# Wet high intensity magnetic separation of some uranium ores of India

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**INTRODUCTION :**

Wet High Intensity Magnetic Separation (WHIMS) or magnetic filtration is relatively a new process used in the mineral industry and it is generally being used for the removal of magnetic impurities, ( from kaolin clay, desulfurisation of coal and separation of weakly magnetic particles of fine sized material ). Run of mine material can be directly treated in the case of clays and coal or a preconcentrate, preferably, in the case of minerals.

Extensive test work has been carried out on many Witwatersrand ores and cyanidation residues using wet high intensity magnetic separations(WHIMS). Keleghan (1977)[1] and Corrans and Levin (1979)[2] report approximately 50% of the residual gold and 60% of the uranium recovery in about 10% of the mass of the feed. This work was carried out using an Eriez CF-30 machine with a nominal capacity of 2 tph. The matrix consisted of soft-iron balls of 4 to 6mm in diameter. Subsequent application of full-scale machines having treatment capacities of 30 tph at Stilfontein gold mine yielded, overall recoveries for ) to recover particles as small as 12 microns.

Uranium recovery from particles down to 12 microns is rather low in flotation and gravity concentration by wet tabling though some interesting results have been obtained in laboratory scale experiments using Bartles and Mozley concentrators and Vanners (Rao 1984).[3]

Due to limited resources of high grade ores medium grade ores assaying higher than 0.02 % $U_3O_8$ are being taken up for direct leaching in India now. But the decision to leach an ore without considering beneficiation possibility is not prudent except from mineral conservation view point and beneficiation processes assuring good recoveries need to be given trial to find out the suitability of the ore for beneficiation.

For the first time in India WHIMS has been tried as a process for upgrading low-grade U-ores and sulphide ore tailings at Mineral Technology Laboratory of Atomic Minerals Division, Hyderabad,[4] using Carpco Model WHIMS 3 × 4 L laboratory High Intensity Wet magnetic separator which is a static cell type separator equipped with a 310 cc removable separating chamber that can accept a variety of interchangeable media.

**Advantages :**

The advantages of this process are less pollution, low operating costs and high recoveries. Unlike other beneficiation processes, this process can be readily used on micron sized particles too. Only disadvantage of this process is, however, the high capital cost.

**Mechanism :**

The magnetic properties of the minerals depend on the electrons present in the outer most orbit, state of the chemical bonds, type of co-ordination and the amount of magnetic elements present in the mineral. ( Malghan and Van Dieed )[5] Most of the primary uranium minerals are known to be paramagnetic in nature. U-minerals occur very rarely as independent minerals and are often found to be associated with the magnetic or paramagnetic gangue minerals in a variety of ores. Such ores are considered suitable for beneficiation by WHIMS.

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In WHIMS the main process variables are magnetic field intensity, matrix type, feed size and grade, pulp density, flow of the pulp and flow of wash water. By suitably matching all the process variables, the optimum concentration can be achieved based on ore mineralogy. As in the other physical separation processes, this too has an upper size limit and generally feeds finer than 20 mesh are suitable for the operation. Just as in other processes, sizing of the feed increases grade of the concentrate and recovery. The matrix that are commonly used in the process are steel balls, fine steel wool, grooved steel plates and rods. Selection of matrix depends on the size of the feed. In the case of balls, fine sized balls are used for fine sized feed and coarse sized balls for coarse sized feeds and for extremely fine sized feeds steel wool or grooved steel plates are used. At lower field strengths some of the magnetics may report in the non-magnetics and at higher fields some of the non-magnetics such as stained grains or unliberated grains may report into the magnetics. A middling product avoids all these problems and helps in increasing the concentrate grade. Middling recycle yields higher recovery. At higher percentage of solids, free flow of particles does not take place and the matrix is loaded beyond its capacity and overflow of particles takes place leading to poor recovery. The wash water requirement also goes up considerably. To overcome all these difficulties a slurry consisting of 20 to 30 % solids is considered ideal for the process. The flow of slurry and flow of wash water also influences the recovery and grade of concentrate. At a high slurry flow rate the matrix is filled to capacity with magnetics in no time and some magnetics overflow along with the non-magnetics. If flow of wash water is less, non - magnetic particles will remain with magnetic, and more of water will bring down magnetic particles into the non-magnetics. By matching the flows of slurry and wash water only, a proper separation can be achieved. For a proper separation of the ore, the influence of all these variables are required to be taken into consideration and by matching all the variables only, an optimum recovery can be achieved.

