Recovering Magnesium from Steelmaking Slag

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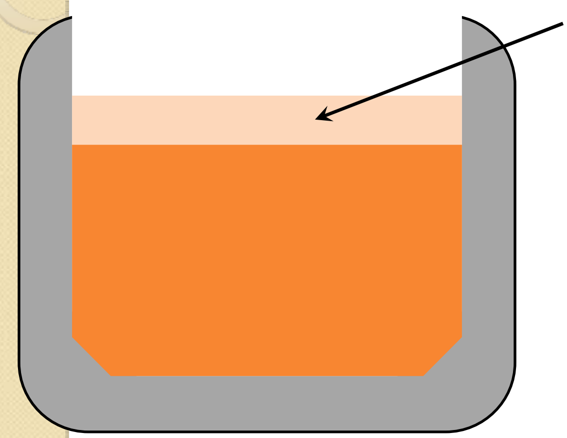


Slag Composition
- 40-50% CaO
- 10-20% SiO_2
- 10-40% FeO
- 5-10% MgO
- 5-10% Other Components

The MgO in the slag comes from the ladle's refractory.

The Magnesium Production Process

General Equation for Pidgeon Process:

$$2MgO + CaO + Si \rightarrow 2Mg_{(g)} + CaSiO_{3\ (s)}$$

• Where the boiling temperature of magnesium is around 1100°C.
• The CaO is already present in the slag.
• The slag is already around 1600°C when it leaves the ladle.
• This process was researched in the 1980's but was found to not be profitable.

Steel Slag

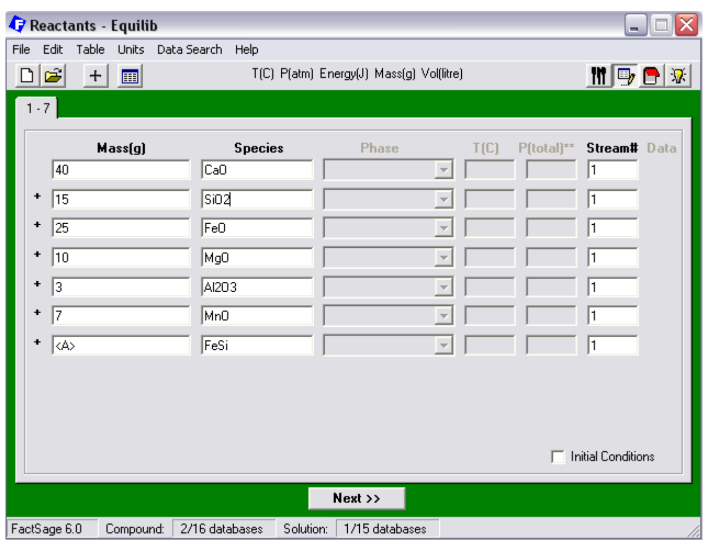
• In 2005, 21 million tons of slag were recycled as aggregate for cement [1].
• The total value of this slag was around $326 million.
• However, approximately 220 to 420 million tons of slag are produced annually.
• Since magnesium is worth around $2000-3000 per ton [2], recovering it from the slag could be very profitable.

Using Slag in Pidgeon Process

Several different compositions of steel slag were investigated:

- Average:
  - $40\ CaO + 15\ SiO_2 + 25\ FeO + 10\ MgO + 7MnO + 3\ Al_2O_3$
- High CaO/low FeO:
  - $52\ CaO + 20\ SiO_2 + 10\ FeO + 10\ MgO + 5MnO + 3\ Al_2O_3$
- Low CaO/high FeO:
  - $30\ CaO + 12\ SiO_2 + 40\ FeO + 10\ MgO + 5MnO + 3\ Al_2O_3$
- Amount of Mg present : 6.030359g

Initial Set-up



Conditions

- Varying:
  - Pressure from 1 to 1E-8 atm.
  - <A> from 0 to 40
- Set:
  - Temperature to 1400°C
- Select gas, liquids and solids.
- Select most solution species.

