

Recovery of Magnetic Iron Content in Beach Sands

Mineral Processing of Ilmenite-Bearing Beach Sands:

Maximizing Magnetic Iron Yield

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Abstract

Preconcentration involves discarding a fraction of the feed before ore processing, so that it contains the least or no mineral of interest. This reduces the mass to be processed in subsequent operations, as well as lowering capital and operating costs. This study seeks to evaluate the possibility of obtaining beneficiation from beach sand samples through gravity separation tests to separate dense minerals, followed by a grinding and low-intensity magnetic separation stage to concentrate the magnetite. The analyzed sample presents opaque minerals such as magnetite, ilmenite, rutile, hematite, titanite, and titanomagnetite. Chemical analysis reveals that the sand contains 62.3% SiO_2 , 8.2% CaO , 8.6% Fe , 1.8% K_2O , 2.0% TiO_2 and 0.23% P_2O_5 . The sand treatment recovered 39.3% of the magnetic iron, with a grade of 56.6%, and 23.4% of the TiO_2 , with a grade of 8.1%. The results indicate that more than 64.7% of the gangue can be discarded. This study demonstrates that physical separation processes can remediate contaminated sands, delivering a potentially profitable product.

Keywords: Beach sand; characterization; magnetic iron

Introduction

Beach sand deposits are accumulations of heavy minerals that form as a result of processes of mechanical erosion, transportation, hydrodynamic sorting (wind in the case of aeolian transport) and ultimately accumulation at suitable sites, leading to the preferential concentration of higher density minerals that are resistant to chemical weathering¹⁾,⁽²⁾. Black sand is found all over the world, and it contains different minerals present due to geographical factors³⁾. They are classified in the group of heavy minerals, because they have a high specific gravity (above 4 kg/L) and are dark in color, which makes them also be called black sand deposits. Valuable heavy minerals associated with such sands are mainly gold, cassiterite, ilmenite, rutile, magnetite, monazite, kyanite, sillimanite, tourmaline, zircon and garnet⁴⁾. In order to recover these minerals, it is very important to characterize and test them, so in recent times many studies have been done with sands from different parts of the world. of the world⁵⁾.

Several beach sand deposits are processed in the United States⁶⁾, Australia⁷⁾, South Africa⁸⁾, Syria⁹⁾, India¹⁰⁾ and Ecuador¹¹⁾, to obtain iron, titanium, zirconium and monazite (a rare earth mineral rich in Ce).

Chile is recognized as a mining country, contributing 14.6% of GDP; it is the leading producer of copper and second in molybdenum. In terms of industrial minerals, it leads the world in iodine production and second in lithium .¹²⁾ This leadership is not guaranteed, as the gradual decline in mineral grades and the depletion of mining companies' resources are contributing factors. The future of

Chilean mining can only be assured through significant cost reductions, the use of clean and renewable energy, and the incorporation of cutting-edge technologies into all processes.

In this scenario, the search for new deposits is inevitable, including ocean mining. This is why beach sands are gaining real importance, since they constitute a real alternative for the development of an essential activity, given the current lack of technical knowledge and uncertainty regarding legal regulations. The studies carried out are restricted to the geology, geophysics, and geochemical characterization of beach sands, but there is no literature on feasibility studies for their use ¹³, ¹⁴.

Beach sands, due to their low grade, are rarely used as a raw material for iron recovery, but reserves of sand containing iron are abundant. Therefore, appropriate beneficiation methods are needed to increase the iron content in sands. For example, ¹⁵ concentrated the iron ore present in sands using a gravity concentration table and magnetic separation. The recovery obtained was 96.75% with a 59.78% Fe content, for a particle size less than 74 micrometers, with a table inclination of 4° and a magnetic intensity of 0.15 T. Beach sands also contain titanium minerals such as ilmenite (FeTiO_3), titanite (CaTiOSiO_4), and titanium oxides (TiO_2) such as rutile, anatase, and brookite, which have the same chemical formula but differ in their crystal structure. The ratio of iron to titanium in ilmenite varies simply due to the ferric oxide content. The crystal form of ilmenite is altered to an amorphous mixture of FeO, Fe₂O₃, and TiO₂ by weathering, and this

alteration may produce rutile, anatase, and leucoxene. The resulting alteration species of ilmenite are known as secondary titanium minerals ¹⁶.

