the separation accuracy of the centrifugal sorting is impaired.

The product of the centrifuge is a pre-concentrate which then requires subsequent cleaning (purifying) either by amalgamating, leaching or similar processing.

The counter-current water flow of the Knelson centrifuge must consist of clear water, otherwise the fine perforations in the centrifuge shell could become clogged, and consequently the centrifuged material in the circular grooves could not be loosened. Furthermore, it is absolutely necessary that the water pressure be kept constant, since even negligible increases in pressure can result in fine-grained concentrate, especially particles of high specific surface area, being carried out in the overflow. Likewise, the flow of feed should not be interrupted. These difficulties with process regulation do not arise in simply-designed centrifuges.

On account of their simple construction, Knudson concentrators and possibly Falcon centrifuges are quite suitable for local manufacturing.

In comparind fluid-bed centrifuges (Knelson) to simple centrifuges, Knelson has the advantage of being able to recover significantly smaller grains of the precious metals and achieving a higher degree of concentration, as a result of the fluidized-bed structure. Whereas the Knelson concentrator can operate continuously for many weeks and, as a result, yields high concentrations of gold, the construction of simple centrifuges allows these to operate semi-continuously with only brief pauses and to produce comparatively larger amounts of pre-concentrate (for example, turbulence can be generated in the Knudson centrifuge only very incompletely and the sorting barrel rotates at lower rpm).

SUITABILITY FOR SMALL SCALE MINING:

The Knelson centrifuge is a very suitable apparatus for winning even the finest fractions of gold from alluvial deposits. Despite relatively high investment costs and the necessity to import the equipment, the investment is amortized relatively quickly through the income from the high recovery of the gold fines. Suitable deposit characteristics are a prerequisite for successful application.

Simple centrifugal separators are, especially when they can be manufactured locally, the most suitable for small-scale mining due to their sturdier, simpler construction.

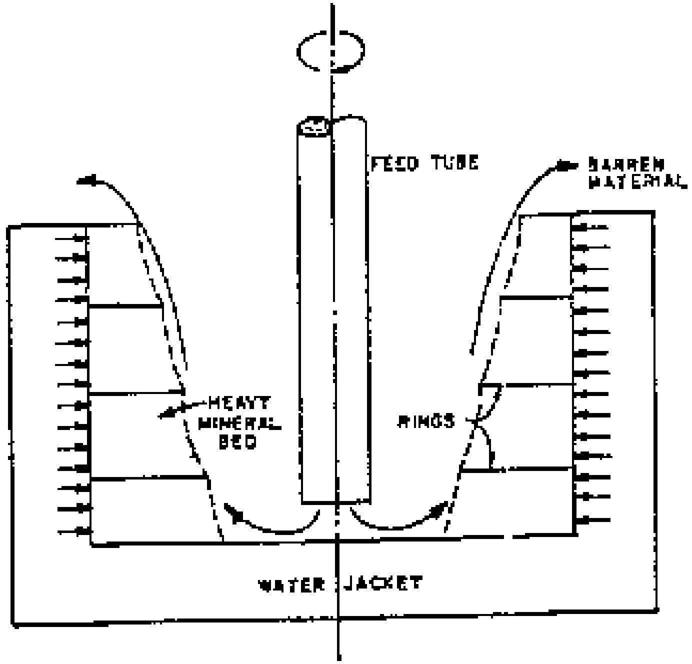


Fig.: Schematic cross-section diagram through the centrifuge of a Knelson concentrator. Source: Knelson.

15.9 Gold pan, batea

Gold Mining
Beneficiation, Gold Beneficiation

germ.:	Sichertrog, Waschpfanne, Schiffchen, Niersch, Saxe
span.:	batea, chua, challa, prune, zuruca (v.), sarten lavador, batea en forma de bote
Southeast Asia:	dulong, dulang

Manufacturers: Krantz, Keene

TECHNICAL DATA:	
Dimensions:	20 50 cm 0, 5 - 25 cm depth / 15 × 15 × 150 cm HWD / ca 45 - 50 cm diameter, 10 cm depth, 35°- 40° inclination (USA)
Weight:	0,5 - 5 kg
Extent of Mechanization:	not mechanized
Form of Driving Energy:	manual
Mode of Operation:	intermittent
Throughput/Capacity:	cat 1 - 5 kg/mini daily performance 100 pans at 20 lbs = 1 t/d
Operating Materials:	
Type:	water
Quantity:	small (can be used in non-flowing water)
ECONOMIC DATA:	
Investment Costs:	approx. 10 to 20 DM
Operating Costs:	labor costs only
Related Costs:	none

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |————|————| high

Maintenance Expenditures:		low |————|————| high
Personnel Requirements:	lots of experience is essential for accurate sorting with high recovery	
Grain Size of Feed:	< approx. 30 mm	
Special Feed Requirements:	free Au as valuable mineral or valuable mineral with very high density	
Recovery:	high, also in the fine grain-size range (lower grain-size limit 20 µm), flakes (flour gold) down to 50,um are recoverable in the gold pan	
Regional Distribution:	worldwide	
Operating Experience:		very good |————|————| bad
Environmental Impact:		low |————|————| very high
Suitability for Local Production:		very good |————|————| bad
Under What Conditions:	simple wood manufacturer or sheet-metal workshop for trays made of galvanized sheet metal	
Lifespan:		very long |————|————| very short

Bibliography, Source: Treptow, Schnabel, Agricola, Calvor, Ramdohr, Lepper, Clennell, Silva, Treptow Collection/Freiberg

OPERATING PRINCIPLE:

Through shaking of the pan, gold settles at the deepest point on the pan's bottom. During washing, the tray is moved in such a way that the middle and deepest part, containing the heavy gold particles, remains almost stationary and the lighter tailings, carried along by the flowing water and subject to the radial acceleration forces near the pan's rim, are discharged. This procedure is repeated until only the gold or the black gold-containing sands remain. The final step performed by the gold penner is to slightly tip the pan and lightly knock on the back of the rim in the direction of inclination. This resembles the bumping-table effect whereby the gold accumulates at the highest point of concentrate fan.

AREAS OF APPLICATION:

- **for analysis in almost all beneficiation processes**
- **for sorting of pre-concentrates, for instance, from sluices**
- **for sorting of gold-containing alluvial deposits**
- **for semi-quantitative analysis of contents exceeding around 10 g/t**

REMARKS:

Gold pans are manufactured from various materials, such as:

- **metal**

- **wood**

- half-shell or rind of pumpkin, squash or melon

- PVC

- animal horn (poruna), historically from Argentina and Mexico (bull horn); still being used in arid mining regions in Chile

- rubber (car tires)

The best have proven to be those made of black PVC:

Advantages:	- cracks do not develop	Disadvantage:	- the surface repells water
	- good gold visibility		
	- durable and long-lasting		
	- light weight		

Chromite or ilmenite sands are recommended as contrast medium (added to the raw material)

Gold tends to undergo flotation. 1 or 2 drops of detergent added to the water, or often also sap from plants (e.f. sisal, spanish: fique) can prevent flotation.

Panning was already described by the Swede Peter Mansson who died in 1536.

The number of individual particles per ounce of gold depends upon the grain size:

small nuggets 10 - 20 mesh: 2200/oz.

big flakes	20 - 40 mesh:	12000/oz. gold
fine flakes	< 40 mesh:	40000/oz.

The minimum particle size visible with the naked eye in a black pan is around 20 ym

The lower limit for manual removal of gold particles is 1 - 2 mm, smaller particles require amalgamation or leaching.

