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Beneficiation of Light Rare Earth Elements from Dubeydib Heavy Mineral Sands Deposits, South Jordan

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ABSTRACT

This study describes the beneficiation of monazite mineral from heavy mineral sands deposit of Dubaydib, South Jordan. The heavy mineral sand sample contained 1.80% monazite [$(Ce,La,Nd,Th)PO_4$] *based on chemical composition of light rare earth elements such as cerium (Ce), lanthanum (La) and neodymium (Nd). It contained low contents of 0.23% La (0.26%* La_2O_3*), 0.50% Ce (0.59%* Ce_2O_3*), 0.21% Nd (0.24%* Nd_2O_3*), 0.08% Y (0.1%* Y_2O_3*), 0.13% Th (0.15%* ThO_2*), 0.015% U (0.018%* U_3O_8*) and 0.66%* P_2O_5*. The major elemental composition of 64.4%* SiO_2*, 6.9%* Al_2O_3*, 6.0%* Fe_2O_3*, 6.5%* TiO_2 *and 3.49% Zr (4.72%* ZrO_2*) are present in the sample. The monazite sand sample contained quartz, plagioclase, mica, rutile, Ilmenite and zircon as major minerals with monazite as minor mineral. For beneficiation studies, the density separation (hydrocyclone and Wilfley shaking table) and froth flotation techniques were used to produce monazite concentrates from heavy mineral sand. The produced monazite concentrate-1 contained 5.5%* La_2O_3*, 10.6%* Ce_2O_3*, 4.8%* Nd_2O_3*, 0.54%* Y_2O_3*, 0.97%* ThO_2 *and 0.11%* U_3O_8*; whereas the concentrate-2 contained 10.3%* La_2O_3*, 21.8%* Ce_2O_3*, 9.2%* Nd_2O_3 *and 1.33%* Y_2O_3*.*

Keywords: *Heavy Mineral Sand, Monazite, Light Rare Earth Elements (LREE), Hydrocyclone, Wilfley Shaking Table, Froth Flotation*

1. Introduction

Monazite is a reddish-brown crystalline phosphate mineral [$(Ce,La,Nd,Th)PO_4$] and a major natural source of light rare-earth elements (Ce, La and Nd) and thorium (Th) extraction on commercial scale. Monazite, among 250 known minerals containing rare earth elements is one of the most important minerals as the primary source of Refs [1-4]. The total rare earth oxide contents of monazite exist in the range of 49.60-73.14% REE_2O_3 with average value of 64.31% REE_2O_3. It is a radioactive mineral due to the presence of thorium (Th) and less content of uranium (U). Monazite contains a significant amount of helium (^2He) due to alpha (α) decay of Th and U, which can be extracted on heating [5]. It is formed when igneous rocks undergo crystallization and clastic sedimentary rocks undergo metamorphism and occurs as small heavy crystals in granitic and gneissic rocks and their detritus as called monazite sands. Monazite is considered as a group of minerals due to variability in rare earth elements composition. There are five most common species of monazite, depending on the relative amounts of rare earth elements in the mineral; monazite-(Ce), $(Ce,La,Nd,Th)PO_4$ (the most common member), monazite-(La), $(La,Ce,Nd)PO_4$, monazite-(Nd), $(Nd,La,Ce)PO_4$, monazite-(Sm), $(Sm,Gd,Ce,Th)PO_4$ and monazite-(Pr), $(Pr,Ce,Nd,Th)PO_4$ [6]. The most common species of the group is monazite-(Ce) which occurs usually in small isolated crystals. Monazite is commonly mined in placer deposits, which are masses of loose sediment mainly consisting of sand. The large deposits of monazite sand occur in Australia, Brazil, China, India, Malaysia, Madagascar, Vietnam and South Africa. Indian beach placers are an important source of monazite [7-11]. It is often mined as a byproduct of heavy mineral deposits.

Monazite and zircon minerals are found in the middle member of Dubaydib Formation (DB2) from the Ordovician age. Dubaydib area is characterized by flat sandy-clayey of alluvial sediments. The sand deposits were transported over a gentle slope from the Arabian-Nubian shield and deposited in the middle member of Dubaydib Formation over a huge area in the south of Jordan [12, 13]. It covers an area of 900 km^2 and is located about 350 km south of Amman city and 100 km north of Aqaba (Fig. 1). The thickness of heavy mineral sand deposit bearing monazite and zircon ranges from 1.5-4.2 meter. The host rock is mainly composed of quartz (SiO_2), plagioclase [$(Na,Ca)Al(Si,Al)Si_2O_8$], biotite [$K(Mg,Fe)_3AlSi_3O_{10}(F,OH)_2$], muscovite [$KAl_2(Si_3Al)O_{10}(OH)_2$] and zircon ($ZrSiO_4$), with small amounts of rutile (TiO_2), monazite [$(Ce,La,Nd,Th)PO_4$] and tourmaline (a crystalline silicate mineral group in which boron is compounded with Al, Fe, Mg, Li, Na and K) [12]. The Dubeydib heavy mineral sand deposit contained an average concentration of 1% rare earth elements.

