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Energy Management Analysis of Lunar Oxygen Production

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Abstract

Energy load models in the process of hydrogen reduction of ilmenite for lunar oxygen production are being developed. The load models will be used as a first step to ultimately determine the optimal energy system needed to supply the power requirements for the process.

Introduction

The goal of this project this year is to determine the energy requirements in the process of hydrogen reduction of ilmenite to produce oxygen. The general approach is shown schematically in Figure 4.5. Our objectives are to determine the energy loads of the processes in the system. Subsequent energy management studies will be made to minimize the system losses (irreversibilities) and to design optimal energy system power requirements.

A number of processes are being proposed as possible candidates for lunar application as outlined in the recent study by Eagle Engineering (1988). Some detailed experimental efforts are being conducted within this project at The University of Arizona. Our priorities are directed toward developing the energy models for each of the proposed processes being considered. Our immediate goals are to identify the variables that would impact energy requirements and energy sources of supply.

Objective

The objective of this study is to develop a preliminary comprehensive energy load model of the lunar oxygen production plant processes. The model, when refined, will be used to help identify energy management opportunities and optimal energy supply source(s).

Research Status

Figure 4.6 is a block diagram of the five component processes in a lunar oxygen production plant that is based on the hydrogen reduction of ilmenite. The subprocesses are: mining, mineral processing, ilmenite reduction, water decomposition, and oxygen liquefaction. Those identified with an asterisk are items for which preliminary models have been developed. Beneath each process block in the diagram are listed the probable energy users associated with each process. The following is a

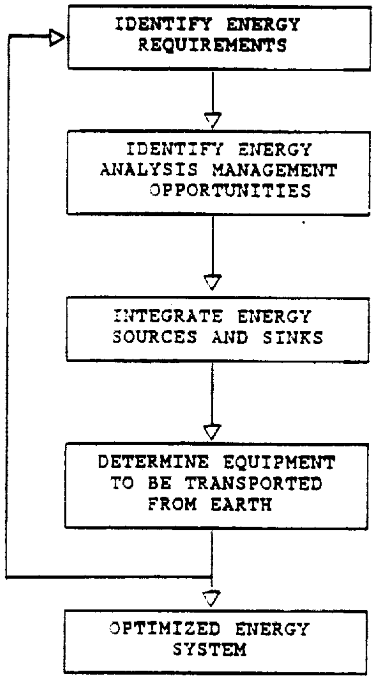
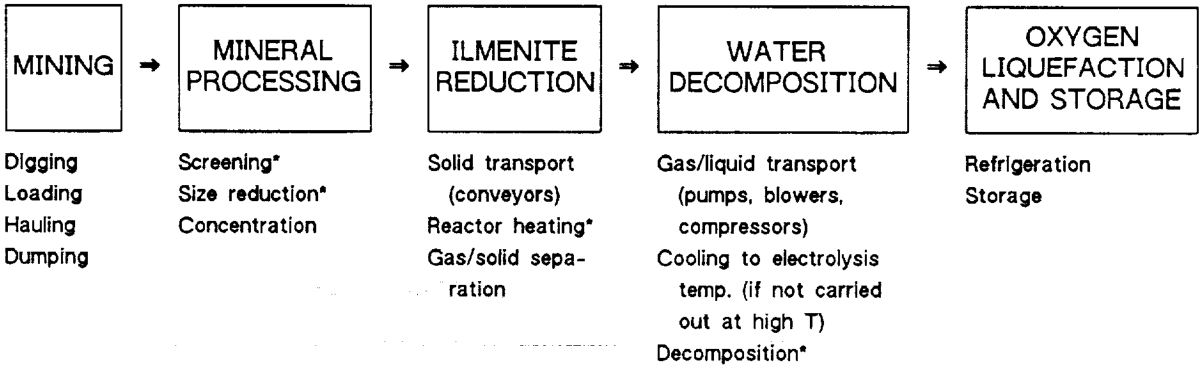


Figure 4.5 Study flow diagram.



*Preliminary energy models developed.

Figure 4.6 Energy consumers in lunar oxygen production.

summary of these models and their associated variables that impact energy supply and demand.

- *Energy Isuses Related to Mining.* Lunar mining devices will probably be electrically powered to operate in a vacuum. Thus, power requirements of terrestrial mining devices, which are mostly powered by internal combustion engines, could not be used to extrapolate power requirements on the Moon.

  The choice of an energy source will depend on the power demands of the mining devices, which depend on the grade of the haul path, the shear strength of the regolith being cut, the size (boulders vs. gravels vs. fines) of the regolith being excavated, and the depth.

  Use of modified terrestrial mining technology vs. specialized lunar mining technology, e.g., lunar rovers that mine and process the ores on location and haul only concentrated ilmenite to the oxygen production plant, needs to be studied. This would affect energy loads and distribution.

- *Energy Issues Related to Mineral Processing.* The particle size of the mined regolith will affect the type of mineral processing equipment (for sorting and size reduction) needed to reduce the ilmenite to specified size. For example, the energy demand of revolving screens is represented by

  $$E = DL \text{ (kw)}$$

  where D is the trommel diameter in meters and L is the trommel length in meters. The energy demand of plane screens is given by

  $$E = kF \text{ (kw)}$$

  where k (in KW/M^2) equals 1.5 for a screen-surface area F of 1 to 2 M^2 and k equals 1.2 for F of 2 to 7 M^2.

