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METHODS AND COSTS OF CONCENTRATING SCHEELITE ORE AT THE SILVER DIKE MILL, MINERAL COUNTY, NEVADA

BY

WILLIAM O. VANDERBURG

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METHODS AND COSTS OF CONCENTRATING SCHEELITE ORE AT THE SILVER DIKE MILL, MINERAL COUNTY, NEV.[1]

By William O. Vanderburg[2]

INTRODUCTION

This paper describing the methods and costs of milling scheelite ore at the Silver Dike concentrator of the Nevada-Massachusetts Co., Inc., is one of a series being prepared by the Bureau of Mines.

In the Silver Dike mill tungsten ore which contains about 1 per cent of scheelite is treated at the maximum rate of 45 tons per 24 hours by tabling followed by magnetic separators to clean the table concentrates. Unusually high-grade concentrates are produced which average between 70 and 75 per cent of WO_3.

ACKNOWLEDGMENT

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LOCATION

The Silver Dike mine and concentrator are on the east flank of the Excelsior Mountains, 12 miles by automobile road southwest of Mina, Mineral County, Nev. The locality is known generally as the Silver Star or Gold Range mining districts. The Hazen branch of the Southern Pacific Railroad connects Mina, the southern terminus of the branch, with the main trunk line at Hazen; trains between Mina and Hazen are run on a daily schedule. The Tonopah & Goldfield Railroad operates a train daily between Mina and Goldfield via Tonopah. A narrow-gage railroad also connects Mina with southern California points by way of Belleville.

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1 - The Bureau of Mines will welcome reprinting of this paper providing the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6604."

2 - Associate mining engineer, U. S. Bureau of Mines.

The Silver Dike property is accessible by automobile road from Mina and all supplies and concentrates are hauled over this road by truck. The topography in the immediate vicinity of the mine and mill is of high relief; the climate is semiarid. The mill is built on the side of a steeply walled canyon. This site presents two features which adversely affect milling operations: namely, insufficient space for the disposal of tailings and a scant water supply.

The elevation of the upper end of the mill building is 6,470 feet above sea level.

POWER

Power for the mine and the mill is generated at the Mono Lake hydro-electric plants of the California-Nevada Power Co. at Bishop Creek and is purchased from the Mineral County Light and Power Co. under a schedule which varies from $0.025 to $0.04 per kilowatt-hour, depending upon the amount used. There is a minimum monthly demand charge in the schedule. The average cost of power when producing scheelite at two-thirds capacity is approximately $0.03 per kilowatt-hour.

From Bishop Creek the power is transmitted at 33,000 volts to a point 6 miles distant from the mine where delivery is accepted. At this point it is stepped down to 6,600 volts for transmission to the mine and mill. At the property it is stepped down further to 440 volts for use by all motors.

The mine is provided with three 30-KV-A. transformers, the mine crushing plant has two 20-KV-A. and the mill three 100-KV-A. transformers. All transformers are equipped with Pellet oxide-film lightning arresters.

Power for emergency lighting purposes is furnished by a 1,500-watt Kohler plant which consumes 1 gallon of gasoline for each four hours that the unit is operating.

WATER

Water for milling and domestic purposes is obtained from two wells sunk in the canyon, one above and the other below the mill site. The lower well which furnishes water for the mill is 50 feet deep and has a flow of 6 gallons per minute. The water is pumped from this well to a 1,200-gallon capacity tank by a No. 6 Stover deep-well pump; from this tank it is elevated about 125 feet to the mill supply tank by a 3 1/2 by 6 inch Fairbanks-Morse horizontal duplex pump. Water for domestic use is supplied by the upper well which is 35 feet deep. It is pumped from the well intermittently and flows by gravity through a 1-inch pipe line to the camp.

The amount of water available in proximity to the property during comparatively dry periods is insufficient for full capacity milling operations and the mill operation is limited to two shifts per day for this reason. A water right in Spearmint Canyon in the Pilot Mountains 12 miles distant has been acquired to overcome this difficulty, and eventually the deficiency in the supply of mill water will be made up from this source.

Equipment has been provided for reclaiming a portion of the water contained in the tailings pulp; the water so recovered is approximately 75 per cent of the mill water used.