In mineral processing sector, beneficiation studies are being used to separate target minerals from gangue minerals by applying differences in their physical properties such as density and magnetic properties. Physical separation techniques can be used to upgrade or to concentrate the ore prior to hydrometallurgical process when the target minerals are present in low concentration. Currently, extensive goal-oriented research work has been conducted to develop beneficiation flowsheet of various REE-bearing deposits [14-20]. In particular, the beneficiation process for placer deposits is well established and includes a combination of gravity, magnetic, electrostatic and flotation beneficiation processes [21-23]. For beneficiation of monazite from heavy mineral sands, shaking table and spiral density separation [24, 25], magnetic [26, 27], electrostatic [28] and froth flotation [29] separation techniques are being used. The quality of monazite is important for the hydrometallurgical process to extract high purity end products of La, Ce, Nd

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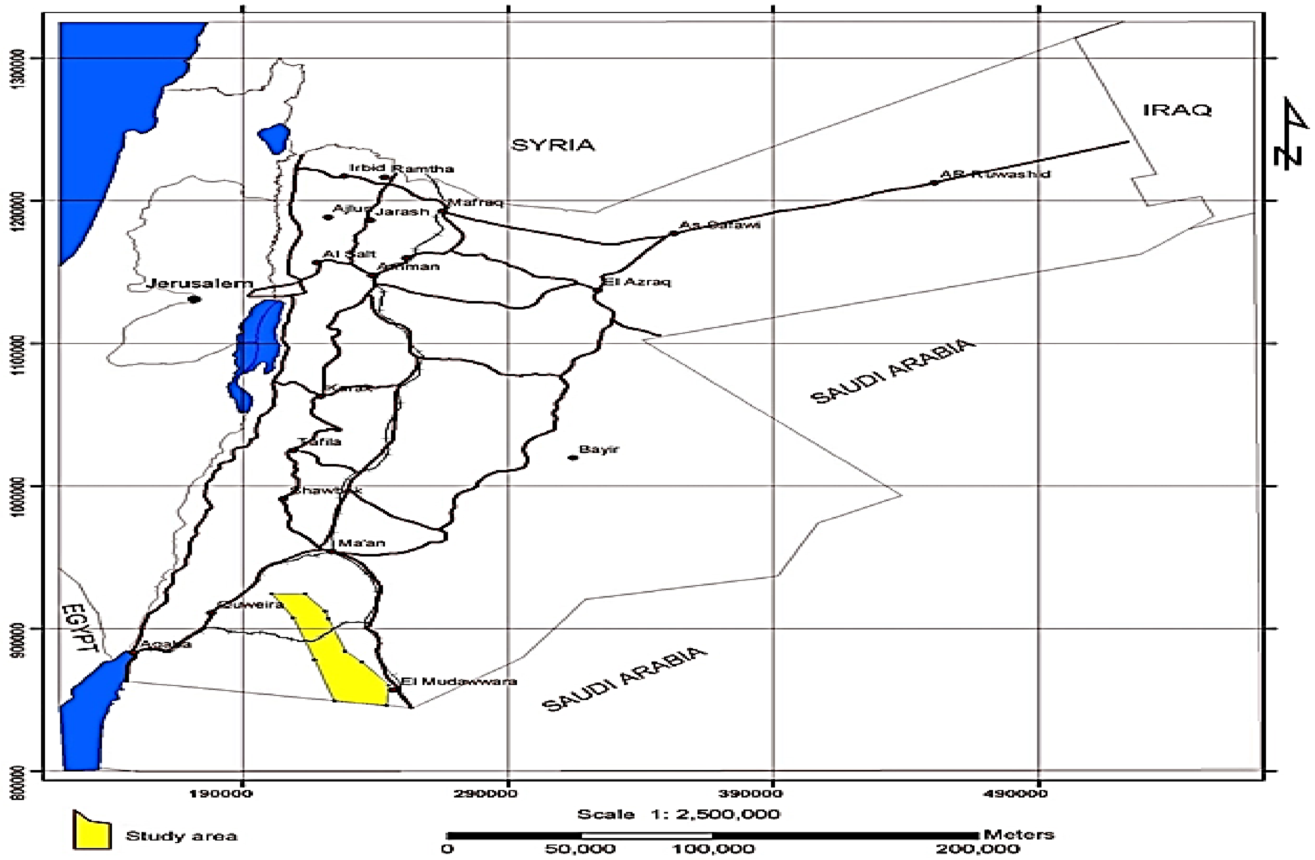


Fig. 1: A simplified Jordan map showing the Dubeydib heavy sand formation (yellow color).

and Y. The present study was conducted to produce monazite concentrate from Dubeydib heavy minerals sand by using density separation (hydrocyclone and shaking table) and froth flotation techniques.

