4-2016

Recycling of Neodymium and Dysprosium from Permanent Magnets

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Dai, Alan X.; Lippincott, Connor A.; Nissan, Michael E.; and Shim, Richard, "Recycling of Neodymium and Dysprosium from Permanent Magnets" (2016). *Senior Design Reports (CBE)*. Paper 81.
http://repository.upenn.edu/cbe_sdr/81

Recycling of Neodymium and Dysprosium from Permanent Magnets

Abstract
This project seeks to recycle neodymium and dysprosium from used neodymium-iron-boron, NdFeB, permanent magnets. Our alternative recycling strategy is based on a method developed by Dr. Eric Schelter of the University of Pennsylvania Department of Chemistry and his research group. This process involves the use of a novel tripodal nitroxide ligand, H_3TriNOX. The proposed process design converts used NdFeB magnets to neodymium and dysprosium. The goal production of neodymium oxide is 126,000 kg/year and of dysprosium oxide is 14,000 kg/year, which would cost $12,500,000 with the current price rate of neodymium and dysprosium. Based on the results of the economic analysis, this project would be unprofitable in the near future.

Disciplines
Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

Professor Leonard Fabiano
Dr. John M. Vohs
Department of Chemical and Biomolecular Engineering
School of Engineering and Applied Science
University of Pennsylvania
220 S. 33rd Street
Philadelphia, PA 19104
April 12, 2016

Dear Professor Fabiano and Dr. Vohs,

Enclosed is our completed proposal for the design project “Recycling of Neodymium and Dysprosium from Permanent Magnets,” as initially proposed by Alan Dai and Connor Lippincott. The proposed design applies the new technology developed by Dr. Eric Schelter of the University of Pennsylvania Department of Chemistry and his research group. This new technology uses a novel tripodal nitroxide ligand, H_3TriNO_X, instead of traditional liquid-liquid extraction, to separate neodymium and dysprosium from each other.

The market for rare earth metals, neodymium and dysprosium, is very promising due to the limited and unstable supply by China that produces 95% of all rare earth metals in the world. Also, recycling neodymium and dysprosium with the newly developed technology is much more environmental friendly compare to the mining of rare earth metals and the traditional method of separating neodymium and dysprosium.

The proposed process design converts used NdFeB magnets to neodymium and dysprosium. The goal production of neodymium is 126,000 kg/year and of dysprosium is 14,000 kg/year, which would cost $12,500,000 with the current price rate of neodymium and dysprosium.

Based on the result of profitability analysis, this project would be unprofitable in the near future. We recommend that this project should only be executed if market prices for neodymium and dysprosium significantly increase due to the uncertainty existing in neodymium and dysprosium supply.

Sincerely,

Alan Dai Connor Lippincott Michael Nissan Richard Shim

RECYCLING OF NEODYMIUM AND DYSPROSIUM FROM PERMANENT MAGNETS

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12 APRIL 2016

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1. Abstract

This project seeks to recycle neodymium and dysprosium from used neodymium-iron-boron, NdFeB, permanent magnets. Our alternative recycling strategy is based on a method developed by Dr. Eric Schelter of the University of Pennsylvania Department of Chemistry and his research group. This process involves the use of a novel tripodal nitroxide ligand, H_3TriNO_X. The proposed process design converts used NdFeB magnets to neodymium and dysprosium. The goal production of neodymium oxide is 126,000 kg/year and of dysprosium oxide is 14,000 kg/year, which would cost $12,500,000 with the current price rate of neodymium and dysprosium. Based on the results of the economic analysis, this project would be unprofitable in the near future.

2. Introduction and Objective-Time Chart

2.1 Background information and project origins

Of the rare earth metals (the 15 lanthanide elements, yttrium, and scandium), two in particular—neodymium and dysprosium—have magnetic and thermal properties that make them ideal for use in modern products that require strong permanent magnets, such as wind turbine generators, electric vehicle motors and hard disk drives. Since the discovery of the $Nd_2Fe_{14}B$ compound in 1982, neodymium magnets have replaced other types of magnets such as Samarium-Cobalt magnets in the many applications and the demand is increasing ever since.

However, the production of neodymium and dysprosium is dominated by China, which has both the abundant natural resources along with the lax regulations that allow it to provide more than 95% of the world's rare earth elements as of 2015. Worsening the supply problem is China's strict quotas, which restrict much of their production from being exported to the United States and other countries. While the U.S. Department of Energy has encouraged the development of better, more economically viable and environmentally responsible, extraction, separation, and processing methods to increase supply, along with the seeking of alternatives to lower demand, they have also highlighted the need for better recycling of the current rare earth products, such as neodymium magnets. [1]

This project seeks to recycle neodymium and dysprosium from used neodymium-iron-boron, NdFeB, permanent magnets. In order to recover neodymium and dysprosium for reprocessing into usable magnets, the elements need to be separated from each other and from other components. Many rare earth separations currently exist, as these elements often need to be extracted from the same ores due to their chemical similarities, but these similarities make them notoriously difficult to separate from one another. Their chemical sameness arises from their approximately equal ionic radii, as differences in electron count between the elements do not significantly affect their outer electronic structure (due to the nature of their f-orbitals). This makes even the most efficient process still intensive, slow, expensive and toxic. [2] [3]

Our alternative recycling strategy is based on a method developed by Dr. Eric Schelter of the University of Pennsylvania Department of Chemistry and his research group. [4] This process involves the use of a novel tripodal nitroxide ligand, H_3TriNO_x. The structure of this ligand gives it the ability to selectively separate rare earth metals based on difference in size of the metal cations. The smaller Dy^{3+} ion forms the monomer $Dy(TriNO_x)$ when dissolved in benzene and the bigger Nd^{3+} ion forms the dimeric $[Nd(TriNO_x)]_2$. These two complexes have drastically different solubility in benzene, leading to a separation factor $S_{Nd/Dy} = 359$, which is ten times better than the current industrial separation standard, the M^{III}-HCl-HDEHP extraction method [5] [3]. After the separation, it is also possible to recycle the H_3TriNO_X ligand, giving the process an additional layer of sustainability and cost-effectiveness.

To make use of this new separation technique, this project encompasses a process from the NdFeB magnets all the way to the purified rare earth metals. The separation process begins with a separation of the rare earths from the iron and boron contained in the magnets by acid dissolution and then precipitation of the rare earths. After that, the rare earth metals are separated into $[Dy(TriNO_X)]_2$ and $[Nd(TriNO_x)]_2$. Both compounds are then treated with oxalic acid, creating $Dy_2(C_2O_4)_3$ and $Nd_2(C_2O_4)_3$ compounds and recycled H_3TriNO_X. Finally, the thermal decomposition of $Dy_2(C_2O_4)_3$ and $Nd_2(C_2O_4)_3$ converts them into Dy_2O_3 and Nd_2O_3.

2.2 Definition of goals, scope, and deliverables

Project Name: Recycling of Neodymium and Dysprosium from Permanent Magnets

Project Champions:

John M. Vohs, Carl V. S. Patterson Professor, University of Pennsylvania

Leonard A. Fabiano, Adjunct Professor, University of Pennsylvania

Project Leaders:

Alan Dai

Connor Lippincott

Michael Nissan

Richard Shim

Specific Goals: Design a plant with a capacity to produce 140,000 kg/yr of neodymium and dysprosium oxides from recycled magnets as a feedstock.

Project Scope:

In-scope:

- Process flow diagram (PFD) and material balances
- Energy balances and utility requirements
- Detailed equipment lists and unit descriptions
- Specification sheets
- Market and profitability analysis
- Cost analysis
- Environmental and safety considerations

Out-of-scope:

- Piping and instrumentation diagram (P&ID) and detailed process control design.

  - Detailed methods of feed magnet procurement.
  - Packaging and distribution of neodymium and dysprosium products.
  - Small-scale test reactor

Deliverables:

- Completed process flow modeling showing all equipment and its specifications, including operating parameters.
- Detailed market and profitability assessment and manufacturing capability analysis.
- Written design report encompassing our design and findings.
- Oral presentation encompassing our design and findings.

Timeline:

- Progress reports on weekly consultant meetings.
- Written design report completely by Tuesday, April 12, 2016.
- Design presentation given on Tuesday, April 19, 2016.

Innovation Map:

The innovation map outlines the value chain of the recycling process of neodymium magnets. The proposed design separates used NdFeB magnets into neodymium oxide and dysprosium oxide, which can be used to make new neodymium magnets. The new supply of neodymium magnets lowers the price of neodymium magnets, stabilizes the often-fluctuating neodymium market monopolized by China and gives an environmentally friendly option to recycle neodymium magnets that are initially processed in a very toxic extraction process. [3]

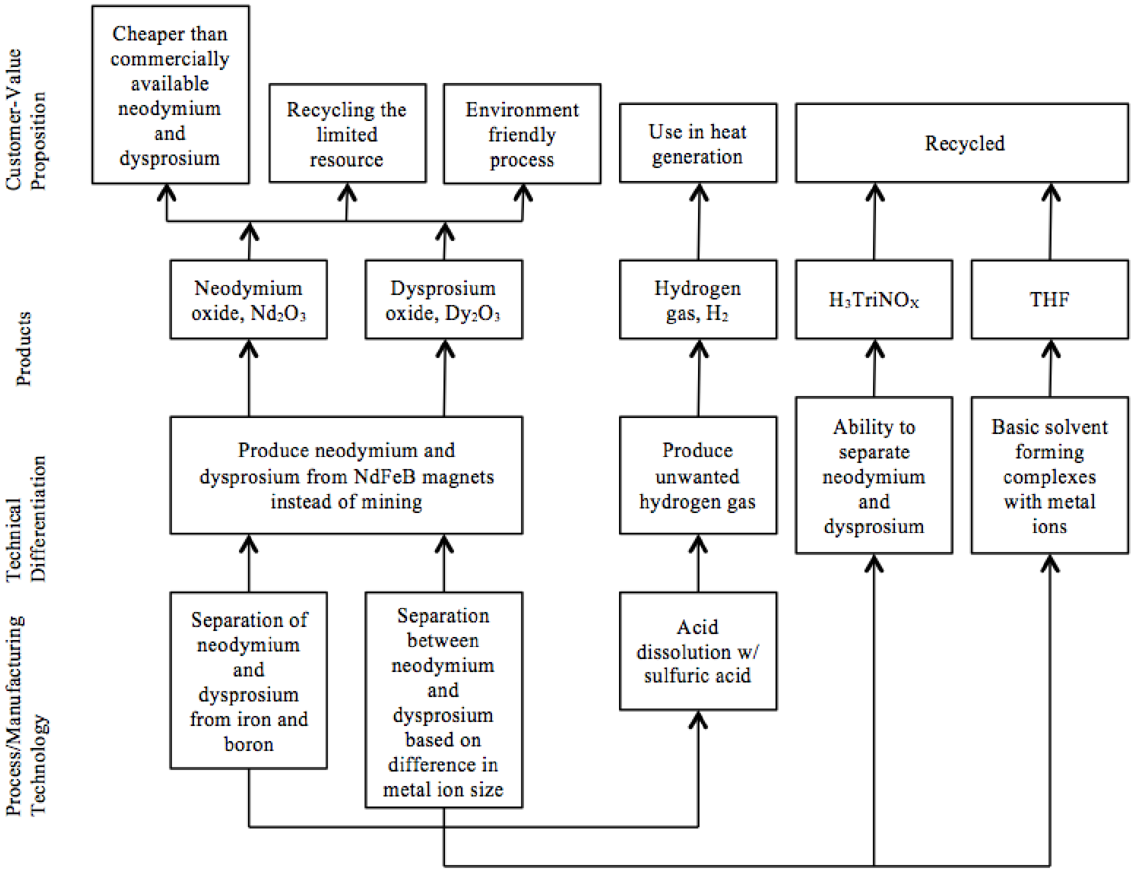


Figure 2.1 Innovation map of the overall process.

2.3 Objective time chart

The goal of this project was to design a process that would create 140,000 kg/year of neodymium and dysprosium oxides from recycled magnets. The many different steps of this analysis included the design of the chemical process from magnet to storage, calculating mass and energy balances, quantifying utility consumption, and determining the economic feasibility of the operation under different parameters. Connor Lippincott, Alan Dai, Michael Nissan, and Richard Shim each acted as project leaders for this work. A deliverable timeline for the process is as follows:

Table 2.1 Objective Time Chart of the Design Project

Completion Date	**Milestone**
February 2, 2016	Submit preliminary material balance and computer-drawn block flow diagram
February 23, 2016	Submit base case material balance and computer-drawn process flow diagram
March 15, 2016	Submit detailed equipment design for a key process unit
March 22, 2016	Major equipment designed
March 29, 2016	Finances completed
April 5, 2016	Initial written reports due
April 12, 2016	Revised written reports due
April 19, 2016	Full day meeting - design presentation

3. Market and Competitive Analysis

Our process seeks to produce pure neodymium and dysprosium oxide—types of rare earth oxides (REO)—by recycling scrap permanent neodymium-iron-boron magnets. Thus, our analysis will address both recent trends in the general rare earth market as well as specifics on neodymium, dysprosium, and permanent magnets.

Rare Earth Elements

Supply Analysis

The current market for rare earth elements (REE) is plagued by supply concerns due to geographically concentrated production and a lack of substitutes. Namely, in recent years, the market has been dominated by a single supplier – China, which holds a quasi-monopoly with over 90% of the world's total production of rare earths (peaking at 97% since 2010), even though it possesses less than 40% of the world's proven REE reserves. This market domination is a continuation of a trend beginning in the mid-1980s, when China began outcompeting the then-world-leading USA due to cheaper labor and energy and laxer regulations. Furthermore, China's REE supply chain is very vertically integrated, with control over the extraction of REO from raw ores, separation into individual REE, processing into metals, and production of end products such as permanent magnets. [6] [7] [8]

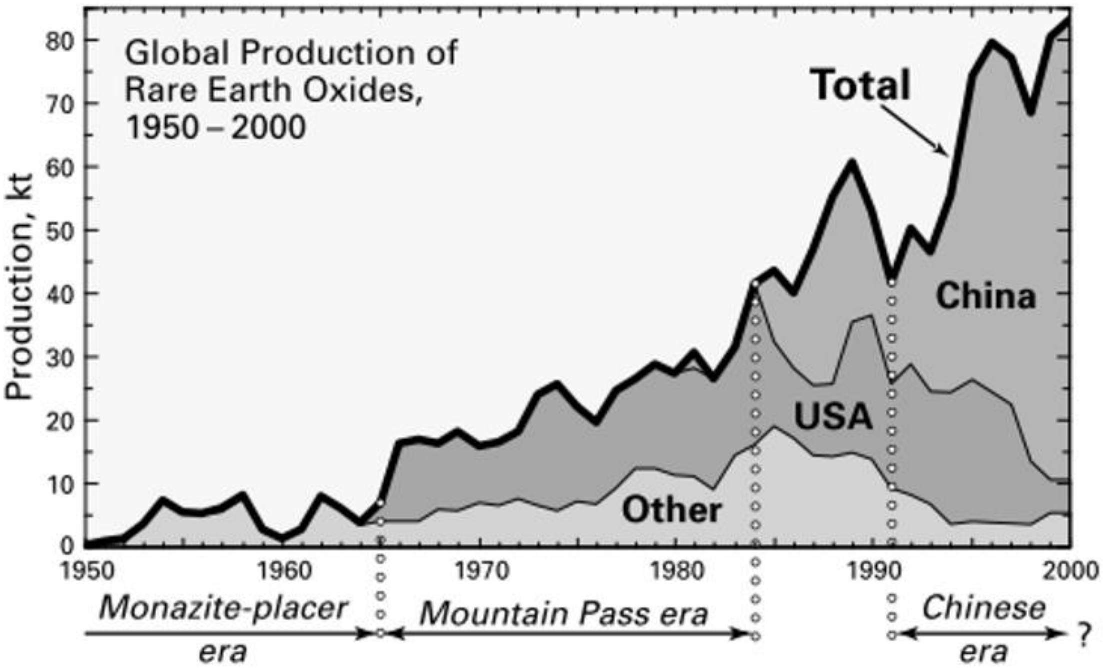


Figure 3.1 Historic Global REO Production in kilotons. [6]

Due to high domestic demand for REE, China has recently imposed export restrictions, including a quota (from 50,145 tons in 2009 to 31,130 tons in 2012 for example) and tariffs (ranging from 15 to 25%). And with their prominent position in the market, these restrictions have turned supply risks into actual supply shortages, resulting in a highly volatile market and raw material prices for the rest of the world, including the USA which is almost completely import-dependent for REE. [6] [7]

The recent bankruptcy of Molycorp in June 2015 represented both the dangers of the volatile market, having suffered from China's decision to relax their REE quotas and subsequent price drop, and the lack of full-fledged domestic competitors in the REE market.

However, In March 2015, economists from the Helmholtz Institute for Resource Technology predicted that growing demand could transform the monopolistic REE market into one with "at least a couple of competitors," lessening supply fears and increasing market volume.

Still, this hinges on the development of competitive production technologies and mitigation of any market interference by the Chinese government. [8]

Demand Analysis

Numerous high-tech industries, from mature sectors like lighting and metallurgy, to emerging sectors like batteries, ceramics, and permanent magnets, are the major contributors to REE demand. The emerging clean energy sectors in particular, which already account for a large share of, are expected to show significant growth. And most of this emerging demand focuses on the elements neodymium (Nd), praseodymium (Pr), and dysprosium (Dy), representing 85% of total emerging REE demand, since the largest segment of these sectors concerns permanent magnets. [6]

Neodymium, Dysprosium, and Permanent Magnets

Permanent rare earth magnets are commonly used in electric motors and generators for many renewable and clean energy applications (such as wind turbines and hybrid vehicles) as well as other technological applications (such as medical imaging, mag-lev trains, computer hard drives, and consumer electronics).

The predominant type of permanent magnet is made of neodymium-iron-boron (NdFeB) material, owing to its higher magnetic power, cheaper bulk metal (iron), and suitable stability compared to available alternatives. What stability issues they do have can be addressed by adding Dy, increasing the temperature threshold at which demagnetization occurs. The exact Dy content of NdFeB magnets varies widely depending on the application (and even within the same application). For instance, hard disk drives have minimal Dy content while wind turbines have 4.1% of their REE mass composed of Dy, and electric cars use 8.7% Dy. [7]

The magnet market, especially when compared to the rare earth market as a whole, has seen strong growth lately: magnets accounted for 55% of Nd demand in 2006 but 80% in 2009 (10% of which were for clean energy applications). In 2010, magnets represented 38% of *total* REE consumption. Accordingly, the NdFeB magnet market has grown from 63,000 metric tons of worldwide production in 2010 (50,000 in China and ≈0 in the US) to 78,000 in 2015 (65,000 in China and 2,000 in the US). [9] Looking ahead, demand projections are optimistic for both the separate Nd and Dy elements as well as NdFeB magnets. Over the next 25 years, it is anticipated that the demand for Nd and Dy will increase by a 700% and 2600%, respectively. [7] This expected surge in demand, combined with market supply concerns, has led the US Department of Energy in 2011 to label most REE as critical materials in the both the short and medium term, with emphasis placed on Nd and Dy. [1]

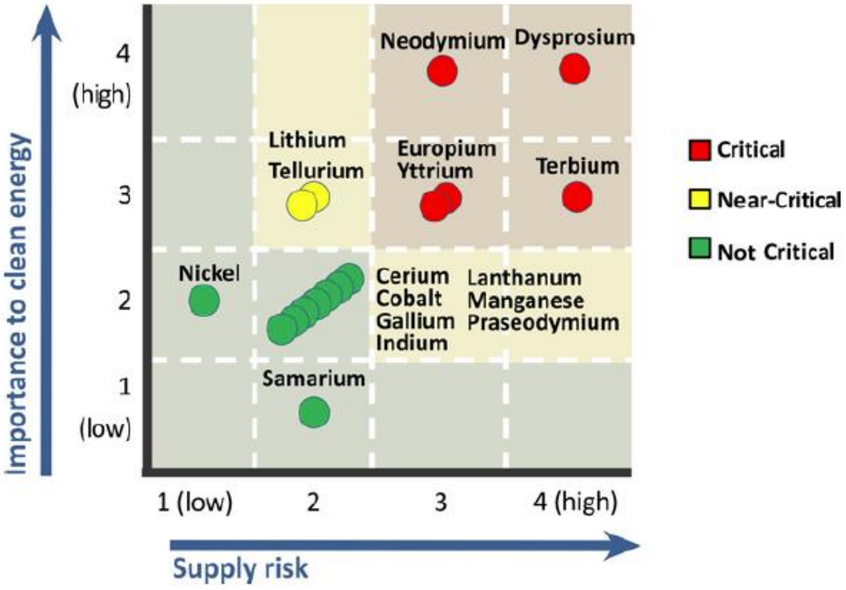


Figure 3.2 Medium Term (2015-2025) Criticality Matrix. [1]

Magnet Recycling

Currently, permanent REE magnet recycling is very much underutilized. In a 2015 analysis, Emmert et al. have found that for magnets in motors and generators (i.e. in clean energy applications), neither substitution of materials nor recycling processes have been sufficiently explored. [10] They also estimate that based on projected demand and scrap REE content, a recycling rate of above 40 % of the projected total demand for Nd can be realistically expected in 20 years. Combined with a price analysis however, they find that this recycling rate must be even higher—more than 50%—over an extended period of time to stymie the REE market price volatility.

With this optimistic market outlook and urging by the DoE, much contemporary research has gone into rare earth magnet recycling processes, the most recent of which was published by Emmert et al. in 2016. [11] (Though the publication date was after we proposed our process design, it involves very similar process steps.)

Recycling also reduces much of the environmental damage linked to REE production (which is again part of the reason China manages to produce more cheaply). When REE are first extracted in mining operations, radioactivity can be released from ores that also contain chemically similar actinides (such as thorium and uranium). Then, the industrial separation of REEs, which involves a 100+ step liquid-liquid extraction process, is very energy and chemical-intensive, leading to large amounts of chemical waste (as toxic sludge) and greenhouse gas production. [6]

Separating Neodymium and Dysprosium

As noted before, rare earth elements are very difficult to separate from one another due to their similar chemical properties. The current commercial Rhüne–Poulenc liquid–liquid extraction (LLE) process (LLE) is very energy-, time- and solvent-intensive [4], and these factors are reflected in the prices of rare earth mixtures vs. pure rare earth compound. For instance, in 2003, the average rare-earth chloride price was $1.50/kg, and ore concentrates were $.73/kg of contained rare earth oxide. Compare this to 95% pure neodymium oxide, which was priced at $28.50/kg (for a 20kg scale). This effect can be further illustrated by scandium metal, a rare element not addressed in our process but with similar purity vs. price trends. Prices in 2003 ranged from $500/kg at 99% purity to $1300/kg at 99.9% purity to up to $6000/kg at 99.99% purity.

Our process not only focuses on recycling magnets but a novel method of separating the product rare earths into 99% pure Nd and Dy oxides. Dy has shown the greatest supply risks that have led to magnet manufacturers looking for alternatives and settling for lower operating temperatures. [9] This is also reflected in its much higher price compared to Nd. No current recycling methods mention separation of REE from each other, since it is a normally taxing process. We seek to take advantage of this opening in the market and possible allow magnet manufacturers to vary the Dy content in the new magnets.

Sales Projections

A November 2015 financial report by the Freedonia Group [12] gives more specific, near-term projections on the REE permanent magnet market, expecting global demand for magnets to increase by 3.5% per year. For the domestic (American) market, this means usage of REE (primarily Nd and Dy) in magnets will reach 7000 metric tons by 2020.

With this projected sales value and a wide-open recycling industry, we seek to enter the market with a modest goal of recycling enough magnets to reach approximately 2% of domestic market share. We seek to recover 127 metric tons of REO from scrap NdFeB magnets per year. These magnets will be 90 wt% Nd and 10% Dy, typical of electric and hybrid car generators.

Currently, prices of REO have decreased dramatically from their peak in early 2011, when Chinese quotas were at their most restrictive and supply fears were at their greatest. However, we are prepared to take advantage of any future price surges in—as well as work towards independence from—this still volatile, China-controlled market. Using current (Dec. 2015) domestic prices of \$60/kg for Nd_2O_3 and \$350/kg for Dy_2O_3, our projected revenue is \$11 million/year once we reach full production.

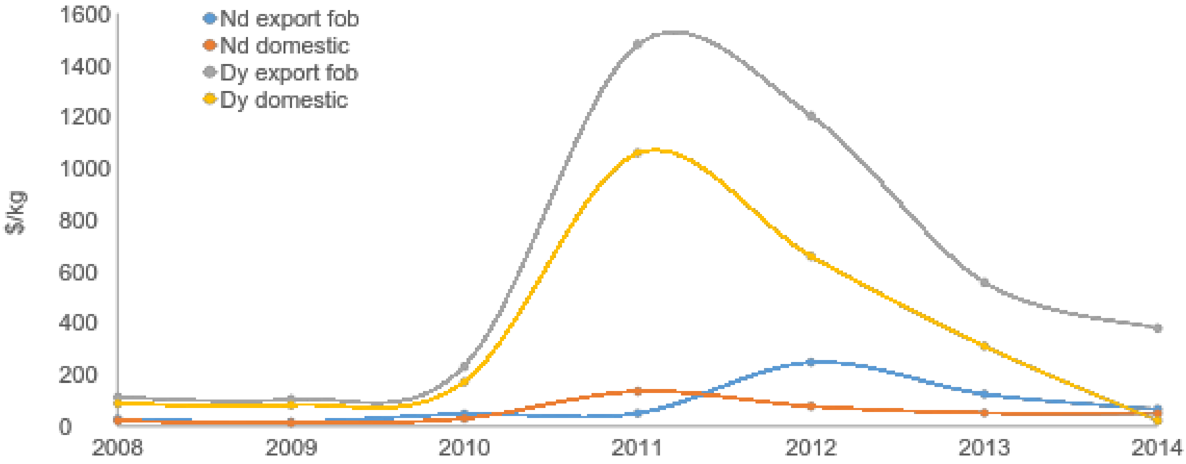


Figure 3.3 Domestic and Export price curves for Nd and Dy oxides, in \$/kg from 2008-2014. Data from Roskill, 2015 [13]

Byproducts

Hexamethyldisilazane (HMDS)

One specialty chemical used in our process produces the silyl compound HMDS as a byproduct, which is then isolated to 99%+ purity via distillation. HMDS is an organic reagent, widely used to add silyl groups to other organic compounds or even laboratory glassware. It is also used to produce strong alkali metal non-nucleophilic bases (such as the potassium amide salt used in our process). [14] At full production, we expect to produce 401 metric tons/year, and although this compound is not commonly sold at an industrial scale, we can predict the market price by extrapolating from lab-scale prices. Thusly, we estimate $12.7 million/year from HMDS sales, which will help to recoup costs from its even more expensive precursor. With its common laboratory use, we are confident that there will sufficient domestic demand for our HMDS byproduct.

4. Preliminary Process Synthesis

When proposing our original process, we envisioned it to revolve around the use of the tridentate nitroxide ligand “TriNOx” in separating neodymium (Nd) and dysprosium (Dy), as developed by Dr. Eric Schelter [4] and patented under US patent number WO2016019044-A1. Our main stipulations were that we should be starting from NdFeB magnets and ending with separated Nd and Dy products.

4.1 Alternative process flowsheets and discussion of most viable flowsheets

Choosing a Rare Earth Salt Synthesis Method

The method of converting rare earth magnets into a form accessible by TriNOx, which would encompass the first third of our entire procedure, was up for discussion. In Schelter’s work, TriNOx was attached to rare earth elements by using a rare earth chloride feed, so we sought a process that would produce a rare earth salt with some sort of stable anion, assuming chemically similar anions would result in similar behavior with TriNOx.

One such process was developed by Onal *et al.* on the laboratory scale to recycle REE from NdFeB magnets, with a focus on recovering Nd and Dy in a sustainable manner—this fit well with our goals. [15] They first dissolved the bulk magnets in concentrated sulfuric acid (at room temperature) to form various metal sulfates. Then, the mixture was roasted to form water-soluble rare-earth sulfates and water-insoluble impurities. This slurry was then leached with water (again at ambient conditions) to recover the REE in the aqueous phase.

This REE sulfate could then be processed to form oxides and pure metals, though they did not do so in their process. The authors tested a variety of conditions, such as acid concentration, roasting time and temperature, drying duration, etc. to arrive at a set of optimal conditions, shown in Figure 4.1. This method seemed very fitting and promising, with enough provided data to let us for equipment specifications and a scaled up process design. However, the end leachate gave the REE in a form incompatible with TriNOx (as far as we knew) and therefore we sought other sources.

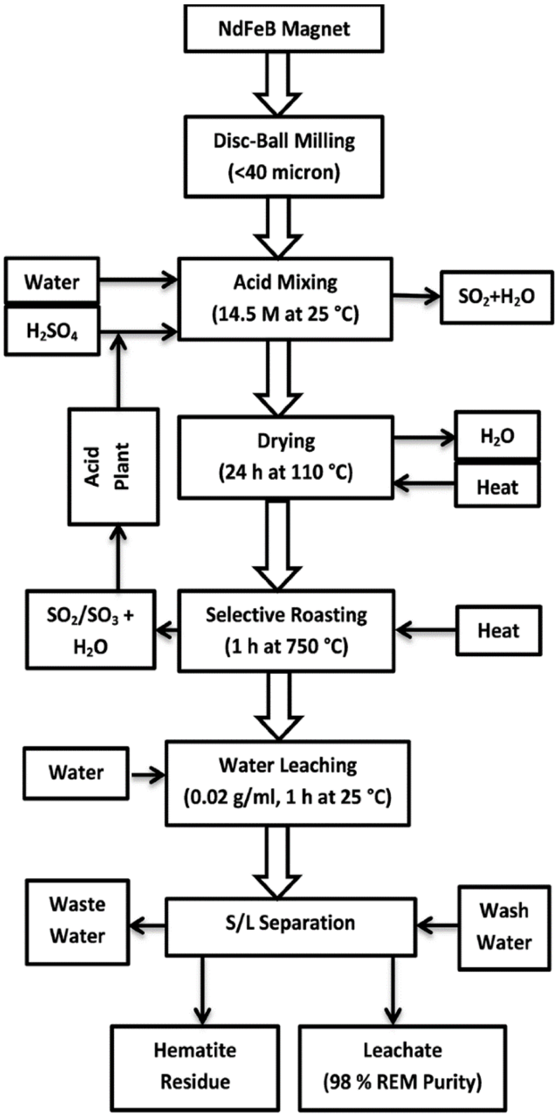


Figure 4.1 Flowsheet showing optimal conditions for Onal's magnet recycling process. [15]

Upon further research, we decided to use a more-established method of NdFeB magnet recycling published by the U.S. Bureau of Mines [16] that gave us the desired rare earth salt product (in the form of rare earth fluorides) along more data at a larger scale and a better sense of legitimacy due to its source and appearance as a citation in other works. Combined with Schelter's proposed separation scheme, we arrived at our first preliminary flowsheet, as seen in our project proposal and shown in Figure 4.2.

First Preliminary Flowsheet

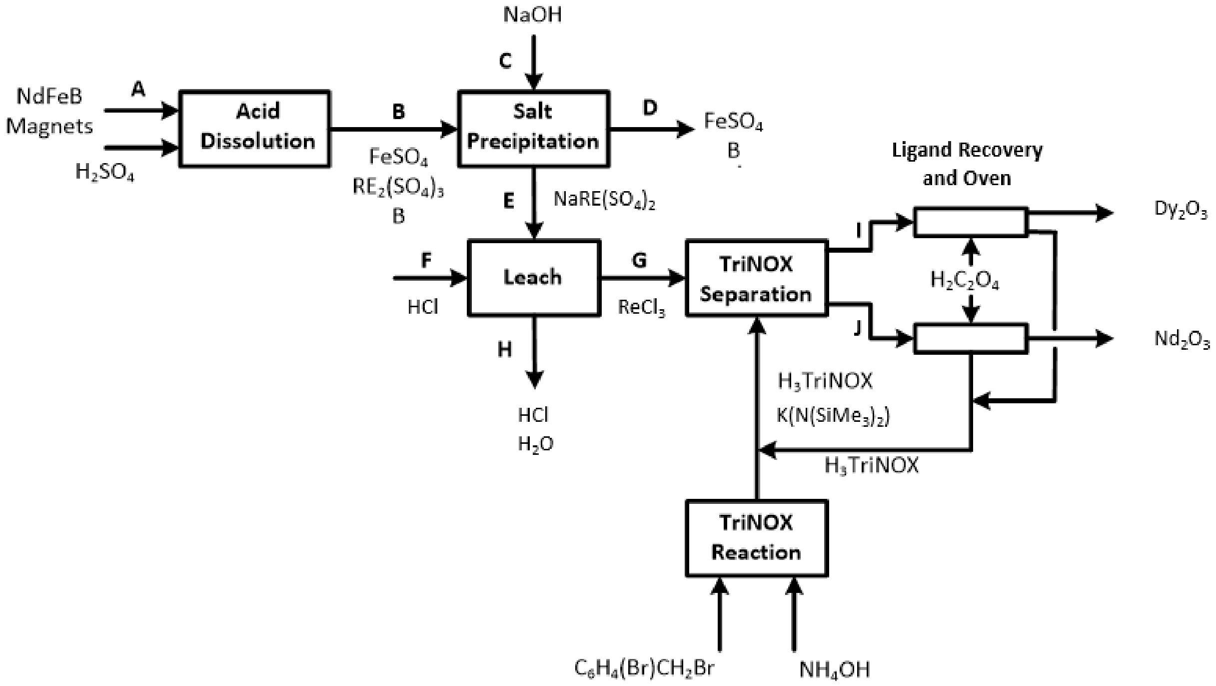


Figure 4.2 Block diagram flowsheet for our preliminary magnet recycling process.

This process contains steps very similar to our final design, but with some important changes to be detailed later. As of now, the magnets (obtained in pure, demagnetized form) would be dissolved in concentrated sulfuric acid to form a mixture of metal sulfates (just like in the Onal paper). Next, the REE would be selectively precipitated by the addition of sodium hydroxide to form insoluble rare earth double salts (indicated as $NaRE_2(SO_4)_2$) in the block diagram). After filtering off the still soluble impurities, the rare earth double salts would then be attacked with hydrofluoric acid (HF) in a “leaching” step to form the more usable rare earth fluorides, which are again isolated as a solid by filtration. [16]

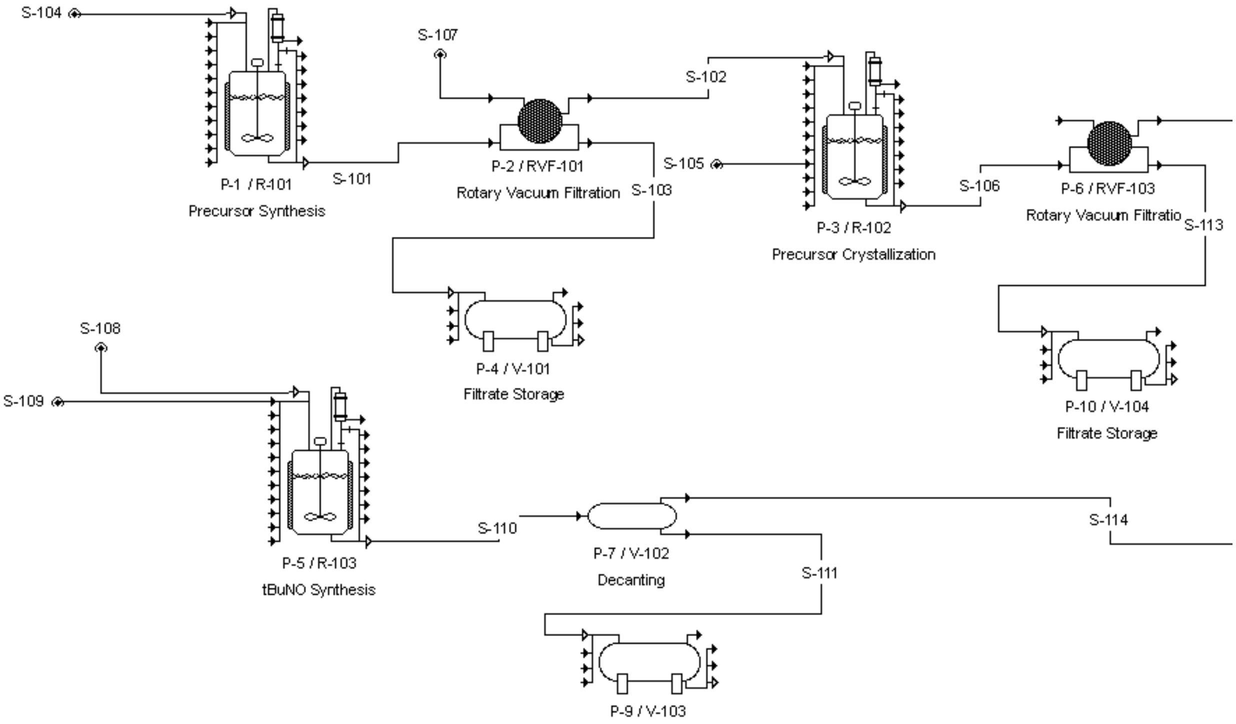
The next section, from rare earth fluoride to the end product, involves Schelter group chemistry, and would remain largely unchanged throughout our design revisions. First, the TriNOx ligand is attached to the rare earth element (which has been a positive ion since the acid dissolution step) with the help of $K(N(SiMe)_2)$ ("K amide") which acts as a base. This new rare earth-TriNOx compound (Re(TriNOx)) possesses a special property that motivates the entire project: when in an organic solvent like toluene, the Dy compound is insoluble, while the Nd compound forms a soluble dimer. This allows us to very simply filter one compound from the other, which is much faster and easier than conventional separation methods. After separation, the Re(TriNOx) compounds can each be converted to the rare earth oxalate salts, which are then roasted (heated in air) to form pure rare earth oxide product. Additionally, TriNOx can be recovered and recycled.

Switching from Fluoride to Chloride

We soon realized that using HF in an industrial process would bring with it significant safety concerns and costs, so we sought to substitute the acid with HCl and instead form rare earth chlorides, which are still compatible with TriNOx. We assumed the acid and resulting rare earth salt would be as viable for separation (from any aqueous salts), citing yet another published lab-scale magnet recycling method, this time using chlorination to recover rare earths from NdFeB magnet scrap. [17] This would also allow us to use less-expensive materials in our equipment, as HCl would be slightly less damaging to reactor and storage tank walls.

Synthesis of TriNOx

Initially, we planned to synthesize our own TriNOx, following the laboratory procedure outlined in the Schelter paper [4] but scaled up. However, soon after developing a mass balance and flowsheet of this process (Figure 4.3), we realized it would entail a significant addition of multiple sections totaling at least 37 process steps and requiring an amount of equipment and plant design, waste and safety considerations, economic calculations, etc. equal to the rest of our design project combined. Thus, we designated the in-house production of TriNOx as out of the scope of this project and opted to outsource it to a specialty chemical producer. Still, we arrived at a baseline cost of $440000/batch, based on prices on input chemicals (at a lab scale) alone, just to recover the amount of TriNOx lost to yield and recovery inefficiencies. This would be a crippling cost even without considering the extra equipment and operating costs, and so we turned to the assumption that we would be able to run our process without any significant TriNOx losses.



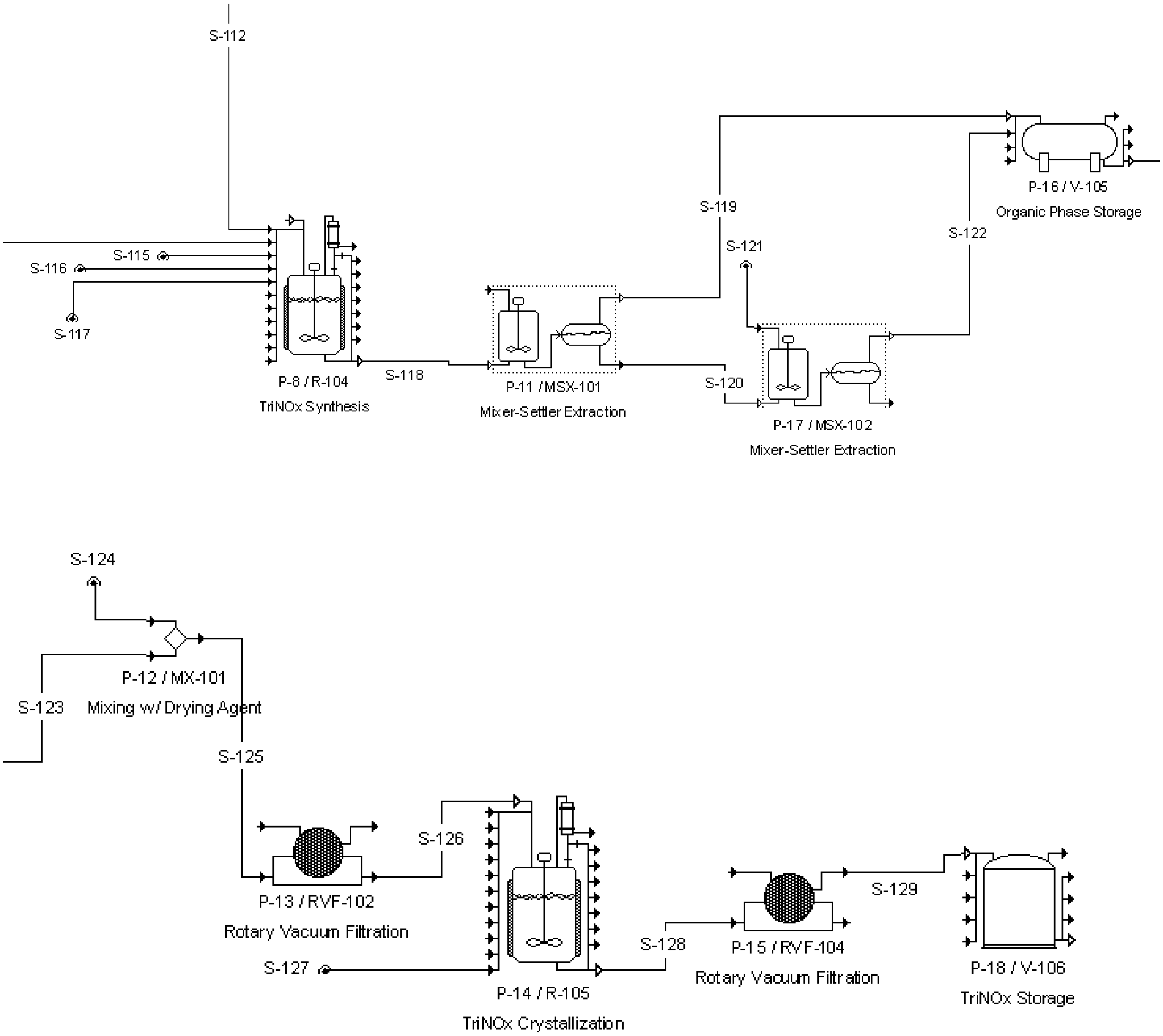


Figure 4.3 Flowsheets for batch synthesis of TriNOx from commercially available chemicals

Treatment of End Streams (Recycling vs. Disposal vs. Sale)

Throughout our process, we create many unwanted mixtures and byproducts as we continue to separate streams from our target rare earth oxide product. We prioritized economics when deciding whether to recycle various streams or send them off as waste as well as deciding how to treat our waste. After our Re(TriNOx) production step, we produce a mixture of tetrahydrofuran (THF) and HMDS as a filtrate. Normally if this stream were just solvent, a separations process would not be economically justifiable to recover the THF at our small scale. However, we realized that HMDS is a valuable byproduct, and that THF and HMDS have dissimilar-enough boiling points to be separated via distillation and obtain a salable purity of HMDS. Thus, we decided to finance distillation equipment to recover as much HMDS as possible, with the added bonus of being able to recycle some THF as well.

