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Processing of Water on the Moon

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A. Electrolysis

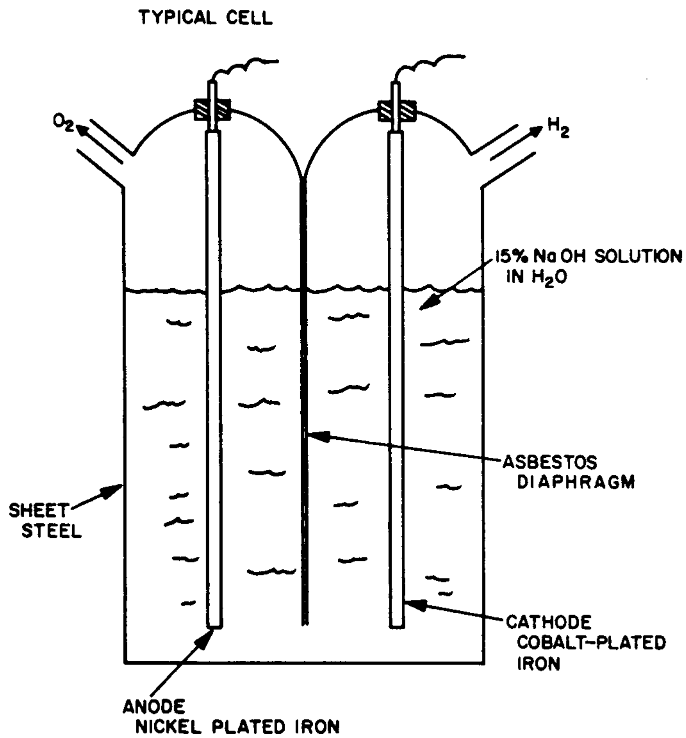
The electrolytic dissociation of water into gaseous forms of hydrogen and oxygen is a well known process that can quickly be summarized in a series of illustrations. Table 1 presents some physical properties of hydrogen and oxygen for purposes of reference. Figure 1 illustrates the chemical process and the equipment used in the industrial production of hydrogen and oxygen by the electrolysis of water. Table 2 summarizes the characteristics of electrolytic H_2-O_2 cells used in industrial practice. It is of interest to note that substantial amounts of power are required for the process and that rather heavy equipments are common to the land-based systems now in use. Very little can be done to reduce the power requirements, for the process as now carried out is relatively efficient, but undoubtedly great savings in weight can be realized.

B. Liquefaction

Having reduced water to gaseous hydrogen and oxygen, the next step in the process considered is to reduce them to their liquid forms for convenient storage and use. Two basic systems for liquefying hydrogen and oxygen are now in use. These systems are based on the so-called Joule-Thomson and Claude liquefaction cycles.

Table 1. Some physical properties of hydrogen and oxygen

	Fluid	
	H_2	O_2
Density of gas @ NTP, lb/ft³	0.0056	0.0892
Density of liquid @ NBP, lb/ft³	4.43	71.5
Normal boiling point, °K	20.4(−422.9°F)	90.1(−297.4°F)
Critical-point temperature, °K	33.3	155
Critical-point pressure, psia	188	730
Latent heat @ NBP, Btu/lb	194.5	91.5
Pre-cool temperature for practical J-T process, °K	65	300



$2H_2O \rightarrow 2H_2 + O_2$

$\Delta H = +2(68{,}317)$ cal/g formula wt

Fig. 1. Electrolytic hydrogen and oxygen production reactions

Table 2. Characteristics of typical electrolytic H_2-O_2 cells

Basis	9 lb $H_2O(l) \rightarrow$ 1 lb $H_2(g)$ + 8 lb $O_2(g)$
Power	27.7 kw-hr
Volts/cell	2.1
Amps/cell	250–14,000
Efficiency	65%
Dry weight	6500 lb
Volume	121 ft³

Figure 2 is a schematic representation of a Joule-Thomson gas liquefier. This system was the first to be applied to the liquefaction of gases, primarily because of the simple nature of the equipment required. This system could be used to produce liquid oxygen on the Moon, but it is very unlikely that it could produce liquid hydrogen because of the unavailability of a heat sink at sufficiently low temperatures for Joule-Thomson pre-cooling. At any rate, this process is relatively inefficient, and for this reason, it has been largely superseded by the Claude process. Certainly, systems patterned after the Claude process are of most interest when considering the liquefaction of gases in the lunar environment.