The amount of magnetic minerals will also influence the recovery and grade.

**Experimental data :**

A number of tests were carried out on different types of U-bearing rock samples using WHIMS technique. Results are discussed here.

**Granites :**

The granite sample from Penevella area, A. P. consists chiefly of quartz, felspar and biotite. The accessory radioactive minerals are uraninite, uranophane, monazite, thorite, cyrtolite and zircon. Uraninite being paramagnetic reports in the magnetics, while uranophane alongwith thorite and zircon goes to the non-magnetics. As such the bulk of radio-activity is with the non-magnetics. As far as uraninite is concerned most of it has been recovered at 20 kilo gauss (KG). But the contribution of uraninite to the overall radioactivity in the sample being rather low only 40 % of the radioactive values were covered in 7.7% wt. of concentrate (Table-1).

The radioactivity of another granite gneiss sample from Serandampalaya is mainly due to garnet and secondary uranium minerals and not due to any primary uranium mineral. Only about 70% of the radioactivity has been found to be associated with magnetic minerals which could be separated at 20 KG but without any enrichment in grade. Excepting garnet associated with radioactivity, no other uranium bearing minerals reported in the magnetic fraction. The secondary uranium minerals present in the sample reported alongwith other gangue minerals in the non-magnetics. In the sample from Binda-Nanganaha, the radioactivity is mainly due to primary uranium minerals and as such a high enrichment ratio of 6.55 could be achieved and 57 % recovery was obtained at 8.6 % wt of concentrate.

**Quartzites :**

The quartzite samples from Jamiri area Arunachal Pradesh are composed mainly of quartz, and felspar with lesser amounts of micaceous minerals and heavy minerals such as zircon, monazite, uraninite, brannerite, ilmenite, magnetite, hematite etc.

WHIMS test on four such samples from Jamiri area indicated that these ores can be concentrated by properly controlling the process variables. An enrichment ratio of 5 to 8 and enrichment in grade upto 1.0% has been achieved though the maximum recovery was 48% only due to distribution of radioactivity in smears on quartz and other gangue minerals (Table-2).

The quartzites from Chinjra area, H. P. where the radioactivity is mainly due pitchblende quartz veins besides other minerals like zircon and rutile yielded concentrates assaying upto 23.7% $eU_3O_8$ at 14.8% wt. and 65% recovery.

**Sandstone** :

The sandstone samples from Nong Maw Mairang, Meghalaya, consist chiefly of quartz, felspar and biotite grains held together by a clayey or siliceous matrix. Zircon and black opaque minerals constitute the accessories. Coffinite is the only uranium mineral, identified in the sample. It occurs around the boundaries and along microfractures of the gangue. The mode of occurrence suggests very fine grinding for liberation of coffinite. The recovery of uranium values from clayey matrix by leaching is rather problematic and hence it is always preferable to beneficiate the clayey portion for the mineral. As such the sample from Nong Maw Mairang was deslimed and both the sand and slime fractions were subjected to WHIMS separately. A recovery of 53 % only was obtained and losses were more in the slime fraction (Table—3).

In the carbonate rich ore sample from Arbail a recovery of 97 % of the radioactive values was obtained at 76% wt. The high wt. percentage of magnetics is due to high percentage of pyrrhotite, siderite, goethite and other magnetic minerals.

**Schists** :

The schistose rocks from Singhbhum district, Bihar, consist of quartz, chlorite, sericite, apatite, opaques and other micaceous minerals like biotite and muscovite. Generally in these rocks uranium minerals occur in close association with chlorite or as inclusions in it. Accordingly these are recovered with chlorite in the magnetic fraction (Table-4). The recovery depends on the percentage of magnetic minerals present and their association with uranium.

In the case of Keruadungri and Turamdih, the samples contain more than 30% of chlorite. The magnetic minerals being more in quantity no proper enrichment was observed. In the case of Bagjatha sample, the amount of chlorite and the association of uranium with non-magnetic minerals being less, the uranium values have got enriched and about 82% recovery was possible by rejecting nearly 50% of the material. Desliming, tabling and WHIMS of the sample gives 78% recovery rejecting 75% of the material.