For other potential waste streams, we implemented a simple recycle if the stream was easily purified (as was the case for solvents removed in crystallizers) or a more complex recycle if the stream was particularly valuable (such as for TriNOx and HMDS). Otherwise, we decided to let the streams go as waste. We considered treating the waste in-house, as the U.S. Bureau of Mines paper had detailed steps on handling the iron sulfate and boron waste streams (from the rare earth double salt precipitation step) [16] but after calculating the costs of custom waste treatment equipment, we decided it was both easier and cheaper to outsource our waste treatment to a utility ($3,500/batch with utility vs. $570,000 bare module cost for equipment).

Combined Equipment

In an attempt to improve our process scheduling and reduce costs, we sought to reduce equipment idle time by combining multiple steps into one piece of suitable equipment. Initially, we planned to purchase separate reactors for both the acid dissolution and salt precipitation steps. As the process design progressed, we noticed that these reactors are exposed to similar conditions in a similar plant location but that each has an operation time well below the bottleneck time (of 24 hours for distillation). Thus, we "combined" these two reactors into R-100, which does not even need to be emptied/cleaned in between steps. This saved us the need for a second nickel-alloy-lined reactor (our first of which cost $222,000).

We also saw the opportunity in Section 3, as after their initial separation, the Nd and Dy compounds are processed identically to form their oxides. Obviously they should not be remixed and processed together to save equipment costs, but they could certainly use the same equipment at different times. Since these steps were also well below the bottleneck time, this was feasible to schedule.

Lastly, we considered using one crystallizer (and one linked heating jacket and condenser) to provide the function of V-201, V-300, and V-301. This would allow us to purchase 2 less jacketed crystallizers and condensers, saving around $900,000 in bare module costs. However, we were afraid that having Nd(TriNOx) and mixed Re(TriNOx) crystallize in the same vessel would lead to contamination of Nd(TriNOx) with some Dy, defeating the purpose of the expensive separation. This was less of a concern in the previous instance where we let Nd and Dy compounds share equipment, as the earlier case only dealt with the compounds in the solid (or slurry) phase and could have the equipment be compartmentalized to prevent accidental contamination from residual material. Crystallizers involve the compounds in solution and need an agitator to access the entire vessel to provide well-mixing of the solution. Still, combining V-201 and V-301, which only process mixed rare earth compounds and pure ligand, may be feasible and should be considered in further analysis of the process.

Use of Storage Tanks

In Section 1, where we require large amounts of aqueous corrosive solutions (acids and bases), we already planned to purchase specially-lined storage tanks to hold the chemicals before use in various magnet processing steps. At first, we considered diluting these solutions to their requisite concentration (as prescribed in the U.S. Bureau of Mines report) [16] in R-100 as needed, which would be highly exothermic, especially for the dilution of concentrated sulfuric acid (commercially available as 98% pure). This would add to the heat evolved from the acid dissolution step itself and dramatically increase the heat duty of the condenser E-100.

To alleviate this, we decided to dilute our solutions beforehand in their storage tanks, equipped with cooling coils, both so we can prepare multiple batches’ worth at once and so we can let the solutions cool more gradually, impart less stress on our heat exchangers, and avoid the risk of over-concentrating our reaction solution due to over-evaporation of water.

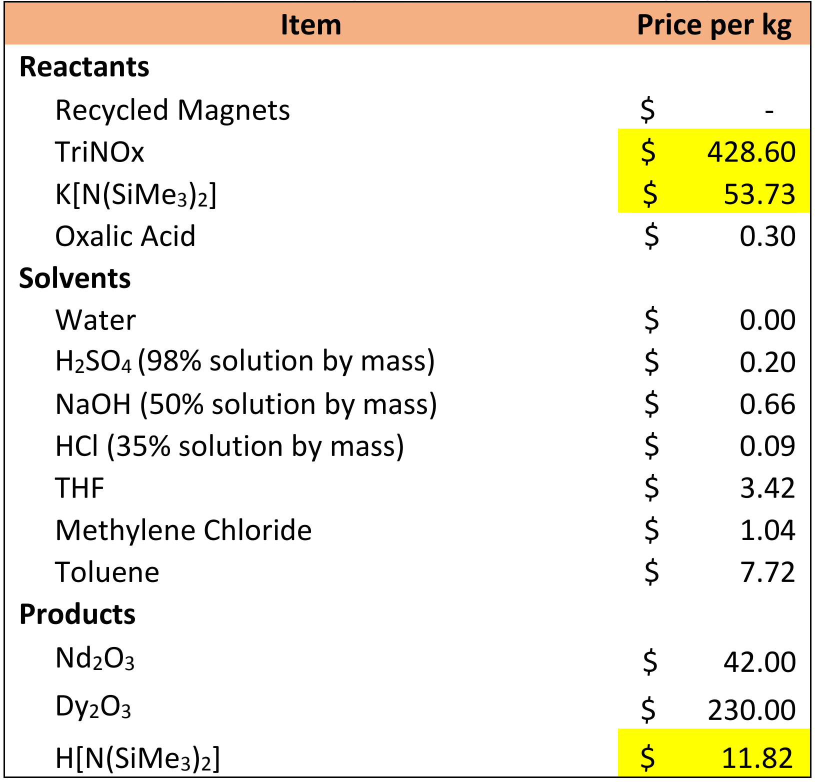
Choice of Scale

While our market analysis was fairly optimistic, predicting ample supply of magnets and demand of rare earth oxides, we still wanted to be careful in choosing a scale for a startup plant in a largely untested industry. We chose 2% of the domestic market as a cautious starting point. Our eventual profitability analysis suggests that further analysis should consider increasing the scale of production to improve profitability.

5. Assembly of Database

The database of commercially available chemicals and solvents used can be found in Appendix section 19.3 as MSDS sheets. Information about the novel TriNOx ligand was pulled from published and unpublished work from the Schelter group. [4] There are a number of safety concerns with this process, including the use of concentrated sulfuric and hydrochloric acids, and potassium bis(trimethylsilyl)amide, which reacts violently with water. Prices for the products are included in table 5.1. The highlighted prices are estimates of industrial scale costs extrapolated from lab scale prices as well as the pricing of similar compounds. These prices undergo a sensitivity analysis in Section 15.

Table 5.1 Chemical prices per kg. Important chemicals are highlighted.



Item	Price per kg
Reactants	
Recycled Magnets	$ -
TriNOx	$ 428.60
$K[N(SiMe_3)_2]$	$ 53.73
Oxalic Acid	$ 0.30
Solvents	
Water	$ 0.00
H_2SO_4 (98% solution by mass)	$ 0.20
NaOH (50% solution by mass)	$ 0.66
HCl (35% solution by mass)	$ 0.09
THF	$ 3.42
Methylene Chloride	$ 1.04
Toluene	$ 7.72
Products	
Nd_2O_3	$ 42.00
Dy_2O_3	$ 230.00
$H[N(SiMe_3)_2]$	$ 11.82

6. Process Flow Diagram and Material Balances

6.1 Process flow diagram

The following pages include the overall process flow diagram.

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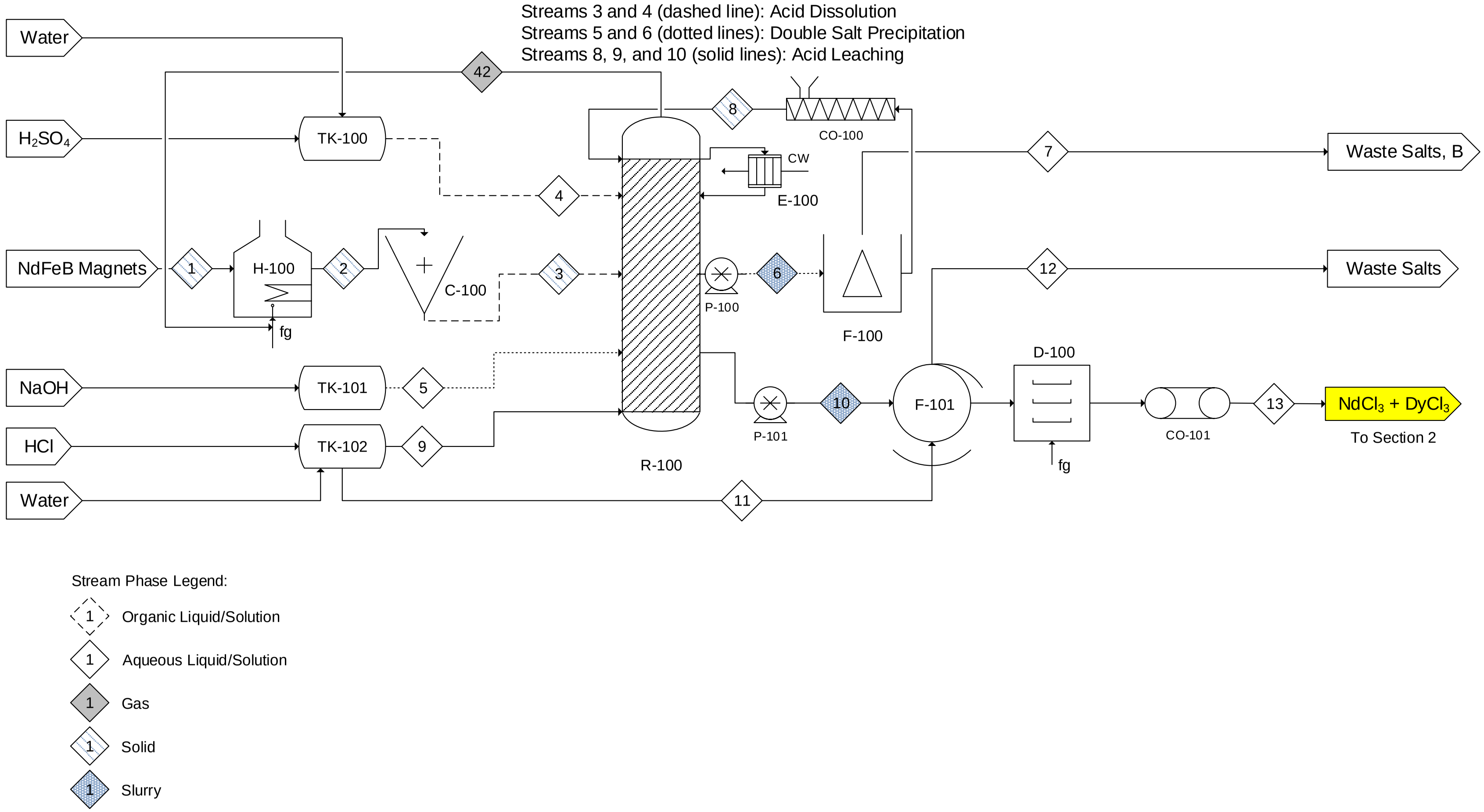
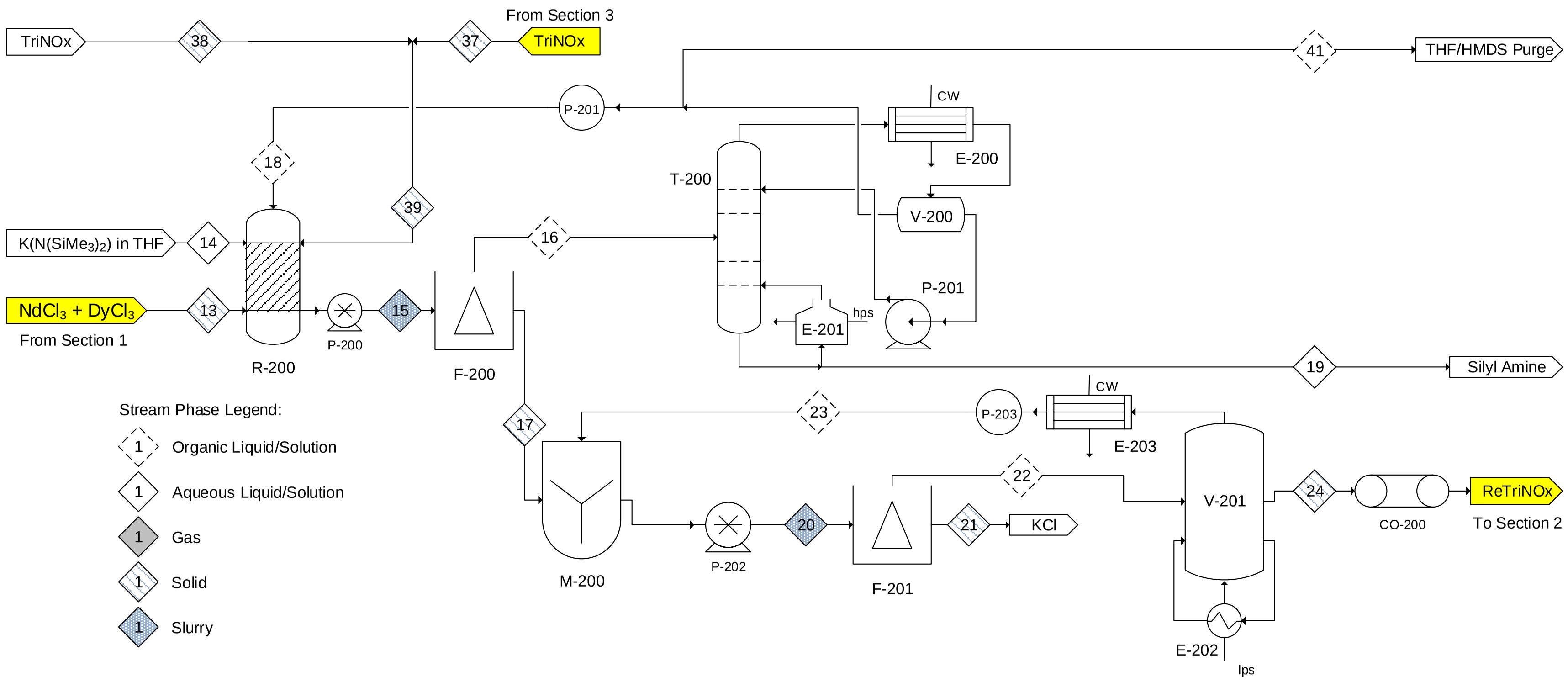
Rare Earth Magnet Recycling
Process Flow Diagram
Section 1
Production of Rare Earth Chloride from Scrap Magnets



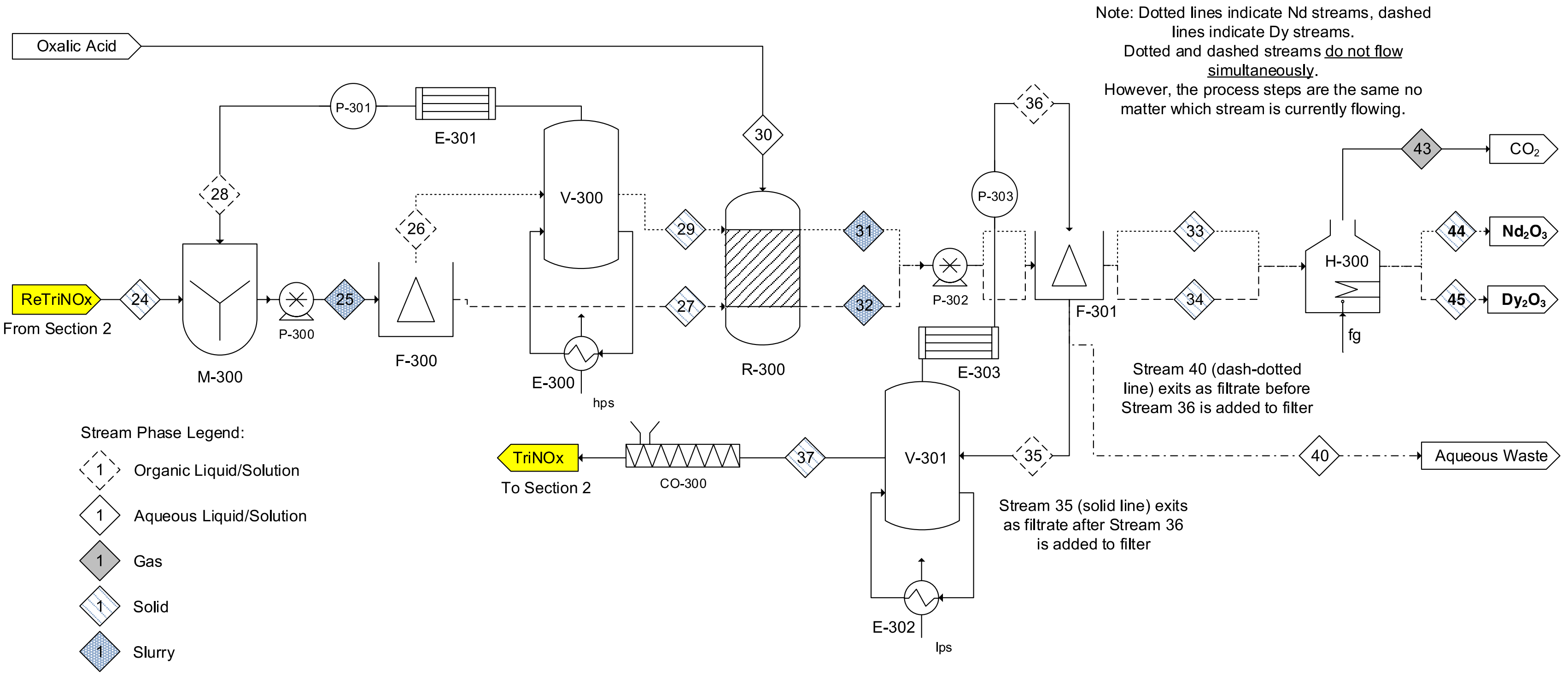
Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	42
Component (kg/batch)														
$(Nd,Dy)_2Fe_{14}B$ (magnetized)	1460	0	0	0	0	0	0	0	0	0	0	0	0	0
$(Nd,Dy)_2Fe_{14}B$ (demagnetized)	0	1460	0	0	0	0	0	0	0	0	0	0	0	0
$(Nd,Dy)_2Fe_{14}B$ (crushed)	0	0	1460	0	0	0	0	0	0	0	0	0	0	0
H_2SO_4	0	0	0	2920	0	0	0	0	0	0	0	0	0	0
NaOH	0	0	0	0	162	0	0	0	0	0	0	0	0	0
$FeSO_4$	0	0	0	0	0	2872	2872	0	0	0	0	0	0	0
B	0	0	0	0	0	15	15	0	0	0	0	0	0	0
H_2	0	0	0	0	0	0	0	0	0	0	0	0	0	60
SO_4^{2-} (aq)	0	0	0	0	0	525	525	0	0	519	0	519	0	0
H_2O	0	0	0	13752	183	13935	13935	0	15006	15006	18884	33890	0	0
$NaRe(SO_4)_2$	0	0	0	0	0	975	0	975	0	0	0	0	0	0
OH- (aq)	0	0	0	0	0	69	69	0	0	0	0	0	0	0
Na^+ (aq)	0	0	0	0	0	31	31	0	0	62	0	62	0	0
$ReCl_3$	0	0	0	0	0	0	0	0	0	677	0	43	634	0
HCl	0	0	0	0	0	0	0	0	2461	0	1888	0	0	0
H^+ (aq)	0	0	0	0	0	0	0	0	0	68	52	120	0	0
Cl^- (aq)	0	0	0	0	0	0	0	0	0	2107	1836	3943	0	0
Total mass	**1460**	**1460**	**1460**	**16672**	**345**	**18422**	**17447**	**975**	**17467**	**18439**	**22660**	**38577**	**634**	**60**

Rare Earth Magnet Recycling
Process Flow Diagram
Section 2
Synthesis of ReTriNOx



Stream Number	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**37**	**38**	**39**	**41**
Component (kg/batch)																
$ReCl_3$	634	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H_3TriNOx	0	0	0	0	0	0	0	0	0	0	0	0	300	1079	1379	0
$K[N(SiMe_3)_2]$	0	1503	0	0	0	0	0	0	0	0	0	0	0	0	0	0
THF	0	1640	11640	11640	0	10000	0	0	0	0	0	0	0	0	0	1640
Re(TriNOx)	0	0	1738	0	1738	0	0	1738	174	1564	0	1564	0	0	0	0
$H[N(SiMe_3)_2]$	0	0	1216	1216	0	0	1216	0	0	0	0	0	0	0	0	trace
KCl	0	0	562	0	562	0	0	562	562	0	0	0	0	0	0	0
DCM	0	0	0	0	0	0	0	20802	0	20802	20802	0	0	0	0	0
Total mass	**634**	**3143**	**15156**	**12856**	**2300**	**10000**	**1216**	**23102**	**736**	**22366**	**20802**	**1564**	**300**	**1079**	**1379**	**1640**

Rare Earth Magnet Recycling
Process Flow Diagram
Section 3
Separation of Neodymium and Dysprosium



Note: Dotted lines indicate Nd streams, dashed lines indicate Dy streams.
Dotted and dashed streams do not flow simultaneously.
However, the process steps are the same no matter which stream is currently flowing.

Stream 40 (dash-dotted line) exits as filtrate before Stream 36 is added to filter

Stream 35 (solid line) exits as filtrate after Stream 36 is added to filter

Stream Number	24	25	26	27	28	29	30	31	32	33	34	35	36	37	40	43	44	45
Component (kg/batch)																		
Re(TriNOx)	1564	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	0	8670	8670	0	8670	0	0	0	0	0	0	0	0	0	0	0	0	0
$[Nd(TriNOx)]_2$	0	1404	1402	2	0	1402	0	0	0	0	0	0	0	0	0	0	0	0
Dy(TriNOx)	0	160	14	146	0	14	0	0	0	0	0	0	0	0	0	0	0	0
$H_2C_2O_4$	0	0	0	0	0	0	305	0	0	0	0	0	0	0	0	0	0	0
H_2O	0	0	0	0	0	0	3203	2908	295	2908	295	0	0	0	3203	0	0	0
H_3TriNOx	0	0	0	0	0	0	0	979	100	0	0	1079	0	1079	0	0	0	0
H_3TriNOx (decomposed)	0	0	0	0	0	0	0	146	15	0	0	151	0	151	0	0	0	0
$Nd_2(C_2O_4)_3$	0	0	0	0	0	0	0	561	1	561	1	0	0	0	0	0	0	0
O_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$Dy_2(C_2O_4)_3$	0	0	0	0	0	0	0	6	61	6	61	0	0	0	0	0	0	0
Nd_2O_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	trace	341
CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	298	0	0
Dy_2O_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	4
DCM	0	0	0	0	0	0	0	0	0	0	0	29180	29180	0	0	0	0	0
Total Mass	**1564**	**10234**	**10086**	**148**	**8670**	**1416**	**3508**	**4600**	**472**	**3475**	**357**	**30410**	**29180**	**1230**	**3203**	**298**	**38**	**345**

6.2 Material balance block

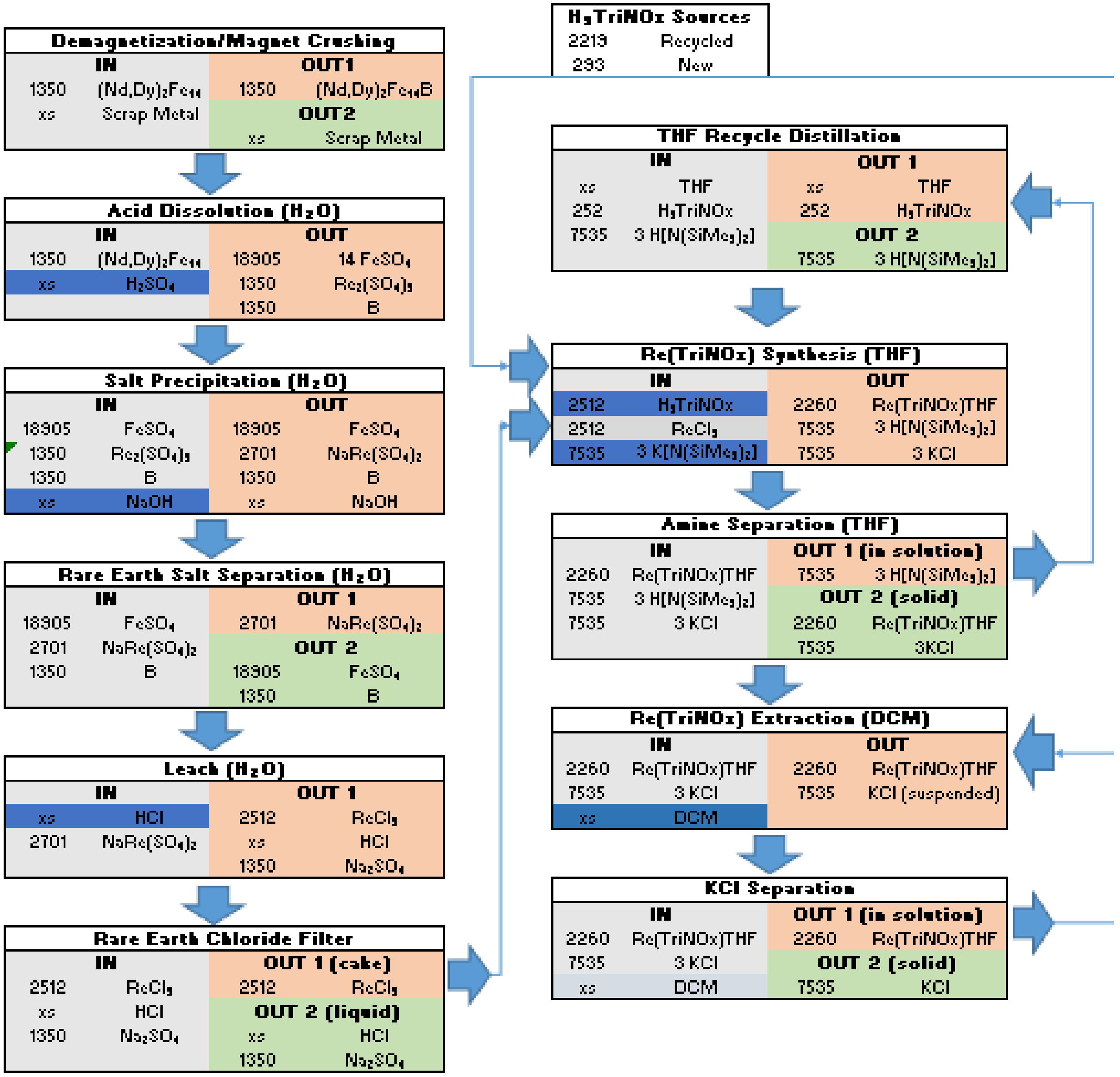
Table 6.1 Overall Component Balances (kg/batch). Shows inputs, outputs, and changes in mass.

Component	Input	Output	Produced	Consumed/Lost/Discarded	Out-In
$(Nd,Dy)_2Fe_{14}B$	1460	0	0	1460	0
B	0	15	15	0	0
$H_3TriNOx$	294	0	0	294	0
$K[N(SiMe_3)_2]$	1503	0	0	1503	0
$H[N(SiMe_3)_2]$	0	1216	1216	0	0
$H_2C_2O_4$	305	0	0	305	0
Nd_2O_3	0	342	342	0	0
Dy_2O_3	0	42	42	0	0
HCl	2461	0	0	2461	0
H_2	0	0	60	60	0
H_2SO_4	2920	0	0	2920	0
CO_2	0	0	298	298	0
Waste Salts*	0	0	6185	6185	0

*Composed of Fe, Na, SO_4, Cl, OH ions

7. Process Description

7.1 General description


Demagnetization/Magnet Crushing
IN
1350 $(Nd,Dy)_2Fe_{14}$
xs Scrap Metal
OUT1
1350 $(Nd,Dy)_2Fe_{14}B$
OUT2
xs Scrap Metal
Acid Dissolution (H_2O)
IN
1350 $(Nd,Dy)_2Fe_{14}$
xs H_2SO_4
OUT
18905 14 $FeSO_4$
1350 $Re_2(SO_4)_3$
1350 B
Salt Precipitation (H_2O)
IN
18905 $FeSO_4$
1350 $Re_2(SO_4)_3$
1350 B
xs NaOH
OUT
18905 $FeSO_4$
2701 $NaRe(SO_4)_2$
1350 B
xs NaOH
Rare Earth Salt Separation (H_2O)
IN
18905 $FeSO_4$
2701 $NaRe(SO_4)_2$
1350 B
OUT 1
2701 $NaRe(SO_4)_2$
OUT 2
18905 $FeSO_4$
1350 B
Leach (H_2O)
IN
xs HCl
2701 $NaRe(SO_4)_2$
OUT 1
2512 $ReCl_3$
xs HCl
1350 Na_2SO_4
Rare Earth Chloride Filter
IN
2512 $ReCl_3$
xs HCl
1350 Na_2SO_4
OUT 1 (cake)
2512 $ReCl_3$
OUT 2 (liquid)
xs HCl
1350 Na_2SO_4
$H_3TriNOx$ Sources
2219 Recycled
293 New
THF Recycle Distillation
IN
xs THF
252 $H_3TriNOx$
7535 3 $H[N(SiMe_3)_2]$
OUT 1
xs THF
252 $H_3TriNOx$
OUT 2
7535 3 $H[N(SiMe_3)_2]$
Re(TriNOx) Synthesis (THF)
IN
2512 $H_3TriNOx$
2512 $ReCl_3$
7535 3 $K[N(SiMe_3)_2]$
OUT
2260 Re(TriNOx)THF
7535 3 $H[N(SiMe_3)_2]$
7535 3 KCl
Amine Separation (THF)
IN
2260 Re(TriNOx)THF
7535 3 $H[N(SiMe_3)_2]$
7535 3 KCl
OUT 1 (in solution)
7535 3 $H[N(SiMe_3)_2]$
OUT 2 (solid)
2260 Re(TriNOx)THF
7535 3KCl
Re(TriNOx) Extraction (DCM)
IN
2260 Re(TriNOx)THF
7535 3 KCl
xs DCM
OUT
2260 Re(TriNOx)THF
7535 KCl (suspended)
KCl Separation
IN
2260 Re(TriNOx)THF
7535 3 KCl
xs DCM
OUT 1 (in solution)
2260 Re(TriNOx)THF
OUT 2 (solid)
7535 KCl

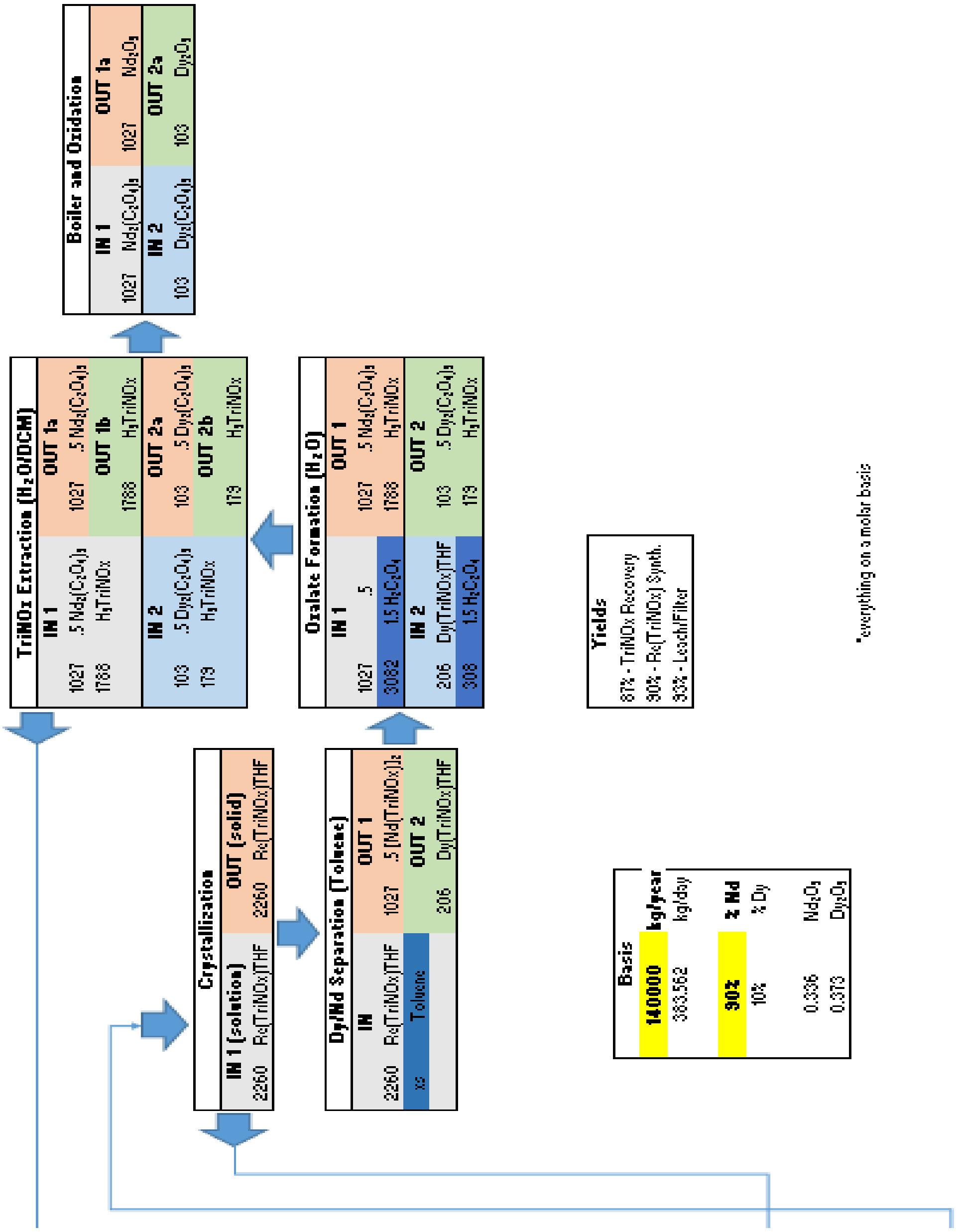


Figure 7.1 The block diagram of the general chemical processes.

The preceding block diagram shows the general chemical processes involved in separating Neodymium and Dysprosium in the form of Nd_2O_3 and Dy_2O_3 from a source of NdFeB Magnets. In order to prepare the magnets for chemical processing, they are first demagnetized by heating above the Curie temperature and then fed into a jaw crusher. This results in magnetically-neutral particles fit for chemical processing.

The particles first undergo acid dissolution with sulfuric acid. This results in the rare-earth metals forming sulfates, $Nd_2(SO_4)_3$ and $Dy_2(SO_4)_3$. The iron also forms a sulfate, $FeSO_4$.

Next, in the same reactor, NaOH is added in order to precipitate the sodium-rare earth salts $Na_2Nd_2(SO_4)_2$ and $Na_2Dy_2(SO_4)_2$. The reaction mixture is sent to a filter, where the sodium-rare earth salts are retrieved, and the reaction mixture, including the still-dissolved $FeSO_4$, is treated as a waste stream.

The sodium-rare earth salts are then “leached,” a process by which they are reacted with a hydrochloric acid solution, resulting in $NdCl_3$ and $DyCl_3$ solids. These solids are filtered from the reaction mixture.

The solids then undergo a reaction with TriNOx, a tridentate nitroxide ligand. This reaction occurs in a THF solution. As a result of this reaction, KCl, NdTriNOx, and DyTriNOx solids are formed and filtered from the rest of the solution.

Dichloromethane, DCM, is added to the reaction mixture, which selectively dissolves NdTriNOx and DyTriNOx. The KCl is filtered off and the DCM solvent of the rare earth TriNOx compounds is evaporated, forming rare earth TriNOx crystals.

The crystals are mixed with toluene, in which only NdTriNOx dissolves. After filtration, the NdTriNOx solution is separated from the DyTriNOx solids and then the toluene is evaporated, leaving two separated solids: NdTriNOx and DyTriNOx.

These solids then each separately undergo a reaction with oxalic acid. The Nd compound forms Neodymium Oxalate, $Nd_2(C_2O_4)_3$ and the Dy compound forms its corresponding oxylate, $Dy_2(C_2O_4)_3$. During this reaction, the TriNOx is displaced by forming H_3TriNOx. DCM is added to dissolve the H_3TriNOx and filter out the solids of interest: the rare earth oxylates.

These two compounds are heated until they undergo a reaction that converts them to the sellable rare earth oxide products, Nd_2O_3 and Dy_2O_3.

7.2 Detailed description

Pretreatment

The standard neodymium magnets are initially electroplated with three 3 layers: nickel, copper and nickel to prevent corrosion. Thus, a pretreatment step to remove a Ni-Cu-Ni protective coating or any other types of coatings is required before processing magnets. This step is out-of-scope because magnets transported to the plant and used in the overall process are already treated to remove a Ni-Cu-Ni protective coating.

Note for all process steps

All conditions are at ambient temperature and pressure (25°C, 1 atm) unless specified. Solids will be transferred downstream via hoppers using gravity. Liquids will be transferred downstream in piping using gravity, controlled by valves. Any solids travelling upstream (e.g. towards previous sections) will be transported using powered conveyor belts, while liquids travelling upstream will be transported using in-line pumps.

Demagnetization

NdFeB magnets initially shipped to the plant are strongly magnetic. Many parts of the plant are constructed with metal alloys and magnetic properties of NdFeB magnets can easily disrupt the overall process. Thus, demagnetization is required before crushing and dissolving magnets to make the treatment of neodymium magnets more efficient. Demagnetization happens when magnets are heated above their Curie temperatures. The Curie temperature of neodymium magnets ranges between 300 °C and 470 °C so the fired heater, H-100, heats NdFeB magnets from 25 °C to 470 °C until they are demagnetized. For each batch, 1,460 kg of feed NdFeB magnets are heated and the total heat duty is 71 kJ/hr and the residence time in the heater is 1 hour. The overall pressure is kept at the atmosphere pressure.

Crushing

Feed NdFeB magnets come in large pieces and should be reduced to smaller sized particles for more effective acid dissolution with less residence time. Larger surface area increases the contact area with acid and allows a faster dissolution of NdFeB magnets. The compression strength of neodymium magnets ranges from 950 MPa to 1,100 MPa, which changes based on the composition of NdFeB magnets. Thus, the Jaw Crusher must be able to crush with compression strength stronger than 1,100 MPa. The Jaw Crusher, C-100, has a feed opening of 500 × 750 mm and a max feed size of 450 mm. A discharge opening size is between 50 and 100 mm and a discharge size of crushed magnets is less than 30 mm. The size of output magnets was decided based on the residence time of acid dissolution. Electric power requirement for crushing is between 20 and 25 kW/batch. If the crushed product is bigger than 30 mm, it goes back to the crusher and is crushed again.

Sulfuric acid dilution

The 98% grade concentrated sulfuric acid, H_2SO_4, is stored in the acid storage vessel, TK-100, and a 2.0 molar concentration sulfuric acid solution is prepared by slowly adding 98% sulfuric acid to water. A 2.0 molar concentration sulfuric acid solution contains 19.2 wt% sulfuric acid and the heat of dilution from the 98% concentrated sulfuric acid to a 2.0 molar concentration sulfuric acid solution is 750 kJ/kg of H_2SO_4.

3,000 kg of 98% sulfuric acid is slowly added into the TK-100 filled with 15,000 L of water to get 18,000 kg of 2 M H_2SO_4 solution. It is important to pour the 98% sulfuric acid into water over a period of 0.5 hours because adding a large amount of H_2SO_4 into water causes violent boiling and splashing of acid. The total heat energy generated during dilution is 2.19×10^6 kJ per cycle. The temperature change during the entire dilution process is 33.5 °C, thus the separate cooling system is not required. The acid storage vessel, TK-100, is a horizontal vessel with the height of 3.0 m and the diameter of 3.0 m. The vessel wall thickness is 15 mm. The operating pressure is kept at 0 psig. The vessel material is Carpenter 20CB-3 that is an austenitic stainless steel possessing excellent resistance to boiling 20 to 40% sulfuric acid and the stress material is carbon steel.

Acid dissolution

During acid dissolution process, 1,460 kg of crushed neodymium magnet is dissolved with 18,000 kg of 2 M H_2SO_4 solution in the acid/base semi-batch reactor, R-100. Initially, R-100 is charged with 18,000 kg of 2 M H_2SO_4 solution through stream 4. Then 1,460 kg of crushed neodymium magnet is added over a period of 2 hours through stream 3. The residence time is 3 hours. Crushed neodymium magnet is not added at once to prevent violent boiling and splashing of acid. The acid dissolution reaction is extremely exothermic and the total heat generated per cycle is -19,700 MJ and the temperature of solution increases by 260 °C while dissolving magnets if without cooling system. Thus, the heat exchanger is required to prevent 2 M sulfuric acid solution from boiling.

The production of 60 kg of hydrogen gas takes place while dissolving 1,460 kg of neodymium magnets in 2 M sulfuric acid solution.

Salt precipitation

The base storage tank TK-101 is charged with 150 L of water and 165 kg of 99% sodium hydroxide pearl is slowly added into the TK-101 to get 315 kg of saturated NaOH solution. The heat duty for this dilution process is -45,000 kJ/batch increasing the temperature of the mixture from 25 °C to 65 °C. The rapid temperature increase of solution might cause solution to splash so water-cooling coil is added.

During salt precipitation process, 315 kg of saturated sodium hydroxide solution is added from the base storage tank TK-101 to the semi-batch reactor R-100 through stream 5. This process generates solid $NaRe(SO_4)_2$ while iron and boron remain as ions. The heat duty for this reaction is 495,000 kJ/batch and this should increase the temperature of R-100 by less than 1°C.

Solid rare earth double salt formation

The S-6 stream containing solid rare earth double salts, $NaNd(SO_4)_2$ and $NaDy(SO_4)_2$ is then filtered out using F-100, the batch bottom-drive vertical basket. The S-6 feed is 18,422 kg/batch and it separates the slurry, S-8 that is 975 kg/batch, from the liquid, S-7 that is 17,447 kg/batch. The bowl diameter is 42.5 in. There is no change in temperature and pressure.

Leaching

The sodium-rare earth salts then undergo an acid-driven reaction known as “leaching”. In this process, the salts are reacted with a hydrochloric acid solution, resulting in $NdCl_3$ and $DyCl_3$

solids. This process occurs in the same reactor (R-100) that housed the acid dissolution and salt precipitation steps. See section 9.3 for its unit description, and section 10.1 for its specification sheet.