Results

Pressure	Mass of FeSi Required	% of Mg Produced as Gas
1E-3	20	10.21
1E-4	40	76.21
1E-5	55	99.84
1E-6	55	99.84
1E-7	55	99.84
1E-8	50	99.63

Highest pressure that allows for 100% of magnesium to turn to gas

Gas Composition

- The reaction at 1400°C, 1E-5 atm and addition of 55g of FeSi yielded the following gas:

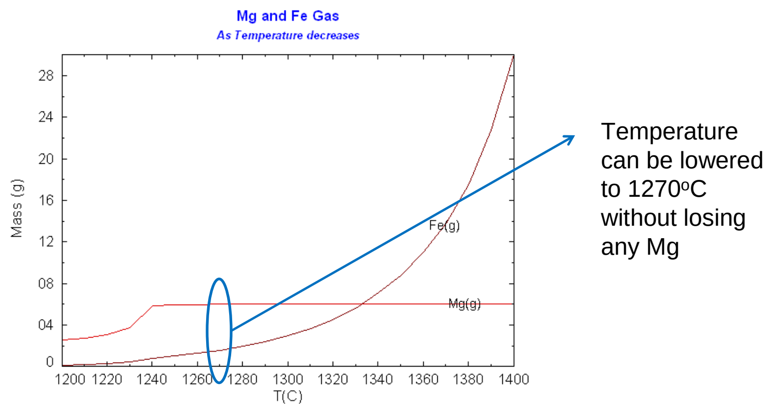
Gas	Mole Fraction
Fe	0.43262
SiO	0.33640
Mg	0.14604
Mn	5.8171E-02
Ca	2.6613E-02
Al	1.6022E-05
Si	2.9753E-06
FeO	3.0112E-07

Recovery of Mg from Gas

- Since magnesium evaporates at a low temperature, it is possible to remove other elements.
- However, when simply lowering temperature or raising pressure, Mg_2SiO_4 forms.
- Therefore, CaO must be added to maintain Mg as a gas and form Ca_2SiO_4 instead.

Removal of Iron

- Since iron has a high boiling point, it can be removed by lowering the temperature.

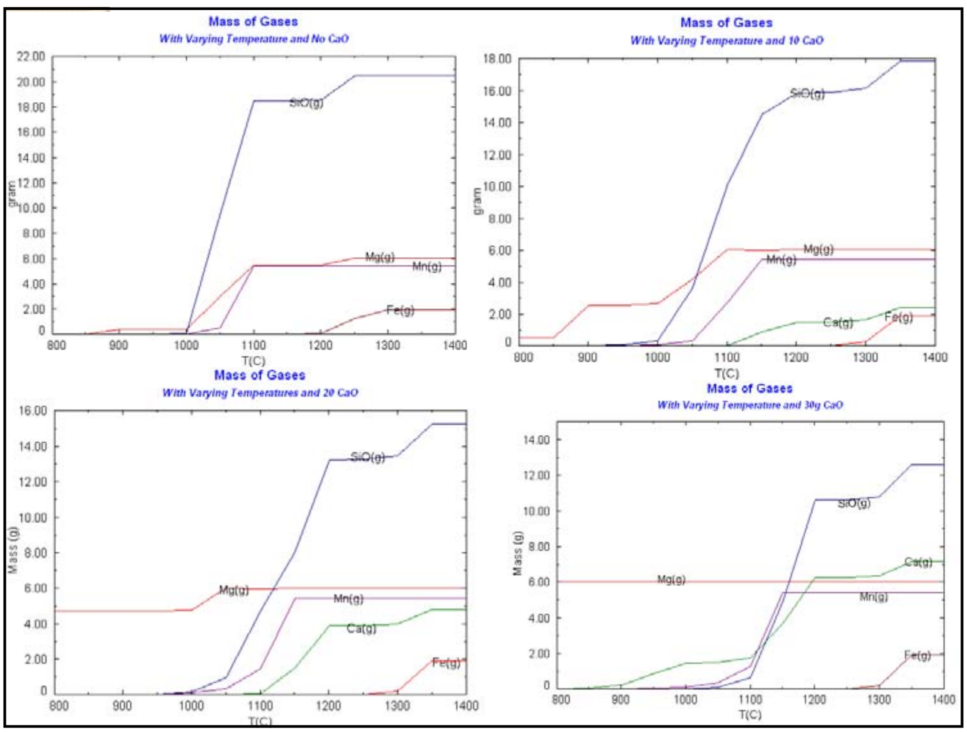


Removal of Other Impurities

- To verify under which conditions pure Mg gas could be obtained, the following were varied:
  - Temperature, from 1200 to 800ºC
  - Mass of CaO added, from 0 to 60g.
- Ideally, we want to obtain:
  - Near 100% mole fraction.
  - Close to 6.03g of Mg(g).

