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The Testing and Concentration of a Tungsten Ore

Turdat S. Simone

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THE TESTING AND
CONCENTRATION OF A TUNGSTEN ORE

By
Turdat S. Simone

Submitted to the Department of Mineral Dressing
in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Metallurgical Engineering

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
MAY, 1940
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INTRODUCTION

At the present time the principal uses for tungsten lie in the manufacture of ferro-alloys and tungsten steels. Due to its hardening and strengthening characteristics it holds an important position among steel hardening metals. The great rush for its production during the World War years clearly points to its importance in the manufacture of armament.

During the past 20 years at least 60 concentrators, ranging in capacity from several tons to 300 tons per day, have been erected in the United States. A great many of these mills were erected hurriedly during the World War and operated for only a short time when the demand for tungsten as a pivotal war mineral was imperative. Frequently these hastily designed and built mills were able to operate only because of the extremely high prices paid for tungsten concentrated at the time.

More than 99 per cent of all tungsten mined goes into the manufacture of the above mentioned ferro-alloys and tungsten steels. Tungsten is an essential element of high-speed steels, which are indispensible in present day manufacturing.

Other uses for the metal are for magnet steel, alloys with aluminum, copper, zinc, nickel, cobalt, and other metals, incandescent lamp filaments, electrical apparatus, X-ray tubes, needles for sound production, and as a catalyst in the production of ammonia from atmospheric nitrogen.
TYPES OF TUNGSTEN DEPOSITS

Ore deposits are usually classified according to the processes involved in their origin. Tungsten deposits are represented in almost every type of deposit. These include: (1) Segregation deposits (2) Granite and pegmatite veins having been formed under pneumatolytic conditions (3) Replacement deposits (4) Contact metamorphic deposits (5) Veins (6) Placers. They are also deposited in sulphide veins, commonly found with cassiterite and associated also with selenite, bismuth, quartz, pyrite, galena, sphalerite, etc.

Segregation Deposits

As the name implies, this type of deposit is formed by the segregation of certain minerals from an igneous mass on cooling. The minerals thus differentiated are present in greater amounts in the deposit than in the rock as a whole.

Segregation deposits are characterized by their irregular form and their freedom from fissures. These deposits are a part of igneous intrusions, and the gangue minerals are those of the parent rock. A tungsten deposit of this type occurs in the Whetstone Mountains, Cochise County, Arizona, where small flat crystals of wolframite are distributed through granite in irregular masses that lie close to small irregular gash veins.
Pegmatites

Pegmatite deposits are related closely to segregation deposits, as they are also end products of crystallization that have been thrust into openings in rocks already consolidated. Pegmatites are commonly found in dykes, but sometimes show pipelike or other irregular forms. The constituent crystals of pegmatite generally are larger than the crystals of igneous rocks or veins. Quartz, feldspars and mica predominate. In addition to these minerals, which are also present in the parent granite from which the pegmatites are derived, pegmatites may include a great variety of other minerals, such as tourmaline, apatite, spodumene, amblygonite, garnet, beryl, columbite, triphylite, lithiophilite, cassiterite, and wolframite. These latter minerals if present in the parent rock occur in very small amounts, so that the pegmatites may be considered a type of segregation deposit. On the other hand some pegmatites which consist largely of quartz show the characteristics of veins.

The best examples of tungsten bearing pegmatites in the United States are in the Harney Peak and Tinton district South Dakota. Although these pegmatites are important as a source of some rare minerals and gems they have been of minor importance as tungsten producers.
Replacement Deposits

Replacement deposits are found where solutions have dissolved the original rock and material of different composition is deposited in the space left by the solution. Deposition may follow solution so closely that the form and texture of the original materials are preserved. Because of their solubility, carbonate rocks are favorable for replacement.

The best known examples of this type of tungsten deposit in the United States occur in the Northern Black Hills near Lead, South Dakota, where flat-lying dolomite limestone has been replaced by silica and wolframite. The ore bodies average about 2 feet in thickness, although they range from lenticular seams a few inches thick to large lens-shaped bodies about 6 feet thick. In general replacement deposits of tungsten ores are irregular in form and erratic in mineral distribution.

