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Concentration of Tungsten Ore from the Potosi Mining District

Ted S. Jordan

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A Thesis

Submitted to the Department of Mineral Dressing

in Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Science

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Mineral Dressing Option

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CONCENTRATION OF TUNGSTEN ORE FROM THE POTOSI MINING DISTRICT

INTRODUCTION

Tungsten is a strategic metal which, at present, is in short supply in the United States. In addition to its need in the defense effort, tungsten is becoming more and more in industrial demand and, as an increasing number of uses for this element are being found, so must additional sources of it be discovered and processed.

The State of Montana contains several large deposits of tungsten ore; and, although the exact tonnages of these deposits are unknown, it is estimated that Montana has about one-third of the tungsten presently being sought by the government.[4] This report is concerned with the low-grade tungsten deposits of the Potosi Mining District. The investigation was undertaken to determine whether or not the Potosi ores could be profitably mined, and to devise flowsheets whereby the ores could be treated to produce concentrates of saleable grade with a satisfactory recovery of the valuable tungsten mineral.

TUNGSTEN

Tungsten may be called the sturdiest of the metals. It has the highest melting point ($3410^{\circ} \pm 20^{\circ}$ C) and

smallest compressibility factor of the known metals, and it is the hardest metal ever used by man.[3] Because of its scarcity it is not used in the pure form, but tungsten is mixed with carbon, iron, and other elements to form alloys characterized by high melting points, extreme hardness, and resistance to acid corrosion. A well-known use of tungsten is in lightbulb filaments and other electronic equipment; its most important military use is as a constituent of armor-piercing shells.

The greatest tungsten deposits in the world are in China, and because of the present Communist domination of that country, it is necessary for national security that a domestic source of this element be found. It is toward this end that the government has attempted to expedite exploitation of our domestic tungsten reserves by granting, to independent operators, certain concessions which will tend to make the mining of tungsten ores a more profitable and promising venture than it has been in the past. Among the concessions are: government loans, generous depreciation and depletion allowances, and a stabilized tungsten price during a five year domestic tungsten purchasing program. The stabilized price program, which is very important to a person about to invest in a tungsten mine, provides for the purchase of tungsten concentrates, by the Administrator of General

Services, at a base price of $63 per short ton unit of contained tungsten trioxide (WO_3), less penalties. The stabilized price is to remain in effect until 1,468,750 short ton units of tungsten have been purchased by the government, or until July 1, 1956, whichever occurs first.[2] Tungsten purchasing schedules of the Administrator of General Services and of the United States Vanadium Company are included in the appendix of this report.

POTOSI MINING DISTRICT

The Potosi Mining District is located in Madison County, twelve miles from Pony, Montana. The district is large, and has many spotty deposits of high grade tungsten ore. Although the area has not been explored or developed to any great extent, it appears to be a potential tungsten source.

The Potosi ore occurs as huebnerite--a manganese tungstate. It is found as seams in massive, white quartz veins or pegmatite dikes.[5] As minerals occurring in pegmatite dikes are "very erratic in grade, persistence and direction; there is no means of predicting the character of the body for any distance from the exposed portion."[5] This leads to the conclusion that a great deal of exploration and a widespread sampling of the veins in the district must be undertaken before the importance of the region as a potential tungsten producer can be evaluated.

Many claims have been taken up in the Potosi District and several are patented.

PREVIOUS TESTWORK

Prior to this investigation, beneficiation tests were run on samples of huebnerite ore from the Potosi Mining District by J. A. Shaffer, Jr.[6] and H. Albright.[1] In each case, concentration by means of flotation, both at ambient and elevated temperatures, was attempted. Although Shaffer and Albright both concluded that further testwork was necessary, the reports of their results have been very useful in this investigation.

UNIT TESTING

Organization of Experimental Work. While reference has been made to previous experimental work performed on the material under investigation, the previous work did not contemplate complete processing of the Potosi huebnerite ore. The experimental work reported herein initially concerns the unit capabilities of several concentrating methods and then the combined effectiveness of several methods in sequence.

After sampling and grinding the ore, aliquot samples were tested by use of several gravity concentration devices to determine the effectiveness of the unit operation. Then a series of flotation tests were conducted

to determine the capabilities and limitations of flotation as a unit operation.

Upon concluding these unit tests, the various methods of concentration that had suggested themselves were co-ordinated to form complete process flowsheets. Tests were then made, following these flowsheets, in order to find the applicability of each process and to determine whether or not the results were reproducible.

Sample Preparation. The sample received for testing weighed 252 pounds. The entire lot was crushed in the laboratory jaw crusher; the minus 8 mesh material was screened out and the remaining material was passed and repassed through the laboratory rolls until all of the material was minus 8 mesh. The material was then coned and quartered once, and passed through a series of Jones riffles until a 60 gram assay sample was obtained. The sample assayed 7.88% WO_3.*

Mineral Identification and Estimation of Liberation. Various sized samples, taken from screen analysis, were examined under a binocular microscope. The mineralogical composition was mainly quartz with hubnerite interlocked; small amounts of pyrite, some feldspars, and a copper stain were noticeable.

* All assaying was performed by C. J. Bartzen, Analyst, Montana Bureau of Mines and Geology.