ORE TREATED

The ore occurs in quartz veins which have an average dip of about 75° and an average width of 3 feet. The length of the ore shoots varies from 60 to 120 feet. The width of the vein mined is determined more by the scheelite content than by structural characteristics of the vein. The country rock is monzonite, and a number of inclusions of this rock are found in the vein filling.

Practically all the past production of scheelite concentrates in the Great Basin region has been derived from contact-metamorphic deposits consisting of limestones altered to tactite by solutions accompanying intrusions of granitic rocks. The Silver Dike deposits are quartz veins of the replacement type and constitute an exception to the usual occurrence of scheelite ore in this district. The ore, in consequence, does not contain serious amounts of copper, bismuth, molybdenum, phosphorous, or other undesirable elements ordinarily present in minerals associated with the contact-metamorphic deposits.

The scheelite crystals in the Silver Dike ore vary in size from 1/16 inch to 2 inches in diameter. Pyrite and, to a lesser extent, manganese sulphide are present in the ore.

The ore is mined by a system of shrinkage stopes; the top of the broken ore in the stopes is kept at a suitable distance from the back by drawing off the excess ore through plank chutes into cars. The ground is solid and little timber support is required. In blasting, practically all of the ore is broken to such size that it will pass through a grizzly with 8-inch openings. Entry to the mine is made by an adit crosscut 900 feet long. Ore is transported to the mine crushing plant by a locomotive operated by storage batteries; the average length of haul is 1,360 feet underground plus 300 feet from the portal of the adit to the bin.

Hand sorting of ore and waste is not practiced at Silver Dike, as it is difficult to distinguish ore from waste because of the intimate association of the mixture and the similarity in appearance of scheelite and quartz. An effort is made to maintain the grade of the ore broken at 1 per cent of scheelite which is equivalent to 0.8 per cent of WO_3, but close supervision in mining and numerous pannings have been found necessary to prevent the admixture of ore and waste in mining operations.

HISTORY OF CONCENTRATOR OPERATIONS

The present Silver Dike property represents a consolidation of two properties originally known as the Silver Dike and Wagner properties. The consolidation comprises a group of 12 contiguous claims. The properties were located for gold and silver in 1915. Although the occurrence of tungsten was known at the time of discovery no effort was made to develop the properties for tungsten until the extraordinary demand for this metal developed during the World War. At this time the Silver Dike property was owned and operated by the Atkins-Kroll Co. of San Francisco. The ore was hauled from the mine to a mill at Sodaville, a distance of 8 miles, by wagons and tractors. The Sodaville mill had capacity to treat 50 tons of ore per day.

In November, 1918, the mine closed down, and shortly afterwards the Sodaville concentrator was dismantled, due to almost complete paralysis of the tungsten industry in the United States. From 1919 to 1924 the production of tungsten concentrates in Nevada ceased because of the depressed condition of the industry.

A 25-ton capacity mill was built on the Wagner Co. property by lessees in 1926 and was operated by them until 1927. The method of treatment used consisted of crushing to 10-mesh size by a jaw crusher and rolls and concentrating the crushed product by tables. The tables produced finished concentrates.

In 1929 both the Wagner and Silver Dike properties were acquired by the Nevada-Massachusetts Co., Inc., under bond and lease. The present mill was erected in 1930.

PRESENT METHOD OF CONCENTRATING

A summary of the present method of ore treatment follows:

1. Crushing mine ore to 3/4-inch size by two Blake-type crushers which operate in series.

2. Crushing from 3/4-inch to minus 12-mesh by two sets of rolls operating in series; the primary rolls are in closed circuit with a trommel having 7/16-inch holes, and the secondary rolls with a 12-mesh Callow screen.

3. The minus 12-mesh material is sized by a 22-mesh Callow screen. The oversize is treated on an Overstrom table; the undersize pulp after thickening is also treated on an Overstrom table. The tables produce concentrates, middlings, and waste tailings.

4. The combined tables concentrates, after drying, are given a short roast to convert pyrite to a magnetic iron sulphide; the sulphide is then removed by a Dings magnetic separator.

