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The optimized recover process of heavy minerals from Korean beach-sand

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Abstract: Optimized recovery of heavy minerals from the near shore sands of Korean Yellow Sea was investigated using physical processing technologies such as gravity concentration and magnetic separation. The head samples were subjected to the three stages effective separation; Head sample was first treated by a spiral separator to recover rough heavy mineral concentrates, which are contained minerals like ilmenite, zircon and rare earth minerals. Much higher beneficiation processes were subsequently taken by wilfley table and magnetic separation according to their magnetic field responses. Heavy minerals were effectively recovered by wilfley table and subsequent recleaning of heavy minerals by magnetic separations was conducted. Qualitative and relative-quantitative analyses of their constituent elements were doing using XRD and XRF.

1. Introduction

Demand on new materials has been increased in recent years because of not only outbreak of new industries but also rapid expansion of new technologies. Especially, rare earth minerals have been gaining much attention of several groups of researchers because their rapid growth of electronic industry requires a considerable increase in the supply of them.

The heavy minerals are mainly distributed in so called "sand rich countries" like Australia, India and U.S.A. and most of them such as ilmenite, zircon, magnetite, and monazite are produced from the placer sand (Reyneke, et al, 2001). In general, placer sand is effectively developed compare to the rock-type ores concerning with mineral liberation; however, it is very hard to develop in Korea because of environmental problems (Ministry of Marine and Fishery, 2002). Now a day, Australia and India have produced the heavy minerals from their near shore that the surrounding geological conditions are mostly similar to Korea as granite and granite-gneiss type (Geza, et al, 2002)

Apart from the heavy minerals, the rare earth minerals that are kind of heavy minerals such as monazite, bastnasite and xenotime are demanded on the fine chemical industries. They are generally contained in their parent rocks in the forms of either essential rock-forming minerals (e.g. amphiboles, pyroxenes, micas, etc.) or accessory components (e.g. zircon, apatite, tourmaline, etc.) occurring in a wide variety of rock types. However, much sandy or massive type monazite is only reserved in Korea and most of researches have been conducted on the beneficiation of the sandy type monazite. In the beneficiation of heavy minerals, it can be said that the general processes are first employed were gravity separations using spiral concentrator and/or wilfley-type table (Wills, 1989).

In this paper, we studied the beneficiation method for recovering rare earth elements from the beach sand, especially near shore of Korean Yellow Sea even though the sand is now produced about 2,000 million tons per year as building materials. The near shore sand of Korean Yellow Sea contains considerable amount of heavy minerals consisting of the rare earth elements such as La, Nd, Gd, Y, and Ce in the form of monazite and non-metallic minerals such as quartz, mica, and feldspar. We employed stages of beneficiation processes to obtain concentrated value added heavy minerals from the beach sand. The series of the processes proposed in this study provide information on the beneficiation method of rare earth minerals and further development process for the massive type rare earth minerals with increasing demand on them to the current industrial and technological materials.

2. Sample and geological conditions

Beach sand on the shores of Korean Yellow Sea area has been investigated as possible sources of heavy minerals such as ilmenite, zircon and rare earth minerals. The placer of Jumundo (sodomyon, Kangwhagun, Kyonggido) is located in about 12km southwest of Kangwha town. The islands are geologically composed of pre-Cambrian biotite-schist with granite intrusion. The beach sand extends for 2 km along the north shore and 1.5km along the southwest shore. Duckjuk deposit is located in west coast of Chungchung Namdo about 20km from DuckJuk island This deposit lies in an elongated shallow tidal mud filled estuary draining into Yellow Sea. The sand of this area is excavated by dredge ship for the purpose of building materials mainly. The geological condition of Duckjuk area is convinced the same as west coastal area referred from lots of published reports that clarify the area is also composing of pre-Cambrian with granite gneiss and scattered island of the area is Mesozoic era.

3. Experimental condition and equipment

The raw beach sand (head material called in this paper) has been treated by a Humpley spiral separator (Carpco, USA) to obtain the primary recovery of heavy minerals. These primary heavy minerals recovered were used as representative samples for the subsequent separations. The secondary gravity separation by a Wilfley shaking table (M.D.Company, Australia) was then employed to recover much heavier minerals from pre-concentrates.

