

## HYDROGEN PRODUCTION FROM WATER

**Isao Abe**

*Office Tera, Chiba, Japan*

**Keywords:** direct thermal decomposition, thermochemical cycles, electrolysis, photolysis photoelectrochemical method), mechano-catalytic splitting

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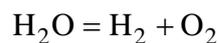
### Summary

Several ways of splitting water to produce hydrogen are introduced. The methods that are not described in separate articles are discussed in a little detail.

### 1. Introduction

Today, hydrogen is most economically produced from hydrocarbons, unless there is abundant hydroelectricity, when water electrolysis is the most economical. But in the future, when it is difficult to use fossil fuels, hydrogen must be produced from water. Splitting water into hydrogen and oxygen is essentially the only way of making hydrogen without fossil fuels such as coal, oil, or natural gas. Theoretically there are several ways of splitting water: direct thermal decomposition, thermochemical cycles, electrolysis, photoelectrolysis, and mechano-catalytic splitting. Since production of hydrogen is the key technology in future hydrogen energy systems, various ways of producing hydrogen have been investigated. At present, only water electrolysis is commercially used and others are in various stages of research and development.

The splitting of water reversibly according to Eq. (1) needs a supply of energy as follows:



$$\Delta H_{298}^0 = 241.93 \text{ kJ/mole} \tag{1}$$

$$\Delta G_{298}^0 = 228.71 \text{ kJ/mole}$$

$$T\Delta S_{298}^0 = 13.22 \text{ kJ/mole}$$

This means that at least the work corresponding to  $\Delta G$  and the heat corresponding to  $T$  multiplied by  $\Delta S$  should be provided to split water into hydrogen and oxygen under standard conditions (25 degree cent and 1 atm). For instance, to split water by electrolysis, the work is provided in the form of electricity. In actual cases, reactions do not proceed reversibly and more work is necessary.

There are various ways to supply this energy to water for splitting. The details of some of them are described in the following articles. Therefore short introductions are given here for these methods.

## 2. Direct Thermal Decomposition

Direct thermal decomposition involves splitting water in one step using only heat. This needs an extremely high temperature (over 5000 K) to be applied to the system, which makes this process unrealistic.

Even partial decomposition needs a high temperature, for example over 2500 K. The lower total pressure favors the higher partial pressure of hydrogen. This makes it difficult to build a reactor that works below the atmospheric pressure at very high temperature. The separation of product gases is also difficult. The produced hydrogen and oxygen must be separated at this high temperature.

Probably some kind of heat resistant membrane will be used, but to develop the materials is not easy and has yet to be done. A selective membrane made of palladium (Pd) or zirconium oxide ( $ZrO_2$ ) has been proposed. Another possibility for gas separation is to use a magnetic field.

The heat source to provide such a high temperature is also a problem. A solar furnace system that concentrates sunlight using large mirrors is the only conceivable source of heat. This method is still in the very early stage of basic research and whether it is industrially feasible is not yet clear.

## 3. Thermochemical Cycles

Since direct thermal decomposition of water is difficult, another way of water splitting using heat is proposed. This is the thermochemical cycle in which multiple-step chemical reactions are used to decompose water into hydrogen and oxygen. By using two or three reactions, it is expected that the reactions can proceed at a lower temperature than in single-step direct decomposition.

A lot of cycles have been proposed and researched, but only a few cycles have reached full cycle testing. The high temperature gas-cooled nuclear reactor is assumed to be the heat source of thermochemical cycles.

Therefore cycles that use heat lower than 1300 K were researched. There are many difficulties in using this method at an industrial level and none of the cycles have reached pilot plant stage. (See *Thermochemical Cycles* for the details.)

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### **Biographical Sketch**

**Isao Abe**, born September 16, 1939, in Osaka, Japan, received his Bachelor of Engineering degree from the Department of Fuel Engineering, Faculty of Engineering, University of Tokyo (1963), and Master of Engineering from the Department of Reaction Chemistry of the same faculty, the same university (1966). He worked for Showa Denko K.K. as a chemical engineer (1966–1999), and was involved in development of the advanced alkaline water electrolyzer under the Sunshine Project of the Japanese government as the director of technical development (1974–1984); during that period, he worked as formal alternate representative of Japan to the YEA Task IV (water electrolysis) workshop. He has been editor-in-chief of *Journal of the Hydrogen Energy System Society of Japan* since 1998.