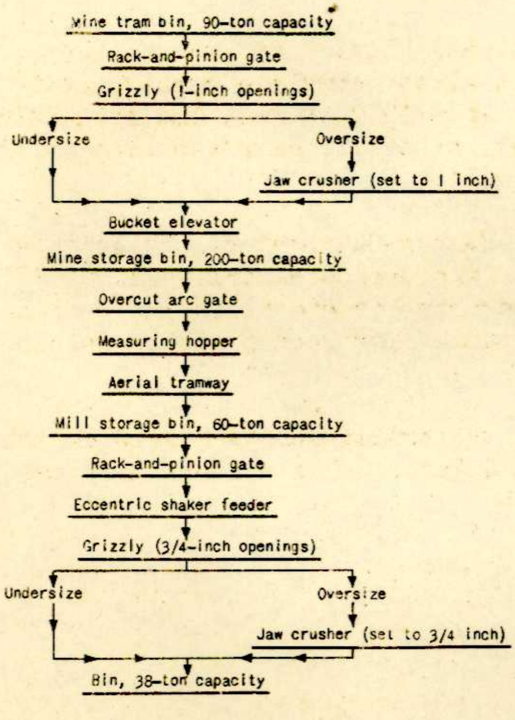

Figure 1.- Flow sheet of coarse and intermediate crushing

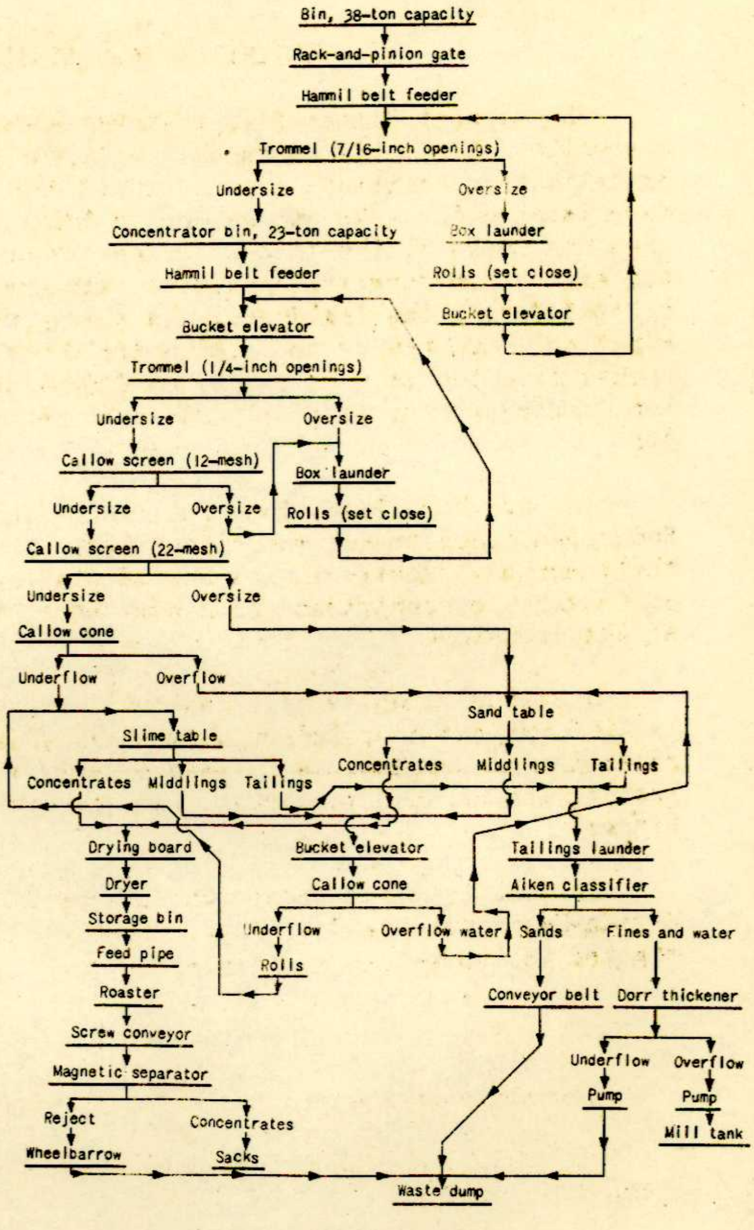

Figure 2.- Flow sheet of the concentrator

5. The table middlings are crushed further by rolls and returned to the table which treats the finer-sized material.

A flow sheet of coarse and intermediate crushing operations is given in Figure 1 and that of the concentrator is presented in Figure 2.