Results

T (°C)	CaO (g)	Mass (g) Mg	Mole Fraction
800	15	3.4018839	0.99993129
800	10	0.51276094	0.99993129
800	25	5.7870963	0.99961878
800	20	4.703946	0.99961878
800	0	0	0.99956883
800	5	0	0.99956883
900	25	5.7866028	0.99886157
900	20	4.7035467	0.99886157
800	30	6.0098927	0.99874548
800	35	6.0095716	0.99874546
800	40	6.0092506	0.99874545
900	15	3.6238457	0.99865067
900	10	2.5397845	0.99865067
900	5	1.4558557	0.99848252

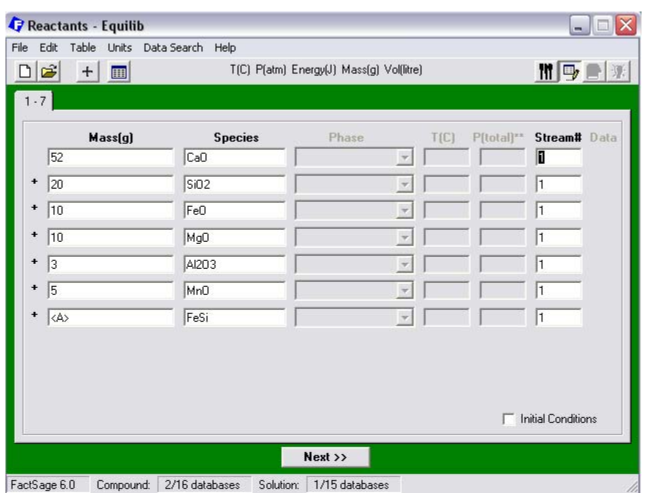


Mg From Gas to Liquid

- The high concentration magnesium gas is then removed.
- The pressure of the gas is raised to 1 atm.
- The magnesium gas becomes liquid and can easily be removed.

P (atm)	T (°C)	Mass Mg(l)	% Recovered
1	800	5.995g	99.41%

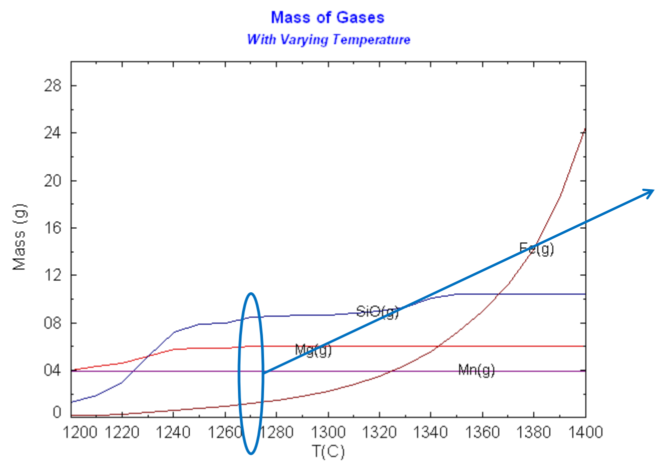
Best Case Scenario



- Requires 30g of FeSi to reduce MgO.

Removal of Impurities

- Can remove most impurities by reducing T.



Can once again lower to 1270ºC without losing Mg.

Removal of Other Impurities

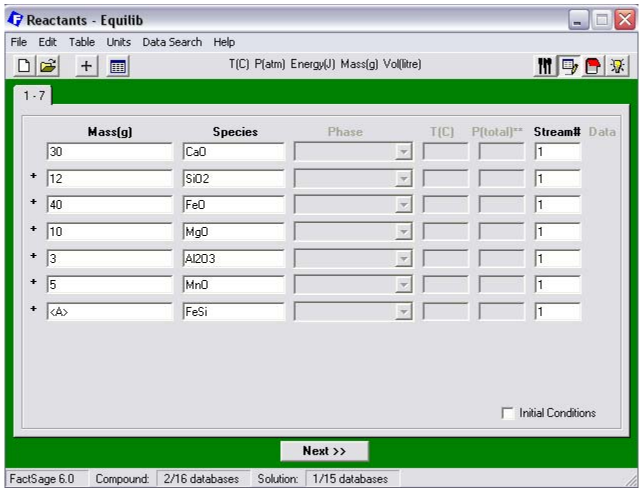
- Other impurities were removed by addition of CaO and lowering T.
- The optimal amount of CaO required and final temperature were as follows:

Alpha	T (ºC)	Mass (g) Mg	Mole Fraction
20	800	5.978139	0.985002

- To transform Mg(g) to Mg(l), the pressure was simply raised to 1 atm:

