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Processing of fine size minerals : Studies on some Indian uranium ores

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ABSTRACT

Conventionally uranium ores are processed by direct chemical leaching techniques. However, the application of chemical leaching for lean tenor and high tonnage uranium ores is being desisted due to obvious environmental concerns. It is in this context that the physical beneficiation methods for the pre-concentration of uranium ores, if feasible, are gaining importance. Adoption of physical beneficiation helps in containing uranium and daughter nuclides in a smaller mass of pre-concentrate, which can be further subjected to conventional chemical processing, leaving bulk of the ore safe for disposal.

In the application of physical beneficiation techniques, particle size plays a significant role. Both the economic mineral of uranium — uraninite and pitchblend, are brittle and report in very fine sizes during comminution, an operation meant for their liberation. It is a well-established fact that concentration of particles finer than 25μm by conventional physical beneficiation methods is very difficult due to the low mass and high surface area. However, with the advent of new fine particle concentrators and techniques the situation has shown tremendous improvement. This paper highlights the studies carried out on the use of both physical (gravity and magnetic) and physico-chemical beneficiation methods for recovering fine size uranium values from some low grade uranium bearing ores of India.

Keywords : *Uranium, Physical beneficiation, Gravity, Magnetic, Shear-flocculation*

INTRODUCTION

Electrical energy is an important infrastructure component for societal development. The per-capita energy consumption of any country indicates its social and economic level of progress. India is one of the countries, which generates bulk of its electrical power using coal-based fuels. However, the rapid dwindling of fossil fuels has already triggered search for alternate power sources. One of the important alternatives is nuclear power. In tune with this national necessity, Department of Atomic Energy has set for itself an ambitious target of producing 20,000 MW (e) by 2020 AD Achieving this target obviously requires enough supply of the nuclear fuel, mainly uranium.

Many of the available uranium resources of India are of lean tenor ($\leq$500 ppm of U_3O_8). Conventionally uranium ores are processed by direct chemical leaching techniques. However, the application of chemical leaching for lean tenor and high tonnage uranium ores is being desisted due to obvious economic and environmental concerns. It is in this context that the physical beneficiation methods for the pre-concentration of uranium ores, if feasible, are gaining importance. The economic uranium minerals-uraninite and pitchblend, are bestowed with useful physical properties like: high specific gravity (11.0) and weakly paramagnetic nature [magnetic susceptibility (emu/cc) of UO_2 1.2 x 1^{0-3}, UO_3 4 x 10^{-5}, U_3O_8 2 x 10^{-4}]. However, these two uranium minerals are also very brittle. The uranium ores of India are not only of low tenor but their mineralisation is also very fine and in highly disseminated state necessitating extensive grinding for adequate liberation. This results in generation of excessive fines due to their inherent brittle nature. It is a well-established fact that concentration of particles finer than 25μm by conventional physical beneficiation methods is very difficult due to the low mass and high surface area. However, with the advent of new fine particle concentrators (both gravity and magnetic) and, other physico-chemical separation techniques the situation has shown tremendous improvement. This paper highlights the studies carried out on use of both physical and physico-chemical beneficiation methods for pre-concentration of uranium minerals from some low grade uranium bearing ores of India with special emphasis on recovery from fine sizes.

GRAVITY SEPARATION

Separations based on specific gravity differences are one of the oldest methods used in mineral beneficiation. Gravity separators are particularly suitable for processing high specific gravity minerals, which are adequately liberated, from the host matrix. The developments of gravity separators based on the principle of Bagnold shear force and on centrifugal acceleration have enlarged the particle size range that can be processed from very coarse to very fine and ultrafine sizes. Unlike other separation techniques like flotation, flocculation etc., gravity separation doesn't generally need chemicals, some of which could be environmentally unsafe. The following discussion gives an account of studies carried out[1,2,3] on pre-concentration of uranium values using fine gravity separators like Bartles Mozley Separator (BMS), Cross Belt Separator (CBC) and Multi Gravity Separator (MGS).