Contact-Metamorphic Deposits

Contact-metamorphic deposits are formed in intruded rocks of calcareous composition by solutions and gases emanating from the intruded magma. Undoubtedly metamorphism destroys the original composition of the carbonate rocks; during the process of destruction an aggregate of characteristic contact-metamorphic minerals is developed—garnet, epidote, calcite, diopside, actinolite, scheelite, and numerous silicates
of calcium, magnesium and iron. This type of tungsten deposit is readily recognized by these minerals. The tungsten mineral in contact metamorphic deposits is invariably scheelinite; it occurs as grains ranging from the size of a pin head to 1 inch or more in diameter, but the smaller sizes usually predominate.

Mineralization of the contact-metamorphic deposits generally follows the structure of the original sedimentary beds. The scheelinite usually is distributed throughout the beds more uniformly than tungsten ores in other types of deposits.

Nearly all the contact-metamorphic tungsten deposits known in the United States were discovered during the World War when the demand for tungsten was great and the prices rose to unprecedented heights. In recent years most of the domestic production of tungsten concentrates has been derived from the contact-metamorphic deposits of the Great Basin region. Contact-metamorphic deposits have been worked in the Mill City and Nightingale districts, Nevada, and near Bishop, California.

Veins

Veins are formed by solutions that have filled cracks or fissures within the rocks. The mineralizing solutions in some places have replaced the wall rocks, but ordinarily such replacement is not so extensive as to obliterate the relationship of these deposits to the fissure. In other places the walls of the veins are "frozen" to the vein matter. Veins containing tungsten ores may occur in single crevices or in two or more parallel zones of shearing. If shearing has been intense a
series of interlacing veins or "stack works" may be formed. Tungsten veins are subject to all the vagaries common to veins containing silver, gold or other ores, such as branching, alternate pinching and swelling, brecciation and sudden changes of direction.

The tungsten minerals may be any of the important ores with wolframite a little more common than ferberite, hubnerite or scheelite. Little by-product tungsten is produced in the United States from veins carrying ores of other metals, although gold, usually in small amounts, is found associated with scheelite and silver in the wolframite group tungsten minerals. In veins in other parts of the world gold, molybdenum, bismuth, tin and copper occur with tungsten ores. In general, tungsten ores in veins are erratic in form, size and distribution of tungsten content.

Quartz and calcite are the most abundant gangue minerals in this type of deposit, although virtually all minerals ordinarily associated with veins may be present. Inclusions of wall rock are often found in vein fillings.

Representative vein type tungsten deposits occur at Boulder, Colorado, at Atolia, California and in the Silver Dyke District near Mina, Nevada. In the past the major production of tungsten concentrated in the United States has been derived from veins.

**Placers**

The agents of erosion—heat and cold, impact of sliding and water carried rocks, vegetable growth and chemical decomposition in conjunction with the mechanical processes of natural
concentration-form placer deposits. Under proper conditions virtually all types of tungsten deposits of sufficient size are possible sources of placer tungsten. As erosion takes place, the tungsten minerals, like gold, platinum, cinnabar, and tin minerals are deposited at the foot of slopes or in streams along with sand and gravel. The minerals associated with tungsten placers are similar in that they are not readily soluble in water or natural solution. Tin is commonly associated with tungsten minerals in various parts of the World. Tungsten placers formed on slopes are likely to have the tungsten minerals uniformly distributed throughout the gravel, whereas those formed by swift streams are likely to be irregular and their minerals may lie in pockets.

Not all tungsten deposits in place are associated with placers. Since tungsten minerals are extremely brittle they have been ground to an impalpable powder by intensive mechanical attrition and carried away in the drainage. Moreover, if conditions are favorable, the tungsten minerals may have been dissolved and thus carried away.