Magnetic separation was continuously adopted by 2 stages. The first stage of magnetic separation was done by a permanent magnetic separator driven by Nd-B-Fe rare earth magnetic(International Process System, USA) and the second stage was conducted using a cross-belt magnetic separator(Boxmag, UK) by eddy current.

The chemical compositions of primary concentrates are presented in Table. 1.

Table 1. Chemical composition of the primary concentrates.

Sample	SiO_2	Al_2O_3	K_2O_3	Fe_2O_3	Na_2O	CaO	MgO	TiO_2	P_2O_5	MnO	Rb_2O	SrO	ZrO_2
Jumundo	47.3	13.7	5.00	18.3	-	0.65	1.59	11.7	0.33	0.69	-	0.33	0.33
Duckjuk	82.2	8.00	5.64	1.40	1.22	0.71	0.34	0.15	0.05	0.11	0.02	0.03	0.17

The separation process presents in this study was schematically illustrated in Fig.1. It shows that the general procedures for the beneficiation of the sand of Korean Yellow coastal area. The head material was divided to the three fractions according to the initial size distribution of head materials (35#, 35~50#, 50#) for effective gravity separation suggested by Kelly. After sieving for desired size, each fraction was then subjected to gravity separation and magnetic separation on their magnetic response for further beneficiation.

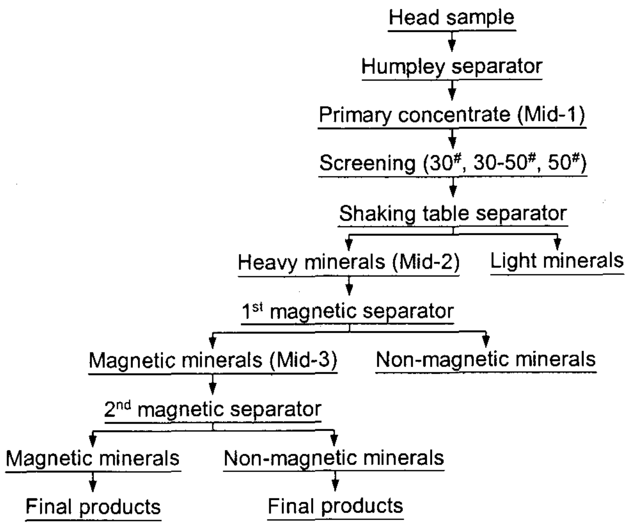

Fig. 1. Flow sheet for the beneficiation of samples.

4. Results and discussion

Gravity separation

The beach sand is an important source of silica in building materials for construction. In other words, the tailing after separation of silica from beach sand will provide a lot of heavy minerals containing valuable components such as monazite, garnet, ilmenite and zircon. The gravitational treatment is commonly employed to throw off the light minerals such as silica, feldspar, mica and hornblende for producing primary concentrates of heavy minerals and these primary concentrates are further treated by magnetic separation, in a row.

As shown in Fig.1, Mid-1 concentrate was obtained by initial spiral separation from the head sample and the concentrate was mainly composed of non-metallic minerals such as quartz, feldspar and mica associated with small amount of heavy minerals. Mid-2 concentrates with various size ranges from 30 to 50mesh were then recovered by shaking table separation after screening of Mid-1 concentrate. After gravity separation, the final products such as ilmenite, zircon, hornblende and monazite were obtained by additional treatment of Mid-2 concentrates through a series of magnetic separations simultaneously.

Humpley spiral separation

Spiral is made with slopes of varying steepness, the angle affecting the specific gravity of concentrate, but having little effect on the concentration grade and recovery. In this study, Humpley spiral separator was first employed to remove light materials such as woods, shells, clays and other slimes from the head materials so that 78.3wt. % is Jumundo Mid-1 and 77.1wt. % is Duckjuk Mid-1, which contain silica in grade over 60wt. % at Jumundo Mid-1 and 82wt. % at Duckjuk Mid-1 were roughly concentrated. Prior to the secondary separation, apart from the silica content, it can be easily considered much more heavy minerals are contained in Jumundo Mid-1 rather than Duckjuk Mid-1.

