

# Beneficiation of low grade wolframite ore from Degana, Rajasthan

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**W**OLFRAMITE is one of the principal minerals containing tungsten and is considered as a strategic mineral because of its importance and short supply. It is a tungstate of iron and manganese (Fe, Mn)  $WO_4$  and generally occurs in prismatic or tabular crystals having a hardness of about 5 and a specific gravity ranging between 7.2 and 7.5. It is usually black in colour and has a good cleavage which causes it to fracture readily into thin flakes. It is fairly magnetic. It usually contains 60.6%  $WO_3$ , though theoretically it should contain 76.5%  $WO_3$ .

Wolframite is commonly found in granite and pegmatite veins and is commonly associated with cassiterite. Much of the wolframite marketed is obtained either from surface deposits, which have resulted from the weathering of the parent rock, or from partly disintegrated veins near the surface from which the mineral can be readily mined.

Gravity methods of concentration are usually employed for pre-concentration of wolframite ore followed by magnetic separation of the concentrate for the production of marketable grade for which the minimum  $WO_3$  content should be 60%. But low grade ore can be converted into synthetic scheelite by chemical treatment. For this purpose, ore containing only 5%  $WO_3$  can also be used.

The principal demand for tungsten concentrates is for the manufacture of ferrotungsten, special alloys, tungsten powder and tungsten carbide. Some high grade tungsten ore is also used for direct charging into alloy steel furnaces. There is a much smaller demand of the ore for the production of ductile tungsten metal and tungsten chemicals.

The principal tungsten ore producing countries are China, the U.S.S.R., the U.S.A., South Korea, North Korea, Bolivia, Brazil, Portugal, Australia, The Belgian Congo, Burma, Argentina and France.

Wolfram deposits (low grade) occur in India at Agargaon, Nagpur; Kalimati, Singhbhum; Chemdapathar, Bankura; Jhirpalla, Ahmedabad; Kadavur, and Ururakanad, Tiruchirapalli; and on Rawat Hill, near Degana, Jodhpur.

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## SYNOPSIS

*Wolframite, one of the principal minerals of tungsten, occurs in eluvial deposits from Rawat hill, near Degana, Jodhpur. The  $WO_3$  content of the ore in general is less than 0.05%. The gangue minerals of the ore are quartz, feldspar, calcareous matter, mica and very little quantities of topaz, magnetite, zircon, monazite, garnet, etc.*

*Because of the vast difference in the specific gravities of wolframite (7.17) and the predominating gangue minerals (2.7), gravity methods of concentration were tried on a sample of that ore. Wet tabling, after desliming of the ground ore (-30 mesh) gave a concentrate assaying 10.4%  $WO_3$ , the recovery being only 35.07%. Wet tabling after hydraulic classification gave better results (grade of conc. 26.6%  $WO_3$ ; recovery 27.54%). Recovery increased to 44.76% (conc. 44.37%  $WO_3$ ) when the coarse fraction (-10+30 mesh) was jigged and fine fraction (-30 mesh) wet tabled. A pneumatic preconcentrator was specially designed and fabricated for the treatment of this ore. It could discard about 81% of the gangue. The rougher concentrates were further jigged or wet tabled depending upon their sizes. The concentrates so obtained were finally upgraded by the magnetic and high tension separator. This method yielded a concentrate of 53.88%  $WO_3$  with a recovery of 61.4%.*

The work reported in this paper was carried out with eluvial ore (pay dirt) from Rawat hill, near Degana, Jodhpur, Rajasthan. It is reported that eluvial ore in that area occurs up to a depth of 5 to 30 ft. The uppermost layer consists of blown sand and usually does not contain any economic mineral. The climate of that area is arid and the average rain fall per year is about 10 inches. Therefore, water is very scarce in this area.

Wolframite concentrates are produced in this area by manual dry panning of clayey material and the assay is about 65%  $WO_3$ . The recovery is said to be very low.

## Early work

In 1942, a concentrating mill was erected at Rawat to work on the ore from the ore body which was estima-

ted to contain about 0.65%  $WO_3$ , but the plant was closed down after some time. The eluvial deposits were exploited for the production of wolframite concentrate again by the Department of Mines and Geology of the Government of Rajasthan during 1950 and 1955. They have again started mining operations on small scale by manual means to meet the requirement for tungsten for defence purposes. Earlier, a low grade ore from Degana assaying 0.11%  $WO_3$  was sent to the National Metallurgical Laboratory, Jamshespur, for beneficiation tests. The results were incorporated in their Report No. IR. 11/52 dated August, 1952. The concentrate assayed 53.3%  $WO_3$ , the recovery being 65.4%.

### Present investigation

A 5-ton consignment of eluvial ore was sent to us by the Department of Mines and Geology, Rajasthan, the contents of which differed from bag to bag. The ore was mostly gravel in some and in the rest it was brownish soil containing a few pieces of gravel. The average mineralogical composition of the ore was approximately as follows:

Quartz 32%; Feldspar 44.7%; Calcareous matter 15.0%; Opaques (magnetite, wolframite, etc.) 0.7%; Mica 2.5%; Others (topaz, zircon, monazite, garnet, etc.) 5.1%

Handpicked pure wolframite from the ore assayed as follows:

$WO_3$  64.8%; FeO 15.8%; MnO 9.7%.

The chemical analysis of wolframite in the ore had been very difficult because of very low concentration. Sampling of the ore was also difficult. The  $WO_3$  content of the ore has been reported to vary from 0.02% to 0.04% and in all cases <0.05%.

Since wolframite is very heavy (specific gravity of hand-picked wolframite from this source was 7.17) and the bulk of gangue being quartz, feldspar, calcareous matter and mica (constituting 94.2% of feed) concentration methods based on gravity difference were adopted.

The following methods of pre-concentration and concentration were adopted.

1. Wet-tabling of sand fraction (-30 mesh) after desliming.
2. Wet-tabling of coarse and fine sand fractions separately followed by jigging of the middling obtained from coarse fraction.
3. Jigging of coarse fraction (+30 mesh) followed by wet-tabling of its hutch; wet-tabling of -30 mesh fraction.
4. Air-tabling (-30 mesh).
5. Pneumatic pre-concentration of coarse (+30 mesh) and fines (-30 mesh) separately followed by jigging of the coarse fraction and tabling of the fine fraction.

It may be noticed that first three methods employ

wet operations only, while the fourth one involves only dry operations and the last one is a combination of both types of operations. All (-30 mesh) concentrates obtained by jigging and wet-tabling have been further upgraded by magnetic separation or high tension separation. Concentrates obtained from coarse fraction (+30 mesh) by gravity separations being of high grade did not undergo any further operation, involving magnetic or H.T. separations.

The run-of-mine ore with ore with sizes ranging from  $2\frac{1}{2}$ " to slimes is first screened to  $+\frac{1}{2}$ " and  $-\frac{1}{2}$ " fractions. The  $+\frac{1}{2}$ " fraction was crushed in a jaw crusher to obtain  $-\frac{1}{2}$ " size. All the material was then passed through a roll crusher followed by a wet ball mill, if necessary, to obtain various size fractions as per requirement of the experiments.

