Energy demand analysis of a practical solar hybrid sulfur cycle: the HySelect project

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Introduction

Concentrated solar thermal energy is a valuable resource for mitigating the effects of climate change. Due to its capacity to reach high operating temperature range (700 ºC – 1000 ºC) (Ho 2017), it has been integrated into several high-temperature processes to produce green hydrogen. Among these processes, the Hybrid Sulfur Cycle (HyS), which consists of four main processes: (1) H_2SO_4 decomposition (> 800 ºC), (2) Gas (SO_2 and O_2) separation, (3) SO_2-depolarized electrolysis (SDE) of water (< 140 °C), and (4) H_2SO_4 concentration, is gaining more attention, especially considering decarbonization of the sulfuric acid industry and circularity aspects (e.g. recirculation of spent sulfuric acid). Furthermore, this cycle has a high coupling potential with the industries such as copper industry (Seyfaee et al. 2021) since SO_2 is considered as a critical waste in these processes.

The HyS has already been investigated in the literature e.g. (Gorensek et al. 2017) or (Guerra Niehoff et al. 2015). However, there are only few studies focusing on the process analysis from a practical point of view of actual implementation of the technology at least in the demonstration scale. For instance, the H_2SO_4 decomposition should be operated at low pressures to avoid complex handling of safety procedures with possible leaks, or SO_2-depolarized electrolysis should maintain the low pressure differential over the membrane (Mališ et al. 2016). In order to realize the solar HyS in the real world, those aspects must be taken into consideration.

Our study focuses on the energy demand analysis of a solar HyS from practical point of view for implementation of a demonstration plant. The energy efficiency of hydrogen production is calculated as one of the indicators of the cycle's practical performance. The calculated values are compared with the results from the literature. The work presented here runs in parallel to flow-sheeting and modelling activities of the HySelect demo plant to be built.

Method

Aspen Plus is used in our study to conduct the energy demand analysis. Most of the unit blocks use the property method ElecNRTL. Figure 1 shows the simple block diagram describing our Aspen model.

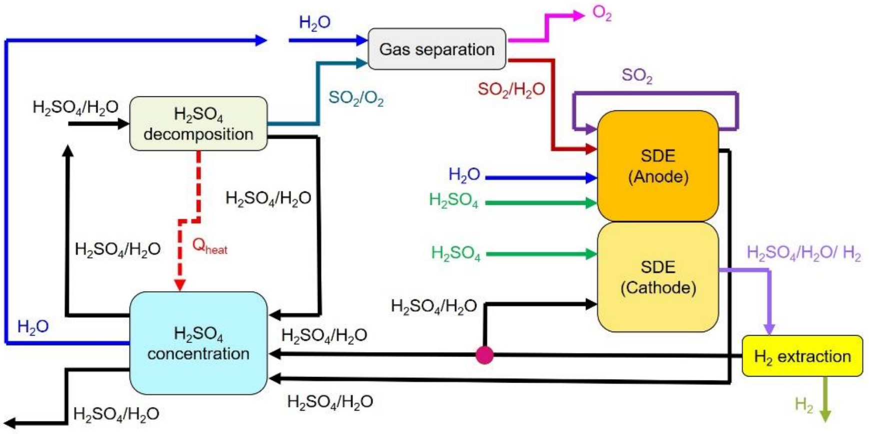

Figure 1. Simple block diagram describing the Aspen model.

As shown in the figure, there are mainly 5 key blocks: (1) H_2SO_4 decomposition, (2) H_2SO_4 concentration, (3) Gas (SO_2 and O_2) separation, (4) SDE, and (5) H_2 extraction. Block (1) needs a large amount of heat and this will be provided by the concentrated solar thermal energy. A detailed concept of the solar receiver-reactor is not yet considered in our initial investigation. In block (2), a multi-effect evaporator concept is used to evaporate the water from H_2O-H_2SO_4 mixtures. Block (3) is simply using the water absorption technology to separate SO_2 from O_2. Block (4) contains the user-defined block connected to an excel sheet, which integrates Kaur's model (Kaur et al. 2018), to predict the performances of SDE in a simple way. Block (5) comprises only the cooling unit and flushing unit to extract H_2 from the flow.

The energy efficiency for hydrogen production is calculated by $\left(n_{H2,out} \cdot LHV_{H2}\right)/\left(W_{elec} + \dot{Q}_{heat}\right)$. Here, $n_{H2,out}$ is the outlet mass flow rate of hydrogen [kg/s], LHV_{H2} is the hydrogen lower heating value [MJ/kg], W_{elec} is the total electrical energy input [MW], and $\dot{Q}_{heat}$ is the total thermal energy input [MW].

Current and expected key results

Table 1 shows the current results of energy demand analysis with other literature results. As shown in the table, the energy efficiency of other literatures is higher than our study. One main reason for this is because Gorensek et al. or Guerra Niehoff et al. use a higher pressure in the acid decomposition process and SDE process. Operating the process at high pressure is advantageous to obtain high energy efficiency.

Table 1. Initial comparison results (SDE operating pressure: 7 bar, SDE operating temperature: 70 ºC, SO_2 conversion rate: 30%, SDE anolyte and catholyte acid concentration: 10 wt%, Acid concentration for decomposition process: 80 wt%, Operating pressure in the decomposition process: 12 bar).

Parameter	Units	Our study	Gorensek et al. 2017	Guerra Niehoff et al. 2015
Applied thermal energy to H_2SO_4 decomposition process	MW	100.0	352.6	85.7
Consumed electric power in SO_2-depolarized electrolysis	MW	10.8	115.8	14.5
Energy efficiency for H_2 production	%	17.5	51.6	30.5

The following Aspen simulations will examine practical conditions and the key results will be shown in the upcoming presentation.

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