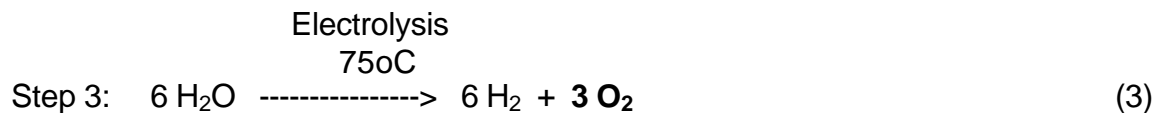
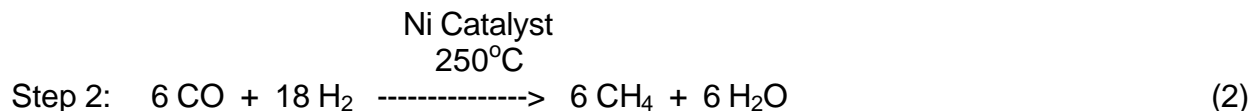
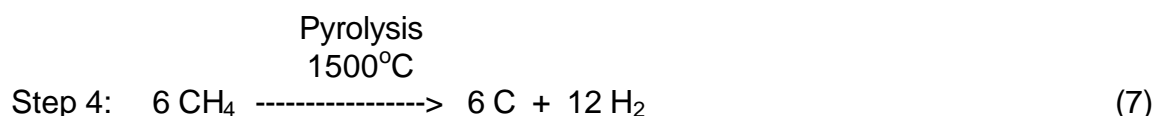
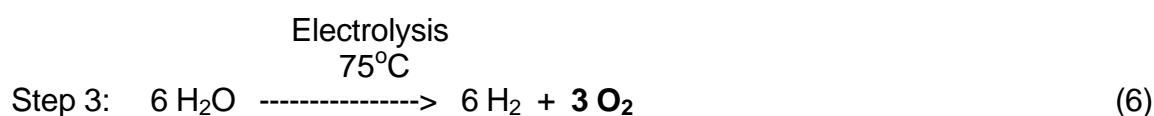
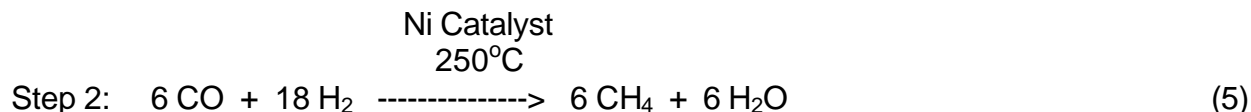
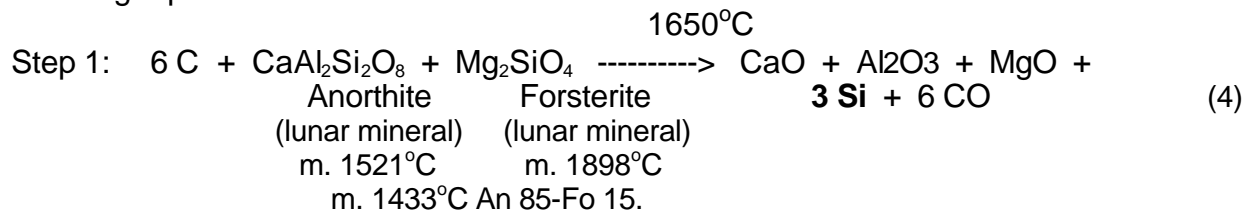


CARBOTHERMAL REDUCTION PROCESS FOR MANUFACTURE OF OXYGEN, SILICON, AND OTHER USEFUL PRODUCTS ON THE MOON: 1961-2001

Research on the Carbothermal Reduction Process for the manufacture of oxygen, silicon, and other useful products on the Moon was initiated in 1961 in laboratories of the Aerojet General Corporation, Azusa, California and has continued, intermittently, to the present time, e.g. in laboratories of Makel Engineering Incorporated, Chico, California and the Space Vacuum Epitaxy Center, Houston, Texas. The three-step, closed-cycle process was reduced to practice in 1962, i.e., oxygen, silicon, iron and slag were produced using granite and basalt, respectively, as the lunar soil simulants and methane and carbon, respectively, as the reducing agents. More recently, i.e., 1994 to 2001, JSC-1, MLS-1a and gruenerite have been used as lunar soil simulants.

$$\text{Step 1: } 6 \text{ CH}_4 + \underset{\substack{\text{Anorthite} \\ \text{(lunar mineral)} \\ \text{m. } 1521^\circ\text{C}}} {\text{CaAl}_2\text{Si}_2\text{O}_8} + \underset{\substack{\text{Forsterite} \\ \text{(lunar mineral)} \\ \text{m. } 1898^\circ\text{C}}} {\text{Mg}_2\text{SiO}_4} \xrightarrow{1650^\circ\text{C}} \text{CaO} + \text{Al}_2\text{O}_3 + \text{MgO} + \underset{\text{m. } 1433^\circ\text{C An 85-Fo 15.}} {3 \text{ Si}} + 6 \text{ CO} + 12 \text{ H}_2 \quad (1)$$

$$\text{CaAl}_2\text{Si}_2\text{O}_8 + \text{Mg}_2\text{SiO}_4 \text{ -----} \text{CaO} + \text{Al}_2\text{O}_3 + \text{MgO} + \mathbf{3\ Si} + \mathbf{3\ O_2}$$

The four-step, closed-cycle Carbothermal Reduction Process is illustrated in the following equations.



As before the four-step, closed-cycle process yields oxygen, for propulsion and life support, and elemental silicon, for photovoltaic power generation.



Both the three-step and four-step processes have been demonstrated as discrete steps. Intergration of the overall processes had not been undertaken.. Step 1, Equation (1), has been demonstrated in a 60% yield, i.e., 60% of the methane was converted to carbon monoxide. Step 1, Equation (4), has been demonstrated in a 95+% yield, i.e, 95+% of the carbon was recovered as carbon monoxide. Step (2), Equations (2) and (5), has been demonstrated in 100% yields, as has Step 3, Equations (3) and (6).

Research is underway to improve the yield obtained in Step 1, Equation (1) and on methods to prepare high grade silicon from JSC-1 as the precursor to the preparation of photovoltaic grade silicon for use in the manufacture of photovoltaic arrays on the Moon. This research will be discussed in the oral presentation. In addition, a review of the research which has been conducted on the Carbothermal Reduction Process for the manufacture of oxygen, silicon, and other useful products on the Moon will be presented.