  Energy consumption in size-reduction machines is related to the hardness of the particles, the initial size, and the reduction achieved. A general model for the work required for size reduction is

  $$dE = -c \frac{dx}{x^{\eta}}$$

  where x is the particle size, $\eta = 1$ for crushing and fine impact pulverizing (coarse particles), $\eta = 2$ for fine grinding and ball milling (fine particles), $\eta = 1.5$ for rough milling of in-between-sized particles, and c is a constant that depends on material strength and brittleness.

- *Energy Requirement for Hydrogen Reduction of Ilmenite.*

$$FeTiO_3(s) + H_2(g) = Fe(s) + TiO_2(s) + H_2O(g)$$

q_{in}	=	$\Sigma(h_o - h_i)$	-	Δh_r	+	q_{loss}
Energy supplied to reactor to sustain the reaction at required T.P.		Sensible heat change of the flow streams due to difference in inlet and outlet Ts		Internal energy (heat of reaction)		Energy loss from reactor

$$\Sigma(h_o - h_i) = h_{Fe}(T_0) + h_{TiO_2}(T_0) + h_{H_2O}(T_0) - h_{FeTiO_3}(T_{i1}) - h_{H_2}(T_{i2}) \ ,$$

where

T_{i1} = temperature of ilmenite entering the reactor
T_{i2} = temperature of hydrogen entering the reactor
T_0 = temperature of the streams leaving the reactor

$$\Delta_{h_r} = \Delta h_f(TiO_2) + \Delta h_f(H_2O) - \Delta h_f(FeTiO_3)$$

where h_f are the enthalpy of formation for the substances at temperature T.

$$q_{loss} = \epsilon A \sigma T^4 \text{ (radiation loss from the reactor to the environment)}$$

where

ϵ = reactor emissivity
A = exterior surface area of reactor
σ = Stefan-Boltzmann constant
T = exterior surface temperature of reactor

- *Energy Requirement for Water Decomposition.*

$$H_2O \Rightarrow H_2 + \frac{1}{2} O_2$$

For the reversible process at constant temperature and pressure, the useful work required is

$$W = \Delta G = \Delta H - T\Delta S \ .$$

The heat (thermal energy) required is $q = T\Delta S$. ΔG, ΔH, and ΔS are changes in the Gibbs free energy, the enthalpy, and the entropy for the reaction. ΔG is the minimum amount of electrical energy for the process to take place endothermally, with an additional amount of heat $T\Delta S$ being added. When the energy supplied to the process is greater than ΔH, the process takes place exothermally and excess heat is given off. Therefore, ΔH is the amount of energy required by the process. This energy can be supplied electrically or thermally. Assuming an efficiency η for the energy source, the total energy required is $E = \Delta H/\eta$.

- *Energy Issues Related to Water Decomposition.* It has been suggested that high-temperature thermal decomposition should be used to decompose water to minimize heating of the recycled hydrogen to the reactor. An energy load model for both electrolysis and thermal decomposition will be developed to evaluate the merits of each.

Problems Encountered

A major uncertainty in lunar oxygen production modeling efforts is the applicability of terrestrial mining techniques to the lunar surface. Power and energy estimates based on terrestrial mining devices must be used at this time, but they may not be appropriate for lunar applications. The lunar mining mechanisms need to be refined in order to develop an appropriate energy load model. The ongoing efforts in lunar mining studies at The University of Arizona and the Colorado School of Mines should be able to provide more insight into the problem.

Future Work

The goal of the upcoming year is to complete the energy load models for the last three process blocks shown in Figure 4.6: ilmenite reduction, water reduction, and oxygen liquefaction. A secondary goal is to develop energy load models for mining and mineral processing.

References

Casper, M. S. (Ed.), 1978, "Hydrogen Manufacture by Electrolysis, Thermal Decomposition and Unusual Techniques," Noyes Data Corporation,

Eagle Engineering, Inc., "Conceptual Design of a Lunar Oxygen Pilot Plant, Lunar Base Systems Study (LBSS), Task 4.2," EEI Report 88-182, NASA Contract No. NAS9-17878, Houston, Texas, 1988.

Engineering, Construction, and Operations in Space, Proceedings of Space 88, American Society of Civil Engineers, 1988.

Justi, E. W., 1987, *A Solar-Hydrogen Energy System*, Plenum Press.

Lynch, A. J., 1977, *Mineral Crushing and Grinding Circuits*, Elksevier Scientific Publishing Company.

Magerowski, A. J., 1984, "Energy Utilization in a Comminution Circuit," paper presented at the International Conference on Mineral Processing and Extractive Metallurgy.

Perry, J. H., *Chemical Engineer's Handbook*,

Trajan, G., 1981, *Mineral Processing*, Vol. 1, *Fundamentals, Comminution, Sizing and Classification*, Akademiai Kiado, Budapest.

Turkdogan, E. T., 1980, *Physical Chemistry of High Temperature Technology*, Academic Press,