NUCLEAR HYDROGEN PRODUCTION: ISOLATING THE NUCLEAR REACTOR AND CHEMICAL FACILITIES

Charles W. Forsberg
Oak Ridge National Laboratory*
P.O. Box 2008
Oak Ridge, Tennessee 37831-6179
Tel: (865) 574-6783; Fax: (865) 574-9512
Email: forsbergcw@ornl.gov

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Introduction

The growing hydrogen (H_2) demand to refine heavy crude oils and the potential future demand for H_2 for automobile fuel cells have created increased interest in methods to produce H_2 using nuclear energy [1]. To assure safe production of H_2, methods are required to isolate the chemical and nuclear facilities. Isolation can be obtained via appropriate engineering design features or, alternatively, by designing the nuclear reactor with intrinsic characteristics that match process requirements and ensure safety. The second approach is described herein.

Three methods have been identified for efficient H_2 production: thermochemical [2] (heat plus water yields H_2 plus O_2), high-temperature electrolysis [3] (heat plus electricity plus water yields H_2 plus O_2), and nuclear-assisted steam reforming of natural gas [2]. All the processes require heat to be supplied at 750+°C over a relatively small temperature range to some type of chemical dissociation reaction and operation at low-pressures. For safety, tritium generated in the nuclear reactor must be kept away from the product H_2 and the nuclear facilities should be isolated from the chemical facilities.

Based on these process and safety requirements, a conceptual design [4] of an Advanced High-Temperature Reactor (AHTR) for H_2 production was developed. Process and safety goals are achieved by the selection of the fuel (graphite-matrix coated-particle fuel similar to gas-cooled reactor fuel) and the coolant (molten fluoride salt [Na/Zr fluoride], which does not react with air, slowly reacts with water, and has a boiling point of ~1400°C). The reactor core is somewhat similar to that of a gas-cooled reactor, except that a molten-salt coolant is used to transfer heat from the reactor core to the heat exchangers in the H_2 production facility. The basis for fuel and coolant selection is as follows.

High-temperature heat

Only one fuel has been demonstrated on a significant scale to operate at or above 750°C: graphite-matrix coated-particle fuels, the most common being the TRISO triple-coated fuel. It is the preferred fuel. The fuel is compatible with helium and molten fluoride salts but not with molten metals or water.

The process heat is required at a nearly constant temperature. Gas-cooled (He, CO_2) reactors have several hundred degree temperature rises across the reactor core to minimize pumping power whereas liquid-cooled (water, sodium, molten salt) reactors have temperature rises of several tens of degrees (Fig. 1). If heat is needed at 750°C, the maximum temperature for the gas coolant may exceed 1000 °C whereas that for the liquid coolant will not exceed 850°C. Liquid coolants are preferred because they minimize peak temperatures and thus minimize high-temperature materials requirements and safety issues.

Catastrophic chemical plant safety

The H_2 production facility will contain large inventories of hazardous chemicals. A low-pressure, non–chemically reactive coolant minimizes safety risks by minimizing the consequence of heat exchanger failures between the chemical and nuclear facilities. High-pressure reactor coolants create the potential for pressurization of the chemical plant and releases of toxic gases With boiling points near 1400°C, molten salts avoid the potential for chemical plant pressurization. Furthermore, they do not react with air and only slowly react with water. Sodium, the traditional low-pressure coolant, is not a candidate because it boils at 883°C and is chemically reactive with air, water, and most chemicals.

Tritium

Tritium must be minimized in the product H_2. Tritium contamination from the reactor can be minimized by engineering barriers or through the choice of fuel and coolant to avoid tritium generation. Coolants such as helium slowly generate tritium (n/p reaction with ^3He). Molten fluoride salts such as Na/Zr fluorides do not generate tritium. Tritium diffusion through metals increases with temperature. The lower peak coolant temperatures in liquid-cooled versus gas-cooled systems minimize diffusion of tritium from reactor fuel and coolant.

