

# Maximizing Efficiency in Two-Step Solar-Thermochemical Fuel Production

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Recent results regarding the efficiency maximization for solar-thermochemical fuel production in two-step cycles are reported. Using advanced numerical models and experimentally determined properties of  $\text{CeO}_2$ , it is shown that an optimal temperature difference can be found between the two steps of a thermochemical cycle, such that efficiency is the highest. Furthermore, a key operating parameter that strongly affects efficiency, the thermal reduction pressure,  $p_{TR}$ , in a vacuum pumped reactor, can be decreased substantially by using multiple thermal reduction chambers, leading to an increase in efficiency.

Fig. 1 shows the efficiency  $\eta_R(\Delta T)$  of a ceria-based reactor for hydrogen production (water splitting), as function of  $\Delta T = T_{TR} - T_{WS}$ , where  $T_{TR}$  is the thermal reduction temperature (taken to be 1773 K in this case), and  $T_{WS}$  is the water splitting temperature. Two values each were used for two key design parameters: solid-solid heat recovery  $\varepsilon_R = 0$  and  $\varepsilon_R = 0.75$ , and steam-steam heat recovery  $\varepsilon_{GG}$  (0.8 and 0.6).[1]

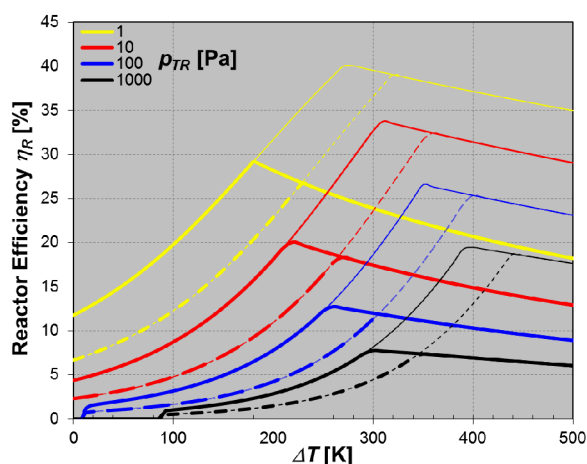


Figure 1. Calculated reactor efficiencies as a function of  $\Delta T$ . Solid lines are for  $\varepsilon_{GG} = 0.8$ , whereas dashed lines are for  $\varepsilon_{GG} = 0.6$ . Thick lines are for  $\varepsilon_R = 0$ , and thin ones for  $\varepsilon_R = 0.75$ . Lines of the same color correspond to the same  $p_{TR}$ .

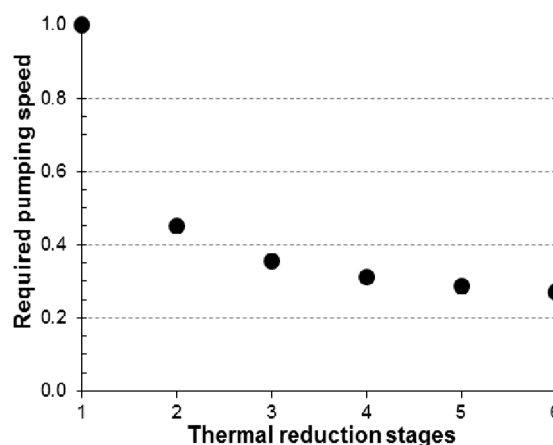


Figure 2. Pumping speed, required to reach a target  $p_{TR}$ , as function of number of thermal reduction stages, relative to the corresponding pumping speed in a reactor with only one thermal reduction stage. The decrease is even more substantial on a per chamber basis.

To address the difficulties in reaching low  $p_{TR}$ , primarily the large volumetric oxygen flow, we show that substantial gains can be achieved by splitting the thermal reduction step of the cycle into as few as 3 or 4 chambers instead of one (Fig.2). A reactor based on a moving packed bed of reactive particles, similar to that described in [2] would be very well suited for this purpose.

## References

- [1] I. Ermanoski, J. E. Miller and M. D. Allendorf, Physical Chemistry Chemical Physics, 2014, DOI: 10.1039/C4CP00978A.
- [2] I. Ermanoski, N. P. Siegel and E. B. Stechel, Journal of Solar Energy Engineering, 2013, 135, 031002-031001 - 031010.