Evaluating the performance of photocatalysts with regard to spectral irradiation using the SoCRatus

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Background

Photochemical or photoelectrochemical processes can be employed for simultaneous treatment of waste water and hydrogen production. Thereby abundant but unsteady solar radiation is used to produce a potent chemical energy carrier. The development and demonstration of suitable reactor devices are addressed in the scope of the German project DuaSol. DLR's test facility SoCRatus (Solar Concentrator with a Rectangular Flat Focus) – see Fig.1 – will be employed in the experimental assessment of developed devices with respect to solar efficiency and stability.

The SoCRatus

First ideas concerning the concentrator were presented in [1]. The SoCRatus specified by a geometric concentration ratio of 20.2 provides homogeneous concentrated solar radiation in the rectangular focus extended to 2500 mm x 100 mm. A representative local standard deviation of irradiation relative to the mean of 2.4% could be determined. [2] The cosine inlet optics of a spectrometer (B&W Tek, Exemplar® LS) covering wavelengths from 250 nm to 850 nm is directly located in the focal plane. Additionally, a pyrheliometer (Kipp & Zonen, SHP-1) for the measurement of direct normal irradiation (DNI) mounted at the concentrator structure allows the calculation of the total solar input on the photochemical system. As a result the solar-to-hydrogen efficiency can be contrasted with efficiencies respecting specific wavelength ranges. Four identical fluid cycles are available for connection to reactors. The product gas leaving the reactors is analysed by micro gas-phase chromatographs after introducing nitrogen as a purge gas into the piping between reactor and tank.

Experimental conditions and results

As can be seen in Fig.2 a suspension reactor was employed in reference experiments with the SoCRatus approaching reaction conditions chosen by Kim et al [3]. One of the two parallel reaction chambers of the reactor was operated with TiO_2-based photocatalysts in a mixture of water, perchloric acid as electrolyte finally adjusting pH 3.1, and 10 vol.-% methanol (@ 20°C) as a model substance for organic contaminants. An example for experimental results is shown in Fig.3 with respect to irradiance conditions and hydrogen evolution. Tracking was performed between 12:02 and 16:13 on 12 February 2015. The mean temperature of the suspension in this time interval was calculated to 25.6°C. The absolute pressure in the reactor reached values slightly above 1 bar. The interaction of the radiation transmitted through the 196.5 cm^2 wide reactor window and the photocatalytic system results in an average hydrogen production of 1940 µmol/h. The hydrogen evolution clearly corresponds to the irradiance respecting the UV-part of the solar spectrum which comprises the wavelengths between 280 nm and 380 nm. The UV-fraction drops in the afternoon leading to a redshift of applied irradiation.

Conclusion

The UV-part of incoming solar radiation varies significantly during a day. The first results of successfully conducted reference experiments confirm that as expected the productivity of the applied TiO_2 based photocatalysts correlates rather with UV irradiance than with DNI.

References

[1] M. Wullenkord, C. Jung, C. Sattler (2012), "*Development of a Concentrator with a Rectangular Flat Focus Used for Hydrogen Production via Photocatalytic Water Splitting Employing Solar Radiation*", Proceedings of the ASME 2012 6th International Conference on Energy Sustainability & 10th Fuel Cell Science, Engineering and Technology Conference (ESFuelCell2012), 23-26 July, San Diego, USA.