Liberation studies indicated that the huebnerite is almost completely freed from quartz at minus 65 plus 100 mesh. Liberation begins at about 20 mesh and gradually increases in degree up to 100 mesh, where it is almost complete. Shaffer found, by the particle-count method, a 10% liberation at 20 mesh, and over 90% liberation at 100 mesh. Inspection of Table I will illustrate relative particle size distribution of the minus 8 mesh material.

TABLE I SCREEN ANALYSIS

Screen Opening Inches (Retained On)	Mesh	Cumulative Weight Per Cent Retained		
		Sample #1	Sample #2	Sample #3
.1046	14	24.3		
.0328	20	39.5	0.03	
.0232	28	52.1	0.06	
.0164	35	62.0	0.16	
.0116	48	70.8	2.45	
.0082	65	77.4	19.54	
.0058	100	83.4	36.87	0.17
.0041	150	87.7	49.58	4.17
.0029	200	90.9	64.13	24.47
	-200	99.9	99.98	100.00

Sample #1--Minus 8 mesh material from rolls crusher

Sample #2--Ten minutes in the rod mill with load A*

Sample #3--Thirty minutes in the rod mill with load B*

* See Grinding, page , Appendix

Grinding. All of the grinding done in the experimental work was in the laboratory rod mill, which is 10 inches deep and 8 inches in diameter. Preliminary grinding tests, followed by screen analysis, were performed in the early stages of the investigation. The purpose of these grinding tests, in addition to preparing material for liberation studies, was to determine the degree of reduction to be expected when preparing a sample for a given unit test. Several different rod loads were used in various stages of the test work; they are referred to by a letter designation in various stages of the report and their composition is listed in the Appendix. All grinding was done at a pulp dilution of 50% solids by weight.

Jigging. The first step in testing the feasibility of gravity concentration was to run two samples through the laboratory Denver Pulsator Jig. The first sample was minus 8 mesh material as prepared by the initial crushing steps, and the second was of the same material after a ten minute grind at rod load "A" in the laboratory rod mill.

The operation produced two excellent concentrates of 70.45 and 73.70% WO_3, but the recoveries were low, 43.2 and 30.2% respectively.

Tabling. An unclassified portion of the minus 8 mesh

material was run over the laboratory Wilfley Table. The concentrate assayed 56.8% WO_3, and the recovery was 62.0%.

Although this recovery was much higher than that shown by jigging, the concentrate was not as high grade as could be produced by jigging and it was decided that tabling could not be used as the sole method of gravity concentration.

Dense Media Testing. After considering the degree of liberation in the coarse size ranges and studying the screen analysis of the minus 8 mesh material from the rolls crusher, it was decided that beneficiation by dense media separation was feasible. Huebnerite has a specific gravity of approximately 7.0 and quartz is about 2.65.

A sample of the minus 8 mesh material was taken and wet-screened to yield a minus 8 plus 48 mesh portion and a minus 48 mesh portion. The coarser material was tested at specific gravities of medium from 2.90 to 2.70, in 0.05 steps, the heaviest solutions being used first. The solutions used were prepared by mixing carbon tetrachloride and acetlyene tetrabromide to obtain the desired densities.

The results obtained compared favorably with those from jigging and tabling. The best concentrate produced was the sink product at specific gravity 2.90, which assayed 42.8% WO_3 and contained 76% of the tungsten in the plus 48 mesh feed and 46% of the tungsten in the entire

sample. A more significant result, however, was that the final float product at specific gravity 2.70 assayed only 0.20% WO_3, containing 2.38% of the tungsten in the feed and 1.45% of the tungsten in the sample. The results of the Dense Media Test are shown in Table II, page 10.

TABLE II DENSE MEDIA TESTING V

Product	Weight %		Cum. Wt. %		Assay	Cum. Assay	% Distribution		Cum. % Distribution	
	in feed	in heads	in feed	in heads	WO_3	WO_3	in feed WO_3	in heads WO_3	in feed WO_3	in heads WO_3
Sink 2.90	11.64	9.79	11.64	9.79	42.8	42.8	76.06	46.15	76.06	46.15
Sink 2.85	4.46	3.75	16.10	13.54	26.2	38.2	17.83	10.82	93.89	56.97
Sink 2.80	2.48	2.09	18.58	15.63	4.3	33.7	1.63	0.99	95.52	57.96
Sink 2.75	1.76	1.48	20.34	17.11	2.1	30.9	0.57	0.34	96.09	58.30
Sink 2.70	1.72	1.45	22.06	18.56	5.8	29.0	1.53	0.93	97.62	59.22
Float 2.70	77.94	65.58	100.00	84.14	0.20	6.55	2.38	1.45	100.00	60.66
Totals	100.00	84.14					100.00	60.66		
-48 Mesh	0.00	15.86		15.86	22.5	9.08		39.30		99.96
-8 + 48 Mesh	100.00	84.14		100.00				60.66		
Totals	100.00							99.96		

Flotation. The use of oleic acid as a collector in huebnerite flotation is common, and it was used with some success in the previous testwork referred to on page 4. It was therefore decided to use oleic acid in the preliminary unit tests. Other flotation reagents used were sodium carbonate, as a pH regulator and sodium (metso) silicate, as a gangue depressant and dispersing agent.