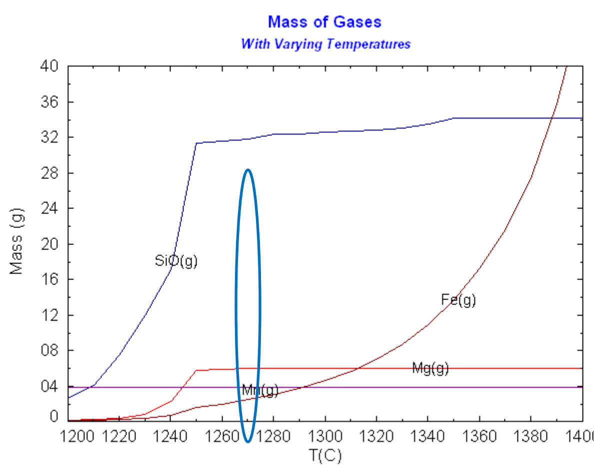
P (atm)	T (ºC)	Mass (g) Mg	% Recovered
1	800	5.975898	99.10%

Worst Case Scenario



- 70g of FeSi required to reduce MgO.

Removal of Impurities



Removal of Other Impurities

- The optimal amount of CaO required and final temperature were as follows:

Alpha	T (°C)	Mass (g) Mg	Mole Fraction
50	800	6.006365	0.998746

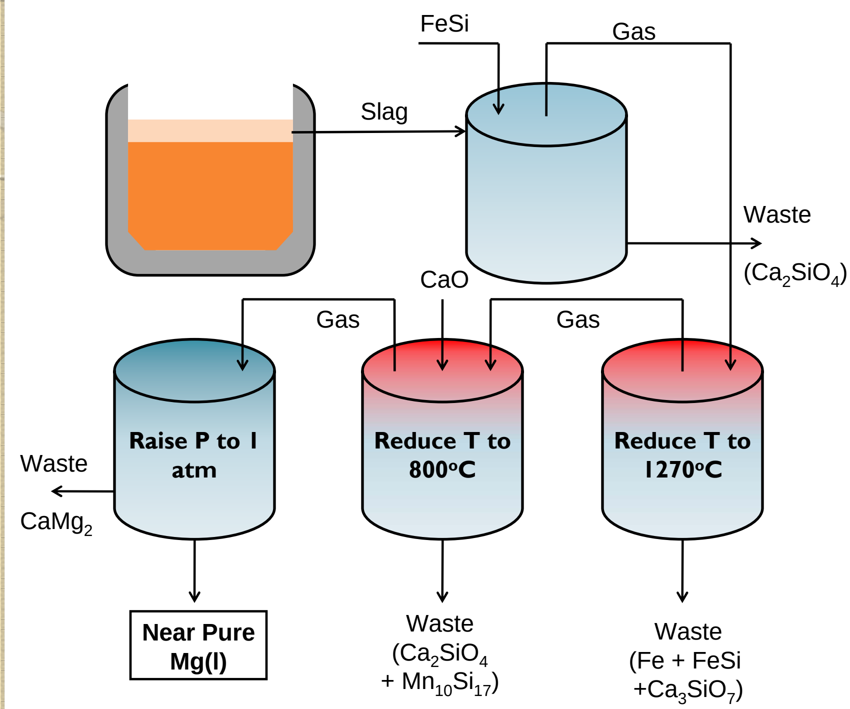
- To transform Mg(g) to Mg(l), the pressure was simply raised to 1 atm:

P (atm)	T (°C)	Mass (g) Mg	% Recovered
1	800	5.991494	99.36%

Summary of the Three Scenarios

- The following table summarizes how much FeSi and CaO were required for each scenario.

	FeSi Required (per g Mg)	CaO Addition (per g Mg)	% Magnesium Recovered
Worst Case	11.61	8.29	99.36%
Average	9.12	4.97	99.41%
Best Case	4.97	3.32	99.10%



Conclusions

- Slag is a by-product of steelmaking which contains 5-10% magnesium.
- This magnesium can be recovered by a variation of the Pidgeon process.
- By reducing temperature and adding CaO, near pure magnesium gas can be produced.
- According to FactSage calculations, 99.1 to 99.41% can be recovered.

Recommendations

- Experimental results need to be done to determine:
  - Whether the results are reproducible.
  - The kinetics of the reaction.
- Determine the feasibility of CaO and FeSi consumption.
- Investigate whether alternatives to CaO and FeSi can be used to reduce consumption.

Thank You

Questions?

References

- Slag info:
  1. http://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel_slag/feslamcs06.pdf
  2. http://www.infomine.com/investment/metalschart.asp?c=magnesium&u=mt&submit1=Display+Chart&x=usd&r=3y#chart
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