2. Materials and Methods

2.1 Heavy mineral sand sample

The heavy mineral sand sample (200-kg) was collected from the Dubeydib deposit site. The sample was crushed, homogenized and the whole sample was pass through 35-mesh size sieve (<500 µm particle size). A representative sub-sample (20 kg) was prepared by thoroughly mixing, coning and quartering technique for chemical and experimental beneficiation studies. Fig. 2 shows the physical appearance of the heavy mineral sand in the field of Dubeydib formation. The mineralogical composition of the heavy mineral sand with mineral formula and specific density is reported in Table 1. X-ray diffraction analysis was carried out to determine the minerals present in the sample.

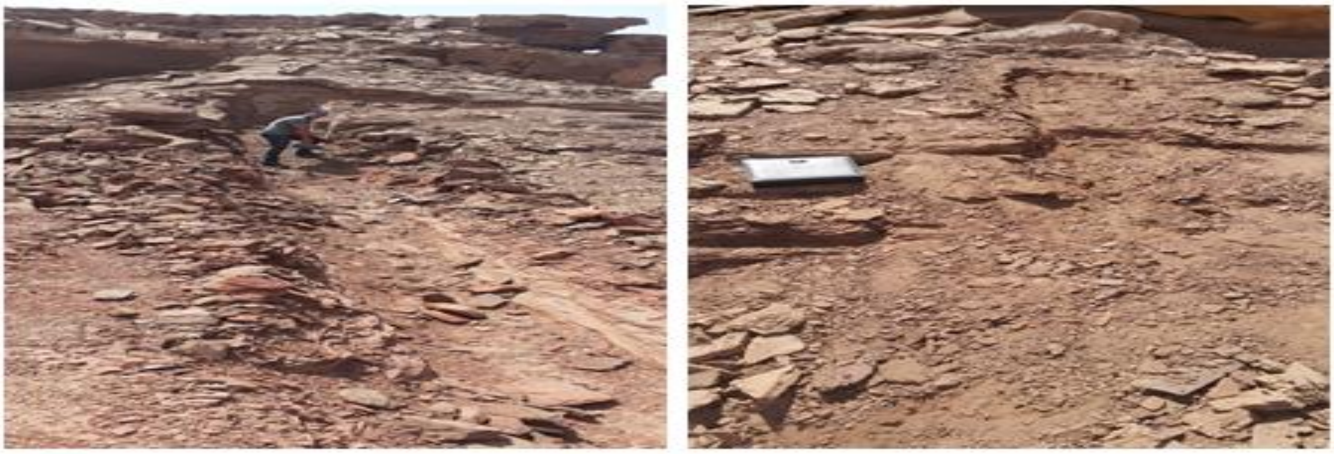


Fig. 2: Dubeydib heavy mineral sands formation – DB2 area

Table 1: Mineralogical characterization of Dubeydib Monazite concentrate

Mineral name	Mineral formula	Specific density (g cm^{-3})
Ce-Monazite	(Ce,La,Nd,Th,Y)PO_4	4.98-5.43
Zircon	$ZrSiO_4$	4.60-4.70
Rutile	TiO_2	4.23
Hafnon	(Hf,Zr)SiO_4	6.97
Hematite	Fe_2O_3	5.26
Ilmenite	$FeTiO_3$	4.70
Quartz	SiO_2	2.65
Plagioclase	$NaAlSi_3O_8$ - $CaAl_2Si_2O_8$	2.60-2.80

2.2 Beneficiation studies

Hydrocyclone separator was used to separate a stream of particles into fine and coarse size fractions. A water sand slurry (1kg sand in 30-litre water; <500 µm particle size) was pumped at 1 bar pressure to enter at the top of the conical wall of hydrocyclone through a vortex finder which created tangential flow and therefore, a strong vortex in the hydrocyclone. The slurry in the cyclone spined in a high velocity vortex and the fine particles capable of remaining in suspension exit out from the top central pipe (overflow) and the coarse particles spiral down to fall through the underflow at the narrow vortex base. Both the fractions (overflow and underflow) were collected, de-watered, dried and weight fractions calculated and analyzed for chemical composition. Fig. 3 shows the hydrocyclone unit and the process of separation fine size and coarse size fractions.

Holman-Wilfley shaking table (Holman Wilfley Ltd, UK), a gravity separation process was used to recover monazite from heavy mineral sand sample. The batch test was conducted using 2 kg of feed sample at 5º angle of the shaking table, 20 mm shaking amplitude and 2-litre/min water flow rate. Three fractions (light, middling and heavy) were collected, dewatered, dried, weighed and analyzed for rare earth elements. Fig. 4 shows the shaking table unit used for present studies.

Fig. 3: Hydrocyclone classifier (laboratory scale) with overflow and underflow fractions.

For froth flotation studies, 250-g sand sample was taken in 2 litre water in the system, the slurry pH 12.0 was adjusted with dil. NaOH solution, 1.0 g sodium silicate (as conditioner), 1.0 ml oleic acid (as collector) and 2-drops of Aero 619 (as frother) added for experimental studies. The slurry was stirred constantly during the addition of chemicals. The system was operated at 500-rpm with aeration to froth the particles. Two fractions (sink and float) were collected, washed with deionized water thoroughly, de-watered, dried, weighed and analyzed for rare earth elements. Fig. 5 shows the froth flotation unit and the mechanism of operation.