The following equipment have been used for concentrating the ore. Vibrating screens, Dorr Bowl rake classifier, Benver continuous ball-rod mill with Akins classifier, Denver type hydraulic classifier, Holman wet concentrating table, laboratory type Deister wet concentration table, K & B jig (10" x 15"); Process plant jigs (8" x 12") and 4" x 6"); Denver (2" x 3") jig, laboratory type Carpcu induced-roll magnetic separator, Stearn's cross belt magnetic separator, Alnico hand-magnet, laboratory type Carpcu high tension separator, pneumatic pre-concentrator and air table.

The following are short descriptions of some experiments with flow-sheets and results.

### Experiment No. WO/14

#### Wet-tabling

The entire feed (203 kg) was ground to -30 mesh and deslimed in a bowl-rake classifier to remove clayey material. The sand fraction was wet-tabled, and the middlings and concentrate were further wet-tabled and the products dried and magnetically separated. The tailings from each operation were mixed, further ground and wet-tabled and the middlings and concentrate dried and magnetically separated.

The steps followed are shown in flow-sheet No. 1 WO/14 in the annexure.

The weights of different products and their  $WO_3$  content and distribution are shown in Table I.

The low grade and low recovery was due to fine grinding of the ore (-30 mesh) to make it suitable for direct wet-tabling and also loss of wolframite in slimes, as it has a tendency to slime when ground.

### Experiment No. WO/15

#### Wet-tabling of sand and slime separately

In this case care was taken to minimise the production of slime, and the latter was also treated in a Holman table. The coarser grind enabled to treat the middling fraction from retabling of the primary concentrate of sand in a Denver Mineral Jig. For upgrading the concentrates, in addition to magnetic separators, H.T. separation was also tried. The retabling concentrate,

FLOW SHEET NO.1 (WO/14)

LOW GRADE WOLFRAMITE ORE  
(-1/4" : 2.30 kg WO<sub>3</sub>-0.04%)

JAW & ROLL CRUSHED

VIBRATORY SCREEN

ROLL CRUSHED  
+ 1/4" -4"

VIBRATORY SCREEN  
+ 30 MESH BALL MILL  
-30 MESH

RAKE BOWL CLASSIFIER

SAND  
HOLMAN TABLE

SLIME (TO WASTE)

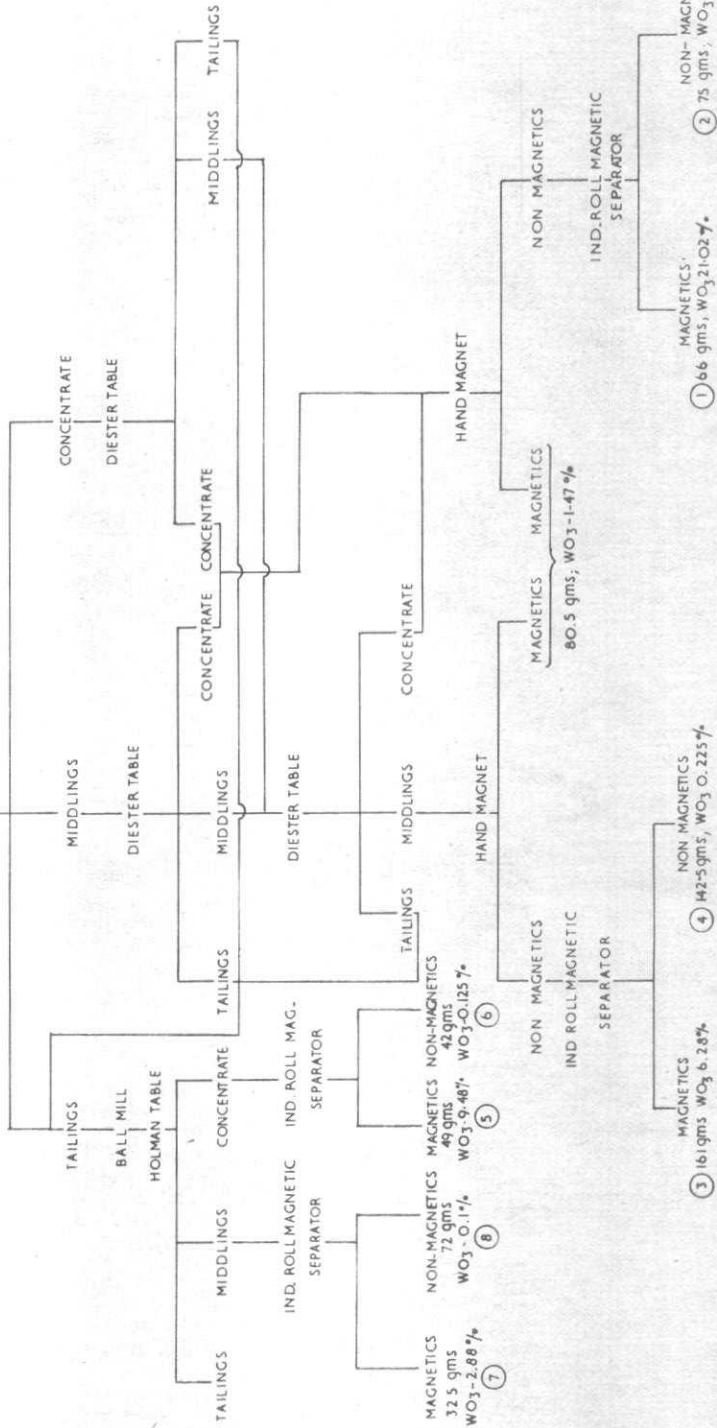


TABLE I Flow sheet No. 1 WO/14 : Assay values of different fractions obtained by wet-tabling followed by magnetic separation from low grade wolframite ore from Degana ; weight of feed : 203 kg. Feed assay <math>0.04\%</math>

| Product no.   | Wt. (in gms) | $WO_3$ % | Distribution %            |
|---------------|--------------|----------|---------------------------|
| Concentrate 1 | 66           | 21.02    | 17.20 Av. grade           |
| Concentrate 3 | 161          | 6.28     | 12.50 = 10.4% $WO_3$      |
| Concentrate 5 | 49           | 9.48     | 5.37 $WO_3$ Dist = 35.07% |
| Middling 7    | 32.5         | 2.88     | Av. Grade = 1.85% $WO_3$  |
| Middling 9    | 80.5         | 1.41     | Av. recovery 2.55%        |