Gold pans are often clearly different in their design depending upon the type of feed to be processed: gold pans used In alluvial deposits are generally significantly flatter (shallower) than those pans used in vein ore mining.

For hand-sorting of fine pre-concentrates, small spray bottles with thin elongated nozzles for sucking up the grain are preferred.

In gold mining in Ecuador, for example, amalgamation is also performed in gold pans. The gold is worked in with a stone for about an hour, after which the mercury, divided into fine beads, is recombined by knocking on the rim of the gold pan. The finest beads, or floured mercury, cannot be refused, due in part to the high surface tension of the mercury or encrustations of fine oxidic mineral dusts, and is carried off and released into the environment during washing of the amalgam. For this reason, this procedure must be considered extremely dangerous and should not be used.

In large-scale facilities, the surface tension of the mercury is relieved by adding cyanide or nitric acid, or less frequently sodium amalgam, caustic soda or

ammonium chloride. This is not possible when processing in a gold pan.

SUITABILITY FOR SMALL-SCALE MINING:

Gold pans are used in small-scale mining because of their high degree of separation in all areas of application (prospecting, exploration, analysis during processing, and beneficiation); their use is indispensible. In beneficiation they are primarily employed for cleaning of pre-concentrates. They are characterized by very low throughput quantities and investment costs.

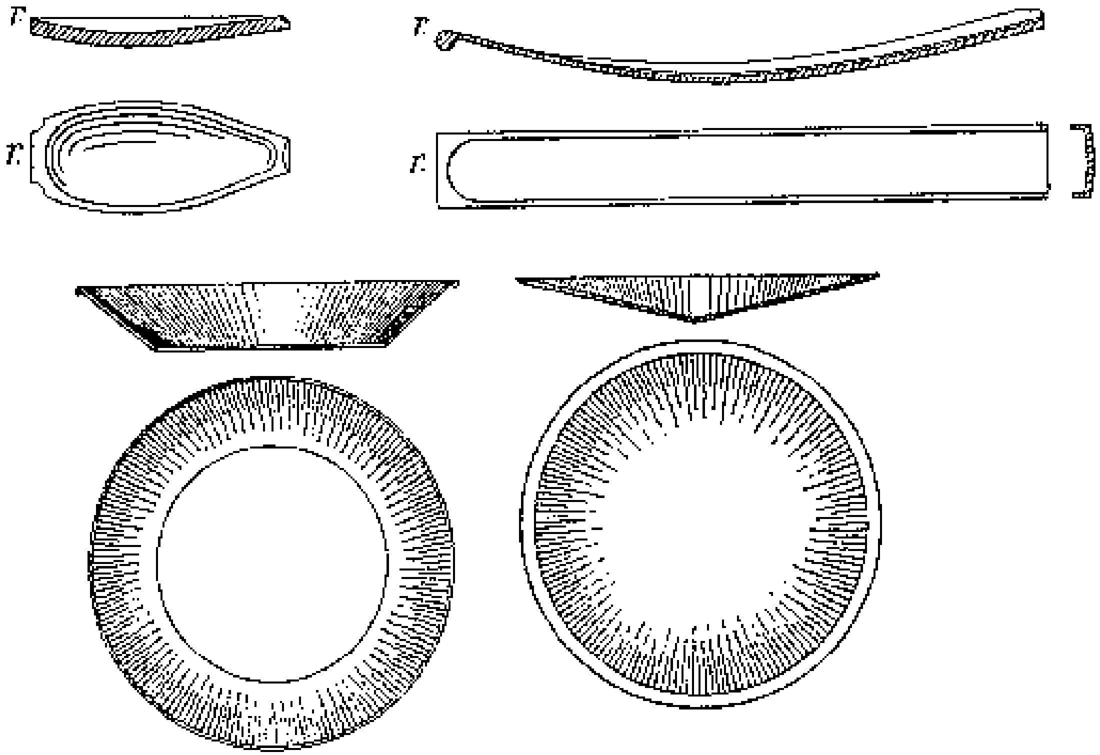


Fig.: Different types of gold pans, above left: "Freiberger" pan, above right: "Salzburger" pan, below left: North American from, below right: Latin American form. Source: Treptow (above) and Schnabel (below).

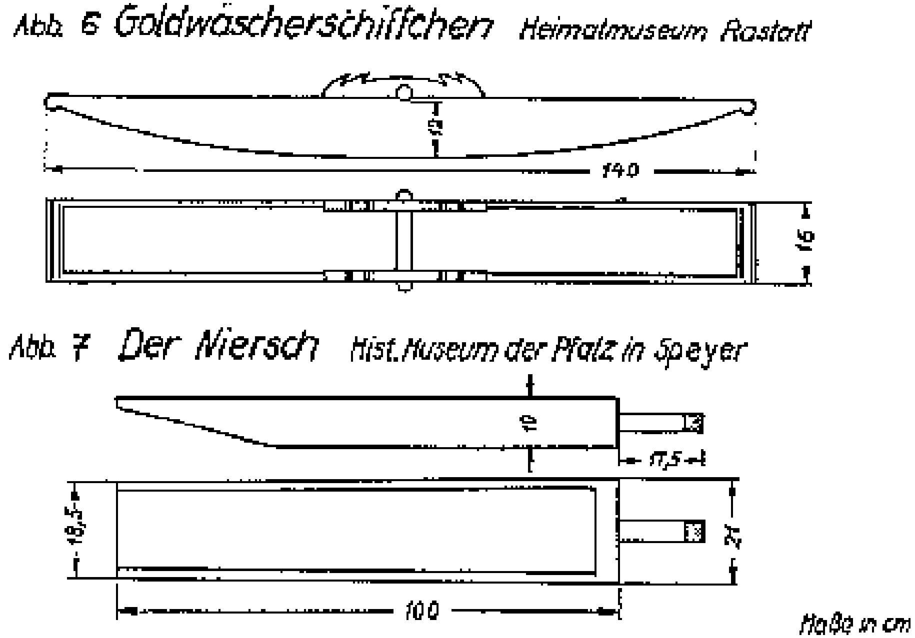


Fig.: Gold pan designs form the Rhine gold mining region (Germany). Source: Lepper.

15.10 Jigs with jig bed, russel jig

Gold Mining
Beneficiation, Gold Beneficiation

germ.:	Setzmaschinen mit Setzbett
span.:	jig con came de boles de promo
Manufacturers:	Mineral Deposits, Denver, IHC Sliedrecht, Goldfield

TECHNICAL DATA:

Dimensions: from 1 × 0,75 × 1 m up to 3,60 × 3 × 3 m LWH with 0,5 × 0,2 m (2

	jig beds) up to several m jig bed sizes
Weight:	from 50 kg
Extent of Mechanization:	fully mechanized
Throughput/Capacity:	4 - 65 t/h
Form of Driving Energy:	electric
Power/Performance:	0,5 to several kW, 50 - 300 thrusts/minute, approx. 25 mm lift
Alternative Forms:	with internal combustion engine, possibly even manual operation for small machines
Operating Materials:	
Type:	lead balls grease
Quantity:	8 - 10 DM/kg

ECONOMIC DATA:

Investment Costs:	from approx. 3000 DM when locally produced
Operating Costs:	mainly costs of energy and labor

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |————|————| high
Maintenance Expenditures:	low |————|————| high
Location	water must be available