Coarse and Intermediate Crushing

The broken ore from the stopes is delivered to the mine tram bin in trains of eight 1-ton capacity cars hauled by a storage-battery locomotive; cars are dumped by hand. The mine tram bin has a capacity of 90 tons and is constructed of wood with the bottom sloping 45°.

The discharge of ore from the bin is controlled by a hand-operated rack and pinion gate. From the bin the material is fed to a grizzly 5 1/2 feet long and 2 feet wide, inclined 40°, and equipped with tapered 3/4 by 3/8 by 2 inch steel bars spaced 1 inch apart. The oversize is crushed to 1 inch size by a 16 by 24 inch Blake-type crusher equipped with corrugated manganese steel wearing plates. The crushed product joins the grizzly undersize and is delivered to a storage bin by a bucket elevator. The elevator is 35 feet long, center to center, and operates at a speed of 50 feet per minute and at an incline of 65°; it is provided with a 6-ply rubber-surfaced belt and buckets which are 8 inches long, 8 inches wide, and 6 inches deep. The storage bin is of wood and has a bottom which slopes 45° in two directions; it has a capacity of 200 tons.

The minus 1-inch product is transported from this storage bin to the mill by an aerial tramway 1,420 feet long; the difference in elevation between the upper and lower terminals is about 500 feet. The tramway is of the single-cable type and is equipped with 1-inch cable made up of 6 strands, 19 wires each, and a hemp core. There are 40 buckets in the line, each having a capacity of 240 pounds. The buckets are loaded while the tramway is in motion by a measuring hopper which operates on an inclined plane. The measuring hopper is filled from the bin by means of a hand-operated overcut-arc gate. The buckets are dumped automatically at the mill by a tripper which releases the hinged bottoms.

The 60-ton capacity receiving bin at the mill is of wooden construction and has a 45° inclined bottom. From this bin the ore is delivered through a rack and pinion gate to a grizzly by an eccentric shaker feeder. The feeder is 5 feet long by 1 foot deep and has a slope of 2 inches per foot; it is driven by chain at a speed of 40 oscillations per minute and with a 4-inch stroke. The grizzly is 4 feet long by 16 inches wide and is made of 3/4 by 3/8 by 3 inch tapered steel bars spaced 3/4 inch apart. The grizzly oversize is crushed to 3/4 inch by a secondary 14 by 18 inch Blake-type crusher equipped with corrugated, white, cast-iron wearing plates. The crusher is operated for approximately four hours per day when running the mill on two shifts. The crushed product joins the grizzly undersize and passes to a 38-ton capacity wooden storage bin of which the bottom slopes at 45°.

Final Crushing and Screening

Referring to Figure 2, the ore from the 38-ton capacity bin is fed to a trommel by a Hammil belt feeder; the trommel is made of 3/16-inch plate having 7/16-inch holes. The feeder belt is 12 inches wide and 18 inches long between pulley centers and travels at a speed of 90 feet per minute. The flow of ore to the feeder is controlled by a rack and pinion gate. The trommel is 4 feet long and 2 feet in diameter; it is inclined at 20° and operates at a speed of 21 r.p.m. in closed circuit with a pair of Allis-Chalmers 14 by 30 inch primary rolls. The trommel oversize is delivered to the rolls by gravity, and the crushed product is returned to the trommel by a bucket elevator. The speed of the rolls is 125 r.p.m. and that of the bucket elevator is 295 feet per minute. The elevator is 29.5 feet between pulley centers, vertically; it is equipped with a 10-inch 6-ply belt having a 1/16-inch rubber-top cover and with buckets 9 inches long, 6 inches wide, and 5 inches deep spaced on 18-inch centers.