TABLE II Flow sheet NO. 2 WO/15 : Assay values of different products obtained from Degana Wolframite by wet tabling, followed by H. T. and magnetic separation ; Feed 505.3 kg. assay <math>0.04\%</math>  $WO_3$

| Product no. | wt. (in gms) | Final products |  |
|-------------|--------------|----------------|--|
|             |              | $WO_3$ %       | Distribution % (assuming feed 0.04% $WO_3$ ) |
| 20          | 12.5         | 18.0           | 1.00   |
| 21          | 11.0         | 16.5           | 0.89 average grade                           |
| 22          | 25.5         | 13.5           | 1.70 26.6% $WO_3$                            |
| 23          | 72.5         | 37.0           | 13.20 distribution                           |
| 25          | 52.0         | 22.8           | 5.88 27.54%                                  |
| 27          | 37.5         | 26.25          | 4.87   |

| (Flow-sheet No. 2) |       | Middlings |                       |
|--------------------|-------|-----------|-----------------------|
| 18                 | 100.7 | 6.5       | 3.25                  |
| 24                 | 13.0  | 5.84      | 0.38 average grade    |
| 26                 | 48.0  | 4.60      | 1.10 4.85% $WO_3$     |
| 29                 | 15.4  | 3.43      | 2.61 average recovery |
| 32                 | 4.0   | 5.44      | 2.53 9.87%            |

from the sand section was closely sieved to produce +60, -60+85, and -85+200 mesh fractions and separately treated in a H.T. separator. The different steps followed are shown in flow-sheet No. 2 and the wt. of different products and their  $WO_3$  content and distribution in Table II.

It will be seen from the above that by treatment of the slime, the recovery was increased by 2.5% and a low grade product obtained. Because the feed was not so much ground as in Expt. No. WO/14 the average grade of the concentrate was much higher. Moreover, about 10% of  $WO_3$  values were recovered as a middling averaging 4.85%  $WO_3$ , which is suitable for leaching.

### Experiment No. WO/16

#### Jigging and wet-tabling

In these series, attempt was made to recover wolframite as coarse as possible. Therefore the ore (705 kg - $\frac{1}{4}$ ") was screened at 30 mesh on a vibrating screen. The +30 mesh fraction was jigged in a Knapp and Bate Jig with 10 mesh wedge-wire type of screen. Steel shots 3/16" was used for ragging. The stroke was 5/8" and rpm of the shaft operating the plunger was 310. Hutch was collected and further jigged in the same jig with 60 mesh wire screen because the particle size was quite fine. No ragging was used. The tailings from re-jigging was further jigged in a Denver Mineral Jig (2" x 3"). The concentrate collected in the primary and secondary jigging, as bed was further jigged in the Denver Mineral Jig. In all cases the tailings from jiggings were further ground in a ball mill to -30 mesh and wet-tabled.

The -30 mesh fraction was classified in a Dorr Bowlrake Classifier into sand and slime, and both fractions were first tabled in Holman wet concentrating

table. The concentrate obtained from the slime fraction was further wet-tabled in a laboratory Deister wet concentrating table. The concentrate and middlings obtained from the sand were mixed and screened at 48 mesh and the -48 mesh fraction was wet-tabled in a laboratory Deister wet concentrating table. The +48 fraction was jigged in the Denver Mineral Jig (2" x 3"). In all cases, the concentrates were dried and magnetically separated.

The steps are shown in flow-sheet No. 3 WO/16.

The weights of different fractions and their assay values are shown in Table III.

It will be seen from the above that although the average grade of concentrate is more or less similar to the Expt. No. WO/15 reported earlier, the recovery has gone up to 58%. This increase in recovery was due to recovering coarse size wolframite by jigging.

### Experiment No. WO/17

#### Air-tabling

The jaw and roll crushed ore (92.9 kg) was screened

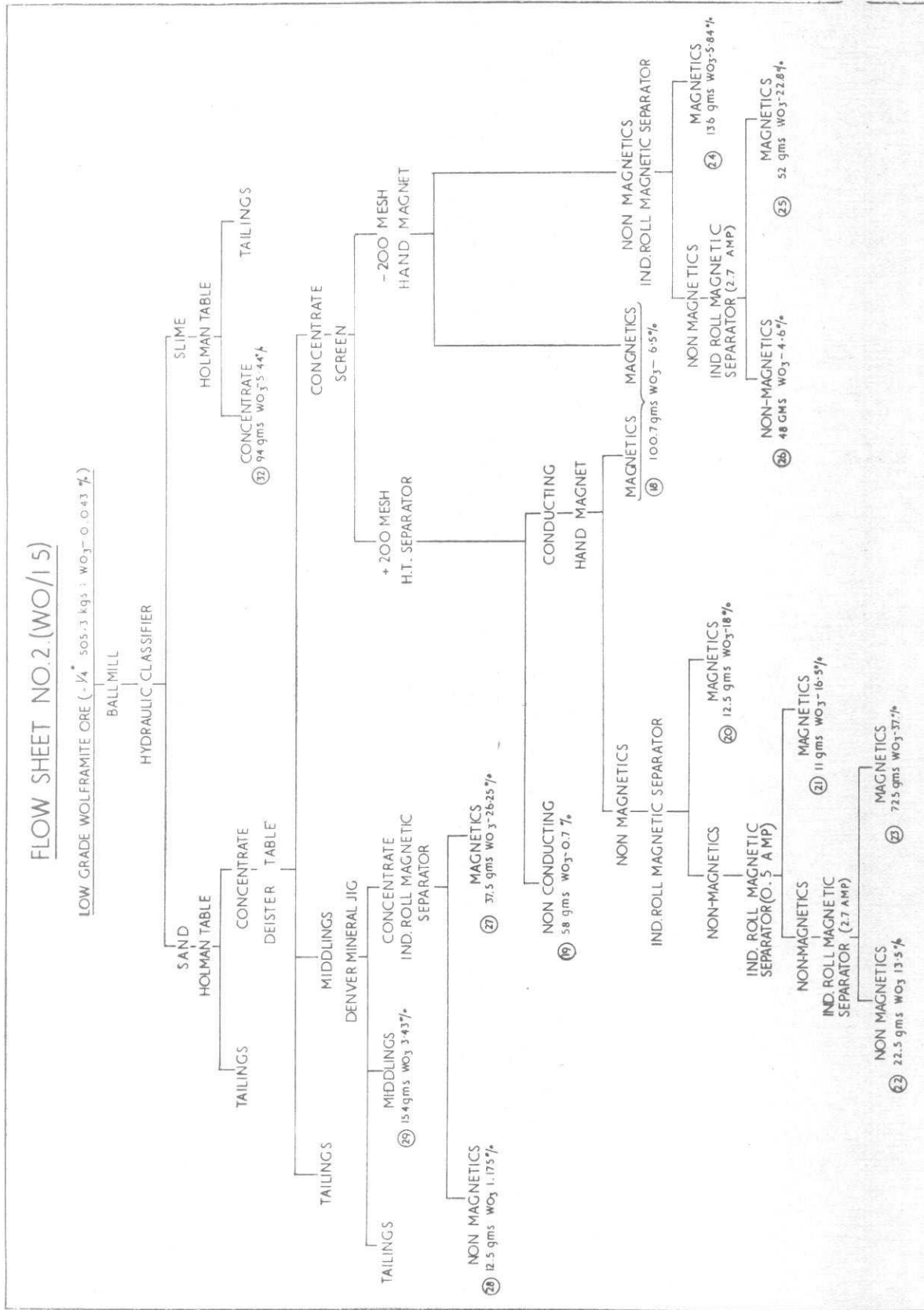


TABLE III Flow sheet No. 3 WO/16 : Assay values of different products obtained from Degana wolframite ore by jigging and wet-tabling and magnetic separation ; weight of feed=705 kg, assay <math><0.04\%</math>