From the standpoint of world production of tungsten concentrated, placers have been the most important producers, the wolframite placers of Kiangsi and Kwangtung, China, being the most productive. The best known tungsten deposits in the United States are at Boulder, Colorado, the Atolia district, California and the Snake Range near Osceola, Nevada. All these placers were worked intensively during the World War and have produced considerable tungsten concentrated.
The ore on which work was to be done for this thesis was contained in three sacks, in the mill building, at the Montana School of Mines. The locality from which the ore came is not known, as the identification tags did not contain this information. The average size of the ore was 3 inches. A briquette was made from a sample of the ore and examined under a microscope for the purpose of identifying the minerals present. (Figure 7) The following minerals were observed under the microscope: wolframite, a little ferberite, pyrite, magnetite, limonite, apatite, with quartz as the gangue. Figure 3 shows contact between wolframite and quartz and intrusion of wolframite in quartz.

A market standard has been set which requires that tungsten concentrates carry upwards of 65% WO₃ and not more than 0.5% each of Sn, Cu, P, As, and S. Lower grades are used in chemical manufacture, which accounts for only a small percentage of the production.

REDUCTION OF THE ORE

The ore was crushed from its initial 3-inch size to about minus 4 mesh in a Dodge crushe in the mill building. It was further reduced to about ten mesh in a gyratory crushe
This photomicrograph shows a polished section of a piece of tungsten ore. It clearly shows the plane of contact between the bright wolframite in the top half of the picture, and the quartz in the bottom half. 
Magnification X 100
and at this stage the whole sample was coned and quartered, one quarter weighing about 40 pounds. This was now used as the representative sample which experiments were continued. All of this sample was put through the rolls to minus 20 mesh. This was then quartered by means of a Jones splitter. One quarter was then reduced in size by means of a bucking board to minus 100 mesh. All qualitative and quantitative chemical analyses were carried out at this size.

ANALYSIS OF THE ORE

The object of chemical analyses at this state was to determine the elements and their amounts present in the head sample.

Qualitative

Microscopic examination showed that tungsten was present either as wolframite or ferberite or hubnerite. Qualitative test showed, by the presence of manganese and iron that the mineral present was beyond doubt wolframite.

Quantitative

The analysis of the ore offers some difficulty, especially in the decomposition of the wolframite. The method employed is as follows:—Three 1-gram samples were taken, each in a 250 cc. beaker; 10cc. aqua-regia were added and allowed to react with the charge. When violent action ceased each sample was allowed to evaporate to dryness. The residue was partially
dissolved by boiling with 20 cc. HCl (1:1) and a few drops of HNO₃. Continued attack with HCl and HNO₃ finally resulted in the complete decomposition of the wolframite. The dry residue was diluted with 100 cc. water and boiled, until the WO₃ precipitate was yellow. This was then filtered, washed carefully with hot HCl (1:1) without the addition of water, to remove all iron. Each charge was then ignited in a porcelain crucible until the filter paper was burned off, the separate charges not being heated above a dull red heat. The charges were then cooled in a desiccator. The product containing SiO₂ and WO₃ was then boiled with ammonium hydroxide. The tungstic acid forms ammonium tungstate but the SiO₂ is insoluble. The solution was then filtered. Silica was left as a residue and the filtrate contained the tungsten as ammonium tungstate. The filtrate was acidified with HCl and boiled until a precipitate was left in the crucible. The residue in the first case was weighed as silica.

<table>
<thead>
<tr>
<th>Weight of the residue:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) 0.89 grams</td>
</tr>
<tr>
<td>(2) 0.90 grams</td>
</tr>
<tr>
<td>(3) 0.89 grams</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weight of ammonium tungstate precipitate:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) 0.023 grams</td>
</tr>
<tr>
<td>(2) 0.022 grams</td>
</tr>
<tr>
<td>(3) 0.022 grams</td>
</tr>
</tbody>
</table>

The percentage of tungsten is: \(0.022 \times 0.7931 \times 100 = 1.76\%\)

**Sizing Analysis**

Five hundred grams of the 20-mesh ore were taken and sized from 48 to 200 mesh on the single Tyler screen scale. The results of the screen analysis are presented in Table 2.