The undersize from the 7/16-inch trommel passes by gravity to a 23-ton capacity wooden surge bin equipped with a 45° sloping bottom. From this bin a second Hammil belt feeder delivers the material to an elevator; the latter discharges into a second trommel equipped with 3/16-inch plate having 1/4 inch holes. The trommel is 4 feet long and 2 feet in diameter; it is inclined at 20° and operates at a speed of 19 r.p.m. and in closed circuit with a pair of 14 by 30 inch secondary Denver Engineering Works rolls. The oversize of the trommel is delivered to the rolls by gravity and the crushed product is returned to the screen by the wet elevator. The secondary rolls operate wet and at a speed of 125 r.p.m. The elevator is 28 feet long between pulley centers vertically and travels at a speed of 300 feet per minute; it is equipped with a 10-inch, 6-ply, 3/16-inch, rubber-surface belt and with cast-steel buckets 9 inches long, 6 inches wide, and 5 inches deep spaced 12 inches apart.

The undersize of the secondary trommel is delivered to a 4 by 2 foot simplex Callow screen equipped with 12-mesh phosphor-bronze cloth which travels at a speed of 70 feet per minute. The oversize is at present returned to the secondary rolls, although it is planned to install a third set of rolls to operate in closed circuit with this screen. The undersize is conveyed to a second 4 by 2 foot simplex Callow screen; the latter is equipped with 22-mesh phosphor-bronze screen cloth which travels at a speed of 60 feet per minute. The oversize and undersize products of this screen comprise the feeds to the sand and slime tables, respectively.

Concentrating

The plus 22-mesh sands and the thickened minus 22-mesh fines are each treated on one Universal Overstrom table; each table produces concentrates, middlings, and waste tailings. The middlings from both tables join and are dewatered in a 4-foot Callow cone; the cone discharge sands are further crushed by a pair of 18 by 4 inch Sturtevant middling rolls and the crushed product is returned to the table treating the undersize of the 22-mesh screen.

The table concentrates are collected in buckets which are emptied from time to time on a 4 by 7 foot drain board. The tailings are conveyed by launder to the dewatering plant.

The Callow cone which thickens the 22-mesh screen undersize before table treatment is 8-foot size and is equipped with a gooseneck discharge; the overflow water from the cone is used as feed water on the sand table.

The elevator of the circuit used for recrushing of table middlings is 18 feet long vertically from center to center of pulleys; it is equipped with an 8-inch belt having buckets 7 inches long, 5 inches wide, and 4 1/2 inches deep spaced 18 inches apart.

Cleaning of Table Concentrates

The table concentrates are shoveled by hand from the drain board into a Channon foundry sand dryer. The concentrates from one week of operation are dried in about three days using wood as fuel. The dried concentrates drop into a concrete storage bin which is 6 by 7 feet in section and 4 feet high.

From the storage bin the product is fed through a 2-inch pipe with plug valve control to a roasting furnace for the purpose of converting the contained pyrite to the magnetic sulphide. Referring to Figure 3, the furnace block, made of concrete, is 11 feet long by 4 1/2 feet wide; it is 6 feet 7 inches high at the discharge end and 8 feet 7 inches high at the feed end. A firebox 18 by 18 inches in section lined with fire brick is built into the upper part of the concrete block; the slope of the firebox is 2 inches per foot. Between the fire brick and the concrete is an insulating layer of diatomaceous earth 3 inches thick. The top of the firebox is covered with flat 15 by 24 by 3 inch tile. The tile are dapped into the brick.

The roaster tube consists of a 12-foot length of 8-inch standard iron pipe equipped with flanges at either end. These flanges rest on flanged rollers, the bearings of the latter being bolted to a steel plate resting on the roller blocks. The tube is driven by chain and gear at a speed of 11 r.p.m. and is connected at the feed end by a hood to an 8-inch diameter stack for removal of the sulphurous gases. The joint between the roaster tube and the hood is sealed with fire clay.

The firebox is heated by an oil burner placed at the discharge end of the tube; plus 27° Baumé oil is atomized by 6-ounce air pressure and burned at the rate of 2 gallons per hour.

The concentrates as fed to the roaster contain about 19 per cent of pyrite the latter is rendered magnetic in the presence of air, the time of roasting is about 5 minutes. The calcines discharge into a trough of a screw conveyor and are conveyed to a shaker-type feeder at the head of a Dings "M-M" magnetic separator. The conveyor is 16 feet long and is equipped with cast-iron flights and a sheet-steel trough. The primary purpose of the conveyor is to allow the concentrates to cool before the magnetic separation. The separator operates at

120 volts and with a current of 12 amperes. The magnetic material is rejected as waste; the cleaned concentrates are packed for shipment in double canvas and burlap sacks which hold about 120 pounds each.