In some cases, magnetite and ilmenite are so closely associated that very fine grinding is required to separate them. Grinding time has a significant impact on treatment costs and on the recovery and grade of Fe and TiO₂ during the magnetic separation process. In such cases, separation by magnetic or gravimetric methods is difficult, so a flotation step is more appropriate. Electrostatic concentration is also used in some cases ¹⁷. When ilmenite is associated with magnetite, concentration has two objectives: one is to produce a high-quality ilmenite concentrate, and the other is to generate magnetite low enough in titanium to be sold as iron ore. In a study conducted on beach sands in South Korea, magnetite was concentrated at a magnetic intensity of 0.05 T, obtaining a recovery of 23.4% and a grade of 95.1%. Ilmenite was concentrated at a magnetic intensity of 0.4 T, achieving a recovery of 55.2% and a grade of 84.2% (18).

Other studies have shown that it is possible to concentrate iron and titanium oxides (Fe-Ti) contained in black sand deposits in Ecuador ¹¹. This study considers an efficient and sustainable preliminary design to concentrate titaniferous iron ores in four stages for the process, which involve collection, drying, sieving and magnetic separation. This proposal returns particles >150 μm and the non-magnetic fraction to the original place, generating minimal environmental impact with the support of natural marine and coastal processes. The economic analysis determined the profitability of the industrial magnetic separation plant, considering national and

international demand, initial investment, total operating costs, inflation rate, taxes and net income.

In recent years, several studies have been conducted on beach sands. For example, in India, sands containing 26.8% Fe and composed of magnetite, ilmenite, rutile, hematite, goethite, and chromite as valuable minerals were beneficiated by low- and high-intensity magnetic concentration, high-voltage separation, and grinding, yielding a concentrate containing 65.2% Fe₂O₃ with a total yield of 37.8% and a recovery of 86%. This product can be used as feed for steelmaking after suitable blending with high-grade iron ore fines ¹⁹.

Beach deposits also contain rare earth elements (REE). Monazite has been recovered as a byproduct from beach sands in Australia, Brazil, India, Malaysia, Thailand, China, New Zealand, Sri Lanka, Indonesia, Zaire, Korea, and the United States. Heavy mineral-rich beach deposits have undergone renewed exploration and development, in part to recover monazite for its rare earth element content.

A study by Saha, Eliason, Golui, Masud, Bezbaruah, and Iskander ²¹, reports easy separation of magnetic compounds from sand samples from seven Southern California beaches, followed by digestion with concentrated acids and oxidants. Sixteen rare earth elements were identified in the sand samples with a predominance of light rare earths. The initial separation of magnetic compounds from sand, and subsequent recovery of rare earths, can potentially reduce chemical usage and cost during rare earth recovery from sand ²¹.

Similarly, a study conducted by Petrache, Santos, Fernández, Castillo, Tabora, Intoy and Reyes ²², in beach sands of the Philippines, demonstrated the presence

of rare earth minerals containing allanite and small amounts of monazite. The collected sample was concentrated using bromoform to separate the heavy minerals from the gangue. It was then ground to a size of 0.044 mm, to liberate the minerals before leaching with a mixture of HCl and HNO_3 . Ammonium hydroxide was added to the acidic solution to precipitate the rare earths, which were then dried in an oven. The precipitate was calcined until oxides formed. The results of the XRD analysis showed the presence of lanthanum oxide with an approximate content of 26% ETR ²².