2.3 Chemical analysis

Wavelength-dispersive X-ray fluorescence spectrometer (Bruker S4 Pioneer WD XRF) was used for elemental analysis of the sand sample and sand fractions obtained during beneficiation studies carried out by hydrocyclone, shaking table and froth flotation techniques. The finely ground sample (0.6 g), less than 200-mesh (<73 µm) or finer was mixed with flux (lithium metaborate ($LiBO_2$); 10:1 ratio (0.6 g sample and 6.0 g flux) as the fusion material and

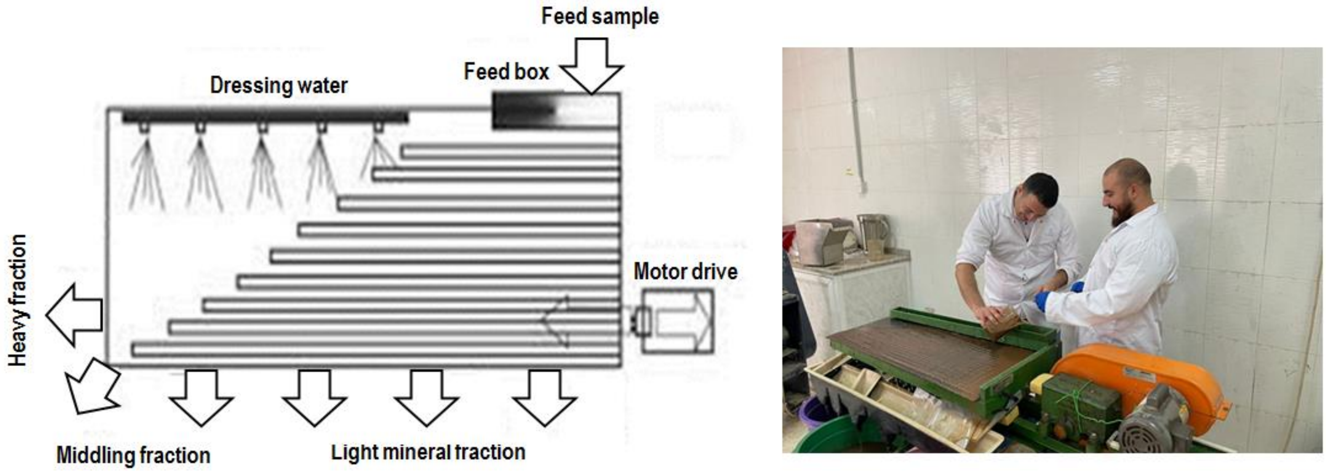
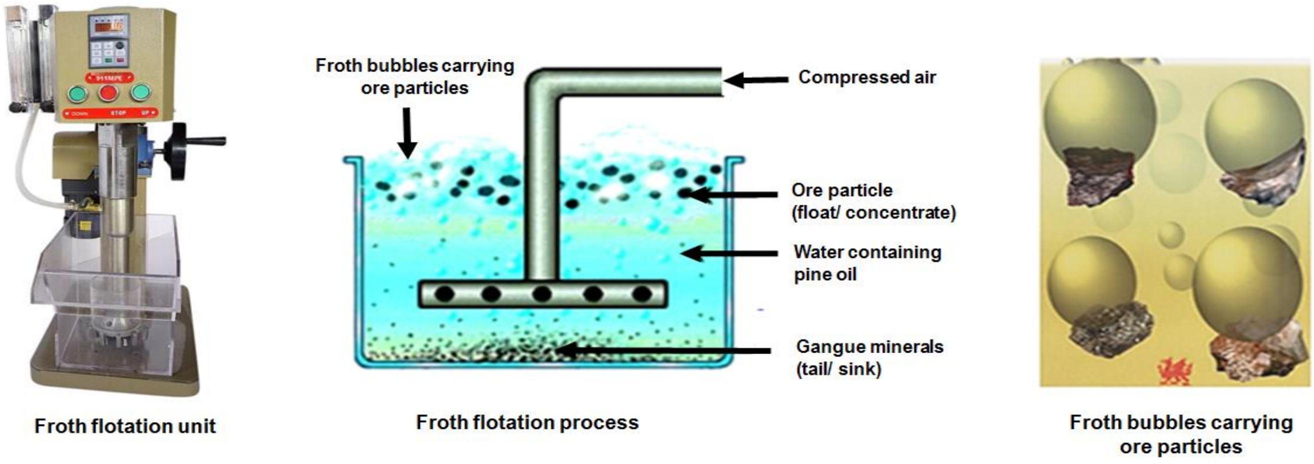


Fig. 4: Wilfley shaking table unit used in the experimental studies and the sketch showing the light, middling and heavy fractions (left) collecting points during beneficiation studies of heavy mineral sand.



