Summary

Nuclear Thermochemical Production of Hydrogen with a Lower-Temperature Iodine-Westinghouse-Ispra Sulfur Process

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The use of inorganic membranes is being investigated to reduce the temperature of the heat required from nuclear reactors for the efficient production of hydrogen (H_2) using thermochemical processes. One of the major barriers to thermochemical H_2 production is the high temperature required for efficient H_2 production. Three of the four highest-rated processes (Westinghouse, Ispra Mark 13, and iodine sulfur) have the same high-temperature step that requires heat input at ~850ºC, which is at the limit of reactor technology. If this temperature could be lowered to 700ºC, current designs of high-temperature reactors could be used for H_2 production. The highly endothermic (heat-absorbing) reaction in each of these processes is:

$$2H_2SO_4 \leftrightarrow 2H_2O + 2SO_3 \leftrightarrow 2SO_2 + 2H_2O + O_2$$

The three thermochemical processes have different lower-temperature chemical reactions. For example, the iodine-sulfur process has two other reactions that, when combined, yield H_2 and oxygen from water and heat.

$$I_2 + SO_2 + 2H_2O \rightarrow 2HI + H_2SO_4$$

$$2HI \rightarrow I_2 + H_2$$

The high-temperature reaction is an equilibrium chemical reaction that requires a catalyst and can proceed in either direction. High temperatures and low pressures drive the reaction towards completion. For operation at 10 bars, the equilibrium percentage completion of this disassociation chemical reaction is estimated to be 31% at 625EC, 79% at 725EC, and 99% at 925EC. The efficiency of dissociation increases significantly at higher temperatures and lower pressures. In real processes, the percentage of completion at each temperature is considerably lower. (The equilibrium state occurs at infinite time.) Detailed studies have concluded that the required temperature will be about 850ºC. After the reaction all the chemicals must be cooled to near room temperature, the SO_2 separated out and sent to the second chemical reaction, and the sulfuric acid reheated to high temperatures. The energy losses in separations and the heat exchangers to heat and cool all the reagents result in a very inefficient and uneconomical process, unless the reaction goes almost to completion.

To drive the chemical reaction to the right at lower temperatures, the SO_2 and O_2 must be separated from the SO_3 at high temperatures. The remaining pure SO_3 will then absorb heat and dissociate into an equilibrium concentration of SO_3, SO_2, and O_2, which can drive the reaction to completion.

We are investigating the use of inorganic membranes (one of several options) for separation of SO_2 and O_2 from SO_3. Inorganic membranes allow smaller and lighter molecules to go through the membrane while the larger molecules are held back. The membrane has high pressure on one side and a lower pressure on the other side, providing the driving force for separation. Analysis indicates that the process should allow nearly complete dissociation of SO_3 at 700ºC. Experiments are being constructed to measure the gas-separation efficiency of different membranes.