NETL Life Cycle Inventory Data
Process Documentation File

Process Name: Magnetic Separation

Reference Flow: 1 kg of Rare earth concentrate

Brief Description: Mined crude ore to rare earth concentrate magnetic separation process for Mountain Pass, CA

Section I: Meta Data

Geographical Coverage: United States **Region:** Mountain Pass, CA

Year Data Best Represents: 2013

Process Type: Energy Conversion (EC)

Process Scope: Gate-to-Gate Process (GG)

Allocation Applied: No

Completeness: All Relevant Flows Captured

Flows Aggregated in Data Set:

☑ Process ☑ Energy Use ☐ Energy P&D ☐ Material P&D

Relevant Output Flows Included in Data Set:

Releases to Air:	☐ Greenhouse Gases	☐ Criteria Air	☐ Other
Releases to Water:	☐ Inorganic	☐ Organic Emissions	☐ Other
Water Usage:	☐ Water Consumption	☑ Water Demand (throughput)	
Releases to Soil:	☐ Inorganic Releases	☐ Organic Releases	☐ Other

Adjustable Process Parameters:

Slurry_feed	*[m^3/hr] Slurry feed rate*
Slurry_solids	*[m^3/m^3] m^3 of solids per m^3 of slurry*
REO_crude	*[kg/kg] kg REO-equivalent per kg of crude ore*
Recovery_rate	*[kg/kg] kg REO-equivalent recovered per kg of REO-equivalent input*

REO_product	*[kg/kg] kg REO-equivalent per kg of rare earth concentrate*
water_recover	[kg/kg] kg of water recycled per kg of water input

Tracked Input Flows:

Crude Ore [Intermediate]	*[Technosphere]*
Water (unspecified) [resource]	*[Resource]*
Electricity [Electric power]	*[Technosphere]*

Tracked Output Flows:

Rare earth concentrate [Intermediate product]	*Reference flow*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage3_O_Magnetic_Separation.2014.01.xlsx*, which provides additional details regarding relevant calculations, data quality, and references.

Goal and Scope

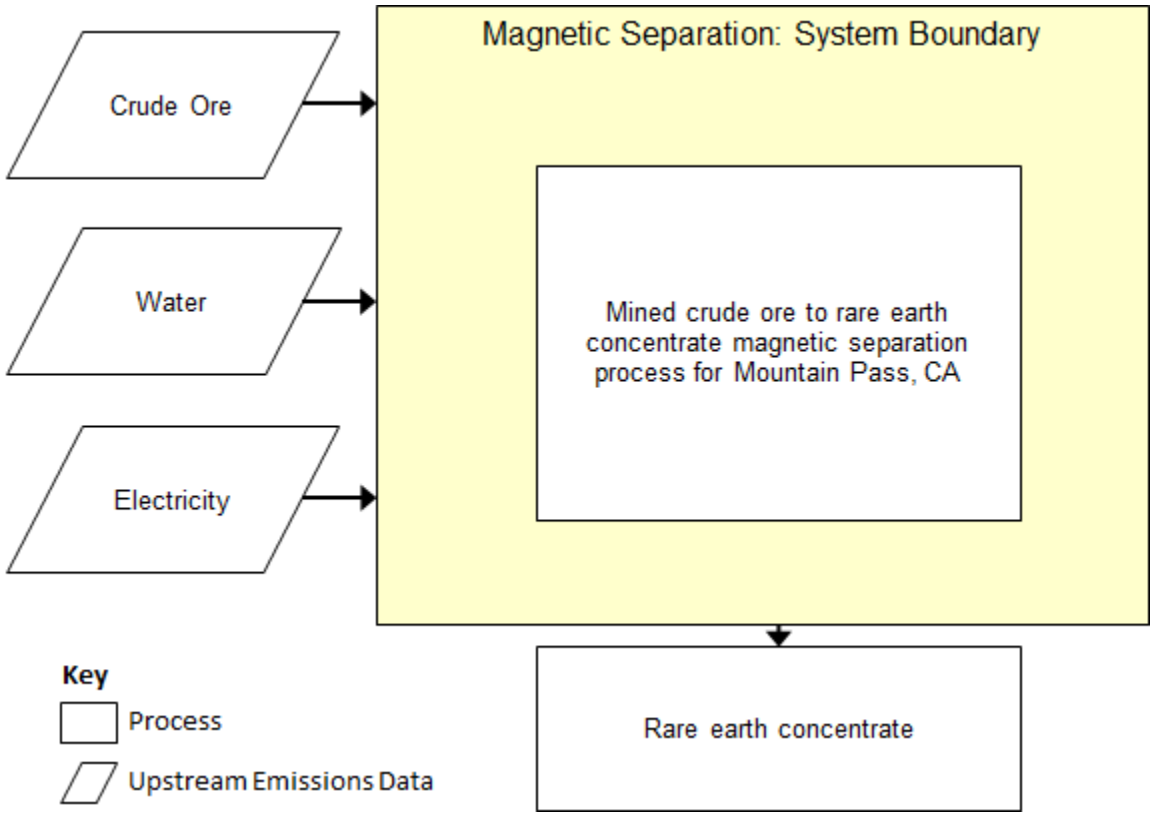
This unit process provides a summary of relevant input and output flows associated with the conversion of mined crude ore to rare earth concentrate via gravity separation. The reference flow of this unit process is: 1 kg of Rare earth concentrate.