The tailings of the concentrator plants of Hindustan Copper Limited, located at Surda, Rakha and Mosaboni (Singhbhum district, Bihar) contain trace quantities of uranium mineral values (80-100 ppm U_3O_8). The contained U_3O_8 values in the copper ores of Singhbhum is about 5000 tonnes. These are recovered at present in part by Uranium Corporation of India Limited, with the help of Wilfley shaking tables with slimes deck. But the recoveries from these plants are rather low (20-40%). The poor recoveries are essentially due to inadequate liberation of uraninite and also due to the significant distribution of uranium values in very fine (<20μm) and ultrafine size (<5μm), which are poorly recovered on the conventional shaking tables. Detailed liberation studies on these ore samples showed significant uranium distributions as fine inclusions in micaceous minerals such as chlorite which are present to the extent of 22%, 10% and 37% by weight in Surda, Rakha and Mosaboni respectively. The uranium distribution closely follows chlorite weight, and it is well known fact that recovery of micaceous minerals on shaking tables is not that efficient. Particle size analysis on the three tailings samples show nearly 32-47% uranium distribution in -400# (<37μm) size fraction, constituting 13-18% by weight. Of these only 15-25% of uranium, values only are recovered on tables.

Extensive studies were carried out on the application of Bartles Mozley Separator (BMS) and Cross Belt Concentrator (CBC) for the pre-concentration of uranium values present in those size fractions which could not be recovered on the shaking tables. The feed preparation for these experiments consists of initial classification of copper plant tailings on a CTS screen with an opening of 100(m followed by treating the screen fines on BMS. The feed material treated on BMS contained as high as 81% by weight in -37μm. The effect of operating parameters of BMS studied were orbital speed, feed flow-rate, deck slope and cycle time. The laboratory studies indicated the scope of recovering about 80% of the uranium values with an enrichment ratio of 2-2.7, the optimal range of parameters determined from the laboratory studies was: orbital speed 210-230 rev/min, flow-rate 75-80 x 10^{-6} $m^3/s/m^2$, slope 1^0-1.5^0, cycle time <10 min (Table 1).

Experiments were also carried out on larger scale in pilot-plant scale BMS equipment housed at Bharat Gold Mines Limited. Fig 1. gives the recovery of uranium values in different size fractions of the BMS pre-concentrate in relation to that in the feed. About 55-80% of the values could be recovered in the size range of 100 to 37μm, with the efficiency increasing with decreasing particle size upto 37μm. Interestingly the efficiency of BMS drops as the particle size becomes very fine, say <20μm.

Based upon the results obtained on BMS and CBC an integrated gravity beneficiation flow-sheet was developed in mid 80's for uranium recovery from

Table 1: Effect of operating parameters of Bartles Mozley Separator on uranium recovery from classified fines (d_{80} 37μm) of Mosaboni copper plant tailings

Parameter	Recovery, %	Enrichment ratio
Orbital Speed (rev.min.)		
210	88	2.1
230	81	2.24
250	73	2.77
Flow rate (cm^3/sec)		
18-21	73	2.77
12-15	89	1.96
Deck Slope (Degrees)		
1.0	77	1.9
1.5	63	2.6
2.0	53	2.4