**Discussion** :

The recovery of uranium from any rock sample mainly depends on the nature of U-minerals present and associated gangue (Table-5). If U-mineral is associated with other paramagnetic minerals which constitute less than 30% of the sample the rock sample is amenable to WHIMS and reasonable recoveries can be expected. In the case of granite samples and other samples containing secondary uranium minerals which are non-magnetic, even at high field strengths, the recovery is rather low in the magnetic fraction. In the case of quartzites, primary U-minerals are recovered largely. Similarly from sandstone and chorite-quartz-schist samples U-minerals associated with chlorite are recovered. Secondary U-mineral bearing rocks are not amenable to WHIMS and they cannot be concentrated by this process. Process variables have also considerable influence on the recovery besides the nature of mineralisation, and these are required to be determined and fixed for each type of ore. It has been observed that primary uranium minerals as small as 5 microns can be recovered by this process and the recoveries are much higher than by gravity concentration using wet tables.

By taking all these things into consideration, an economical recovery can be achieved only in the case of ores with suitable mineralogy after matching all the process variables like liberation, pulp density, pulp flow, wash water flow, matrix type, percentage of slimes and field intensity. The order of amenability of the various types of Indian ores tested thus appears to be Quartzite > Standstones > Schists> Granites.

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**Table—1 : Granites**

| Product | Penvella | | | Serandampalaya | | | Binda Nagnaha | | |
|---|---|---|---|---|---|---|---|---|---|
| | % Wt. | % $eU_3O_8$ | % Dt. | % Wt. | % $eU_3O_8$ | % Dt. | % Wt. | % $eU_3O_8$ | % Dt. |
| Mags | 7.71 | 0.178 | 40.35 | 45.68 | 0.083 | 68.45 | 8.63 | 0.308 | 56.96 |
| Non-Mags | 92.29 | 0.034 | 59.65 | 54.32 | 0.032 | 31.55 | 91.37 | 0.026 | 43.04 |
| | 100.00 | 0.034 | 100.00 | 100.00 | 0.055 | 100.00 | 100.00 | 0.047 | 100.00 |
| Enrichment ratio | | 5.24 | | | 1.50 | | | 6.55 | |

**Table—2 : Quartzites**

| Product | Sample No. 1 (Jamiri) | | | Sample No. 2 (Jamiri) | | | Sample No. 3 (Jamiri) | | |
|---|---|---|---|---|---|---|---|---|---|
| | % Wt. | % $eU_3O_8$ | % Dt. | % Wt. | % $eU_3O_8$ | % Dt. | % Wt. | % $eU_3O_8$ | % Dt. |
| Mags Conc. | 7.52 | 0.46 | 48.28 | 6.96 | 0.145 | 34.43 | 3.54 | 0.264 | 29.38 |
| Non-Mags | 92.48 | 0.04 | 51.72 | 93.04 | 0.021 | 65.57 | 96.46 | 0.023 | 70.62 |
| Tails | 100.00 | 0.07 | 100.00 | 100.00 | 0.029 | 100.00 | 100.00 | 0.031 | 100.00 |
| Enrichment ratio | | 6.57 | | | 5.00 | | | 8.52 | |

| Product | Sample No. 4 (Jamiri) | | | Sample (Chinjra) | | |
|---|---|---|---|---|---|---|
| | % Wt. | % $eU_3O_8$ | % Dt. | % Wt. | % $eU_3O_8$ | % Dt. |
| Mags Conc. | 5.47 | 0.159 | 26.45 | 14.80 | 23.74 | 65.09 |
| Non-mags | 94.53 | 0.026 | 73.55 | 85.19 | 2.21 | 34.91 |
| Tails | 100.00 | 0.033 | 100.00 | 99.99 | 5.10 | 100.00 |
| Enrichment ratio | | 4.82 | | | 4.40 | |