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Wt. in Grams</th>
<th>% Wt.</th>
<th>Cumulative Wt. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>257.4</td>
<td>51.5</td>
<td>51.5</td>
</tr>
<tr>
<td>65</td>
<td>60.5</td>
<td>12.1</td>
<td>63.6</td>
</tr>
<tr>
<td>100</td>
<td>53.5</td>
<td>10.7</td>
<td>74.3</td>
</tr>
<tr>
<td>150</td>
<td>37.4</td>
<td>7.4</td>
<td>81.8</td>
</tr>
<tr>
<td>200</td>
<td>22.8</td>
<td>4.5</td>
<td>86.3</td>
</tr>
<tr>
<td>270</td>
<td>68.0</td>
<td>13.6</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>499.6</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

A similar test was carried out with 500 grams of the ore starting with 20 mesh as before, but in this case the screening was carried out by washing the several sizes through the screens with water. Table 3 gives the results of the test.

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Wt. in Grams</th>
<th>% Wt.</th>
<th>Cumulative Wt. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>50.0</td>
<td>10.2</td>
<td>10.2</td>
</tr>
<tr>
<td>35</td>
<td>92.3</td>
<td>18.6</td>
<td>28.8</td>
</tr>
</tbody>
</table>

(continued)
TABLE 3 (continued)

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Wt. in Grams</th>
<th>% Wt.</th>
<th>Cumulative Wt. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>36.3</td>
<td>17.4</td>
<td>46.2</td>
</tr>
<tr>
<td>65</td>
<td>67.2</td>
<td>13.6</td>
<td>59.8</td>
</tr>
<tr>
<td>100</td>
<td>51.0</td>
<td>10.3</td>
<td>70.1</td>
</tr>
<tr>
<td>150</td>
<td>32.8</td>
<td>6.7</td>
<td>76.8</td>
</tr>
<tr>
<td>200</td>
<td>28.4</td>
<td>5.6</td>
<td>82.6</td>
</tr>
<tr>
<td>270</td>
<td>87.2</td>
<td>17.4</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>495.2</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

The weight percentages and cumulative weight percentages for the different mesh sizes showed that either wet screening or dry screening would do in the treatment of the ore.

**Float and Sink Analysis**

About 30 grams from each mesh size from the above screen analysis were taken and tested by the sink-and-float method. For this experiment a separatory funnel was used. Acetylene tetrabromide was put in the separatory funnel with the sample of ore. After thoroughly shaking, the two fractions were allowed to collect as sink and float products. After filtering the two products, they were washed several times with carbon tetrachloride. The results of the analysis have been set out in Table 4.
The float and sink products were examined under a microscope in order to determine the size of particle liberation. The results of the examination are set out in Table 5 below:

**TABLE 5**

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Sink</th>
<th>Float</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Liberation poor</td>
<td>Liberation poor</td>
<td>Silica stained w/Fe</td>
</tr>
<tr>
<td>35</td>
<td>Liberation poor</td>
<td>Liberation poor</td>
<td>Silica stained w/Fe</td>
</tr>
<tr>
<td>48</td>
<td>Liberation good</td>
<td>Liberation good</td>
<td>Silica clean</td>
</tr>
<tr>
<td>65</td>
<td>Liberation good</td>
<td>Liberation good</td>
<td>Silica clean</td>
</tr>
<tr>
<td>100</td>
<td>Liberation good</td>
<td>Liberation good</td>
<td>Silica clean</td>
</tr>
<tr>
<td>200</td>
<td>Liberation good</td>
<td>Liberation good</td>
<td>Silica clean</td>
</tr>
</tbody>
</table>

From the above table it will be seen that the size at which the wolframite is free from the gangue is 48 mesh. A quantitative analysis was run on the float products starting
from plus 48 mesh. A very high percentage of silica, traces of tungsten and manganese were found in all the samples.

A briquette was made from a portion of the plus 48 mesh sink product for examination by microscopic methods. Figure 2 shows the main constituents of the sink product to be wolframite (hubnerite), pyrite, limonite, and a few particles of transparent gangue.

COMMERCIAL CONCENTRATION OF ORE

In almost all cases of commercial concentration of tungsten ores gravity methods predominate. Variations in treatment comprise hand sorting ahead of the jigs, rough classification prior to tabling, magnetic separation of roasted concentrate, tabling the slimes or flotation of the slimes. The particular method adopted depends upon the size of dissemination.