For one batch, 970 kg of the sodium-rare earth salts will react with 17,000 kg of aqueous HCl solution that is 14% HCl by mass. This HCl solution is formed from diluting a 35% stock solution in the reactor before the reaction occurs. The heat evolved by the dilution process and the leaching reaction is small—increasing the temperature of the reaction mixture by no more than 2.5 °C (see the headings labelled “Enthalpy changes for uncommon reactions” and “Enthalpy changes for acid dilution” in section 19.1 for a description of a process similar to the one that led to this conclusion). For this reason, the decision was made to not include a heat exchanger after this process occurs.

The reaction mixture is transferred to a rotary vacuum filter (F-101) along stream 10. This stream includes rare earth chloride solids as well as dissolved sodium, chloride, and sulfate ions. The solids are filtered from the reaction mixture, leaving a filter cake on top of the filter. This filter cake is then washed with three additional 7000-kg portions of the 14% HCl solution.

The filter cake is transferred to a dryer (D-100), while the filtrate liquid—the dilute acid with dissolved ions—is treated for waste disposal. See section 9.3 for the unit description of the dryer.

ReTriNOx Synthesis and Isolation

The 634 kg of rare earth chlorides are transferred to reactor R-200, where it is reacted with H_3TriNOx and $K(N(SiMe_3)_2)$, also referred to as KHMDS. 1379 kg of H_3TriNOx comes from two different sources, 87% from a recycle stream from after the ligand recovery stage, and

13% from a new stream. 1503 kg of KHMDS, a reactant that will react violently with water, is stored in a 48% by weight solution in THF before being added to the reaction. This reaction takes 12 hours and requires a total of 13785 L of THF, according to Bogart et al [4].

The products of this reaction are 1564 kg of rare earth TriNOx complexes, 1216 kg of $H(N(SiMe_3)_2)$, 562 kg of KCl, and 174 kg of additional side products. Because this process is so novel, all of the side reactions have yet to be characterized. However, the following separations work to isolate the rare earth TriNOx complexes regardless. The reaction performs at 90% yield, and has very little heat of reaction.

At this point, the TriNOx complexes and the KCl are solids and are filtered away by centrifuge, leaving the THF and $H(N(SiMe_3)_2)$ (a liquid) to go down stream 16 to the distillation column, T-200. In this distillation column, the $H(N(SiMe_3)_2)$ is purified to 99% so that it can be resold, recovering some of the expense from KHMDS. A purge stream is also required as $H(N(SiMe_3)_2)$ would build up otherwise. This distillation column is run in steady-state as it takes almost exactly 24 hours to recycle the necessary 10,000 L THF for the Re(TriNOx) reaction.

The KCl and Re(TriNOx) cake from the centrifuge is then added to mixer M-200 with 15641 L DCM, which selectively dissolves the Re(TriNOx). The KCl is then filtered using another centrifuge and becomes waste. The DCM + Re(TriNOx) stream then is sent to a crystallizer, which removes and recycles the DCM for future use, while leaving 1564 kg of Re(TriNOx) solid. This solid is then able to be separated.

Nd/Dy Separation

In mixer M-300, 1564 kg of Re(TriNOx) is mixed with 10,000 L of Toluene, which selectively creates and dissolves the dimer $[Nd(TriNOx)]_2$, while the monomer Dy(TriNOx) stays as a solid in solution. It has shown the ability to do this at a 99% purity, ample for our purposes. Using the assumed basis of a 90/10 feed split of Nd/Dy, we are then left with 1416 kg of 99% pure $[Nd(TriNOx)]_2$ and 148 kg of 99% Dy(TriNOx). This slurry is sent through centrifuge F-300, which keeps the Dy(TriNOx) cake and sends the $[Nd(TriNOx)]_2$ to crystallizer V-300 which removes and recycles the toluene. From here on, the two TriNOx complexes follow parallel, but not overlapping, paths to becoming oxide.

Formation of rare earth oxalates

For the following steps, streams S-30, S-35, S-36, S-40, and S-43 have one mass flow value given, representing the total amount used/produced in one batch (with both $Nd_2(TriNOx_2)$ and Dy(TriNOx)). The amount used/produced when processing the Nd and Dy compounds respectively will be in a 9.57:1 mass ratio, equal to the relative total mass of the Nd and Dy compounds themselves. In other words, 90.5% of the mentioned streams will be used to process $Nd_2(TriNOx)$ and 9.5% will be used for Dy(TriNOx).

While the $Nd_2(TriNOx)_2$ is crystallizing from toluene, the solid Dy(TriNOx) cake (S-27, 148 kg), with trace amount of $Nd_2(TriNOx)_2$, from filter F-300 is mixed with oxalic acid solution (S-30, 332 kg) in R-300 in a 1:3 molar ratio of Dy(TriNOx) to oxalic acid ($H_2C_2O_4$). The two compounds exchange ions and the reaction forms dysprosium oxalate ($Dy_2(C_2O_4)_3$) and protonated H_3TriNOx ligand, which both precipitate out of the aqueous solution.

This slurry of $Dy_2(C_2O_4)_3$ and H_3TriNOx in water (S-32, 472 kg) is transferred via slurry pump P-302 from R-300 to F-301 and the water is removed as a filtrate (S-40, 333 kg). The resulting cake is washed with dichloromethane (DCM) (S-36, 2772 kg) which dissolves all of the

H_3TriNOx for recovery. A second filtration gives a wet $Dy_2(C_2O_4)_3$ cake (S-34, 357 kg) and H_3TriNOx in DCM solution as the filtrate (S-35, 2890 kg).

When the $Dy_2(C_2O_4)_3$ slurry is being processed in F-301, R-300 will be washed and the now-crystallized Nd_2(TriNOx)$_2$ will be transferred into R-300. The Nd compounds will proceed through the exact same steps as the Dy compounds went through. To be specific, the solid Nd_2(TriNOx)$_2$ (S-29, 1416 kg), with trace amount of Dy(TriNOx), is mixed with oxalic acid solution (S-30, 3176 kg) in R-300 in a 2:3 molar ratio of Nd_2(TriNOx)$_2$ to oxalic acid ($H_2C_2O_4$). The two compounds exchange ions and the reaction forms neodymium oxalate ($Nd_2(C_2O_4)_3$) and protonated H_3TriNOx ligand, which both precipitate out of the aqueous solution.

At this point, the $Dy_2(C_2O_4)_3$ will have been transferred from F-301 to the fired heater H-300.

As with Dy, this slurry of $Nd_2(C_2O_4)_3$ and H_3TriNOx in water (S-31, 4600 kg) is transferred via cleaned slurry pump P-302 from R-300 to F-301 and the water is removed as a filtrate (S-40, 3168 kg). The resulting cake is washed with DCM (S-36, 26408 kg) which dissolves all of the H_3TriNOx for recovery. A second filtration gives a wet $Nd_2(C_2O_4)_3$ cake (S-33, 3475 kg) and H_3TriNOx in DCM solution as the filtrate (S-35, 27520 kg).

The streams S-35 and S-40 from both the Nd and Dy processing are combined.

Oxalate roasting to form rare earth oxides

Wet $Dy_2(C_2O_4)_3$ (S-34) will enter H-300 first and will be heated to 800°C by combusting fuel gas. In atmospheric oxygen, this will evaporate any residual water and “roast” the oxalate, which reacts to form the corresponding dysprosium oxide product (Dy_2O_3) (S-45, 38 kg) and releases CO_2 (S-43, 28 kg), not including flue gases from fuel gas combustion. This dry, 99.9% pure Dy_2O_3 is then allowed to cool to ambient temperature and collected as a product.

Then, wet $Nd_2(C_2O_4)_3$ will enter a cleaned H-300 and also heated to 800°C by combusting fuel gas to remove water and roast the oxalate to the oxide (Nd_2O_3) (S-44, 345 kg) and release CO_2 (S-43, 270 kg), again not including any flue gases. The 99.0% pure Nd_2O_3 is allowed to cool to ambient temperature and collected as a product.

Recycling of H_3TriNOx

The filtrate from centrifuge F-301 (S-35, 30410 kg), containing H_3TriNOx dissolved in DCM, is transferred to crystallizer V-301. Low pressure steam (1440 kg, 4.5 bar abs) is flowed through the crystallizer jacket and the DCM solution is well-mixed in order to fully evaporate the DCM solvent. The resulting H_3TriNOx crystals (S-37) are removed and recycled to R-200 in Section 2. The vaporized DCM is condensed in E-303 using cooling water (60000 kg, heated from 7.2°C to 19.4°C) and cooled to an ambient 25°C before being recycled as S-36 and pumped back to F-301 in the next batch.

7.3 Gantt Chart

Below is our Gantt chart which shows the scheduling of each piece of process equipment. Our bottleneck is the THF Distillation which takes 24 hours/batch, making each batch in turn take 24 hours.

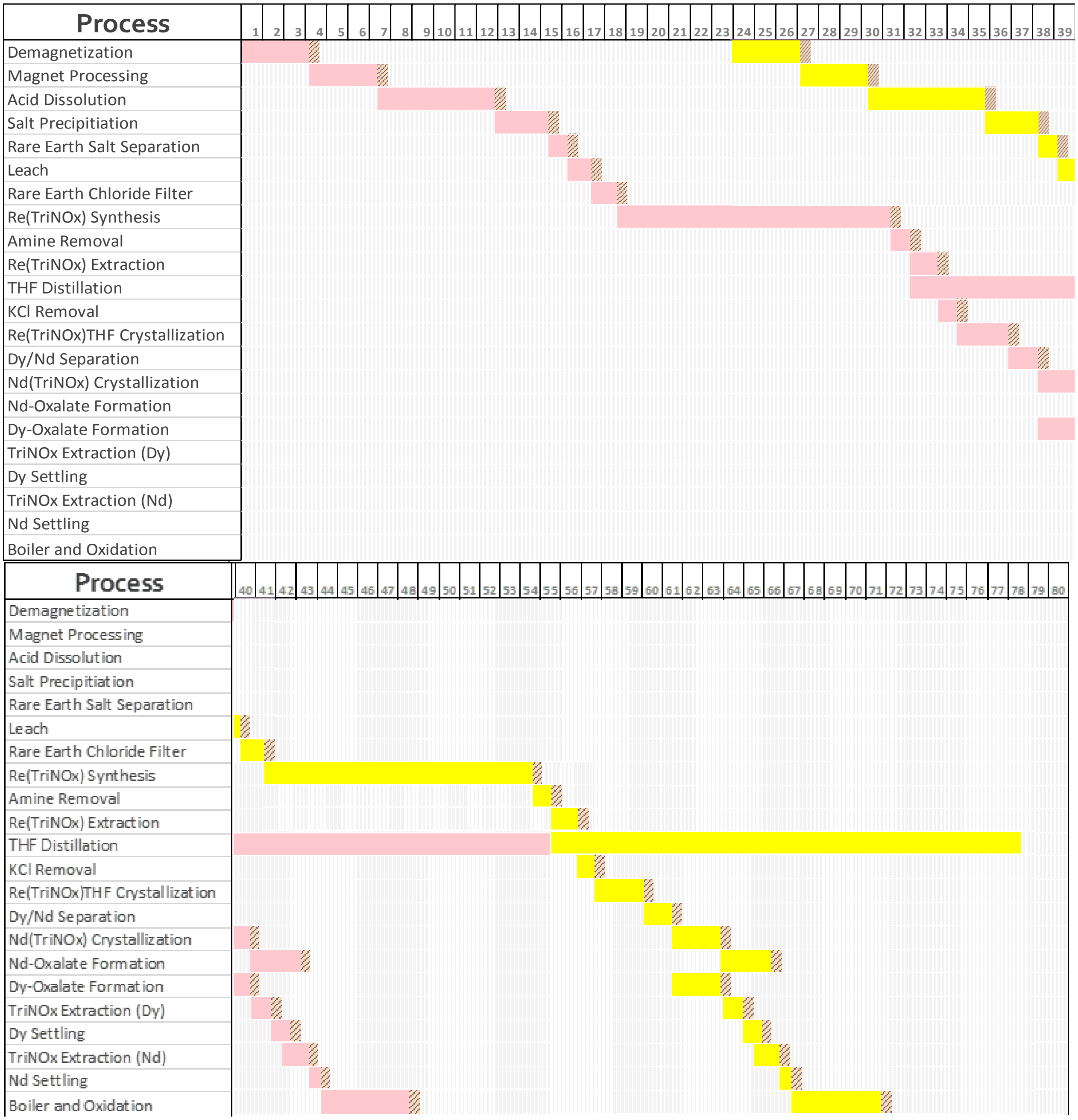


Figure 7.2 Gantt Chart

8. Energy Balance and Utility Requirements

Table 8.1 The overall energy balance and utility requirement

Unit No.	Description	Utility Requirement (kJ/batch)	Source Type	Energy Exchange Description (if applicable)
H-100	Demagnetizer (heater)	75000	Fuel Gas	
C-100	Magnet crusher	135000	Electricity	
E-100	Condenser for acid dissolution	-41000000	Cooling water	140000 kg of cooling water heated from 25 °C to 93.5 °C
F-100	Rotary vacuum filter for double salts and ReCl	44000	Electricity	
F-101	Rotary vacuum filter for double salts and ReCl	44000	Electricity	
R-100	Agitator for reactor R-100	546000	Electricity	
D-100	Rare earth chloride dryer	370148	Fuel Gas	
R-200	Agitator for reactor R-200	1210000	Electricity	
P-100	Positive displacement pump for slurries	34500	Electricity	
CO-100	Conveyor for solids	53	Electricity	
CO-101	Conveyor for solids	38	Electricity	
P-101	Positive displacement pump for slurries	33500	Electricity	
P-200	Positive displacement pump for slurries	21000	Electricity	
F-200	Salt/organics filter	44000	Electricity	
E-200	Condenser (THF Distillation)	-376450	Cooling water	30000 kg of cooling water heated from 7.2 °C to 55.5 °C
P-201	Reflex pump	13000	Electricity	
E-201	Reboiler (THF Distillation)	397590	Steam	20000 kg of steam cooled from 232 °C to 175 °C
M-200	DCM/solids from F-200 mixer	50000	Electricity	
F-201	KCl/organics filter	81000	Electricity	
V-201	DCM evaporator/ReTriNOx crystallizer	See E-202	--	
E-202	Crystallizer heated jacket	3152450	Steam	
E-203	Condenser	-3053450	Cooling water	60000 kg of cooling water heated from 7.2 °C to 19.4 °C
P-202	Slurry pump	30000	Electricity	
P-203	Inline pump	31000	Electricity	
CO-200	Conveyor for solids	79	Electricity	
M-300	ReTriNOx and toluene mixer	86000	Electricity	

F-300	Nd/Dy filter	81000	Electricity	
V-300	Toluene evaporator	see E-300	--	
E-300	Crystallizer heated jacket	5043920	Steam	
E-302	Crystallizer heated jacket	3150450	Steam	
R-300	Agitator for reactor R-201	48000	Electricity	
V-301	DCM evaporator	See E-302	--	
E-301	Condenser	-5043920	Cooling water	100000 kg of cooling water heated from 7.2 °C to 19.1 °C
E-303	Condenser	-3053450	Cooling water	60000 kg of cooling water heated from 7.2 °C to 19.4 °C
F-301	ReOxalate/TriNOx filter	81000	Electricity	
H-300	Oxalate cooker	97816	Fuel Gas	
P-300	Positive displacement pump for slurries	12000	Electricity	
P-301	Inline pump	13000	Electricity	
P-302	Positive displacement pump for slurries	15000	Electricity	
P-303	Inline pump	38201	Electricity	
M-301	Mixer	50000	Electricity	

Utility	**Energy Requirement per Batch (MJ)**
Cooling water	52527
Steam	11744
Fuel Gas	543
Electricity	2741

8.1 Heat Integration

With various heat exchangers located throughout our plant, some used as condensers to cool a hot stream and others used as heaters/reboilers to heat a cold stream, it was possible to integrate the exchangers such that certain process flows were used to heat/cool others rather than using utilities. We considered two best cases for minimum utility requirements based on our process temperatures and heat duties and a ΔT_{min} = 15°C: One using the steam normally entering condenser E-100 to completely provide heat for the dichloromethane (DCM) evaporators V-201 and V-301 (through their heated jackets E-202 and E-302, respectively). We assume we would install appropriate control equipment to divert just enough steam from E-100 and use the already existing heat exchangers E-202 and E-302. This would save $27.54 of steam (high pressure and low pressure) per batch and $11.56 of cooling water per batch. The second case is the same as the first with the addition of using the hot toluene normally entering E-301 to heat the toluene in V-300 through E-300. This would save $29.66 of steam and $10.04 of cooling water per batch total. In the second case, we would also require an additional heat exchanger, as additional steam is needed to fully heat the toluene in V-300 (and additional cooling water is needed to cool the toluene in E-301), which would have a bare module cost of $10000-30000 based on the equipment costs for exchangers in the current process. Assuming the higher end price of $30000, we would need to produce 2023 batches to break even, or 6.13 years of 330 day/year operation.

However, ultimately heat integration is unfeasible in our mostly batch process not because of costs but due to timing issues. The stream from R-100 needs to be quickly and constantly condensed in E-100 during the acid dissolution step to prevent overconcentration of the acid solution in the reactor, which does not overlap fully with any process that would be able to use this heat, according to the Gantt chart. Similarly, the hot toluene entering E-301 is produced by the heating of V-300, while the heat integration suggests that toluene can be used *to heat* V-300. Therefore the stream would need to wait for an entire batch time to provide useful heat. This is also not feasible as the toluene is to be recycled for an even earlier step in the next batch and thus must be condensed earlier. We find that the minimal savings from heat integration is not worth disrupting the timing of the process and possible lengthening batch times.

9. Equipment List & Unit Descriptions

9.1 Equipment list

Table 9.1 List of all equipment

ID Name	Equipment Description
Magnet Processing	
C-100	Magnet Crusher
Heat Exchangers	
D-100	Dryer for $ReCl_3$
E-100	Water Condenser for R-100
E-200	Reflux Condenser for T-200
E-201	Reboiler for T-200
E-202	Heated Jacket for V-201
E-203	Condenser for DCM
E-300	Heated Jacket for V-300
E-301	Condenser for Toluene from V-300
E-302	Heated Jacket for V-301
E-303	Condenser for DCM
H-100	Heater used to demagnetize NdFeB magnets
H-300	Cooker to form Re_2O_3
V-200	Reflux accumulator for T-200
V-201	Crystallizer for Re(TriNOx)
V-300	Crystallizer for Nd(TriNOx)
V-301	Crystallizer for Recycled H_3TriNOx
Mixers/Settlers	
M-200	Mixer for Re(TriNOx) extraction with DCM
M-300	Mixer for Re(TriNOx) and Toluene
Reactors	
R-100	Reactor for acid dissolution and salt precipitation
R-101	Same equipment as R-100, used for leaching
R-200	Reactor for Re(TriNOx) Synthesis
R-300	Reactor to form $Re_2(C_2O_4)_3$

ID Name	**Equipment Description**
Storage and Stream Transportation	
CO-100	Conveyor Belt for solid $NaRe(SO_4)_2$
CO-101	Conveyor Belt for $ReCl_3$
CO-200	Conveyer Belt for Re(TriNOx)
P-100	Slurry pump from R-100 to F-100
P-101	Slurry pump from R-101 to F-101
P-200	Slurry pump from R-200 to F-200
P-201	Reflux pump for T-200
P-202	Slurry pump from M-200 to F-201
P-203	Pump for DCM from E-203 to M-200
P-300	Slurry Pump from M-300 to F-300
P-301	Pump from E-301 to M-300
P-302	Pump from R-300 to M-301
P-303	Pump from E-303 to M-301
TK-100	Tank for H_2SO_4
TK-101	Tank for NaOH
TK-102	Tank for HCl
Separations	
F-100	Filter used to isolate solid $NaRe(SO_4)_2$
F-101	Used to isolate $ReCl_3$
F-200	Filter used to separate Re(TriNOx)/HCl and THF/HMDS
F-201	Filter used to isolate Re(TriNOx)
F-300	Filter to separate Nd(TriNOx) and Dy(TriNOx)
F-301	Filter for H_3TriNOx Extraction and $Re_2(C_2O_4)_3$ isolation
T-200	Distillation column for THF/HMDS

9.2 Unit descriptions—pretreatment

Fired Heater (H-100)

The fired heater, H-100, is required to demagnetize the initial neodymium magnets. When neodymium magnets are heated above their Curie temperatures, magnets will become austenitic and lose their magnetic properties due to magnetic poles pointing different directions. The Curie temperature of neodymium magnets ranges between 300 °C and 470 °C and changes based on chemical contents on neodymium magnets. Usually, neodymium magnets with the high dysprosium content have higher Curie temperature.

The fired heater, H-100, is constructed with carbon steel and is field fabricated meaning it is built on site. It heats 1,460 kg of feed (neodymium magnets) from 25 °C to 470 °C to ensure all magnets are demagnetized. The heater temperature should based on Curie temperature of the input neodymium magnets. The heater temperature should get lower to save energy if the Curie temperature is lower due to the composition of neodymium magnets. The total heat duty is 71 kJ/hr and the residence time in the heater is 1 hour. The overall pressure is kept at 0 psig.

Jaw Crusher (C-100)

The jaw crusher, C-100, is required to crush the neodymium magnets to reduce large magnets into smaller particles. This step is required because smaller sized magnets have larger surface area and allow for more effective acid dissolution with less residence time. The compression strength of neodymium magnets ranges between 950 MPa and 1,100 MPa and it can change based on the composition of neodymium magnets.

The Jaw crusher, has a feed opening of 500 × 750 mm and a max feeding size of 425 mm. A max feeding size was selected based on the estimated size of feed magnets, which is less than 400 mm. A discharge opening size is between 50 and 100 mm and a discharge size of crushed magnets is less than 30 mm. The size of crushed magnets was decided based on the residence time of acid dissolution step. The capacity of C-100 is 45 ton/hr and a rotational speed of its motor is 1440 rpm. Electric power required for C-100 is between 20 and 25 kW per cycle depending on the amount of magnets processed. The total machine size is 1,900 × 1,900 × 1,900 mm. The jaw crusher step shows 100% yield of neodymium magnets.

9.3 Unit descriptions—acid dissolution, salt precipitation & leaching

Reactor (R-100)

This reactor is used for both the acid dissolution and salt precipitation steps. During acid dissolution, 1460 kg of crushed neodymium magnet is dissolved with 18,000 kg of 2 M H_2SO_4 solution in this reactor. Initially, R-100 is charged with 18,000 kg of 2 M H_2SO_4 solution through stream 4. Then 1,460 kg of crushed neodymium magnet is added over a period of 2 hours through stream 3. The residence time is 3 hours. Crushed neodymium magnet is added gradually over a period of 0.5 via hopper in order to prevent violent boiling and splashing of acid. The acid dissolution reaction is extremely exothermic and the total heat generated per cycle is -19,700 MJ and the temperature of solution increases by 260 °C while dissolving magnets if without cooling system. Thus, the heat exchanger is required to prevent 2 M sulfuric acid solution from boiling.

The production of 60 kg of hydrogen gas takes place while dissolving 1,460 kg of neodymium magnets in 2 M sulfuric acid solution.

In the leaching step, the purpose of this reactor is to house the reaction between the sodium-rare earth salts and the HCl solution. During this process, the reactor remains close to room temperature—the reaction begins at 25 °C and ends at 27.4 °C, as the process is mildly exothermic. The process occurs for approximately 45 minutes at atmospheric pressure. The reactor is constructed from carbon steel with a protective lining made of Carpenter-20CB3 that protects the structure from the acidic environment within. It has a diameter of 7.5 ft, a height of 15.1 ft, and a weight of 10,200 lbs. This reactor has a cost of $222,000. The feed streams to this reactor are S-8 and S-9. The effluent stream is S-10. The specification sheet for this reactor can be found in section 10.2.

Storage Tanks (TK-100, TK-101, TK-102)

TK-100 is used for dilution of 2.0 M sulfuric acid solution with 98 % sulfuric and storage of 2.0 M sulfuric acid. TK-100 is a horizontal storage tank with the height of 10 ft and the diameter of 10 ft. There are two feed streams: pure water stream and 98 % H_2SO_4 stream. 15,000 kg of water is initially fed to the TK-100 and 3,000 kg of 98 % H_2SO_4 is added to TK-100 over a period of 0.5 hours to prevent rapid splashing of water due to heat generation. The overall heat duty per batch is -2.19×10^6 kJ/batch. TK-100 is constructed with Carpenter 20CB-3 to prevent corrosion by H_2SO_4 and withstand increased temperature during dilution. There is a separate cooling water system in TK-100 to prevent feed from increasing temperature significantly. TK-100 remains at 1 atm. Carbon steel is used as the stress material and the overall weight is 13,000 lbs. Vessel costs $134,000,000, platform & ladders cost $3,200, agitator costs $60,000 and chilled water coil costs $10,000. The total bare-module cost is $490,000.

TK-101 is used for dissolving 98 % solid NaOH into water to produce saturated NaOH and storing saturated NaOH. TK-101 is a horizontal storage tank with the height of 3 ft and the diameter of 2 ft. There are two feed streams: pure water stream and NaOH pearl (solid) stream. 150 kg of water is initially fed to the TK-101 and 165 kg of 98 % NaOH pearl is added to TK-

101 over a short period. The overall heat duty per batch is -4.5 × 10^4 kJ/batch increasing the temperature by 40 °C if without the cooling system. Thus, there is a separate cooling water system in TK-100 to prevent feed from increasing temperature significantly. TK-101 is constructed with Inconel-600 to prevent corrosion by NaOH and withstand increased temperature during dilution. TK-101 remains at 1 atm. Carbon steel is used as the stress material and the overall weight is 450 lbs. Vessel costs $36,700,000, platform & ladders cost $2,300, agitator costs $20,000 and chilled water coil costs $7,000. The total bare-module cost is $150,000.

TK-102 is used for storage of diluted HCl solution. TK-102 is a horizontal storage tank with the height of 10 ft and the diameter of 10 ft. There are two feed streams: pure water stream and HCl stream. 15,000 kg of water is initially fed to the TK-102 and 2,500 kg of HCl solution is added to TK-102 over a period of 0.5 hours to prevent rapid splashing of water due to heat generation. The overall heat duty per batch is -1.02 × 10^5 kJ/batch. TK-100 is constructed with Carpenter 20CB-3 to prevent corrosion by HCl and withstand increased temperature during dilution. There is a separate cooling water system in TK-102 to prevent feed from increasing temperature significantly. TK-102 remains at 1 atm. Carbon steel is used as the stress material and the overall weight is 13,000 lbs. Vessel costs $134,000,000, platform & ladders cost $3,200, agitator costs $60,000 and chilled water coil costs $10,000. The total bare-module cost is $490,000.

TK-100 and TK-102 have exactly the same specification.

Rotary Vacuum Filter (F-101)

This filter is used to separate the $NdCl_3$ and $DyCl_3$ solids that form during the leaching step from the rest of the reaction mixture. The reaction mixture (stream S-10), which includes the suspended rare earth chloride solids, is sent to this filter for rotary vacuum filtration. After filtration, the filter cake remains on top of the filter, while the filtrate is removed to be processed as waste (stream S-12). The filter cake is then washed with an additional three 7,000-kg portions of the 0.14 mass percent HCl solution (stream S-11) to further remove impurities. The filtration and washing process takes a total of 50 minutes to complete. The filter cake is then removed and sent to dryer D-100 via stream S-13. This process occurs at room temperature and atmospheric pressure. The vacuum pump provides a very small pressure difference that drives water out of the filter cake. This pump works by passing just over 2 m^3/min of air through the filter cake. It has a diameter of 3.7 ft and a length of 3.87 ft. It costs $242,000.

Dryer (D-100)

The purpose of this dryer is to remove any excess moisture from the filter cake that is passed on from filter F-101 via stream S-13. The result is dry solid $NdCl_3$ and $DyCl_3$.

9.4 Unit descriptions—Re(TriNOx) Synthesis

Reactor (R-200)

Reactor R-200 is used in the Re(TriNOx) synthesis reaction. It is fed with 634 kg of $ReCl_3$ from stream 13, then 3143 kg of 48% KHMDS solution in THF from stream 14, then 10000 kg of recycled THF from stream 18 then finally 1379 kg of H_3TriNOx from stream 39. These additions are each scheduled for approximately 20 minutes. The residence time of this reaction is 12 hours, and it takes place at RT and 1 atm, with no noticeable heat of reaction. The reactor is made of carbon steel and weighs 9035 lbs. Its height is 13.5 feet and its diameter is 6.8 feet, with a wall thickness of .5 inches. The purchase cost is $55,900 and the total bare module cost is $232,700. Additionally it requires an agitator of 36.4 Hp, which adds an additional cost of $28,100, bringing the total to $260,800.

Distillation Column (T-200)

This distillation column is for the purpose of recovering $H(N(SiMe_3)_2)$ so that it can recover some of the cost of KHMDS. Feed stream 16 is split into distillate stream 18 and bottoms stream 19. The distillate stream includes a purge so that excess $H(N(SiMe_3)_2)$ does not build up in the column, with a fraction of .14824 leaving the distillate stream in the purge. The reflux ratio is .300 and there are 25 trays spaced at .6096 meters apart. The height of the column is 62 feet and the diameter is 1.5 feet. It is made of Carbon Steel and the weight is 7761 lbs. The purchase cost is $60,200 and the total bare module cost is $250,500.

Mixer (M-200)

This mixer is used to dissolve Re(TriNOx) in DCM while not dissolving KCl in order to ease their separation. 15641 L of pure DCM from stream 23 is mixed with a 76:24 ratio of Re(TriNOx) to KCl. A 41.3 Hp agitator, costing $30,200, is required to mix the slurry. The mixer is made of carbon steel lined with stainless steel 304, which is less corrosive to DCM. Costing the lining was done using Chauvel et al [18]. The weight was 9307 lbs, the height was 14.1 feet and the diameter was 7.1 feet. The wall thickness was .5 inches and the total bare module cost was $277,100.

9.5 Unit descriptions—neodymium and dysprosium separation

Mixer (M-300)

This mixer is used to fully dissolve the soluble portion of S-24, $Nd_2(TriNOx)_2$, in toluene from S-28, assisting in the dissolution by mechanical agitation. It consists of a carbon steel vessel (height = 16.2 ft, diameter = 8.1 ft, wall thickness = 0.5 in, weight = 11844 lb) and a carbon steel agitator using 62 Hp of electricity. The total cost is $281,200 ($243,900 for the vessel bare module cost and $37,300 for the agitator).

Crystallizer (V-300)

This crystallizer is a stainless steel jacketed vessel (V = 777 ft^3) equipped with an agitator, used to evaporate toluene from a $Nd_2(TriNOx)_2$ – toluene solution (S-26) in order to obtain purified $Nd_2(TriNOx)_2$ (S-29) and recycle the toluene vapor back into M-300 as S-28, after condensation through E-301. The crystallizer is heated via high pressure steam (2800 kg, 32 bar abs) through its jacket (E-300), with agitator mixing ensuring a uniform distribution of heat throughout the vessel. Its total bare module cost is $430,000.

Crystallizer (V-301)

This crystallizer is a vessel identical to V-300. It is a stainless steel jacketed vessel (V = 777 ft^3) equipped with an agitator. Its function is to evaporate DCM from a $H_3TriNOx$ – DCM solution (S-35) in order to obtain purified $H_3TriNOx$ (S-37) and recycle the DCM vapor back into F-301 as S-36, after condensation through E-303. The crystallizer is heated via high pressure steam (1440 kg, 4.5 bar abs) through its jacket (E-302), with agitator mixing ensuring a uniform distribution of heat throughout the vessel. Its total bare module cost is $430,000.

Reactor (R-300)

Reactor R-300 is a vertical vessel (weight = 2251 lb, diameter = 4 ft, height = 8 ft, wall thickness = .375 in) used to house the two rare-earth oxalate formation reactions. Its bulk material is carbon steel but to protect against oxalic acid, the inside is lined with glass. It is also equipped with an agitator using 7.6 Hp of electricity. Re(TriNOx) is fed into the reactor (S-27 and S-29) and reacts with aqueous oxalic acid (S-30) to form rare earth oxalates and H_3TriNOx (S-31 and S-32). Nd and Dy compounds are reacted in separate steps. As Re(TriNOx) is insoluble in water, a strong agitator is necessary to promote contact of Re(TriNOx) with oxalic acid and allow for faster reactions. See section 7.2 (Detailed Process Descriptions) under "Formation of Rare Earth Oxalates" for full reaction and input/output details. R-300's total bare module cost, including the agitator, is $115,800.

Fired Heater (H-300)

H-300 is a fired heater used to dry and "roast" rare earth oxalates (S-33 and S-34) by heating them to 800°C for one hour, forming rare earth oxide products (S-44 and S-45) and releasing CO_2. It is fed fuel gas (10.54 kg/batch), which is combusted to provide enough heat to reach the roasting temperature. Nd and Dy compounds are heated in separate steps. Its total bare-module cost is $16,400.

9.6 Unit descriptions—etc.

Pumps (P-100, P-101, P-200, P-201, P-202, P-203, P-300, P-301, P-302, P-303)

There are 10 cast-iron centrifugal pumps in this process. Since the overall process is not continuous and involves various reactors that are batch reactors, pumps function as a tool to transfer materials from equipment to equipment. The pumps are constructed with cast iron to prevent rust. Fan cooled motor ensures are used for protection against corrosion, moisture and dust that might exist in the ambient air. Pump heads for pumps are calculated based on the height difference between previously used equipment to the next. Pumps are assumed to have no loss in material, thus the feed and effluent have the same quantity and composition. The pump outlet pressure was calculated based on a 25 psi loss in pipe flow and calculated pump heads. Pumps that are included as a part of distillation column are explained in the distillation column section.

Batch Basket Centrifugal Filters (F-100, F-200, F-201, F-300, F-301)

These four filters are all Batch Basket Centrifugal Filters, used to separate solids from liquids. These were chosen for their price and their effectiveness with smaller amounts of solid in batch processes. F-100 is used to separate aqueous boron and waste salts from the solid $NaRe(SO_4)_2$. F-200 is used to separate the liquid $THF/H(N(SiMe_3)_2)$ from the solid KCl/Re(TriNOx). F-201 is used to separate the DCM solution of Re(TriNOx) from undissolved KCl. F-300 is used to separate $[Nd(TriNOx)]_2$ in toluene from solid Dy(TriNOx). F-301 is used to separate solid $Re_2(C_2O_4)_3$ and H_3TriNOx from water, before being rinsed with DCM to collect the H_3TriNOx. All filters, except F-100, have a 20 inch diameter based on their load, which results in a cost of $34,900. F-100 has a bowl diameter of 42.5 inches and costs $74,200. All are made of stainless steel 304.

Conveyor Belts (CO-100, CO-101, CO-200, CO-300)

Conveyor belts are used to transport solids between sections or upstream, where gravity through hoppers was not available to automatically transport solids. Each conveyor has a width of 24 in, length if 100 ft, an energy requirement of 1.06 HP, and a total cost of $83,000.

10. Specification Sheets

10.1 Reactors, mixers, and furnaces

Identification	**Item**	Reactor
	Item No.	R-100
	No. Required	1
Function 1: Acid Dissolution	Dissolving metal in acid to making rare earth sulfate	
Function 2: Salt Precipitation	Reaction that forms double salt	
Function 3: Leach	Reaction with HCl to produce rare earth chlorides	
Operation 1 - Acid Dissolution		
	Feed	*Effluent*
Stream	S-3, S-4	Still in Reactor
Quantity (kg/batch)	18132	
Temperature (°C)		
Composition - mass basis		
$(Nd,Dy)_2Fe_{14}B$	0.08	trace
H_2SO_4	0.16	0
$FeSO_4$	0	0.16
$Re_2(SO_4)_3$	0	0.04
B	0	trace
H_2	0	trace
SO_4^{2-} (aq)	0	0.04
H_2O	0.76	0.76
Operation 2 - Salt Precipitation		
	Feed	*Effluent*
Stream	S-5, Reactor Mix	S-6
Quantity (kg/batch)	18421	
Temperature (°C)		
Composition - mass basis		
$FeSO_4$	0.16	0.16
$Re_2(SO_4)_3$	0.04	trace
B	trace	trace
NaOH	0.01	0
SO_4^{2-} (aq)	0.04	0.03
$NaRe(SO_4)_2$	0	0.05
OH-	0	trace
Na^+ (aq)	0	trace
H_2O	0.76	0.76

Operation 3 - Leach		
	Feed	*Effluent*
Stream	S-8, S-9	S-10
Quantity (kg/batch)	18438	18438
Temperature (°C)		
Composition - mass basis		
NaNd(SO4)2(s)	0.05	trace
HCl	0.13	trace
H2O	0.81	0.81
NdCl3 (s)	0	0.04
Na+(aq)	0	trace
Cl-(aq)	0	0.11
H+(aq)	0	trace
SO42-(aq)	0	0.03
Design Data		
Construction Material	Carbon Steel lined with Carpenter 20CB-3	
Weight (lb)	15153	
Diameter (ft)	8.3	
Height (ft)	16.5	
Wall thickness (in)	0.563	
Purchase cost	$89,300.00	
Total bare module cost	$371,500.00	
Agitator Data		
Hp Required	66.1	
Purchase Cost	$39,500.00	
Total Cost	$411,000.00	

Identification	**Item**	Reactor
	Item No.	R-200
	No. Required	1
Function: Re(TriNOx) Synthesis	Attaching TriNOx ligand to Rare Earth to ease separation	
Operation - Re(TriNOx) Synthesis		
	Feed	*Effluent*
Stream	S-1, S-2, S-6, S-27*	S-3*
Quantity (kg/batch)	15771	
Pressure (atm)		
Composition - mass basis		
ReCl$_3$	0.04	trace
TriNOx	0.09	0.01
K[N(SiMe$_3$)$_2$]	0.10	0.01
Re(TriNOx)	0	0.10
H[N(SiMe$_3$)$_2$]	0	0.07
KCl	0	0.03
THF	0.78	0.78
Design Data		
Construction Material	Carbon Steel	
Weight (lb)	9035	
Diameter (ft)	6.8	
Height (ft)	13.5	
Wall thickness (in)	0.5	
Purchase cost	$55,900.00	
Total bare module cost	$232,700.00	
Agitator Data		
Hp Required	36.4	
Purchase Cost	$28,100.00	
Total Cost	$260,800.00	

Identification	**Item**	Reactor
	Item No.	R-300
	No. Required	1
Function 1: Nd oxalate formation	Create Nd oxalate and prepare TriNOx for recycling	
Function 2: Dy oxalate formation	Create Dy oxalate and prepare TriNOx for recycling	
Operation 1 - Nd(Oxalate) Formation		
	Feed	*Effluent*
Stream	S-1, S-2, S-6, S-27*	S-3*
Quantity (kg/batch)	4560	
Pressure (atm)		
Composition - mass basis		
$[Nd(TriNOx)]_2$	0.31	trace
$H_2C_2O_4$	0.06	0
$Nd_2(C_2O_4)_3$	0	0.12
TriNOx	0	0.21
Decomposed TriNOx	0	0.03
H_2O	0.63	0.63
Operation 2 - Dy(Oxalate) Formation		
	Feed	*Effluent*
Stream	S-1, S-2, S-6, S-27*	S-3*
Quantity (kg/batch)	511	
Pressure (atm)		
Composition - mass basis		
Dy(TriNOx)	0.31	trace
$H_2C_2O_4$	0.06	0
$Dy_2(C_2O_4)_3$	0	0.12
TriNOx	0	0.21
Decomposed TriNOx	0	0.03
H_2O	0.63	0.63
Design Data		
Construction Material	Carbon Steel lined with Glass Lining	
Weight (lb)	2251	
Diameter (ft)	4	
Height (ft)	8	
Wall thickness (in)	0.375	
Purchase cost	$25,100.00	
Total bare module cost	$104,300.00	
Agitator Data		
Hp Required	7.6	
Purchase Cost	$11,500.00	
Total Cost	$115,800.00	

Identification	**Item**		Mixer
	Item No.		M-200
	No. Required		1
Function: Re(TriNOx) Extraction	Dissolving Re(TriNOx) in DCM while keeping KCl in suspension		
Operation - Re(TriNOx) Extraction			
	Feed	*Feed*	*Effluent*
Stream	17	23	20
Quantity (kg/batch)	2300	20802	23102
Pressure (atm)			
Composition - mass basis			
Re(TriNOx)	0.76	0.00	0.08
KCl	0.24	0.00	0.02
DCM	0.00	1.00	0.90
Design Data			
Construction Material	Carbon Steel lined with Stainless Steel 304		
Weight (lb)	9307		
Diameter (ft)	7.1		
Height (ft)	14.1		
Wall thickness (in)	0.5		
Purchase cost	$59,400.00		
Total bare module cost	$246,900.00		
Agitator Data			
Hp Required	41.3		
Purchase Cost	$30,200.00		
Total Cost	$277,100.00		

Identification	**Item**		Mixer
	Item No.		M-300
	No. Required		1
Function: Nd/Dy Separation	Dissolving Nd(TriNOx) in Toluene while keeping Dy(TriNOx) in suspension		
	Operation - Nd/Dy Separation		
	Feed	*Feed*	*Effluent*
Stream	24	28	25
Quantity (kg/batch)	1564	8670	10234
Pressure (atm)			
Composition - mass basis			
Re(TriNOx)	1.00	0.00	0.00
Toluene	0.00	0.00	0.85
$[Nd(TriNOx)]_2$	0.00	0.00	0.14
Dy(TriNOx)	0.00	1.00	0.02
	Design Data		
Construction Material	Carbon Steel		
Weight (lb)	11844		
Diameter (ft)	8.1		
Height (ft)	16.2		
Wall thickness (in)	0.5		
Purchase cost	$58,600.00		
Total bare module cost	$243,900.00		
	Agitator Data		
Hp Required	62		
Purchase Cost	$37,300.00		
Total Cost	$281,200.00		

Identification	**Item**		Crystallizer
	Item No.		V-201, V-300, V-301
	No. Required		1
Function 1: Re(TriNOx) Crystallization		Remove DCM	
Function 2: Nd(TriNOx) Crystallization		Remove Toluene	
Function 3: H_3TriNOx Crystallization		Remove DCM	
Operation - Re(TriNOx) Crystallization			
	Feed	*Effluent*	*Effluent*
Stream	22	23	24
Quantity (kg/batch)	22366	20802	1564
Pressure (atm)	1	1	1
Composition - mass basis			
Re(TriNOx)	0.07	0.00	1.00
DCM	0.93	1.00	0.00
Operation - Nd(TriNOx) Crystallization			
	Feed	*Effluent*	*Effluent*
Stream	26	28	29
Quantity (kg/batch)	10086	8670	1416
Pressure (atm)	1	1	1
Composition - mass basis			
$[Nd(TriNOx)]_2$	0.14	0.00	0.99
Dy(TriNOx)	trace	0.00	0.01
Toluene	0.86	1.00	0.02
Operation - H_3TriNOx Crystallization			
	Feed	*Effluent*	*Effluent*
Stream	35	36	37
Quantity (kg/batch)	30410	29180	1230
Pressure (atm)			
Composition - mass basis			
H_3TriNOx	0.04	0.00	0.88
H_3TriNOx (decomposed)	0.01	0.00	0.12
DCM	0.96	1.00	0.00
Design Data			
Construction Material	Stainless Steel 304		
Volume (ft^3)	777		
Purchase cost	$626,300.00		
Total bare module cost	$1,290,200.00		