**Table – 3 : Sandstones**

| Product | Nongmaw Mairang | | | Core sample No. 1 (Arbail) | | |
|---|---|---|---|---|---|---|
| | °/₀ Wt. | °/₀ $eU_3O_8$ | °/₀ Dt. | °/₀ Wt. | °/₀ $eU_3O_8$ | °/₀ Dt. |
| Mags | 25.85 | 0.096 | 53.84 | 76.00 | 0.085 | 97.50 |
| Non-Mags | 74.15 | 0.028 | 46.16 | 24.00 | 0.011 | 2.50 |
| | 100.00 | 0.046 | 100.00 | 100.00 | 0.066 | 100.00 |
| Enrichment ratio | | 2.09 | | | 1.29 | |

| Product | Core sample No. 2 (Arbail) | | | Core sample No. 3 (Arbail) | | |
|---|---|---|---|---|---|---|
| | °/₀ Wt. | °/₀ $eU_3O_8$ | °/₀ Dt. | °/₀ Wt. | °/₀ $eU_3O_8$ | °/₀ Dt. |
| Mags | 70.61 | 0.068 | 95.3 | 72.92 | 0.046 | 93.23 |
| Non-Mags | 29.39 | 0.008 | 4.7 | 27.08 | 0.009 | 6.77 |
| | 100.00 | 0.050 | 100.00 | 100.00 | 0.036 | 100.00 |
| Enrichment ratio | | 1.36 | | | 1.28 | |

**Table—4 : Chlorite-quartz-schist**

| Product | °/₀ Wt. | °/₀ $eU_3O_8$ | °/₀ Dt. | °/₀ Wt. | °/₀ $eU_3O_8$ | °/₀ Dt. |
|---|---|---|---|---|---|---|
| | Keruadongri | | | Turamdih | | |
| Mags | 84.45 | 0.046 | 90.33 | 51.04 | 0.031 | 63.89 |
| Non-Mags | 15.55 | 0.027 | 9.67 | 48.96 | 0.018 | 36.11 |
| | 100.00 | 0.043 | 100.00 | 100.00 | 0.024 | 100.00 |
| Enrichment ratio | | 1.07 | | | 1.27 | |
| | Bagjata ( –40 ) (1) | | | Bagjata ( –60 ) (2) | | |
| Mags | 50.73 | 0.062 | 81.98 | 43.89 | 0.059 | 78.40 |
| Non-Mags | 49.27 | 0.014 | 18.02 | 56.11 | 0.013 | 21.60 |
| | 100.00 | 0.037 | 100.00 | 100.00 | 0.033 | 100.00 |
| Enrichment ratio | | 1.67 | | | 1.79 | |
| | Bagjata ( –100) (3) | | | Bagjata ( –40) Tabling/WHIMS | | |
| Mags | 49.12 | 0.046 | 82.13 | 27.90 | 0.091 | 74.10 |
| Non-Mags | 50.88 | 0.009 | 17.87 | 72.10 | 0.012 | 25.90 |
| | 100.00 | 0.027 | 100.00 | 100.00 | 0.034 | 100.00 |
| Enrichment ratio | | 1.70 | | | 2.68 | |
| | Bagjata ( –60) (5) Tabling/WHIMS | | | Bagjata ( –100) (6) Tabling/WHIMS | | |
| Mags | 24.31 | 0.107 | 77.09 | 22.01 | 0.111 | 77.70 |
| Non-Mags | 75.69 | 0.010 | 22.91 | 77.99 | 0.009 | 22.30 |
| | 100.00 | 0.034 | 100.00 | 100.00 | 0.031 | 100.00 |
| Enrichment ratio | | 3.15 | | | 3.58 | |