The simple ores are usually of higher grades than the complex ores and the tungsten mineral is usually more coarsely disseminated. Modern practice recognizes the friability of tungsten minerals and the sole endeavor is to crush so as to produce as little slime as possible and to begin removal of the concentrate as soon as the mineral is free.

In treating higher grade ore, tailing from slime tables and vanners is usually run over rag frames and the frame concentrate cleaned or shipped to electric furnace plants or floated.
This photomicrograph, taken at 100 magnifications, shows bright particles of pyrite interspersed among dark particles of wolframite. For this photograph concentrates from 45 mesh sink and float tests were used.
LABORATORY CONCENTRATION OF THE ORE

Due to the considerable difference in specific gravities between wolframite (7.4) and gangue (2.7) it was decided that a good concentration might be obtained by classifying and tabling the coarse sizes. Since sink-and-float tests showed that complete liberation was obtained at 48 mesh gravity concentration seemed feasible.

Classification

A constriction-plate hydraulic classifier (Fig. 3) was used, each charge being about 15 pounds. Three spigot products were drawn off, after the slimes had been removed. The slimes were saved and their treatment will be discussed later. The spigot products were coarse enough to be tabled. After classifying several samples of the ore the author's conclusions are that in milling practice the product should be graded according to size as it passes through the mill, thus eliminating as much of the tungsten minerals as possible from the various sizes by machines best adapted for their recovery. This procedure is important in that: (1) It would give a higher recovery by preventing slime loss in subsequent regrinding operations and (2) It would reduce the amount of equipment necessary for the treatment of slimes if such equipment is employed. It is important in milling practice that a clean sand-slime separation be made, so that these products can be treated on separate
A constriction plate hydraulic classifier, used by the author in the laboratory concentration of the tungsten ore.
machines. As in all gravity concentration slime treatment presents the most difficult problem. The best practice would be to reduce the amount of slimes to a minimum, separate it from the sand and treat it in as long a series of machines as is consistent with economy.

**TABLE 8**

This operation was carried out on a laboratory size Wilfley table with 340 strokes per minute. The length of each stroke being 1.5 inches. A very good concentration of the wolframite was obtained. Table 6 indicates the results obtained and the chemical analysis of these results.

<table>
<thead>
<tr>
<th>Product</th>
<th>Weight</th>
<th>Assay WO₃</th>
<th>S %</th>
<th>P %</th>
<th>Total WO₃</th>
<th>S %</th>
<th>P %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrate</td>
<td>10.2</td>
<td>78.8</td>
<td>3.6</td>
<td>.92</td>
<td>78.7</td>
<td>90.0</td>
<td>49.6</td>
</tr>
<tr>
<td>Middling</td>
<td>34.3</td>
<td>4.04</td>
<td>.09</td>
<td>.06</td>
<td>13.60</td>
<td>8.8</td>
<td>10.92</td>
</tr>
<tr>
<td>Tailing</td>
<td>45.0</td>
<td>.57</td>
<td>.009</td>
<td>.02</td>
<td>2.40</td>
<td>.97</td>
<td>4.80</td>
</tr>
<tr>
<td>Slimes</td>
<td>10.5</td>
<td>5.06</td>
<td>.01</td>
<td>.30</td>
<td>5.00</td>
<td>.27</td>
<td>34.48</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
<td>10.21</td>
<td>.41</td>
<td>.19</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The concentration in itself is sufficiently high in WO₃ content to require no further enriching. The chief difficulty lies in the high sulphur and phosphorus content of the concentrate. As stated before the percentage of sulphur and that of the phosphorus must be below 0.5% in order that the concentrate may be considered of commercial grade.
On examining the concentrate under a microscope it was noticed that iron was present in the form of pyrite \((\text{FeS}_2)\) limonite \((2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O})\) magnetite \((\text{Fe}_3\text{O}_4)\) and some free iron that was introduced into the ore from the use of the bucking board in comminution. The only sulphur that would be present in the ore in any great amounts must have come from the pyrite.