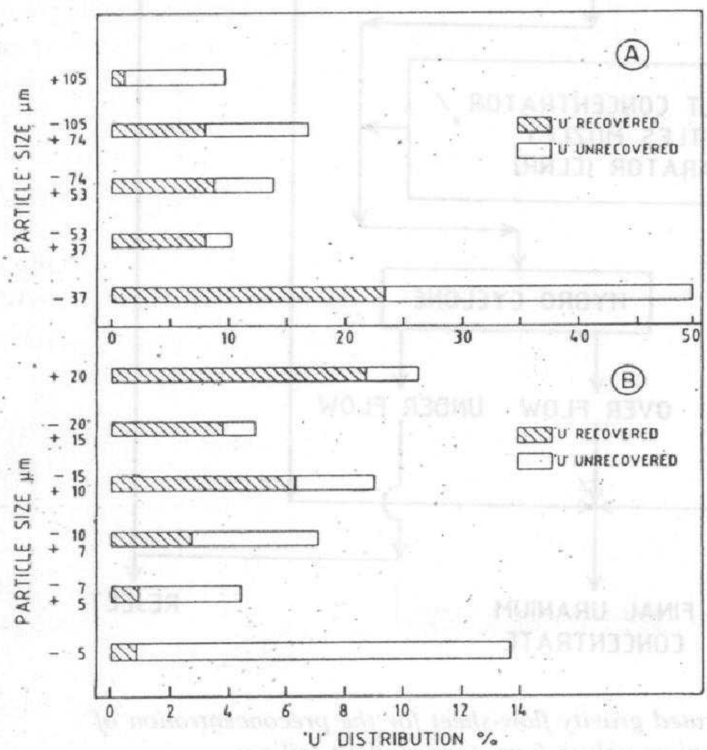

Fig. 1 : Recovery of uranium in different size fractions in BMS concentrate of copper plant tailings from Mosabani. (A) Sizing on standard test sieves and (B) Sub-sieve analysis of -37 micron fraction on cyclosizer

copper plant tailings. The flowsheet is given in Fig.2 which is self-explanatory. The combined gravity pre-concentrate (tables + CBC) carried a recovery of 47% (Mosaboni) and 64% (Surda) with an enrichment ratio of 7.5 and 9 respectively. The fines being lost in the BMS and CBC tailings were recovered by using small diameter hydrocyclone thus enhancing the overall recovery to 53 from Mosaboni and 72 from Surda copper tailings with an enrichment ratio of 5.9 and 7 respectively.

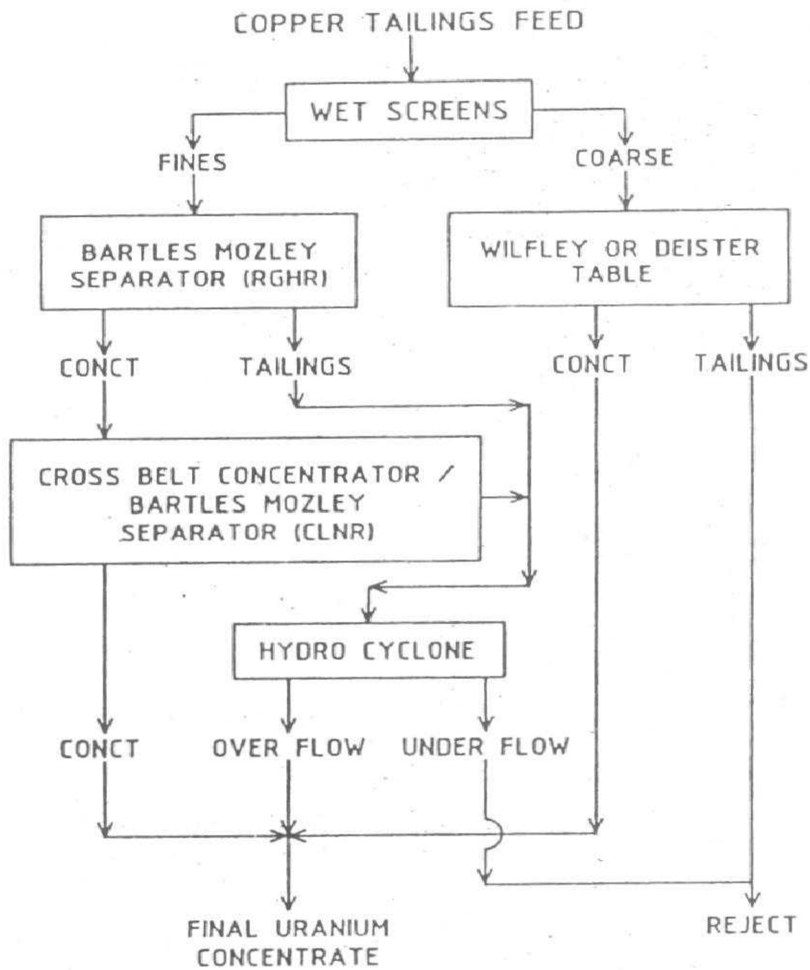

Fig. 2 : Integrated gravity flow-sheet for the preconcentration of uranium values from copper plant tailings