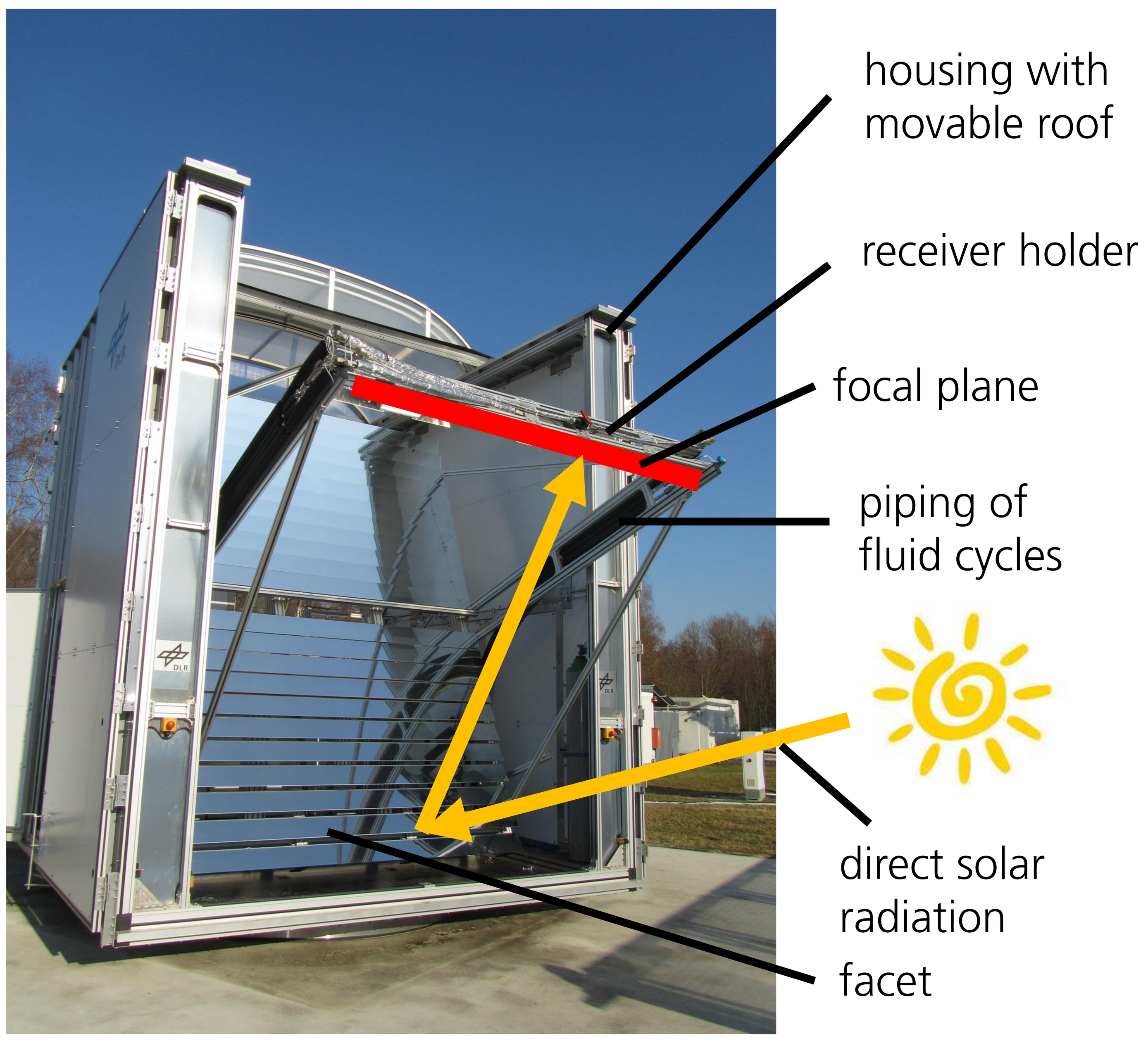

Figure 1: DLR's 2-axis tracking test facility SoCRatus (Solar Concentrator with a Rectangular Flat Focus) with 22 planar aluminium facets facing solar reactors mounted at the receiver holder

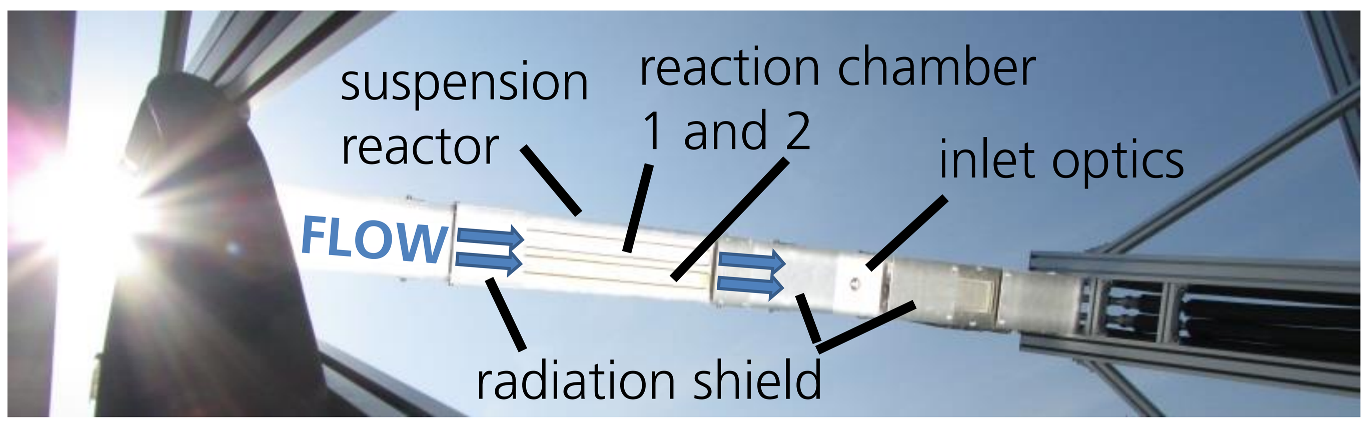

Figure 2: Irradiated suspension reactor and inlet optics of the spectrometer located in the focal plane of the SoCRatus