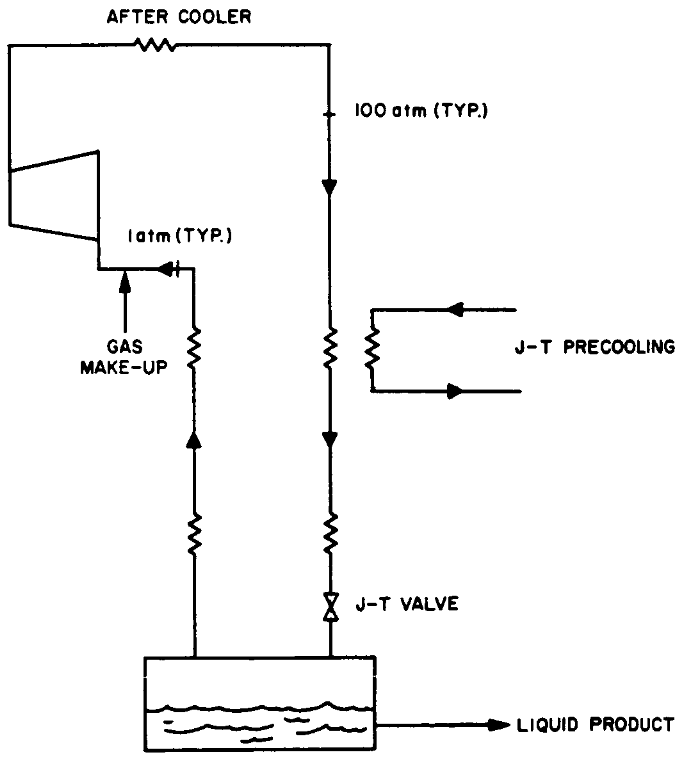


Fig. 2. Schematic representation of Joule-Thomson gas liquefier

Figure 3 shows a schematic representation of a gas liquefier operating on the Claude cycle. The use of low-temperature expansion engines is fundamental to this cycle, making possible more efficient operation at lower pressure levels. This is translated in terms of power and weight savings.

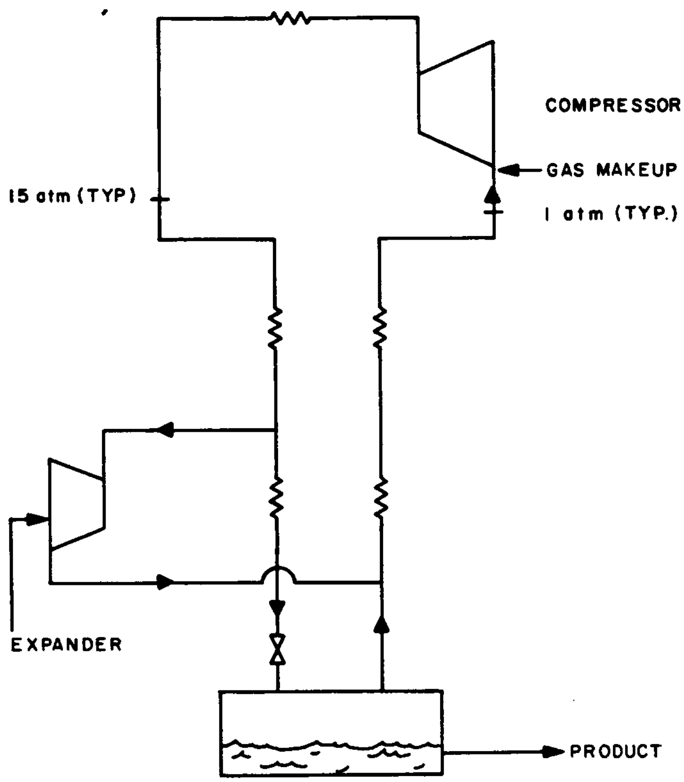


Fig. 3. Schematic representation of gas liquefier using expansion engines

Typical characteristics of an oxygen liquefier operating on the Claude cycle are shown in Table 3. Table 4 shows typical characteristics of a hydrogen liquefier. These Tables indicate a rather substantial power requirement for liquefaction, although it is lower than

Table 3. Typical characteristics of oxygen liquefier (expansion engine cycle)

Reversible work requirement	0.08 kw-hr/lb
Actual shaft work requirement	0.32-0.40 kw-hr/lb
Ratio of shaft work to heat extraction	10:1
Weight of industrial plant (exclusive of power supply and buildings)	250–500 lb/kw
Estimated weight of lunar plant (exclusive of power supply and buildings)	50–100 lb/kw

Table 4. Typical characteristics of hydrogen liquefier (expansion engine cycle)

Reversible work requirements	2 kw-hr/lb
Actual shaft work requirements	8-10 kw-hr/lb
Ratio of shaft work to heat extraction	70:1
Weight of industrial plant (exclusive of power supply and buildings)	300–600 lb/kw
Estimated weight of lunar plant (exclusive of power supply and buildings)	70–140 lb/kw

that for separation. In addition, a fairly substantial plant weight requirement can be noted. The estimated weights of lunar plants are derived from studies of space-borne refrigeration systems.

Tables 3 and 4 do not show requirements for plant maintenance. The maintenance requirements for liquefaction plants now in operation are incompatible with the needs of lunar liquefaction operations. However, developments in progress hold promise for the realization of systems giving unattended reliable service for periods measured in many thousands of hours.

One of the really significant technical problems associated with the processes described is the requirement to reject substantial amounts of heat to the environment. The only obvious way of rejecting this heat is with a space radiator. As can be seen in Table 5, the radiator area (and, by inference, radiator weight) will be large.

In summary, the processing of water to liquid hydrogen and oxygen on the Moon introduces some challenging technological problems. Certainly the need for light-weight, efficient, reliable systems is obvious. The problem of heat rejection is unusual. A careful analysis of the logistics of lunar base operations coupled with an investigation of a creative approach to the design of systems particularly suited to the lunar environment is needed before the characteristics of near-optimum systems can be defined.

Table 5. Maximum heat rejection to space vs radiator area

Temperature, °K	Heat rejection, kw/ft^2
300	4.32×10^{-2}
90	3.58×10^{-4}
20	9.65×10^{-7}