10.2 Pumps, conveyors, and storage tanks

Identification	**Item**		Slurry Pump
	Item No.		P-100
	No. Required		1
Function: Pump rare earth clorides into F-100			
Operation - Batch			
Duty (kJ)	34500	*Feed*	*Effluent*
Stream		S-6	S-6
Quantity (kg/batch)		18422	18422
Pressure (atm)		1	1
Composition - mass basis			
	ReCl3 (s)	0.037	0.037
	Na+ (aq)	0.003	0.003
	Cl- (aq)	0.114	0.114
	H+ (aq)	0.004	0.004
	(SO4)2- (aq)	0.028	0.028
	H2O (l)	0.814	0.814
Design Data			
Subtype	Centrifugal Pumps		
Construction Material	Cast Iron		
Pump Type	3600 RPM, HSC, 100 - 450 ft, 100 - 1500 gpm, 150 Hp		
Flow Rate (gpm)	973		
Height (ft)	100		
Purchase Cost	$5,250.00		
Total Bare-Module Cost	$21,010.00		

Identification		**Item**	Slurry Pump
		Item No.	P-101
		No. Required	1
Function: Pump rare earth clorides, excess HCl and waste salts to F-101			
Operation - Batch			
Duty (kJ)	33500	*Feed*	*Effluent*
Stream		S-10	S-10
Quantity (kg/batch)		18439	18439
Pressure (atm)		1	1
Composition - mass basis			
ReCl3 (s)		0.037	0.037
Na+ (aq)		0.003	0.003
Cl- (aq)		0.114	0.114
H+ (aq)		0.004	0.004
(SO4)2- (aq)		0.028	0.028
H2O (l)		0.814	0.814
Design Data			
Subtype		Centrifugal Pumps	
Construction Material		Cast Iron	
Pump Type		3600 RPM, HSC, 100 - 450 ft, 100 - 1500 gpm, 150 Hp	
Flow Rate (gpm)		974	
Height (ft)		100	
Purchase Cost		$5,250.00	
Total Bare-Module Cost		$21,020.00	

Identification	**Item**	Slurry Pump
	Item No.	P-200
	No. Required	1
Function: Pump the mixture of THF, Re(TriNOx), H[N(SiMe3)2] and KCl to F-200		
Operation - Batch		

		Feed	*Effluent*
Duty (kJ)	21000		
Stream		S-15	S-15
Quantity (kg/batch)		15156	15156
Pressure (atm)		1	1
Composition - mass basis			
THF		0.768	0.768
Re(TriNOx)		0.115	0.115
H[N(SiMe3)2]		0.080	0.080
KCl		0.037	0.037

Design Data	
Subtype	Centrifugal Pumps
Construction Material	Cast Iron
Pump Type	3600 RPM, HSC, 100 - 450 ft, 100 - 1500 gpm, 150 Hp
Flow Rate (gpm)	1125
Height (ft)	100
Purchase Cost	$5,500.00
Total Bare-Module Cost	$21,130.00

Identification	**Item**		Inline Pump
	Item No.		P-201
	No. Required		1
Function: Pump the recycling THF back to R-200			
Operation - Batch			
Duty (kJ)	13000	*Feed*	*Effluent*
Stream		S-18	S-18
Quantity (kg/batch)		10000	10000
Pressure (atm)		1	1
Composition - mass basis			
THF		1.000	1.000
Design Data			
Subtype	Centrifugal Pumps		
Construction Material	Cast Iron		
Pump Type	3600 RPM, HSC, 40 - 500 ft, 50 - 900 gpm, 75 Hp		
Flow Rate (gpm)	600		
Height (ft)	40		
Purchase Cost	$3,950.00		
Total Bare-Module Cost	$13,040.00		

Identification		**Item**	Slurry Pump
		Item No.	P-202
		No. Required	1
Function: Pump Re(TriNOx), KCl and DCM from M-200 to F-201			
Operation - Batch			
Duty (kJ)	30000	*Feed*	*Effluent*
Stream		S-20	S-20
Quantity (kg/batch)		23102	23102
Pressure (atm)		1	1
Composition - mass basis			
KCl		0.024	0.024
DCM		0.900	0.900
Re(TriNOx)		0.075	0.075
Design Data			
Subtype		Centrifugal Pumps	
Construction Material		Cast Iron	
Pump Type		3600 RPM, HSC, 40 - 500 ft, 50 - 900 gpm, 75 Hp	
Flow Rate (gpm)		900	
Height (ft)		40	
Purchase Cost		$4,420.00	
Total Bare-Module Cost		$14,570.00	

Identification	**Item**		Inline Pump
	Item No.		P-203
	No. Required		1
Function: Pump the recycling DCM back to M-200			
Operation - Batch			
Duty (kJ)	31000	*Feed*	*Effluent*
Stream		S-23	S-23
Quantity (kg/batch)		1564	1564
Pressure (atm)		1	1
Composition - mass basis			
DCM		1.000	1.000
Design Data			
Subtype	Centrifugal Pumps		
Construction Material	Cast Iron		
Pump Type	3600 RPM, HSC, 40 - 500 ft, 50 - 900 gpm, 75 Hp		
Flow Rate (gpm)	60		
Height (ft)	40		
Purchase Cost	$2,900.00		
Total Bare-Module Cost	$9,600.00		

Identification		**Item**	Slurry Pump
		Item No.	P-300
		No. Required	1
Function: Pump the solid DyTriNOx and aqueous NdTriNOx mixture to F-300			
Operation - Batch			
Duty (kJ)	12000	*Feed*	*Effluent*
Stream		S-25	S-25
Quantity (kg/batch)		10234	10234
Pressure (atm)		1	1
Composition - mass basis			
Toluene		0.847	0.847
[Nd(TriNox)]2		0.137	0.137
Dy(TriNOx)		0.016	0.016
Design Data			
Subtype		Centrifugal Pumps	
Construction Material		Cast Iron	
Pump Type		3600 RPM, HSC, 40 - 500 ft, 50 - 900 gpm, 75 Hp	
Flow Rate (gpm)		650	
Height (ft)		40	
Purchase Cost		$4,030.00	
Total Bare-Module Cost		$13,300.00	

Identification		**Item**	Inline Pump
		Item No.	P-301
		No. Required	1
Function: Pump the recycling toluene back to M-300			
Operation - Batch			
Duty (kJ)	13000	*Feed*	*Effluent*
Stream		S-28	S-28
Quantity (kg/batch)		8670	8670
Pressure (atm)		1	1
Composition - mass basis			
	Toluene	1.000	1.000
Design Data			
Subtype		Centrifugal Pumps	
Construction Material		Cast Iron	
Pump Type		3600 RPM, HSC, 40 - 500 ft, 50 - 900 gpm, 75 Hp	
Flow Rate (gpm)		500	
Height (ft)		40	
Purchase Cost		$3,780.00	
Total Bare-Module Cost		$12,500.00	

Identification	**Item**		Slurry Pump
	Item No.		P-302
	No. Required		1
Function: Pump the neodymium oxalate, dysprosium oxalate and H3TriNOx (S-31, S-32) to M-301			
Operation - Batch			
Duty (kJ) 15000	*Feed*		*Effluent*
Stream	S-31	S-32	S-31/S-32
Quantity (kg/batch)	4600	472	5072
Pressure (atm)	1	1	1
Composition - mass basis			
H_2O	0.632	0.625	0.632
H_3TriNOx	0.213	0.212	0.213
(Decomp) H_3TriNOx	0.032	0.032	0.032
$Nd_2(C_2O_4)_3$	0.122	0.002	0.111
$Dy_2(C_2O_4)_3$	0.001	0.129	0.013
Design Data			
Subtype	Centrifugal Pumps		
Construction Material	Cast Iron		
Pump Type	3600 RPM, HSC, 40 - 500 ft, 50 - 900 gpm, 75 Hp		
Flow Rate (gpm)	300		
Height (ft)	40		
Purchase Cost	$3,400.00		
Total Bare-Module Cost	$11,200.00		

Identification		**Item**	Slurry Pump
		Item No.	P-303
		No. Required	1
Function: Pump the DCM (S-36) to M-301			
Operation - Batch			
Duty (kJ)	38201	*Feed*	*Effluent*
Stream		S-36	S-36
Quantity (kg/batch)		29180	29180
Pressure (atm)		1	1
Composition - mass basis			
	DCM	1.000	1.000
Design Data			
Subtype		Centrifugal Pumps	
Construction Material		Cast Iron	
Pump Type		3600 RPM, HSC, 40 - 500 ft, 50 - 900 gpm, 75 Hp	
Flow Rate (gpm)		900	
Height (ft)		40	
Purchase Cost		$4,400.00	
Total Bare-Module Cost		$14,600.00	

Identification	**Item**	Solids Conveyor
	Item No.	CO-100
	No. Required	1
Function: Convey solid sodium rare earth sulfate salt from R-100 to F-100		
Operation - Batch		
Duty (kJ) 53		*Feed*
Stream		8
Quantity (kg/batch)		975
Pressure (atm)		1
Composition - mass basis		
NaRe(SO4)2 (s)		1.00
Design Data		
Subtype	Belt conveyor	
Width (in)	24	
Length (ft)	100	
HP	0.72	
Operating time (s)	100	
Purchase Cost	$51,600.00	
Total Bare-Module Cost	$83,076.00	

Identification	**Item**	Solids Conveyor
	Item No.	CO-101
	No. Required	1
Function: Convey solid ReCl3 from D-100 to R-200		
Operation - Batch		
Duty (kJ) 38		*Feed*
Stream		13
Quantity (kg/batch)		634
Pressure (atm)		1
Composition - mass basis		
ReCl3 (s)		1.00
Design Data		
Subtype	Belt conveyor	
Width (in)	24	
Length (ft)	100	
HP	0.50	
Operating time (s)	100	
Purchase Cost	$51,600.00	
Total Bare-Module Cost	$83,076.00	

Identification	**Item**	Solids Conveyor
	Item No.	CO-200
	No. Required	1
Function: Convey solid ReTriNOx from V-201 to M-300		
Operation - Batch		
Duty (kJ)	79	*Feed*
Stream		24
Quantity (kg/batch)		1564
Pressure (atm)		1
Composition - mass basis		
ReTriNOx (s)		1.00
Design Data		
Subtype	Belt conveyor	
Width (in)	24	
Length (ft)	100	
HP	1.06	
Operating time (s)	100	
Purchase Cost	$51,600.00	
Total Bare-Module Cost	$83,076.00	

Identification	**Item**	Solids Conveyor
	Item No.	CO-300
	No. Required	1
Function: Convey solid H_3TriNOx from V-301 to R-200		
Operation - Batch		
Duty (kJ)	79	*Feed*
Stream		24
Quantity (kg/batch)		300
Pressure (atm)		1
Composition - mass basis		
H_3TriNOx (s)		1.00
Design Data		
Subtype	Belt conveyor	
Width (in)	24	
Length (ft)	100	
HP	1.06	
Operating time (s)	100	
Purchase Cost	$51,600.00	
Total Bare-Module Cost	$83,076.00	

Identification	**Item**		Horizontal Vessel
	Item No.		TK-100
	No. Required		1
Function: Dilution of 2.0 M sulfuric acid with 98% sulfuric acid and storage of 2.0 M sulfuric acid			

Operation - Semi-Batch

	Feed		*Effluent*
Stream	Water	H2SO4 (98%)	S-31/S-32
Quantity (kg/batch)	15000	3000	18000
Temperature (°C)	25	25	58.5
Heat Duty (kJ/batch)	-	-	-2,190,000
Pressure (atm)	1	1	1
Composition - mass basis			
H2O	1.000	0.020	0.808
H2SO4	0.000	0.980	0.192

Design Data

Subtype	Horizontal Vessel
Vessel Material	Carpenter 20CB-3
Height/Length (ft)	10
Diameter (ft)	10
Operating Pressure (atm)	1
Stress Material	Carbon Steel (SA-285 Grade C)
Design Temperature (F)	from -20 to 650
Vessel weight (lbs)	13,049
Vessel Cost	$133,500.00
Platforms & Ladders Cost	$3,200.00
Associated Cost:	
Agitator	$60,000.00
Chilled water coil	$10,000.00
Purchase Cost	$136,700.00
Total Bare-Module Cost	$486,800.00

Identification	**Item**		Horizontal Vessel
	Item No.		TK-101
	No. Required		1
Function: Storage tank for saturated NaOH			
Operation - Semi-Batch			
	Feed		*Effluent*
Stream	Water	NaOH pearl (99%)	S-31/S-32
Quantity (kg/batch)	150	165	315
Temperature (°C)	25	25	65
Heat Duty (kJ/batch)	-	-	-45,000
Pressure (atm)	1	1	1
Composition - mass basis			
H2O	1.000	0.000	0.476
NaOH	0.000	0.990	0.519
Misc.	0.000	0.010	0.005
Design Data			
Subtype	Horizontal Vessel		
Vessel Material	Inconel-600		
Height/Length (ft)	3		
Diameter (ft)	2		
Operating Pressure (atm)	1		
Stress Material	Carbon Steel (SA-285 Grade C)		
Design Temperature (F)	from -20 to 650		
Vessel weight (lbs)	450		
Vessel Cost	$36,700.00		
Platforms & Ladders Cost	$2,300.00		
Associated Cost:			
Agitator	$20,000.00		
Chilled water coil	$7,000.00		
Purchase Cost	$39,000.00		
Total Bare-Module Cost	$146,000.00		

Identification	**Item**		Horizontal Vessel
	Item No.		TK-102
	No. Required		1
Function: Storage tank for diluted HCl solution			
Operation - Semi-Batch			
	Feed		*Effluent*
Stream	Water	HCl	Diluted HCl Solution
Quantity (kg/batch)	15000	2500	17500
Temperature (°C)	25	25	26
Heat Duty (kJ/batch)	-	-	-102,000
Pressure (atm)	1	1	1
Composition - mass basis			
H_2O	1.000	0.020	0.808
H2SO4	0.000	0.980	0.192

Design Data	
Subtype	Horizontal Vessel
Vessel Material	Carpenter 20CB-3
Height/Length (ft)	10
Diameter (ft)	10
Operating Pressure (atm)	1
Stress Material	Carbon Steel (SA-285 Grade C)
Design Temperature (F)	from -20 to 650
Vessel weight (lbs)	13,049
Vessel	
Cost	$133,500.00
Platforms & Ladders Cost	$3,200.00
Associated Cost:	
Agitator	$60,000.00
Chilled water coil	$10,000.00
Purchase Cost	$136,700.00
Total Bare-Module Cost	$486,800.00

Identification	**Item**	Storage Tank
	Item No.	V-200
	No. Required	1
Function: Store THF	Store THF as part of the distillation	
Design Data		
Construction Material	Carbon Steel	
Weight (lb)	2224	
Diameter (ft)	3	
Height (ft)	9	
Wall thickness (in)	0.5	
Purchase Cost	$19,400.00	
Total Bare-Module Cost	$59,100.00	

10.3 Heat exchangers

Identification			**Item**	Condenser	
			Item No.	E-100	
			No. Required	1	
Function: Condenses water that evaporates from acid dissolution process, returns it to reaction mixture					
Operation - Condensation					
Duty (kJ)	41000000	*Feed*		*Effluent*	
Stream		from R-100 top		to R-100	
Description		Vapor from reaction mixture	Cooling Water input	Water returned to reaction mixture	Cooling Water output
Quantity (kg/batch)		18200	140000	18200	140000
Temperature (C)		101	25	100	93.5
Composition - mass basis					
H_2O		1.00	1.00	1.00	1.00
H_2SO_4		trace	0	trace	0
Design Data					
Construction Material	Carbon Steel				
Weight (lb)	5190				
Labor cost	$23,614.00				
Tube material cost	$4,009.00				
Material cost-except tubes	$3,459.00				
Total Bare-Module Cost	$31,082.00				

Identification			**Item**		Condenser
			Item No.		E-200
			No. Required		1
Function: Condenses THF vapor so that it can be returned to distillation tower T-200					
Operation - Condensation					
Duty (kJ)	376450	*Feed*		*Effluent*	
Stream		S-18'	-	S-18	-
Description		THF vapor	Cooling Water input	THF liquid	Cooling Water output
Quantity (kg/batch)		12255	30000	12255	30000
Temperature (C)		65.98	7.22	25.0	55.5
Composition - mass basis					
	THF	1.00	0.00	1.00	0.00
	amine	trace	0.00	trace	0.00
	water	0.00	1.00	0.00	1.00
Design Data					
Construction Material		Carbon Steel			
Weight (lb)		4804.2			
Labor cost		$17,600.00			
Tube material cost		$4,062.00			
Material cost-except tubes		$4,122.00			
Total Bare-Module Cost		$25,792.00			

Identification		**Item**		Reboiler	
		Item No.		E-201	
		No. Required		1	
Function: Reboils amine so that it can be returned to distillation tower T-200					
Operation - Condensation					
Duty (kJ)	397590	*Feed*		*Effluent*	
Stream		S-19'	-	S-19''	-
Description		amine liquid	Steam input	amine vapor	Steam output
Quantity (kg/batch)		31348	20000	31348	20000
Temperature (C)		124.7	232.0	126.0	175.2
Composition - mass basis					
	THF	trace	0.00	trace	0.00
	amine	1.00	0.00	1.00	0.00
	water	0.00	1.00	0.00	1.00
Design Data					
Construction Material		Carbon Steel			
Weight (lb)		3028.4			
Labor cost		$14,700.00			
Tube material cost		$1,319.00			
Material cost-except tubes		$2,715.00			
Total Bare-Module Cost		$18,691.00			

Identification			**Item**		Condenser
			Item No.		E-203
			No. Required		1
Function: Condenses DCM from V-201 to send it back to mixer M-200					
Operation - Condensation					
Duty (kJ)	3053450	*Feed*		*Effluent*	
Stream		S-23'	-	S-23	-
Description		DCM vapor	Cooling Water input	DCM liquid	Cooling Water output
Quantity (kg/batch)		8493	60000	8493	60000
Temperature (C)		40	7.22	25.0	19.4
Composition - mass basis					
	DCM	1.00	0.00	1.00	0.00
	H3TriNOx	trace	0.00	trace	0.00
	water	0.00	1.00	0.00	1.00
Design Data					
Construction Material		Carpenter - 20			
Weight (lb)		800			
Labor cost		$10,200.00			
Tube material cost		$4,800.00			
Material cost-except tubes		$6,700.00			
Total Bare-Module Cost		$22,000.00			

Identification			**Item**		Condenser
			Item No.		E-301
			No. Required		1
Function: Condenses toluene in stream S-28 in order to recycle it					
		Operation - Condensation			
Duty (kJ)	5043920	*Feed*		*Effluent*	
Stream		S-28	-	S-28'	-
Description		Toluene vapor	Cooling Water input	Toluene liquid	Cooling Water output
Quantity (kg/batch)		9214	100000	9214	100000
Temperature (C)		110.6	7.22	25.0	19.1
Composition - mass basis					
	toluene	1.00	0.00	1.00	0.00
	water	0.00	1.00	0.00	1.00
		Design Data			
Construction Material		Carbon Steel			
Weight (lb)		770			
Labor cost		$8,205.00			
Tube material cost		$303.00			
Material cost-except tubes		$1,496.00			
Total Bare-Module Cost		$10,003.00			

Identification	**Item**	Condenser
	Item No.	E-303
	No. Required	1

Function: Condenses DCM to send it to the settler

Operation - Condensation

Duty (kJ)	-3053450	*Feed*		*Effluent*	
Stream		S-36	-	S-36'	-
Description		DCM vapor	Cooling Water input	DCM liquid	Cooling Water output
Quantity (kg/batch)		8493	60000	8493	60000
Temperature (C)		40	7.22	25.0	19.4
Composition - mass basis					
	DCM	1.00	0.00	1.00	0.00
	H3TriNOx	trace	0.00	trace	0.00
	water	0.00	1.00	0.00	1.00

Design Data

Construction Material	Carpenter - 20
Weight (lb)	800
Labor cost	$10,200.00
Tube material cost	$4,800.00
Material cost-except tubes	$6,700.00
Total Bare-Module Cost	$22,000.00

10.4 Separators

Identification	**Item**	Distillation Column		
	Item No.	T-200		
	No. Required	1		
Function: Separate THF/HMDS				
Operation - THF Distillation				
	Feed	*Effluent*	*Effluent*	*Effluent*
Stream	16	18	19	41
Quantity (kg/hr)	561	439	51	72
Pressure (atm)	1	1	1	1
Temperature (°C)	57	66	125	66
Composition - mass basis				
THF	0.91	1.00	trace	1.00
$H[N(SiMe_3)_2]$	0.09	trace	1.00	trace
Design Data				
Construction Material	Carbon Steel			
Weight (lb)	7761			
Diameter (ft)	1.5			
Height (ft)	62			
Wall thickness (in)	0.617			
Purchase cost	$60,200.00			
Total bare module cost	$250,500.00			

Identification	**Item**	Rotary Vacuum Filter	
	Item No.	F-101	
	No. Required	1	
Function: Separate Rare earth chlorides from waste acid			
Operation - ReCl Filtration			
	Feed	*Effluent*	
Stream	S-10, S-11	S-12	S-13
Quantity (kg/batch)	3432	2803	629
Pressure (atm)	1	1	1
Composition - mass basis			
ReCl3 (s)	0.037	trace	0.99
Na+ (aq)	0.003	0.003	trace
Cl- (aq)	0.114	0.119	trace
H+ (aq)	0.004	0.004	trace
(SO4)2- (aq)	0.028	0.029	trace
H2O (l)	0.814	0.845	trace
Design Data			
Construction Material	Carbon Steel		
Diameter (ft)	3.70		
Height (ft)	3.87		
Purchase cost	$242,415.00		
Total bare module cost	$242,415.00		

Identification	**Item**	Batch Bottom-Drive Vertical Basket	
	Item No.	F-100	
	No. Required	1	
Function: Separate rare earth double salt from waste aqueous salts			
Operation - ReCl Filtration			
	Feed	*Effluent*	
Stream	S-6	S-7	S-8
Quantity (kg/batch)	18422	17447	975
Pressure (atm)	1	1	1
Temperature (C)	25	25	25
Composition - mass basis			
FeSO4	0.15590	0.16461	0
B	0.00081	0.00086	0
(SO4)2- (aq)	0.02850	0.03009	0
H2O	0.75643	0.79870	0
NaRe(SO4)2	0.05293	0.00000	1
OH- (aq)	0.00375	0.00395	0
Na+ (aq)	0.00168	0.00178	0
Design Data			
Construction Material	Stainless Steel		
Bowl Diameter (in.)	42.5		
Purchase cost	$74,196.50		
Total bare module cost	$74,196.50		

Identification	**Item**	Batch Bottom-Drive Vertical Basket	
	Item No.	F-200	
	No. Required	1	
Function: Separate Re(TriNOx) and KCl solids from THF and HDMS liquids			
Operation - Re(TriNOx) Filtration			
	Feed	*Effluent*	
Stream	S-15	S-16	S-17
Quantity (kg/batch)	15156	12856	2300
Pressure (atm)	1	1	1
Temperature (C)	25	25	25
Composition - mass basis			
THF	0.7680	0.9054	0.0000
Re(TriNOx)	0.1147	0.0000	0.7557
HMDS	0.0802	0.0946	0.0000
KCl	0.0371	0.0000	0.2443
Design Data			
Construction Material	Stainless Steel		
Bowl Diameter (in.)	20		
Purchase cost	$34,916.00		
Total bare module cost	$34,916.00		

Identification	**Item**	Batch Bottom-Drive Vertical Basket	
	Item No.	F-201	
	No. Required	1	
Function: Separate Re(TriNOx)-DCM solution from KCl solid			
Operation - KCl Filtration			
	Feed	*Effluent*	
Stream	S-20	S-21	S-22
Quantity (kg/batch)	23102	736	22366
Pressure (atm)	1	1	1
Temperature (C)	25	25	25
Composition - mass basis			
Re(TriNOx)	1738	174	1564
KCl	562	562	0
DCM	20802	0	20802
Design Data			
Construction Material	Stainless Steel		
Bowl Diameter (in.)	20		
Purchase cost	$34,916.00		
Total bare module cost	$34,916.00		

Identification	**Item**	Batch Bottom-Drive Vertical Basket	
	Item No.	F-300	
	No. Required	1	
Function: Separate [Nd(TriNOx)]2 in toluene solution from solid Dy(TriNOx)			
Operation - Dy(TriNOx) Filtration			
	Feed	*Effluent*	
Stream	S-25	S-26	S-27
Quantity (kg/batch)	10234	10086	148
Pressure (atm)	1	1	1
Temperature (C)	25	25	25
Composition - mass basis			
Toluene	0.84718	0.85961	0.00000
[Nd(TriNOx)]2	0.13719	0.13900	0.01351
Dy(TriNOx)	0.01563	0.00139	0.98649
Design Data			
Construction Material	Stainless Steel		
Bowl Diameter (in.)	20		
Purchase cost	$34,916.00		
Total bare module cost	$34,916.00		

10.5 Miscellaneous

Identification	**Item**	Jaw Crusher
	Item No.	C-100
	No. Required	1
Function: Crush NdFeB magnets into smaller particles		
Operation - Batch		
	Feed	*Effluent*
Stream	S-2	S-3
Quantity (kg/batch)	1460	1460
Pressure (atm)	1	1
Composition - mass basis		
(Nd,Dy)2Fe14B	1.000	1.000
Design Data		
Feed Rate (ton/hr)	10	
Feed Opening (mm)	500 x 750	
Max Feeding (mm)	425	
Discharge Opening (mm)	50	
Capacity (ton/hr)	10	
REV	275	
Power (kW)	20 -25	
Purchase Cost	$ 18,000.00	
Total Bare-Module Cost	$ 25,000.00	

11. Equipment Cost Summary

This section contains a table of the calculated bare module prices of each piece of equipment used in the process and gives the source of the pricing. In addition to the Seider Correlations and ASPEN, Chauvel et al.’s *Manual of Process Economic Evaluation* provided insight on pricing lined reactors [18]. Examples of these calculations are shown in the appendix. Bare module factors were chosen in accordance with Figure 11.2, which is also from Seider et al [19].

Table 11.1 Equipment Summary

ID Name	Type	Price	Source
Storage and Stream Transportation			
CO-100	Conveyor Belt	$ 83,100.00	Seider Correlation
CO-101	Conveyor Belt	$ 83,100.00	Seider Correlation
CO-200	Conveyor Belt	$ 83,100.00	Seider Correlation
P-100	Slurry Pump	$ 21,000.00	Seider Correlation
P-101	Slurry Pump	$ 21,000.00	Seider Correlation
P-200	Slurry Pump	$ 21,100.00	Seider Correlation
P-201	Inline Pump	$ 13,040.00	Seider Correlation
P-202	Slurry Pump	$ 14,570.00	Seider Correlation
P-203	Inline Pump	$ 9,600.00	Seider Correlation
P-300	Slurry Pump	$ 13,300.00	Seider Correlation
P-301	Inline Pump	$ 12,500.00	Seider Correlation
P-302	Inline Pump	$ 11,200.00	Seider Correlation
P-303	Inline Pump	$ 14,600.00	Seider Correlation
TK-100	Storage Tank	$ 486,800.00	Seider Correlation
TK-101	Storage Tank	$ 146,000.00	Seider Correlation
TK-102	Storage Tank	$ 486,800.00	Seider Correlation
Total		**$ 1,520,810.00**	
Separations			
F-100	Batch Basket Centrifugal Filter	$ 74,200.00	Seider Correlation
F-101	Rotary Vaccuum Filter	$ 242,400.00	Seider Correlation
F-200	Batch Basket Centrifugal Filter	$ 34,900.00	Seider Correlation
F-201	Batch Basket Centrifugal Filter	$ 34,900.00	Seider Correlation
F-300	Batch Basket Centrifugal Filter	$ 34,900.00	Seider Correlation
F-301	Batch Basket Centrifugal Filter	$ 34,900.00	Seider Correlation
T-200	Distillation column	$ 250,500.00	Seider Correlation
Total		**$ 671,800.00**	

ID Name	Type	Price	Source
Magnet Processing			
C-100	Jaw Crusher	$ 24,800.00	Seider Correlation
Heat Exchangers			
D-100	Dryer	$ 28,300.00	Seider Correlation
E-100	Condenser	$ 98,600.00	ASPEN
E-200	Condenser	$ 81,800.00	ASPEN
E-201	Reboiler	$ 59,300.00	ASPEN
E-203	Condenser	$ 69,700.00	ASPEN
E-301	Condenser	$ 31,700.00	ASPEN
E-303	Condenser	$ 69,700.00	ASPEN
H-100	Heater	$ 13,400.00	Seider Correlation
H-300	Heater	$ 16,400.00	Seider Correlation
V-200	Reflux Accumulator	$ 59,100.00	Seider Correlation
V-201	Batch Crystallizer	$ 1,290,200.00	Seider Correlation
Total		**$ 1,818,200.00**	
Mixers/Settlers			
M-200	Mixer	$ 277,100.00	Seider Correlation
M-300	Mixer	$ 281,200.00	Seider Correlation
Total		**$ 558,300.00**	
Reactors			
R-100	Reactor	$ 411,000.00	Seider Correlation
R-200	Reactor	$ 260,800.00	Seider Correlation
R-300	Reactor	$ 115,800.00	Seider Correlation
Total		**$ 787,600.00**	

Total Bare Module Costs	**$ 5,381,510.00**
Total Fixed Cost per kg product per batch	**$ 14,050.94**

Table 11.2 Relevant Bare-Module Factors

Equipment Type	**Bare-Module Factor**
Furnaces and direct-fired heaters, Shop Fabricated	2.19
Shell-and-tube heat exchangers	3.17
Vertical Pressure Vessels	4.16
Horizontal Pressure Vessels	3.05
Pumps and Drivers	3.30
Centrifuges	2.03
Bucket Conveyors	1.74
Crushers	1.39
Crystallizers	2.06
Dryers	2.06

12. Fixed-Capital Investment Summary

A rigorous economic analysis was made possible by Brian Downey's Profitability Analysis 4.0 Spreadsheet [20]. The total permanent investment of the plant is $7.43MM. These were calculated beginning with the purchase costs of the equipment, available in the spec sheets in Chapter 10. The bare-module costs in Figure 11.1 were calculated using these purchase costs and their corresponding bare-module factors, available in Figure 11.2. After bare-module costs were calculated, cost of site preparations and cost of service facilities were estimated at 5% of total bare module costs. These two costs combined gave the Direct Permanent Investment (DPI) of about $5.92MM. Cost of contingencies and contractor fees was estimated at 18% of DPI. This cost and DPI combined become Depreciable Capital (DC), which is about $6.99MM. The cost of land and the cost of plant startup were valued at 2% and 10% of DC, respectively. Due to the plant's New Mexico location, there is a .95 site factor. All of this is shown in Figure 12.1, using information from Seider et al [19].

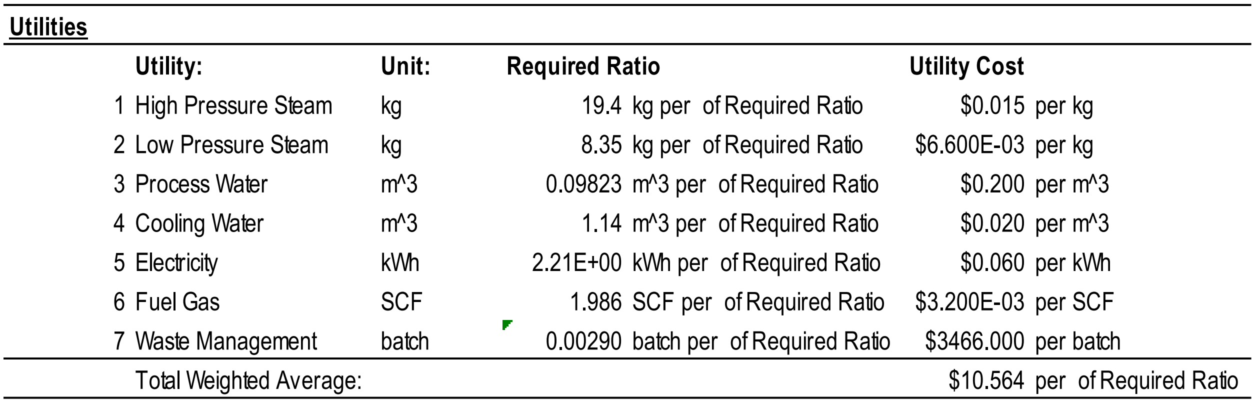
Investment Summary

Total Bare Module Costs:				
Fabricated Equipment	$	4,748,300		
Process Machinery	$	633,210		
Spares	$	-		
Storage	$	-		
Other Equipment	$	-		
Catalysts	$	-		
Computers, Software, Etc.	$	-		
Total Bare Module Costs:			**$**	**5,381,510**
Direct Permanent Investment				
Cost of Site Preparations:	$	269,076		
Cost of Service Facilities:	$	269,076		
Allocated Costs for utility plants and related facilities:	$	-		
Direct Permanent Investment			**$**	**5,919,661**
Total Depreciable Capital				
Cost of Contingencies & Contractor Fees	$	1,065,539		
Total Depreciable Capital			**$**	**6,985,200**
Total Permanent Investment				
Cost of Land:	$	139,704		
Cost of Royalties:	$	-		
Cost of Plant Start-Up:	$	698,520		
Total Permanent Investment - Unadjusted			$	7,823,424
Site Factor				0.95
Total Permanent Investment			**$**	**7,432,253**

Figure 12.1 Investment Summary

13. Operating Cost—Cost of Manufacture

The operating costs of the process boil down to the costs of raw materials, utilities, and operations/maintenance. The raw materials' costs were shown in Section 5 and will also be presented in the input summary for the business case in Section 15. Utilities were priced using Seider et al and can be seen in Figure 13.1. [19] Operations and maintenance, referred to as Fixed Costs, were calculated using Brian Downey's Profitability Analysis 4.0 Spreadsheet [20]. Fixed Costs were calculated using six employees per shift: two for each of the three sections of the process. Maintenance, quality control, and management personnel will also be required and are accounted for by the Fixed Cost summary in Figure 13.2. The following Figure 13.3 shows the estimations used to calculate the Fixed Costs. Finally, the Variable Cost Summary in Figure 13.4 combines the raw materials, utilities, and additional general expenses in one chart. These general expenses are based on the amount of the product, in this case Nd_2O_3.



Utilities

	Utility:	Unit:	Required Ratio		Utility Cost	
1	High Pressure Steam	kg	19.4	kg per of Required Ratio	$0.015	per kg
2	Low Pressure Steam	kg	8.35	kg per of Required Ratio	$6.600E-03	per kg
3	Process Water	m^3	0.09823	m^3 per of Required Ratio	$0.200	per m^3
4	Cooling Water	m^3	1.14	m^3 per of Required Ratio	$0.020	per m^3
5	Electricity	kWh	2.21E+00	kWh per of Required Ratio	$0.060	per kWh
6	Fuel Gas	SCF	1.986	SCF per of Required Ratio	$3.200E-03	per SCF
7	Waste Management	batch	0.00290	batch per of Required Ratio	$3466.000	per batch
	Total Weighted Average:				$10.564	per of Required Ratio

Figure 13.1 Utility Ratios and Costs

Fixed Cost Summary

Operations			
	Direct Wages and Benefits	$	2,496,000
	Direct Salaries and Benefits	$	374,400
	Operating Supplies and Services	$	149,760
	Technical Assistance to Manufacturing	$	1,800,000
	Control Laboratory	$	1,950,000
	Total Operations	**$**	**6,770,160**
Maintenance			
	Wages and Benefits	$	314,334
	Salaries and Benefits	$	78,583
	Materials and Services	$	314,334
	Maintenance Overhead	$	15,717
	Total Maintenance	**$**	**722,968**
Operating Overhead			
	General Plant Overhead:	$	231,696
	Mechanical Department Services:	$	78,320
	Employee Relations Department:	$	192,536
	Business Services:	$	241,485
	Total Operating Overhead	**$**	**744,036**
Property Taxes and Insurance			
	Property Taxes and Insurance:	$	139,704
Other Annual Expenses			
	Rental Fees (Office and Laboratory Space):	$	-
	Licensing Fees:	$	-
	Miscellaneous:	$	-
	Total Other Annual Expenses	**$**	**-**
Total Fixed Costs		**$**	**8,376,869**

Figure 13.2 Fixed Cost Summary

Fixed Costs

Operations

Operators per Shift:	6	(assuming 5 shifts)
Direct Wages and Benefits:	$40	/operator hour
Direct Salaries and Benefits:	15%	of Direct Wages and Benefits
Operating Supplies and Services:	6%	of Direct Wages and Benefits
Technical Assistance to Manufacturing:	$60,000.00	per year, for each Operator per Shift
Control Laboratory:	$65,000.00	per year, for each Operator per Shift

Maintenance

Wages and Benefits:	4.50%	of Total Depreciable Capital
Salaries and Benefits:	25.00%	of Maintenance Wages and Benefits
Materials and Services:	100.00%	of Maintenance Wages and Benefits
Maintenance Overhead:	5.00%	of Maintenance Wages and Benefits

Operating Overhead

General Plant Overhead:	7.10%	of Maintenance and Operations Wages and Benefits
Mechanical Department Services:	2.40%	of Maintenance and Operations Wages and Benefits
Employee Relations Department	5.90%	of Maintenance and Operations Wages and Benefits
Business Services	7.40%	of Maintenance and Operations Wages and Benefits

Property Taxes and Insurance

Property Taxes and Insurance:	2.00%	of Total Depreciable Capital

Straight Line Depreciation

Direct Plant: 8.00% of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities

Allocated Pla 6.00% of 1.18 times the Allocated Costs for Utility Plants and Related Facilities

Other Annual Expenses

Rental Fees (Office and Laboratory Space):	$0
Licensing Fees:	$0
Miscellaneous:	$0

Depletion Allowance

Annual Depletion Allowance:	$0

Figure 13.3 Methods for Calculating Fixed Costs

Variable Cost Summary

Variable Costs at 100% Capacity:			
General Expenses			
	Selling / Transfer Expenses:		$ 143,434
	Direct Research:		$ 229,494
	Allocated Research:		$ 23,906
	Administrative Expense:		$ 95,622
	Management Incentive Compensation:		$ 59,764
Total General Expenses			$ 552,219
Raw Materials		$438.578 per kg of Nd2O3	$49,926,025
Byproducts		$67.261 per kg of Nd2O3	($7,656,737)
Utilities		$10.564 per kg of Nd2O3	$1,202,567
Total Variable Costs			**$ 44,024,074**

Figure 13.4: Variable Cost Summary

14. Other Important Considerations

14.1 Environmental problems and solutions

The proposed plant can have a significant impact on the environment because the process involves various toxic chemicals such as sulfuric acid, hydrochloric acid, sodium hydroxide and THF that can be extremely dangerous when exposed to the environment without proper treatment. Systems that immediate report leaks must be set up to prevent disaster and should be regularly checked by safety experts.

Processes involving acids and bases make use of large volume of water and produce wastewater. The Environmental Protection Agency (EPA) regulates the discharge and treatment of wastewater under the Clean Water Act (CWA). The National Pollutant Discharge Elimination System (NPDES) issues permits to all wastewater dischargers and treatment facilities. These permits establish specific discharge limits, monitoring and reporting requirements and may also require these facilities to undertake special measures to protect the environment from harmful pollutants. Wastewater released through waste streams must be treated before released and wastewater should satisfy wastewater standards for industry set by the CWA.

The air quality concern regulated under the Clean Air Act (CAA) is due to the formation of CO_2 and H_2 in the process. H_2 gas is transported to the heat furnace, H-100, to heat magnets. This step is environmentally friendly, emitting no carbon and no greenhouse gases while being safe to operate. The CAA limits emissions of CO_2 because CO_2 is a major greenhouse gas. In the overall process, CO_2 production is 298 kg/batch.

The EPA regulates non-hazardous and hazardous solid waste with the Resource Conservation and Recovery Act (RCRA). Industrial waste does not go into the municipal solid waste stream and therefore is landfilled or processed separately.

Recycling of THF and H_3TriNO_X decreases the amount of chemicals that need to be treated before released through waste streams and makes the process more environmentally friendly.

14.2 Process controllability

The plant operation is 330 days per year to allow for 35 days of maintenance operations throughout the year.

Additional reactors for R-100, R-101, R-200 and R-300 should be equipped, allowing for maintenance of an individual reactor without stopping the entire process for an extended period of time and reducing the production of neodymium oxide and dysprosium oxide. Reactors should be checked for corrosion because acids and bases used for reactions cause corrosion of metal-alloy reactors despite using acid/base resistant metal-alloys for these reactors. For the same reason, storage tanks for acids and bases should be equipped. Extra equipment other than reactors and storage tanks can be equipped but is not required because other equipment is relatively long lasting.

All operations must immediately stop once problems are found with process equipment and maintenance should continue until all problems are fixed and normal process is possible. However, maintenance of process equipment should be minimal due to careful material selections and process designing.

14.3 Safety and health concerns

Some chemicals used in this process are also extremely hazardous and cause acute and chronic health effects in case of skin contact, of eye content, of ingestion and of inhalation. All operators and employees must go through a required 1 month training period, be an expert on safety procedures and be equipped with safety equipment at all times. The Material Safety Data Sheets attached in Appendix give information on all chemicals used in the overall process.

A corrosive chemical either destroys living tissue or causes permanent change in such tissue through chemical action. Many corrosive chemicals such as sulfuric acid and hydrochloric acid are involved in this process. Corrosives can destroy both skin and tissues underneath the skin; corrosives destroy eyes, the respiratory system, and any other living tissue. Corrosive effects include impaired sight or permanent blindness, severe disfigurement, permanent severe breathing difficulties, even death.

Some streams and equipment in this process operate at high temperatures. Especially, processes involving acids and bases include exothermic reactions that significantly increase temperatures of reactors. All steps in this process are designed so that they do not reach 100 ºC to prevent boiling of water. Despite not too extreme temperatures, it is important to make sure that operators and employees are fully aware of high temperatures because liquids at this temperature can easily cause a burn.

Crushing NdFeB magnets into small particles create magnet powders. When exposed to the air, magnet powders become fine dust that cause respiratory diseases. It is important to make sure that crushed magnet is not exposed to the air for environmental and safety purpose.

A safety manual for operators and employees must be written by experts and be present at various locations within the plant. A safety manual is used as a guide to deal with all types of disasters.

14.4 Plant startup

Due to large amount of chemicals and many steps involved in the overall process, plant startup is complicated and requires attention. The safe and efficient methods for the transport of feedstock and chemicals are required. Additionally, the storage of feedstock and chemicals are also required before they are used for the process. Chemicals are stored in storage tanks after chemicals are transported to prevent them from going through unwanted chemical reactions. Reactors are stowed with chemicals and water if needed before chemical reactions take place. A natural gas fired heater temperature is raised to the Curie temperature of the type of neodymium magnet used. Because the overall process is not continuous, only equipment that needs to be turned on should be turned on to save costs. However, it is important to turn on equipment at the right time to prevent a delayed process.