Wilfley table separation

Wilfley table is known to be very effective for gravity separation in laboratories or mineral industries due to low operation cost by a flowing film of water over an inclined flat. In this study, table separation was adjusted at the strokes of 260~280 per minute and the slop angle of 4 degree.

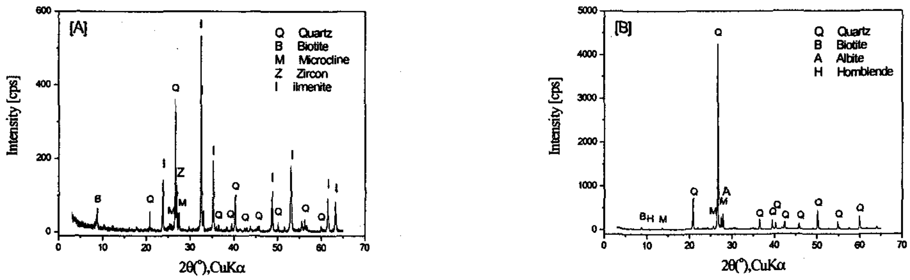

Fig. 2. X-ray diffraction patterns of Mid-2 concentrates (A: Jumundo, B: Duckjuk).

The separation results were presented in Fig. 2. In the sample of Jumundo, considerable products of ilmenite and zircon were concentrated to heavy minerals by gravity separation, on the contrary, silica was a main mineral associated with small amount of microcline even though light minerals. After wilfley table separations of the two samples, in the case of Jumundo Mid-1, the three parts of the products were obtained; 8.8wt. % and 15.9wt. % as ilmenite and zircon of heavy minerals and 53.4wt. % was discharged as silica of light minerals. In the case of Duckjuk Mid-1, 7.8wt. % was concentrated as mixed heavy minerals and 69.3wt. % was discharged as silica of light minerals.

Magnetic separation

Magnetic separation was carried out for further beneficiation of Mid-2 concentrates obtained by gravity separation. Because it is commonly convinced that the Mid-2 concentrates mainly consist of heavy minerals as various magnetic minerals with different magnetic responses; ferromagnetic (ilmenite, Ion-oxide minerals, etc.), diamagnetic (quartz, feldspar, mica, etc.) and paramagnetic (monazite, rare earth phosphates, etc.), a magnetic separator having strong magnetic field intensity would be well adopted to recover all the magnetic materials in advance. In addition, if they contain considerable amount of ferromagnetic, magnetic separation adopted weak magnetic intensity could be applied to recover them for promoting the concentration of monazite as much as possible.

Rare-earth Magnetic Separator (OHGMS)

Even though very weak paramagnetic minerals, OHGMS could be successfully adapted to recovered most of the magnetic minerals from Mid-2 concentrates regardless of their magnetic field intensities. A strong magnetic field driven by Nd-B-Fe magnet was adopted in this study. This study can do strong magnetic field intensity would be well adopted to recover all the magnetic materials in advance. The recovery ratio is 22.5wt. % of magnetic minerals was recovered from the Jumundo Mid-2 and 1.8wt.% of magnetic minerals was recovered of Duckjuk Mid-2.

In the sample of Jumundo Mid-2, most of ilmenite was recovered in the magnetic fraction; on contrary, zircon and monazite were concentrated in the non-magnetic fraction. In the sample of Duckjuk Mid-2, unfortunately, heavy minerals were not detected in the XRD pattern caused by XRD analysis deviation for small amount of mineral components that is not be able to detect of heavy mineral due to very low concentration.

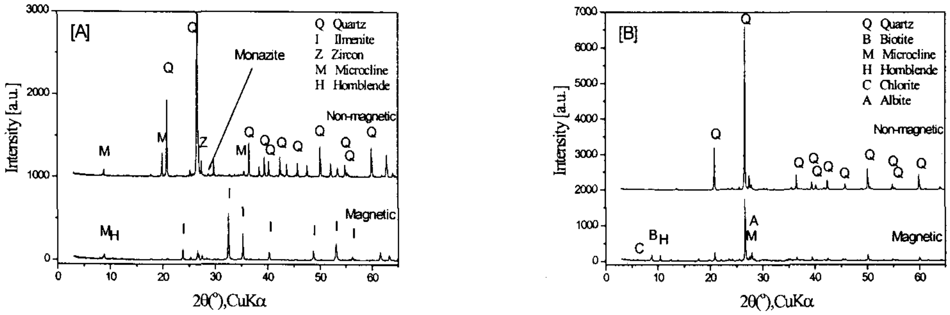

Fig. 3. X-ray diffraction patterns of Mid-3 concentrates (A: Jumundo, B: Duckjuk).