The preliminary flotation consisted of five tests, all conducted in a 600 gram Fagergren Laboratory Flotation Machine at a pulp dilution of about 20% solids. Many difficulties were encountered in the first tests; the machine was unable to lift the coarser particles at normal agitation and when the rotar speed was increased, the agitation destroyed most of the froth and lifted a large portion of the gangue to the top of the machine. A screen analysis of the first concentrate indicated that the machine was not capable of lifting any particle larger than 100 mesh. Because of this, grinding tests were conducted to determine the rod load and grinding time necessary to reduce all of a sample to minus 100 mesh (See Table I, page 6).

Because of visual inspection of the products from the first three tests showed that the results of these tests were not positive enough for evaluation, they were

not assayed. The two final tests were assayed, but the results were disappointing; they also indicated that the results were poor and not reproducible.

At this stage, it was decided to discontinue further flotation testing until a cell capable of lifting the heavy huebnerite particles, without bringing up the gangue and destroying the froth, could be obtained.

Summary of Unit Testing Operations. While none of the operations performed in the unit tests could be used satisfactorily as the sole concentration method for the Potosi huebnerite ore, the test results indicate that each of the methods tried would fit well into a process flowsheet.

Jigging could be used to take off a much desired hi-grade concentrate, if subsequent operations were capable of showing an acceptable recovery. Tabling could be used in place of jigging if it happened that the potential mill operators already had a table; and it could be used in connection with a jig to take off a second lower grade concentrate and yield a low-grade tailing which could be cleaned by flotation. Dense Media Separation presents a method of discarding a large amount of clean tailing, thereby greatly minimizing the grinding expense; and yielding a low-grade concentrate which could be sold as such or enriched by further treatment.

With the above conclusions in mind, three process flowsheets were drawn up and laboratory tests were run to determine probable results which could be achieved if the flowsheet were followed in an actual milling operation.

PROCESS FLOWSHEETS

For all flotation tests in this phase of the investigation, a 1000 gram Fagergren Laboratory Flotation Cell was used. This cell was employed because of its shape, which may be described as a cylinder imposed upon an inverted cone; the lower (conical) portion makes up approximately two-thirds of the depth of the cell. This cell was used so that it would be possible to have an agitation strong enough to lift the huebnerite particles without having a turbulence which would break the froth.

As time was an important factor in this investigation, it was not possible to conduct further preliminary flotation tests; so it was decided to follow the scheme which had given the best results in the previous testwork. It should be noted here that all prior flotation tests were run on unaltered feed material, while the samples floated in this phase had been subjected to one or more concentration method before flotation was

attempted. It is quite possible that this alteration of feed could greatly affect the subsequent flotation, especially reagent consumption. As stage addition of reagents is often desireable in the flotation of non-metallics, it was decided that this method of reagent addition should be followed.

As this investigation was progressing, other tests in the Mineral Dressing Laboratories disclosed that cotton-seed oil foots was a good collector in the flotation of scheelite, another tungsten ore--a calcium tungstate mineral. This reagent was tried in several of the tests, using the scheme of stage addition. The solution used contained acidulated cotton-seed oil foots, an equal amount of S-470 (American Cyanamid Co.), and a small amount of caustic, all in aqueous solution. The composition of this collector is shown in the appendix.

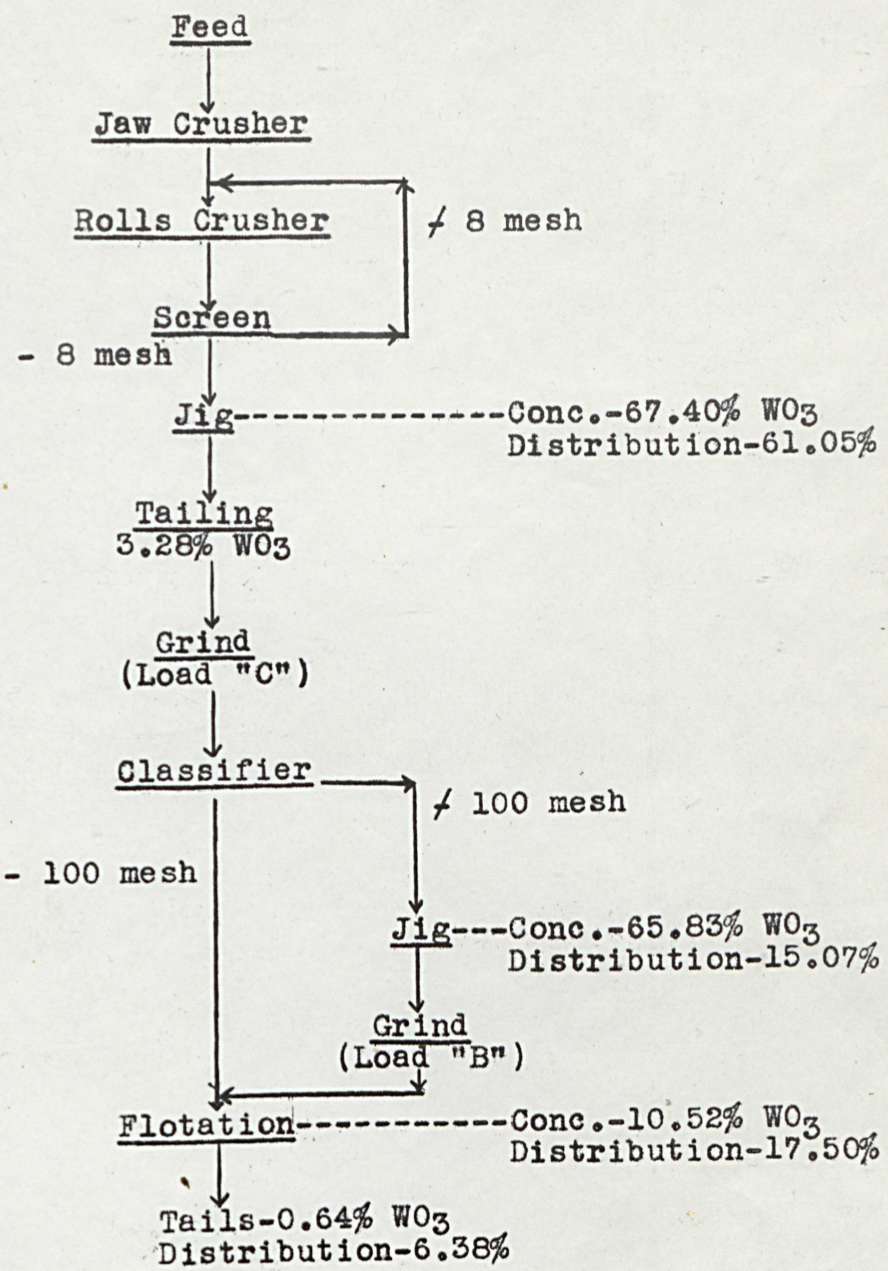
Flowsheet No. I: As each of the preliminary jigging tests indicated that this device would produce a high-grade concentrate, but not bring about an acceptable recovery, this flowsheet was designed to simulate a plant using a jig as the primary concentration device and employing flotation to recover the material lost in jigging.