14.5 Plant layout when critical

The required equipment for the plant includes distillation columns, reactors, storage vessels, heaters, filters, pumps and etc. Due to the large number of equipment, the plant site needs to be around or bigger than 50,000 ft^2. A majority of the plant will be attributed to chemical storages, chemical reactors and distillation columns.

14.6 Plant Location

The operating costs of this process are sensitive to the proximity of NdFeB magnets to the plant site. Costs associated with the transportation of NdFeB magnets can be minimized with increasing proximity to the source. Also, the fixed costs are sensitive to the value of plant site.

Costs associated with buying or renting the land can be mitigated with selecting the right location for the plant. The primary source of used NdFeB magnets is wind turbines. The data on the number of wind turbines indicates southwest and southern regions of the country are locations with the most wind turbines, thus with the most chance of having used NdFeB magnets. The vast amounts of water are needed for this process and the location is needed to be near a water source like a river for consistent water supply. Factoring in the value of plant site, the state of New Mexico is the most favorable plant location. To sum up, if this plant is to be competitive, it has to be located where there is a large supply of NdFeB magnets, low fixed costs associated with buying or renting the plant site and a large supply of water.

14.7 Waste Management

There are a number of waste streams in the process. They include both solid wastes as well as organic compounds dissolved in various solvents. In this section, two waste treatment methods are compared: (1) the cost of building on-site waste water treatment equipment, and (2) the cost of sending the solid and liquid waste for offsite treatment and disposal.

Waste Stream	Components	kg/batch	Actual waste processing (landfill or wastewater)	Waste Processing Costs	Outsourcing costs
7	FeSO4	2872			$948
	B	15			$5
	SO42-	525			$173
	H2O	13935			
	OH-	69			$23
	Na+	31			$10
	total	17447	Wastewater treatment (Primary + Secondary + Tertiary)	$185,285	$1,159
12	SO42-	519			$171
	H2O	33890			
	Na+	62			$20
	ReCl3	43			$7
	H+	120			$40
	Cl-	3943			$1,301
	total	38577	Wastewater treatment (Primary + Secondary + Tertiary)	$307,885	$1,540
41	THF	1640	Wastewater treatment (Primary + Secondary + Tertiary)	$40,798	$541
	HMDS	trace			
21	KCl	562	Landfill. Less than $170/batch.	$96	$96
	Re(TriNOx)	174	Landfill.	$30	$30
40	Water	3203			
	H2C2O4	305			$101
	total	3508	Wastewater treatment (Primary + Secondary)	$32,431	$101
43	CO2	298	Vented. CO2 scrubber will be used if necessitated by local regulations		
			Total costs	**$566,524**	**$3,466**

Primary treatment: physical separations and insoluble organics separations

Secondary treatment: removing dissolved organic compounds
Tertiary treatment: removing dissolved inorganic compounds

Figure 14.1 Waste stream summary

The costs under “waste processing costs” are f.o.b. cost estimates based on equations from the Seider & Seader text. Taking a stream that requires primary, secondary, and tertiary treatment as an example, the f.o.b. cost estimate is $88,000Q^{0.64}$ where Q is the volumetric flowrate in gal/min. The outsourcing cost estimates are $0.33/kg organic removed and $0.17/kg solid waste. These estimates are also from the Seider &Seader text. The above table shows that building on-site waste water treatment equipment would be an expensive venture, costing $567,000—and not worth the price for an operation as small as this. The per-batch waste treatment price of $3,466 is by no means inexpensive, but—at least in this stage of a project like this—it makes more sense economically than building a relatively expensive water treatment facility.

15. Profitability Analysis—Business Case

As it is designed now, this process is not profitable for a number of reasons. First, as outlined in the market analysis, the price of the rare earth oxides is highly volatile. As of April 2016, however, the prices were at their lowest points since 2010. Dy_2O_3 has lost up to 90% of its peak 2011/2012 value while Nd_2O_3 lost up to 75%. Additionally, two of the necessary raw materials, H_3TriNOx and $K[N(SiMe_3)_2]$, are not industrially available and would theoretically be very expensive.

As the process is designed right now, the NPV is negative $114MM, as shown in Figure 15.1. The profitability calculations were generated using inputs given in Figure 15.2, along with the aforementioned equipment, raw materials, utilities, variable costs, working capital, total permanent investment, and fixed costs.

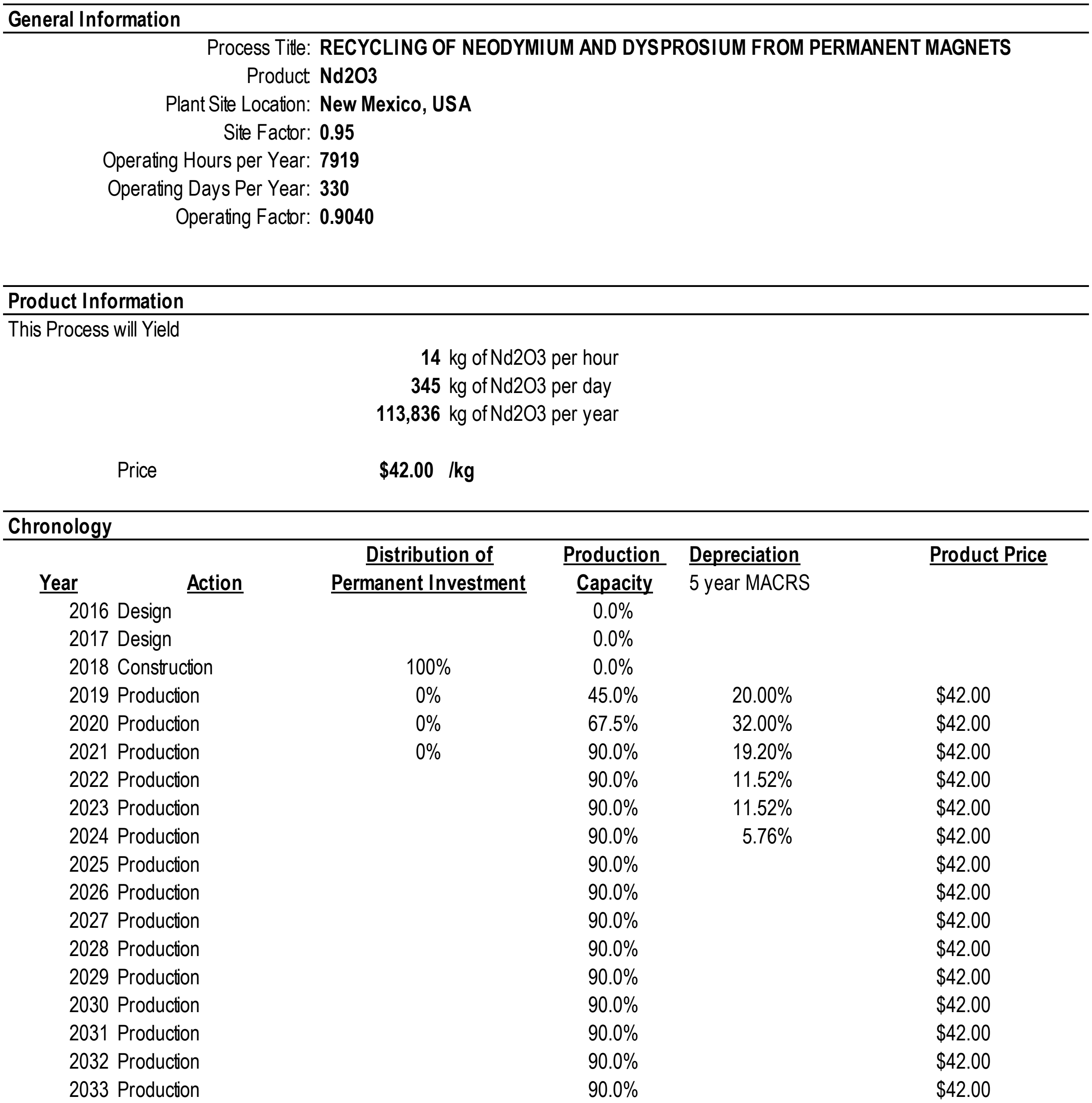
Profitability Measures

The Internal Rate of Return (IRR) for this project is	Negative IRR
The Net Present Value (NPV) of this project in 2016 is	$ (114,052,400)

ROI Analysis (Third Production Year)

Annual Sales	**4,303,008**
Annual Costs	**(47,998,535)**
Depreciation	**(594,580)**
Income Tax	**16,387,340**
Net Earnings	**(27,902,768)**
Total Capital Investment	**5,005,792**
ROI	**-557.41%**

Figure 15.1 Profitability at Current Status



General Information

Process Title:	**RECYCLING OF NEODYMIUM AND DYSPROSIUM FROM PERMANENT MAGNETS**
Product:	**Nd2O3**
Plant Site Location:	**New Mexico, USA**
Site Factor:	**0.95**
Operating Hours per Year:	**7919**
Operating Days Per Year:	**330**
Operating Factor:	**0.9040**

Product Information

This Process will Yield

14	kg of Nd2O3 per hour
345	kg of Nd2O3 per day
113,836	kg of Nd2O3 per year

Price **$42.00 /kg**

Chronology

Year	Action	Distribution of Permanent Investment	Production Capacity	Depreciation 5 year MACRS	Product Price
2016	Design		0.0%		
2017	Design		0.0%		
2018	Construction	100%	0.0%		
2019	Production	0%	45.0%	20.00%	$42.00
2020	Production	0%	67.5%	32.00%	$42.00
2021	Production	0%	90.0%	19.20%	$42.00
2022	Production		90.0%	11.52%	$42.00
2023	Production		90.0%	11.52%	$42.00
2024	Production		90.0%	5.76%	$42.00
2025	Production		90.0%		$42.00
2026	Production		90.0%		$42.00
2027	Production		90.0%		$42.00
2028	Production		90.0%		$42.00
2029	Production		90.0%		$42.00
2030	Production		90.0%		$42.00
2031	Production		90.0%		$42.00
2032	Production		90.0%		$42.00
2033	Production		90.0%		$42.00

Figure 15.2 Inputs at Current Status

However, the lack of profitability on the first try does not mean that the process is worthless. A sensitivity analysis was done with respect to the prices of the rare earth oxides and the raw materials in Figure 15.3. Here, we see in the top-right corner that the current prices of the raw materials ($438.58/kg of product) and rare earth oxides ($42/kg of product) give us a negative IRR. It is important to note that the raw materials cost is over 99% due to the prices of

H_3TriNOx and $K[N(SiMe_3)_2]$, each being about half of the total raw materials cost. There are a number of ways that these costs could come down. First, the Schelter lab is actively seeking a different reactant than $K[N(SiMe_3)_2]$, which serves only as a non-nucleophilic base. A cheaper option could be up to two orders of magnitude cheaper than $K[N(SiMe_3)_2]$, bringing the total raw materials cost down to the $219.29 range. At that point, there would only have to be a 500% surge in rare earth oxide pricing to begin to break even, which is not impossible.

Assuming that a replacement base can be found, the next problem is H_3TriNOx. The calculated cost per kg of H_3TriNOx based on similar chemicals was $428.60, which is much higher than any other chemical used. There is a possibility, that with the amount of bulk we are intending to buy, that the price goes down on its own. However, another way that our costs may be reduced is if the yields on H_3TriNOx recycling go up. On a small lab scale, 87% was achieved, but it would not be unreasonable for a larger scale, better controlled reaction to improve its yield. Going from 87% to 93.5% recovery would cut the cost of new H_3TriNOx in half. Combined with the reduced cost in base, the raw materials cost would be down in the $109.65 range, where a not-unprecedented 400% rise in rare earth oxide price would give a 45.97% IRR. Using these prices, a legitimate cash flow summary was generated in Figure 15.4.

	Raw Materials Cost			
Rare Earth Oxide Price	$ 109.65	$ 219.29	$ 328.94	$ 438.58
$ 42.00	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$ 84.00	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$ 126.00	14.09%	Negative IRR	Negative IRR	Negative IRR
$ 168.00	45.97%	Negative IRR	Negative IRR	Negative IRR
$ 210.00	71.98%	23.41%	Negative IRR	Negative IRR
$ 252.00	95.62%	53.20%	Negative IRR	Negative IRR
$ 294.00	117.62%	78.73%	31.82%	Negative IRR
$ 336.00	138.33%	102.12%	60.35%	1.19%

Figure 15.3 Sensitivity Analysis

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2016	0%		-	-	-	-	-	-	-	-	-	-	-	-
2017	0%		-	-	-	-	-	-	-	-	-	-	-	-
2018	0%		-	(7,432,300)	(680,700)	-	-	-	-	-	-	-	(8,112,900)	(6,134,500)
2019	45%	$168.00	8,606,000	-	(340,300)	(1,966,900)	(8,376,900)	(1,397,000)	-	(3,134,800)	1,159,900	(1,974,900)	(918,200)	(6,738,300)
2020	68%	$168.00	12,909,000	-	(340,300)	(2,950,300)	(8,376,900)	(2,235,300)	-	(653,400)	241,800	(411,700)	1,483,300	(5,890,200)
2021	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	(1,341,200)	-	3,560,300	(1,317,300)	2,243,000	3,584,100	(4,108,300)
2022	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	(804,700)	-	4,096,700	(1,515,800)	2,580,900	3,385,600	(2,644,600)
2023	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	(804,700)	-	4,096,700	(1,515,800)	2,580,900	3,385,600	(1,371,800)
2024	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	(402,300)	-	4,499,100	(1,664,700)	2,834,400	3,236,800	(313,700)
2025	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	-	-	4,901,400	(1,813,500)	3,087,900	3,087,900	564,100
2026	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	-	-	4,901,400	(1,813,500)	3,087,900	3,087,900	1,327,400
2027	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	-	-	4,901,400	(1,813,500)	3,087,900	3,087,900	1,991,100
2028	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	-	-	4,901,400	(1,813,500)	3,087,900	3,087,900	2,568,200
2029	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	-	-	4,901,400	(1,813,500)	3,087,900	3,087,900	3,070,100
2030	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	-	-	4,901,400	(1,813,500)	3,087,900	3,087,900	3,506,500
2031	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	-	-	4,901,400	(1,813,500)	3,087,900	3,087,900	3,886,000
2032	90%	$168.00	17,212,000	-	-	(3,933,700)	(8,376,900)	-	-	4,901,400	(1,813,500)	3,087,900	3,087,900	4,216,000
2033	90%	$168.00	17,212,000	-	1,361,400	(3,933,700)	(8,376,900)	-	-	4,901,400	(1,813,500)	3,087,900	4,449,300	4,629,400

Figure 15.4 Cash flow summary

16. Conclusions and Recommendations

In short, our project has implemented a method developed by Dr. Eric Schelter and his research group on recycling neodymium and dysprosium from used NdFeB permanent magnets. A thorough analysis of materials, utilities, equipment, and profitability has been done on our project and our group has concluded that the overall process will not soon be profitable based on the total permanent investment of $7.4MM, the total fixed costs of $8.4MM, and a negative estimated IRR.

We strongly recommend that more research be done before moving forward with this process. Finding a cheaper replacement for $K(N(SiMe_3)_2)$ and increasing the recycle rate of H_3TriNOx would make this process much more likely to be profitable. It would be smart to wait for the price for neodymium and dysprosium to spike in a manner similar to 2011 before investing as well. It is important to note, however, that there is something to be gained from independence from the Chinese market monopoly even if the profit margins are not great. As we see more and more people needing rare earth elements, processes like this will only become more vital.

Even though this project is not currently economically viable, the technology to recycling NdFeB magnets will gain more and more momentum as rare earth supply becomes less stable and rare earth gets depleted quickly while the demand of neodymium and dysprosium continues to rise.

16.1 Uncertainties and Further Research

Since our process is based on novel research and is still reliant on laboratory data, there exist many uncertainties in our project that we have tried to address with reasonable assumptions.

First and foremost are our assumptions about TriNOx chemistry. We have used data from the Schelter paper and assumed that the lab results translate to a larger industrial scale. We have also idealized the reactions in that many yield losses and byproducts are ignored to prevent complications in our process design. Many other assumptions were made to simplify various project steps, though we are sure none were gross misrepresentations of actual phenomena. These included typical simplifications such as constant heat capacities and heats of vaporization with changing temperature and the existence of perfect control units on each piece of process equipment, etc.

With these uncertainties in mind, further research is recommended to either optimize the TriNOx behavior to match that expected in our design or elucidate the true properties of TriNOx in our process conditions and scale.

We also recommend the development of a cheaper base to use as an alternative to $K(N(SiMe_3)_2)$, which is one of the most expensive variable costs. To this end, the Schelter lab is currently working on testing various other bases that can be used in the Re(TriNOx) formation step.

Lastly, we suggest applying the Schelter lab's rare earth separation technology (the use of TriNOx to create differentially soluble rare earth complexes) to separate other combinations of REE, not just Nd and Dy. While the two elements addressed in this project are proven to be separable and also are found together in a clean energy application with a significant market, other combinations of elements have just as much demand for an easy separation method, as again, most rare earths are difficult to separate from each other.

17. Acknowledgements

The success of this project was largely due to the aid of a group of experts and professionals whom we would like to thank. We would like to thank our faculty advisor, Dr. John Vohs, for his consistent guidance and expertise. We would also like to thank professors Mr. Leonard Fabiano and Dr. Warren Seider for the knowledge and wisdom that they have shared with us. We would also like to express our gratitude to Dr. Eric J. Schelter, whose work has inspired many aspects of this project, and to Ms. Denice Gorte, who has facilitated meetings with professors and other experts every week. We would also like to extend a very sincere thanks to the expert consultants that provided us with knowledge and guidance on a weekly basis: Mr. Adam A. Brostow, Dr. Richard Bockrath, Mr. Gary Sawyer, Mr. David M. Kolesar, and Dr. Ivan Baldychev.

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19. Appendix

19.1 Design procedures and detailed calculations for process units

Agitators for Reactors

The duration that mixing would occur for each reactor was based on two factors: (1) the length of time required for the reaction to occur; and (2) the length of time required to achieve complete mixing. (1) is determined by laboratory results, while (2) is determined by the empirical equation below:

$$\theta_{95} = \frac{5.40}{Po^{\frac{1}{3}} N} \left(\frac{T}{D}\right)^2$$

source: CerCell, *Power Number…* and *Mixing (process engineering)*

θ_{95} is defined as the time required to achieve a well-mixed state. T is the diameter of the tank, D is the diameter of the impeller, N is the speed of the impeller, and Po is a dimensionless factor known as the power number, which is based on the geometry of the impeller. N = 1 rotation/second was deemed a suitable balance between power consumption and speed of mixing for all the reactors in this process.

The power consumption of each agitator is described by the following equation:

$$P = Po \rho N^3 D^5$$

source: CerCell, *Power Number…* and *Mixing (process engineering)*

ρ is the density of the fluid being mixed.

Enthalpy changes for uncommon reactions

In this process, there are chemical reactions whose thermal properties are not thoroughly tabulated. For such reactions. The enthalpy of reaction is determined by subtracting the enthalpy of formation of the reactants from that of the products. Taking the acid dissolution step as an example:

Inputs	**mol**	**ΔHf(kJ/mol)**	**ΔH(kJ)**
(Nd,Dy)2Fe14B	1350	-9.6	-12964
H+ (aq)	45914	0	0
SO42- (aq)	22957	-908	-20833296
Outputs			
Fe2+ (aq)	18906	-941	-17794518
Re3+(aq)	2701	-697	-1882689
SO42- (aq)	22957	-908	-20833296

$$\Delta H_{rxn} = \sum \Delta H_{outputs} - \sum \Delta H_{inputs} = \mathbf{1.9 \times 10^{7}} \boldsymbol{kJ}$$

Enthalpy changes for acid dilution

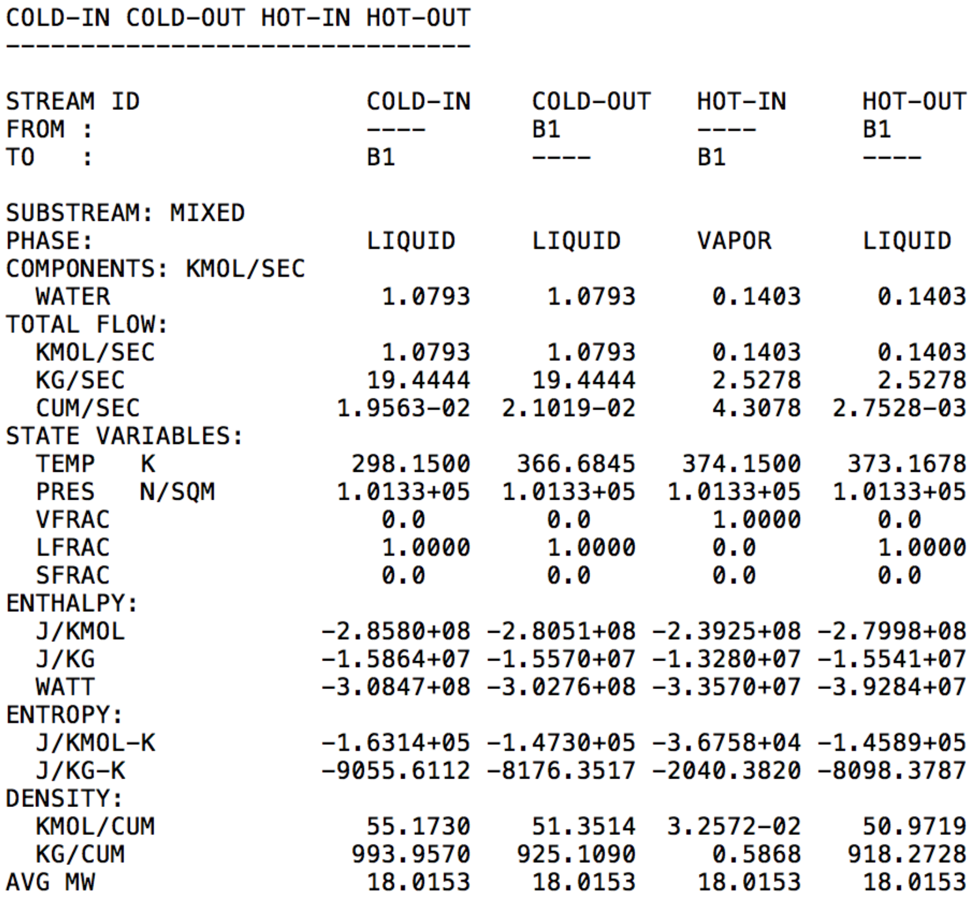
For the steps that involve dilution of a stock solution of acid (e.g. acid dissolution), there is an enthalpy change associated with the exothermic process of diluting the acid. These enthalpy changes were calculated by creating an Aspen process that included two streams—one water and one acid stock solution—that are fed into a mixer and exit as one stream. The change in enthalpy and temperature were recorded for the processes that involve acid dilution.

Heat Exchangers

For the heat exchangers in this process, the desired heat duty is calculated by estimating the anticipated temperature change with the equation $q = mc\Delta T$. q, the heat transferred during the process, is known, as it is calculated as a combination of reaction enthalpy and acid dilution enthalpy, shown above. m is the mass of the fluid that undergoes heat exchange. c is the specific heat of the material. For mixtures of materials, Aspen was used to estimate the specific heat. For Taking the condenser E-100 as an example, the heat transferred to the reaction mixture was calculated. The temperature increase was then calculated. It was discovered that the temperature increases beyond the point of vaporization, so condenser E-100 was built to condense water that evaporates from the reaction mixture back into the reactor, based on the heat of vaporization of water.

19.2 Relevant portions of computer outputs

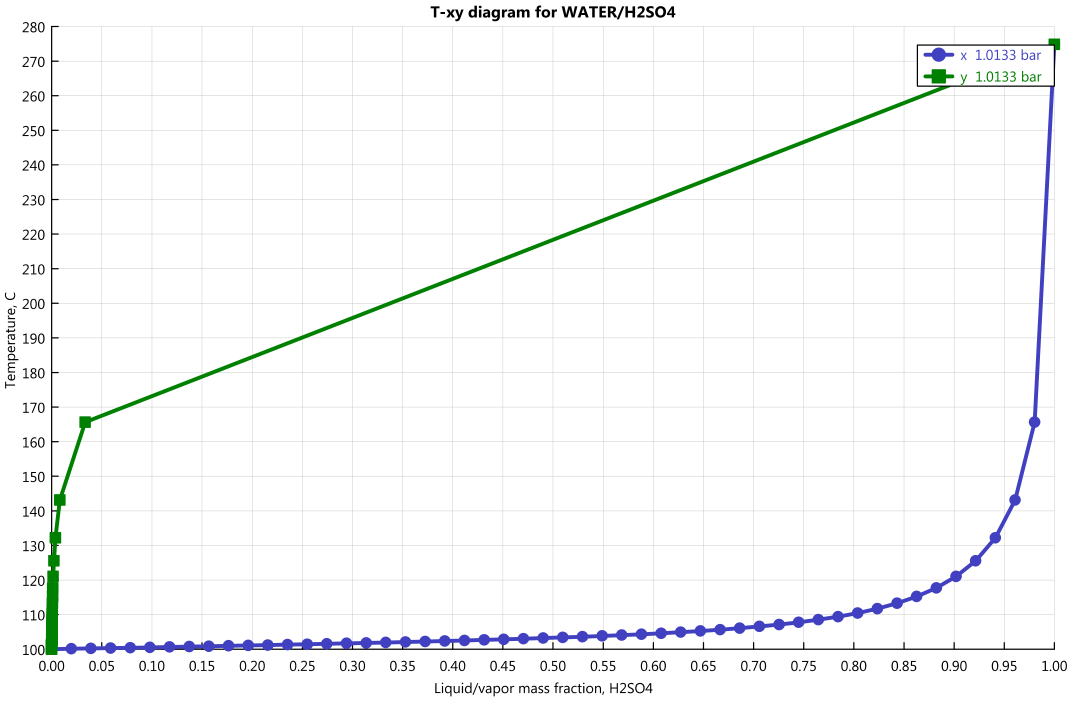
Acid dissolution condenser (E-100) Streams



```
COLD-IN COLD-OUT HOT-IN HOT-OUT
-------------------------------

STREAM ID                COLD-IN    COLD-OUT   HOT-IN     HOT-OUT
FROM :                   ----       B1         ----       B1
TO   :                   B1         ----       B1         ----

SUBSTREAM: MIXED
PHASE:                   LIQUID     LIQUID     VAPOR      LIQUID
COMPONENTS: KMOL/SEC
  WATER                    1.0793     1.0793     0.1403     0.1403
TOTAL FLOW:
  KMOL/SEC                 1.0793     1.0793     0.1403     0.1403
  KG/SEC                  19.4444    19.4444     2.5278     2.5278
  CUM/SEC               1.9563-02  2.1019-02     4.3078  2.7528-03
STATE VARIABLES:
  TEMP   K               298.1500   366.6845   374.1500   373.1678
  PRES   N/SQM          1.0133+05  1.0133+05  1.0133+05  1.0133+05
  VFRAC                   0.0        0.0        1.0000     0.0
  LFRAC                   1.0000     1.0000     0.0        1.0000
  SFRAC                   0.0        0.0        0.0        0.0
ENTHALPY:
  J/KMOL               -2.8580+08 -2.8051+08 -2.3925+08 -2.7998+08
  J/KG                 -1.5864+07 -1.5570+07 -1.3280+07 -1.5541+07
  WATT                 -3.0847+08 -3.0276+08 -3.3570+07 -3.9284+07
ENTROPY:
  J/KMOL-K             -1.6314+05 -1.4730+05 -3.6758+04 -1.4589+05
  J/KG-K               -9055.6112 -8176.3517 -2040.3820 -8098.3787
DENSITY:
  KMOL/CUM                55.1730    51.3514  3.2572-02    50.9719
  KG/CUM                 993.9570   925.1090     0.5868   918.2728
AVG MW                    18.0153    18.0153    18.0153    18.0153
```

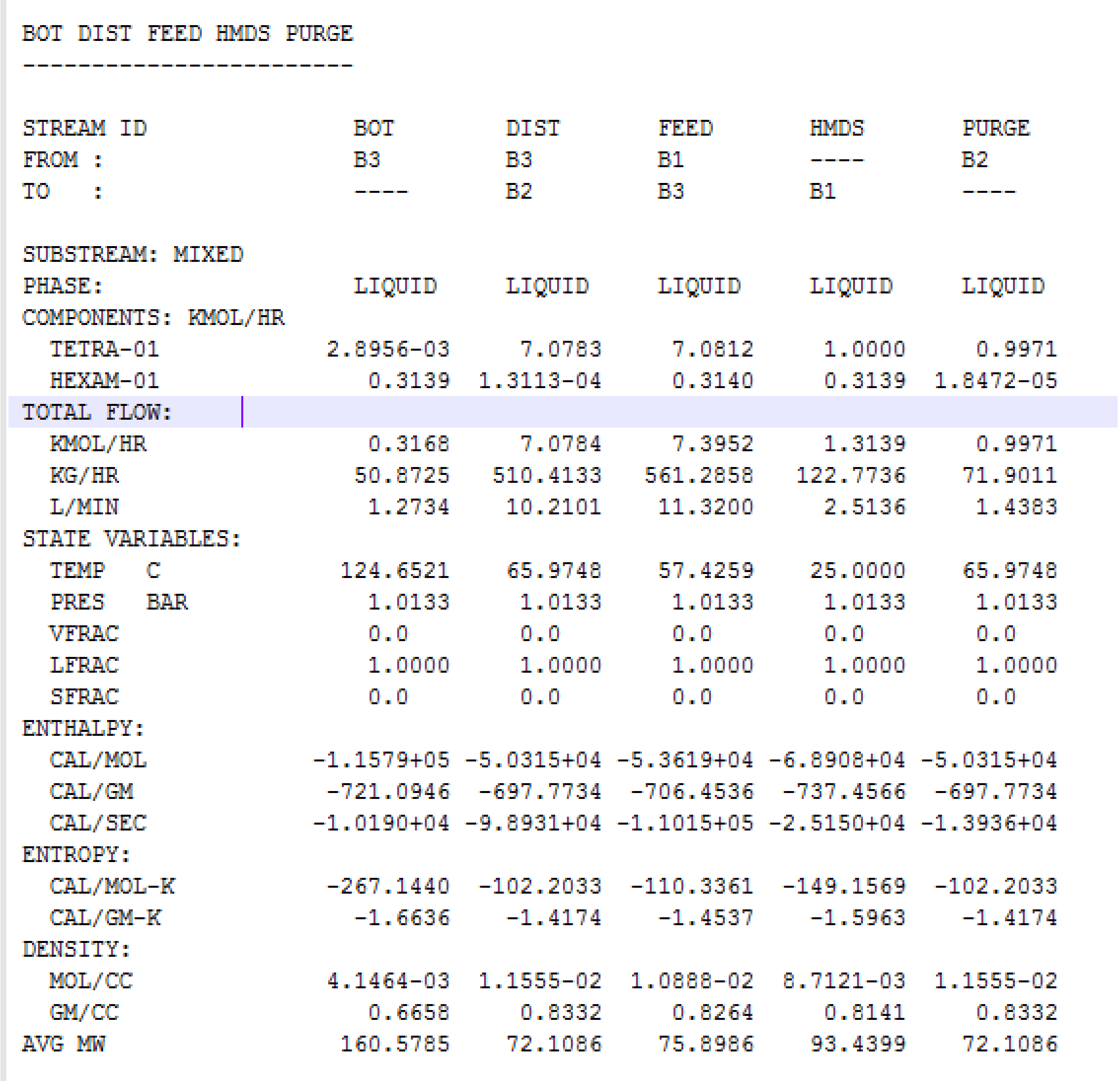
The highly exothermic acid dilution process required for the acid dissolution reaction causes much of the water in the reaction mixture to vaporize, necessitating a condenser that returns the vapors to the reaction mixture. The stream table above shows the necessary utility flows and temperature changes involved in that condenser.

Water-sulfuric acid mixing interactions

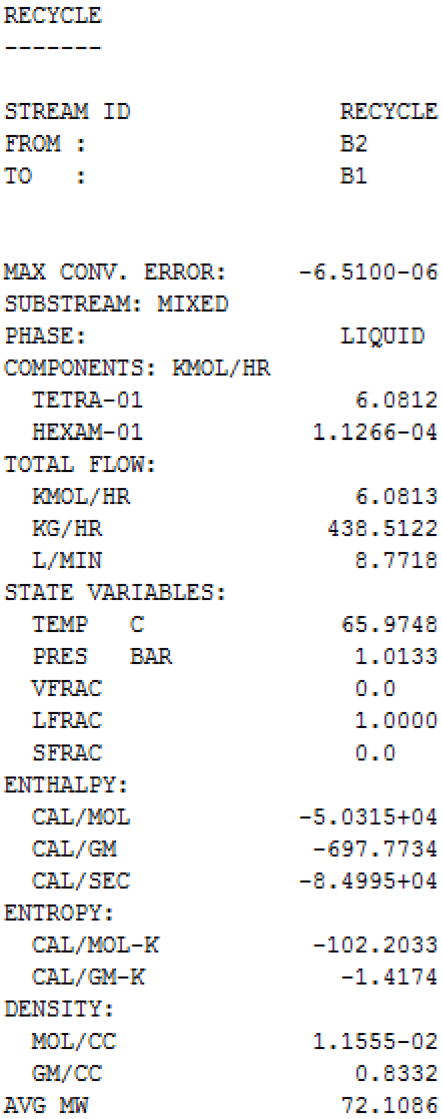


The T-xy diagram above shows that the vapor leaving the acid dissolution reaction mixture will likely have a small fraction of sulfuric acid.

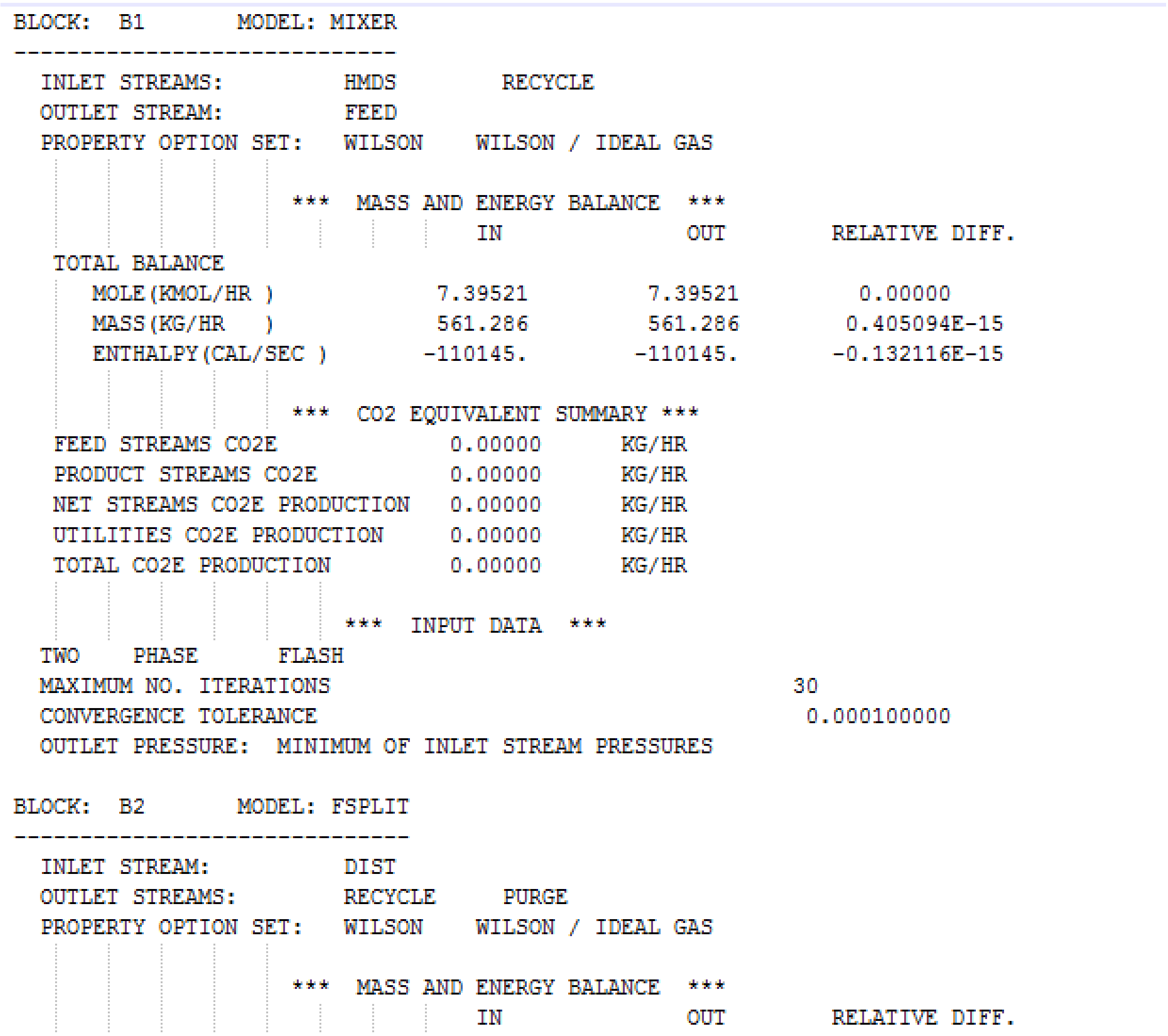
T-200 (ASPEN output for THF Distillation)



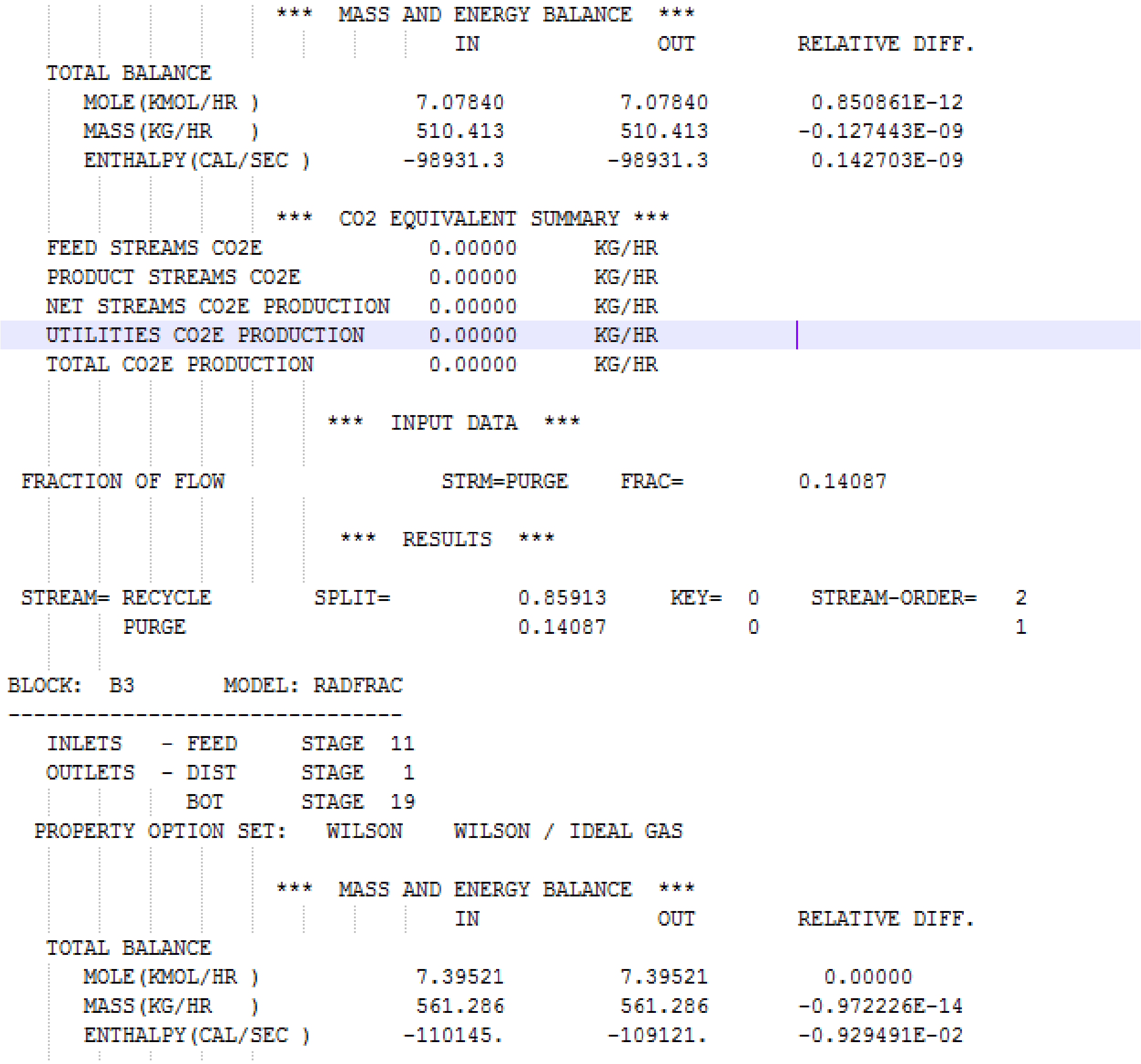
```
BOT DIST FEED HMDS PURGE
------------------------


STREAM ID               BOT         DIST        FEED        HMDS        PURGE
FROM :                  B3          B3          B1          ----        B2
TO   :                  ----        B2          B3          B1          ----

SUBSTREAM: MIXED
PHASE:                  LIQUID      LIQUID      LIQUID      LIQUID      LIQUID
COMPONENTS: KMOL/HR
  TETRA-01            2.8956-03      7.0783      7.0812      1.0000      0.9971
  HEXAM-01               0.3139  1.3113-04      0.3140      0.3139  1.8472-05
TOTAL FLOW:
  KMOL/HR                0.3168      7.0784      7.3952      1.3139      0.9971
  KG/HR                 50.8725    510.4133    561.2858    122.7736     71.9011
  L/MIN                  1.2734     10.2101     11.3200      2.5136      1.4383
STATE VARIABLES:
  TEMP   C             124.6521     65.9748     57.4259     25.0000     65.9748
  PRES   BAR             1.0133      1.0133      1.0133      1.0133      1.0133
  VFRAC                  0.0         0.0         0.0         0.0         0.0
  LFRAC                  1.0000      1.0000      1.0000      1.0000      1.0000
  SFRAC                  0.0         0.0         0.0         0.0         0.0
ENTHALPY:
  CAL/MOL            -1.1579+05 -5.0315+04 -5.3619+04 -6.8908+04 -5.0315+04
  CAL/GM               -721.0946   -697.7734   -706.4536   -737.4566   -697.7734
  CAL/SEC            -1.0190+04 -9.8931+04 -1.1015+05 -2.5150+04 -1.3936+04
ENTROPY:
  CAL/MOL-K            -267.1440   -102.2033   -110.3361   -149.1569   -102.2033
  CAL/GM-K               -1.6636     -1.4174     -1.4537     -1.5963     -1.4174
DENSITY:
  MOL/CC              4.1464-03  1.1555-02  1.0888-02  8.7121-03  1.1555-02
  GM/CC                  0.6658      0.8332      0.8264      0.8141      0.8332
AVG MW                 160.5785     72.1086     75.8986     93.4399     72.1086
```