Cross Belt Magnetic Separator (CBMS)

Fig.4. shows the separation characteristics of magnetic minerals according to the variation of magnetic intensities applied. The amount of magnetic fractions was decreased in yield with increasing the magnetic intensity up to 12,000Gauss. Most of ilmenite was concentrated at magnetic intensities below 3,800Gauss in Jumundo Mid-2 concentrate. Heavy minerals with weaker magnetic response such as zircon, microcline and silica were recovered as non-magnetic fractions when magnetic intensity was charged up to 12,000Gauss.

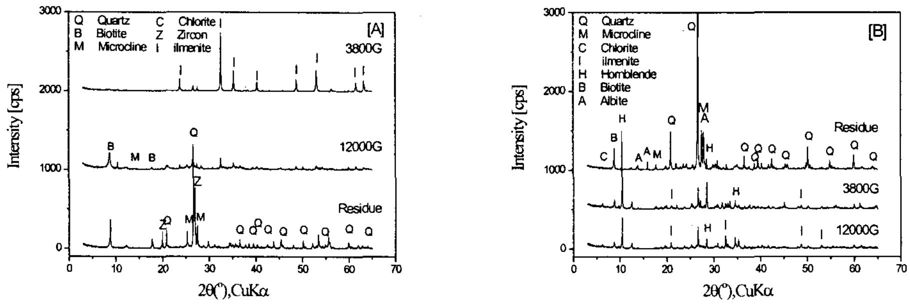

Fig. 4. X-ray diffraction patterns of Mid-4 as a function of magnetic intensity (A: Jumundo, B: Duckjuk).

In the Duckjuk Mid-3, except for very small amount of ilmenite recovered by CBMS at 1200Gauss, the peaks of ilmenite was gradually decreased as magnetic intensity increased. In view of these results, though the constituent minerals and geological conditions of the target areas are almost the same situation, but it is estimated results shows their amounts of magnetic minerals contained are different in the sampling sites of Korean Yellow Sea.

Overall beneficiation characteristics

Jumundo beach sand

Fig. 5. shows that the variation of mineral contents with Jumundo sand during the beneficiation processes. This sand is originally taking care of ilmenite placer mine in 1940's. The mineral composition of Jumundo area is very simple in which it consists of silica and ilmenite mainly. The primary concentrate after spiral separation contains ilmenite approximately 10.9wt.%.

We applied the beneficiation processes; each step rapidly increased ilmenite yield after table separation, weak and strong magnetic separations. It will be able to achieve 78.8wt. % of ilmenite yield about 7 times

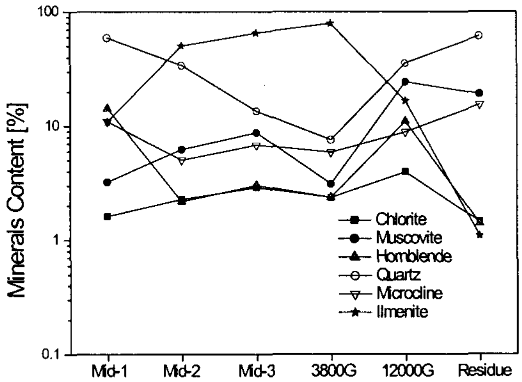

Fig. 5. Variation of mineral contents in Jumundo sand according to the beneficiation process.

concentrated product. Consequently, the recoveries of each stage are as follows; mineral contents of each process of table separation, weak and strong magnetic separation and final residues are 15.97wt%, 15.1wt %, 13.07wt%, 0.58wt% and 1.41 wt%, respectively.