A sample of the minus 8 mesh material from the rolls crusher was jigged and a high-grade concentrate was obtained. The jig tails were ground for 10 minutes, using rod load "C", and a Laboratory Fahrenwald Hydraulic Classifier was used to separate the plus 100 and minus 100 mesh fractions. The minus 100 mesh portion was then taken to flotation, while the coarser material was jigged, to produce another high-grade concentrate. The tails from the second jigging operation were ground, using load "B", and taken to flotation.

This flowsheet is outlined on page 16, and the data from two separate tests is there presented in a composite form. Complete data for each test will be found in the appendix.

Although each of the flotation tests was run separately, they are shown as one step in Flowsheet No. 1, because this method would more closely simulate actual plant practice.

PROCESS FLOWSHEET NO. I



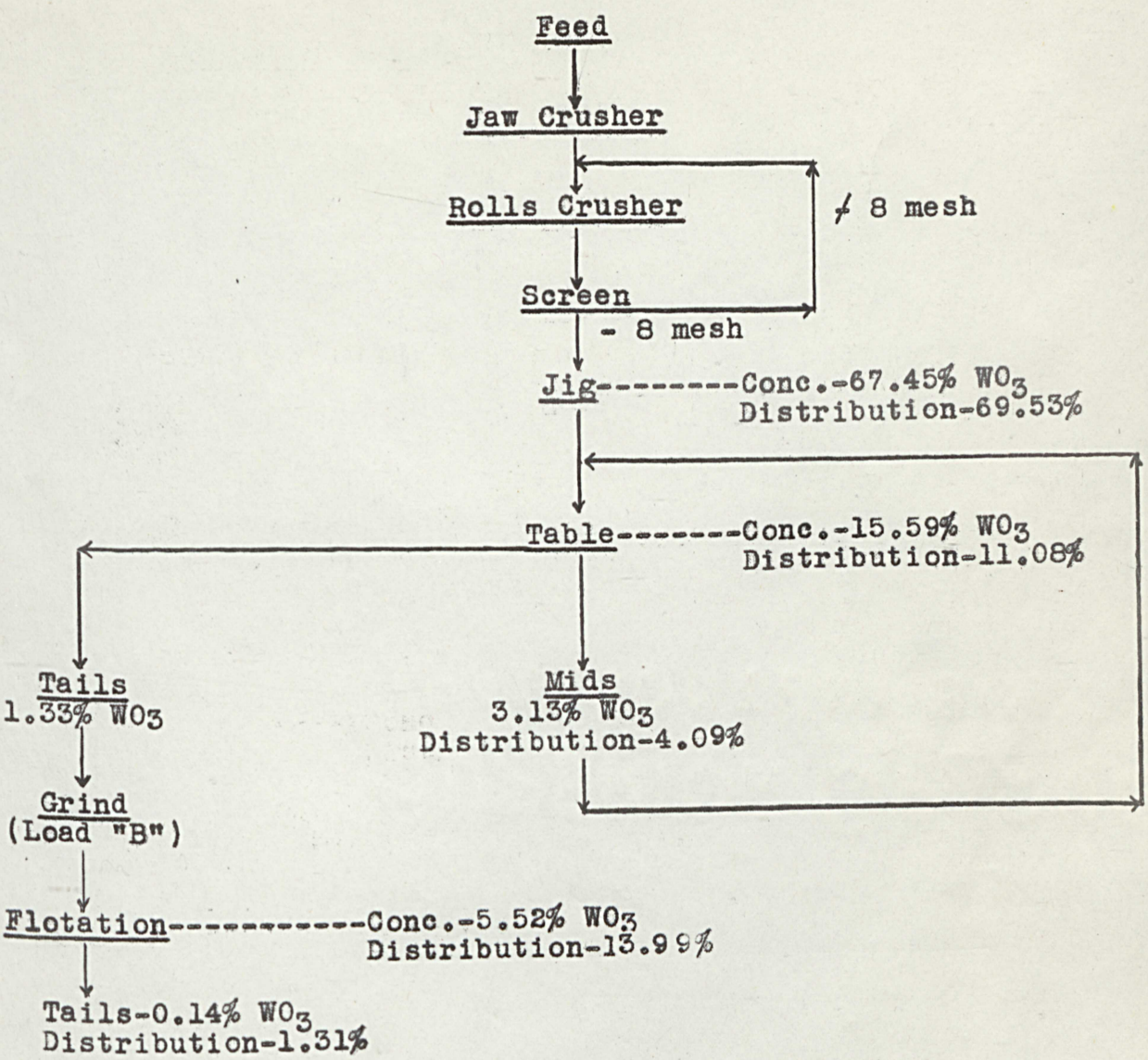
Recovery--93.62%

Flowsheet No. 2: This method was followed to determine the capabilities of an all gravity plant, and to find out what improvement could be expected if flotation were added to such a plant.

Samples of minus 8 mesh feed were jigged and a high-grade concentrate was obtained. The jig tails were then dried and passed over the table. This operation yielded three products: (1) a concentrate which, although it cannot be considered as high-grade, would be marketable under reasonably favorable conditions, (2) a low-grade middling which in actual plant practice would probably be recirculated in the gravity concentration circuit, and (3) a low-grade tailing which could be discarded in an all-gravity plant, operating under favorable mining and marketing conditions, or retreated by flotation if the plant were so equipped. The tailings from the tabling test were then ground for 10 minutes, using rod load "B", and the material was taken to flotation. A low-grade flotation concentrate was produced, and the final tailing was very low in tungsten.

This flowsheet is shown on page 18, and the data from two separate tests is there presented in a composite form. Complete data for each test will be found in the appendix.

