Environmentally and Economically Conscious Magnesium Production: Solar Thermal Electrolytic Production of Mg from MgO

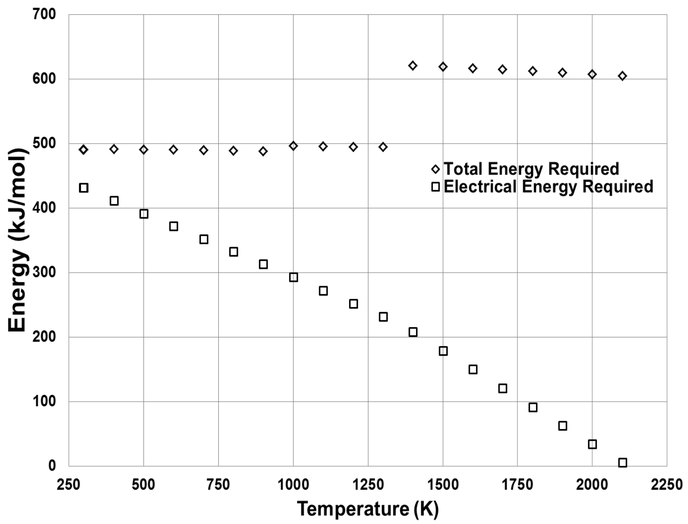
Palumbo, R. [1], Beyers, E.[1], Diver, R.[2], Duncan, S.[1], Fosheim, J.[1], Kissinger, P. [3], Nudehi, S.[1], Ogland-Hand, J. [1], Saks, L.[3], Schoer, J.[1], Schrader, A.[1], Venstrom, L.[1]

1.Valparaiso University 2. Diver Solar LLC 3. Purdue University 4. Chrysler Corporation

Overview

One method for increasing automobile fuel efficiency is the substitution of steel components with lighter Mg components of equivalent strength. Current methods for Mg production include the Pidgeon Process, a highly polluting and energy intensive method yielding inexpensive Mg, and Western Electrolysis, a less energy intensive method yielding more expensive Mg. To reduce the overwhelming environmental and economic impact of Mg, a new solar thermal electrolytic process has been developed for the production of Mg from MgO. Through this process, liquid Mg is produced in a solar reactor utilizing a combination of concentrated solar and electrical energy. This new process is expected to produce Mg at $2.50 per kg, with costs decreasing as the technology is developed further. This process requires approximately 8.3 – 11.5 kW-hr/kg-Mg of energy and produces only 4.1 kg-CO_2/kg-Mg. Both values are significantly reduced compared to current production methods.

Promise of Solar Electrolysis



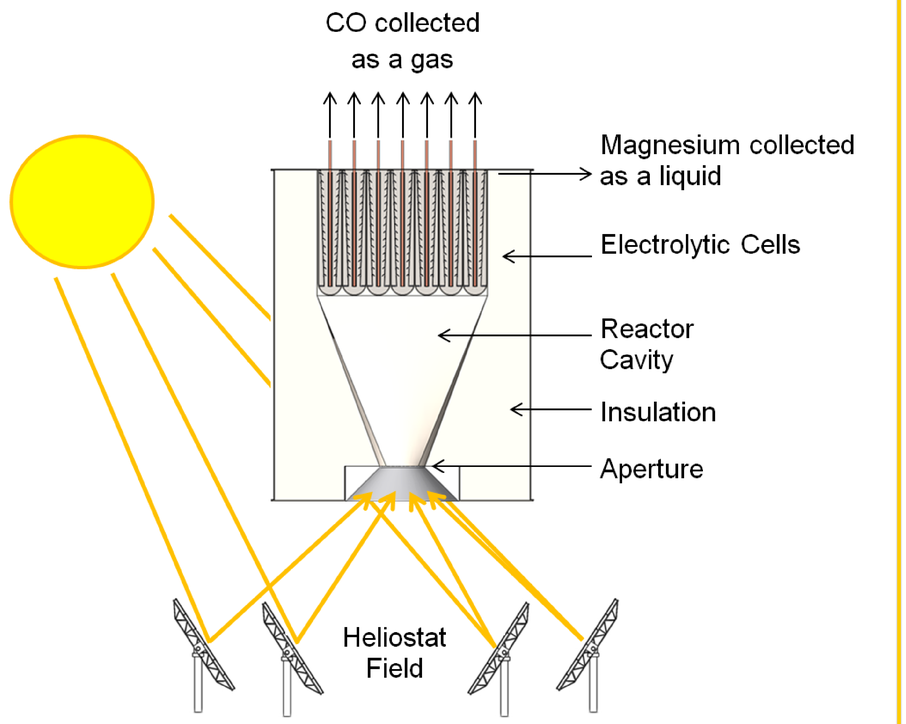
Electrochemical reactions require input energy to break the bonds between reactants. Traditionally, this energy is supplied solely by electricity. However, in our process, a portion of the overall reaction energy is supplied by process heat from concentrated solar radiation. The above graph illustrates this substitution, and also highlights that the fraction of solar energy applied to the process is temperature dependent. The operation of our proposed process will occur between 1200 K and 1250 K.