The work carried out on BMS and CBC was followed up on new generation of fine gravity concentrators like: Multi gravity separator (MGS), Knelsons Concentrator etc., which entered the commercial market in early 90's. These machines are designed to give high centrifugal acceleration, which aids in pinning down very fine and ultrafine size particles. Feasibility studies were conducted on Multi Gravity Separator for uranium pre-concentration from sizes, which were not recovered in BMS/CBC. The experiments were carried out on a synthetic feed prepared from Narwapahar uranium ore. The d50 cut size of the feed for MGS experiments was 15µm having a head assay of containing 540 ppm U_3O_8. At optimum operating conditions of drum speed, shake frequency and shake amplitude a concentrate analysing about 2161 ppm U_3O_8 was obtained with 93% recovery. This high recovery implies efficient recovery in very and ultrafine sizes also.

MAGNETIC SEPARATION

Another important attribute, which may be utilised for uranium pre-concentration from the ores, is its paramagnetic property. Beneficiation of magnetic minerals in a magnetic separator depends on the magnetic susceptibility of the mineral, magnetic force (F_m) acting on the particle, viscous or drag forces and gravitational forces. The magnetic forces pull the magnetically susceptible particles in one direction for getting them captured on the surface of the matrix of the separator. The other forces pull all the other particles in another direction and they also compete with magnetic forces in driving off the magnetic particles in their own direction. The magnetic force acting on the particle is dependent both on the intensity of the magnetic field and the field gradient as follows:

$$F_m = {}^1/_2\ \mu_o\ (X_p - X_f)$$

Where X_p and X_f are the magnetic susceptibilities of the particle and fluid medium respectively and μ_o is the permittivity of the vacuum.

Several advances have taken place with respect to magnet and matrix design inorder to increase both the intensity and gradient of the magnetic field particularly for capturing particles in very fine and ultrafine sizes. Some of the industrially used magnetic separators for fine particle recovery are: wet high intensity magnetic separator, (WHIMS), high gradient magnetic separator (HGMS) and super-conducting high gradient magnetic separator (SC-HGMS). All these separators were used for uranium recovery from copper plant tailings.

Wet High Intensity Magnetic Separation

Wet high intensity magnetic separation (WHIMS) tests on the copper plant tailings have been carried out in a continuously operated pilot-plant scale equipment of Boxmag Rapid design. The matrix collecting the magnetic particles is made of wedge-bar assembly with a gap of 1mm. Separation carried out at a magnetic flux density of 1.8 Tesla. The operating parameters affecting the performance of the WHIMS like: matrix drum speed, % solids in the feed, feed flowrate and number of recycles were studied in detail. Results show that the uranium present in the copper plant tailings are amenable to magnetic separation in WHIMS and that recoveries in the range of 75% -85% are achievable at an enrichment ratio of 1.7. Very high recoveries were obtained in particle sizes upto 15μm (Fig.3). The recoveries obtained are very much higher than that obtained by using fine gravity machines; however the weight percent collection is also very high, 45 to 50%.