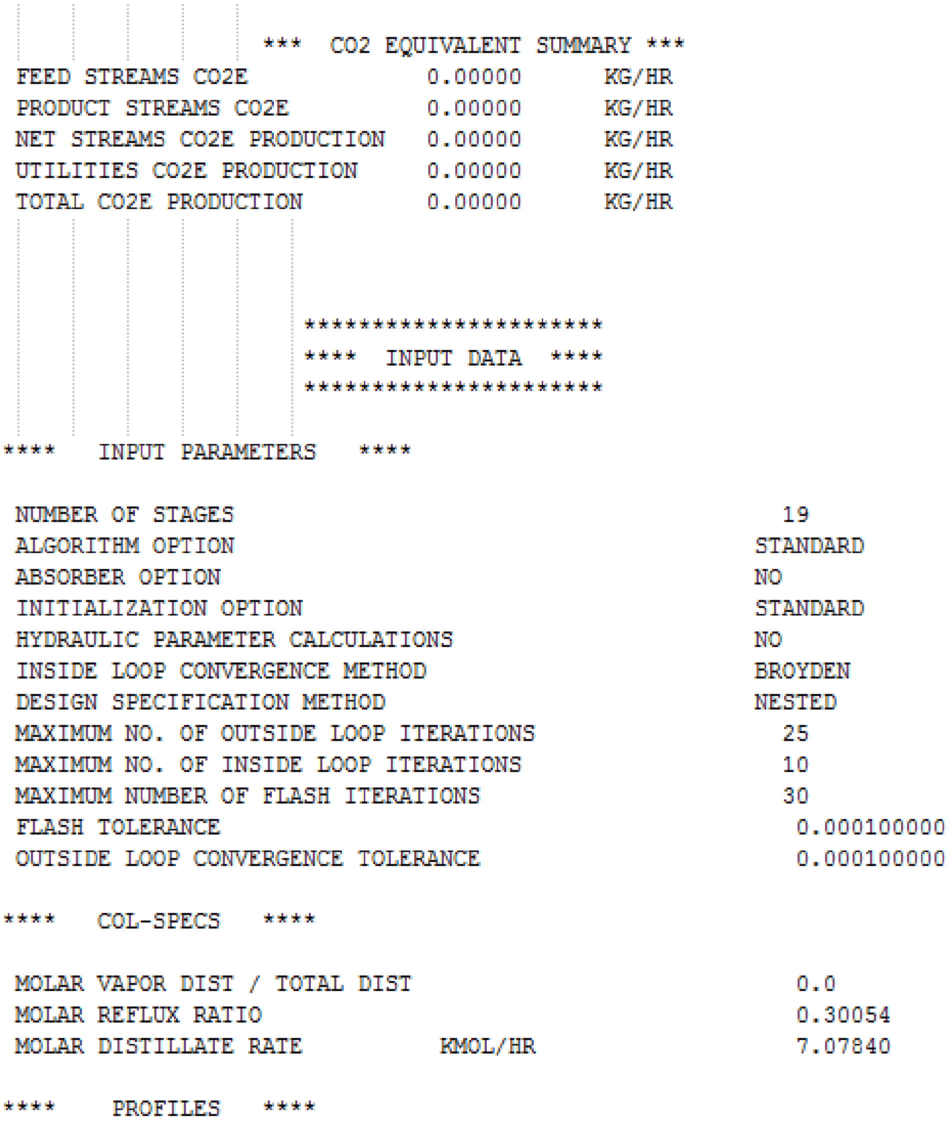
```
RECYCLE
-------

STREAM ID                   RECYCLE
FROM :                      B2
TO   :                      B1


MAX CONV. ERROR:     -6.5100-06
SUBSTREAM: MIXED
PHASE:                      LIQUID
COMPONENTS: KMOL/HR
  TETRA-01                    6.0812
  HEXAM-01                 1.1266-04
TOTAL FLOW:
  KMOL/HR                     6.0813
  KG/HR                     438.5122
  L/MIN                       8.7718
STATE VARIABLES:
  TEMP   C                   65.9748
  PRES   BAR                  1.0133
  VFRAC                       0.0
  LFRAC                       1.0000
  SFRAC                       0.0
ENTHALPY:
  CAL/MOL                -5.0315+04
  CAL/GM                  -697.7734
  CAL/SEC                -8.4995+04
ENTROPY:
  CAL/MOL-K               -102.2033
  CAL/GM-K                  -1.4174
DENSITY:
  MOL/CC                  1.1555-02
  GM/CC                       0.8332
AVG MW                       72.1086
```



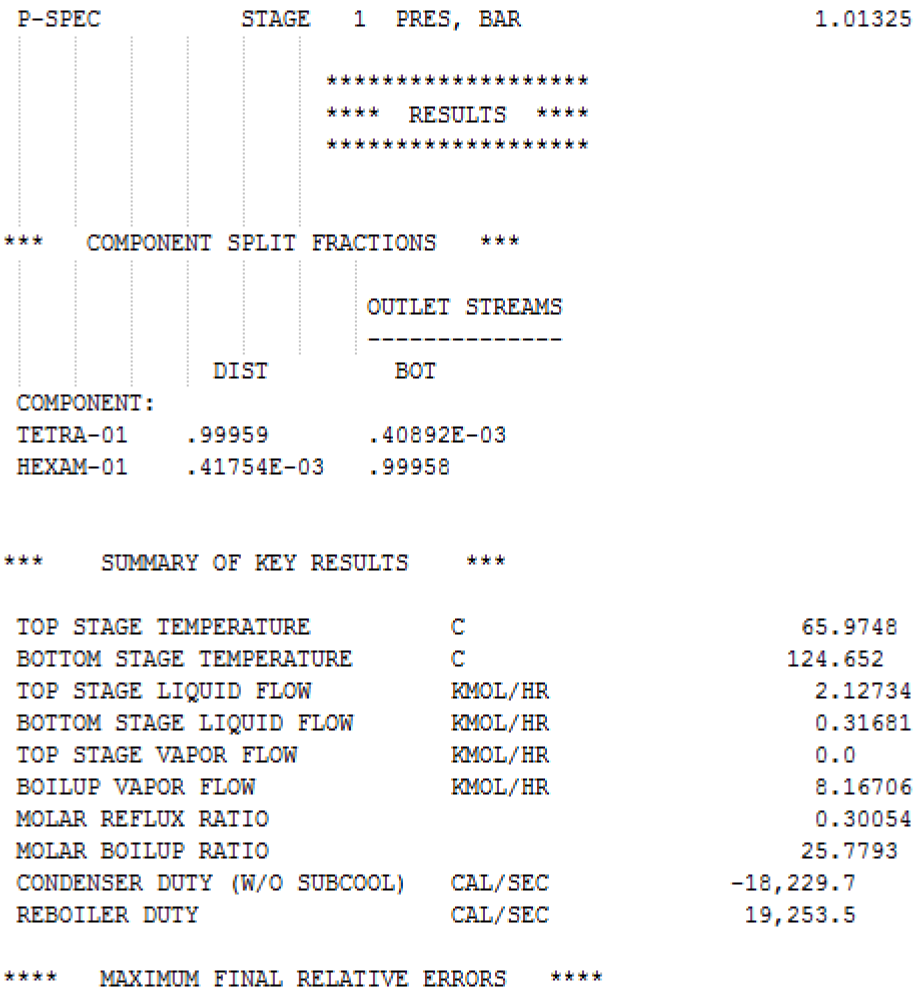
```
BLOCK:  B1       MODEL: MIXER
-----------------------------
  INLET STREAMS:         HMDS        RECYCLE
  OUTLET STREAM:         FEED
  PROPERTY OPTION SET:   WILSON    WILSON / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN                OUT          RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            7.39521         7.39521           0.00000
      MASS(KG/HR   )            561.286         561.286          0.405094E-15
      ENTHALPY(CAL/SEC )       -110145.        -110145.         -0.132116E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             0.00000      KG/HR
   PRODUCT STREAMS CO2E          0.00000      KG/HR
   NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         0.00000      KG/HR

                         ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                       0.000100000
  OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

BLOCK:  B2       MODEL: FSPLIT
------------------------------
  INLET STREAM:          DIST
  OUTLET STREAMS:        RECYCLE     PURGE
  PROPERTY OPTION SET:   WILSON    WILSON / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN                OUT          RELATIVE DIFF.
```



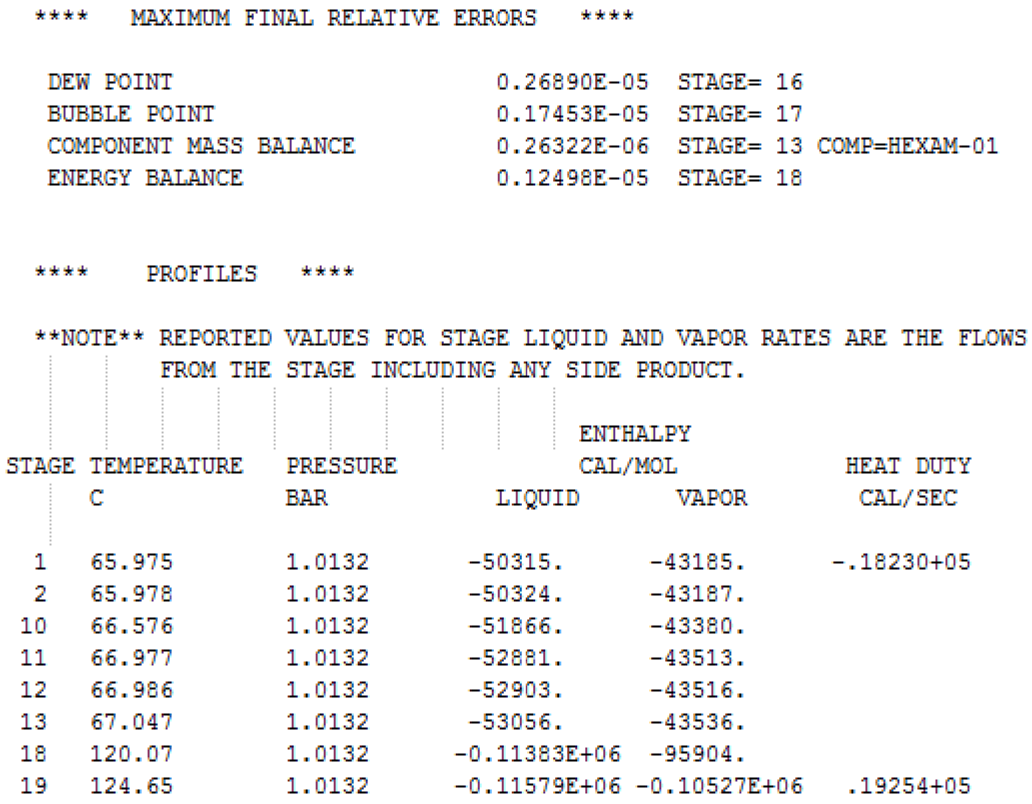
```
                         ***  MASS AND ENERGY BALANCE  ***
                                   IN                OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            7.07840           7.07840        0.850861E-12
      MASS(KG/HR   )            510.413           510.413       -0.127443E-09
      ENTHALPY(CAL/SEC )       -98931.3          -98931.3        0.142703E-09

                         ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E                 0.00000       KG/HR
   PRODUCT STREAMS CO2E              0.00000       KG/HR
   NET STREAMS CO2E PRODUCTION       0.00000       KG/HR
   UTILITIES CO2E PRODUCTION         0.00000       KG/HR
   TOTAL CO2E PRODUCTION             0.00000       KG/HR

                             ***  INPUT DATA  ***

 FRACTION OF FLOW                   STRM=PURGE    FRAC=         0.14087

                              ***  RESULTS  ***

 STREAM= RECYCLE        SPLIT=          0.85913     KEY=  0    STREAM-ORDER=   2
         PURGE                          0.14087           0                    1

BLOCK:  B3       MODEL: RADFRAC
-------------------------------
   INLETS   - FEED      STAGE  11
   OUTLETS  - DIST      STAGE   1
              BOT       STAGE  19
  PROPERTY OPTION SET:   WILSON    WILSON / IDEAL GAS

                         ***  MASS AND ENERGY BALANCE  ***
                                   IN                OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            7.39521           7.39521         0.00000
      MASS(KG/HR   )            561.286           561.286       -0.972226E-14
      ENTHALPY(CAL/SEC )       -110145.          -109121.       -0.929491E-02
```



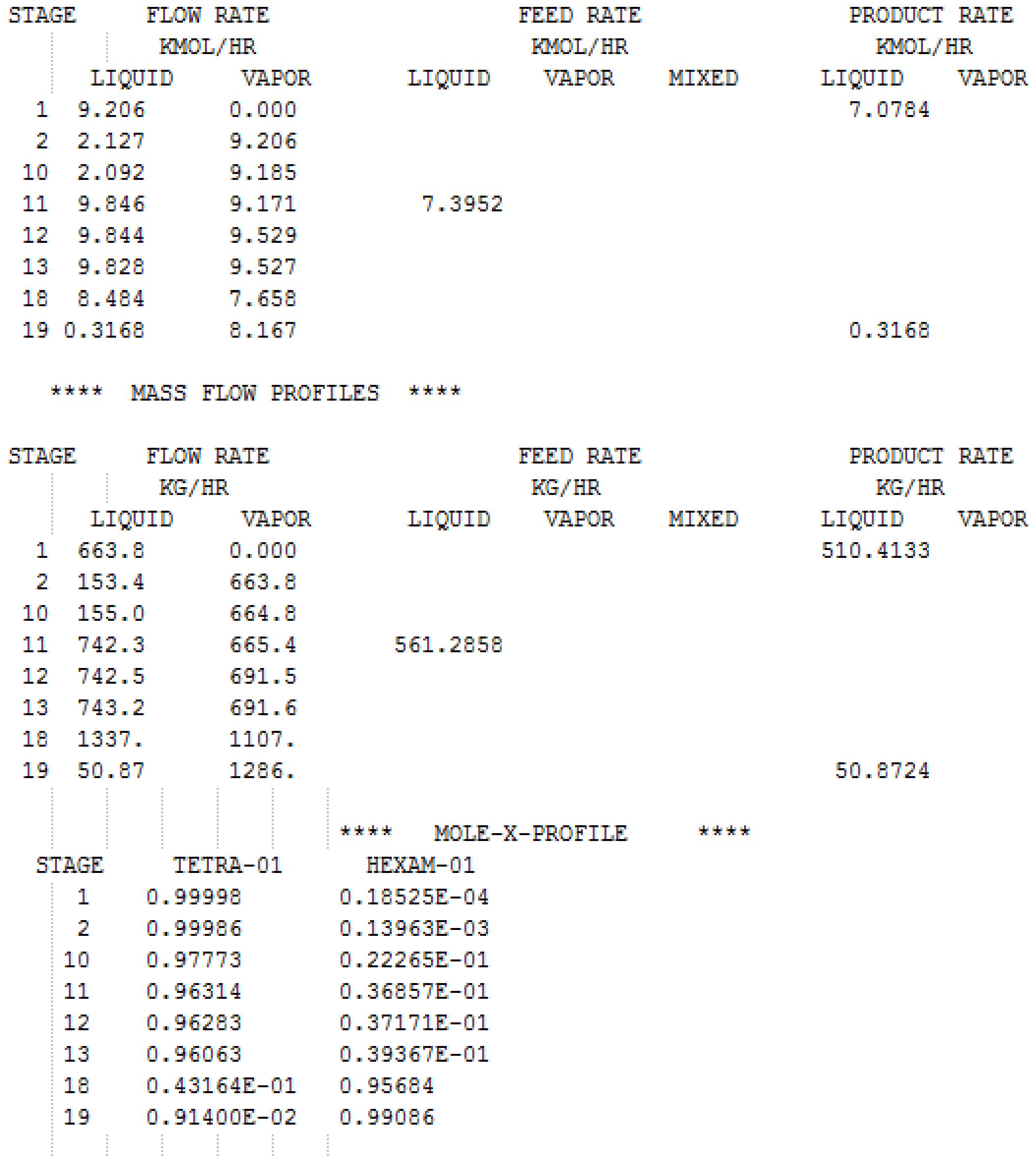
```
                   ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E             0.00000      KG/HR
 PRODUCT STREAMS CO2E          0.00000      KG/HR
 NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
 UTILITIES CO2E PRODUCTION     0.00000      KG/HR
 TOTAL CO2E PRODUCTION         0.00000      KG/HR



                      **********************
                      ****  INPUT DATA  ****
                      **********************

****   INPUT PARAMETERS   ****

 NUMBER OF STAGES                                         19
 ALGORITHM OPTION                                       STANDARD
 ABSORBER OPTION                                        NO
 INITIALIZATION OPTION                                  STANDARD
 HYDRAULIC PARAMETER CALCULATIONS                       NO
 INSIDE LOOP CONVERGENCE METHOD                         BROYDEN
 DESIGN SPECIFICATION METHOD                            NESTED
 MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                   25
 MAXIMUM NO. OF INSIDE LOOP ITERATIONS                    10
 MAXIMUM NUMBER OF FLASH ITERATIONS                       30
 FLASH TOLERANCE                                           0.000100000
 OUTSIDE LOOP CONVERGENCE TOLERANCE                        0.000100000

****   COL-SPECS   ****

 MOLAR VAPOR DIST / TOTAL DIST                             0.0
 MOLAR REFLUX RATIO                                        0.30054
 MOLAR DISTILLATE RATE          KMOL/HR                    7.07840

****    PROFILES   ****
```



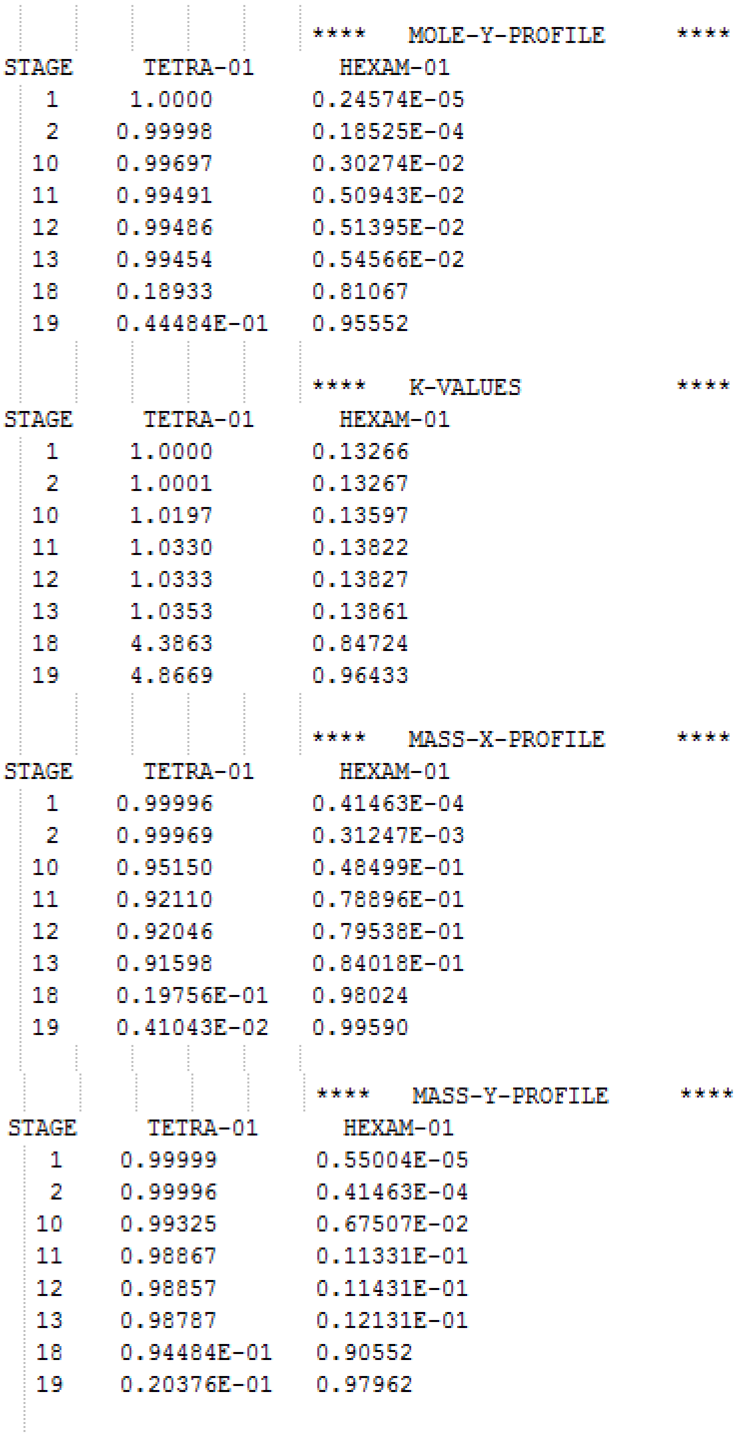
```
 P-SPEC          STAGE   1  PRES, BAR                     1.01325

                        *******************
                        ****  RESULTS  ****
                        *******************


***   COMPONENT SPLIT FRACTIONS   ***

                          OUTLET STREAMS
                          --------------
            DIST          BOT
 COMPONENT:
 TETRA-01    .99959       .40892E-03
 HEXAM-01    .41754E-03   .99958


***    SUMMARY OF KEY RESULTS    ***

 TOP STAGE TEMPERATURE          C                        65.9748
 BOTTOM STAGE TEMPERATURE       C                       124.652
 TOP STAGE LIQUID FLOW          KMOL/HR                   2.12734
 BOTTOM STAGE LIQUID FLOW       KMOL/HR                   0.31681
 TOP STAGE VAPOR FLOW           KMOL/HR                   0.0
 BOILUP VAPOR FLOW              KMOL/HR                   8.16706
 MOLAR REFLUX RATIO                                       0.30054
 MOLAR BOILUP RATIO                                      25.7793
 CONDENSER DUTY (W/O SUBCOOL)   CAL/SEC              -18,229.7
 REBOILER DUTY                  CAL/SEC               19,253.5

****   MAXIMUM FINAL RELATIVE ERRORS   ****
```



```
 ****   MAXIMUM FINAL RELATIVE ERRORS   ****

  DEW POINT                        0.26890E-05  STAGE= 16
  BUBBLE POINT                     0.17453E-05  STAGE= 17
  COMPONENT MASS BALANCE           0.26322E-06  STAGE= 13 COMP=HEXAM-01
  ENERGY BALANCE                   0.12498E-05  STAGE= 18


 ****    PROFILES   ****

 **NOTE** REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
          FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

                                          ENTHALPY
STAGE TEMPERATURE   PRESSURE              CAL/MOL           HEAT DUTY
      C             BAR            LIQUID       VAPOR        CAL/SEC

  1   65.975        1.0132       -50315.      -43185.      -.18230+05
  2   65.978        1.0132       -50324.      -43187.
 10   66.576        1.0132       -51866.      -43380.
 11   66.977        1.0132       -52881.      -43513.
 12   66.986        1.0132       -52903.      -43516.
 13   67.047        1.0132       -53056.      -43536.
 18   120.07        1.0132      -0.11383E+06  -95904.
 19   124.65        1.0132      -0.11579E+06 -0.10527E+06   .19254+05
```



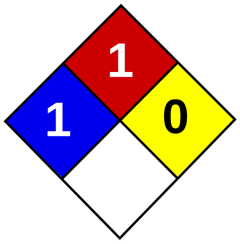
```
STAGE     FLOW RATE                  FEED RATE               PRODUCT RATE
           KMOL/HR                    KMOL/HR                  KMOL/HR
       LIQUID      VAPOR       LIQUID     VAPOR     MIXED      LIQUID     VAPOR
  1   9.206       0.000                                          7.0784
  2   2.127       9.206
 10   2.092       9.185
 11   9.846       9.171         7.3952
 12   9.844       9.529
 13   9.828       9.527
 18   8.484       7.658
 19 0.3168        8.167                                          0.3168

   ****  MASS FLOW PROFILES  ****

STAGE     FLOW RATE                  FEED RATE               PRODUCT RATE
           KG/HR                      KG/HR                    KG/HR
       LIQUID      VAPOR       LIQUID     VAPOR     MIXED      LIQUID     VAPOR
  1   663.8       0.000                                        510.4133
  2   153.4       663.8
 10   155.0       664.8
 11   742.3       665.4       561.2858
 12   742.5       691.5
 13   743.2       691.6
 18   1337.       1107.
 19   50.87       1286.                                         50.8724

                                       ****   MOLE-X-PROFILE     ****
    STAGE      TETRA-01       HEXAM-01
       1     0.99998       0.18525E-04
       2     0.99986       0.13963E-03
      10     0.97773       0.22265E-01
      11     0.96314       0.36857E-01
      12     0.96283       0.37171E-01
      13     0.96063       0.39367E-01
      18     0.43164E-01   0.95684
      19     0.91400E-02   0.99086
```



```
                        ****   MOLE-Y-PROFILE     ****
STAGE     TETRA-01       HEXAM-01
   1       1.0000       0.24574E-05
   2      0.99998       0.18525E-04
  10      0.99697       0.30274E-02
  11      0.99491       0.50943E-02
  12      0.99486       0.51395E-02
  13      0.99454       0.54566E-02
  18      0.18933       0.81067
  19      0.44484E-01   0.95552

                        ****   K-VALUES           ****
STAGE     TETRA-01       HEXAM-01
   1       1.0000       0.13266
   2       1.0001       0.13267
  10       1.0197       0.13597
  11       1.0330       0.13822
  12       1.0333       0.13827
  13       1.0353       0.13861
  18       4.3863       0.84724
  19       4.8669       0.96433

                        ****   MASS-X-PROFILE     ****
STAGE     TETRA-01       HEXAM-01
   1      0.99996       0.41463E-04
   2      0.99969       0.31247E-03
  10      0.95150       0.48499E-01
  11      0.92110       0.78896E-01
  12      0.92046       0.79538E-01
  13      0.91598       0.84018E-01
  18      0.19756E-01   0.98024
  19      0.41043E-02   0.99590

                        ****   MASS-Y-PROFILE     ****
STAGE     TETRA-01       HEXAM-01
   1      0.99999       0.55004E-05
   2      0.99996       0.41463E-04
  10      0.99325       0.67507E-02
  11      0.98867       0.11331E-01
  12      0.98857       0.11431E-01
  13      0.98787       0.12131E-01
  18      0.94484E-01   0.90552
  19      0.20376E-01   0.97962
```

19.3 Material Safety Data Sheets (MSDS)

These sheets are included at the end of the report.



Health	1
Fire	1
Reactivity	0
Personal Protection	E

Material Safety Data Sheet

Boron MSDS

Section 1: Chemical Product and Company Identification

Product Name: Boron

Catalog Codes: SLB1825

CAS#: 7440-42-8

RTECS: ED7350000

TSCA: TSCA 8(b) inventory: Boron

CI#: Not available.

Synonym:

Chemical Name: Boron

Chemical Formula: B

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Boron	7440-42-8	100

Toxicological Data on Ingredients: Boron: ORAL (LD50): Acute: 650 mg/kg [Rat]. 560 mg/kg [Mouse].

Section 3: Hazards Identification

Potential Acute Health Effects: Slightly hazardous in case of skin contact (irritant, permeator), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:
Slightly hazardous in case of skin contact (permeator), of ingestion, of inhalation. CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention if irritation occurs.

Skin Contact: Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops.

Serious Skin Contact: Not available.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: 580°C (1076°F)

Flash Points: Not available.

Flammable Limits: Not available.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances:
Slightly flammable to flammable in presence of open flames and sparks, of heat. Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:
Slightly explosive in presence of open flames and sparks. Non-explosive in presence of shocks.

Fire Fighting Media and Instructions:
Flammable solid. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray or fog. Cool containing vessels with water jet in order to prevent pressure build-up, autoignition or explosion.

Special Remarks on Fire Hazards:
Material in powder form, capable of creating a dust explosion. When amorphous boron is heated in dry ammonia, reaction proceeds with incandescence and hydrogen is evolved. Boron ignites in bromine vapor at 700 C. Boron ignites in chlorine @ 410 C. Fluorine attacks boron @ ordinary temperature and the resulting mass becomes incandescent. Iodic acid attacks boron below 40 deg. C and the resulting mass becomes incandescent. Concentrated nitric acid and boron react so violently that the mass is raised to incandescence. A mixture of boron and sulfur becomes incandescnet at 600 C. A reaction between nitrosyl fluoride and boron is accompanied by incandescence.

Special Remarks on Explosion Hazards:
Fine dust dispersed in air in sufficient concentrations, and in the presences of an ignition source is a potential dust explosion hazard. Silver fluoride reacts explosively Boron at ordinary temperatures.

Section 6: Accidental Release Measures

Small Spill: Use appropriate tools to put the spilled solid in a convenient waste disposal container.

Large Spill:
Flammable solid. Stop leak if without risk. Do not touch spilled material. Use water spray curtain to divert vapor drift. Prevent entry into sewers, basements or confined areas; dike if needed. Eliminate all ignition sources. Call for assistance on disposal.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe dust. Wear suitable protective clothing. If ingested, seek medical advice immediately and show the container or the label. Keep away from incompatibles such as oxidizing agents, acids.

Storage:
Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection: Safety glasses. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (Amorphous solid powder or lumps.)

Odor: Not available.

Taste: Not available.

Molecular Weight: 10.81 g/mole

Color: Brown.

pH (1% soln/water): Not applicable.

Boiling Point: 2550°C (4622°F)

Melting Point: 2300°C (4172°F)

Critical Temperature: Not available.

Specific Gravity: 2.37 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: Not available.

Solubility:
Insoluble in cold water, hot water, diethyl ether. If finely divided, it is soluble in boiling sulfuric acid and most molten metals such as copper, iron, magnesium, aluminum, and calcium. Insoluble in alcohol.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Heat, ignition sources, incompatible materials

Incompatibility with various substances: Reactive with oxidizing agents, acids.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Interaction of powdered boron and steam may become violent at red heat. The highly exothermic reactions with water might become combustive or explosive processes at sufficiently high temperatures and pressures. Incompatible with sodium peroxide, sodium carbonate, potassium nitrate, ammonia, iodic acid, nitric acid, nitrosyl fluoride, phosphorous, silicon, silver fluoride, lead dioxide, cesium carbide, rubidium carbide, cupric oxide, nitric oxide.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Inhalation. Ingestion.

Toxicity to Animals: Acute oral toxicity (LD50): 560 mg/kg [Mouse].

Chronic Effects on Humans: Not available.

Other Toxic Effects on Humans: Slightly hazardous in case of skin contact (irritant, permeator), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans:
Potential Health Effects: Skin: May cause skin irritation. Eyes: May cause eye irritation. Inhalation: May cause respiratory tract and mucous membrane irritaitoin. Prolonged or repeated inhalation may affect respiration, and metabolism (weight loss, anorexia) Ingestion: Prolonged or repeated ingestion may affect the brain, liver, heart. Chronic poisoning (from ingestion, skin absorption, or absorption from body cavities or mucous membranes) causes anorexia, weight loss, vomiting, mild diarrhea, skin rash, alopecia, convulsions (or other nervous system disturbances), and anemia

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: CLASS 4.1: Flammable solid.

Identification: : Flammable solid, n.o.s UNNA: 1325 PG: III

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Boron

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):
R11- Highly flammable. R22- Harmful if swallowed. S16- Keep away from sources of ignition - No smoking.

HMIS (U.S.A.):

Health Hazard: 1

Fire Hazard: 1

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 1

Flammability: 1

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Safety glasses.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/09/2005 04:24 PM

Last Updated: 05/21/2013 12:00 PM

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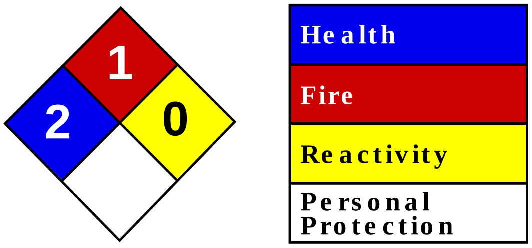

Material Safety Data Sheet

Dichloromethane MSDS

Section 1: Chemical Product and Company Identification

Product Name: Dichloromethane

Catalog Codes:

Synonyms: Methylene chloride; Methane dichloride; Methylene bichloride; Methylene dichloride; Dichloromethane; DCM.

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
75-09-2	Methylene chloride	>99.5	200-838-9

Hazard Symbols: XN

Risk Phrases: 40

Section 3: Hazards Identification

EMERGENCY OVERVIEW: Appearance: colorless liquid. This substance has caused adverse reproductive and fetal effects in animals. Potential cancer hazard.

Warning!: Causes eye and skin irritation. Causes respiratory tract irritation. Harmful if swallowed. May be harmful if inhaled. May cause central nervous system effects. Methylene chloride is metabolically converted to carbon monoxide after systemic absorption, which yields increased concentrations of carboxyhemoglobin in the blood. May cause kidney damage.

Target Organs: Blood, kidneys, heart, central nervous system, liver, lungs, pancreas.

Potential Health Effects:

Eye: Contact with eyes may cause severe irritation, and possible eye burns.

Skin: May be absorbed through the skin. Causes irritation with burning pain, itching, and redness. Prolonged exposure may result in skin burns.

Ingestion: Causes gastrointestinal irritation with nausea, vomiting and diarrhea. May cause kidney damage. May cause central nervous system depression, characterized by excitement, followed by headache, dizziness, drowsiness, and nausea.

Advanced stages may cause collapse, unconsciousness, coma and possible death due to respiratory failure. May cause carboxyhemoglobinemia.

Inhalation: Inhalation of high concentrations may cause central nervous system effects characterized by nausea, headache, dizziness, unconsciousness and coma. Causes respiratory tract irritation. May cause narcotic effects in high concentration. Vapors may cause dizziness or suffocation. May cause blood changes. Overexposure may cause an increase in carboxyhemoglobin levels in the blood. Can produce delayed pulmonary edema. Because of its high volatility, airborne concentrations of methylene chloride can accumulate in poorly ventilated areas. Odor is a poor indicator of possibly dangerous air concentrations of methylene chloride.

Chronic: Possible cancer hazard based on tests with laboratory animals. Prolonged or repeated skin contact may cause dermatitis. May cause reproductive and fetal effects. Laboratory experiments have resulted in mutagenic effects. Chronic exposure may cause lung, liver, and pancreatic tumors. May cause conjunctivitis and/or corneal burns.

Section 4: First Aid Measures

Eyes: In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical aid.

Skin: In case of contact, flush skin with plenty of water. Remove contaminated clothing and shoes. Get medical aid if irritation develops and persists. Wash clothing before reuse.

Ingestion: If swallowed, do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical aid.

Inhalation: If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.

Notes to Physician: Treat symptomatically and supportively.

Section 5: Fire and Explosion Data

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Use water spray to keep fire-exposed containers cool. No flash point in conventional closed tester, but forms flammable vapor-air mixtures in larger volumes and may be an explosion hazard in a confined space.

Extinguishing Media: Use water spray, dry chemical, carbon dioxide, or appropriate foam.

Flash Point: Not applicable.

Autoignition Temperature: 556 deg C (1,032.80 deg F)

Explosion Limits, Lower: 13 vol %

Upper: 23 vol %

NFPA Rating: (estimated) Health: 2; Flammability: 1; Instability: 0

Section 6: Accidental Release Measures

General Information: Use proper personal protective equipment as indicated in Section 8.

Spills/Leaks: Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container. Avoid runoff into storm sewers and ditches which lead to waterways. Clean up spills immediately, observing precautions in the Protective Equipment section. Remove all sources of ignition. Provide ventilation.

Section 7: Handling and Storage

Handling: Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Avoid contact with eyes, skin, and clothing. Keep container tightly closed. Keep away from heat, sparks and flame. Use only with adequate ventilation. Avoid breathing vapor or mist.

Storage: Store in a tightly closed container. Keep from contact with oxidizing materials. Store in a cool, dry, well-ventilated area away from incompatible substances. Store below 40#C. Keep away from active metals.

Section 8: Exposure Controls/Personal Protection

Engineering Controls: Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use adequate general or local exhaust ventilation to keep airborne concentrations below the permissible exposure limits.

Exposure Limits:

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Methylene chloride	50 ppm TWA	2300 ppm IDLH	25 ppm TWA (8 hr); 125 ppm STEL (15 min); 12.5 ppm Action Level (See 29 CFR 1910 .1052)

OSHA Vacated PELs: Methylene chloride: 500 ppm TWA

Personal Protective Equipment:

Eyes: Wear chemical goggles.

Skin: Wear appropriate protective gloves to prevent skin exposure.

Clothing: Wear appropriate protective clothing to prevent skin exposure.

Respirators: A respiratory protection program that meets OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions warrant a respirator's use.

Section 9: Physical and Chemical Properties

Physical State: Liquid

Appearance: colorless

Odor: ethereal odor - chloroform-like

pH: Not available.

Vapor Pressure: 350 mm Hg @ 20 deg C

Vapor Density: 2.93 (Air=1)

Evaporation Rate: Not available.

Viscosity: Not available.

Boiling Point: 40 deg C

Freezing/Melting Point: -97 deg C

Decomposition Temperature: Not available.

Solubility: Slightly soluble.

Specific Gravity/Density: 1.33 (Water=1)

Molecular Formula: CH_2Cl_2

Molecular Weight: 84.92

Section 10: Stability and Reactivity Data

Chemical Stability: Stable at room temperature in closed containers under normal storage and handling conditions. May form explosive mixtures in atmospheres having high oxygen content.

Conditions to Avoid: Excess heat, attacks some plastics, rubber, and coatings, confined spaces, When no water is present, dichloromethane is not corrosive to metals. At high temperatures and in the presence of water (causing slow decomposition forming HCl), corrosion of iron, some stainless steels, copper and aluminum can occur..

Incompatibilities with Other Materials: Strong oxidizing agents, strong bases, chemically active metals.

Hazardous Decomposition Products: Hydrogen chloride, phosgene, carbon monoxide, carbon dioxide.

Hazardous Polymerization: Will not occur.

Section 11: Toxicological Information

RTECS#:

CAS#: 75-09-2: PA8050000

LD50/LC50: CAS# 75-09-2: Draize test, rabbit, eye: 162 mg Moderate; Draize test, rabbit, eye: 10 mg Mild; Draize test, rabbit, eye: 500 mg/24H Mild; Draize test, rabbit, skin: 810 mg/24H Severe; Draize test, rabbit, skin: 100 mg/24H Moderate; Inhalation, mouse: LC50 = 14400 ppm/7H; Inhalation, rat: LC50 = 52 gm/m3; Oral, mouse: LD50 = 873 mg/kg; Oral, rat: LD50 = 1600 mg/kg;

Carcinogenicity: CAS# 75-09-2:

ACGIH: A3 - Confirmed animal carcinogen with unknown relevance to humans

California: carcinogen, initial date 4/1/88

NIOSH: potential occupational carcinogen

NTP: Suspect carcinogen

OSHA: Possible Select carcinogen

IARC: Group 2B carcinogen

Epidemiology: There are few reports of injury despite widespread use of dichloromethane (ACGIH, 1991). Solvent abuse has led to death (Harbison, 1998).

Teratogenicity: Inhalation, rat: TCLo = 4500 ppm/24H (female 1-17 day(s) after conception) Effects on Newborn - behavioral.; Inhalation, rat: TCLo = 1250 ppm/7H (female 6-15 day(s) after conception) Specific Developmental Abnormalities - musculoskeletal system and urogenital system.

Reproductive Effects: Reproductive effects have occurred in experimental animals.

Neurotoxicity: No information available.

Mutagenicity: DNA inhibition: Human, Fibroblast = 5000 ppm/1H (Continuous).; Morphological transformation: Rat, Embryo = 160 umol/L.; DNA damage: Oral, rat = 1275 mg/kg.; Inhalation, mouse: TCLo = 2000 ppm/5H/2Y-C (Tumorigenic - Carcinogenic by RTECS criteria--Lungs, Thorax, or Respiration - Tumors).

Other Studies: See actual entry in RTECS for complete information.

Section 12: Ecological Information

Ecotoxicity: Fish: Bluegill/Sunfish: 230mg/L; 24H; StaticFish: Fathead Minnow: 196mg/L; 96H; This chemical has a moderate potential to affect some aquatic organisms. It is resistant to biodegradation, and has a low potential to persist in the aquatic environment. 96-hr. EC50 (loss of equilibrium); Fathead minnow: 99mg/L; 96-hr. EC10: 66.3 mg/L. Bluegill sunfish: 96-hr. LC50=220 mg/L; Water flea: 24-hr. LC50=2270 mg/L; No observed effect level:1550 mg/L.

Environmental: Terrestrial: Expected to evaporate from near surface soil into the atmosphere; expected to leach. Aquatic: Primarily lost by evaporation to the atmosphere which should take several hours depending on wind and mixing conditions.

Atmospheric: Will degrade by reaction with hydroxyl radicals with a half life of several months. . Dichloromethane is reported to completely biodegrade under aerobic conditions with sewage seed or activated sludge between 6 hours to 7 days. Not expected to bioconcentrate due to its low octanol/water coefficient.

Physical: No information available.

Other: No information available.

Section 13: Disposal Considerations

RCRA P-Series: None listed.

RCRA U-Series: CAS# 75-09-2: waste number U080.

Section 14: Transport Information

	US DOT	IATA	RID/ADR	IMO	Canada TDG
Shipping Name:	DICHLOROMETHANE				METHYLENE CHLORIDE
Hazard Class:	6.1				6.1
UN Number:	UN1593				UN1593
Packing Group:	III				III

Section 15: Other Regulatory Information

US FEDERAL:

TSCA: CAS# 75-09-2 is listed on the TSCA inventory.

Health & Safety Reporting List: CAS# 75-09-2: Effective 10/4/82; Sunset 10/4/92

Chemical Test Rules: None of the chemicals in this product are under a Chemical Test Rule.

Section 12b: None of the chemicals are listed under TSCA Section 12b.

TSCA Significant New Use Rule: None of the chemicals in this material have a SNUR under TSCA.

SARA:

CERCLA Hazardous Substances and corresponding RQs: CAS# 75-09-2: 1000 lb final RQ; 454 kg final RQ

SARA Section 302 Extremely Hazardous Substances: None of the chemicals in this product have a TPQ.

SARA Codes: CAS # 75-09-2: acute, chronic.

Section 313: This material contains Methylene chloride (CAS# 75-09-2, 99 5%),which is subject to the reporting requirements of Section 313 of SARA Title III and 40 CFR Part 373.

Clean Air Act: CAS# 75-09-2 is listed as a hazardous air pollutant (HAP). This material does not contain any Class 1 Ozone depletors. This material does not contain any Class 2 Ozone depletors.

Clean Water Act: None of the chemicals in this product are listed as Hazardous Substances under the CWA. CAS# 75-09-2 is listed as a Priority Pollutant under the Clean Water Act. CAS# 75-09-2 is listed as a Toxic Pollutant under the Clean Water Act.

OSHA: None of the chemicals in this product are considered highly hazardous by OSHA.