Electrochemical Reaction

$$MgO_{(s)} + C_{(s)} \overset{E_{in}}{\Leftrightarrow} Mg_{(l)} + CO_{(g)}$$

The reaction is accomplished in an electrolytic cell where the combination of solar process heat and electricity supply enough energy to react MgO particles with a Carbon anode. Liquid Mg and gaseous CO are produced and harvested.

Industrial Process

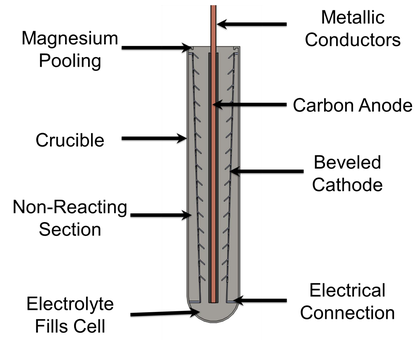


Industrial scaled process for Mg production using solar thermal electrolysis

Solar radiation is conveyed to the electrolytic cells by using a field of mirrors called heliostats and a reactor through the following process.

1) Reactor sits atop tower in center of heliostat mirror field
2) Heliostat field tracks sun and reflects sunlight into reactor aperture
3) Reactor geometry delivers incident solar radiation to electrolytic cells
4) Electricity applied to electrolytic cell
5) Mg and CO produced and collected

Electrolytic Cell



Electrolytic cell design based upon 1932 patent by Louis E. Ward

1) CO forms at the anode and Mg forms at the cathode
2) Mg is less dense than the electrolyte and therefore pools at the surface
3) To prevent Mg and CO from re-reacting, and to simplify Mg collection, small bevels are machined into the cathode which direct the Mg along the outer edge of the cell
4) Mg liquid will overflow from the cell and be collected
5) CO gas is collected as it exits the cell and can be used as a fuel source for other processes

Performance Calculations Summary

1) Calculate ΔH of electrochemical reaction (Total Reaction Energy)
2) Calculate ΔG of electrochemical reaction (Minimum Electrical Energy)
3) Calculate required solar energy from difference of ΔH and ΔG
4) Calculate solar radiation entering aperture
5) Perform energy balances within reactor and calculate surface temperatures
6) Calculate performance parameters

Performance Parameter Comparison

Metric	Pidgeon Process	Western Electrolysis	Proposed Process
Total Process Energy	102 kWh/kg-Mg	43.6 kWh/kg-Mg	8.3-11.5 kWh/kg-Mg
CO_2 Emissions	37 kg-CO_2/kg-Mg	6.9 kg-CO_2/kg-Mg	4.1 kg-CO_2/kg-Mg
Production Cost	2.50 USD/kg-Mg	3.31 USD/kg-Mg	2.50 USD/kg-Mg

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