Boundary and Description

Rare earth concentrate recovery from crude ore by magnetic separation is a less commonly utilized beneficiation process for rare earth oxide production. This unit process is based on Outotec SLon Wet High-Intensity Magnetic Separators (SLon WHIMS), which is highly efficient for separating moderately to highly paramagnetic materials (Dobbins *et al.* 2007). Crushed and milled bastnasite crude ore, which contains gangue minerals barite, calcite, strontianite, and quartz (Gupa & Krishnamurthy 2004), is made into a slurry and then fed through a feed inlet into a matrix housed inside a vertical separating ring. The paramagnetic bastnasite containing

rare earth oxides (REO) is attracted to the matrix and are then carried outside of the magnetic field and flushed to the magnetic concentrate trough (Outotec 2013). Similarly, the non-magnetic particles pass through the matrix into the non-magnetic collection hoppers. This process assumes a 35% recovery rate (Jordens *et al.* 2012, NETL) and a bastnasite content of 10% in crude ore. **Table 1** shows the parameters utilized in developing the unit process for rare earth concentrate recovery from crude ore via magnetic separation.

Figure 1: Unit Process Scope and Boundary



Multiple regression analyses were performed to determine factors for magnetic separation performance. Simple linear regression was used for pump motor power and flushing water requirement based on the slurry feed rates. The maximum slurry feed rates are used to generate the pump motor coefficient because it is likely that the pump would be sized based on the maximum feed rate. For the flushing water ranges are provided for the coefficient to account for the fact that the flushing water requirement varies along with the slurry feed rates.

For generating the magnetic field, a two-factor linear regression was performed to account for changes in performance due to the capacity of the separator as well as the required field strength (Metso Minerals, 2011). A different set of data is used because the Metso Minerals technical specifications include head power while the Falcon

concentrators only included rectifier output, which doesn't necessarily translate to required electrical power. Only the expected coefficient values are carried forward to the data summary sheet for simplicity. If desired, 5-95 percent values for both coefficients are available in the "Magnetic_field_power" worksheet.

The cooling water demand uses a power regression for the Falcon concentrators, see Equation [1]. As with the pumping power, it is assumed that the cooling water rating is for maximum capacity, so only that value is used in the calculations. See **Figure 2** for the results of the regression analysis.

$$\dot{V} = b \cdot x^m \quad [1]$$

where,
$\dot{V}$ is the volumetric flow rate in m^3/hr
b is the coefficient
m is the exponent