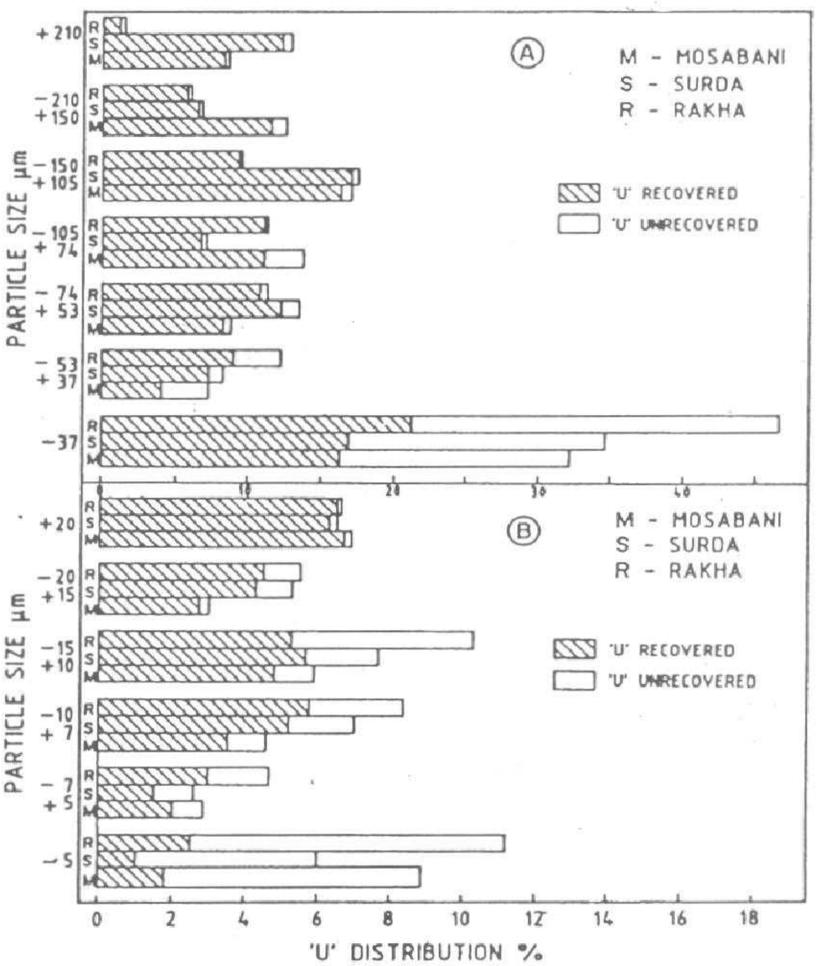

Fig. 3 : Recovery of uranium in different fractions of WHIMS magnetic concentrate of copper plant tailings. (A) Sizing on standard test sieves. (B). Subsieve analysis of -37 micron fraction on cyclosizer

An analysis of the results indicated that two characteristics of the tailings, the mineralogy and particle size of the valuable mineral affect the overall performance. The high micaceous mineral content (chlorite and biotite), which have higher magnetic susceptibility than uranium minerals report in the magnetic stream, diluting the enrichment factor of U_3O_8. However, collection of mica in the magnetic fraction improves the recovery, as considerable amounts of uranium minerals are associated with micaceous minerals as composite.

The particle capture efficiency curves of WHIMS (Fig.4) indicate poor collection at sizes finer than 15μm. These finer sized particles experience higher fluid drag force and hence have greater probability of reporting in the non-magnetics stream during separation in WHIMS. To recover such particles higher magnetic force than what is feasible in WHIMS is necessary. Such high forces can be attained in high gradient or superconducting magnetic separators.