| Product no.<br>(flow sheet<br>No. 3) | Final products |   | Distribution %<br>(assuming feed<br>=0.04% <math&gt;wo_3&lt; math&gt;)<="" th=""> </math&gt;wo_3&lt;> |
|--------------------------------------|----------------|---|---|
|                                      | Wt (in gms)    | <math&gt;wo_3&lt; math=""><br/>%</math&gt;wo_3&lt;> |   |
| 3                                    | 209            | 51.9  | 38.40   |
| 8                                    | 39             | 10.9  | 1.58  |
| 11                                   | 155            | 7.1   | 3.90 average grade  |
| 13                                   | 49             | 39.2  | 6.80 24.6% <math&gt;wo_3&lt; math&gt;<="" td=""> </math&gt;wo_3&lt;>                                  |
| 25                                   | 170            | 7.52  | 4.55 distribution   |
| 27                                   | 16.5           | 24.5  | 1.42 58.05%   |
| 30                                   | 37.5           | 10.5  | 1.40  |
| Middlings                            |                |   |   |
| 20                                   | 11             | 3.75  | 0.15 average grade<br>2.45% <math&gt;wo_3&lt; math&gt;<="" td=""> </math&gt;wo_3&lt;>                 |
| 23                                   | 107            | 2.25  | 0.86 distribution<br>1.01%  |

in a vibratory screen at 30 mesh and the +30 fraction was dry ground in stages in crushing rolls and screened till no +30 mesh material was left. The ground material was then treated in a laboratory air classifier and the products were collected separately. The coarse fraction (66.5 kg) was then treated in a pneumatic table (8' x 3'). The concentrate was further treated in a dry magnetic separator. Similarly, the middling was again treated in the pneumatic table and the concentrate was treated in a magnetic separator. Similar treatment was given to the fine fraction (26.4 kg).

The flowsheet No. 4 shows the steps followed. The weights of different fractions and their assay values are shown in Table IV.

The screen analysis of feed, coarse fraction and fine fraction are given in Table V.

The concentrate also contained other economic minerals like zircon, monazite, etc. The mineralogical composition of important fractions are given in Table VI.

The results of air-tabling were not successful because of two reasons as follow :

1. The feed was of extremely low grade. Precon-

TABLE IV Flow sheet No. 4 WO/17 : Assay values of different products obtained from Degana wolframite ore in a pneumatic table

| Total feed      | =92.9 kg.  |   |  |
|-----------------|--|---|--|
| Coarse fraction | =66.5 kg.  |   |  |
| Fine fraction   | =26.4 kg.  |   |  |
| Feed assay      | <math><0.04\%</math> <math&gt;wo_3&lt; math&gt;<="" td=""> </math&gt;wo_3&lt;> |   |  |
| Concentrate     |  |   |  |
| Product no.     | Wt. in gms.  | <math&gt;wo_3&lt; math&gt;%<="" th=""> <th>Distribution%</th> </math&gt;wo_3&lt;> | Distribution%  |
| 8               | 60   | 17.62   | 28.5   |
| Middlings       |  |   |  |
| 5               | 20   | 1.88  | 1.01 Av. grade<br>=1.52% <math&gt;wo_3&lt; math&gt;<="" td=""> </math&gt;wo_3&lt;> |
| 9               | 46   | 1.90  | 2.35 Av. recovery<br>=6.17%  |
| 14              | 85   | 1.23  | 2.81   |

centration is essential before tabling, but no process was known at that time.

2. The particles were angular as distinct from rounded beach sand grains and hence were not suitable for the type of equipment used (cloth top).

#### Experiment No. WO/18

##### *Jigging of the coarse fraction and wet-tabling of the fines*

Earlier experiments have indicated that the ore should not be crushed fine as wolframite has a tendency to get crushed finely and may be difficult to recover. In earlier experiments difficulties were also experienced for retreatment of the jigged products for want of suitable size jigs. Two Denver type mineral jigs (8" x 12" and 4" x 6") were specially procured for these experiments. As usual the ore was screened at  $\frac{1}{4}$ " and the coarse pebbles were jaw crushed followed by roll crushing. The  $\frac{1}{4}$ " +30 mesh fraction was jigged and -30 mesh fraction was classified in a hindered settling classifier and the different products were tabled separately in a Holman wet concentrating table (8' x 3'), the products from Holman table were treated in a laboratory Deister table.

The wet concentrates from -30 fraction obtained in different stages were dried and subjected to magnetic separation in two stages, first by a low intensity Stearn's magnetic separator (cross-belt type) for the removal of highly magnetic minerals, e.g. ilmenite, and the non-







TABLE V Screen analysis of ground wolframite ore, coarse and fine fractions from air-classifier which were separately treated in pneumatic table

| Tyler screen     | Ground ore %wt. retained | Coarse fraction %wt. retained | Fine fraction %wt. retained |
|------------------|--------------------------|-------------------------------|-----------------------------|
| + 35             | 28                       | 36                            | —                           |
| + 65             | 28                       | 36                            | —                           |
| +100             | 10                       | 12                            | 10                          |
| +150             | 8                        | 8                             | 8                           |
| +200             | 4                        | 4                             | 8                           |
| +270             | 4                        | 2                             | 8                           |
| +325 }<br>-325 } | 18                       | 2                             | 58                          |

magnetics have been further treated in a Carpcio induced roll magnetic separator with a high intensity magnetic field for the recovery of weakly magnetic wolframite. The different steps adopted in this run are shown in flow sheet No. 5 in the annexure.

The WO<sub>3</sub> contents of the principal products and their distribution are shown in Table VII.