DEWATERING AND DISPOSAL OF TAILINGS

The table tailings pulp is conveyed by a launder to an Aikens classifier which is 11 feet long and set with a slope of 2 1/2 inches per foot. The classifier sands are conveyed to the waste dump by a conveyor which is 99 feet long between centers; the belt is 16-inch, 8-ply canvas and rubber, with a 1/16-inch rubber-top cover. The classifier overflow pulp is fed to a 13 1/2 by 8 1/2 foot Dorr thickener for reclaiming of water. The thickener rakes travel at a speed of 1 revolution in 8 minutes. The thickener underflow is delivered to the waste dump by a 1-inch eccentric-driven diaphram pump; the thickener overflow is delivered to the 5,760-gallon capacity main supply tank by a 1 1/2-inch centrifugal pump.

As previously noted, the amount of ground available for the storing of tailings is limited because of the fact that the mill is located in a narrow canyon which has steeply sloping sides. The road to the camp follows the bottom of the canyon, and the expense of building another road at a higher elevation is prohibitive. Eventually, when additional water is made available by the installation of a pipe line from Spearmint Canyon the tailings will be sluiced to a point several miles below the mill site where the canyon is wider.

LAUNDERS

Due to the abrasive action of the mill pulp, the launders are lined on the bottoms with steel plate or with armorite; the latter is a high-quality rubber vulcanized to a fiber base. The bottom of the launder which conveys the mill tailings to the pump is protected with block riffles made of 2 by 4 inch material and placed 12 inches apart.

CONTROL OF OPERATIONS

A rapid and reliable method for the determination of WO_3 in tungsten ores by chemical methods has not been devised. With the present standard methods in use it is difficult to obtain accurate results unless extreme care is exercised in manipulation. Because of the expense involved and the time required for accurate chemical determinations, mill operations at Silver Dike are controlled by panning. This method has proved rapid and reliable at Silver Dike when done by an experienced operator. A 6-inch frying pan is used for the estimation.

A specific gravity method for the approximate determination of tungsten trioxide content has been used in the Boulder and Atolia tungsten districts, but such a method is not applicable when the ore contains heavy minerals other than scheelite or when the specific gravity of the gangue minerals varies.

MARKETING OF CONCENTRATES

Concentrates produced by the Nevada-Massachusetts Co. are sold with a quality guarantee similar to the tabulation which follows:

Tungsten trioxide ... per cent ...	65 to 70
Tin .... per cent maximum	Trace
Copper .... do	0.05
Arsenic .... do	.035
Sulphur .... do	.75
Antimony .... do	.035
Phosphorous .... do	.05
Bismuth .... do	.035

The only undesirable elements contained in the shipping concentrates from Silver Dike are sulphur and copper, and the amounts of these elements are well within the limits prescribed by the quality guarantee under which sales are made.

The Nevada-Massachusetts Co., Inc., maintains its own selling agency. Samples of carload lots of concentrates are sent to custom assayers by buyer and seller and are sold on the analyses thus reported if within the limits previously agreed upon. If not within the prescribed limits, another sample is sent to an umpire assayer, and the sample which has an analysis closest to the result reported by the umpire is averaged with the umpire assay for the basis of sale.

EXPERIMENTAL WORK WITH FLOTATION METHODS

Preliminary experimental work by the Bureau of Mines at Rolla, Mo., on Silver Dike ore by flotation methods indicates that scheelite is floated readily. A sample weighing 200 pounds was crushed to minus 10-mesh in an Abbe mill. The pulp was then treated in a mechanical-agitation type of flotation machine which produced rough concentrates and tailings. The concentrate were cleaned twice, the latter operations producing finished concentrates and middlings. The tabulations which follow give the results of this test and the quantities and the kinds of reagents used.