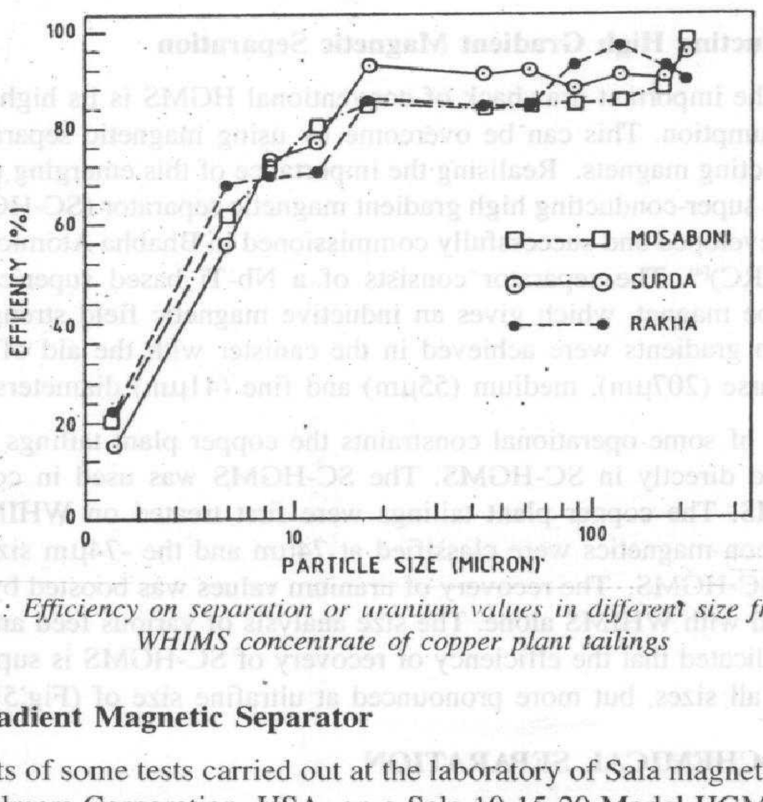

Fig. 4 : Efficiency on separation or uranium values in different size fractions of WHIMS concentrate of copper plant tailings

High Gradient Magnetic Separator

Results of some tests carried out at the laboratory of Sala magnetics Division, Allis Chalmers Corporation, USA, on a Sala 10-15-20 Model HGMS with classified fines (<100μm) of Mosaboni copper plant tailings are given in Table 2. After three stages of sequential passing with increasing magnetic field, the last being at 1.5 T, 93.5% of the uranium values are recovered in the magnetic stream in about 49.5% weight at an enrichment ratio of 1.9. The final non-magnetics analysed as low as 22 ppm U_3O_8. Results of HGMS have indeed proved that higher magnetic force would enhance the particle capture probability of para-magnetic particles even in very-and ultra-fine sizes.

Table 2: High gradient magnetic separator tests on classified fines (-100µm) of mosabani Copper Plant Tailings. Feed : U_3O_8 109 ppm, Non-Mags.: U_3O_8 22ppm.

Applied Mag. Field	Magnetics (Cumulative)			
(k. Gauss)	Wt%	U_3O_8 (ppm)	Dist%	E.R.
5	18.76	257	44.17	2.57
10	34.36	239	75.20	2.20
15	46.63	207	89.34	1.90

Super-conducting High Gradient Magnetic Separation

One of the important drawback of conventional HGMS is its high electrical power consumption. This can be overcome by using magnetic separators with super-conducting magnets. Realising the importance of this emerging technique, a proto-type super-conducting high gradient magnetic separator (SC-HGMS) was designed, developed and successfully commissioned in Bhabha Atomic Research Centre (BARC)[4]. The separator consists of a Nb-Ti based super-conducting solenoid type magnet, which gives an inductive magnetic field strength of 3.5 Tesla. High gradients were achieved in the canister with the aid of magnetic wool of coarse (207µm), medium (55µm) and fine (41µm) diameters.

Because of some operational constraints the copper plant tailings could not be processed directly in SC-HGMS. The SC-HGMS was used in conjunction with WHIMS. The copper plant tailings were first treated on WHIMS at 1.5 Tesla. The non-magnetics were classified at 74µm and the -74µm size fraction was fed to SC-HGMS. The recovery of uranium values was boosted by 5% over that obtained with WHIMS alone. The size analysis of various feed and product fractions indicated that the efficiency of recovery of SC-HGMS is superior than WHIMS at all sizes, but more pronounced at ultrafine size of (Fig.5) <5µm.

PHYSICO-CHEMICAL SEPARATION

It is clear from the foregoing discussion that recovery of uranium values in the 5-15µm size range is the difficult aspect in uranium beneficiation by physical separation methods. Physico-chemical separation techniques like: selective flotation, flocculation etc., are generally used for recovery of particles in the very fine and ultrafine size range. Flocculation studies were carried out in our laboratory