FLOWSHEET NO. 2



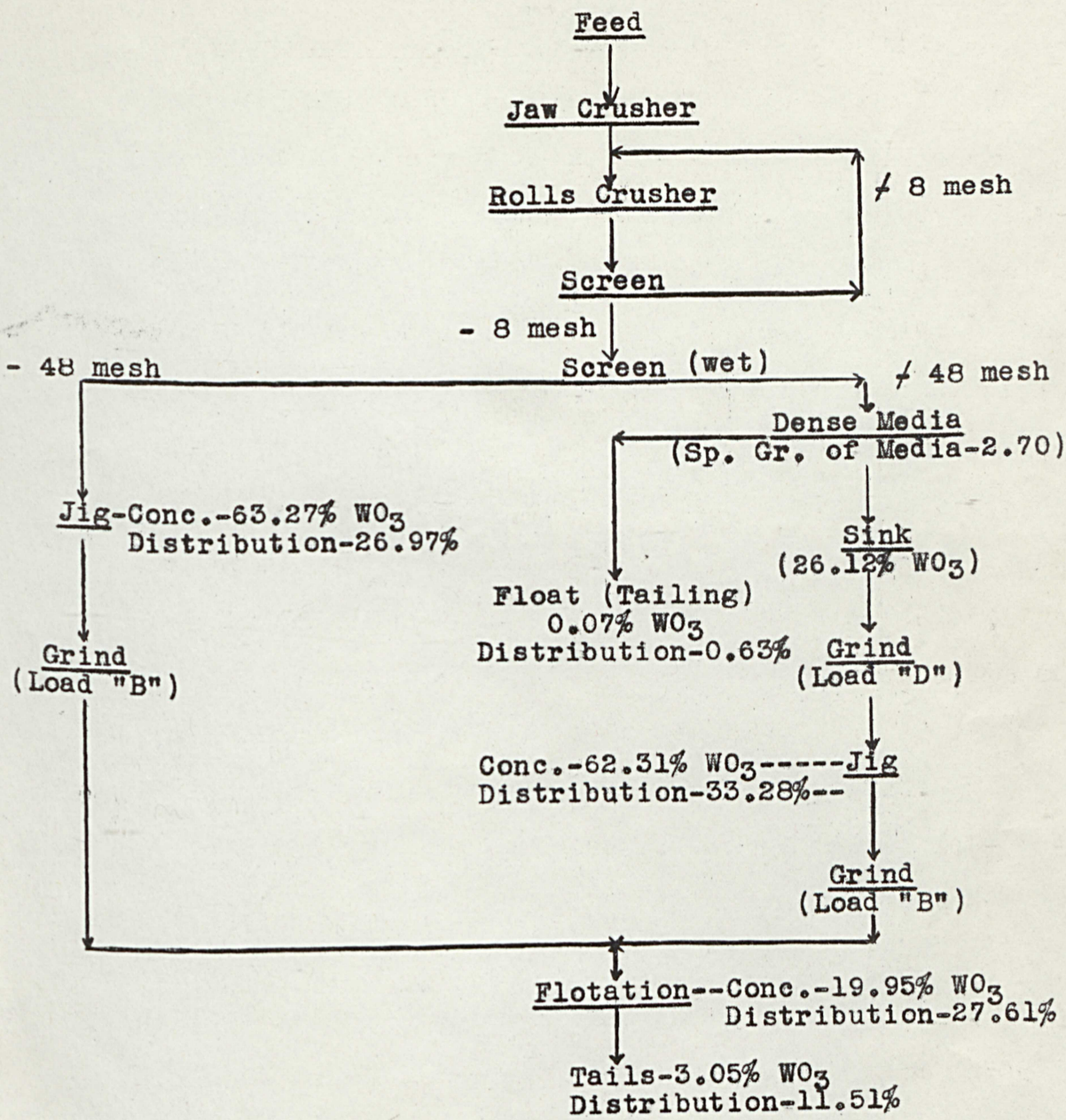
Recovery--98.69%

Flowsheet No. 3: This method of processing is presented last because the use of a dense media plant would not be likely if a small-scale operation were undertaken with little venture capital. The main advantage of applying dense media separation to this ore is that a large amount of relatively clean tailing could be rejected by this means, and thus eliminated from the following grinding and flotation circuits. This would result in a substantial reduction in grinding costs and in reagent consumption. If the plant feed were of much lower grade than was the feed in these tests, it is almost certain that the float product from a dense media operation would have to be ground and retreated if an acceptable recovery were to be realized.

In these tests the minus 8 mesh feed was wet-screened to separate the plus 48 and minus 48 mesh fractions. The minus 48 mesh portion was jigged and the jig tails were ground and taken to flotation. The minus 8 plus 48 mesh material was subjected to dense media separation, and the low-grade float product was discarded. The sink product was ground and jigged, and the jig tails were taken to flotation.

The test results are shown on page 20, and in the appendix. Separate flotations are again indicated as one operation on page 20.

FLOWSHEET NO. 3



Recovery--87.86%

DOLLAR VALUE OF CONCENTRATES PRODUCED

The following tables are presented to illustrate the probable dollar yields from the sale of concentrates produced by a mill employing one of the flowsheets here developed. It is assumed that the concentrates containing over 55% WO_3 are sold to the General Services Administrator and that those below grade are sold to the United States Vanadium Company. (For marketing schedules, see appendix.) The values reported represent the gross income from the sale of the concentrates; no accounting was made for mining, milling, shipping, or other expenses. The figures used are the composite data from two separate tests, as shown in the Flowsheet diagrams.