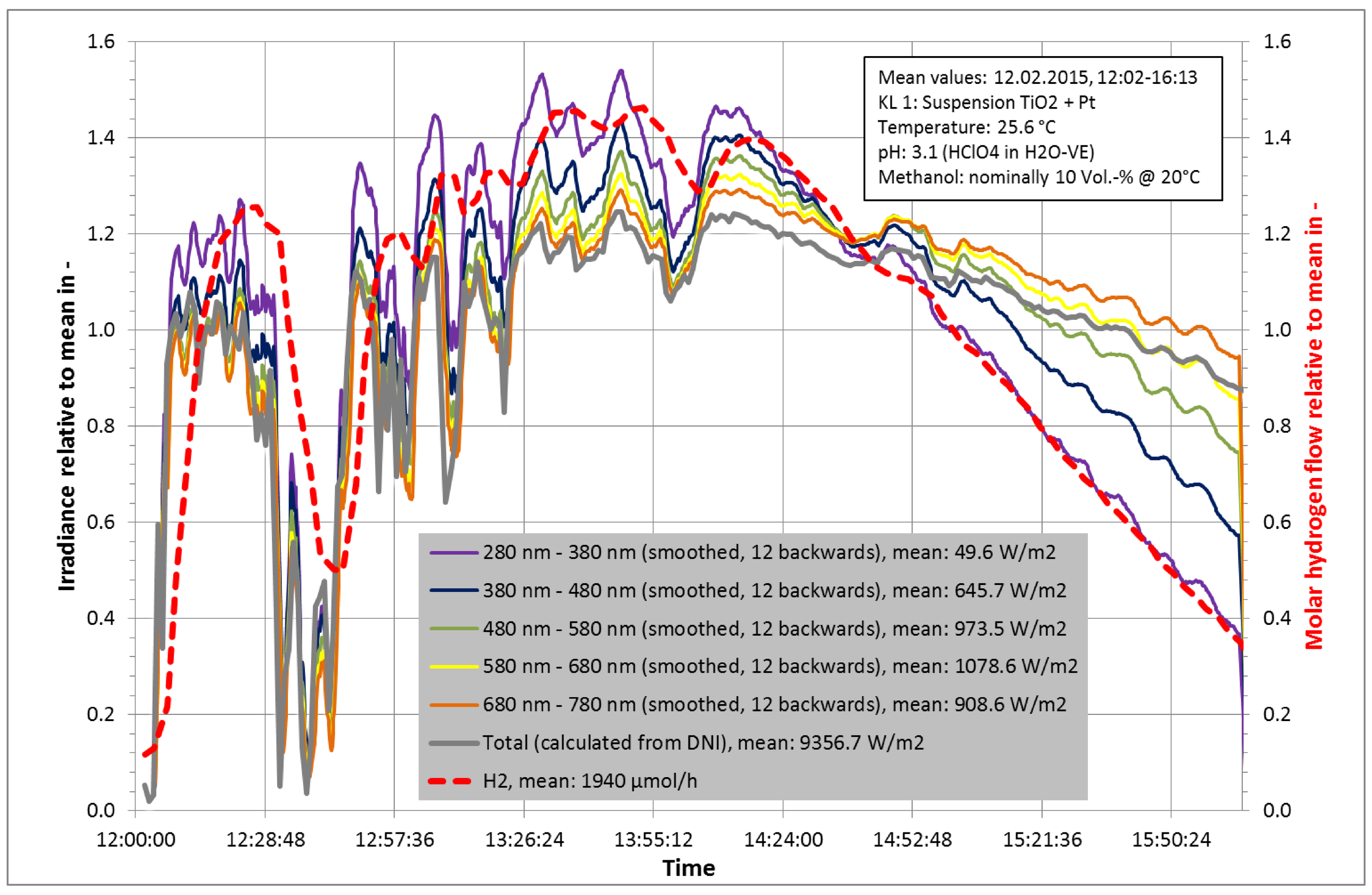

Figure 3: Irradiance of suspension 1 at the inner surface of the quartz window in different wavelength ranges and the evolution of hydrogen relative to mean values regarding the test duration from 12:02 to 16:13 on 12 February 2015

[2] M. Wullenkord, C. Jung, C. Sattler (2014), "*Design of a Concentrator with a Rectangular Flat Focus and Operation with a Suspension Reactor for Experiments in the Field of Photocatalytic Water Splitting*", Proceedings of the ASME 2014 8th International Conference on Energy Sustainability & 12th Fuel Cell Science, Engineering and Technology Conference (ESFuelCell2014), 30 June-2 July, Boston, USA.

[3] J. Kim, D. Monllor-Satoca, W. Choi, *Energy & Environmental Science* 5 (2012) 7647.

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