Results of experimental flotation test

	Weight per cent	Assays per cent WO_3	Per cent of total WO_3
Flotation concentrates ..	3.4	62.72	89.7
Flotation middlings	21.7	1.03	9.4
Flotation tailings	74.9	0.03	0.9
Composite	100.0	2.38	100.0

Flotation reagents used

	Weight per ton of ore treated, pounds		
	Roughing	Cleaning	Total
Pine oil	0.12	---	0.12
Oleic acid	.16	---	.16
Sodium oleate	.40	---	.40
Sodium carbonate	.75	0.75	1.50
Sodium silicate	---	.40	.40

It has been found that the amount of reagents can be varied widely without seriously affecting either the grade of concentrates produced or the recovery of WO_3. In one test the concentrates produced contained 79 per cent of WO_3 as compared to 62.72 per cent in the preceding tabulation; the recovery of WO_3 in the former test was but slightly less than that obtained in the latter.

An analysis of milling losses at Silver Dike indicates that the chief loss is not due to included grains but is due to the inability of tables to make a high recovery of the slimed scheelite. The method of crushing used at Silver Dike employs two stages of Blake-type crushers followed by three stages of rolls; this practice is designed to prevent the sliming of scheelite and thereby decrease the loss in the tailings of the table treating the finer portion of the ore. The experimental flotation work described indicates that the treatment of Silver Dike ore by flotation methods is feasible and that the successful application of these methods would not only simplify the preparation of the ore for concentration by eliminating a number of the crushing stages but would also increase the recovery of the WO_3.

LABOR

When the mill is operated on a 2-shift basis, five men are required to run the mine and mill crushing plants, tables, roaster, aerial tramway, and accessory equipment. Two men are employed on the rolls and crusher at the mill, two are required for the tables, magnetic separator, and roaster, one man on the day shift operates the mine crusher, aerial tramway, and does general repair work about the mill.

The wage scale for mill labor is $5 per shift of eight hours.

METALLURGICAL DATA

Metallurgical data for a two months period in 1931 are given in Table 1.

Table 1. - Metallurgical data

Ore milled	.... dry tons	1,140
Moisture content of ore	.... per cent	3
Days operated	....	48
Hours operated per day	....	16
Average ore milled per day	.... dry tons	24.2
Average WO_3 content in mill feed	.... per cent	0.8
Average WO_3 content per ton of mill feed ...	.... pounds	16
Concentrates produced	.... do	20,062
Analysis of concentrates:		
Tungsten trioxide	.... per cent	73.38
Sulphur	.... do	0.17
Copper	.... do	0.003
WO_3 produced in concentrates	units of 20 pounds	736.1
WO_3 lost in tailings	do	126
WO_3 recovered (estimated)	.... per cent	80.7
Ratio of concentration, tons into 1	....	114
Net water consumption per ton of ore treated	.... tons	1.2

COSTS

A summary of milling costs for a two months' period in 1931 is given in Table 2; distribution of labor, power, and supplies is indicated in Table 3.

Table 2. - Summary of milling costs

	Cost per ton of ore treated 1/			
	Labor	Power	Supplies	Totals
Aerial tramway	$0.104	$0.135	--	$0.239
Crushing to 3/4 inch	.104	.271	--	.375
Crushing, screening, and conveying	.339	.422	$0.276	1.037
Tabling	.208	.082	--	.290
Roasting, magnetic separation, sacking	.104	.033	.162	.299
Dewatering and pumping	.130	.135	--	.265
Supervision	.066	--	--	.066
Miscellaneous	.052	--	.026	.078
Totals	1.107	1.078	0.464	2.649

1/ Direct costs only.

Table 3. - Distribution of labor, power, and supplies

Labor (per ton of dry ore):		
Aerial tramway	man-hours	0.151
Crushing to 3/4 inch	do	.168
Crushing, screening, and conveying	do	.540
Tabling	do	.334
Roasting, magnetic separation, sacking	do	.184
Dewatering and pumping	do	.209
Miscellaneous	do	.084
Total	do	1.670
Ore treated per 8-hour man-shift	tons	4.78
Power (per ton of dry ore):		
Aerial tramway	kilowatt-hours	4.45
Crushing to 3/4 inch	do	8.91
Crushing, screening and conveying	do	13.83
Tabling	do	2.66
Roasting, magnetic separation	do	1.08
Dewatering and pumping	do	4.44
Total	do	35.37
Labor, part of total cost	per cent	41.9
Power, part of total cost	do	40.7
Supplies, part of total cost	do	17.4