Indonesian beach sands also contain iron and other minerals. Therefore, the iron content of beach sands needs to be increased so that they can be used as a raw material in the steel industry. Magnetic separation was used to concentrate the iron into different particle sizes. The best results were obtained for sand particles smaller than 149 micrometers, with a current of 5 amperes and a recovery of 65.041 %.

Indian red sand, containing 5.5% heavy minerals, of which 3.7% is ilmenite, and other minerals such as zircon, sillimanite, and garnet, is gravitationally concentrated in spirals, followed by high-intensity dry magnetic separation and then electrostatic separation. The resulting ilmenite concentrate contains 99.1% ilmenite, with a recovery of 94 %.

Similarly, black sands from Ecuadorian beaches contain between 25 and 28% TiO_2 and their concentration process does not have good metallurgical results in the removal of impurities by conventional physical or mechanical treatments. Due to its characteristics, it is not possible to obtain an ilmenite concentrate with a

percentage higher than 75% ²⁵ . For this reason, Perez and Sharadqah ²⁶ , subjected these sands to thermal, chemical and ion exchange treatments, obtaining a final product (TiO₂) with a purity of 92% ²⁶ .

Chile has 6,435 km of coastline, and in some locations, coastal sands contain heavy minerals, which have accumulated there due to their enrichment in iron oxides, iron-titanium, zircon, and other heavy minerals. They therefore constitute deposits of diverse economic interest. Therefore, this study aims to characterize and propose a technological scheme to recover magnetic iron contained in sands from Las Salinas beach, Atacama Region, with the aim of also recovering other minerals, such as ilmenite, titanite, zircon, and minerals containing rare earth elements, as a way to stimulate interest in beach sand processing.

Experimental Part

Sand samples were collected from Las Salinas beach in the Caldera commune of the Atacama Region. Approximately 232 kg of sand were collected per sample and sifted through an 18-mesh (1 mm) sieve to remove shells, plastics, cans, and wood. The sand was then homogenized using the cone-cut method and successive quartering until samples were obtained for particle size analysis, chemical analysis, specific gravity, and for conducting various tests.

The particle size analysis of the sample was carried out using a series of standard sieves. A Le Chatelier flask and a pycnometer were used to determine the density of the sand and the products obtained. Each determination was performed in triplicate to assess the density of the material under operating conditions.

The chemical and physical characterization of the sand and each product obtained in the tests was carried out by volumetric chemical analysis, X-ray diffraction and scanning electron microscopy Zeiss EVO MA 10, with an energy dispersive X-ray analyzer (EDS), a low vacuum analyzer for secondary electrons and an analyzer for STEM mode.

A Wilfley laboratory table (model 13A) with a solids percentage of 20% was used in the gravitational concentration tests. The pulp was agitated for 10 minutes to break up the fine aggregates adhering to the coarse particles. The table operated under the following conditions: feed 500 g min^{-1} , inclination angle 8° , wash water 8 L min^{-1} , water flow rate 3.0 L min^{-1} and additional water flow rate 2.5 L min^{-1} . The fractions were collected in different buckets. After treatment, the fractions were filtered, dried and refined by passing them through a sieve with an opening of 53 micrometers and finally analyzed to quantify the test.

Magnetic concentration tests were carried out in a low-intensity wet drum magnetic concentrator (Metso-Outotec). The ground table concentrate is separated at a magnetic intensity of 0.070 T, drum speed of 25 rpm, feed flow rate of 1.2 L min^{-1} , wash water flow rate of 1.0 L min^{-1} and 30% solids, resulting in magnetic concentrate and non-magnetic tailings.

Results and Discussions

Table 1 presents the results of the particle size analysis performed on the Las Salinas beach sand. It shows that 0.2% of the feed material had a particle size less than 75 micrometers, verifying that the sand did not contain fine particles, a beneficial condition for magnetic concentration processes.

Table 1 Granulometric analysis of the sand sample from Las Salinas beach.

