Energy Management Study for Lunar Oxygen Production

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Abstract

Energy management opportunities in the process of hydrogen reduction of ilmenite for lunar oxygen production are being investigated. An optimal energy system to supply the power requirements for the process will be determined.

Introduction

Oxygen is one of the most important materials necessary for space exploration and colonization. It provides life support on space stations and fuel for propulsion. The high cost of payload delivery from Earth and the high fuel requirement make any long-distance space journey unfeasible. Oxygen production in space, such as on the moon or asteroids, can provide "refueling stations" for life support, combustion, and propellant.

Different processes have been proposed for oxygen production in space. These processes will require high thermal and electrical power. This project examines the power requirements of one such process. Specifically, lunar oxygen production from ilmenite reaction with hydrogen will be studied to optimize its energy requirements.

Objective

The objective of the study is to determine an optimal energy system which would provide power for lunar oxygen production through hydrogen reduction of ilmenite. Ultimately, the goal is to develop an analytical model which would determine an appropriate optimal energy system for any given oxygen production process.

Background

The basic reactions for hydrogen reduction of ilmenite to produce oxygen are:

$$FeTiO_3 + H_2 \longrightarrow Fe + TiO_2 + H_2O \quad (1)$$

$$H_2O \longrightarrow H_2 + (1/2)O_2 \quad (2)$$

The first reaction occurs endothermically at temperatures ranging from 700°C to 1000°C. The per-pass conversion of H_2 to H_2O is about 5% at 900°C. The second reaction occurs through electrolysis, or thermal water splitting. As can be seen, there is a tremendous energy requirement, not just to meet the thermal and electrical demands for the reactions to take place, but also for mining the ores, separating ilmenite from the ores, and pumping different materials through the system.

Figure 3.2 illustrates the process with a simplified block diagram. Mined regolith first passes through a beneficiator, where ilmenite is separated from non-ferrous ores. The ilmenite is then sent to the reactor, where hydrogen is introduced. The hydrogen removes oxygen from the FeO component in ilmenite to form water. Water is then separated into components of hydrogen and oxygen through electrolysis. The oxygen is then cooled, liquefied, and stored. The hydrogen is recycled through the system.

Approach

The energy management study for the ilmenite hydrogen reduction process will include the following:

1. Preparation of the ilmenite hydrogen reduction process flow diagram and determination of the appropriate temperatures and pressures for ilmenite feed, ilmenite/hydrogen reaction, water splitting, and the liquefied oxygen product. (This information will be developed with support from the Department of Chemical Engineering.)
2. Use of computer programs (presently available or newly developed) to perform mass, energy, and exergy balance of all the components in the ilmenite hydrogen reduction process. This analysis will show the irreversibilities of the various components, identify the ones which are high contributors to irreversibilities, and, as a result, determine energy management opportunities.
3. Application of the "Pinch Method" and use of commerically available computer programs to identify the various hot and cold streams in the process which could be used for process heat integration. Hot streams are those which need to be cooled; cold streams are those which need to be heated. The general approach of the Pinch Method is to combine all the hot streams in the process and plot them on an enthalpy-versus-temperature chart. All the cold streams are combined and put on the same chart. The point where the smallest ΔT occurs beteen the two curves is the pinch. The hot streams above the pinch should be utilized for preheating purposes. The cold streams below the pinch should be utilized for precooling. Thus, the Pinch Method shows how various flow streams may be integrated to reduce heating and cooling requirements. For example, since it is desirable to reject heat in the spent feeds at as close to ambient temperature as possible, the high-temperature slag exiting the reactor may be used to preheat recycled hydrogen.

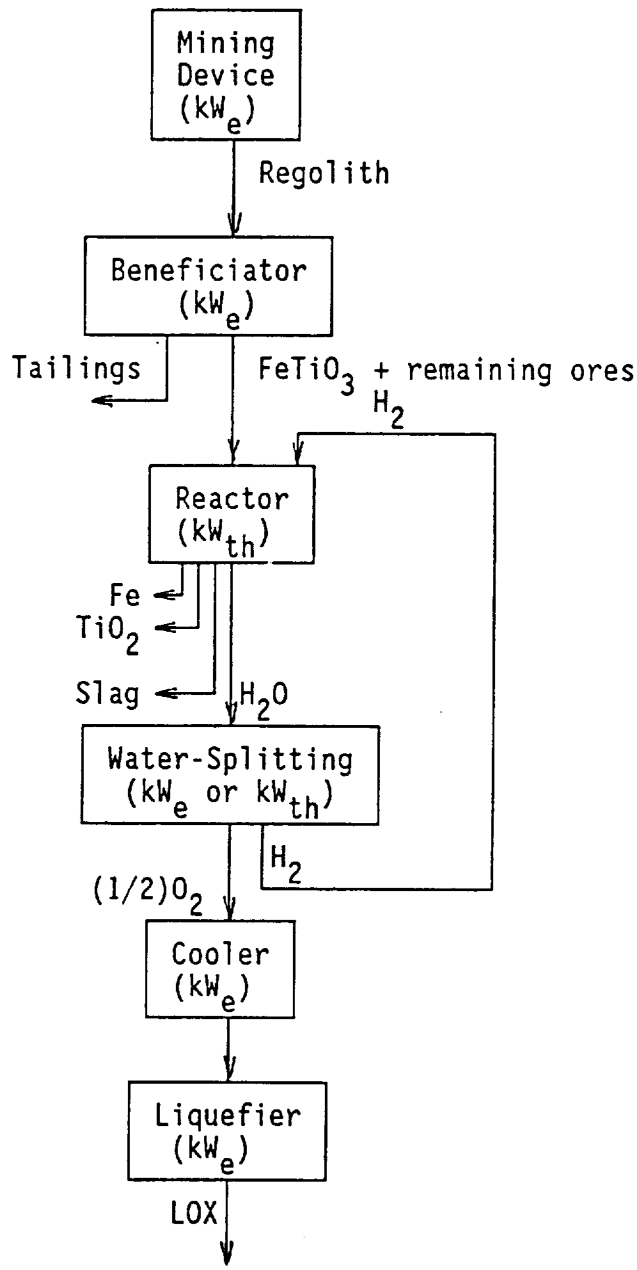

Figure 3.2. Block diagram for the process of hydrogen reduction of ilmenite to produce oxygen.

4. Exploration of opportunities to minimize the use of electrical energy. For example, investigate the current status of research in thermal water splitting to determine if the technology could be applied to replace the electrolysis portion of the ilmenite hydrogen reduction process.
5. Determination of the optimum source(s) of energy by setting the energy and capital (mass) targets.

Research Status and Results to Date

Due to problems with University registration, this project was not formally begun until January 1989 and, therefore, no analysis results have been obtained at this time.

The research effort thus far has been limited to reading references on related subjects:

1. W. W. Mendell (Ed.), *Lunar Bases and Space Activities of the 21st Century*, Lunar and Planetary Institute, Houston, 1985.
2. T. J. Kotas, *The Exergy Method of Thermal Plant Analysis*, Anchor Brendon Ltd., Essex, 1985.
3. T. Rosenqvist, *Principles of Extractive Metallurgy*, McGraw-Hill Ind., 1974.
4. Papers on the application of the Pinch Method to various industrial processes.

Future Work

Approach items (1) and (2) are expected to be completed during the next report period. The process flow diagram, as well as the process mass, energy, and exergy balance, will be presented in the next status report. The pinch analysis should also begin during this time.

IV. DATA BASE DEVELOPMENT