STATE: CAS# 75-09-2 can be found on the following state right to know lists: California, New Jersey, Pennsylvania, Minnesota, Massachusetts.

The following statement(s) is(are) made in order to comply with the California Safe Drinking Water Act: WARNING: This product contains Methylene chloride, a chemical known to the state of California to cause cancer. California No Significant Risk Level: CAS# 75-09-2: 200 #g/day NSRL (inhalation); 50 #g/day NSRL (except inhalation)

European/International Regulations:

European Labeling in Accordance with EC Directives:

Hazard Symbols: XN

Risk Phrases: R 40 Limited evidence of a carcinogenic effect.

Safety Phrases: S 23 Do not inhale gas/fumes/vapour/spray. S 24/25 Avoid contact with skin and eyes. S 36/37 Wear suitable protective clothing and gloves.

WGK (Water Danger/Protection): CAS# 75-09-2: 2

Canada - DSL/NDSL: CAS# 75-09-2 is listed on Canada's DSL List.

Canada - WHMIS: This product has a WHMIS classification of D1B, D2A.

Canadian Ingredient Disclosure List: CAS# 75-09-2 is listed on the Canadian Ingredient Disclosure List.

Exposure Limits: CAS# 75-09-2: OEL-AUSTRALIA:TWA 100 ppm (350 mg/m3);Carcinogen OEL- AUSTRIA:TWA 100 ppm (360 mg/m3) OEL-BELGIUM:TWA 50 ppm (174 mg/m3);Ca rcinogen OEL-CZECHOSLOVAKIA:TWA 500 mg/m3;STEL 2500 mg/m3 OEL-DENMAR K:TWA 50 ppm (175 mg/m3);Skin;Carcinoge OEL-FINLAND:TWA 100 ppm (350 mg/m3);STEL 250 ppm (870 mg/m3) OEL-FRANCE:TWA 100 ppm (360 mg/m3);ST EL 500 ppm (1800 mg/m3) OEL-GERMANY:TWA 100 ppm (360 mg/m3);Carcinoge n OEL-HUNGARY:STEL 10 mg/m3;Carcinogen OEL-JAPAN:TWA 100 ppm (350 mg /m3) OEL-THE NETHERLANDS:TWA 100 ppm (350 mg/m3);STEL 500 ppm OEL-TH E PHILIPINES:TWA 500 ppm (1740 mg/m3) OEL-POLAND:TWA 50 mg/m3 OEL-RU SSIA:TWA 100 ppm;STEL 50 mg/m3 OEL-SWEDEN:TWA 35 ppm (120 mg/m3);STEL 70 ppm (25 mg/m3);Skin OEL-SWITZERLAND:TWA 100 ppm (360 mg/m3);STEL 500 ppm OEL-THAILAND:TWA 500 mg/m3;STEL 1000 mg/m3 OEL-TURKEY:TWA 50 0 ppm (1740 mg/m3) OEL-UNITED KINGDOM:TWA 100 ppm (350 mg/m3);STEL 25 0 ppm OEL IN BULGARIA, COLOMBIA, JORDAN, KOREA check ACGIH TLV OEL I N NEW ZEALAND, SINGAPORE, VIETNAM check ACGI TLV

Section 16: Other Information

Created: 04/19/2005 12:24 PM

Last Updated: 05/21/2013 12:00 PM

SIGMA-ALDRICH

sigma-aldrich.com

SAFETY DATA SHEET

Version 3.4
Revision Date 06/28/2014
Print Date 02/02/2016

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Dysprosium(III) chloride

Product Number : 325546
Brand : Aldrich

CAS-No. : 10025-74-8

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : (314) 776-6555

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Skin irritation (Category 2), H315
Eye irritation (Category 2A), H319
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Warning

Hazard statement(s)	
H315	Causes skin irritation.
H319	Causes serious eye irritation.
H335	May cause respiratory irritation.

Precautionary statement(s)	
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P271	Use only outdoors or in a well-ventilated area.
P280	Wear protective gloves/ eye protection/ face protection.
P302 + P352	IF ON SKIN: Wash with plenty of soap and water.
P304 + P340	IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.
P305 + P351 + P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove

	contact lenses, if present and easy to do. Continue rinsing.
P312	Call a POISON CENTER or doctor/ physician if you feel unwell.
P321	Specific treatment (see supplemental first aid instructions on this label).
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P337 + P313	If eye irritation persists: Get medical advice/ attention.
P362	Take off contaminated clothing and wash before reuse.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : Cl_3Dy
Molecular Weight : 268.86 g/mol
CAS-No. : 10025-74-8
EC-No. : 233-039-9

Hazardous components

Component	Classification	Concentration
Dysprosium trichloride		
	Skin Irrit. 2; Eye Irrit. 2A; STOT SE 3; H315, H319, H335	-

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

Hydrogen chloride gas, Metal oxides

5.3 Advice for firefighters

Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Store under inert gas. Moisture sensitive. Keep in a dry place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Safety glasses with side-shields conforming to EN166 Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min

Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
impervious clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
For nuisance exposures use type P95 (US) or type P1 (EU EN 143) particle respirator.For higher level protection use type OV/AG/P99 (US) or type ABEK-P2 (EU EN 143) respirator cartridges. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: powder
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 680 °C (1,256 °F) - lit.
f)	Initial boiling point and boiling range	no data available
g)	Flash point	not applicable
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	3.67 g/mL at 25 °C (77 °F)
n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information

no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity

no data available

10.2 Chemical stability

Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions

no data available

10.4 Conditions to avoid

Avoid moisture.

10.5 Incompatible materials

Strong oxidizing agents

10.6 Hazardous decomposition products

Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - mouse - 5,443 mg/kg

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
Inhalation - May cause respiratory irritation.

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: JW0700000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

no data available

12.2 Persistence and degradability

no data available

12.3 Bioaccumulative potential

no data available

12.4 Mobility in soil

no data available

12.5 Results of PBT and vPvB assessment

PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Dysprosium trichloride	10025-74-8	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Dysprosium trichloride	10025-74-8	

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

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16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Eye Irrit.	Eye irritation
H315	Causes skin irritation.
H319	Causes serious eye irritation.
H335	May cause respiratory irritation.
Skin Irrit.	Skin irritation
STOT SE	Specific target organ toxicity - single exposure

HMIS Rating

Health hazard:	2
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	2
Fire Hazard:	0
Reactivity Hazard:	0

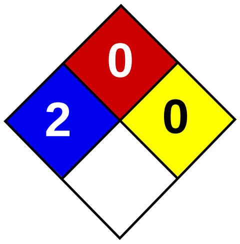
Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.4 Revision Date: 06/28/2014 Print Date: 02/02/2016



Health	2
Fire	0
Reactivity	0
Personal Protection	E

Material Safety Data Sheet

Ferrous sulfate MSDS

Section 1: Chemical Product and Company Identification

Product Name: Ferrous sulfate

Catalog Codes: SLF1516

CAS#: 13463-43-9

RTECS: Not available.

TSCA: TSCA 8(b) inventory: No products were found.

CI#: Not available.

Synonym: Ferrous Sulfate Hydrate; Ferrous Sulfate Dried Powder

Chemical Name: Ferrous Sulfate

Chemical Formula: $FeSO4.xH2O$

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Ferrous sulfate	13463-43-9	100

Toxicological Data on Ingredients: Ferrous sulfate LD50: Not available. LC50: Not available.

Section 3: Hazards Identification

Potential Acute Health Effects: Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to kidneys, liver, cardiovascular system, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation: Not available.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Not applicable.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Do not breathe dust. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If you feel unwell, seek medical attention and show the label when possible. Avoid contact with skin and eyes.

Storage:
Hygroscopic. Keep container tightly closed. Keep container in a cool, well-ventilated area. Do not store above 24°C (75.2°F).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Splash goggles. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid.

Odor: Not available.

Taste: Not available.

Molecular Weight: 151.9 g/mole + H20

Color: Grayish -white to yellowish. (Light.)

pH (1% soln/water): Not available.

Boiling Point: Not available.

Melting Point: Not available.

Critical Temperature: Not available.

Specific Gravity: Not available.

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water.

Solubility: Soluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Incompatibles

Incompatibility with various substances: Not available.

Corrosivity: Not available.

Special Remarks on Reactivity:
Hygroscopic. Loses water at about 300 C. No other information found.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Inhalation. Ingestion.

Toxicity to Animals:
LD50: Not available. LC50: Not available.

Chronic Effects on Humans: May cause damage to the following organs: kidneys, liver, cardiovascular system, central nervous system (CNS).

Other Toxic Effects on Humans: Hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: May affect genetic material (mutagenic)

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: May cause skin irritation. Eyes: May cause eye irritation. Inhalation: May cause respiratory tract irritation. Ingestion: Harmful if swallowed. May cause gastrointestinal tract distrubances and irritation with nausea, vomiting, colic, constipation, diarrhea, black stool. May also affect behavior/Central Nervous System (somnolence -general depressed activity), respiration, cardiovascular system, liver, kidneys (pink urine discoloration). Chronic Potential Health Effects: Repeated exposure via ingestion may increase iron levels in the liver, and spleen. Damage may occur to spleen and liver.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: No products were found.

Other Regulations: OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):
R36/38- Irritating to eyes and skin. S2- Keep out of the reach of children. S46- If swallowed, seek medical advice immediately and show this container or label.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 0

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 0

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/09/2005 05:33 PM

Last Updated: 05/21/2013 12:00 PM

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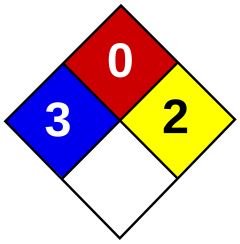

Health	3
Fire	0
Reactivity	2
Personal Protection	

Material Safety Data Sheet

Sulfuric acid MSDS

Section 1: Chemical Product and Company Identification

Product Name: Sulfuric acid

Catalog Codes: SLS2539, SLS1741, SLS3166, SLS2371, SLS3793

CAS#: 7664-93-9

RTECS: WS5600000

TSCA: TSCA 8(b) inventory: Sulfuric acid

CI#: Not applicable.

Synonym: Oil of Vitriol; Sulfuric Acid

Chemical Name: Hydrogen sulfate

Chemical Formula: H2-SO4

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Sulfuric acid	7664-93-9	95 - 98

Toxicological Data on Ingredients: Sulfuric acid: ORAL (LD50): Acute: 2140 mg/kg [Rat.]. VAPOR (LC50): Acute: 510 mg/m 2 hours [Rat]. 320 mg/m 2 hours [Mouse].

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of skin contact (corrosive, irritant, permeator), of eye contact (irritant, corrosive), of ingestion, of inhalation. Liquid or spray mist may produce tissue damage particularly on mucous membranes of eyes, mouth and respiratory tract. Skin contact may produce burns. Inhalation of the spray mist may produce severe irritation of respiratory tract, characterized by coughing, choking, or shortness of breath. Severe over-exposure can result in death. Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Classified 1 (Proven for human.) by IARC, + (Proven.) by OSHA. Classified A2 (Suspected for human.) by ACGIH. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to kidneys, lungs, heart, cardiovascular system, upper respiratory tract, eyes, teeth. Repeated or prolonged exposure to the substance can produce target organs damage. Repeated or prolonged

contact with spray mist may produce chronic eye irritation and severe skin irritation. Repeated or prolonged exposure to spray mist may produce respiratory tract irritation leading to frequent attacks of bronchial infection. Repeated exposure to a highly toxic material may produce general deterioration of health by an accumulation in one or many human organs.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention immediately.

Skin Contact:
In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Cover the irritated skin with an emollient. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention immediately.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek immediate medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if symptoms appear.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion:
Products of combustion are not available since material is non-flammable. However, products of decompostion include fumes of oxides of sulfur. Will react with water or steam to produce toxic and corrosive fumes. Reacts with carbonates to generate carbon dioxide gas. Reacts with cyanides and sulfides to form poisonous hydrogen cyanide and hydrogen sulfide respectively.

Fire Hazards in Presence of Various Substances: Combustible materials

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available. Slightly explosive in presence of oxidizing materials.

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards:
Metal acetylides (Monocesium and Monorubidium), and carbides ignite with concentrated sulfuric acid. White Phosphorous + boiling Sulfuric acid or its vapor ignites on contact. May ignite other combustible materials. May cause fire when sulfuric acid is mixed with Cyclopentadiene, cyclopentanone oxime, nitroaryl amines, hexalithium disilicide, phorphorous (III) oxide, and oxidizing agents such as chlorates, halogens, permanganates.

Special Remarks on Explosion Hazards:
Mixtures of sulfuric acid and any of the following can explode: p-nitrotoluene, pentasilver trihydroxydiaminophosphate, perchlorates, alcohols with strong hydrogen peroxide, ammonium tetraperoxychromate, mercuric nitrite, potassium chlorate, potassium permanganate with potassium chloride, carbides, nitro compounds, nitrates, carbides, phosphorous, iodides, picratres, fulminats, dienes, alcohols (when heated) Nitramide decomposes explosively on contact with concentrated sulfuric acid. 1,3,5-Trinitrosohexahydro-1,3,5-triazine + sulfuric acid causes explosive decompositon.

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container. If necessary: Neutralize the residue with a dilute solution of sodium carbonate.

Large Spill:
Corrosive liquid. Poisonous liquid. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not get water inside container. Do not touch spilled material. Use water spray curtain to divert vapor drift. Use water spray to reduce vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal. Neutralize the residue with a dilute solution of sodium carbonate. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep locked up.. Keep container dry. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Never add water to this product. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, reducing agents, combustible materials, organic materials, metals, acids, alkalis, moisture. May corrode metallic surfaces. Store in a metallic or coated fiberboard drum using a strong polyethylene inner package.

Storage:
Hygroscopic. Reacts. violently with water. Keep container tightly closed. Keep container in a cool, well-ventilated area. Do not store above 23°C (73.4°F).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Face shield. Full suit. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves. Boots.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 1 STEL: 3 (mg/m3) [Australia] Inhalation TWA: 1 (mg/m3) from OSHA (PEL) [United States] Inhalation TWA: 1 STEL: 3 (mg/m3) from ACGIH (TLV) [United States] [1999] Inhalation TWA: 1 (mg/m3) from NIOSH [United States] Inhalation TWA: 1 (mg/m3) [United Kingdom (UK)]Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid. (Thick oily liquid.)

Odor: Odorless, but has a choking odor when hot.

Taste: Marked acid taste. (Strong.)

Molecular Weight: 98.08 g/mole

Color: Colorless.

pH (1% soln/water): Acidic.

Boiling Point:
270°C (518°F) - 340 deg. C Decomposes at 340 deg. C

Melting Point: -35°C (-31°F) to 10.36 deg. C (93% to 100% purity)

Critical Temperature: Not available.

Specific Gravity: 1.84 (Water = 1)

Vapor Pressure: Not available.

Vapor Density: 3.4 (Air = 1)

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water.

Solubility:
Easily soluble in cold water. Sulfuric is soluble in water with liberation of much heat. Soluble in ethyl alcohol.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability:
Conditions to Avoid: Incompatible materials, excess heat, combustible material materials, organic materials, exposure to moist air or water, oxidizers, amines, bases. Always add the acid to water, never the reverse.

Incompatibility with various substances:
Reactive with oxidizing agents, reducing agents, combustible materials, organic materials, metals, acids, alkalis, moisture.

Corrosivity:
Extremely corrosive in presence of aluminum, of copper, of stainless steel(316). Highly corrosive in presence of stainless steel(304). Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Hygroscopic. Strong oxidizer. Reacts violently with water and alcohol especially when water is added to the product. Incompatible (can react explosively or dangerously) with the following: ACETIC ACID, ACRYLIC ACID, AMMONIUM HYDROXIDE, CRESOL, CUMENE, DICHLOROETHYL ETHER, ETHYLENE CYANOHYDRIN, ETHYLENEIMINE, NITRIC ACID, 2-NITROPROPANE, PROPYLENE OXIDE, SULFOLANE, VINYLIDENE CHLORIDE, DIETHYLENE GLYCOL MONOMETHYL ETHER, ETHYL ACETATE, ETHYLENE CYANOHYDRIN, ETHYLENE GLYCOL MONOETHYL ETHER ACETATE, GLYOXAL, METHYL ETHYL KETONE, dehydrating agents, organic materials, moisture (water), Acetic anhydride, Acetone, cyanohydrin, Acetone+nitric acid, Acetone + potassium dichromate, Acetonitrile, Acrolein, Acrylonitrile, Acrylonitrile +water, Alcohols + hydrogen peroxide, ally compounds such as Allyl alcohol, and Allyl Chloride, 2-Aminoethanol, Ammonium hydroxide, Ammonium triperchromate, Aniline, Bromate + metals, Bromine pentafluoride, n-Butyraldehyde, Carbides, Cesium acetylene carbide, Chlorates, Cyclopentanone oxime, chlorinates, Chlorates + metals, Chlorine trifluoride, Chlorosulfonic acid, 2-cyano-4-nitrobenzenediazonium hydrogen sulfate, Cuprous nitride, p-chloronitrobenzene, 1,5-Dinitronaphthlene +

sulfur, Diisobutylene, p-dimethylaminobenzaldehyde, 1,3-Diazidobenzene, Dimethylbenzylcarbinol + hydrogen peroxide, Epichlorohydrin, Ethyl alcohol + hydrogen peroxide, Ethylene diamine, Ethylene glycol and other glycols, , Ethylenimine, Fulminates, hydrogen peroxide, Hydrochloric acid, Hydrofluoric acid, Iodine heptafluoride, Indane + nitric acid, Iron, Isoprene, Lithium silicide, Mercuric nitride, Mesityl oxide, Mercury nitride, Metals (powdered), Nitromethane, Nitric acid + glycerides, p-Nitrotoluene, Pentasilver trihydroxydiaminophosphate, Perchlorates, Perchloric acid, Permanganates + benzene, 1-Phenyl-2-methylpropyl alcohol + hydrogen peroxide, Phosphorus, Phosphorus isocyanate, Picrates, Potassium tert-butoxide, Potassium chlorate, Potassium Permanganate and other permanganates, halogens, amines, Potassium Permanganate + Potassium chloride, Potassium Permanganate + water, Propiolactone (beta)-, Pyridine, Rubidium aceteylene carbide, Silver permanganate, Sodium, Sodium carbonate, sodium hydroxide, Steel, styrene monomer, toluene + nitric acid, Vinyl acetate, Thalium (I) azidodithiocarbonate, Zinc chlorate, Zinc Iodide, azides, carbonates, cyanides, sulfides, sulfites, alkali hydrides, carboxylic acid anhydrides, nitriles, olefinic organics, aqueous acids, cyclopentadiene, cyano-alcohols, metal acetylides, Hydrogen gas is generated by the action of the acid on most metals (i.e. lead, copper, tin, zinc, aluminum, etc.). Concentrated sulfuric acid oxidizes, dehydrates, or sulfonates most organic compounds.

Special Remarks on Corrosivity:
Non-corrosive to lead and mild steel, but dillute acid attacks most metals. Attacks many metals releasing hydrogen. Minor corrosive effect on bronze. No corrosion data on brass or zinc.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation. Ingestion.

Toxicity to Animals:
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 2140 mg/kg [Rat.]. Acute toxicity of the vapor (LC50): 320 mg/m3 2 hours [Mouse].

Chronic Effects on Humans:
CARCINOGENIC EFFECTS: Classified 1 (Proven for human.) by IARC, + (Proven.) by OSHA. Classified A2 (Suspected for human.) by ACGIH. May cause damage to the following organs: kidneys, lungs, heart, cardiovascular system, upper respiratory tract, eyes, teeth.

Other Toxic Effects on Humans:
Extremely hazardous in case of inhalation (lung corrosive). Very hazardous in case of skin contact (corrosive, irritant, permeator), of eye contact (corrosive), of ingestion, .

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:
Mutagenicity: Cytogenetic Analysis: Hamster, ovary = 4mmol/L Reproductive effects: May cause adverse reproductive effects based on animal data. Developmental abnormalities (musculoskeletal) in rabbits at a dose of 20 mg/m3 for 7 hrs.(RTECS) Teratogenecity: neither embryotoxic, fetoxic, nor teratogenetic in mice or rabbits at inhaled doses producing some maternal toxicity

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: Causes severe skin irritation and burns. Continued contact can cause tissue necrosis. Eye: Causes severe eye irritation and burns. May cause irreversible eye injury. Ingestion: Harmful if swallowed. May cause permanent damage to the digestive tract. Causes gastrointestial tract burns. May cause perforation of the stomach, GI bleeding, edema of the glottis, necrosis and scarring, and sudden circulatory collapse(similar to acute inhalation). It may also cause systemic toxicity with acidosis. Inhalation: May cause severe irritation of the respiratory tract and mucous membranes with sore throat, coughing, shortness of breath, and delayed lung edema. Causes chemical burns to the repiratory tract. Inhalation may be fatal as a result of spasm, inflammation, edema of the larynx and bronchi, chemical pneumonitis, and pulmonary edema. Cause corrosive action on mucous membranes. May affect cardiovascular system (hypotension, depressed cardiac output, bradycardia). Circulatory collapse with clammy skin, weak and rapid pulse, shallow respiration, and scanty urine may follow. Circulatory shock is often the immediate cause of death. May also affect teeth(changes in teeth and supporting structures - erosion, discoloration). Chronic Potential Health Effects: Inhalation: Prolonged or repeated inhalation may affect behavior (muscle contraction or spasticity), urinary system (kidney damage), and cardiovascular system, heart (ischemic heart leisons), and respiratory system/lungs(pulmonary edema, lung damage), teeth (dental discoloration, erosion). Skin: Prolonged or repeated skin contact may cause dermatitis, an allergic skin reaction.

Section 12: Ecological Information

Ecotoxicity: Ecotoxicity in water (LC50): 49 mg/l 48 hours [bluegill/sunfish].

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Sulfuric acid may be placed in sealed container or absorbed in vermiculite, dry sand, earth, or a similar material. It may also be diluted and neutralized. Be sure to consult with local or regional authorities (waste regulators) prior to any disposal. Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Class 8: Corrosive material

Identification: : Sulfuric acid UNNA: 1830 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
Illinois toxic substances disclosure to employee act: Sulfuric acid New York release reporting list: Sulfuric acid Rhode Island RTK hazardous substances: Sulfuric acid Pennsylvania RTK: Sulfuric acid Minnesota: Sulfuric acid Massachusetts RTK: Sulfuric acid New Jersey: Sulfuric acid California Director's List of Hazardous Substances (8 CCR 339): Sulfuric acid Tennessee RTK: Sulfuric acid TSCA 8(b) inventory: Sulfuric acid SARA 302/304/311/312 extremely hazardous substances: Sulfuric acid SARA 313 toxic chemical notification and release reporting: Sulfuric acid CERCLA: Hazardous substances.: Sulfuric acid: 1000 lbs. (453.6 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS D-1A: Material causing immediate and serious toxic effects (VERY TOXIC). CLASS E: Corrosive liquid.

DSCL (EEC):
R35- Causes severe burns. S2- Keep out of the reach of children. S26- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. S30- Never add water to this product. S45- In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

HMIS (U.S.A.):

Health Hazard: 3

Fire Hazard: 0

Reactivity: 2

Personal Protection:

National Fire Protection Association (U.S.A.):

Health: 3

Flammability: 0

Reactivity: 2

Specific hazard:

Protective Equipment:
Gloves. Full suit. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Face shield.

Section 16: Other Information

References:
-Material safety data sheet emitted by: la Commission de la Santé et de la Sécurité du Travail du Québec. -The Sigma-Aldrich Library of Chemical Safety Data, Edition II. -Hawley, G.G.. The Condensed Chemical Dictionary, 11e ed., New York N.Y., Van Nostrand Reinold, 1987.

Other Special Considerations: Not available.

Created: 10/09/2005 11:58 PM

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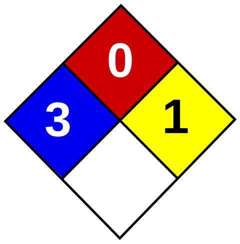

Health	3
Fire	0
Reactivity	1
Personal Protection	

Material Safety Data Sheet

Hydrochloric acid MSDS

Section 1: Chemical Product and Company Identification

Product Name: Hydrochloric acid

Catalog Codes: SLH1462, SLH3154

CAS#: Mixture.

RTECS: MW4025000

TSCA: TSCA 8(b) inventory: Hydrochloric acid

CI#: Not applicable.

Synonym: Hydrochloric Acid; Muriatic Acid

Chemical Name: Not applicable.

Chemical Formula: Not applicable.

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Hydrogen chloride	7647-01-0	20-38
Water	7732-18-5	62-80

Toxicological Data on Ingredients: Hydrogen chloride: GAS (LC50): Acute: 4701 ppm 0.5 hours [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of skin contact (corrosive, irritant, permeator), of eye contact (irritant, corrosive), of ingestion, . Slightly hazardous in case of inhalation (lung sensitizer). Non-corrosive for lungs. Liquid or spray mist may produce tissue damage particularly on mucous membranes of eyes, mouth and respiratory tract. Skin contact may produce burns. Inhalation of the spray mist may produce severe irritation of respiratory tract, characterized by coughing, choking, or shortness of breath. Severe over-exposure can result in death. Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.

Potential Chronic Health Effects:
Slightly hazardous in case of skin contact (sensitizer). CARCINOGENIC EFFECTS: Classified 3 (Not classifiable for human.) by IARC [Hydrochloric acid]. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to kidneys, liver, mucous membranes, upper respiratory tract, skin, eyes, Circulatory System, teeth. Repeated or prolonged exposure to the substance can produce target

organs damage. Repeated or prolonged contact with spray mist may produce chronic eye irritation and severe skin irritation. Repeated or prolonged exposure to spray mist may produce respiratory tract irritation leading to frequent attacks of bronchial infection. Repeated exposure to a highly toxic material may produce general deterioration of health by an accumulation in one or many human organs.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention immediately.

Skin Contact:
In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Cover the irritated skin with an emollient. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention immediately.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek immediate medical attention.

Ingestion:
If swallowed, do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: of metals

Explosion Hazards in Presence of Various Substances: Non-explosive in presence of open flames and sparks, of shocks.

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards:
Non combustible. Calcium carbide reacts with hydrogen chloride gas with incandescence. Uranium phosphide reacts with hydrochloric acid to release spontaneously flammable phosphine. Rubidium acetylene carbides burns with slightly warm hydrochloric acid. Lithium silicide in contact with hydrogen chloride becomes incandescent. When dilute hydrochloric acid is used, gas spontaneously flammable in air is evolved. Magnesium boride treated with concentrated hydrochloric acid produces spontaneously flammble gas. Cesium acetylene carbide burns hydrogen chloride gas. Cesium carbide ignites in contact with hydrochloric acid unless acid is dilute. Reacts with most metals to produce flammable Hydrodgen gas.

Special Remarks on Explosion Hazards:

Hydrogen chloride in contact with the following can cause an explosion, ignition on contact, or other violent/vigorous reaction: Acetic anhydride AgClO + CCl4 Alcohols + hydrogen cyanide, Aluminum Aluminum-titanium alloys (with HCl vapor), 2-Amino ethanol, Ammonium hydroxide, Calcium carbide Ca3P2 Chlorine + dinitroanilines (evolves gas), Chlorosulfonic acid Cesium carbide Cesium acetylene carbide, 1,1-Difluoroethylene Ethylene diamine Ethylene imine, Fluorine, HClO4 Hexalithium disilicide H2SO4 Metal acetylides or carbides, Magnesium boride, Mercuric sulfate, Oleum, Potassium permanganate, beta-Propiolactone Propylene oxide Rubidium carbide, Rubidium, acetylene carbide Sodium (with aqueous HCl), Sodium hydroxide Sodium tetraselenium, Sulfonic acid, Tetraselenium tetranitride, U3P4 , Vinyl acetate. Silver perchlorate with carbon tetrachloride in the presence of hydrochloric acid produces trichloromethyl perchlorate which detonates at 40 deg. C.

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container. If necessary: Neutralize the residue with a dilute solution of sodium carbonate.

Large Spill:
Corrosive liquid. Poisonous liquid. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not get water inside container. Do not touch spilled material. Use water spray curtain to divert vapor drift. Use water spray to reduce vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal. Neutralize the residue with a dilute solution of sodium carbonate. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep locked up.. Keep container dry. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Never add water to this product. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, organic materials, metals, alkalis, moisture. May corrode metallic surfaces. Store in a metallic or coated fiberboard drum using a strong polyethylene inner package.

Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Face shield. Full suit. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves. Boots.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
CEIL: 5 (ppm) from OSHA (PEL) [United States] CEIL: 7 (mg/m3) from OSHA (PEL) [United States] CEIL: 5 from NIOSH CEIL: 7 (mg/m3) from NIOSH TWA: 1 STEL: 5 (ppm) [United Kingdom (UK)] TWA: 2 STEL: 8 (mg/m3) [United Kingdom (UK)]Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Pungent. Irritating (Strong.)

Taste: Not available.

Molecular Weight: Not applicable.

Color: Colorless to light yellow.

pH (1% soln/water): Acidic.

Boiling Point:
108.58 C @ 760 mm Hg (for 20.22% HCl in water) 83 C @ 760 mm Hg (for 31% HCl in water) 50.5 C (for 37% HCl in water)

Melting Point:
-62.25°C (-80°F) (20.69% HCl in water) -46.2 C (31.24% HCl in water) -25.4 C (39.17% HCl in water)

Critical Temperature: Not available.

Specific Gravity:
1.1- 1.19 (Water = 1) 1.10 (20%and 22% HCl solutions) 1.12 (24% HCl solution) 1.15 (29.57% HCl solution) 1.16 (32% HCl solution) 1.19 (37% and 38%HCl solutions)

Vapor Pressure: 16 kPa (@ 20°C) average

Vapor Density: 1.267 (Air = 1)

Volatility: Not available.

Odor Threshold: 0.25 to 10 ppm

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, diethyl ether.

Solubility: Soluble in cold water, hot water, diethyl ether.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Incompatible materials, water

Incompatibility with various substances:
Highly reactive with metals. Reactive with oxidizing agents, organic materials, alkalis, water.

Corrosivity:
Extremely corrosive in presence of aluminum, of copper, of stainless steel(304), of stainless steel(316). Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Reacts with water especially when water is added to the product. Absorption of gaseous hydrogen chloride on mercuric sulfate becomes violent @ 125 deg. C. Sodium reacts very violently with gaseous hydrogen chloride. Calcium phosphide and hydrochloric acid undergo very energetic reaction. It reacts with oxidizers releasing chlorine gas. Incompatible with, alkali metals, carbides, borides, metal oxides, vinyl acetate, acetylides, sulphides, phosphides, cyanides, carbonates. Reacts with most metals to produce flammable Hydrogen gas. Reacts violently (moderate reaction with heat of evolution) with water especially when water is added to the product. Isolate hydrogen chloride from heat, direct sunlight, alkalies (reacts vigorously), organic materials, and oxidizers (especially nitric acid and chlorates), amines, metals, copper and alloys (e.g. brass), hydroxides, zinc (galvanized materials), lithium silicide (incandescence), sulfuric acid(increase in temperature and pressure) Hydrogen chloride gas is emitted when this product is in contact with sulfuric acid. Adsorption of Hydrochloric Acid onto silicon dioxide results in exothmeric reaction. Hydrogen chloride causes aldehydes and epoxides to violently polymerize. Hydrogen chloride or Hydrochloric Acid in contact with the folloiwng can cause explosion or ignition on contact or

Special Remarks on Corrosivity:

Highly corrosive. Incompatible with copper and copper alloys. It attacks nearly all metals (mercury, gold, platinium, tantalum, silver, and certain alloys are exceptions). It is one of the most corrosive of the nonoxidizing acids in contact with copper alloys. No corrosivity data on zinc, steel. Severe Corrosive effect on brass and bronze

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation.

Toxicity to Animals:
Acute oral toxicity (LD50): 900 mg/kg [Rabbit]. Acute toxicity of the vapor (LC50): 1108 ppm, 1 hours [Mouse]. Acute toxicity of the vapor (LC50): 3124 ppm, 1 hours [Rat].

Chronic Effects on Humans:
CARCINOGENIC EFFECTS: Classified 3 (Not classifiable for human.) by IARC [Hydrochloric acid]. May cause damage to the following organs: kidneys, liver, mucous membranes, upper respiratory tract, skin, eyes, Circulatory System, teeth.

Other Toxic Effects on Humans:
Very hazardous in case of skin contact (corrosive, irritant, permeator), of ingestion, . Hazardous in case of eye contact (corrosive), of inhalation (lung corrosive).

Special Remarks on Toxicity to Animals:
Lowest Published Lethal Doses (LDL/LCL) LDL [Man] -Route: Oral; 2857 ug/kg LCL [Human] - Route: Inhalation; Dose: 1300 ppm/30M LCL [Rabbit] - Route: Inhalation; Dose: 4413 ppm/30M

Special Remarks on Chronic Effects on Humans:
May cause adverse reproductive effects (fetoxicity). May affect genetic material.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: Corrosive. Causes severe skin irritation and burns. Eyes: Corrosive. Causes severe eye irritation/conjuntivitis, burns, corneal necrosis. Inhalation: May be fatal if inhaled. Material is extremely destructive to tissue of the mucous membranes and upper respiratory tract. Inhalation of hydrochloric acid fumes produces nose, throat, and larryngeal burning, and irritation, pain and inflammation, coughing, sneezing, choking sensation, hoarseness, laryngeal spasms, upper respiratory tract edema, chest pains, as well has headache, and palpitations. Inhalation of high concentrations can result in corrosive burns, necrosis of bronchial epithelium, constriction of the larynx and bronchi, nasospetal perforation, glottal closure, occur, particularly if exposure is prolonged. May affect the liver. Ingestion: May be fatal if swallowed. Causes irritation and burning, ulceration, or perforation of the gastrointestinal tract and resultant peritonitis, gastric hemorrhage and infection. Can also cause nausea, vomitting (with "coffee ground" emesis), diarrhea, thirst, difficulty swallowing, salivation, chills, fever, uneasiness, shock, strictures and stenosis (esophogeal, gastric, pyloric). May affect behavior (excitement), the cardiovascular system (weak rapid pulse, tachycardia), respiration (shallow respiration), and urinary system (kidneys- renal failure, nephritis). Acute exposure via inhalation or ingestion can also cause erosion of tooth enamel. Chronic Potential Health Effects: dyspnea, bronchitis. Chemical pneumonitis and pulmonary edema can also

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Class 8: Corrosive material

Identification: : Hydrochloric acid, solution UNNA: 1789 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
Connecticut hazardous material survey.: Hydrochloric acid Illinois toxic substances disclosure to employee act: Hydrochloric acid Illinois chemical safety act: Hydrochloric acid New York release reporting list: Hydrochloric acid Rhode Island RTK hazardous substances: Hydrochloric acid Pennsylvania RTK: Hydrochloric acid Minnesota: Hydrochloric acid Massachusetts RTK: Hydrochloric acid Massachusetts spill list: Hydrochloric acid New Jersey: Hydrochloric acid New Jersey spill list: Hydrochloric acid Louisiana RTK reporting list: Hydrochloric acid Louisiana spill reporting: Hydrochloric acid California Director's List of Hazardous Substances: Hydrochloric acid TSCA 8(b) inventory: Hydrochloric acid TSCA 4(a) proposed test rules: Hydrochloric acid SARA 302/304/311/312 extremely hazardous substances: Hydrochloric acid SARA 313 toxic chemical notification and release reporting: Hydrochloric acid CERCLA: Hazardous substances.: Hydrochloric acid: 5000 lbs. (2268 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS D-2A: Material causing other toxic effects (VERY TOXIC). CLASS E: Corrosive liquid.

DSCL (EEC):
R34- Causes burns. R37- Irritating to respiratory system. S26- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. S45- In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

HMIS (U.S.A.):

Health Hazard: 3

Fire Hazard: 0

Reactivity: 1

Personal Protection:

National Fire Protection Association (U.S.A.):

Health: 3

Flammability: 0

Reactivity: 1

Specific hazard:

Protective Equipment:
Gloves. Full suit. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Face shield.

Section 16: Other Information

References:
-Hawley, G.G.. The Condensed Chemical Dictionary, 11e ed., New York N.Y., Van Nostrand Reinold, 1987. -SAX, N.I. Dangerous Properties of Indutrial Materials. Toronto, Van Nostrand Reinold, 6e ed. 1984. -The Sigma-Aldrich Library of Chemical Safety Data, Edition II. -Guide de la loi et du règlement sur le transport des marchandises dangeureuses au canada. Centre de conformité internatinal Ltée. 1986.

Other Special Considerations: Not available.

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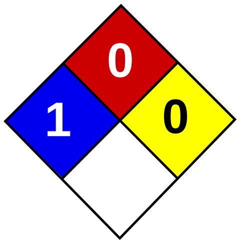

Health	1
Fire	0
Reactivity	0
Personal Protection	E

Material Safety Data Sheet

Potassium chloride MSDS

Section 1: Chemical Product and Company Identification

Product Name: Potassium chloride

Catalog Codes: SLP3334, SLP5143, SLP2317, SLP4126

CAS#: 7447-40-7

RTECS: TS8050000

TSCA: TSCA 8(b) inventory: Potassium chloride

CI#: Not available.

Synonym:

Chemical Name: Potassium Chloride

Chemical Formula: KCl

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Potassium chloride	7447-40-7	100

Toxicological Data on Ingredients: Potassium chloride: ORAL (LD50): Acute: 2500 mg/kg [Guinea pig]. 2600 mg/kg [Rat]. 1500 mg/kg [Mouse].

Section 3: Hazards Identification

Potential Acute Health Effects: Slightly hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to blood, cardiovascular system. Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:

Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention.

Skin Contact:
Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops. Cold water may be used.

Serious Skin Contact: Not available.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation: Not available.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if symptoms appear.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Not applicable.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available. Slightly explosive in presence of oxidizing materials.

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: May result in explosion with potassium permanganate and sulfuric acid.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

Section 7: Handling and Storage

Precautions:
Do not ingest. Do not breathe dust. If ingested, seek medical advice immediately and show the container or the label. Keep away from incompatibles such as oxidizing agents, acids, moisture.

Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area. Hygroscopic

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection: Safety glasses. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid.

Odor: Odorless.

Taste: Saline. (Strong.)

Molecular Weight: 74.55 g/mole

Color: White.

pH (1% soln/water): Not available.

Boiling Point: 1420°C (2588°F)

Melting Point: 770°C (1418°F)

Critical Temperature: Not available.

Specific Gravity: 1.987 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water.

Solubility:
Soluble in cold water, hot water. Very slightly soluble in methanol, n-octanol.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Incompatible materials

Incompatibility with various substances: Reactive with oxidizing agents, acids.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Hygroscopic. Incompatible with KMnO4, H2SO4, BrF3, and BrCl3. May react violently with BrF3.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Inhalation. Ingestion.

Toxicity to Animals: Acute oral toxicity (LD50): 1500 mg/kg [Mouse].

Chronic Effects on Humans: May cause damage to the following organs: blood, cardiovascular system.

Other Toxic Effects on Humans: Slightly hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:
May affect genetic material. Passes through the placental barrier in animal.

Special Remarks on other Toxic Effects on Humans:
Actute Potential Health Effects: Skin: May cause skin irritation Eye: Dust may cause eye irritation. Inhalation: Dust may cause respiratory tract irritation. Low hazard for usual industrial handling Ingestion: May affect behavior (coma, change in motor activity, listlessness, vertigo, mental confusion, paresthesias, general weakness, flaccid paralysis), metabolism, blood (change in clotting factor, electrolytic imbalance), cardiovascular (hypotension, circulatory disturbances, cardiac arrhythmias, heart block), and respiratory, gastrointestinal (irritation of GI tract, nausea, vomiting, diarrhea, abdominal discomfort, purging), and urinary(impairment of renal function) systems. Acute potassium intoxication by mouth is rare because large single doses usually induce vomiting, and because in the absence of pre-existing kidney damage potassium is rapidly excreted. Maximal nontoxic oral dose of KCl in man varies from 0.2g to 1 g of potassium/kg/day depending upon efficiency of individual excretory mechanism; lower doses sometimes cause impairment of renal function as shown by reduced inulin, and urea clearance. Chronic Potential Health Effects: May affect blood and cardiovascular system.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Potassium chloride

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):
R36- Irritating to eyes. S26- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. S39- Wear eye/face protection.

HMIS (U.S.A.):

Health Hazard: 1

Fire Hazard: 0

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 1

Flammability: 0

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Safety glasses.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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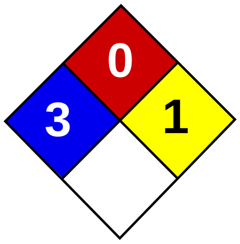
Last Updated: 05/21/2013 12:00 PM



Health	3
Fire	0
Reactivity	2
Personal Protection	J

Material Safety Data Sheet

Sodium hydroxide MSDS

Section 1: Chemical Product and Company Identification

Product Name: Sodium hydroxide

Catalog Codes: SLS3298, SLS1081, SLS2503, SLS3925, SLS1705

CAS#: 1310-73-2

RTECS: WB4900000

TSCA: TSCA 8(b) inventory: Sodium hydroxide

CI#: Not available.

Synonym: Caustic Soda

Chemical Name: Sodium Hydroxide

Chemical Formula: NaOH

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Sodium hydroxide	1310-73-2	100

Toxicological Data on Ingredients: Sodium hydroxide LD50: Not available. LC50: Not available.

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of skin contact (corrosive, irritant, permeator), of eye contact (irritant, corrosive), of ingestion, of inhalation. The amount of tissue damage depends on length of contact. Eye contact can result in corneal damage or blindness. Skin contact can produce inflammation and blistering. Inhalation of dust will produce irritation to gastro-intestinal or respiratory tract, characterized by burning, sneezing and coughing. Severe over-exposure can produce lung damage, choking, unconsciousness or death. Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to mucous membranes, upper respiratory tract, skin, eyes. Repeated or prolonged exposure to the substance can produce target organs damage. Repeated exposure of the eyes to a low level of dust can produce eye irritation. Repeated skin exposure can produce local skin destruction, or dermatitis. Repeated inhalation of dust can produce varying degree of respiratory irritation or lung damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention immediately.

Skin Contact:
In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Cover the irritated skin with an emollient. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention immediately.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek immediate medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: metals

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available. Slightly explosive in presence of heat.

Fire Fighting Media and Instructions: Not available

Special Remarks on Fire Hazards:
sodium hydroxide + zinc metal dust causes ignition of the latter. Under proper conditions of temperature, pressure and state of division, it can ignite or react violently with acetaldehyde, ally alcohol, allyl chloride, benzene-1,4-diol, chlorine trifluoride, 1,2 dichlorethylene, nitroethane, nitromethane, nitroparaffins, nitropropane, cinnamaldehyde, 2,2-dichloro-3,3-dimethylbutane. Sodium hydroxide in contact with water may generate enough heat to ignite adjacent combustible materials. Phosphorous boiled with NaOH yields mixed phosphines which may ignite spontanously in air. sodium hydroxide and cinnamaldehyde + heat may cause ignition. Reaction with certain metals releases flammable and explosive hydrogen gas.