It will be seen from the above that the main product No. 1 is obtained by jigging  $\frac{1}{4}$ " +30 mesh fraction. The next best product was No. 5 which was obtained

TABLE VII Flow-sheet No. 5 WO/18 ; WO<sub>3</sub> contents of different products obtained from Degana wolframite ore by jigging and wet-tabling followed by magnetic separation feed 1,007 kg. assay <0.04% WO<sub>3</sub>

| Product no.  | Wt. (gms) | WO <sub>3</sub> % | Distribution %                              |
|--------------|-----------|-------------------|---|
| Concentrates |           |                   |   |
| 1            | 260.0     | 57.05             | 36.82 Average grade =44.37% WO <sub>3</sub> |
| 5            | 34.0      | 47.80             | 4.03 recovery =44.76%                       |
| 11           | 135.0     | 11.67             | 3.91  |
| Middlings    |           |                   |   |
| 2            | 117       | 2.40              | 0.69  |
| 3            | 113       | 2.99              | 0.84 Average grade =2.94% WO <sub>3</sub>   |
| 7            | 72        | 5.30              | 0.95  |
| 9            | 100       | 1.85              | 0.46 Av. recovery =6.17%                    |
| 13           | 101       | 3.75              | 0.94  |
| 14           | 342       | 2.70              | 2.29  |

TABLE VI Mineralogical composition of important fractions obtained by pneumatic tabling followed by magnetic separation of wolframite ore from Degana

| Fraction no. | Wt. kg/100t | Opaque | Garnet | Zircon | Monazite | Topaz | Calcite | Quartz | Others |
|--------------|-------------|--------|--------|--------|----------|-------|---------|--------|--------|
| 5            | 16.1        | 52.2   | 24.3   | 2.1    | 0.8      | 6.8   | 3.8     | 6.0    | 4.0    |
| 6            | 87.2        | 6.2    | 0.9    | 1.1    | 1.0      | 70.2  | 2.9     | 15.7   | 2.0    |
| 7            | 227.0       | 3.0    | Tr     | Tr     | Tr       | 0.6   | 10.0    | 86.4   | —      |
| 8            | 17.2        | 70.0   | 20.0   | 0.3    | 0.8      | 1.2   | 3.5     | 1.0    | 3.2    |
| 9            | 49.5        | 12.7   | 0.4    | 5.2    | 2.5      | 53.1  | 1.5     | 20.0   | 4.6    |
| 10           | 237.0       | 9.3    | Tr     | 9.3    | Tr       | Tr    | 6.5     | 74.9   | —      |
| 13           | 19.4        | 79.0   | Tr     | 0.5    | 4.5      | 6.3   | 1.2     | 2.8    | 5.7    |
| 14           | 91.5        | 16.8   | 1.8    | 8.6    | 5.6      | 4.4   | 3.3     | 15.6   | 43.9   |
| 15           | 397.0       | 0.6    | 0.2    | 0.1    | 0.6      | Tr    | 7.7     | 90.3   | 0.5    |

from the tailings of the second and the third jigs by regrinding and tabling, followed by dry magnetic separations. Product No. 11 which is rather low grade (11.67% WO<sub>3</sub>) has been obtained from the wet-tabling circuit, which is rather elaborate. The products branded as middlings are obtained by either wet-tabling of —30 mesh fractions followed by dry magnetic separation (Product Nos. 7, 9, 13, 14) or by jigging followed by dry magnetic separation (Products Nos. 2, 3). The average grade of the final products is below marketable grade and hence it is necessary to further upgrade the same. But the quantities obtained as products from more than 1 tonne of ore amounted to a few grammes; hence further tests on them were not possible.

However, to assess the possibility of further upgrading each product for recovery of other economic minerals in addition to wolframite, the products have been examined mineralogically. The results are shown in Table VIII.

It will be seen from the above that the products designated as concentrate earlier (Nos. 1, 5 and 11)

contain mainly non-conducting silicate minerals as gangue and the latter can be removed by H. T. separation. The products Nos. 2, 6 and 8 are very rich in topaz, which may not have any market at present. The products Nos. 9, 11, 14 and 15 contain monazite from 0.9 to 4.1% which is recoverable by ore dressing methods. The garnet-rich fractions are 9, 11, 13 and 14 and the quality of garnet is also good for abrasives. The garnet is also recoverable, by treatment of the minerals in a H. T. separator and magnetically separating the non-conducting fraction. Similarly, the zircon-rich fractions 9, 11, 12 and 14 can also be retreated for the recovery of zircon.

The product Nos. 6, 8, 10, 12, 15 were analysed for their tin contents but the report indicates presence of tin only in two products as follows:

| Product No. | Tin   |
|-------------|-------|
| 6           | 0.96% |
| 12          | 0.25% |

TABLE VIII Mineralogical composition of products in flow sheet No. 5 WO/18—1,007 kg

