Summary

Lowering Peak Temperatures for Nuclear Thermochemical Production of Hydrogen

Charles Forsberg

Oak Ridge National Laboratory*
P.O. Box 2008
Oak Ridge, TN 37831-6179
Tel: (865) 574-6783
Fax: (865) 574-9512
E-mail: forsbergcw@ornl.gov

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C. W. Forsberg
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6179, United States of America
Tel: (865) 574-6783; Fax: (865) 574-9512; E-mail: forsbergcw@ornl.gov

The efficient production of hydrogen using nuclear energy requires matching the nuclear reactor and the thermochemical processes to convert heat plus water into hydrogen and oxygen. The major challenges are the high temperatures required to produce hydrogen efficiently. Consequently, Oak Ridge National Laboratory is investigating nuclear reactor options and thermochemical cycles to minimize those temperatures while efficiently producing hydrogen. We are examining the molten-salt-cooled Advanced High-Temperature Reactor (AHTR) to produce the heat. The use of a low-pressure liquid coolant minimizes the temperature drops between the hottest fuel elements in the reactor and the thermochemical cycle, thus minimizing peak reactor temperatures. Simultaneously, we are examining the use of inorganic membranes to minimize the temperatures required for the efficient production of hydrogen using the (1) sulfur–iodine, (2) Westinghouse, and (3) Ispra Mark 13 thermochemical hydrogen processes.

ADVANCED HIGH-TEMPERATURE REACTOR

The molten-salt-cooled AHTR is a new reactor concept designed to provide high reactor-coolant exit-temperature heat (750 to 1000EC) to enable efficient low-cost thermochemical production of hydrogen. The reactor uses a graphite-matrix coated-particle fuel similar to that used in high-temperature helium-cooled reactors. The coolant is a molten fluoride salt. Because the boiling points for molten fluoride salts are near ~1400EC, the reactor can operate at very high temperatures and atmospheric pressure. The efficient liquid cooling minimizes the temperature drop between the hottest fuel elements and the thermochemical hydrogen process. By using a low-pressure liquid coolant, the peak reactor fuel temperatures are 100–300EC lower than those for similar gas-cooled reactors.

INORGANIC MEMBRANE THERMOCHEMICAL PROCESSES

All of the proposed efficient methods to thermochemically produce hydrogen require high temperatures. Three of the four highest-rated processes (sulfur–iodine, Westinghouse, and Ispra Mark 13) have the same high-temperature step that requires heat input at ~850ºC, which is near the limits of proven materials. To deliver heat at 850ºC, the reactor must operate at much higher temperatures (fuel, coolant, and structures). If this peak temperature could be lowered to 700ºC, proven materials and designs of high-temperature reactors could be used for hydrogen production. Methods are being investigated to lower this peak temperature.

The highly endothermic (heat-absorbing), high-temperature gas-phase reaction in each of these hydrogen production processes is as follows: $2H_2SO_4$] $2H_2O + 2SO_3$] $2H_2O + 2SO_2 + O_2$. The high-temperature sulfur trioxide (SO_3) dissociation 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 625ºC, 79% at 725ºC, and 99% at 925ºC.

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. We are investigating the use of inorganic membranes 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. As the SO_3 dissociates, the reaction products (SO_2 and O_2) go through the membrane and are removed from the SO_3. Because of this removal process, the SO_3 never reaches an equilibrium concentration with SO_2 and O_2. It continues to dissociate until the reaction is complete. Analysis indicates that the process should allow nearly complete dissociation of SO_3 at 700ºC. An experimental program has been initiated.