Froth flotation unit **Froth flotation process** **Froth bubbles carrying ore particles**

Fig. 5: Froth flotation cell and phenomenon of flotation process for separation of minerals

glass-forming agent) then placed into a platinum crucible. The crucible was set onto melting position and then the sample was fully automatically oxidized, melted at 1000-1200 ºC, stirred and cast. A high-frequency electromagnetic induction heating and fusing machine (Bead Sampler NT-2000; Nippon Thermonics) was used for glass beads preparation. The platinum crucibles (CS-2 type; 95% Pt – 5% Au) were used for making glass beads from a mixture of powdered rock sample and alkali flux. The cold fusion bead was placed into the XRF for measurement.

3. Results and discussion

3.1 Feed sample analysis

The chemical composition of the heavy mineral sand sample is given in Table 2. It contained 64.4% SiO_2, 6.9% Al_2O_3, 6.5% TiO_2, 6.0% Fe_2O_3, 4.7% ZrO_2 and 2.6% K_2O as major constituents of the sand sample. The sample contained low concentrations of light rare earth elements of 0.22% La (0.26% La_2O_3), 0.50% Ce (0.59% Ce_2O_3) and 0.20% Nd (0.24% Nd_2O_3) with 0.08% Y (0.1% Y_2O_3) as heavy rare earth element.

Table 2: WD-XRF analysis of Dubeydib heavy mineral sand sample

Constituents	Results(%)	Constituents	Results(%)	Constituents	Results(%)
SiO_2	64.40	P_2O_5	0.66	Ba	0.05
Al_2O_3	6.90	SO_3	0.18	Y	0.08
Fe_2O_3	6.01	Mn	0.02	La	0.225
TiO_2	6.50	Zr	3.50	Nd	0.208
K_2O	2.60	Hf	0.12	Ce	0.50
Na_2O	0.43	V	0.04	Mo	0.05
MgO	0.85	Cr	0.03	Th	0.19
CaO	1.18	Sr	0.03	U	0.021

It is indicated from the analytical data that the sample contained total contents of 1.02% REE (1.20% REEO). Cerium (Ce) concentration in the sample is double of the contents of La and Nd (Table 2). It is indicated that the sand sample contained monazite-Ce. Uranium (0.021% U) and thorium (0.19% Th) as radioactive elements.

3.2 Hydrocyclone beneficiation

Hydrocyclone classified fine size particles (overflow fraction) and coarse size particles (underflow fraction) of heavy mineral sand during beneficiation process. The weight fractions and chemical analysis data of rare earth elements (La, Ce, Nd and Y) of overflow and underflow fractions are reported shown in Table 3. The weight of overflow fraction of 118.30 g (11.83% wt) and underflow fraction of 857.50 g (85.75% wt) with weight loss of 24.20 g (2.42% wt) was obtained. The overflow fraction (fine size fraction) contained 688 ppm Ce and 54 ppm Y with contents of La and Nd. The concentrations of P_2O_5 and SiO_2 in the overflow fraction were decreased Al_2O_3, Fe_2O_3 and TiO_2 contents increased as compared to feed sample. The underflow fraction (coarse or heavy fraction) contained higher concentrations of La, Ce, Nd and Y than the feed sand sample. It contained 2309 ppm La, 5496 ppm Ce and 2435 ppm Nd (Table 3). The rare earth elements (La, Ce, Nd and Y) present in the sample are constituents of monazite mineral [$(Ce,La,Nd,Th)PO_4$] which is a phosphate mineral having high specific density of 4.98-5.43 g/cm^3. The monazite mineral remained in the underflow fraction due to its high density resulted an increase in the concentrations of REE which is indicated from high phosphate content in the underflow fraction (Table 3).

Table 3: Distribution of La, Ce, Nd and Y in overflow and underflow fractions of hydrocyclone beneficiation studies

Description	Fraction weight		Major elements (%)					Rare earth elements (ppm)			
	(g)	(%)	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	TiO_2	La	Ce	Nd	Y
Feed sample	1,000	100.0	63.4	6.9	6.0	0.66	6.5	2253	5001	2082	798
Overflow	118.3	11.8	29.0	20.6	6.5	0.13	1.5	N.D.	688	N.D.	54
Underflow	857.5	85.5	56.2	27.4	7.7	0.72	11.3	2309	5496	2435	857
Loss	24.2	2.4	-	-	-	-	-	-	-	-	-

The high concentrations of Fe_2O_3 and TiO_2 in the underflow fraction correspond to high density minerals of hematite (5.26 g/cm^3), ilmenite (4.70 g/cm^3) and rutile (4.23 g/cm^3) (Table 1). The hydrocyclone is gravity separation device used in slurry pulps to separate a stream of particles into coarse and fine particles fractions based on mineral particle density. Hydrocyclone separators are used worldwide in mining and mineral processing industries for classification, de-sliming and de-watering applications. Zircon (4.60-4.70 g/cm^3) and hafnon (6.97 g/cm^3) are high density minerals and quartz (2.65 g/cm^3) and plagioclase (2.60-2.80 g/cm^3) are low-density minerals.