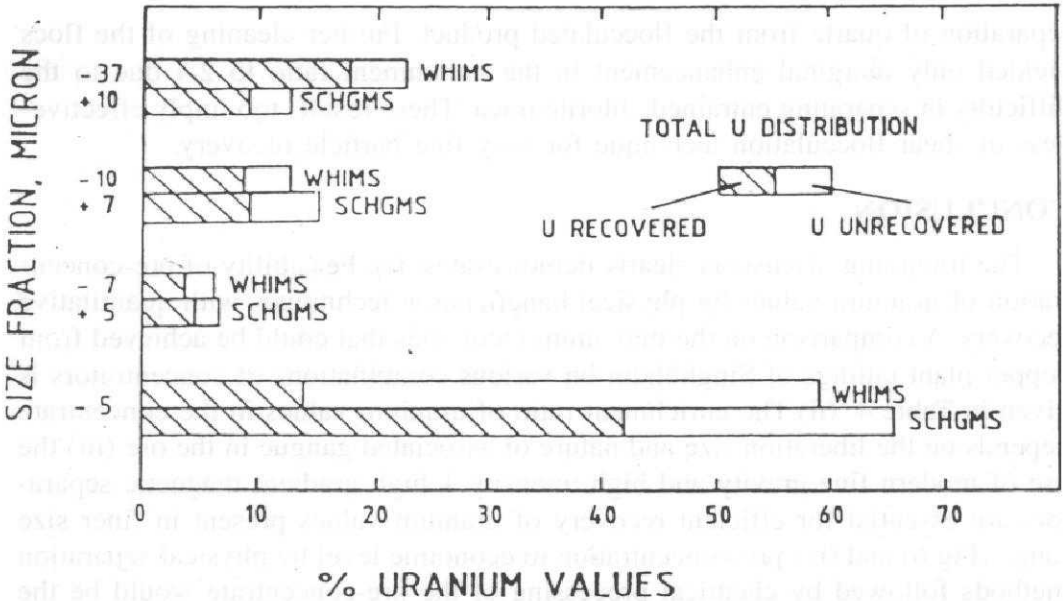

Fig. 5 : Comparison between WHIMS and SC-HGMS results

for the concentration of uranium values (very and ultrafine size) using polyacryl amide flocculant grafted with specific functional groups like glyoxal bis (2 hydroxy anil). Though this reagent gave an enrichment ratio of 2, the shelf life of the polymer was not long. In view of this shear induced flocculation was studied using alkyl phosphoric acid ester, $(RO)_2PO(OH)$ or $(OR)PO(OH)_2$, an organic reagent widely used in solvent extraction of uranium and many other metals[5]. The feed material used for these studies was -10 +5μm size fraction of Jaduguda uranium ore analysing 400 ppm of U_3O_8. The main gangue here is quartz (36%) and chlorite mica (48%). The variables studied are: influence of suspension pH; concentrations of surfactant, bridging liquid, dispersant and shear rate. At optimum conditions, the aggregated product was enriched by 1.7 times in uranium content carrying about 90% of the values (Table 3). There was near complete

Table 3 : Shear flocculation test on Jaduguda uranium ore (Feed U_3O_8 400 ppm, % Solids 5, pH 7.5, alkyl phosphoric acid ester 600 ppm, iso-octane 10% (V/V), sodium silicate 1000 ppm, shear 1500 rpm.

Product	U_3O_8 (ppm)	Rec.%	E.R.
Flocs (rghr. stage)	679	89	1.7
Dispersed fraction (rghr.stage)	95	11	—
Flocs (silicate cleaning stage)	948	79	2.37
Dispersed fraction (silicate cleaning stage)	200	10	—

separation of quartz from the flocculated product. Further cleaning of the flocs yielded only marginal enhancement in the enrichment ratio to 2.4 due to the difficulty in separating entrained chlorite mica. These results too imply effectiveness of shear flocculation technique for very fine particle recovery.

CONCLUSION

The foregoing discussion clearly demonstrates: (i). Feasibility of pre-concentration of uranium values by physical beneficiation techniques with quantitative recovery. A comparison on the maximum recoveries that could be achieved from copper plant tailings of Singhbhum on various combinations of concentrators is given in Table 4. (ii).The enrichment ratio of uranium values in the concentrate depends on the liberation size and nature of associated gangue in the ore (iii) the use of modern fine gravity and high intensity + high gradient magnetic separators are essential for efficient recovery of uranium values present in finer size range (Fig.6) and (iv) pre-concentration to economic level by physical separation methods followed by chemical processing of the pre-concentrate would be the environmentally safer route for processing low-grade uranium ores.

