Internally circulating fluidized-bed reactor for hydrogen production with inherent CO_2 capture using chemical looping reforming

Mogahid Osman[1], Abdelghafour Zaabout[2], Schalk Cloete[2], Shahriar Amini[1,2]*
[1]Norwegian University of Science and Technology, [2]SINTEF Materials and Chemistry
Trondheim, Norway
*shahriar.amini@ntnu.no

Highlights

- The internally circulating reactor (ICR) aims to simplify scale-up of pressurized chemical looping processes.
- This work applies the ICR to chemical looping reforming (CLR) for hydrogen production with inherent CO_2 capture.

1. Introduction

Chemical looping reforming of natural gas is one of the most promising technologies for hydrogen production with inherent CO_2 capture on terms of efficiency and economy. Pressurized operation of chemical looping based processes is necessary for maximizing their energy efficiency especially when it used for power production with combined cycle operation, and it reduces the energy penalty for H_2 and CO_2 compression. However, there are many challenges facing the pressurized operation of the conventional dual fluidized-bed reactor. This study provides the prospects and opportunities that exist for novel application of the internally circulating reactor (ICR) to be used for pressurized chemical looping reforming.

The ICR concept consists of a single reactor that combines two sections, (i.e., the fuel and air sections) with internal physical separations. Specifically, the concept aims to simplify the design, ease the solid circulation, avoid using costly gas/solid separation system, (i.e., cyclone and loop seals), operate at high pressure easily in a single pressurized vessel and eventually bring the chemical looping technology a step closer to commercialization [1,2].

The aim of this study is to experimentally study the feasibility of H_2 production by means of chemical looping reforming using ICR concept, as well as to obtain some insights about this type of reactor in term of configuration and operation conditions.

2. Methods

The ICR unit shown in Figure 1 has been constructed and is currently being commissioned. The reactor is equipped with four pressure probes for measuring the pressure difference between different positions. Accurate flow rates of feeding gases are obtained by means of mass flow controllers. A NiO/Al_2O_3 oxygen carrier is used with an average particle size of 200 µm. The reactor was placed in a cylindrical shell to accommodate a maximum pressure of 10 bar. Heating is achieved by an electric heater implemented around both sections. Temperature is measured and controlled by means of a thermocouple inserted inside each section. Outlet gases are analyzed using an MS gas analyzer.

The following reactions are considered in the fuel and air sections:

$CH_4 + H_2O \leftrightarrow CO + 3H_2$ $CO + H_2O \leftrightarrow CO_2 + H_2$	Catalytic reactions over Ni catalyst in the fuel section.

$CH_4 + 4NiO \rightarrow 4Ni + CO_2 + 2H_2O$ $CO + NiO \rightarrow Ni + CO_2$ $H_2 + NiO \rightarrow Ni + H_2O$	Reduction reactions with NiO in the fuel section.
$2Ni + O_2 \rightarrow 2NiO$	Oxidation with Ni in the air section.

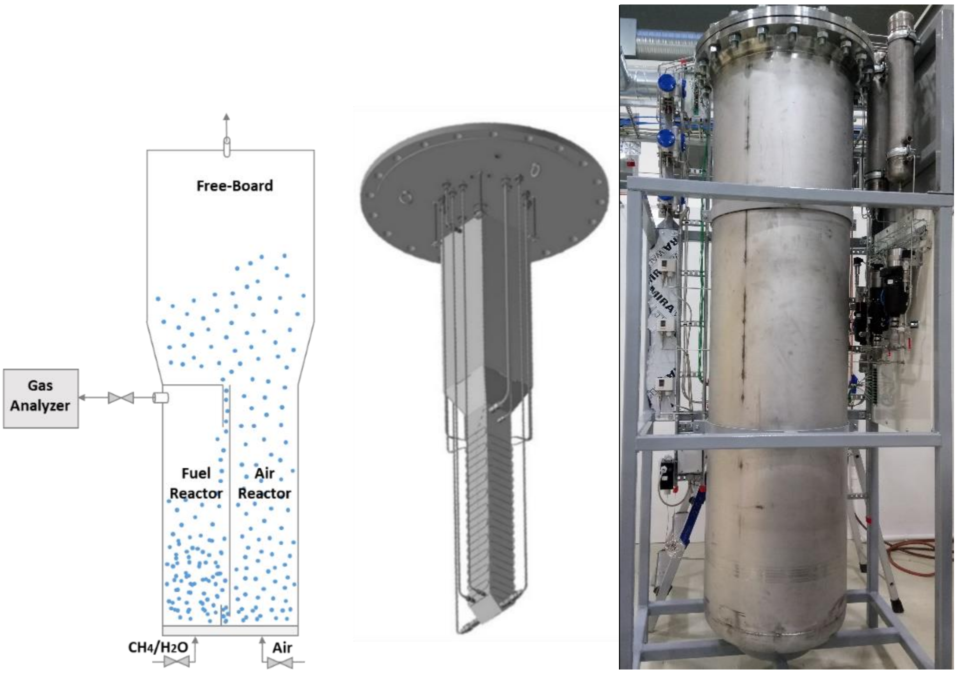

Figure 1. The ICR unit.

3. Results and discussion

Cold flow experiments in the ICR unit shown in Figure 1 revealed the operating conditions required for achieving steady solids circulation between the two sections. These operating conditions were scaled to hot conditions via conventional scaling laws and will be used as a starting point in the reactive experiments.

The primary aim of the reactive experiments will be to demonstrate autothermal operation of the CLR process in the ICR under pressurized conditions. Experiments will be carried out at different temperatures, pressures and steam/carbon ratios to gain a complete understanding of reactor behavior. Reactor performance will be quantified in terms of the fuel and air conversion achieved as well as the degree of undesired gas leakage between the two reactor sections. Gas leaking with the circulating solids through the interconnecting ports will decrease CO_2 capture and purity, and must be minimized. Previous work has shown that CO_2 capture and purity of ~95% can be achieved when reactor operation is optimized [2].

References

[1] A. Zaabout, S. Cloete, S. Amini, Chemical Engineering & Technology, 39 (2016) 1413-1424.

[2] S. Cloete, A. Zaabout, S. Amini, Energy Procedia, 114 (2017) 446-457.

Keywords

Hydrogen Production; Chemical Looping Reforming; Internally circulating fluidized-bed reactor; Pressurized operation