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Gas Switching Water Splitting (GSWS) for high efficiency Hydrogen Production: Sensitivity to the oxygen carrier iron content

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Highlights

- Gas Switching Water Splitting (GSWS) process for energy efficient hydrogen production.
- The GSWS process aims to simplify process scale-up under pressurized conditions.
- Oxygen carrier iron content affects CO_2 capture efficiency and purities of CO_2 and H_2.
- An oxygen carrier with about 60% iron active content is being manufactured and tested under the GSWS conditions with different fuels.

1. Introduction

With the increase in global energy demand and the concern of climate change, hydrogen is considered as a key energy carrier of the future. Hydrogen production through water splitting in a chemical looping process seems to be a viable solution [1]. This process produces hydrogen by reacting water with FeO (or Fe) to form Fe_3O_4, which is further oxidized to Fe_2O_3 by oxygen in air to generate the heat needed to complete the cycle autothermally (Figure 1 - left).

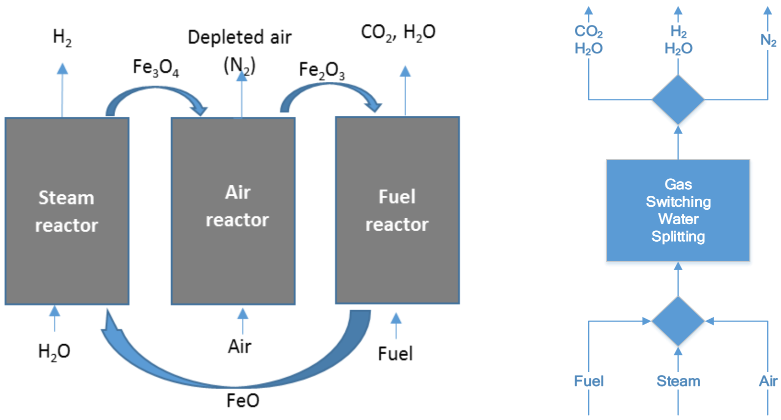

Figure 1. Left: a simplified scheme of the water-splitting process completed following the chemical looping route. Right: Gas switching technology applied water splitting, GSWS.

This three-step process is conventionally completed in three reactors with the iron-based oxygen carrier circulating between them, a configuration that is indeed difficult to pressurize and scale up. It was therefore proposed to complete this process using the Gas Switching Technology [2], where the three steps are completed in the same reactor by alternating the gas feeds into the oxygen carrier (Figure 1 - right), thereby facilitating operation under pressurized conditions. However, gas mixing between the stages takes place when switching between them, thereby reducing the CO_2 capture efficiency and purities of CO_2 and hydrogen. It is therefore important that the fuel and steam stages are long enough to minimize the extent of the mixing of different gases in the system to achieve an acceptable capture efficiency and purity.

2. Methods

Oxygen carrier particles containing 60 wt% Fe_2O_3 were produced via spray-drying, followed by calcination at 1300°C. The material was chosen due to its high cyclic stability under relevant reaction conditions, as determined using a thermogravimetric analyzer in a preliminary study.

A theoretical calculation was completed to investigate the effect of iron content in the oxygen carrier on the capture efficiency of CO_2 and purities of CO_2 and H_2. Additionally, experimental tests are being completed under the GSWS conditions on an oxygen carrier with a high iron content (60 wt%). The tests are done in a fluidized bed reactor of 5 cm diameter and 80 cm height (including a freeboard). The fuel time, steam flowrate, temperature and pressure are varied in the study. The GSWS performance is quantified based on the gas composition measurement at the reactor outlet.

3. Results and discussion

A typical GSWS cycle completed with an oxygen carrier with 36% Fe_2O_3 loading supported on Al_2O_3 and CO at 900°C as fuel is shown in Figure 2. An average steam conversion to H_2 of 36% was achieved at the expense of high fuel slip. At the start of the reduction stage, complete fuel conversion was achieved because Fe_2O_3 was present. However, fuel slip started early in the fuel stage due to thermodynamic and kinetic limitations when reducing Fe_3O_4, requiring improved reactor and process design to maximize fuel utilization and process efficiency.

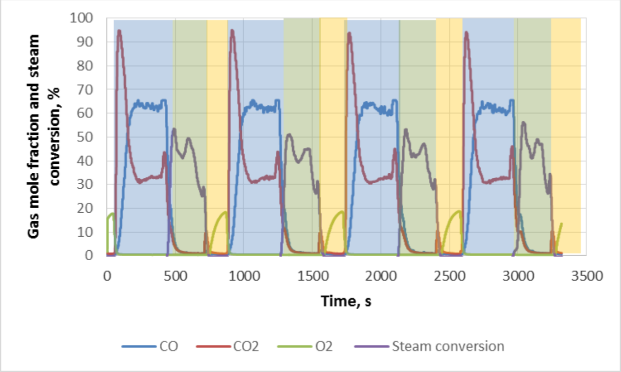

Figure 2. Transient gas composition measured over four cycles of GSWS experiments. Fuel stage in blue; steam stage in green; air stage in yellow.

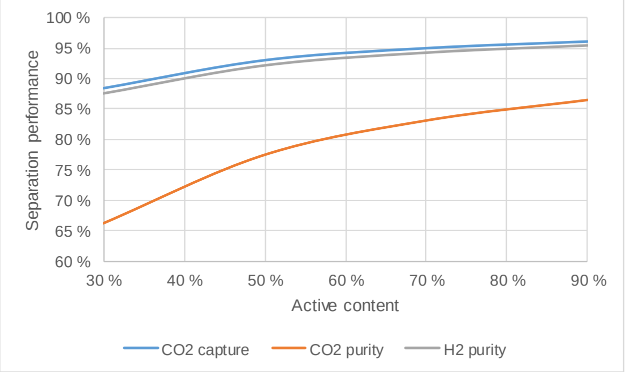

Figure 3. Estimation of GSWS separation performance with CH_4 as fuel with different percentage loading of the active content of Fe_2O_3 at 800 °C and 20 bar.

Figure 3 shows separation efficiency estimates completed using mass balance calculations assuming a perfectly mixed reactor. Clearly, CO_2 capture, CO_2 purity and H_2 purity increase substantially with increasing oxygen carrier active content. More active content in the oxygen carrier facilitates longer fuel, steam and air stages, thereby reducing the impact of the undesired mixing when switching between inlet gases. Higher active content may also enhance reaction rate and reduce the fuel slip observed in Figure 2. It is therefore highly desirable to have a high iron content in the oxygen carrier used in the GSWS concept.

References

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Keywords

Chemical Looping, Water Splitting, Gas Switching, Hydrogen Production.