Tamaño (µm)	% en peso	% peso pasante
–1000 + 850	0,1	100,0
–850 + 600	1,1	99,9
–600 + 425	7,5	98,8
–425 + 300	19,2	91,3
–300 + 212	32,8	72,1
–212 + 150	26,9	39,3
–150 + 106	9,3	12,4
–106 + 75	2,9	3,1
–75	0,2	0,2
Total	100	–

Similarly, it is deduced that 80% of the particles have an average size of 348 micrometers, while the passing d50 has a size of 238 µm.

Table 2 shows the laws of the different elements obtained from the chemical analysis carried out on the beach sand sample.

Table 2 Chemical analysis performed on the initial head of the sands.

%SiO ₂	%Fe	%CaO	%TiO ₂	%K ₂ O	%P	% Zr	V	% ETR
62,3	8,6	8,2	2,0	1,8	0,1	0,05	0,04	0,0149

The table shows a high percentage of silica (62.3%), iron (8.6%), lime (8.2%), titanium (2.0% TiO₂), potash (1.8%), phosphorus (0.1%), zirconium (0.05%), rare earth elements (REE) (0.0149%). The mineralogical analysis of the sand indicated the presence of quartz, calcite, pargasite, ankerite, augite, epidote, giniite, phillipsite, illite, magnetite, labradorite, anorthoclase, albite, orthoclase, hematite, ilmenite, rutile, anatase, zirconite and monazite, which are of great importance in reserves and economic viability²⁷.

Figure 1 shows the distribution of Fe, P, SiO₂, TiO₂, K₂O and CaO as a function of the particle size, showing a high presence of these elements in the coarse fraction (149 µm), which contains 94.4% of the silica, 94% of the alkaline oxides (K₂O and CaO), 77.9% of the phosphorus, 57.9% of TiO₂ and 46.8% of Fe. A high concentration is also observed in the 105 µm size. Since the particle size of beach sand is quite coarse, it is hypothesized that the minerals are not completely released, which is why a grinding stage must be carried out to allow the release of these minerals.

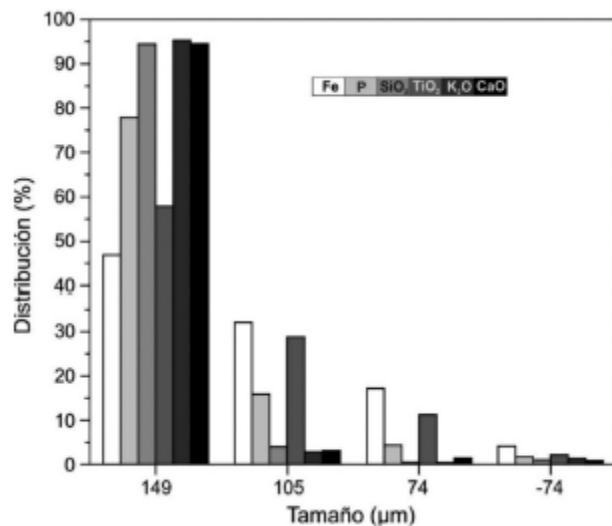


Figure 1 Distribution of elements by size

Figure 2 shows the optical microscopy of the sand, revealing the different minerals and gangue, grain shapes, and assemblages. It displays particles of magnetite (Mt), quartz (Qz), carbonate (Car), ilmenite (Ilm), and monazite (Mon).



Figure 2 Photomicrograph of sand particles contained in beach sand.

Figure 3 shows the microphotograph from the scanning electron microscope analysis, which shows magnetite (Mt), hematite (Hm), and ilmenite (Ilm) minerals. The grain size is observed to be between 50 and 300 micrometers. Based on the above considerations, it is established that beach sand contains: quartz, calcite, pargasite, ankerite, augite, epidote, illite, magnetite, labradorite, anorthoclase, albite, orthoclase, hematite, ilmenite, rutile, anatase, zirconite, and monazite.