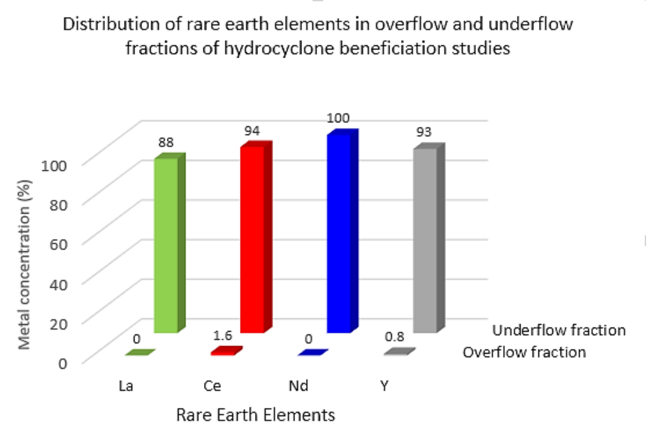


Fig. 6: Distribution of rare earth and radioactive elements in overflow and underflow fractions of Dubeydib heavy mineral sand.

The distribution of La, Ce, Nd and Y in the overflow and underflow fractions of the hydrocyclone beneficiation of Dubeydib heavy mineral sand is shown in Fig. 6. It is indicated that overflow fraction contained negligible amount of rare earth elements. The rare earth elements are mainly ≥88% present in the underflow fraction. It contained 88% La, 94% Ce, 100% Nd and 93% Y distribution of these elements in the underflow fraction. It is indicated that the rare earth elements are concentrated in the overflow fraction (Fig. 6).

3.3. Wilfley shaking table beneficiation

A standard laboratory scale Wilfley shaking table to utilize the gravity concentration process to fractionate both particle density and particle size into light (waste), middling and heavy (monazite concentrate) fractions of Dubaydib heavy mineral sand. During shaking table beneficiation process, five fractions of light, middling-1, middling-2, heavy-1 and heavy-2 were obtained. The weight fractions and chemical analysis of these fractions are reported in Table 4. The weight fractions of 11.1% light, 71.2% middling (middling-1 and middling-2) and 15% heavy (heavy-1 and heavy-2) fractions obtained from heavy mineral sand during Wilfley shaking table beneficiation process. A weight loss of 3.0% wt was also observed.

It is indicated from the analytical data that the light rare earth elements (La, Ce and Nd) are not present in the light fraction of the heavy mineral sand by gravity separation shaking table (Table 4). Only, 125 ppm Y content was observed in the light fraction. The low content of phosphate (0.12% P_2O_5) corresponds to less amount of phosphate mineral (monazite) present in the light fraction. The weight fraction of middling-1 (10.2% wt) exhibited the presence of 1006, 2275, 857 and 408 ppm La, Ce, Nd and Y, respectively. The phosphate content of 0.48% P_2O_5 is also high as compared to light fraction (0.12% P_2O_5). The weight fraction of middling-2 fraction was 61% wt with low contents of rare earth elements as compared to middling-1 fraction. It is indicated from the low phosphate content (0.38% P_2O_5) in this fraction. The concentrations of La, Ce, Nd and Y are higher in the heavy-1 fraction as compared to middling-2 fraction. The rare earth elements concentrated in the heavy-2 fraction which contained 36763 ppm La (3.68% La), 66459 ppm Ce (6.65% Ce), 30192 ppm Nd (3.02% Nd) and 6172 ppm Y (0.62% Y) (Table 4). The monazite-rich heavy-2 fraction contained total rare earth elements of 13.96% ∑REE (16.32% ∑REO) and 8.20% P_2O_5. It is indicated from the beneficiation data that the concentration of REE increased with an increase of phosphate content in the heavy fraction which is mainly attributed to monazite-rich fraction. The shaking table gravity separation process has to be re-tabled to produce monazite-rich concentrate from heavy mineral sand. The gravity separation recovered 76.6% monazite from Senegalese heavy mineral sands deposit [30, 31].

Table 4: Chemical composition of light, middling and heavy fractions of Wilfley shaking table beneficiation studies of Dubeydib heavy mineral sand

Description	Fraction weight		Major elements (%)					Rare earth elements (ppm)			
	(g)	(%)	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	TiO_2	La	Ce	Nd	Y
Feed sample	2000	100	63.4	6.91	6.01	0.66	6.51	2253	5001	2082	798
Light fraction	222	11.1	31.8	18.13	19.68	0.12	4.20	N.D.	N.D.	N.D.	125
Middling-1	204	10.2	64.7	7.69	5.93	0.48	6.72	1006	2275	857	408
Middling-2	1219	61.0	71.2	5.96	4.58	0.38	6.13	489	1153	474	319
Heavy-1	224	11.2	52.0	3.90	4.47	0.61	13.30	1402	2806	1218	1291
Heavy-2	70	3.5	22.0	1.15	1.87	8.20	7.62	36763	66459	30192	6172
Loss	61	3.1	-	-	-	-	-	-	-	-	-