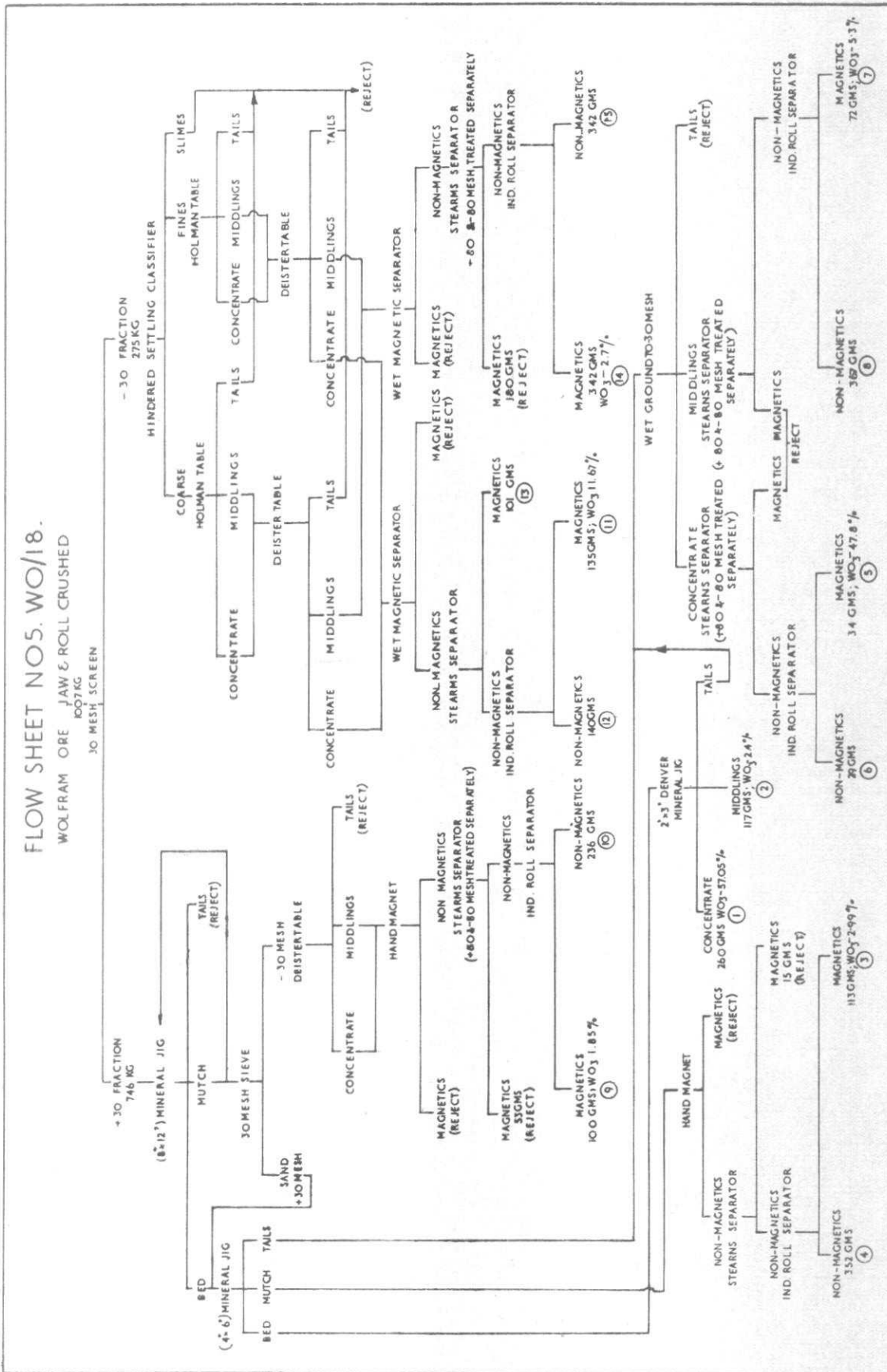
| Product no. | Wt. (gms) | Wolframite : 1 | Opagues† 2 | Topaz 3 | Quartz 4 | Micas 5 | Zircon 6 | Garnet 7 | Monazite 8 | Tourmaline 9 | Calcareous matter 10 | Others ‡ 11 |
|-------------|-----------|----------------|------------|---------|----------|---------|----------|----------|------------|--------------|----------------------|-------------|
| 1           | 260       | 78.6           | 9.9        | 5.0     | 4.6      | 0.8     | 0.6      | Tr       | —          | Tr           | 0.5                  | —           |
| 2           | 117       | 3.3            | 9.2        | 73.8    | 7.7      | 4.2     | 0.1      | Tr       | —          | Tr           | 2.0                  | —           |
| 3           | 113       | 4.0            | 27.8       | 19.0    | 35.8     | 7.4     | 0.2      | 1.3      | 0.3        | Tr           | 4.2                  | —           |
| 4           | 352       | 7.4*           |            | 62.1    | 27.1**   |         | 0.1      | nil      | 0.2        | —            | 3.0                  | 0.1         |
| 5           | 34        | 66.0           | 9.3        | 21.2    | 1.3      | 0.2     | 0.8      | 0.2      | —          | —            | —                    | 1.0         |
| 6           | 29        | 8.3*           |            | 90.2    | 0.5**    |         | 0.3      | 0.7      | —          | —            | —                    | —           |
| 7           | 72        | 7.3            | 37.3       | 49.6    | 2.1      | 2.6     | 0.3      | 0.6      | 0.1        | —            | —                    | 0.1         |
| 8           | 367       | 1.4*           |            | 94.8    | 3.0**    |         | —        | 0.3      | —          | —            | 0.3                  | 0.2         |
| 9           | 100       | 2.5            | 29.0       | 22.3    | 6.5      | 1.0     | 11.6     | 20.1     | 1.7        | 3.1          | —                    | 2.2         |
| 10          | 236       | 4.6*           |            | 66.5    | 22.8**   |         | 3.8      | 0.2      | —          | —            | 1.5                  | 0.6         |
| 11          | 135       | 16.0           | 23.9       | 11.4    | 1.1      | 0.6     | 17.6     | 17.2     | 4.1        | Tr           | 0.8                  | 7.3         |
| 12          | 140       | 11.6*          |            | 53.6    | 8.3**    |         | 25.7     | 0.4      | 0.3        | —            | 0.1                  | —           |
| 13          | 101       | 5.2            | 77.6       | 0.5     | Tr       | 0.1     | 0.4      | 15.9     | Tr         | Tr           | 0.1                  | 0.1         |
| 14          | 342       | 3.7            | 30.6       | 12.0    | 10.1     | 3.7     | 12.1     | 17.7     | 1.1        | 1.3          | 0.5                  | 7.2         |
| 15          | 942       | 5.3*           |            | 64.4    | 21.2**   |         | 6.3      | 0.2      | 0.9        | —            | 1.0                  | 0.7         |

† Ilmenite, leucosene, rutile, magnetites, etc.

‡ Amphiboles and pyroxenes

\* Combined (1 and 2)

\*\* Combined (4 and 5)



Therefore, it will be seen that the eluvial ore from Degana can produce not only wolframite (in two grades, the low grade being suitable for chemical treatment) but also monazite, zircon, garnet and tin, if the elaborate flowsheet No. 5 is adopted.

It has already been pointed out earlier that by jigging alone, most of the recoverable wolframite is recovered at a fairly high grade (products Nos. 1 and 5). Therefore, if only three-stage jigging is adopted for crushed and screened ore ( $-\frac{1}{4}$ " + 30 mesh), the grade of concentrate would be 55.98%  $WO_3$ , the recovery being 40.85%. As has already been stated, the grade of concentrate can be improved by H. T. separation with a slight fall in recovery.

#### Experiment No. WO/20

##### *Pneumatic pre-concentration and jigging and tabling of classified feed*

The object of this experiment was to reject as much gangue as possible in a dry process and thereby increase the efficiency of wet operations and reduce the water requirements. As wolframite particles are brittle and large sized, care was taken to avoid over-grinding and to recover the valuables in as coarse a state as possible. As about 39% of the feed was above +10 mesh size and it contributes to minimum 50% of wolframite, which is not liberated at that stage, it had to be crushed to -10 mesh size where most of the wolframite is liberated. As close sized feed increases the efficiency of ore dressing operations, the feed sizes were taken as -10+30 and -30 mesh fractions. Further, most of the wolframite was expected to be contributed by -10+30 mesh fraction. The -30 mesh fraction was of far lower grade. It has also been found that the run-of-

TABLE IX Flow sheet No 6 WO/20 : Results obtained by treating Degana ore in a pneumatic pre-concentrator

| Fraction       | Wt. % | Conc. wt. % | Midd. wt. % | Reject wt. % |
|----------------|-------|-------------|-------------|--------------|
| -30 R.O.M.     | 49.8  | 4.0         | —           | 45.8         |
| -30 crushed    | 14.0  | 1.47        | —           | 12.53        |
| -10+30 R.O.M.  | 12.4  | 0.5         | 3.5         | 8.4          |
| -10+30 crushed | 23.8  | 0.7         | 8.4         | 14.7         |
| Feed           | 100.0 | 6.67        | 11.9        | 81.43        |

mine ore fractions differ from the crushed ore fractions in particle shape and size range and that the -30 mesh fraction of run-of-mine ore contains also heavy minerals like monazite, zircon, garnet, etc., which would report in the heavy fraction during the pre-concentration. So it was decided to treat the -10+30 and -30 mesh fractions from the crushing operations of coarser materials separately from the same sized fractions from run-of-mine ore.