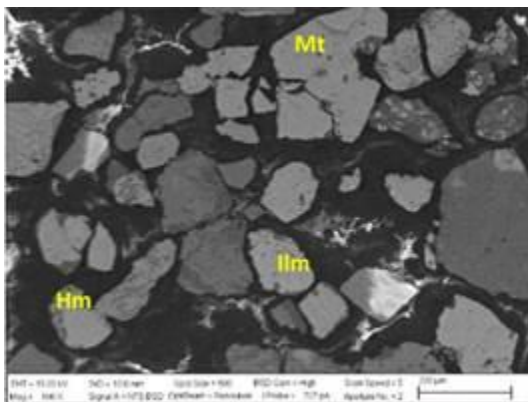


Figure 3 SEM image of microanalysis spots.

Figure 4 shows the treatment applied to the sand. It begins with gravimetric concentration on a Wilfley gravity separation table, where the resulting concentrate undergoes a grinding stage to obtain a particle size 100% less than 212 μm . The ground concentrate then undergoes a low-intensity magnetic separation stage in a wet drum magnetic concentrator, obtaining a magnetic concentrate.

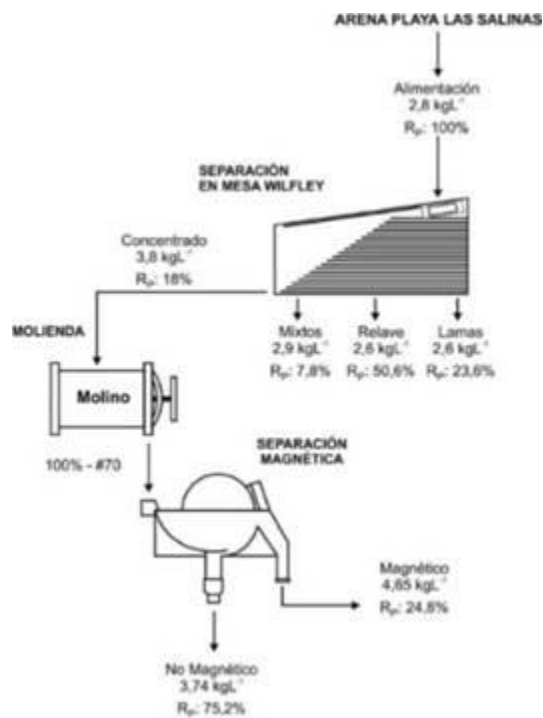


Figure 4 Sand concentration scheme of Las Salinas beaches.

Figure 5 shows the results obtained in the gravimetric separation test, where 18.0% of the fed weight corresponds to the concentrate, with an iron grade of 35.8% and recovery of 79.6%, TiO₂ grade of 8.6% and recovery of 70.6%.

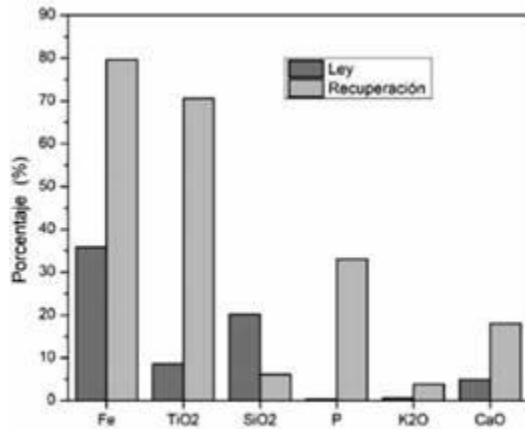


Figure 5 Results of gravitational concentration on the Wilfley table.

The concentrate obtained from the Wilfley table was subjected to a grinding stage. The results of the particle size analysis of the concentrate and the ground concentrate are shown in [Figure 6](#) . It is observed that 53.6% of the concentrate particles are under 150 micrometers in size, while the ground concentrate reaches 98.5%. Although the particle size distribution of the ground concentrate is small, studies have shown that for efficient grinding of magnetite, it must be demagnetized and the agglomerated particles dispersed to produce good liberation ²⁸ .