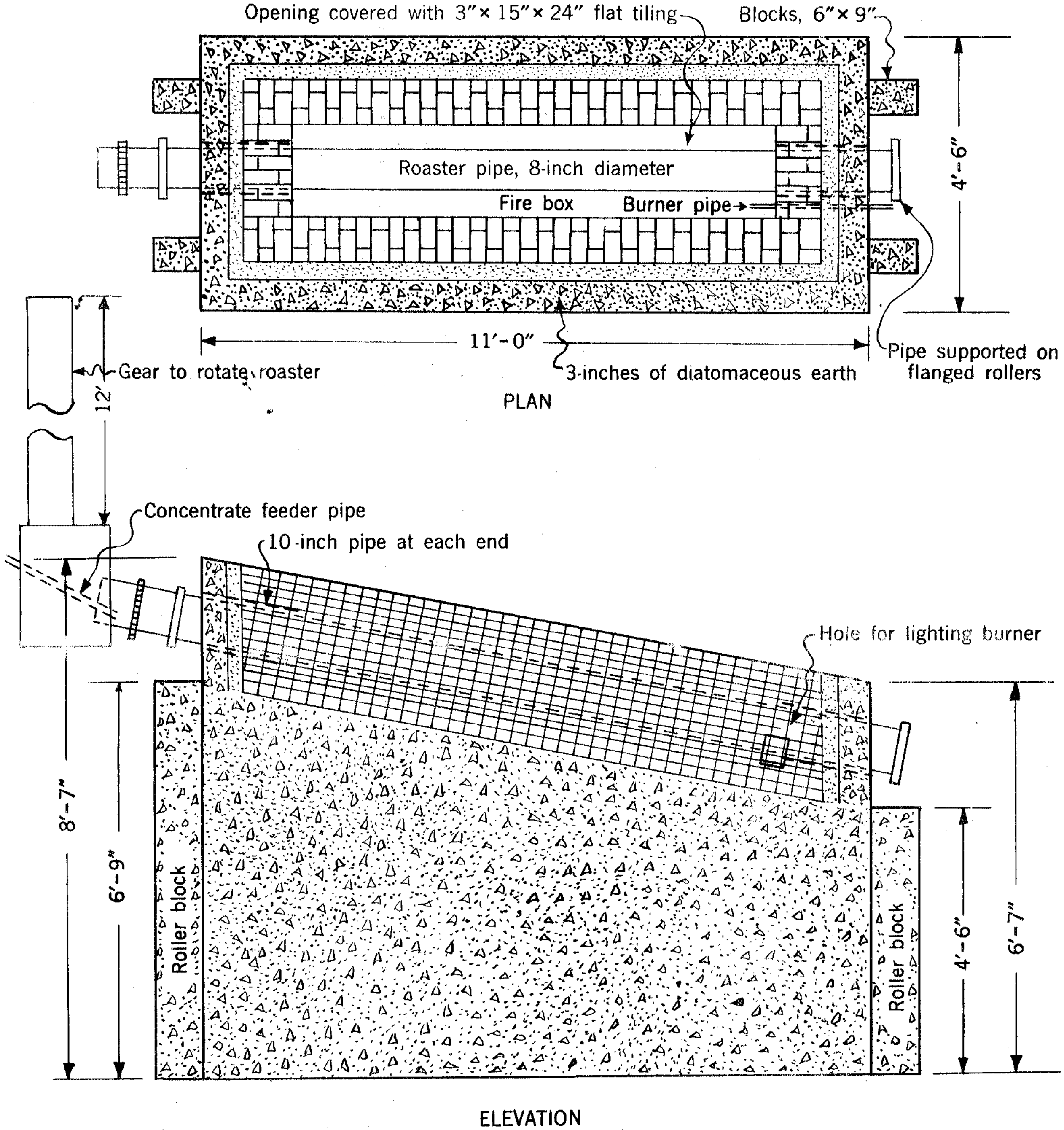

Figure 3—Plan and elevation of roaster