Since government purchasing agents penalize certain impurities above a maximum allowable percentage, several of the concentrates produced were analyzed for copper, iron, and sulphur. The presence of these elements was noted in the microscopic examination. The assays showed that the content of each of these elements was far below the maximum allowed; for this reason, their presence is not indicated in the data sheets.

FLOWSHEET NO. I

Product	Wt. %	% WO_3	Per Cent Recovery	Dollar Value per ton of ore treated
1st Jig Conc.	7.09	67.40	61.05	$301.14
2nd Jig Conc.	1.79	65.83	15.07	74.34
Flot. Conc.	13.01	10.52	17.50	52.06
Final Tails	78.11	0.64	(6.38)	(Loss)
Totals	100.00	7.83	(100.00)	$427.54

Recovery = 93.62%

FLOWSHEET NO. 2

Product	Wt. %	% WO_3	Per Cent Recovery	Dollar Value per ton of ore treated
Jig Conc.	7.07	67.45	69.53	$300.51
Table Conc.	4.86	15.59	11.08	28.88
Table Mids.	8.79	3.13	4.09	(Recirculated)
Flot. Conc.	17.32	5.52	13.99	29.76
Final Tails	61.96	0.14	(1.31)	(Loss)
Totals	100.00	6.86	100.00	$359.15

Recovery = 98.69%

FLOWSHEET NO. 3

Product	Wt. %	% WO_3	Per Cent Recovery	Dollar Value per ton of ore treated
1st Jig Conc.	2.70	63.27	26.97	$107.73
2nd Jig Conc.	3.38	62.31	33.28	132.93
Flot. Conc.	8.76	19.95	27.61	70.00
Flot. Tails	23.98	3.05	(11.51)	(Loss)
Dense Media Float	61.18	0.07	(0.63)	(Loss)
Totals	100.00	6.34	(100.00)	$310.66

Recovery = 87.86%

CONCLUSIONS

Each of the process flowsheets developed could be followed to concentrate an ore similar in character and grade to the sample available for the tests reported herein. The final selection would depend upon the daily tonnage to be treated; the water, power and other facilities available; the equipment, if any, already in the possession of the potential operators; and upon the judgment of the operating management.

RECOMMENDATIONS

It is recommended that no further testwork be done on the Potosi ores until sufficient exploration has been carried out to determine the grade and extent of the huebnerite deposits in the Potosi District.