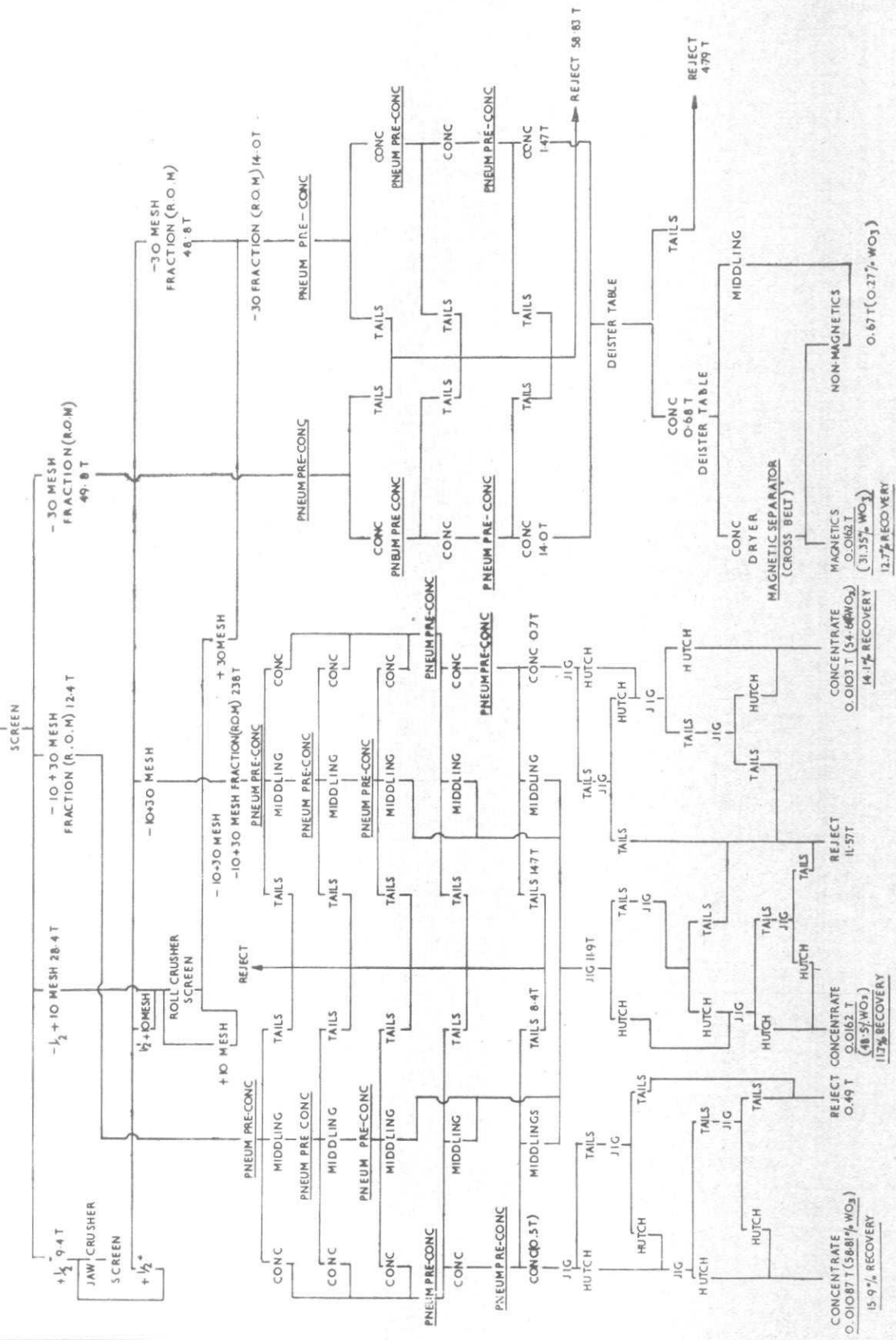
The run-of-mine ore was screened into four fractions  $+\frac{1}{2}$ ",  $-\frac{1}{2}$ " + 10 mesh, -10+30 mesh and -30 mesh sizes by using vibrating screens. The  $+\frac{1}{2}$ " size fraction was crushed to  $-\frac{1}{2}$ " size using the laboratory jaw crusher with  $\frac{1}{2}$ " screen in circuit. The  $-\frac{1}{2}$ " + 10 mesh size crushed fraction from the jaw crusher along with the  $-\frac{1}{2}$ " + 10 mesh size fraction from the run-of-mine ore was fed to the laboratory crushing rolls with 10

TABLE X Flow sheet No. 6 WO/20 : Assay values of different products obtained from Degana wolframite ore by pneumatic pre-concentration, jigging and tabling followed by magnetic and H. T. separation ; feed 1800 kg, assay < 0.04%  $WO_3$

| Fraction   | Overall Wt. % | Operation to obtain final concentrate                       | Conc. overall Wt. % | Assay $WO_3$ % | Recovery overall % |
|--|---------------|---|---------------------|----------------|--------------------|
| I -30 mesh crushed + R.O.M. conc. from Pn. pre-conc.           | 5.47          | Tabling and magnetic separation and H. T. separation        | 0.01                | 56.4           | 12.0               |
| II -10+30 mesh R.O.M. conc. from Pn. pre-conc.                 | 0.5           | Jigging   | 0.0108              | 58.81          | 15.9               |
| III -10+3 mesh crushed conc. from Pn. pre-conc.                | 0.7           | Jigging   | 0.0103              | 54.61          | 14.1               |
| IV -10+30 mesh R.O.M. and crushed middlings from Pn. pre-conc. | 11.9          | Jigging   | 0.016               | 48.5           | 19.4               |
| II+III+IV  | 13.1          | Jigging   | 0.0371              | 53.2           | 49.4               |
| I+II+III+IV  | 18.57         | Tabling and mag. separation and jigging and H.T. separation | 0.0471              | 53.88          | 61.4               |

FLOW SHEET NO. 6. WO/20.

RUN OF MINE ORE  
100 TONS (0.04 WO<sub>3</sub>)  
(FEED ACTUALLY USED 1800 KG)



mesh and 30 mesh size screens in circuit to get the -10+30 and -30 mesh size crushed fractions separate from the same size fractions from run-of-mine ore above.

All the four fractions -10+30 and -30 mesh sizes from run-of-mine ore and crushed material were fed separately through a pneumatic pre-concentrator to reject as much gangue material as possible. Pneumatic pre-concentrator is a device designed in this laboratory. It makes use of a streamlined wind force to blow away the lighter and finer materials. The feed is allowed to fall vertically into a horizontal wind current. This operation was thought to give best results because of great specific gravity difference between that of wolframite (7.2) and that of the 95% of the gangue (2.7). The pre-concentrator used in these experiments consisted of a rectangular frame with a hopper and electrically vibrated feeder at the upper deck and a powerful fan (axial flow type) of 18" diameter for the treatment of the coarse size feed (-10+30 mesh size) and one of the 12" diameters for the treatment of the fine size feed (-30 mesh size) on the lower deck. Parallel (horizontal) vanes were fitted in front of both the fans to make the air blow in a streamlined fashion. The collection of products was done in a rectangular trough placed in the direction of wind and cuts were made after examining the spread of falling material. In case of -30 mesh size fraction, a concentrate only was collected in each and in case of -10+30 mesh size fractions in addition to concentrate a middling also was collected. The weight percentage of different fractions produced in the pre-concentrator with different feeds are given in Table IX.

It can be seen that reject in run-of-mine ore fractions was larger than in the crushed ore fractions in -30 mesh size fractions.