Requirements:	
Grain Size of Feed:	50 ym - 2.5 mm gold grain-size fraction is recovered; nuggets larger than 2,5 mm are concentrated on the screen bottom underneath the jig bed.
Special Feed Requirements:	gold must exist as liberated free gold
Replaces other Equipment:	troughs, sluices, other Jigs, Gold Saver
Regional Distribution:	available on the world market, widespread in gold mining in Australia, Indonesia
Operating Experience:	very good |—————|—————| bad
Environmental Impact:	low |—————|—————| very high
Suitability for Local Production:	very good |——————————| bad
Under What Conditions:	possibly as manual jig or jig with pedal-drive, can be entirely produced by local metal manufacturing shops. For motorized jigs, imported drive units are mostly used.
Lifespan:	very long |—————|—————| very short

Bibliography, Source: Manufacturer's information, Silva, Schubert, Horway

OPERATING PRINCIPLE:

The Russel Jig with Jig bed for processing gold is a two-staged diaphragm Jig with an internal double-action diaphragm membrane. In comparison to conventional Jigs, this type of construction substantially reduces the drive-power required. The pulsating water flows through a coarse screen mesh of, for example, 1.6 mm wire thickness and 2.5 mm screen openings. A Jig bed, consisting of lead balls (SPb approx. 11.3 g/cm³), rests on the bottom of this screen; the lead ball diameter of 4.1 mm has been dimensioned to correspond to the screen openings. Thereby, the Jig bed, which settles onto the screen bottom in the densest volumetric arrangement, is capable of completely closing the screen openings, resulting in higher separation precision and lower quantities of concentrate. The jig's pulse frequencies can be regulated between 50 and 300 min-1. Similarly, the pulse width and the quantity of supplementary water added can also be regulated. The addition of water occurs in the Jig bed above the screen. In this respect, jig types which operate with a constant water quantity (with suction) are differentiated from those in which water is added only during the respective suction-stroke of the diaphragm (without suction). The later is accomplished by regulating with a rotary piston valve.

AREAS OF APPLICATION:

Jigs of the above-described design are used to produce concentrates from alluvial gold or platinum ores. For larger quantities of feed material, the jig is used initially to achieve pre-concentrates, which are then refed into the jig for secondary processing to yield concentrates. Smaller feed quantities are jigged only once and then subsequently processed in an amalgam trap for secondary cleaning or to produce final concentrates.

SPECIAL AREAS OF APPLICATION:

Jigs with jig beds, or Russel jigs, are standard components of mobile pilot-scale beneficiation plants and small mobile production units.

REMARKS:

The simple construction and low specific-energy requirement of the diaphragm jig with Jig bed (Russel Jig) appear to support local production of a manually or pedal-driven Jig of this type. Jig bed size in the order of 2 × 40 × 20 cm should still permit manual operation.

Modern Russel jigs are of modular construction, consisting of several units. These are fashioned from circular segments which are assembled into a round unit. This has the advantage that, with a relatively simpler central feed input, large quantities of feed material can be processed and sorted. The geometry of the jig bed causes the cross-flow to become relatively smaller toward the rim, which increases the processing duration and therefore separation precision.

By modifying the bed material (balls of lighter specific-density), these fine-grain Jigs can also be used for winning well-classified tin or tungsten ores.

The thickness of the jig bed is determined by the granulation of the feed material: for coarse feed, the bed should be 7 to 12 times thicker than the upper grain-size of the concentrate, and for finer feed (< 2 mm) about 20 times the maximum grain-size. The diameter of the bed grains should be 3 to 4 times that of the upper grain-size in the concentrate.

If a Jig is operated with suction, fine fractions are quickly and accurately drawn through the processing, while coarse fractions migrate only very slowly through the jig bed and screen mesh. In jigs run without suction, the effect is reversed.

If several consecutively-arranged jig beds are used, the grain sizes of the jig-bed particles increase In the direction of feed input.

The length of duration of feed material in the jig can be varied by changing the ratio of cross-current flow: quantity of supplementary water.

The use of a heavy-material trap, such as a riffled sluice, installed in the light-material discharge outlet in the Jig bed is highly recommended for the recovery of jig-bed material which has been undesirably flushed out.

The large diaphragm dilations can be achieved by using a rubber car hose as the membrane element The complicated insertion of the diaphragm connecting-rod through the jig's settling-box wall can also be accomplished with the help of a locally-available standard part, namely the bellow which covers the gear-shift-lever slot in a car, which can be used to seal the opening around the rod.

As bed material for locally-manufactured jigs, lead buckshot (for hunting purposes) can be used, which is freely sold on the market in developing countries.

The concentrate or underflow valves in the jig bed should always be slightly open during operation and the concentrate continuously discharged in order to avoid sedimentation and clogging of drain outlets.

SUITABILITY FOR SMALL-SCALE MINING:

Jigs with Jig beds for producing gold pre-concentrates at high factors of concentration with comparatively high throughput are very appropriate for small-scale mining; they require, however, a motorized drive system.

15.11 Gold leaching

Gold Mining
Beneficiation, Gold Beneficiation

engl:	cyanide leaching, (agitation leaching, vat leaching, heap leaching)
germ.:	Goldlaugung, cyanidische Laugung (Ruhrlaugung, Behalterlaugung, Haufenlaugung)
span.:	lixivacion de oro, lixiviacion, lixiviacion con cianuro (lixiviacion por agitacion, lixiviacion en tanques, lixiviacion en piles)
Manufacturers:	HBS-Equipment (cell for electrolytic + absorptive separation), Denver

TECHNICAL DATA:	
Dimensions:	leaching tanks several m³ in volume
Weight:	brick masonry basins
Extent of Mechanization:	fully mechanized
Mode of Operation:	semi-continuous, continuous
Power:	varies according to type of leaching procedure chosen, from 100 W for small percolation leaching plants (pump drive) up to several kW for larger

	agitation-leaching plants
Form of Driving Energy:	electric drive for pumps and filter
Technical Efficiency:	three various categories of efficiency are differentiated: leaching efficiency, adsorption efficiency (= f (activated carbon quality, etc.)), stripping efficiency (degree of stripping does not influence processing results if activated carbon is reused in the circuit because gold is not lost in the process) the sum of the different efficiencies leads to recovery values which lie at approx. 90 - 95 % for agitation leaching, approx. 80 - 90 % for vat leaching and ca 50 - 80 % for heap leaching.
Operating Materials:	
Type:	sodium cyanide (NaCN) or calcium cyanide/black cyanide ($Ca(CN)_2$)
Quantity:	Concentration: 1 - 5 kg/t (ave. 1,5), Consumption: up to 8 kg/t, compressed air, CaO, Zn and $PbNO_3$ or activated carbon
ECONOMIC DATA:	
Investment Costs:	for small percolation-leaching plants only minimal costs for the masonry construction of leaching basins, precipitating basins and leach collection containers, totalling approx. 1000 DM depending upon cost of materials. For industrial-scale plants, (e.g. CIP - carbon-in pulp process) costs are extremely high at 1.000.000 DM minimum.
Operating Costs:	high costs due to consumption of reagents, approx. 50 % of operating costs are for cyanide; also energy-intensive technique, especially the

	Merrill-Crowe-Procedure
Related Costs:	costs for sludge ponds, especially in leaching facilities where finely-ground ores are processed