The Potosi ore has shown itself to be very amenable to several methods of concentration; this is because of its occurrence with but one gangue mineral, and because of the large difference in specific gravities of the valuable and waste constituents. It is therefore assumed that, if the District contains sufficient huebnerite to warrant extensive development, suitable means of concentrating the mined material will be available.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Albright, H., Flotation of Huebnerite, Montana School of Mines, unpublished thesis, 1952.

2. G. S. A.--113, General Services Administration, Office of Public Information and Reports, May 10, 1951.

3. Metals Handbook, 7th edition, Cleveland, Ohio, The American Society For Metals, 1948, p. 1144.

4. McGlashan, Donald W., and Perry F. Roys,"The Tungsten Situation In Montana As A Factor In National Defense," Miscellaneous Contributions No. 12, State of Montana, Bureau of Mines and Geology, 1951, p. 3.

5. Potosi Tungsten, (O. P. 265-1-91-47 W. P. 3622), Butte, Montana, April, 1942, Mineral Resources Survey, Work Projects Administration.

6. Shaffer, James A. Jr., Beneficiation Of A Tungsten Ore, Montana School of Mines, unpublished thesis, 1951.

APPENDIX

APPENDIX

Exhibit I

Schedule for the Purchase of
Huebnerite Concentrates by the
Administrator of General Services.[2]

1. Percentage of tungsten trioxide (WO_3) required:
   Standard 60.0%
   Minimum. 55.0%

2.(a) Maximum percentage allowances of the following elements without penalty:

Tin (Sn)	0.25%
Copper (Cu)	0.10
Arsenic (As)	0.10
Antimony (Sb)	0.10
Bismuth (Bi)	1.00
Molybdenum (Mo)	0.50
Phosphorus (P)	0.05
Sulphur (S)	0.50
Manganese (Mn)	(*)
Lead (Pb)	0.20
Zinc (Zn)	0.10

*Not specified.

(b) The minimum base price shall be subject to the following adjustments:

(1) For each short ton unit of delivered tungsten trioxide (WO_3) the sum of twenty cents ($.20) shall be deducted from the base price for each one per cent of tungsten trioxide (WO_3) below the standard requirements set forth in subparagraph (a) of this Section. No tungsten concentrates not meeting the minimum requirements set forth in said subparagraph (a) will be accepted.

(2) For each short ton unit of delivered tungsten trioxide (WO_3) a deduction of twenty-five cents ($.25) shall be made for each of the following increments in excess of the maximum allowances (subparagraph (a)), as to each of the following elements:

Copper (Cu)	0.01%
Phosphorus (P)	0.01
Arsenic (As)	0.10
Bismuth (Bi)	0.50
Molybdenum (Mo)	0.10
Tin (Sn)	0.10
Sulphur (S)	0.10
Antimony (Sb)	0.10
Manganese (Mn)	1.00
Lead (Pb)	0.10

Exhibit II

UNITED STATES VANADIUM COMPANY
A Division of Union Carbide and Carbon Corporation
BISHOP, CALIFORNIA

TUNGSTEN CONCENTRATE PURCHASING SCHEDULE

October 1, 1952

The United States Vanadium Company is purchasing at its Pine Creek Plant, concentrates of scheelite or scheelite and powellite which meet its specifications.* The Company will accept such a concentrate after it has metallurgically tested a representative sample of the concentrate, and only if the test indicates the concentrate to be amenable to the processes employed by the Company, with the Company (or its agents) being the sole judge of the acceptability of such concentrates. Acceptable concentrates will be purchased by the Company under the terms and conditions listed next below and which are subject to change without advance notice.

1. DEDUCTIONS AND TREATMENT CHARGES

The Company will make outright purchase of acceptable concentrates, delivered f.o.b. the Company's plant, on the basis of the net WO_3 content of the concentrate. No deductions as such are made for handling,

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* The U. S. Vanadium Company will accept huebnerite concentrates if metallurgical tests show them to be amenable to its processing method.

sampling, treatment charges, metallurgical losses or impurities.

2. PURCHASE RATES

The following purchase rates are effective as of this date. These rates are subject to change or adjustment by the Company, and further, the Company reserves the right to withdraw, at any time, any offer it makes to purchase.

WO_3 CONTENT	PRICE PER SHORT TON UNIT WO_3
5% to and including 5.999%	$31.00
6% " " " 6.999%	33.00
7% " " " 7.999%	35.00
8% " " " 9.999%	37.00
10% " " " 15.999%	38.00
16% " " " 24.999%	40.00
25% " " " 29.999%	41.00
30% " " " 34.999%	42.00
35% " " " 39.999%	43.00
40% " " " 44.999%	44.00
45% and higher	45.00

The Company normally does not purchase concentrates containing less than 5% WO_3. However, should an exception be made and the Company agrees to accept such material, the purchase rates shall be determined at the time of the acceptance agreement. It shall be the shipper's responsibility to ascertain the WO_3 content of all material prior to shipment. The Company does not do custom assaying.

No payment will be made for metals other than tungsten contained in delivered concentrate.