N.D. = Not detectable (below detection limit)

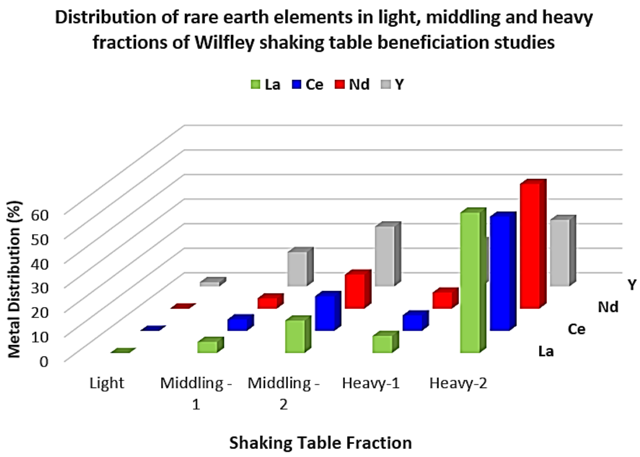


Fig. 7: Distribution of La, Ce, Nd and Y in various fractions of Wilfley shaking table beneficiation studies of Dubeydib heavy mineral sand.

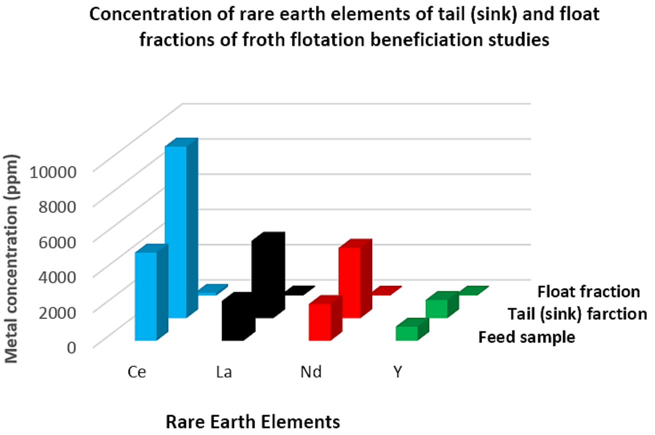


Fig. 8: Concentration of Ce, La, Nd and Y in heavy mineral sand (feed sample), tail (sink) and float fractions of froth flotation beneficiation studies.

The distribution (%) of rare earth elements (La, Ce, Nd and Y) in the various fractions obtained from heavy mineral sand during shaking table beneficiation process is shown in Fig. 7. It is indicated that monazite-rich concentrate fraction (heavy-2) contained the highest contents of 57% La, 47% Ce, 51% Nd and 27% Y. The light fraction (waste) contained 1.7% Y with no contents of La, Ce and Nd. The middling-2 fraction having 61% weight fraction contained 13-27% rare earth elements. This fraction and middling-2 and heavy-1 fractions required re-tabled process to separate REE to produce monazite-rich concentrate. The monazite rich fraction cannot be concentrated to a salable grade by single step or solely separation technique. Hence, monazite fraction has to be re-tabled to separate high recovery from the treated sand. The shaking tabletop strip part is treated for monazite recovery.

3.4. Froth flotation beneficiation

Rare earth elements are floatable using cationic collectors such as oleic acid and sodium oleate in the pH range of 7-11 [32]. Zirconium minerals are depressed at ~~a~~ pH greater than 10 by using sodium silicate and oleic acid for flotation of monazite ore sample to concentrate Zr. The conditioning time for flotation was 6 min and 2 drop of aero float (Aero 619) was added into sample water slurry. The tail (sink) fraction of 48 g and float fraction of 201 g were recovered. The tail fraction has the 1/5th weight of the float fraction. The rare earth elements (monazite mineral) were separated and recovered in the tail fraction which contained 737 ppm Ce (0.97% Ce), 4389 ppm La (0.44% La), 3992 Nd (0.4% Nd) and 1092 ppm Y (0.11% Y) (Fig. 8). The float fraction (major fraction by weight) has negligible amounts of REE. It is indicated that the REE containing monazite mineral is separated and recovered in the tail (sink) fraction in froth flotation beneficiation studies.

A monazite-rich concentrate (concentrate-1) was produced by combining hydrocyclone and shaking table density separation techniques (Table 5). In the first step, heavy mineral sand was separated into overflow and underflow fractions using hydrocyclone and then underflow fraction was used as feed material for Wilfley shaking table. The shaking tabletop strip part was used for the separation and recovery of heavy fraction to produce of monazite-rich concentrate. The chemical analysis of the concentarte-1 are reported in Table 5. It contained 5.48% La_2O_3, 10.54% Ce_2O_3, 4.78% Nd_2O_3 and 0.55% Y_2O_3. The total rare earth elements in the monazite concentrate were 21.40% ∑REEO. The high phosphate content of 10.80% P_2O_5 indicated the monazite-rich mineralization in the concentrate sample. It is indicated that the hybrid gravity separation process (hydrocyclone + shaking table) produced concentrate containing high content of 21.40% ∑REO as compared to monazite-rich fraction (heavy-2) solely produced by shaking table experiment which contained 16.32% ∑REO (section 3.3). The existence of 1.05% Al_2O_3, 3.9% TiO_2 and 1.53% Fe_2O_3 in the concentrate indicated the presence of minerals containing Al, Ti, and Fe as impurities.