It was decided that the sulphur content would be greatly reduced by removal of this sulphide of iron.

**Roasting**

Taggart says that "pyrite may be converted by roasting either to \(\text{Fe}_7\text{S}_8\) or to \(\text{Fe}_3\text{O}_4\) both of which are highly magnetic, according to the nature of the roast. When heated in the presence of air, pyrite decrepitates at 60° C., and as the temperature is raised loses sulphur more and more rapidly until at 400° C the magnetic sulphide, \(\text{Fe}_7\text{S}_8\) is formed, the sulphur igniting and passing off as \(\text{SO}_2\) gas. If the period of subject-ion to heat is short, only the surface of the pyrite is altered, and \(\text{Fe}_7\text{S}_8\) is formed, but the particles to be lifted by the magnet in a field of high intensity."

**Arthur F. Taggart**  "Handbook of Ore Dressing"

John Wiley and Sons.
Further roasting at 500 to 600° C. with limited air and an atmosphere of CO, H, and SO₂ results in conversion to the highly magnetic Fe₃O₄, more or less complete according to the duration of the roast and size of the particles.

About 500 grams of the concentrate were dried and placed in an earthenware dish, a similar dish being placed on this as a cover. The temperature of the assay furnace in which the concentrate was roasted was carefully regulated by means of a Hoskins Chromel-Alumel thermoelectric pyrometer. The temperature was kept a little above 400° C. in the furnace, the door left open, and the lid of the dish placed so that the sample was exposed to air.

After fifteen minutes the dish was taken out and the sample examined. It was noticed that the pyrite particles were no longer present as such. There were some brown particles present; undoubtedly the magnetic Fe₇S₈. This was confirmed by examination under a microscope.

According to Taggart "roasted materials must be cooled before passing through the separators, on account of the destructive effect on the machines and difficulty in handling. Cooling must be done out of the presence of air in order to prevent re-oxidation".

The separation was effected by means of the magnetic separator in Figure 4. Power was supplied by a 3/4 K. W. 125 volt Westinghouse D. C. generator; two straight, pointed tip magnets picking up the magnetic material which was fed into a glass tube between these magnets.
Figure 4.

Laboratory magnetic separator used by the author in the separation of magnetic Fe₇S₈ from roasted tungsten concentrates.
A briquette of the magnetic substance was made
(See Fig. 5) Examination under a microscope showed that
there were very few particles of pyrite, but there were
present many brown particles of Fe₇S₈, magnetite, and some
feebly magnetic Fe₂O₃.

The wolframite concentrate obtained after the removal
of the magnetic substances was analyzed for sulphur and
phosphorus. The results of the analysis are set down in
Table 7. below.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>0.085%</td>
<td>0.039</td>
</tr>
</tbody>
</table>

The properties of the wolframite were unaffected by the
roasting, for no change takes place in the ore even at 500°C.
The decrease in the phosphorus content might be attributable
to the following, as stated by Gaudin ** "........apatite may
occur as an impurity in magnetic iron ores". The magnetite was
removed and with it the apatite which contains most of the
phosphorus.

This concentrate containing 78.8% WO₃ equivalent, 0.085% S
and 0.039% phosphorus, is a good commercial concentrate and may
be shipped to tungsten refineries, as such.

** A. M. Gaudin "Principles of Mineral Dressing" First Ed.
McGraw-Hill Book Company, Inc. N. Y. 1939
This photomicrograph shows tungsten concentrates after FeS₂ had been magnetized and removed as Fe₇S₈. One particle of unmagnetized FeS₂ may be seen in the center of the picture. Magnification X 100
FLotation OF SliMes

Flotation tests were made on the slimes without previous grinding and conditioning. Because of the fineness of the slimes it was decided that for the first test grinding could be dispensed with. Table 8 gives the reagents used in the first flotation test on the slimes.