CONDITIONS OF APPLICATION:

	heap leaching
Operating Expenditures:	low |————|————| high
	CIP
Maintenance Expenditures:	low—|high
Personnel Requirements:	depends on type of leaching of extreme importance is a precise control of the process, especially with regard to the homogeneity of concentrations, feeds and slurry characteristics
Location Requirements:	very high space requirements for heap leaching
Grain Size of Feed:	< 0.1 mm for agitation leaching; <10 mm for vat leaching of 2 - 4 day duration; < 50 mm for heap leaching of 3 - 6 week duration
Special Feed Requirements:	minerals of arsenic, antimony, manganese and especially soluble oxidic copper, which are extremely deleterious and cause high cyanide consumption, high gold losses in organic CH-bonding, graphite, etc., require the use of CIL (carbon-in-leach process). Pyrrhotine (magnetic pyrite) is also a detrimental mineral: it binds cyanide ions and consumes oxygen

	during decomposition.
Replaces other Equipment:	all other methods of cleaning pre-concentrate in gold beneficiation, e.g. manual sorting, amalgamation, gravimetric processes, smelting
Regional Distribution:	worldwide more than 70 % of all gold is won by leaching. Cyanide leaching, however, is cost intensive, difficult to control and involves complicated technical equipment, restricting its application to large-scale mining operations.
Operating Experience:	very good |—————|—————| bad
Environmental Impact:	low |—————|—————| very high
	The dangers associated with leaching operation lie in the possibility of cyanide being released as a result of leaks, haphazard handling, etc. Cyanide is highly toxic; only trained personnel should operate leaching operations to ensure safe use; large space requirements heap leaching
	heap leaching
Suitability for Local Production:	very good |—————|—————| bad
	CIP
Under What Conditions:	for small percolation leaching plants, the simple brickwork provides very good possibilities for local construction
Lifespan:	very long |—————|—————| very short

Bibliography, Source: Krone/Erzmetall (German publication), Ullmann, Rollwagen

in Erzmetall 41/2, Beyer, Bugnosen, DE 3429458 Al, Seeton, Meza S.

OPERATING PRINCIPLE:

Agitation leaching

The cyanide gold leaching exploits the ability of gold to build soluble cyanide complexes. Specifically, the ore is subject to the following procedure: After grinding of the raw ore to < 0,1 mm, the resulting slurry is treated with CaO as lime milk to bring the pH-value to around 10 · 11,5 and then thickened to 40 - 50 % solids (by mass). Sodium cyanide is added to the slurry in the agitation tank at a concentration of 100 ppm NaCN; the solids are held in suspension either by means of a stirrer or by injected compressed air (In Pachucas). At a pH-value of between 10 and 1 1,5, at which point the dissociation balance shifts In favour of the cyanide ions, the following chemical reaction takes place:

$$2Au + 4NaCN + 1/2\ O_2 + H_2O \rightarrow 2NaAu(CN)_2 + 2NaOH$$

The leaching duration lasts between 12 and 24 hours, producing solutions containing gold. concentrations of about 4 - 6 ppm.

Vat leaching

In vat leaching, pre-crushed or agglomerated ores in containers (vats) are flooded with a cyanide leaching solution of specified pH-value. The leaching process proceeds analagous to the above-described chemical process. At the end of the exposure time, a clear leachate solution is withdrawn through a filter tube.

Percolation leaching

Tailings derived from gravimetric beneficiation processes are often leached by percolation leaching. Large open tanks (of up to more than 100 m in volume) are equipped with a leachate outlet on the bottom, sometimes constructed as a double bottom with filter cloth or gravel. These tanks are filled with the ores to be leached, the leachate solution is alternately added and then allowed to seep down through the ore: the trickling speed should exceed 8 - 10 cm/h; rates below 2 cm/in are very disadvantageous, and indicate that the feed material requires prior desilting or desliming. After sprinkling of the leachate solution, the solution level sinks to the bottom, during which air and therefore oxygen for oxidation penetrate into the ore layer. This process is repeated daily for the duration of leaching, which ranges from a few days to more than a month.

The leachate can be added in varying concentrations, that is: first, highly concentrated, then less concentrated, and later as washing leachate.

Heap leaching

Depending upon the leachability, coarsely-crushed ore is placed onto a leakproof basin on the ground which has been sealed with clay, asphalt and/or a tarp covering. The ore is then doused with leachate solution. Upon completion of the leaching process, a clear gold-containing cyanide complex solution is drawn off.

Depending upon the nature of the gold-cyanide complex solution, various methods can be used for further processing:

For clear solutions:

- In the Merrill-Crowe Process the solution is separated from unsoluble components in a cloth-lined vacuum filter or a suspended filtering candle and is completely deaerated with a vacuum cylinder (otherwise oxidation occurs in subsequent steps which leads to high gold losses). The oxygen concentration is consequently reduced to about 0.5 mg/l. Following the addition of zinc dust and lead nitrate solution (from local elements), the cementation of the gold takes place according to the following reaction:

$$2\ NaAu(CN)_2 + 2Zn \rightarrow 2\ Au + Na_2[Zn(CN)_4].$$

Gold and excess zinc are filtered through a filter press (the cyanide solution is re-circulated), and the solid materials are then treated with diluted sulfuric acid in order to wash out the excess zinc. The gold slime is then calcined at approx. 800° C and subsequently melted at 1200° C with borax and silicate fluxing agents.

- A significantly simplified variation, however associated with higher gold losses, is the zinc precipitation method. This is performed using a calotte of nested screens containing loosely-layered fine zinc shavings with large specific surface area The leachate solution is then applied from underneath, flowing upward through the screens. The gold separates out onto the zinc shavings and becomes visible as a black discoloration. When all the shavings are loaded with gold, these are melted and the gold collected (possibly performed by buyers or service organizations).

Recent patent literature also describes the cementation of gold from slightly-turbid cyanide leachate in reaction vessels filled with zinc granules and shaken by means of a vibrator which supposedly leads to faster cementing, higher recovery, lower zinc consumption, and a greatly simplified processing procedure.

- A third possibility is the CIC (Carbon in Column) Process in which clear gold-cyanide- complex solution flows from the bottom upwards through a cylinder filled with activated carbon, whereby the gold adsorbs onto the carbon. Activated carbon which is completely saturated with gold can contain as much as 20 - 30 kg gold/l, marketed either as ashed gold or as gold concentrate.

For slurries:

- In the Carbon-in-Pulp Process, in which granulated activated carbon is added to the slurry, the precious-metal cyanide complex is adsorbed onto the activated carbon. This is then mechanically separated (by screening) and washed out with a strong alkaline sodium-cyanide leaching solution, possibly under conditions of increased pressure and temperature; subsequently the gold is recovered electrolytically by collecting it together with silver and copper on steel wool electrodes. Upon completion of the process, the activated carbon must be regenerated (a costly endeavor). Alternatively, the gold-saturated activated carbon can be incinerated to ash.

- Gold-containing ores that also contain organic substances (which as semi-activated medium can potentially absorb gold from the leachate), are processed using the CIL (Carbon-in-Leach-Process), in which the leachate already contains the activated carbon when it is added to the ore. The more active carbon absorbs, which can then be mechanically separated as described above for the CIP Process. Slurries with a small proportion of suspended material can be filtered in gravel-bed filters; this is the cheapest method, involving the least equipment, for purifying solutions.

For purifying slurries, the CCD method (counter current decantation) is also applied, a process in which several thickeners are charged in counter-current system (opposite direction); the thickened sludge from one is again fed back into the previous thickener, and the overflow is directed into the next thickener.

REMARKS:

The process was developed in South Africa in 1889.

In agitation leaching operations, the leaching can partly begin already in the mill by performing wet grinding in a cyanide leach. This has the advantages in that absolutely fresh (uncontaminated) mineral surfaces come into contact with the solution.