Table 5: Chemical composition of produced monazite concentrates from Dubeydib heavy mineral sand

Description	Beneficiation process	Metal concentration (%)				
		La_2O_3	Ce_2O_3	Nd_2O_3	Y_2O_3	∑REEO
Feed sample	-	0.26	0.59	0.24	0.10	1.20
Concentrate-1	Hydrocyclone + Wilfley shaking table	5.48	10.54	4.78	0.55	21.40
Concentrate-2	Hydrocyclone +Wilfley shaking table + Froth flotation	10.3	21.82	9.15	1.33	53.60

Similarly, a monazite-rich concentrate (concentrate-2) was produced from the Dubeydib heavy mineral sand by the combination of two gravity separation techniques (hydrocyclone+shaking table) and froth flotation beneficiation process. The overall schematic presentation of the combined beneficiation studies is shown in Fig. 9. The monazite-rich heavy fraction of sand sample produced by hydrocyclone and shaking table was used as feed material for the separation and recovery of monazite concentrate by froth flotation. The monazite-rich concentrate was separated and recovered in the sink (tail) fraction, de-watered, washed with ethanol to remove adhering organic compound(s) from the surface of the particle, dried and analyzed by WD XRF. The chemical analysis of the produced monazite-rich concentrate is reported in Table 5. The analysis data showed the presence of 8.76% La (10.3% La_2O_3), 18.63% Ce (21.82% Ce_2O_3), 7.84% Nd (9.15% Nd_2O_3) and 1.05 % Y (1.33% Y_2O_3). The total rare earth contents present in the concentrate are 45.7% ∑REE (53.6% ∑REO). It is indicated that the concentrate-2 produced by the combination of three beneficiation techniques (hydrocyclone+ shaking table + froth flotation) exhibited high contents of rare earth elements as compared to concentarte-1 produced by combined gravity separation techniques (hydrocyclone + shaking table).

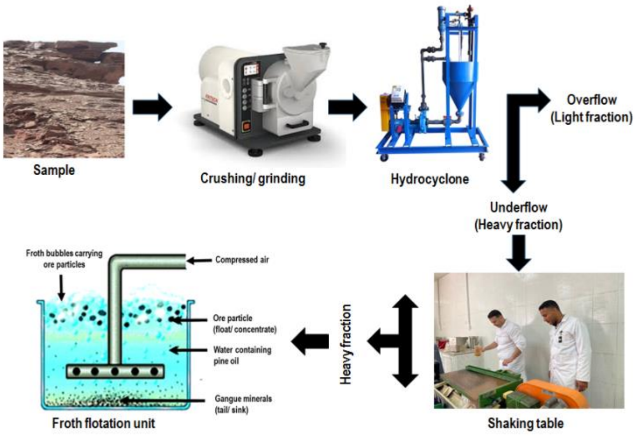


Fig. 9: Schematic presentation of the overall beneficiation process for production of monazite concentrate-2 from Dubeydib heavy mineral sand

From the beneficiation studies, it is observed that the separation and recovery of REE from Dubeydib heavy mineral sand in the concentrates produced by solely hydrocyclone, shaking table, combined hydrocyclone + shaking table and combined hydrocyclone + shaking table + froth flotation techniques contained rare earth contents of 1.30%, 16.32%, 21.40% and 53.6% ∑REO, respectively. It is indicated that the monazite-rich concentrate cannot be produced to a salable grade by single step or solely separation technique. Generally, monazite contains about 70% ∑REO, with REE fraction constituted by 20 to 30% Ce_2O_3, 10 to 40% La_2O_3 and significant amounts of Nd, Pr and Sm [33].

4. Conclusions

Dubaydib heavy mineral sand contains monazite-Ce mineral as source of light rare earth elements (La, Ce and Nd) and yttrium (Y). A number of experimental beneficiation studies were carried out to produce monazite-rich concentrate from heavy mineral sand by using hydrocyclone, shaking table and froth flotation. The results showed that the separation and recovery of monazite from Dubaydib Formation by shaking table is much higher than hydrocyclone gravity separation technique under present experimental conditions. The best combination of two gravity separation techniques (hydrocyclone+shaking table) produced monazite-rich concentrate containing 21.4% ∑REO) and the combined three techniques (hydrocyclone+shaking table + froth flotation) gave high values of monazite mineral which contained 53.6% ∑REO. The results obtained proved that the increase of phosphate content, the concentrations of La, Ce, Nd and Y increased in the recovered concentrate.

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