<table>
<thead>
<tr>
<th>REAGENTS</th>
<th>FIRST ROUGHER</th>
<th>FIRST CLEANER</th>
<th>SECOND CLEANER</th>
<th>THIRD CLEANER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oleic acid</td>
<td>0.90 lb/T.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium oleate</td>
<td>0.35 lb/T.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acid dichromate</td>
<td>0.05 lb/T.</td>
<td>0.15 lb/T.</td>
<td>0.25 lb/T.</td>
<td>0.30 lb/T.</td>
</tr>
</tbody>
</table>

The results of the above test are set out in Table 9.

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>$%WO_3$</th>
<th>SULPHUR</th>
<th>PHOSPHORUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrate</td>
<td>31.6</td>
<td>2.32</td>
<td>0.74</td>
</tr>
<tr>
<td>Middlings</td>
<td>9.7</td>
<td>1.70</td>
<td>0.20</td>
</tr>
<tr>
<td>Tailings</td>
<td>0.08</td>
<td>0.80</td>
<td>0.18</td>
</tr>
</tbody>
</table>

The total recovery from the three products would be 41.38% if the middlings were returned to the circuit.

Another test was made using different reagents. The reagents are given in Table 10.

The slimes were first reground to minus 100 mesh in an Abbe pebble mill.
TABLE 10

FOR SULPHIDE FLATION: lb./ton

Soda ash.......................... 0.50
Sodium silicate..................... .40
Potassium amyl xanthate............ .20
Pine Oil No. 5...................... .08

FOR WOLFRAMITE FLATION lb./ton

Pine oil........................... .08 (in rougher)
Oleic acid........................ 1.50 (in rougher)
Potassium acid dichromate........ .20 (in 2nd cleaner)

The results of the test are set out in Table 11. The recovery was 84.9% of the WO₃ in concentrates containing 62.1 percent WO₃ and 0.45% S. A total recovery of 97% is indicated after middlings retreatment, which in this case would not involve regrinding.

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>WEIGHT, PERCENT</th>
<th>ASSAY, PERCENT</th>
<th>PERCENT OF TOTAL WO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd. cl. conc.</td>
<td>19.1</td>
<td>62.07 0.69</td>
<td>.021 84.9</td>
</tr>
<tr>
<td>2nd. cl. midds.</td>
<td>1.8</td>
<td>26.78</td>
<td>.059 3.5</td>
</tr>
<tr>
<td>1st. cl. conc.</td>
<td>20.9</td>
<td>59.09</td>
<td>.030 88.4</td>
</tr>
<tr>
<td>1st. cl. midds.</td>
<td>6.1</td>
<td>21.19</td>
<td>.054 9.2</td>
</tr>
<tr>
<td>Rougher concs.</td>
<td>27.0</td>
<td>50.48</td>
<td>.033 97.6</td>
</tr>
<tr>
<td>Rougher Tails</td>
<td>57.8</td>
<td>.30</td>
<td>.014 1.2</td>
</tr>
<tr>
<td>Sul. conc.</td>
<td>15.2</td>
<td>1.68 38.08</td>
<td>.059 1.2</td>
</tr>
<tr>
<td>TOTALS &amp; COMP.</td>
<td>100.0</td>
<td>13.97</td>
<td>100.0</td>
</tr>
</tbody>
</table>
CONCLUSION

It is the author's conclusion that this tungsten ore, may be treated in a manner similar to other tungsten ores, in so far as a general treatment is concerned.

Gravity concentration is undoubtedly the best method of treatment, followed by tabling of the slimes. Flotation of the slimes were found to produce a high concentrate and may be adapted in the mill treatment.
SUGGESTIONS FOR FURTHER STUDY

1. Throughout these tests, no attempt was made to determine the gold and silver content of the ore. Almost all tungsten ores contain appreciable amounts of these precious metals, and an interesting problem would consist in determining their amounts and their method of extraction. This would necessitate a complete change in the flow sheet, as the precious metals are invariably associated with the tungsten minerals.

2. If gold and silver were present, fine grinding would be necessary and the pyrite could be floated selectively from the gold and silver.

3. Tin has often been found associated with tungsten ores, and an investigation into the presence of this metal in the ore under treatment would present an interesting study.
BIBLIOGRAPHY

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