**Table—5 : Wet high intensity magnetic separation of uranium ores**

| Locality | Rock type | Feed | Mags conc. | | | Non-mags tails | | | Minerals present in the rock | Enrichment ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Assay $\% U_3O_8$ | % Wt. | % $U_3O_8$ | % Dt. | % Wt. | % $U_3O_8$ | % Dt. | | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
| Penvella, Mehboobnagar dist. (A.P.) | Granite | 0.034 | 7.71 | 0.178 | 40.35 | 92.29 | 0.034 | 59.65 | Cyrtolite, thorite, uraninite, monazite, uranophane, rutile, chamosite, epidote, hematite, quartz, feldspar, zircon and garnet. | 5.24 |
| Serandampalaya-Salem dist. (T. N.) | — do — | 0.055 | 45.68 | 0.083 | 68.45 | 54.32 | 0.032 | 31.55 | Garnet, Reibeckite, fluorapatite, allanite, hematite and spessartite garnet. | 1.50 |
| Binda-Nagnaha-Palamau dist. (Bihar) | — do — | 0.047 | 8.63 | 0.308 | 56.96 | 91.37 | 0.026 | 43.04 | Quartz, felspar, biotite, zircon uraninite, uranophane, autunite, apatite. | 6.55 |
| Jamiri (Arunachal Pradesh) | Quartzite | 0.07 | 7.52 | 0.46 | 48.28 | 92.48 | 0.04 | 51.72 | Quartz, felspar, brannertie, uraninite. | 6.57 |
| — do — | — do — | 0.029 | 6.96 | 0.145 | 34.43 | 73.04 | 0.021 | 65.57 | — do — | 5.0 |
| — do — | — do — | 0.031 | 3.54 | 0.264 | 29.38 | 96.46 | 0.023 | 70.62 | — do — | 8.52 |
| — do — | — do — | 0.033 | 5.47 | 0.159 | 26.45 | 94.53 | 0.026 | 73.55 | — do — | 4.82 |
| Nong-Mawmairang | Sandstone | 0.046 | 25.85 | 0.096 | 53.84 | 74.15 | 0.028 | 46.16 | Quartz, sericite, clay, limonite, coffinite, zircon. | 2.09 |
| Arbail, N. Kanara dist., Karnataka | Calc. arenite (Roasted rock sample) | 0.040 | 58.34 | 0.057 | 82.47 | 41.67 | 0.017 | 17.53 | Pyrite, muscovite, quartz, uraninite, bravoite, calcite, goethite, siderite. | 1.43 |

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
|---|---|---|---|---|---|---|---|---|---|---|
| — do — | Core samples | 0.066 | 76.0 | 0.085 | 97.5 | 24.0 | 0.011 | 2.50 | — do — | 1.29 |
| — do — | — do — | 0.050 | 70.61 | 0.068 | 95.3 | 29.39 | 0.008 | 4.7 | — do — | 1.36 |
| — do — | — do — | 0.036 | 72.92 | 0.046 | 93.23 | 27.08 | 0.009 | 6.77 | — do — | 1.28 |
| Kerua Dongri, STB, Bihar | Chlorite quartz-schist | 0.043 | 84.45 | 0.046 | 90.33 | 15.55 | 0.027 | 9.67 | Quartz, chlorite, sericite, biotite, magnesite, apatite, uraninite. | 1.07 |
| Turamdih, STB Bihar | — do — | 0.024 | 51.04 | 0.031 | 63.89 | 48.96 | 0.018 | 36.11 | Quartz, chlorite, sericite biotite, magnetite, apatite, uraninite. | 1.27 |
| Bagjata, STB, Bihar | — do — (—40mesh) Direct WHIMS | 0.038 | 50.76 | 0.062 | 81.98 | 49.21 | 0.014 | 18.02 | Quartz, sericite, chlorite, magnetite, apatite, uraninite. | 1.63 |
| — do — | (60mesh) — do — | 0.033 | 43.89 | 0.059 | 78.02 | 56.11 | 0.013 | 21.98 | — do — | 1.79 |
| — do — | (100mesh) — do — | 0.027 | 49.12 | 0.046 | 83.15 | 50.88 | 0.009 | 16.85 | — do — | 1.70 |
| — do — | — do — (—60mesh) Wet tabling WHIMS | 0.034 | 24.31 | 0.107 | 77.46 | 75.69 | 0.010 | 22.54 | — do — | 3.15 |
| — do — | — do — (—40mesh) Direct WHIMS | 0.034 | 27.90 | 0.091 | 74.10 | 72.10 | 0.012 | 25.90 | — do — | 2.68 |
| — do — | —do— (—100mesh) Wet tabling WHIMS | 0.031 | 22.01 | 0.111 | 77.70 | 77.99 | 0.009 | 22.30 | — do — | 3.58 |
| Chinjra, Kulu dist. (H. P) | Quartzite (— 60mesh) Directo WHIMS | 5.40 | 14.80 | 23.74 | 65.09 | 85.19 | 2.21 | 34.91 | Quartz, felspar, chlorite, hematite, zircon, rutile, pitchblende / uraninite. autunite, uranophane. | 4.40 |