Special Remarks on Explosion Hazards:
Sodium hydroxide reacts to form explosive products with ammonia + silver nitrate. Benzene extract of allyl benzenesulfonate prepared from allyl alcohol, and benzene sulfonyl chloride in presence of aquesous sodium hydroxide, under vacuum distillation, residue darkened and exploded. Sodium Hydroxde + impure tetrahydrofuran, which can contain peroxides, can

cause serious explosions. Dry mixtures of sodium hydroxide and sodium tetrahydroborate liberate hydrogen explosively at 230-270 deg. C. Sodium Hydroxide reacts with sodium salt of trichlorophenol + methyl alcohol + trichlorobenzene + heat to cause an explosion.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. If necessary: Neutralize the residue with a dilute solution of acetic acid.

Large Spill:
Corrosive solid. Stop leak if without risk. Do not get water inside container. Do not touch spilled material. Use water spray to reduce vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal. Neutralize the residue with a dilute solution of acetic acid. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep container dry. Do not breathe dust. Never add water to this product. In case of insufficient ventilation, wear suitable respiratory equipment. If you feel unwell, seek medical attention and show the label when possible. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, reducing agents, metals, acids, alkalis, moisture.

Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area. Hygroscopic. Deliquescent.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Splash goggles. Synthetic apron. Vapor and dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor and dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
STEL: 2 (mg/m3) from ACGIH (TLV) [United States] TWA: 2 CEIL: 2 (mg/m3) from OSHA (PEL) [United States] CEIL: 2 (mg/m3) from NIOSHConsult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (Deliquescent solid.)

Odor: Odorless.

Taste: Not available.

Molecular Weight: 40 g/mole

Color: White.

pH (1% soln/water): 13.5 [Basic.]

Boiling Point: 1388°C (2530.4°F)

Melting Point: 323°C (613.4°F)

Critical Temperature: Not available.

Specific Gravity: 2.13 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water.

Solubility: Easily soluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Incompatible materials, moisture, moist air

Incompatibility with various substances:
Highly reactive with metals. Reactive with oxidizing agents, reducing agents, acids, alkalis, moisture.

Corrosivity: Not available.

Special Remarks on Reactivity:
Hygroscopic. Much heat is evolved when solid material is dissolved in water. Therefore cold water and caution must be used for this process. Sodium hydroxide solution and octanol + diborane during a work-up of a reaction mixture of oxime and diborane in tetrahyrofuran is very exothermic, a mild explosion being noted on one occassion. Reactive with water, acids (mineral, non-oxidizing, e.g. hydrochloric, hydrofluoric acid, muriatic acid, phosphoric), acids (mineral, oxidizing e.g. chromic acid, hypochlorous acid, nitric acid, sulfuric acid), acids (organic e.g. acetic acid, benzoic acid, formic acid, methanoic acid, oxalic acid), aldehydes (e.g. acetaldehyde, acrolein, chloral hydrate, foraldehyde), carbamates (e.g. carbanolate, carbofuran), esters (e.g. butyl acetate, ethyl acetate, propyl formate), halogenated organics (dibromoethane, hexachlorobenzene, methyl chloride, trichloroethylene), isocyanates (e.g. methyl isocyanate), ketones (acetone, acetophenone, MEK, MIBK), acid chlorides, strong bases, strong oxidizing agents, strong reducing agents, flammable liquids, powdered metals and metals (i.e aluminum, tin, zinc, hafnium, raney nickel), metals (alkali and alkaline e.g. cesium, potassium, sodium), metal compounds (toxic e.g. berylium, lead acetate, nickel carbonyl, tetraethyl lead), mitrides (e.g. potassium nitride, sodium nitride), nitriles (e.g. acetonitrile, methyl cyanide), nitro compounds (organic e.g. nitrobenzene, nitromethane), acetic anhydride, chlorohydrin, chlorosulfonic acid, ethylene cyanohydrin, glyoxal, hydrosulfuric acid, oleum, propiolactone, acylonitrile, phorosous pentoxide, chloroethanol, chloroform-methanol, tetrahydroborate, cyanogen azide, 1,2,4,5 tetrachlorobenzene, cinnamaldehyde. Reacts with formaldehyde hydroxide to yield formic acid, and hydrogen.

Special Remarks on Corrosivity: Very caustic to aluminum and other metals in presence of moisture.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation. Ingestion.

Toxicity to Animals:
LD50: Not available. LC50: Not available.

Chronic Effects on Humans:
MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. May cause damage to the following organs: mucous membranes, upper respiratory tract, skin, eyes.

Other Toxic Effects on Humans:
Extremely hazardous in case of inhalation (lung corrosive). Very hazardous in case of skin contact (corrosive, irritant, permeator), of eye contact (corrosive), of ingestion, .

Special Remarks on Toxicity to Animals:
Lowest Published Lethal Dose: LDL [Rabbit] - Route: Oral; Dose: 500 mg/kg

Special Remarks on Chronic Effects on Humans: May affect genetic material. Investigation as a mutagen (cytogenetic analysis)

Special Remarks on other Toxic Effects on Humans:

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Class 8: Corrosive material

Identification: : Sodium hydroxide, solid UNNA: 1823 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
Illinois toxic substances disclosure to employee act: Sodium hydroxide Illinois chemical safety act: Sodium hydroxide New York release reporting list: Sodium hydroxide Rhode Island RTK hazardous substances: Sodium hydroxide Pennsylvania RTK: Sodium hydroxide Minnesota: Sodium hydroxide Massachusetts RTK: Sodium hydroxide New Jersey: Sodium hydroxide Louisiana spill reporting: Sodium hydroxide California Director's List of Hazardous Substances: Sodium hydroxide TSCA 8(b) inventory: Sodium hydroxide CERCLA: Hazardous substances.: Sodium hydroxide: 1000 lbs. (453.6 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): CLASS E: Corrosive solid.

DSCL (EEC):
R35- Causes severe burns. S26- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. S37/39- Wear suitable gloves and eye/face protection. S45- In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

HMIS (U.S.A.):

Health Hazard: 3

Fire Hazard: 0

Reactivity: 2

Personal Protection: j

National Fire Protection Association (U.S.A.):

Health: 3

Flammability: 0

Reactivity: 1

Specific hazard:

Protective Equipment:
Gloves. Synthetic apron. Vapor and dust respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/09/2005 06:32 PM

Last Updated: 05/21/2013 12:00 PM

SIGMA-ALDRICH

sigma-aldrich.com

SAFETY DATA SHEET

Version 3.4
Revision Date 06/28/2014
Print Date 02/02/2016

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Neodymium(III) chloride

Product Number : 449946
Brand : Aldrich

CAS-No. : 10024-93-8

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : (314) 776-6555

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Skin irritation (Category 2), H315
Eye irritation (Category 2A), H319
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Warning

Hazard statement(s)	
H315	Causes skin irritation.
H319	Causes serious eye irritation.
H335	May cause respiratory irritation.

Precautionary statement(s)	
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P271	Use only outdoors or in a well-ventilated area.
P280	Wear protective gloves/ eye protection/ face protection.
P302 + P352	IF ON SKIN: Wash with plenty of soap and water.
P304 + P340	IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.
P305 + P351 + P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove

	contact lenses, if present and easy to do. Continue rinsing.
P312	Call a POISON CENTER or doctor/ physician if you feel unwell.
P321	Specific treatment (see supplemental first aid instructions on this label).
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P337 + P313	If eye irritation persists: Get medical advice/ attention.
P362	Take off contaminated clothing and wash before reuse.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : Cl_3Nd
Molecular Weight : 250.60 g/mol
CAS-No. : 10024-93-8
EC-No. : 233-031-5

Hazardous components

Component	Classification	Concentration
Neodymium trichloride		
	Skin Irrit. 2; Eye Irrit. 2A; STOT SE 3; H315, H319, H335	-

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

Hydrogen chloride gas, neodymium oxides

5.3 Advice for firefighters

Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols.
Provide appropriate exhaust ventilation at places where dust is formed.Normal measures for preventive fire protection.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Moisture sensitive. Keep in a dry place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Safety glasses with side-shields conforming to EN166 Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min

Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
impervious clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
For nuisance exposures use type P95 (US) or type P1 (EU EN 143) particle respirator.For higher level protection use type OV/AG/P99 (US) or type ABEK-P2 (EU EN 143) respirator cartridges. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

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9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: powder
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 784 °C (1,443 °F) - lit.
f)	Initial boiling point and boiling range	no data available
g)	Flash point	not applicable
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	4.134 g/mL at 25 °C (77 °F)
n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information

no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity

no data available

10.2 Chemical stability

Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions

no data available

10.4 Conditions to avoid

Avoid moisture.

10.5 Incompatible materials

Strong oxidizing agents

10.6 Hazardous decomposition products

Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - mouse - 3,692 mg/kg

Dermal: no data available

no data available

Skin corrosion/irritation
Skin - rabbit
Result: Mild skin irritation - 24 h

Serious eye damage/eye irritation
Eyes - rabbit

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
Inhalation - May cause respiratory irritation.

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: QO8750000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date

Neodymium trichloride	10024-93-8	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Neodymium trichloride	10024-93-8	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

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16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Eye Irrit.	Eye irritation
H315	Causes skin irritation.
H319	Causes serious eye irritation.
H335	May cause respiratory irritation.
Skin Irrit.	Skin irritation
STOT SE	Specific target organ toxicity - single exposure

HMIS Rating

Health hazard:	2
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	2
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.4 Revision Date: 06/28/2014 Print Date: 02/02/2016

MATERIAL SAFETY DATA SHEET

SECTION 1 - PRODUCT NAME

Product Name: Sintered Neodymium Iron Boron (NdFeB) Permanent Magnet

SECTION 2 - HAZARDOUS INGREDIENTS

Chemical Name: Sintered Neodymium Iron Boron (NdFeB) Permanent Magnet

Material or Component	**Weight %**	**CAS No.**	**ACGUH TLV (mg/m^3)**	**Notes**
Neodymium	≈ 33%	7440-00-8	Not established	
Iron	≈ 65%	7439-89-6	10 (oxide)	
Boron	≈ 1.3%	7440-42-8	10	
Nickel	0.01-0.4%	7440-02-0	1 (dust) / 0.1 (fume)	Plating
Copper	0.01-0.2%	7440-50-8	1 (dust) / 0.2 (fume)	Plating
Dysprosium	0-4%	7429-91-6	Not established	May be used in high-temp grades
Cobalt	0-5%	7440-48-4	0.02	May be used in high-temp grades

SECTION 3 - PHYSICAL CHARACTERISTICS

Boiling Point: N/A
Vapor Pressure: (mm Hg.) N/A
Vapor Density: (air = 1) N/A
Specific Gravity: 7.4
Melting Point: Above 1000°C (1832°F)
Evaporation Rate: N/A
Odor: No odor
Solubility in Water: Not soluble
Appearance: Silver-gray metal

SECTION 4–FIRE AND EXPLOSION HAZARD DATA

Flash Point: N/A
FLAMMABLE LIMITS: N/A
LEL: N/A
UEL: N/A
Extinguishing Media: Dry chemicals without Oxygen Compounds or sand
Special Fire Fighting Procedures: Do not use Halon agents or water on smoldering, burning powder.

Unusual Fire and Explosion Hazard(s):
Dry powders of neodymium magnets will oxidize, smolder, and burn rapidly in the presence of air or oxygen. Maintain powders in water slurry or in inert atmospheres of nitrogen or argon to prevent spontaneous combustion. Magnets may spark on impact. Handle carefully in explosive atmospheres.

SECTION 5 - REACTIVITY DATA

Stability:	Stable
Conditions to Avoid:	Avoid exposure of powdered magnet material to air, oxygen or halogenated hydrocarbons, and to elevated temperatures above 150°C.
Incompatibility (Materials to Avoid):	Fine powders are incompatible with air, oxygen, halogentated hydrocarbons and strong oxidizers.

SECTION 6 - HEALTH HAZARD DATA

Health Hazards (Acute & Chronic):	Prolonged skin contact may cause irritation or allergenic dermatitis.
Emergency and First Aid Procedures:	
Skin:	Brush off powders and wash well with soap and water.
Eyes:	Flush with running water for 15 minutes.

SECTION 7- PRECAUTIONS FOR SAFE HANDLING AND USE

Spill Procedure:	Sweep up dust and store in water slurry or sealed containers utilizing inert atmosphere such as argon or nitrogen to prevent spontaneous combustion.
Waste Disposal Method:	Dispose in accordance with federal, state, and local regulations.

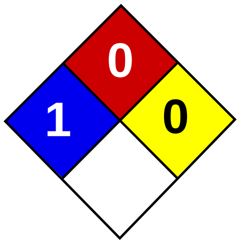
SECTION 8 - CONTROL MEASURES

Respiratory Protection:	Use NIOSH approved respirator when TLV is exceeded.
Eye Protection:	Use safety glasses or goggles when handling magnets.
Skin Protection:	Protective gloves are recommended when handling magnetized part or parts which may have sharp edges.
Ventilation:	Use wet machining/grinding processes and adequate local ventilation to reduce dust levels.
Work / Hygienic Practices:	Use personal protection equipment when required. Use good personal hygiene practices. Keep magnetized parts away from mechanical/electrical instruments which may be damaged by high magnetic fields.

WARNING

RARE EARTH MAGNETS ARE EXTREMELY POWERFUL!
They have very strong magnetic forces which make them attract to other magnets and other ferromagnetic materials such as iron or steel.
HANDLE WITH EXTREME CAUTION!

The above information is believed to be correct but does not purport to be all-inclusive and shall be used only as a guide. K&J Magnetics, Inc. shall not be held liable for any damage resulting from handling or from contact with the above product.



Health	1
Fire	0
Reactivity	0
Personal Protection	F

Material Safety Data Sheet

Neodymium (III) Oxide MSDS

Section 1: Chemical Product and Company Identification

Product Name: Neodymium (III) Oxide

Catalog Codes: SLN2563, SLN1609

CAS#: 1313-97-9

RTECS: QP0185000

TSCA: TSCA 8(b) inventory: Neodymium (III) Oxide

CI#: Not available.

Synonym: Neodymium Trioxide; Dineodymium trioxide; Neodymia; Neodymium (3+) oxide

Chemical Name: Neodymium (III) Oxide

Chemical Formula: Nd_2O_3

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Neodymium (III) Oxide	1313-97-9	100

Toxicological Data on Ingredients: Not applicable.

Section 3: Hazards Identification

Potential Acute Health Effects: Slightly hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. Repeated or prolonged exposure is not known to aggravate medical condition.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention if irritation occurs.

Skin Contact: Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops.

Serious Skin Contact: Not available.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation: Not available.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if symptoms appear.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Not applicable.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

Section 7: Handling and Storage

Precautions:
Do not ingest. Do not breathe dust. If ingested, seek medical advice immediately and show the container or the label. Keep away from incompatibles such as oxidizing agents, acids, moisture.

Storage:
Hygroscopic. Keep container tightly closed. Keep container in a cool, well-ventilated area. Do not store above 23°C (73.4°F).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Safety glasses. Synthetic apron. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves (impervious).

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (Powdered solid.)

Odor: Odorless.

Taste: Not available.

Molecular Weight: 336.48 g/mole

Color: Bluish-grey (Light.)

pH (1% soln/water): Not applicable.

Boiling Point: Not available.

Melting Point: 2270°C (4118°F)

Critical Temperature: Not available.

Specific Gravity: 7.24 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: 11.6 (Air = 1)

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: Not available.

Solubility: Insoluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Dust generation, moisture, air, incompatible materials.

Incompatibility with various substances: Reactive with oxidizing agents, acids, moisture.

Corrosivity: Not available.

Special Remarks on Reactivity:
Incompatible with strong acids, strong oxidants, moisture, and air. Neodynium (III) oxide absorbs NH3 and CO2 from air. Protect from moisture.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Inhalation. Ingestion.

Toxicity to Animals: Acute oral toxicity (LD50): >5000 mg/kg [Rat].

Chronic Effects on Humans: Not available.

Other Toxic Effects on Humans: Slightly hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: May affect genetic material.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: Although it is not known to be irritating to skin. However, contact, particularly with any open wound or broken skin, may cause skin irritation, and reddness. Eyes: Dust may cause eye irritation. Inhalation: Dust may cause respiratory tract irritation. Prolonged exposure to dusts may result in chronic bronchitis, with symptoms of coughing and shortness of breath. Ingestion: Ingetion of large quantites may cause digestive (gastrointestinal) tract irritation.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Neodymium (III) Oxide

Other Regulations: EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):
This product is not classified according to the EU regulations. S24/25- Avoid contact with skin and eyes.

HMIS (U.S.A.):

Health Hazard: 1

Fire Hazard: 0

Reactivity: 0

Personal Protection: F

National Fire Protection Association (U.S.A.):

Health: 1

Flammability: 0

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves (impervious). Synthetic apron. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Safety glasses.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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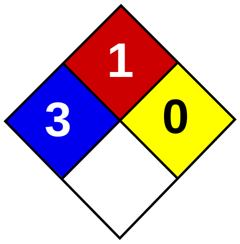
Last Updated: 05/21/2013 12:00 PM



Health	3
Fire	1
Reactivity	0
Personal Protection	J

Material Safety Data Sheet

Oxalic acid dihydrate MSDS

Section 1: Chemical Product and Company Identification

Product Name: Oxalic acid dihydrate

Catalog Codes: SLO1429, SLO1054

CAS#: 6153-56-6

RTECS: Not available.

TSCA: TSCA 8(b) inventory: No products were found. It is a hydrate and exempt from TSCA inventory requirements.

CI#: Not applicable.

Synonym: Ethanedioic Acid, dihydrate

Chemical Name: Oxalic Acid, dihydrate

Chemical Formula: (COOH)2.2H2O

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Oxalic acid dihydrate	6153-56-6	100

Toxicological Data on Ingredients: Oxalic acid dihydrate LD50: Not available. LC50: Not available.

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation. Hazardous in case of skin contact (permeator), of eye contact (corrosive). Slightly hazardous in case of skin contact (corrosive). The amount of tissue damage depends on length of contact. Eye contact can result in corneal damage or blindness. Skin contact can produce inflammation and blistering. Inhalation of dust will produce irritation to gastro-intestinal or respiratory tract, characterized by burning, sneezing and coughing. Severe over-exposure can produce lung damage, choking, unconsciousness or death. Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to kidneys, the nervous system, mucous membranes, heart, brain, skin, eyes. Repeated or prolonged exposure to the substance can produce target organs damage. Repeated exposure of the eyes to a low level of dust can produce eye irritation. Repeated skin exposure can produce local skin destruction, or dermatitis. Repeated inhalation of dust can produce varying degree of respiratory irritation or lung damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention immediately.

Skin Contact:
In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Cover the irritated skin with an emollient. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek immediate medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: May be combustible at high temperature.

Auto-Ignition Temperature: Not available.

Flash Points: Not available.

Flammable Limits: Not available.

Products of Combustion: These products are carbon oxides (CO, $CO2$).

Fire Hazards in Presence of Various Substances:
Slightly flammable to flammable in presence of heat. Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:
Slightly explosive in presence of open flames and sparks. Non-explosive in presence of shocks.

Fire Fighting Media and Instructions:
SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray, fog or foam. Do not use water jet.

Special Remarks on Fire Hazards: As with most organic solids, fire is possible at elevated temperatures

Special Remarks on Explosion Hazards:
Fine dust dispersed in air in sufficient concentrations, and in the presences of an ignition source is a potential dust explosion hazard.

Section 6: Accidental Release Measures

Small Spill:

Use appropriate tools to put the spilled solid in a convenient waste disposal container. If necessary: Neutralize the residue with a dilute solution of sodium carbonate.

Large Spill:
Corrosive solid. Stop leak if without risk. Do not get water inside container. Do not touch spilled material. Use water spray to reduce vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Eliminate all ignition sources. Call for assistance on disposal. Neutralize the residue with a dilute solution of sodium carbonate. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep container dry. Keep away from heat. Keep away from sources of ignition. Empty containers pose a fire risk, evaporate the residue under a fume hood. Ground all equipment containing material. Do not ingest. Do not breathe dust. Never add water to this product. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, metals, alkalis.

Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Splash goggles. Synthetic apron. Vapor and dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor and dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 1 STEL: 2 (mg/m3) from ACGIH (TLV) [United States] TWA: 1 STEL: 2 (mg/m3) from OSHA (PEL) [United States] TWA: 1 STEL: 2 (mg/m3) from NIOSH [United States] TWA: 1 STEL: 2 (mg/m3) [United Kingdom (UK)] TWA: 1 STEL: 2 (mg/m3) [Canada]Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (Crystalline solid)

Odor: Odorless.

Taste: Not available.

Molecular Weight: 126.07 g/mole

Color: Colorless. White.

pH (1% soln/water): Not available

Boiling Point: Not available.

Melting Point: 101.5°C (214.7°F)

Critical Temperature: Not available.

Specific Gravity: Density: 1.653 @ 18.5 eg. C(Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: 4.4 (Air = 1)

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, diethyl ether.

Solubility:
Soluble in cold water, diethyl ether. Soluble in alcohol, glycerol. Insoluble in benzene, petroleum ether. Solubility in cold water: 1g/7ml. Solubility in hot water: 1g/2ml

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Excess heat, incompatible materials, dust generation.

Incompatibility with various substances: Reactive with oxidizing agents, metals, alkalis.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Incompatible with chlorites, hypochlorites, silver and silver compounds, furfuryl alcohol. Hygroscopic; keep container tightly closed.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Inhalation. Ingestion.

Toxicity to Animals:
LD50: Not available. LC50: Not available.

Chronic Effects on Humans:
May cause damage to the following organs: kidneys, the nervous system, mucous membranes, heart, brain, skin, eyes.

Other Toxic Effects on Humans:
Very hazardous in case of skin contact (irritant), of ingestion, of inhalation. Hazardous in case of skin contact (permeator), of eye contact (corrosive). Slightly hazardous in case of skin contact (corrosive).

Special Remarks on Toxicity to Animals:
LD50 data for Oxalic acid, ahydrous (CAS no. 144-62-7): LD50[rat] - Route: oral; Dose: 7500 mg/kg

Special Remarks on Chronic Effects on Humans: May cause adverse reproductive effects based on animal test data. No human data found.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: Causes skin irritation. Rare chemical burns may occur. Harmful if absorbed through the skin. Eyes: Causes severe eye irritation with possible burns. It may result in corneal damage and conjunctivitis. Inhalation: Causes irritation of the respiratory tract, ulceration of the mucous membranes. Inhalation of oxalic acid may also cause digestive disturbances such as nausea and vomiting as well as affecting the nerves and urinary system and causing

headache, muscular irrritability, weakness, and albuminuira Ingestion: Harmful if swallowed. Causes severe digestive tract irritation and possible burns. It may affect the cardiovascular system, and urinary system. Symptoms may include vomiting (often bloody or with coffee-ground appearance), diarrhea, bloody stool, hypermotility, abdominal pain, intense burning pain in the throat, esophagus, stomach, ulceration/burning of the mouth, esophagus, and stomach, severe purging, weak pulse, hypotension, caridac irregularities, cardiovascular collapse. Other symptoms may include convulsions, headache, twitching, tetany, stupor, coma, tingling of fingers and toes, muscular irritability. Renal damage, as evidenced by oliguria, albuminuria, hematuria, may occur because Oxalic acid can bind calcium to form calcium oxalate which is insoluble at physiological pH. The calcium oxalate formed might precipitate in the kidney tubules. Hypocalcemia may also occur, which is what may affect the function of the heart and nerves and cause the above cardiovasular and nervous system effects. Chronic Potential Health Effects: Skin: Prolonged or repeated exposure may cause localized pain and cyanosis of the fingers, and even

Section 12: Ecological Information

Ecotoxicity:
Ecotoxicity in water (LC50): 4000 mg/l 24 hours [Fish (Bluegill)]. 1000 ppm 0.5 hours [Fish (Goldfish)]. 100 ppm 0.3 hours [Fish (Trout)].

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Class 8: Corrosive material

Identification: : Corrosive Solid, Acidic, Organic, n.o.s. (Oxalic Acid, Dihydrate) UNNA: 3261 PG: III

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations: Pennsylvania RTK: Oxalic acid dihydrate

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). Oxalic Acid, anhydrous (CAS no. 144-62-7) is listed on the Canadian DSL Oxalic Acid, dihydrate (CAS 6153-56-6) is not listed on the Canadian DSL. EINECS no. for Oxalic Acid, anhydrous: 205-634-3 EINECS no. for Oxalic Acid, dihydrate: unlisted Oxalic Acid, dihydrate is on the inventory lists for China, Japan, and Philippines.

Other Classifications:

WHMIS (Canada): CLASS E: Corrosive solid.

DSCL (EEC):
R21/22- Harmful in contact with skin and if swallowed. S24/25- Avoid contact with skin and eyes.

HMIS (U.S.A.):

Health Hazard: 3

Fire Hazard: 1

Reactivity: 0

Personal Protection: j

National Fire Protection Association (U.S.A.):

Health: 3

Flammability: 1

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Synthetic apron. Vapor and dust respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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Last Updated: 05/21/2013 12:00 PM

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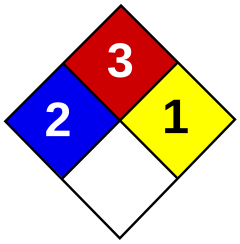


Health	2
Fire	3
Reactivity	0
Personal Protection	H

Material Safety Data Sheet

Tetrahydrofuran MSDS

Section 1: Chemical Product and Company Identification

Product Name: Tetrahydrofuran

Catalog Codes: SLT3136, SLT2254

CAS#: 109-99-9

RTECS: LU5950000

TSCA: TSCA 8(b) inventory: Tetrahydrofuran

CI#: Not available.

Synonym: Tetrahydrofuran stabilized with BHT; THF; Butylene Oxide; Cyclotetramethylene oxide; 1,4-Epoxybutane

Chemical Name: Tetrahydrofuran

Chemical Formula: C4H8O

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Tetrahydrofuran	109-99-9	100

Toxicological Data on Ingredients: Tetrahydrofuran: ORAL (LD50): Acute: 1650 mg/kg [Rat]. VAPOR (LC50): Acute: 21000 mg/m 3 hours [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of skin contact (irritant), of eye contact (irritant). Slightly hazardous in case of skin contact (permeator), of ingestion, of inhalation.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to blood, kidneys, lungs, liver, upper respiratory tract, skin, eyes, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: 321°C (609.8°F)

Flash Points: CLOSED CUP: -14.5°C (5.9°F). OPEN CUP: -20°C (-4°F).

Flammable Limits: LOWER: 2% UPPER: 11.8%

Products of Combustion: These products are carbon oxides (CO, CO_2).

Fire Hazards in Presence of Various Substances:
Highly flammable in presence of open flames and sparks, of heat. Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Explosive in presence of open flames and sparks, of heat.

Fire Fighting Media and Instructions:
Flammable liquid, soluble or dispersed in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use alcohol foam, water spray or fog.

Special Remarks on Fire Hazards: Vapor may travel considerable distance to source of ignition and flash back. May form explosive mixtures with air.

Special Remarks on Explosion Hazards:
Reacts explosively with lithium-aluminum alloys, and Sodium Aluminum Hydride, Potassium hydroxide, Calcium Hydride.
It is normally stable, however, prolonged storage, and exposure to air and light may cause formation of unstable explosive peroxides especially when anhydrous and unless it is inhibited against peroxide formation. Explosive in the form of vapor when exposed to heat or flame.

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container.

Large Spill:
Flammable liquid. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents.

Storage:
Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame). Prolonged exposure to air and light may form unstable explosive peroxides unless it is inhibited against peroxide formation

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 590 STEL: 737 (mg/m3) from ACGIH (TLV) [United States] Inhalation TWA: 200 STEL: 250 (ppm) from ACGIH (TLV) [United States] Inhalation TWA: 590 STEL: 735 (mg/m3) from NIOSH [United States] Inhalation TWA: 200 STEL: 250 (ppm) from NIOSH [United States] Inhalation TWA: 200 STEL: 250 (ppm) from OSHA (PEL) [United States] Inhalation TWA: 590 STEL: 735 (mg/m3) from OSHA (PEL) [United States] Inhalation TWA: 100 STEL: 200 (ppm) [United Kingdom (UK)] Inhalation TWA: 300 STEL: 599 (mg/m3) [United Kingdom (UK)] Inhalation3 Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Ethereal. Fruity.

Taste: Pungent.

Molecular Weight: 72.11 g/mole

Color: Colorless.

pH (1% soln/water): Not available.

Boiling Point: 65°C (149°F) @ 760 mm Hg

Melting Point: -108.3°C (-162.9°F)

Critical Temperature: 267°C (512.6°F)

Specific Gravity: 0.8892 (Water = 1)

Vapor Pressure: 19.3 kPa (@ 20°C)

Vapor Density: 2.5 (Air = 1)

Volatility: 100% (v/v).

Odor Threshold: 20 ppm - 50 ppm

Water/Oil Dist. Coeff.: The product is more soluble in oil; log(oil/water) = 0.5

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, diethyl ether, acetone.

Solubility:
Easily soluble in diethyl ether, acetone. Partially soluble in cold water. Solubility in water is 30%. Miscible with alcohols, ketones, esters, hydrocarbons, and ethers. Very soluble in benzene, ethanol, and chloroform.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Heat, ignition sources (sparks, flames), light, air, and incompatible materials

Incompatibility with various substances: Reactive with oxidizing agents, acids, alkalis.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Reacts violently with Bromine. Addition of anhydrous chlorides (hafnium tetrachloride, titanium tetrachloride, and zirconium tetrachloride) directly to tetrahydrofuran will cause a violent exothermic reaction. Also incompatible with Calcium Hydride + heat, caustics (e.g. ammonia, ammonium hydroxide, calcium hyroxide, potassium hydroxide, sodium hydroxide), metal halides, moisture, lithium tetrahydroaluminate, borane, 2-aminophenol + potassium dioxide, sodium tetrahydroaluminate, and 2-aminophenol. Prolonged exposure to air and light may form unstable peroxides especially when anhydrous and unless it is inhibited against peroxide formation.

Special Remarks on Corrosivity: It will attack some forms of plastics, rubber, coatings.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact.

Toxicity to Animals:
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 1650 mg/kg [Rat]. Acute toxicity of the vapor (LC50): 24000 mg/m3 2 hours [Mouse].

Chronic Effects on Humans:
MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. May cause damage to the following organs: blood, kidneys, lungs, liver, upper respiratory tract, skin, eyes, central nervous system (CNS).

Other Toxic Effects on Humans:
Hazardous in case of skin contact (irritant). Slightly hazardous in case of skin contact (permeator), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:
It is excreted in mother's milk. May cause cancer based on animal data. No human data found at this point. May cause adverse reproductive effects (fetotoxicity) based on animal data. No human data found at this point. May affect genetic material.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: Causes skin irritation. May be absorbed through skin and cause symptoms similar those of inhalation and ingestion. Eyes: Contact with eyes may cause severe irritation with possible eye burns. Vapors may cause eye irritation. Inhalation: May cause upper respiratory tract (nose, throat) irriation. High concentrations may affect behavior/ central nervous system (central nervous system depression/effects characterized by headache, general anesthetic, dizziness, somnolence, muscle weakness, loss of conciousness, and coma), respiration (respiratory stimulation, dyspnea), and gastrointestinal tract (nausea, vomiting). Ingestion: May cause gastrointestinal irritation with nausea, vomiting, and diarrhea, abdominal pain. May also affect the liver and behavior/central nervous system with symptoms similar to inhalation. Chronic Potential Health Effects: Skin: Prolonged or repeated skin contact may cause defatting and dermatitis. Eyes: Prolonged or repeated eye contact may cause conjunctivitis. Inhalation: Prolonged or repeated exposure to vapors may affect the liver, kidneys, muculosketal system, endrocrine system (spleen and thymus), blood, cardiovascular system, thymus, spleen, and lungs (lung damage). Ingestion: Prolonged or repeated exposure from ingestion may affect the blood, and metabolism.

Section 12: Ecological Information

Ecotoxicity: Ecotoxicity in water (LC50): 2160 mg/l 96 hours [Fish (Fathead Minnow)].

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: CLASS 3: Flammable liquid.

Identification: : Tetrahydrofuran UNNA: 2056 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
Connecticut hazardous material survey.: Tetrahydrofuran Illinois toxic substances disclosure to employee act: Tetrahydrofuran Illinois chemical safety act: Tetrahydrofuran New York release reporting list: Tetrahydrofuran Rhode Island RTK hazardous substances: Tetrahydrofuran Pennsylvania RTK: Tetrahydrofuran Minnesota: Tetrahydrofuran Massachusetts RTK: Tetrahydrofuran Massachusetts spill list: Tetrahydrofuran New Jersey: Tetrahydrofuran New Jersey spill list: Tetrahydrofuran Louisiana spill reporting: Tetrahydrofuran California Director's List of Hazardous Substances: Tetrahydrofuran TSCA 8(b) inventory: Tetrahydrofuran TSCA 4(a) proposed test rules: Tetrahydrofuran TSCA 8(a) PAIR: Tetrahydrofuran TSCA 8(a) IUR: Tetrahydrofuran TSCA 8(d) H and S data reporting: Tetrahydrofuran: effective data: 3/11/94; sunset date: 6/30/98 CERCLA: Hazardous substances.: Tetrahydrofuran: 1000 lbs. (453.6 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS B-2: Flammable liquid with a flash point lower than 37.8°C (100°F). CLASS D-2B: Material causing other toxic effects (TOXIC).

DSCL (EEC):
R11- Highly flammable. R19- May form explosive peroxides. R36/37- Irritating to eyes and respiratory system. S16- Keep away from sources of ignition - No smoking. S29- Do not empty into drains. S33- Take precautionary measures against static discharges.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 3

Reactivity: 0

Personal Protection: h

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 3

Reactivity: 1

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

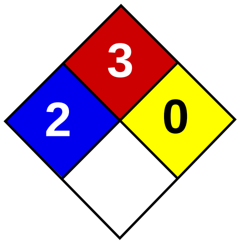
Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/10/2005 08:29 PM

Last Updated: 05/21/2013 12:00 PM



Health	**2**
Fire	**3**
Reactivity	**0**
Personal Protection	**H**

Material Safety Data Sheet
Toluene MSDS

Section 1: Chemical Product and Company Identification

Product Name: Toluene

Catalog Codes: SLT2857, SLT3277

CAS#: 108-88-3

RTECS: XS5250000

TSCA: TSCA 8(b) inventory: Toluene

CI#: Not available.

Synonym: Toluol, Tolu-Sol; Methylbenzene; Methacide; Phenylmethane; Methylbenzol

Chemical Name: Toluene

Chemical Formula: C6-H5-CH3 or C7-H8

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Toluene	108-88-3	100

Toxicological Data on Ingredients: Toluene: ORAL (LD50): Acute: 636 mg/kg [Rat]. DERMAL (LD50): Acute: 14100 mg/kg [Rabbit]. VAPOR (LC50): Acute: 49000 mg/m 4 hours [Rat]. 440 ppm 24 hours [Mouse].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (permeator).

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: A4 (Not classifiable for human or animal.) by ACGIH, 3 (Not classifiable for human.) by IARC. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to blood, kidneys, the nervous system, liver, brain, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: 480°C (896°F)

Flash Points: CLOSED CUP: 4.4444°C (40°F). (Setaflash) OPEN CUP: 16°C (60.8°F).

Flammable Limits: LOWER: 1.1% UPPER: 7.1%

Products of Combustion: These products are carbon oxides (CO, CO2).

Fire Hazards in Presence of Various Substances:
Flammable in presence of open flames and sparks, of heat. Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:
Flammable liquid, insoluble in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray or fog.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards:
Toluene forms explosive reaction with 1,3-dichloro-5,5-dimethyl-2,4-imidazolididione; dinitrogen tetraoxide; concentrated nitric acid, sulfuric acid + nitric acid; N2O4; AgClO4; BrF3; Uranium hexafluoride; sulfur dichloride. Also forms an explosive mixture with tetranitromethane.

Section 6: Accidental Release Measures

Small Spill: Absorb with an inert material and put the spilled material in an appropriate waste disposal.

Large Spill:
Toxic flammable liquid, insoluble or very slightly soluble in water. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not get water inside container. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents.

Storage:
Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 200 STEL: 500 CEIL: 300 (ppm) from OSHA (PEL) [United States] TWA: 50 (ppm) from ACGIH (TLV) [United States] SKIN TWA: 100 STEL: 150 from NIOSH [United States] TWA: 375 STEL: 560 (mg/m3) from NIOSH [United States] Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Sweet, pungent, Benzene-like.

Taste: Not available.

Molecular Weight: 92.14 g/mole

Color: Colorless.

pH (1% soln/water): Not applicable.

Boiling Point: 110.6°C (231.1°F)

Melting Point: -95°C (-139°F)

Critical Temperature: 318.6°C (605.5°F)

Specific Gravity: 0.8636 (Water = 1)

Vapor Pressure: 3.8 kPa (@ 25°C)

Vapor Density: 3.1 (Air = 1)

Volatility: Not available.

Odor Threshold: 1.6 ppm

Water/Oil Dist. Coeff.: The product is more soluble in oil; log(oil/water) = 2.7

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, diethyl ether, acetone.

Solubility:
Soluble in diethyl ether, acetone. Practically insoluble in cold water. Soluble in ethanol, benzene, chloroform, glacial acetic acid, carbon disulfide. Solubility in water: 0.561 g/l @ 25 deg. C.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Heat, ignition sources (flames, sparks, static), incompatible materials

Incompatibility with various substances: Reactive with oxidizing agents.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Incompatible with strong oxidizers, silver perchlorate, sodium difluoride, Tetranitromethane, Uranium Hexafluoride. Frozen Bromine Trifluoride reacts violently with Toluene at -80 deg. C. Reacts chemically with nitrogen oxides, or halogens to form nitrotoluene, nitrobenzene, and nitrophenol and halogenated products, respectively.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation. Ingestion.

Toxicity to Animals:
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 636 mg/kg [Rat]. Acute dermal toxicity (LD50): 14100 mg/kg [Rabbit]. Acute toxicity of the vapor (LC50): 440 24 hours [Mouse].

Chronic Effects on Humans:
CARCINOGENIC EFFECTS: A4 (Not classifiable for human or animal.) by ACGIH, 3 (Not classifiable for human.) by IARC. May cause damage to the following organs: blood, kidneys, the nervous system, liver, brain, central nervous system (CNS).

Other Toxic Effects on Humans:
Hazardous in case of skin contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (permeator).

Special Remarks on Toxicity to Animals:
Lowest Published Lethal Dose: LDL [Human] - Route: Oral; Dose: 50 mg/kg LCL [Rabbit] - Route: Inhalation; Dose: 55000 ppm/40min

Special Remarks on Chronic Effects on Humans:
Detected in maternal milk in human. Passes through the placental barrier in human. Embryotoxic and/or foetotoxic in animal. May cause adverse reproductive effects and birth defects (teratogenic). May affect genetic material (mutagenic)

Special Remarks on other Toxic Effects on Humans:

Acute Potential Health Effects: Skin: Causes mild to moderate skin irritation. It can be absorbed to some extent through the skin. Eyes: Cauess mild to moderate eye irritation with a burning sensation. Splash contact with eyes also causes conjunctivitis, blepharospasm, corneal edema, corneal abraisons. This usually resolves in 2 days. Inhalation: Inhalation of vapor may cause respiratory tract irritation causing coughing and wheezing, and nasal discharge. Inhalation of high concentrations may affect behavior and cause central nervous system effects characterized by nausea, headache, dizziness, tremors, restlessness, lightheadedness, exhilaration, memory loss, insomnia, impaired reaction time, drowsiness, ataxia, hallucinations, somnolence, muscle contraction or spasticity, unconsciousness and coma. Inhalation of high concentration of vapor may also affect the cardiovascular system (rapid heart beat, heart palpitations, increased or decreased blood pressure, dysrhythmia,), respiration (acute pulmonary edema, respiratory depression, apnea, asphyxia), cause vision disturbances and dilated pupils, and cause loss of appetite. Ingestion: Aspiration hazard. Aspiration of Toluene into the lungs may cause chemical pneumonitis. May cause irritation of the digestive tract with nausea, vomiting, pain. May have effects similar to that of acute inhalation. Chronic Potential Health Effects: Inhalation and Ingestion: Prolonged or repeated exposure via inhalation may cause central nervous system and cardiovascular symptoms similar to that of acute inhalation and ingestion as well liver damage/failure, kidney damage/failure (with hematuria, proteinuria, oliguria, renal tubular acidosis), brain damage, weight loss, blood (pigmented or nucleated red blood cells, changes in white blood cell count), bone marrow changes, electrolyte imbalances (Hypokalemia, Hypophostatemia), severe, muscle weakness and Rhabdomyolysis. Skin: Repeated or prolonged skin contact may cause defatting dermatitis.

Section 12: Ecological Information

Ecotoxicity:
Ecotoxicity in water (LC50): 313 mg/l 48 hours [Daphnia (daphnia)]. 17 mg/l 24 hours [Fish (Blue Gill)]. 13 mg/l 96 hours [Fish (Blue Gill)]. 56 mg/l 24 hours [Fish (Fathead minnow)]. 34 mg/l 96 hours [Fish (Fathead minnow)]. 56.8 ppm any hours [Fish (Goldfish)].

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: CLASS 3: Flammable liquid.

Identification: : Toluene UNNA: 1294 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
California prop. 65: This product contains the following ingredients for which the State of California has found to cause cancer, birth defects or other reproductive harm, which would require a warning under the statute: Toluene California prop. 65 (no significant risk level): Toluene: 7 mg/day (value) California prop. 65 (acceptable daily intake level): Toluene: 7 mg/day (value) California prop. 65: This product contains the following ingredients for which the State of California has found to cause birth defects which would require a warning under the statute: Toluene Connecticut hazardous material survey.: Toluene Illinois

toxic substances disclosure to employee act: Toluene Illinois chemical safety act: Toluene New York release reporting list: Toluene Rhode Island RTK hazardous substances: Toluene Pennsylvania RTK: Toluene Florida: Toluene Minnesota: Toluene Michigan critical material: Toluene Massachusetts RTK: Toluene Massachusetts spill list: Toluene New Jersey: Toluene New Jersey spill list: Toluene Louisiana spill reporting: Toluene California Director's List of Hazardous Substances.: Toluene TSCA 8(b) inventory: Toluene TSCA 8(d) H and S data reporting: Toluene: Effective date: 10/04/82; Sunset Date: 10/0/92 SARA 313 toxic chemical notification and release reporting: Toluene CERCLA: Hazardous substances.: Toluene: 1000 lbs. (453.6 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS B-2: Flammable liquid with a flash point lower than 37.8°C (100°F). CLASS D-2A: Material causing other toxic effects (VERY TOXIC).

DSCL (EEC):
R11- Highly flammable. R20- Harmful by inhalation. S16- Keep away from sources of ignition - No smoking. S25- Avoid contact with eyes. S29- Do not empty into drains. S33- Take precautionary measures against static discharges.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 3

Reactivity: 0

Personal Protection: h

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 3

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/10/2005 08:30 PM

Last Updated: 05/21/2013 12:00 PM

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