In the CIP-Leaching, it is often the extremely high cost of the activated carbon which renders the procedure uneconomical in developing countries. At the same

time, there are good possibilities in many areas in developing countries where activated carbon could be locally produced. Raw materials such as coconut husks are particularly well suited for such purposes. Coconut shell carbon is known particularly for its hardness and fine porosity. However, the raw material, namely the coconut shells, which are usually used as heating fuel, are relatively expensive. Moreover, the quality standards are very high: the shells must be clean and very fresh. For these reasons, imported activated carbon has been employed so far in small-scale mining in developing countries.

High costs occur due to consumption of reagents, particularly the consumption of cyanide through oxidation, release of HCN and reactions with accompanying substances in the ores. In CIP-leaching, abrasion of the loaded activated carbon is problematic (gold losses).

The agitation leaching processes ground products or finely-crushed ores, the vat leaching processes pre-crushed ores, the heap leaching processes coarsely crushed crude ore. Heap leaching is less expensive, but with respect to the comparatively low recovery (approx. 50 %) is less recommended (the process is better suited for low grade ores). Ores which can be leached in the stockpile in a coarsely-crushed form are rare. Gold particles which, for example, are bound within quartz cannot be leached without grinding to liberate them.

Tailings from gold leaching operations must be stockpiled or collected in a sludge pond. Excessive CN-contents decompose over time under the influence of ultra-violet radiation.

In general, agitation leaching and vat leaching, and also heap leaching for easily-

leachable ores, appear to be the most suited for small-scale mining; these methods require substantially less equipment for the leaching, adsorption and winning of gold from clear slurries than other methods.

High temperatures tend to cause decomposition of cyanide leaching solutions, whereas low temperatures drastically reduce the speed of reaction. The economical optimum lies at a leaching temperature of about 20 C, which in colder climates is attained through artificial heating. In all cases, leaching tanks and vessels should be covered since UV-radiation leads to decomposition of the leaching solution.

To avoid environmental hazards, leaching tanks and vessels should be covered on top with wire mesh to prevent humans, animals and especially birds from gaining direct access to the toxic solution. Pachuca tanks for compressed-air agitation leaching of the slurry have a height which corresponds to at least three times the diameter of the tank.

Leaching tanks for percolation leaching should not be too deep. Very deep tanks inhibit the penetration of air during the sinking of the leachate level, thereby insufficiently supplying the ore with the necessary oxygen for leaching.

Leached ores can be removed from vat leaching plants and tanks by means of a bottom gate or, even simpler, by flushing with large quantities of water.

Cyanide leaching allows the processing of a very wide spectrum of gold ores, for example, ores with fine-grained free gold (down to sub-microscopic gold occurences such as in vulcanises or carbonates), gold from soluble sulfides, and

gold attached to the surface of sulfides. Refractory ores, for example, with gold-containing pyrites are not leachable without further processing (e.g. roasting).

Ores which exhibit varying intergrowth relationships can be selectively comminuted in order to attain liberation without overgrinding. Ores with coarse gold intergrowths in quartz or with finer gold intergrowths in sulfides and their interspaces are frequently encountered. In this case, the sulfides from the primary grinding circuit can be gravimetrically separated (for example in a jig) and selectively finely ground in a second grinding circuit.

Gold-containing cyanide leachates should always be immediately further treated, otherwise there is danger that colioids (mostly aluminum, iron or magnesium hydrates) settle out of the clear solution which hinder the precipitation of gold onto the zinc shavings or zinc dust. Furthermore, the Ca-rich leachates can precipitate calcium carbonate by absorbing CO_2 from the air.

Zinc wool for precipitation should have a thickness of approx. 0.02 mm. It then exposes between 10 and 20 m^2 of specific surface area pro kg and has a volume of approx. 10 lifers. Optimal quantities are approx. 30 lifers of zinc wool for every m^3 leachate/24 hours. Solutions which have passed through the zinc wool precipitation are dropped into the supply tank from greater heights so as to enrich it with oxygen as it falls through the air.

High, cylindrical leach tanks, such as pachucas, can be built out of cement rings stacked on top of each other. For leaching in an acidic medium (for example, with thiourea), these cement rings can simply be lined with synthetic resin.

Leaching is especially suitable for ores containing fine-grained gold particles of high specific surface area With feed of coarser grain-size fractions the leaching speed drops. Therefore, these coarser fractions are usually separated in a prior gravity beneficiation, leaving only the tailings and the fine fractions to be leached.

Leaching speed may be increased by leaching under pressure; this method, however, is characterized by enormously high investment costs and is therefore not appropriate for small-scale mining.

EXPERIENCES IN LEACHING IN SMALL-SCALE MINING:

In Brazilian gold mining at its smallest scale, a technique could be observed in which raw ores are mixed with cement via shovelling and thus agglomerated. A leaching process which produces pure solutions is conducted in small vessels (for example, diesel barrels). The adsorption of the gold-cyanide-complex takes place on locally produced Babacu-nut-carbons, which are subsequently incinerated to ashes.

In small-scale gold ore mining in Colombia and Ecuador, percolation leaching plants are in operation in which the tailings from amalgamation plants and gravimetric beneficiation processes are leached. Here the slurry-flow falls in a sedimentation basin, which has the effect of desilting the sands. The sedimented material is then sufficiently permeable to produce a pure solution during leaching. The brick leaching tanks have a capacity of 20 - 100 t and are situated above the precipitation basin in which the gold is precipitated onto the zinc shavings. Subsequently, the solution drains into the leachate supply tank. A small pump, driven by a gasoline-engine, pumps the leachate into the leaching tank once daily.

The investment costs for this type of facility are minimal and, depending upon the cost of building materials and wages, total less than 5000 DM.

Electrolytic separation of gold from the cyanide leachate is performed in Philippine mining using locally-produced cells constructed from batteries, where the anodes are made of stainless-steel screen mesh and the cathodes of steel wool The gold-containing leachate continuously flows through these cells in which a 12 V, 60 A electrical current has been applied The gold is later shaken out of the steel wool and collected, and the steel wool reused.

SUITABILITY FOR SMALL-SCALE MINING:

Cyanide leaching yields high recovery particularly in the beneficiation of ores containing fine gold fractions. However, its dependence on large quantities of reagents, some toxic, and the difficulties in controlling the processes are problematic for small-scale mining application. In medium-scale plants where specialized knowledge is readily available, gold leaching is an economic alternative which can even serve, among others, as a substitute for the environmentally detrimental amalgamation processing.

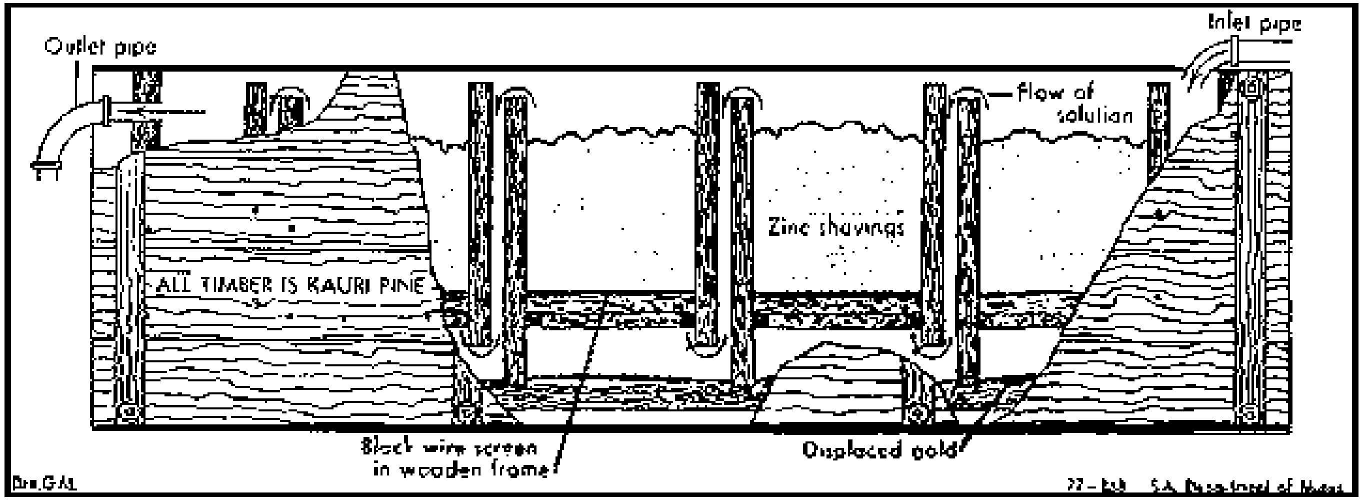


Fig.: A zinc precipitation plant made of wood. Source: Armstrong.