Duckjuk beach sand

Fig. 6. shows that the variation of mineral contents with Duckjuk sand during the beneficiation processes by XRD patterns reference. As shown in the figure, the ilmenite content of primary concentrate was 0.44wt. % and the ratio of concentration were rapidly increased to 15.7 wt. % after weak magnetic separation. That is about 36 times compared to primary products. In addition, hornblende was initially contented 0.48wt.% in the primary concentrate and it was also increased dramatically up to 56.8wt.% by strong magnetic separation. It is estimated about 110 times compare to the primary concentrates.

In case of biotite, it is more contented than that of hornblende in the primary concentrate but the separation efficiency was not good at recovery ratio after strong magnetic separation. It was considered to be the mineralogical character of biotite, which always contains and associates with iron materials. Silica and feldspar were also divided as high grade concentrates at recovery ratio about 70-80wt.%. The recoveries of Duckjuk sand at each stage are as follows; mineral contents of each process of table separation, weak and strong magnetic separation and residues are 7.75wt%, 1,79wt%, 0.62wt%, and 1.23 wt%, respectively.

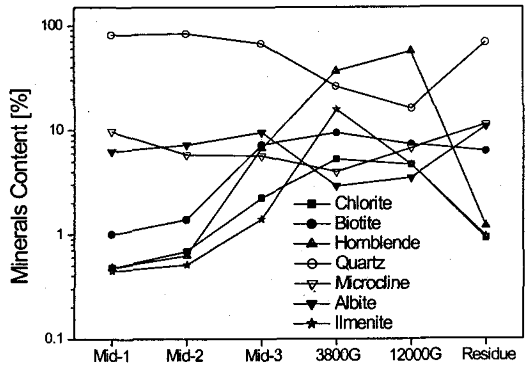

Fig. 6. Variation of mineral contents in Duckjuk sand according to the beneficiation process.

Fig. 7 shows the chemical concentration of Duckjuk sand according to the beneficiation process by XRF analysis reference. Duckjuk sample is simple mineral composition that we assumed of TiO_2, K_2O, CaO and ZrO_2 means ilmenite, microcline, hornblende and zircon, respectively. It is confirming as a similar mineral component with XRD patterns (Fig.6) and XRF analysis (Fig.7). The detailed mineral components analysis is more precious results can be showing the XRF. In case of the ilmenite content of primary concentrate was 0.15wt. % and the ratio of concentration were rapidly increased to 9 wt. % after weak magnetic separation. That is about 60 times concentration compare to primary concentrate. In addition, the Zircon was initially contented 0.16wt.% in the primary concentrate and the concentration was steadily increased up to 0.3wt.% after strong magnetic separation. It is estimated about 2 times concentration compare to the primary concentrates. In this chapter, we must have been studied more and detailed analysis technology needed for the development of huge resources in the near shore area.

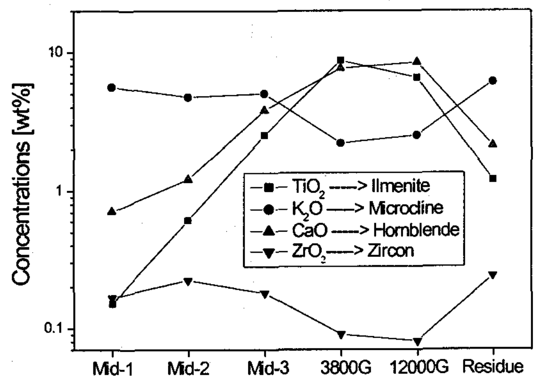

Fig. 7. Variation of chemical concentration in Duckjuk sand according to the beneficiation process by XRF.

5. Conclusion

Heavy minerals contained rare earth chemical components were recovered from the beach sand, Korean Yellow Sea by applying the sequential concentration process of gravity concentration and magnetic separation. The products of Jumundo sand contained considerable amount of heavy minerals associated with rare earth minerals such as La, Ce and Nd. Although concentrated heavy minerals was not detected by XRD analysis in the Duckjuk sand. In case of XRF analysis, it worth mention that much of valuable minerals could be recoverable by adopting the physical separation technologies suggested in this study and the results derived from the study showed that the recoveries of rare earth minerals from beach sand were greatly potential in the aspect of mineral industry.

Acknowledgment

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