TABLE XI Flow sheet No. 6 WO/20 : Mineralogical analysis of the concentrates

| Fraction | Opauques | Quartz+<br>Topaz | Micas<br>and ore | Mona-<br>zite | Zircon | Garnet |
|----------|----------|------------------|------------------|---------------|--------|--------|
| I*       | 64.0     | 6.7              | 0.5              | Tr            | Tr     | 28.8   |
| II       | 97.0     | 2.5              | 0.5              | Tr            | Tr     | Tr     |
| III      | 97.0     | 2.5              | 0.5              | Tr            | Tr     | Tr     |
| IV       | 91.6     | 3.3              | 0.7              | 1.0           | 0.8    | 2.6    |

\* Before H. T. Separation

The concentrates from -30 mesh size fractions of run-of-mine ore and crushed materials were mixed and treated on laboratory Deister table. As the wolframite streak was very thin to be collected separately, a broader streak was collected and the collected material was tabled again. Even then a clear streak could not be collected because of very low quantity of the material available, but when treating larger quantities, it is hoped that tabling can be repeated to give required grade of wolframite without any further dry treatment. But in the present case, the concentrate from the table had to be dried and subjected to magnetic separation on a laboratory cross-belt magnetic separator with maximum amperage. Even then a magnetic fraction assaying only 31.35% WO<sub>3</sub> with about 35% of gangue minerals out of which garnet was responsible for 29.0% was obtained. It was further cleaned on laboratory high tension separator to give a concentrate containing 98.5%

TABLE XII Summary and recommendations : Results obtained in different experiments

| Expt. No. | Principal methods of operation |   | Concentrate               |            | Middlings                 |            |
|-----------|--------------------------------|---|---------------------------|------------|---------------------------|------------|
|           | Wet/Dry                        | Processes adopted   | Grade (WO <sub>3</sub> %) | Recovery % | Grade (WO <sub>3</sub> %) | Recovery % |
| WO/14     | Wet                            | Wet-tabling   | 10.4                      | 35.07      | 1.85                      | 2.55       |
| WO/15     | Wet and Dry                    | Wet-tabling mag. separation, high tension separation                | 26.6                      | 27.54      | 4.85                      | 9.87       |
| WO/16     | Wet and Dry                    | Jigging, wet-tabling, mag. separation high tension separation       | 24.6                      | 58.05      | 2.45                      | 1.01       |
| WO/17     | Dry                            | Pneumatic tabling   | 17.62                     | 28.5       | 1.52                      | 6.17       |
| WO/18     | Wet and Dry                    | Jigging, wet-tabling, mag. separation                               | 44.37                     | 44.76      | 2.94                      | 6.17       |
| WO/20     | Wet and Dry                    | Pneumatic conc. jigging wet-tabling+mag. separation H.T. separation | 53.88                     | 61.4       | 5.1                       | 0.7        |

of opaques and assaying 56.4 WO<sub>3</sub>% but losing 0.7% of wolframite. As there was not much magnetite in the table concentrate, avoiding magnetic separation and direct treatment of table concentrate in further closely sized fractions on high tension separator may reduce the loss and improve the recovery. But in the interest of recovery, it is better to avoid both magnetic separation and high tension separation and get a cleaner concentrate by another tabling or two, when large materials are available for treatment. High tension separation can be resorted to if necessary for the middlings from the final tabling.

The -10+30 mesh size fraction concentrates from pneumatic preconcentrator were treated separately in jigs. The middlings of both the fractions from pneumatic preconcentrator were mixed and treated separately from concentrates on jigs as they were of lower grade than the concentrates above. The three fractions separately were treated first on the laboratory jig of (4" × 6") with R.P.M. of the shaft operating the plunger about 450 and stroke of plunger ½" and with ¾" steel shots as raggings. As the aim was to collect concentrate as hutch only, water was cut off during the suction movement. Each time, the tailings were jigged again. The hutch of each fraction collected was separately cleaned on a smaller laboratory jig of (2" × 3") keeping the conditions of operation same as in the case of larger jig. Again the tailings were jigged once more. The hutch from the middling fractions contained impurities like quartz, topaz, micas, monazite, zircon and garnet along with rag-iron most of the impurities were finer-grained than the opaques and perhaps were liberated due to attrition during jigging operations. The middlings from jigging operations, on being ground further and subject to wet-tabling and magnetic separation, did not yield any concentrate of worthwhile grade and recovery. The results of wet-tabling and jigging of different fractions are shown in Table X and the mineralogical com-

position of different concentrates are given in Table XI.

It will be seen from the above table that Experiment No. WO/20 gave the best result. We believe that the improved performance was due to the following :

- (a) Prior removal of major portion of gangue (sand and slime) by the pneumatic concentrator.
- (b) Because of the above, the jigging and wet-tabling operations were very efficient.

Therefore, we recommend a flow-sheet similar to WO/20 with the few modifications as follows :

1. If by jigging alone the grade of concentrate cannot be enriched beyond 53%, the jig concentrate should be lightly ground and wet-tabled.
2. When wet-tabling the concentrate of the -30 mesh fraction, attempt should be made to collect separately the wolframite streak so that it would not need upgrading further. If necessary, wet-tabling can be done on closely sized fractions.
3. If gravity separations fail to give a high grade concentrate, then only either magnetic or H. T. separation should be resorted to. We recommend H. T. separation instead of magnetic separation, as the former is superior to remove the majority of the impurities like garnet, zircon, etc.

#### Acknowledgement

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## Discussions

Mr Sunil Dey (Chemical and Metallurgical Design Co. (P) Limited, New Delhi) : Whenever air separation is required for a material consisting of coarse and fine particles it is the usual practice to separate the particles by means of a mechanical air-separator. The separation of fines as suggested by Dr Majumdar could perhaps be modified on this line.

Mr G. P. Mathur (NML) : It is reported that pneumatic preconcentration followed by magnetic and high tension separations yielded a good grade of concentrate but the overall recovery of wolfram was only 61.4%. Were any studies made to find out why the recovery was low and were any steps taken to minimize the tailing loss ?

Mr R. N. Misra (NML) : Did the author find the existence of Sn? If so what was the distribution of tin in the two fractions?

Is the pneumatic concentrator comparable to air-classifiers?

Dr K. K. Majumdar (Author) : In reply to Mr Misra it is only in one sample that a few specs of cassiterite were noticed. The quantity was so small that further work was not carried out.

We have not done any work on a air-classifier in this connection. It is therefore difficult to say how this compares with the pneumatic pre-concentrator the

preformance of which has been presented in the paper.

On the question of tailing loss raised by Mr Mathur, I have already mentioned that the  $WO_3$  content of the ore is less than .04% and the feed itself could not be chemically analysed. The tailings produced after pre-concentration were naturally of still lower grade. Therefore, it could not be assayed and hence, could not be followed up.

In reply to Mr Dey, the materials were separated into different fractions by screening and no difficulty was experienced in the subsequent operations. Therefore, the necessity of using a mechanical air-separator was not felt.