15.12 Gold separation by smelting

Gold Mining
Beneficiation, Gold Beneficiation

germ.: Schmeiztrennung von Gold
span.: separacion del oro por fundicion

TECHNICAL DATA:	
Dimensions:	oven approx. 1 × 1 × 1 m
Throughput/Capacity:	thermal heating up to about 1200° C
Form of Driving Energy:	gasoline, oil, coal or wood burner; or electric oven
Mode of Operation:	intermittent
Technical Efficiency:	very high recovery

Technical Efficiency:	very high recovery
Operating Materials:	
Type:	various fluxing agents, coating agent and precious-metal collector (the latter only when fire assay is applied (Dokimasie))
ECONOMIC DATA:	
Investment Costs:	refractory (fireclay) crucible, graphite crucible, oxide-ceramic crucible, crucible tongs, agitator, mortar, iron crucible, and heating facility (crucible oven) to 2.000° C, totalling about 5000 DM when of Latin American production
Operating Costs:	cost of energy, labor costs, cost of reagents, cost of crucibles (20 to 35 (max) melts/crucible)
Related Costs:	possibly cost of presses for the manufacture of crucibles and cupels.

CONDITIONS OF APPLICATION:

Operating Expenditures:	low |—————|—————| high
Maintenance Expenditures:	low |—————|—————| high
Personnel Requirements:	extensive experience is necessary, especially for the quantitative separation by fire assay
Recovery:	through the use of precious-metal collectors, recovery can be quasi quantitative (100 %)
Replaces other Equipment:	as a beneficiation technique, replaces other methods for winning pure gold from pre-concentrates, e.g. hand picking. As an analytical technique, fire

	assay is the simplest, fastest and above all the most accurate method of gold analysis.
Regional Distribution:	in gold analysis worldwide, as a beneficiation technique very rare
Operating Experience:	very good |————|————| bad
Environmental Impact:	low |————|————| very high
	during use of this process, gases of volatile and possibly toxic components are emitted into the atmosphere; also, depending upon energy source, detrimental exhaust gases.
Suitability for Local Production:	very good |————|————| bad
Under What Conditions:	oven cannot be locally produced by non-specialized manufacturing plants; crucibles and cupels can be locally manufactured
Lifespan:	very long |—————————| very short
	short service life especially of crucibles and cupels

Bibliography, Source: Chemikerausschu der GDMB

OPERATING PRINCIPLE:

To separate gold from the heavy minerals, the enriched pre-concentrate is placed in a crucible with borax and baking powder or ammonium chloride (NH_4CI) and

heated to a temperature of 1200° C. This causes the oxidic minerals such as limonite, ilmenite, etc. to melt. In the solid-liquid system which is created, liquid gold concentrates at the bottom of the crucible underneath the slag. The melting temperature of gold is 1063° C.

In the "fire assay" method, the material to be separated, normally a sample for determing precious metal content, is melted together with the excess lead and flux. Through the addition of oxidation or reduction agents, as well as slag-forming agents, the melt separates into the precious-metal containing lead regulus and a slag extensively free of precious metals. The lead regulus is then separated and further processed by the so-called cupellation process. The regulus is heated in a cupel a crucible made of bone ashes - whereby the lead is oxidized in the liquid melt and is either volatized or absorbed by the cupel material (especially the magnesium component therein). What remains is an almost perfectly round preclous-metal grain which allows precise quantitative conclusions to be drawn, either by weighing or by size-comparison with a linear scale, concerning the Initial content of the feed material.

AREAS OF APPLICATION:

Melting to produce pure precious metals from concentrates, employed as a separation technique In small-scale mining.

Fire assay, as the most important method of analysis for gold contents in mined ore, can no longer be ignored; In addition to free gold, other gold occurrences, such as gold contained in pyrite, can also be determined.

REMARKS:

This technique or method is not applicable for platinum group metals due to their significantly higher melting point (platinum 1769° C, rhodium 1966° C, palladium 1550° C, osmium 2700° C, iridium 2454° C).

As an analytical method, fire assay captures and reveals the entire gold content of a sample, including the diadochic contents in the pyrite lattice such as dispersed gold. The recoverable free-gold contents are determined by panning.

Cost of analysis with imported crucibles and cupels is about 4 - 6 US$ per sample, compared to 2 - US$ when locally. manufactured crucibles and cupels are used. Crucibles of clay can be locally formed and fired. It must be taken into consideration, however, that only clay which is completely free of gold should be used, since during melting the crucible material is also melted, and any gold contained in the crucible material could accordingly alter the analytical results. Cupels can also be locally manufactured from a mixture of bone ashes or magnesium and common, commercially-traded cement.

SUITABILITY FOR SMALL-SCALE MINING:

Gold separation by smelting is an inexpensive and very accurate method of achieving marketable products when the concentration of gold is adequate (determined by previous sample melting). Fire assay is the most Important analytical method for determing gold contents in ores.

Cupels made of Bone Ashes

Size	Upper diameter mm	Lead adsorption capacity gr	Height mm	Weight gr
1	22	4	11	4
2	24	7	13	7
4	30	13	14	13
5	33	18	16	18
6	35	24	18	24
7	40	30	19	30
8	50	60	25	60
9	60	100	27	100
10	88	300	33	300

Fig.: Cupels: sizes, lead-adsorption capacity and shape.
Source: Frick-Dausch

Table: The most important sample reagents. Source: Frick-Dausch

Name of Sampler	Composition	Tasks and Characteristics
Quartz	SiO_2	scorification, fluxing agent, acidic
Glass	x Na_2O y CaO z SiO_2	scorification, fluxing agent, acidic (weaker than quartz)
Borax	$Na_2B_4O_7$ $10H_2O$	scorification, fluxing agent, acidic
Borax glass or molten borax	$Na_2B_4O_7$	scorification, fluxing agent, acidic

Phosphorus salt	$Na(NH_4)HPO_4$ $4H_2O$	scorification, fluxing agent, seldom used
Soda	Na_2CO_3	scorification fluxing agent, desulfurization
Sodium bicarbonate	$NaHCO_3$	scorification fluxing agent, desulfurization
Potassium carbonate		
(Potash)	K_2CO_3	scorification, fluxing agent, desulfurization
Lead (II) oxide	PbO	scorification, fluxing agent, desulfurization,
		oxidizing, collector, basic
Tartaric	$KHC_4H_4O_6$	reducing agent and basic fluxing agent
Charcoal		reducing agent
Flour		reducing agent
Potassium Cyanide	KCN	reducing agent and neutral fluxing agent
Iron	Fe	reduing agent, desulfurization, basic scorification agent
Salpeter (salts of nitric acid)	KNO_3 $(NaNO_3)$	oxidizing agent, desulfurizination, basic fluxing agent
Assay lead	Pb	collector
White lead	$2\ PbCO_3\ Pb(OH)_2$	collector, also desulfurizing, oxidizing basic fluxing agent
Lead acetate	$Pb(CH_3COO)2$ $3H_2O$	collector, sometimes also desulfurizing basic fluxing agent
Sodium chloride	NaCl	coating agent

