Particles Fluidized Bed Receiver/Reactor with a Beam-Down Solar Concentrating Optics: First Performance Test on Two-Step Water Splitting with Ceria Using a Miyazaki Solar Concentrating System

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1. Introduction

A novel concept of a windowed, particles fluidized bed solar receiver/reactor has proposed by Niigata University [1,2]. A fluidized bed of particles is directly irradiated by concentrated solar radiation in the receiver/reactor which has a transparent quartz window on top of the reactor (Fig. 1). Concentrated solar radiation passes downward though the window and directly heats the particles in an upper region of the particles fluidized bed. The internally-circulating fluidization can be created by passing gas with a faster flow rate from the center region of the bottom distributor, which promotes good heat transfer by particles from the top to bottom of the bed to create uniform temperature distribution through the bed.

One of targeted solar thermochemical processes for this windowed fluidized bed solar receiver/reactor is “a two-step water splitting cycle with non-volatile metal oxide. A two-step thermochemical water splitting cycle with a redox metal oxide, such as ferrite or non-stoichiometric cerium oxide (ceria), proceed as followings [1-3]:

$$MO_x \rightarrow MO_{x-\delta} + \delta/2O_2 \quad T > 1300^\circ C \quad \text{(Thermal reduction or T-R step)} \quad (1)$$

$$MO_{x-\delta} + \delta H_2O \rightarrow MO_x + \delta H_2 \quad T < 1000^\circ C \quad \text{(Water decomposition or W-D step)} \quad (2)$$

The windowed fluidized bed solar reactor concept was successfully demonstrated using a ceria particles bed using a 30-kW_{th} big sun-simulator using 19 xenon-arc lamps at Niigata University [3].

This receiver/reactor concept needs to be combined with a beam-down (BD) type solar concentrator. Niigata University and University of Miyazaki has started an R&D joint project since 2011, to demonstrate the up-scaled fluidized bed receiver/reactor on solar. A new type of 100kW_{th} BD solar concentrating system with a secondly elliptical reflector (Fig. 2) was built in August, 2012 at the campus of University of Miyazaki for solar demonstration of the receiver/reactor [4]. The optical technologies of the BD system were provided by MITAKA KOHKI Co. Ltd (Fig. 3).The performance test of this new beam-down system with/without a CPC was done in 2012-2014 [4,5].

This paper reports the first performance test on the two-step water splitting with ceria by the windowed, fluidized bed solar reactor at the Miyazaki 100-kW_{th} BD solar concentrating system.

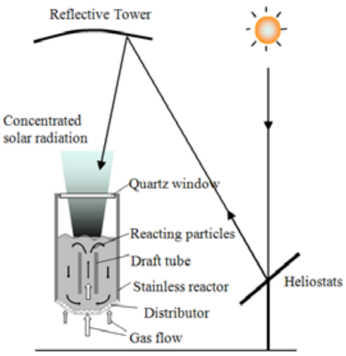

Fig. 1 Particle fluidized bed receiver/reactor with a beam-down solar concenterating optics

Fig. 2 100-kW_{th} beam-down solar concentrating system at Miyazaki, Japan

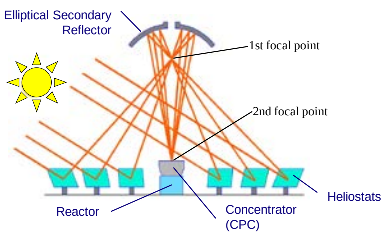

Fig. 3 Principle of a novel beam-down system with a ellipical secondary reflector

2. Experimental method

The solar reactor was fabricated for solar performance test at the Miyazaki BD solar concentrating system (Fig. 4). The body of the reactor was made of Inconel and stainless steel. The receiver has a quartz window with a diameter of 75 cm at the ceiling. About 20 kg of ceria (CeO_2) with particle size of 100 - 300 μm was loaded in the reactor. The diameter and the high of the static sand bed were both 25 cm. The distributor at the bottom of the bed has many holes with 0.5 mm diameter. The gas distributor of an Inconel perforated plate at the bottom of the bed was made by many holes with 0.5 mm diameter. In order to provide the jet flow along the central axial region at the bottom-inlet, the density of holes in the central axial region of the perforated plate was increased than the near wall region to create an internally-circulating fluidization. The reactor was placed below the exit of a CPC (Compound Parabolic Concentrator) [5] at the Miyazaki BD solar concentrating system (Fig. 4). Initially, air was passed through the CeO_2 particles bed to fluidize the particles beforehand, and the bed was heated up to 900˚C by electric pre-heaters placed around the reactor. After reaching 900˚C, a passing gas was switched from air to N_2 gas and the irradiation onto the top bed surface with concentrated solar radiation from the BD system was started to perform the T-R step of CeO_2 particles. After the T-R step, the bed temperature was decreased to 800-900˚C by stopping the solar irradiation. Then, the bed temperature was kept at around 800-900˚C by the electric pre-heaters surrounding the reactor. An H_2O/N_2 gas mixture was, then, fed to the reactor to perform the W-D step in the reactor. A thermocouple was inserted into the central positon of the particles bed to measure the bed temperature (T_b). The outlet gas and external reactor wall temperatures were also measured by other thermocouples.

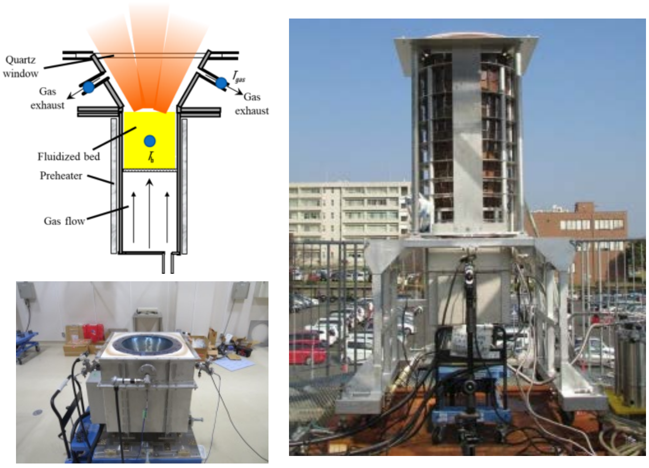

Fig. 4 Solar fludized bed reactor (upper & lower left) and the reactor located below the exit of CPC at Miyazaki beam-down solar concentrationg system (right)

3. Results

The first solar test of the reactor was carried out in December. The central bed temperature (T_b) of the solar reactor reached around 1200˚C within 20 min of the solar irradiation during the T-R step. After reaching 1200˚C, however, the T_b decreased by the cloud passages. The outlet nitrogen gas temperature was around 1000˚C during the T-R step. After the T-R step, the central bed temperature was cooled to 800˚C and the fed gas was switched from nitrogen to H_2O/N_2 gas mixture to perform the W-D step. The sharp and small peak of hydrogen evolution was observed within 20 min of the W-D step.

A higher bed temperature exceeding 1300˚C during the T-R step is expected to attain if solar test is carried out in other seasons expect for winter in Japan or at a lower latitude region than Miyazaki, Japan. The next solar campaign of the reactor test will be carried out in Sep. 2018 and the results will be also presented.

References

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