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Simulation of flux distributions on the foam absorber with solar reactor for thermo-chemical two-step water splitting H_2 production cycle by the 45 kW_{th} KIER solar furnace

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Abstract

The flux distributions on the device in the solar reactor with the solar furnace were studied. This study aims to understand of characters of concentrated sun rays through KIER solar furnace and design of device shape for uniform heat distribution on the device surface. For the calculation of heat flux on the device with the KIER solar furnace, the optical modeling program Soltrace was used. At first, the KIER 45 kW_{th} solar furnace and flat disk type device shape was simulated for understand of past experimental results. And then 3 cylinder shape device model and 1 conical shape device model was suggested and the heat flux intensity on the device was calculated. Finally, 5 models which is including flat disk type device shape, 3 cylinder shape, and 1 conical shape device models was calculated and compared. The results show that the concentrated sun rays from dish and heat flux intensity are has a directional characteristic concentrated to normal direction than perpendicular direction. The results will be applied to next solar demonstrations which are design of new solar reactor and new device shape.

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Keywords: Foam device, Two-step water splitting, Solar reactor, Solar furnace, Heat flux

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1. Introduction

Concentrated solar radiation is used as the energy source for high temperature process heat to drive chemical reactions towards the production of storable and transportable fuels. Various solar chemical receiver/absorbers or reactors with redox materials has been proposed, developed and tested for realizing hydrogen production using a concentrated solar radiation [1]. The concept of using metal oxides as substrate for thermochemical production of hydrogen was suggested by Nakamura (1977), in which cycling between Fe_3O_4 and FeO was demonstrated [2]. Among the variety of metal oxides, ceria has emerged as an attractive redox material due to its ability to rapid conduct oxygen contributing to fast redox kinetics, as compared to ferrite-based metal oxides [1].

The two step water splitting cycle based on nonstoichiometric ceria is represented by following equations.

$$CeO_2 \rightarrow CeO_{2-\delta} + 1/2\delta O_2 \quad (1)$$
$$CeO_{2-\delta} + \delta H_2O \rightarrow CeO_2 + \delta H_2 \quad (2)$$

The first step (Thermal reduction) is highly endothermic (ΔH = 198 kJ/mol CeO_2 at 2300 K) and heat is supplied by concentrated solar radiation and oxygen is released. In the reduction step, ceria is thermally reduced to a nonstoichiometric state in which it can react with steam. The second step (Water decomposition) is exothermic (ΔH = − 125 kJ/mol at 700 K), in which case hydrogen is produced [3-5]. Several studies examined the suitability of ceria for thermochemical fuel production, applying thermochemical study and CO_2/H_2O splitting with the reticulated pure ceria [6].

Niigata University has developed ceramic foam devices whose foam matrix is made of MgO-partially stabilized zirconia (MPSZ). The MPSZ foam matrix has superior characteristics as compared with SiSiC and SiC[7], including high heat resistance and chemical inertness with iron oxide at high temperature. Also, the foam structure can effectively absorb light irradiation owing to its specifically large surface area. These foam devices were possible for multi-cycling the two-step water splitting process [8-11]. Niigata University started an international project for solar two-step water splitting cycle using a foam device reactor: a joint research project between Niigata University (Japan) and Korea Institute of Energy Research (Korea) started in 2012. The reactive water splitting foam device was developed and prepared by Niigata University, and involves coating zirconia foam with ceria [12]. The objectives of the project are to develop reactive foam devices with ceria as the working material, to design and fabricate a solar reactor with the reactive foam device, and finally, to demonstrate its performance in sunlight with a KIER 45 kW_{th} solar furnace. From 2012 to 2013, the thermochemical two-step water splitting cycle which use a ceria coated ceramic foam device as a redox material for hydrogen production with a 45kW_{th} solar furnace, have been validated by the hydrogen production.

However, due to the ceria coated foam device having a disk shape, the distribution of heat flux on the device was non-uniform. It was verified by photographs captured by the CCD camera during the experiment. Figure 1 shows the photograph of device surface at the thermal reduction step, in which is seen, significantly, the release of oxygen at the center, not the side-activated are. The feature point of CeO_2 material is the discoloration phenomenon between reduced phase and the oxidized phase. The reduced phase of CeO_2 shows a darker color than in the original state. In fact, the flux distribution in the solar reactor (or on the device surface) has a direct effect on the efficiency of hydrogen production. The radiation flux distribution in the solar reactor depended on directional distribution and quantity of concentrated energy in the focal region of solar concentrating system [13, 14].

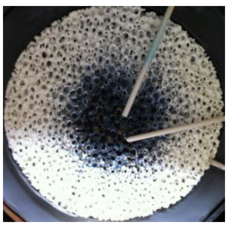

Fig 1. A photograph of ceria coated foam device under the thermal reduction step