Sodium chloride	NaCl	coating agent
Fluorite	CaF_2	inert neutral fluxing agent
Greenland spar cryolite	Na_3AlF_6	dissolves Al_2O_3
Ammonium carbonate	$(NH_4)2CO_3$	desulfurizing, volatilizing

1 The earlier common names have been kept

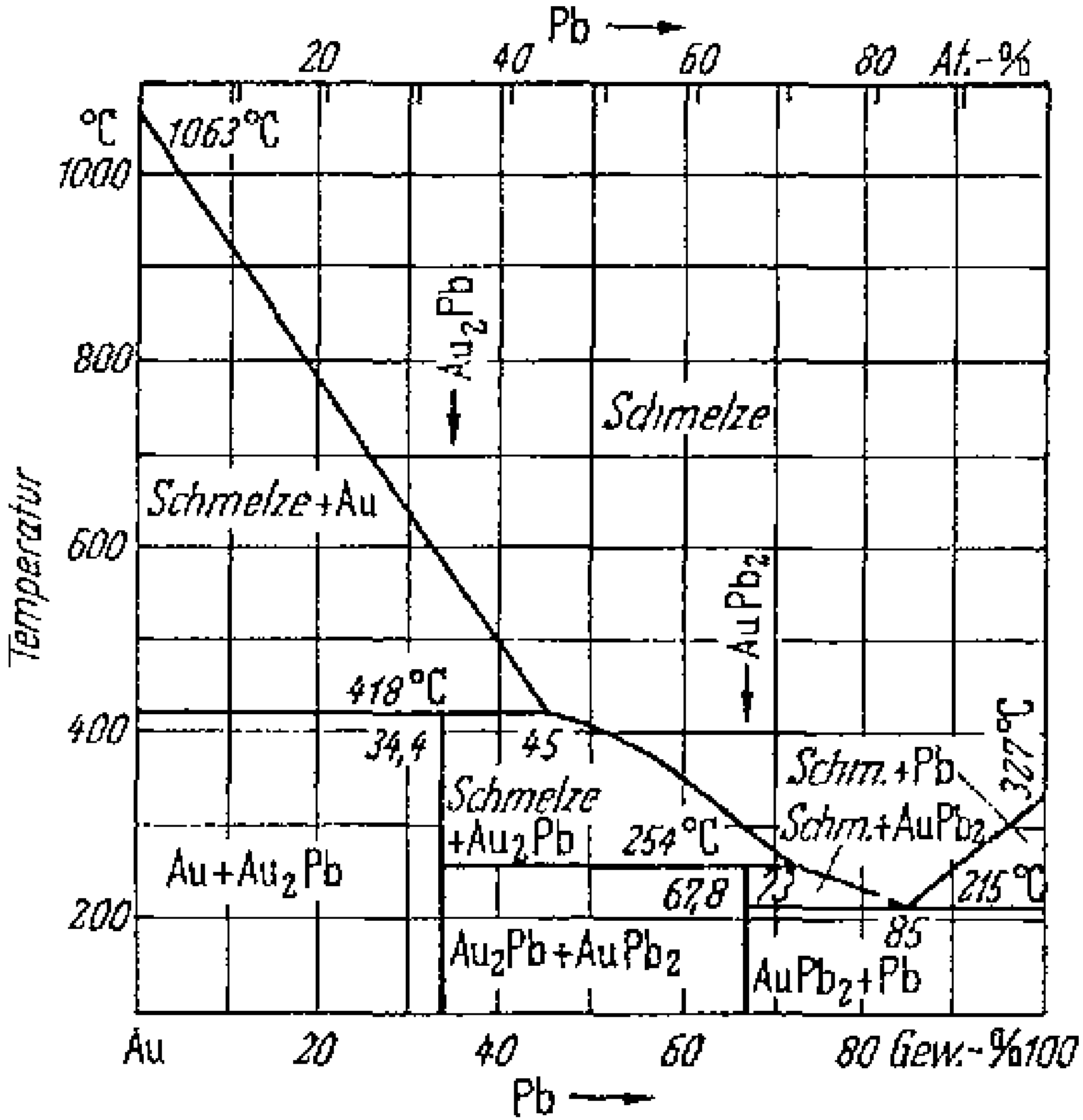


Fig.: Phase diagram of gold-lead melting. Source: Frick-Dausch.

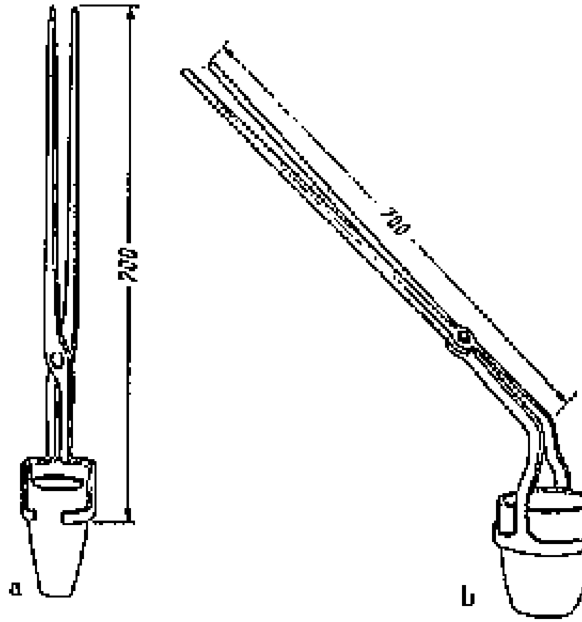


Fig.: Crucible tongs. Source: Frick-Dausch. a) strainght from; b) curved form

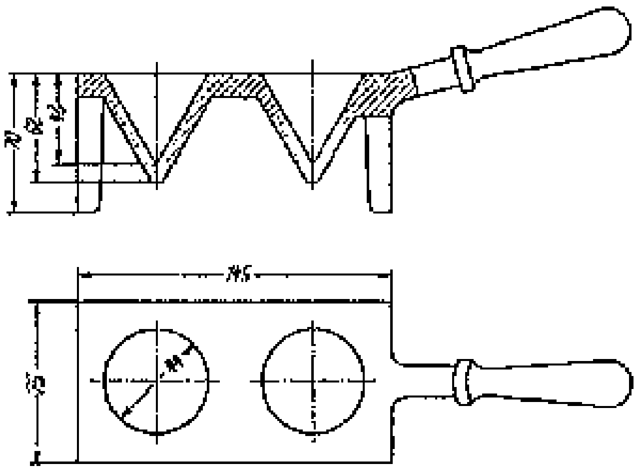
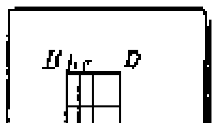
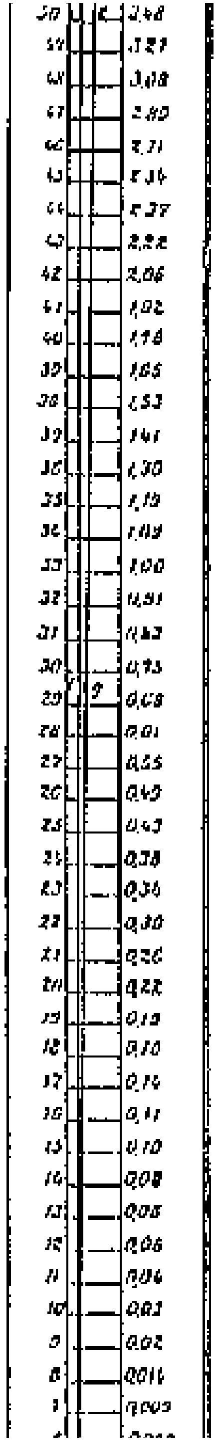


Fig.: Mold for fire assay. Source: Frick-Dausch.