Physical isolation

The nuclear and chemical facilities can be separated by distance so that severe events in one facility do not impact the other. Low-pressure high-temperature molten salts have low pumping costs and low heat loses and are traditionally used in the chemical industry for heat transfer.

Conclusions

It is relatively easy to produce electricity from a wide variety of heat sources. Consequently, nuclear power plants have been chosen on the basis of reactor characteristics with the thermal-to-electricity conversion systems designed to match the reactor. Efficient H_2 production requires high temperatures, low pressures, tritium control, and attention to both chemical plant as well as nuclear plant safety. The nuclear reactor design should be chosen to match the requirements of the chemical plant. Such a strategy minimizes safety and system design issues.

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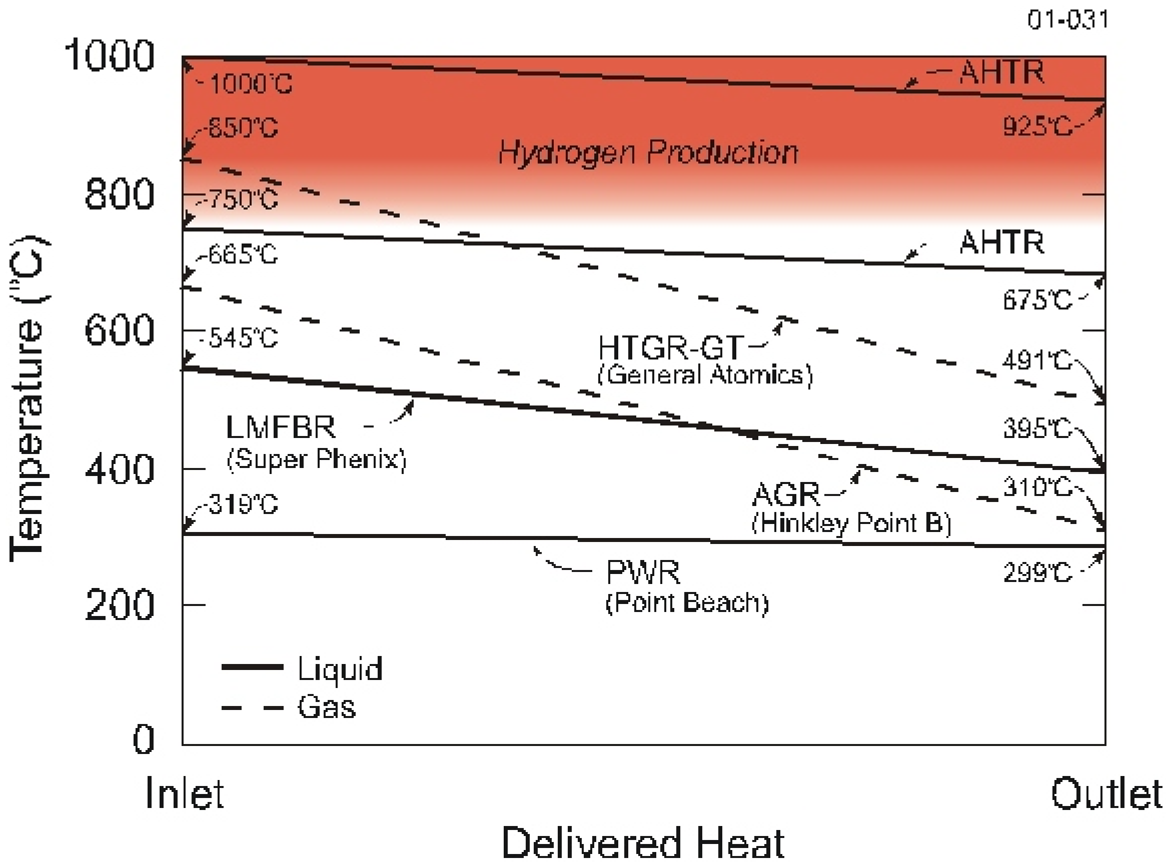

Fig. 1. Temperature of Delivered Heat for Reactors with Different Coolants