Figure 2: Regression results for cooling water

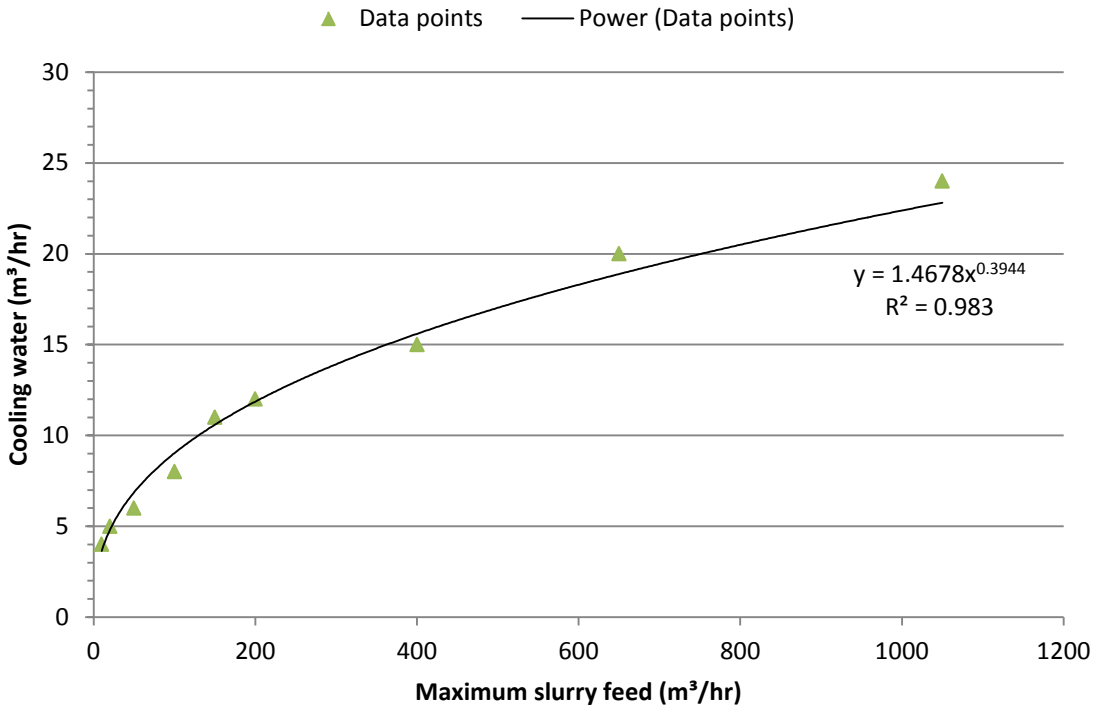


Table 1: Parameters for Magnetic Separation Calculations

Parameter	Value	Max/Min	Unit	Reference
REO content in crude ore	7.0	N/A	%	Pradip, Fuerstenau D.W. 2013
Recovery rate	35.0	N/A	%	Jordens *et al.* 2012, NETL
Density of crude ore	3.586E+03	N/A	kg/m^3	Braun *et al.* 2010, Ralph & Chau 2013
Slurry feed rate	1.050E+03	1.05E+03/5.00E+00	m^3/hr	Outotec 2013, NETL
Slurry feed percent solids	25.0	40.0/10.0	%	Outotec 2013

Table 2: Unit Process Input and Output Flows

Flow Name	Value	Units (Per Reference Flow)
Inputs		
Crude Ore [Intermediate]	2.94E+01	kg
Water (unspecified) [resource]	6.04E+01	kg
Electricity [Electric power]	1.21E-02	kWh
Outputs		
Rare earth concentrate [Intermediate product]	1.000E+00	kg
Water [Water]	5.73E+01	kg

* **Bold face** clarifies that the value shown *does not* include upstream environmental flows.

Embedded Unit Processes

None.

References

Braun *et al.* 2010 — Braun T., Swanson B., Volk J. (2010). Engineering Study for Re-Start of the Mountain Pass Rare Earth Element Mine and Processing Facility Mountain Pass, California. SRK Consulting. Lakewood, CO.

Dobbins *et al.* 2007 — Dobbins, M., Domenico J., Dunn P. (2007). A discussion of magnetic separation techniques for concentrating ilmenite and chromite ores. The 6th Heavy Minerals Conference 'Back to Basics', The Southern African Institute of Mining and Metallurgy.

Hans-Jörg Althaus *et al.* 2007 — Althaus H.J., Chudacoff M., Hischier R., Jungbluth N., Osses M. and Primas A. (2007). Life Cycle Inventories of Chemicals. Ecoinvent report No. 8, v2.0. EMPA Dubendorf, Swiss Centre for Life Cycle Inventories, Dübendorf, CH, from www.ecoinvent.org

Jordens *et al.* 2012 — Jordens A., Cheng Y.P., Waters K.E. (2012). A review of beneficiation of rare earth elements bearing minerals. Minerals Engineering 41. Elsevier. http://dx.doi.org/10.1016/j.mineng.2012.10.017

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Metso Minerals 2011	Metso Minerals (2011). High gradient magnetic separators technical specification. Retrieved 4/1/2014 from http://www.metso.com/miningandconstruction/MaTobox7.nsf/DocsByID/74BF2AA6E114783BC1256BD6003F75B0/$File/TS_HGMS_continuous-en.pdf
Pradip, Fuerstenau D.W. 2013	Pradip, Fuerstenau D.W. (2013). Design and development of novel flotation reagents for the beneficiation of Mountain Pass rare-earth ore. Minerals and Metallurgical Processing. Vol. 30, No. 1, pp. 1-9Sepro Mineral Systems 2013 Sepro Mineral Systems (2013). Falcon 'C' Continuous Gravity Concentrators. Sepro Mineral Systems Corp. Langley, British Columbia, Canada. http://www.seprosystems.com/falcon-c-gravity-concentrators-specifications

Section III: Document Control Information

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