42
2,06
1,65
1,53
1,41
1,30
1,00
0,68
0,55
0,40
0,43
0,38
0,36
0,30
0,26
0,22
0,10
0,10
0,08
0,06
0,04
0,02

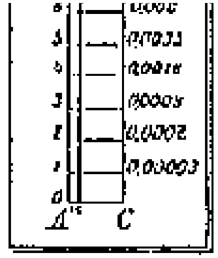


Fig.: Standardized reference scale for the determination of gold content from fire assays. Source: Frick-Dausch.

15.13 Gold-coal-agglomeration

Gold Mining
Beneficiation, Gold Beneficiation

engl.:	coal-gold agglomeration, CGA
germ.:	Gold-coal-agglomeration
span.:	aglomeracion oro-carbon

TECHNICAL DATA:	
Extent of Mechanization:	fully mechanized
Power:	for agitating and pumping, several kW
Form of Driving Energy:	electric for mixing, agitating
Throughput/Capacity:	not known, since it has not yet been applied in large-scale industrial operations, British Petroleum operates with a 1 t/h pilot plant (see

	House), 30 min contact time gave optimal results
Technical Efficiency:	loading of the agglomerate in large-scale plant operations to between 1000 and 5000 g/t is possible
Operating Materials:	
Type:	oil, activated carbon
ECONOMIC DATA:	
Investment Costs:	not known
Operating Costs:	high cost of reagents, conservative cost estimates show that operating costs for CGA are less than those for leaching
Related Costs:	costs of grinding and settling basin, thickener or sludge pond for treating tailings

CONDITIONS OF APPLICATION:

Grain Size of Feed:	0.2 - 200 ym gold particles can be agglomerated
Special Feed Requirements:	gold, electrum (Ag-bearing Au), gold telluride, also for ores with significantly less than 1 g Au/t
Recovery:	over 90 % in pilot plants
Replaces other Equipment:	this technique is used for obtaining meltable gold concentrates and should replace amalgamation, leaching, and other methods.
Regional Distribution:	so far not applied in large scale operations; used in pilot plants in Australia
Operating	information not yet available

Experience:

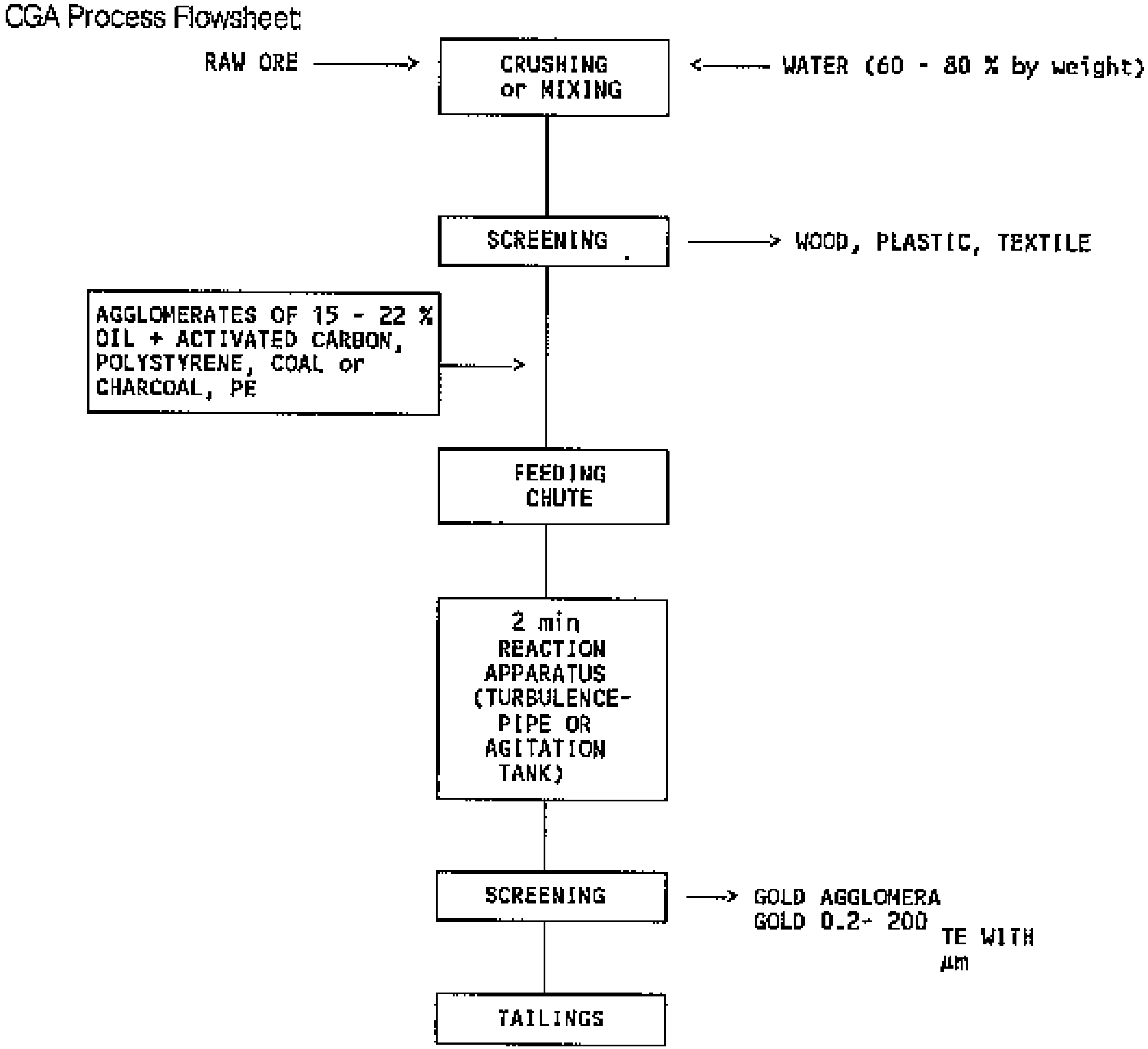
Environmental Impact: low |————|————| very high

high sludge loading; pollution through discharge and consumption of reagents, which are produced by highly energy-intensive and environmentally detrimental processes (for example the production of activited carbon). Positive effect if it proves successful as a substitute for amalgamation.

Bibliography, Source: F 530793, USA 4, 597, 791, House

OPERATING PRINCIPLE:

In a BP-gold-coal-agglomeration pilot project, the high-grade gold-containing fine-grained slurry is transposed by activated carbon into an oil suspension. The hydrophobia of the gold is being utilized in this process. The gold then agglomerates onto the oil-saturated activated carbon particles. Following agitation of the slurry-reagents-mixture, the gold-oil-activated carbon agglomerate is mechanically separated.



CGA Process Flowsheet:

SUITABILITY FOR SMALL-SCALE MINING:

Suitability for small-scale mining application is not yet assessible due to insufficient operational data.