EXHIBIT III

COMPOSITION OF COTTON-SEED OIL FOOTS

Acidulated Cotton-seed Oil Foots	3.5%
Caustic	0.5%
American Cyanamid Co. S-470	3.5%
H_2O	92.5%
	100.0%

TABLE III GRINDING

Load	Number and Size of Rods				
	1/4 in.	1/2 in.	3/4 in.	1 1/4 in.	1 1/2 in.
"A"			4	4	2
"B"	12	4	8	2	
"C"			4	2	2
"D"			4	2	

TABLE IV JIGGING

	Sample #1	Sample #2
Composite Assay of Feed (WO_3)	5.72%	5.38%
Assay of Concentrate	70.45%	73.70%
Assay of Tailings	3.38%	3.82%
Wgt. % of Concentrate	3.50	3.20
Recovery (WO_3)	43.20%	30.20%

TABLE V TABLING

Wgt. Percent of Concentrate	Assay of Concentrate (WO_3)	Recovery (WO_3)
8.6	56.8	62.0%

TABLE VI FLOTATION

Test No.	Reagents (lb/ton) Na_2CO_3	Na_2SiO_3	Oleic	pH	Recovery	Concentrate (WO_3)
4	1.5	1.0	0.40	8.0	80.8%	26.6%
5	12.0	1.0	0.40	8.5	32.5%	30.4%

TABLE VII

Data For Process Flowsheet No. 1

Test #1

Product	Wt. %	% WO_3	Per Cent Recovery
1st Jig Conc.	7.11	66.0	56.92
2nd Jig Conc.	1.72	65.8	13.71
1st Flot. Conc.	4.36	6.3	3.29
1st Flot. Tails	16.89	3.4	6.92
2nd Flot. Conc.	7.84	19.4	18.45
2nd Flot. Tails	62.08	0.1	0.71
Totals	100.00	8.24	100.00

Recovery = 92.37%

Test #2

Product	Wt. %	% WO_3	Per Cent Recovery
1st Jig Conc.	7.06	68.8	65.50
2nd Jig Conc.	1.88	66.2	16.71
1st Flot. Conc.	6.08	9.2	7.55
1st Flot. Tails	15.83	1.5	3.23
2nd Flot. Conc.	7.73	5.2	5.39
2nd Flot. Tails	61.42	0.2	1.62
Totals	100.00	7.42	100.00

Recovery = 95.15%

TABLE VII (Cont'd)

Flotation Data

Flotation Feed	Test No.	Reagents lb/ton				pH
		Oleic	C. O. F.	Na_2CO_3	Na_2SiO_3	
Classifier Overflow	1		150	2.7	2.7	9.9
2nd Jig Tails	1		100	1.6	1.6	9.6
Classifier Overflow	2		35	2.7	2.7	9.9
2nd Jig Tails	2	1.2		1.6	1.6	9.6

TABLE VIII

Data For Process Flowsheet No. 2 VII

Test #1

Product	Wt. %	% WO_3	Per Cent Recovery
Jig Conc.	6.76	64.1	67.55
Table Conc.	5.27	19.2	15.76
Table Mids.	8.77	3.1	4.21
Flot. Conc.	15.38	4.8	11.54
Final Tails	63.82	0.1	0.94
Totals	100.00	6.41	100.00

Recovery = 99.06%

TABLE VIII (COnt'd)

Test #2

Product	Wt. %	% WO_3	Per Cent Recovery
Jig Conc.	7.25	70.6	71.31
Table Conc.	4.61	11.4	7.38
Table Mids.	8.81	3.2	3.90
Flot Conc.	18.48	6.1	15.74
Final Tails	60.85	0.2	1.67
Totals	100.00	7.18	100.00

Recovery = 98.33%

Flotation Data

Flotation Feed	Test No.	Reagents lb/ton			pH
		C. O. F.	Na_2CO_3	Na_2SiO_3	
Table Tails	1	100	1.6	1.6	9.6
Table Tails	2	55	1.6	1.6	9.6

TABLE IX VIII

Data For Process Flowsheet No. 3

Test #1

Product	Wt. %	% WO_3	Per Cent Recovery
1st Jig Conc.	2.94	62.6	29.07
2nd Jig Conc.	3.48	54.3	29.86
1st Flot. Conc.	2.71	13.3	5.69
1st Flot. Tails	17.41	2.5	6.95
2nd Flot. Conc.	3.13	38.2	18.80
2nd Flot. Tails	7.09	7.7	8.68
Dense Media Float	63.24	0.1	0.95
Totals	100.00	6.33	100.00

Recovery = 83.42%

Test #2

Product	Wt. %	% WO_3	Per Cent Recovery
1st Jig Conc.	2.45	64.0	24.72
2nd Jig Conc.	3.26	70.9	36.38
1st Flot. Conc.	8.02	11.5	14.49
1st Flot. Tails	15.61	0.2	0.47
2nd Flot. Conc.	3.75	27.6	16.38
2nd Flot. Tails	7.85	5.7	7.09
Dense Media Float	59.06	0.05	0.47
Totals	100.00	6.35	100.00

Recovery = 91.97%

TABLE IX (Cont'd)

Flotation Data

Flotation Feed	Test No.	Reagents lb/ton				pH
		Oleic	C. O. F.	Na_2CO_3	Na_2SiO_3	
1st Jig Tails	1		55		2.0	7.4
2nd Jig Tails	1		100	1.0	1.0	9.3
1st Jig Tails	2	0.60		1.5	1.0	9.1
2nd Jig Tails	2		250	1.0	1.0	9.7

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