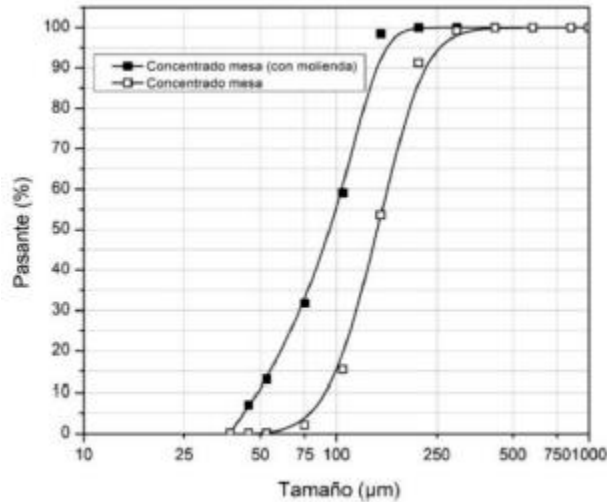


Figure 6 Granulometric analysis of the gravitational concentrate and the ground concentrate.

The ground gravitational concentrate was subjected to wet low-intensity magnetic concentration, the results of which are shown in [Figure 7](#). It presents the metallurgical grades and recoveries obtained through the chemical analysis performed on the magnetic concentrate sample.

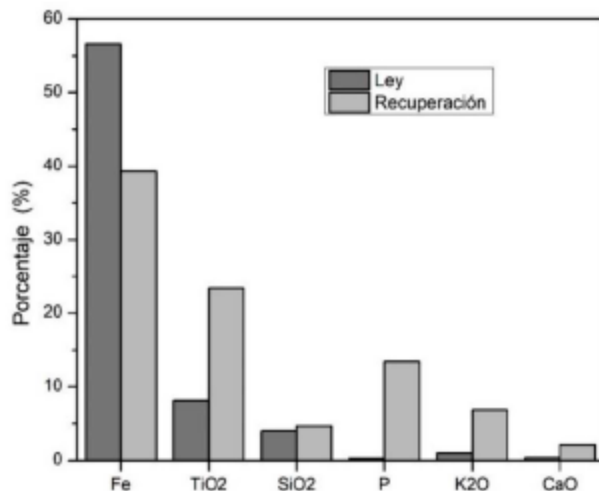


Figure 7 Results of magnetic concentration of beach sand.

The iron grade in the magnetic concentrate is observed to be 56.6% with a recovery of 39.3%. In the case of TiO_2 the grade is 8.1% with a metallurgical recovery of 23.4%. The iron grade and iron recovery can be increased by decreasing the particle size, but the costs incurred in grinding to obtain sizes smaller than 74 micrometers²⁹ must be taken into account .

Since the magnetic concentrate has a high iron and titanium content, it follows that the magnetite could contain titanium within its structure. The titanium content can be reduced by using a magnetic field intensity of 0.07 T to concentrate the magnetite, since at these magnetic intensity values the ilmenite could not be concentrated; it would also be necessary to apply flotation to the concentrate to float the ilmenite and/or subject it to heat treatment, leaching, solvent extraction or ion exchange to obtain TiO_2 pigment^{18, 19, 26} .

CONCLUSIONS

The behavior of iron-bearing minerals in beach sands from Las Salinas, Atacama Region, was studied. Commercial-quality iron concentrates (up to 56.6% Fe) were obtained by gravitational concentration on a Wilfley table, followed by grinding of the concentrate and treatment in a wet-drum magnetic separator. It was observed that more than 90% of the iron contained in the sands is in the form of magnetite. Similarly, X-ray diffraction analysis to determine the different minerals occurring in the beach sand deposit confirmed the presence of quartz, magnetite, ilmenite, rutile, zircon, and monazite.

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