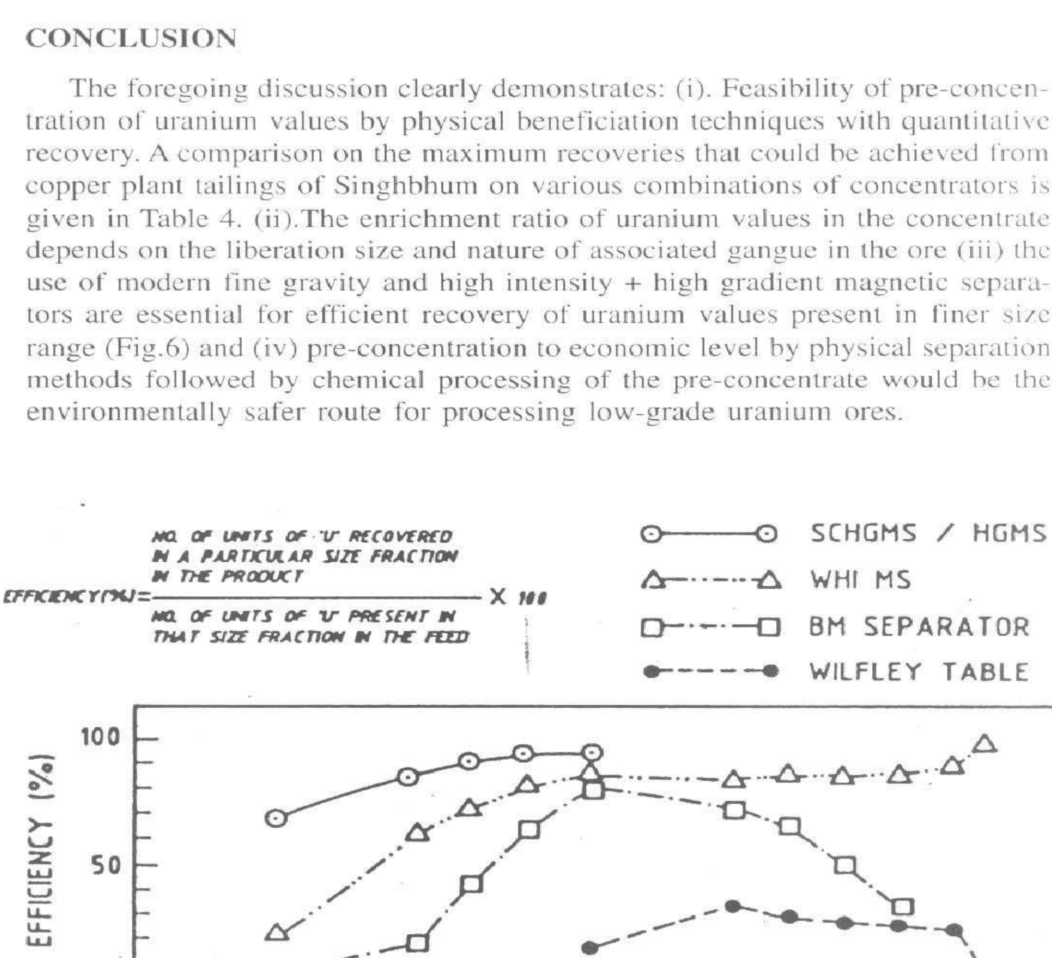

Fig. 6 : Comparison of the efficiencies of separation of uranium values in different size fractions in different gravity and magnetic separators (data on Mosabani copper plant tailings).

Table 4 : Uranium recoveries from copper plant tailings by various flowsheets

Unit operations	Surda	Rakha	Mosaboni
Flowsheet with wet shaking tables (WST) alone	40-45%	35-40%	18-22%
Flowsheet with WST - BMS-CBC	60-70%	55-60%	47-55%
Flowsheet with WHIMS	80-85%	70-75%	80-85%
Flowsheet with WHIMS - SCHGMS	85-90%	75-80%	85-90%

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