CPFD Simulation of Sorption Enhanced Gasification in a Pressurized Fluidized Bed System

Alessandro Antonio Papa[1], Armando Vitale[1*], Umberto Pasqual Laverdura[2], Andrea Di Carlo[1]

1 Department of Industrial and Information Engineering and Economics, University of L'Aquila, Piazzale E. Pontieri 1, Monteluco di Roio, 67100 L'Aquila, Italy

2 Dipartimento di Tecnologie Energetiche e Fonti Rinnovabili, ENEA Centro di ricerche Casaccia,

Via Anguillarese, 391, Santa Maria di Galeria, 00123 Roma, Italy

**Corresponding author: armando.vitale@graduate.univaq.it*

Highlights

- Design of high-pressure DFB gasifier with lock hopper system.
- Devolatilization kinetic obtained by experimental tests at 1 bar.
- Validation of carbonation and gasification kinetics with lab scale experimental results.
- Simulation of high-pressure sorption enhanced gasification.

1. Introduction

Increasing the contribution of renewable energy to the global energy grid is essential for mitigating the contradiction between the growing demand for energy and the need to reduce anthropogenic greenhouse gas emissions. To reach the "net-zero" scenario, hydrogen and synthetic fuels play a key role, particularly in the hard-to-abate sectors. Gasification presents opportunities to produce carbon neutral or carbon negative hydrogen (if combined with carbon capture, storage processes) through the conversion of heterogeneous waste materials. Regardless of downstream processes, the producer gas must contain as few impurities and inert species as possible. In particular, synthetic fuels or hydrogen production processes require a syngas with a H_2/CO ratio from 1 to 4 without CO_2 [1]. Sorption enhanced gasification (SEG) integrates dual-bed gasification and calcium looping processes to produce hydrogen-rich synthesis gas. The sorbent material (typically CaO-based) acts as CO_2 and heat carrier between combustor and gasifier reactors. In the gasifier, fluidized by the steam, the CO_2 is captured by the sorbent, shifting the equilibrium of the water gas shift (WGS) reaction to the products, thus improving the H2 yield. In the combustor, fluidized by air, the residual char from the gasification process is burned to produce heat for the regeneration of the sorbent and for the thermal needs of the gasification reactions. However, the reactions involved in the process show different trends with temperature. CO_2 separation occurs between 550 and 750 °C at ambient pressure, with a separation efficiency of 95 % at 600 °C [2]. However, tar and carbon conversion are favored by high temperatures. Increasing the operating pressure would enhance the driving force of the carbonation reaction, improving its efficiency at high temperatures. Furthermore, the syngas product could be directly fed to high-pressure gas cleaning units. However, the calcination temperature increases with pressure, so sintering problems can occur in a pressurized system [3].

The aim of this work is to study the behavior of a pressurized fluidized bed gasifier that will be integrated with a fluidized bed combustor operating instead at atmospheric pressure. The fluid dynamics of the gasifier were studied using a computational particles fluid dynamics (CPFD) model to identify the optimal operating conditions and size of the lock hopper system that guarantee the correct recirculation of the bed between the two reactors.

2. Methods

To study the fluid dynamics inside the gasifier the CPFD software Barracuda Virtual Reactor® was used. The simulations were carried out implementing devolatilization kinetics obtained experimentally at 1 bar, while literature reaction rates were used for gasification [4] and carbonation [5].

3. Results and discussion

Figure 1 shows a comparison between experimental data obtained in a bench-scale reactor operating at 1 bar and 650 °C with (Figure 1a) and without (Figure 1b) sorbent in the bed and simulation results. The simulation results are in good agreement with the experimental composition with deviation in the range of the usual variations of the product gas composition during operation.

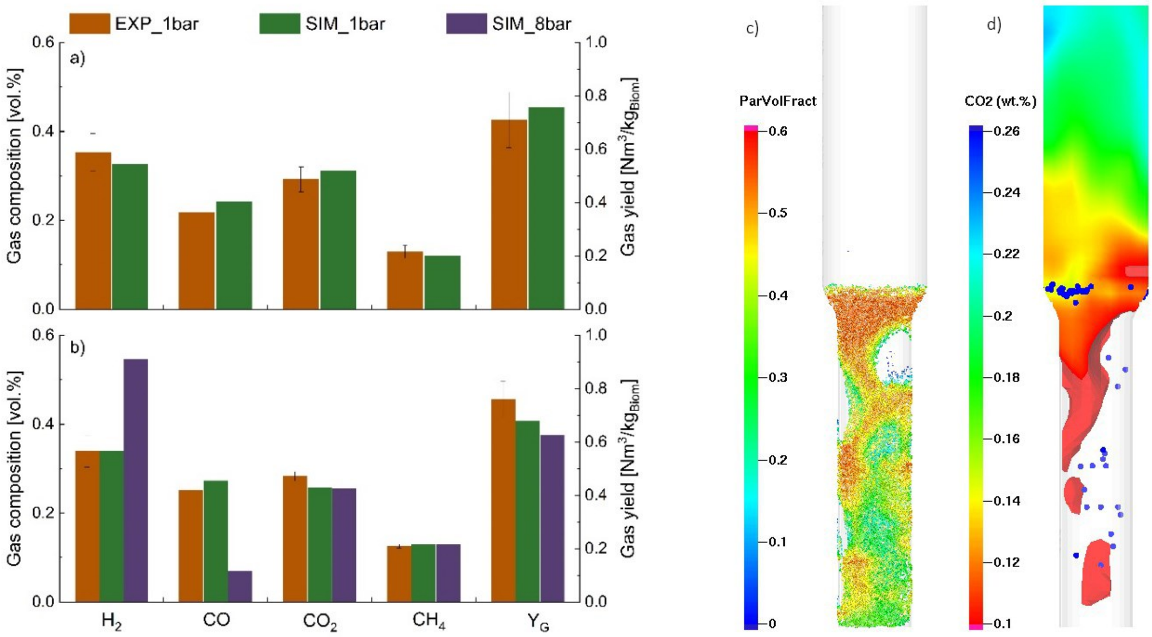

Figure 1. Comparison of simulation results with experimental data: a) without CO_2 sorbent, b) with CO_2 sorbent. c) Particle volume fraction in the reactor; d) Biomass distribution in the bed (blue dot) e CO_2 content along the height of the reactor

4. Conclusions

Preliminary results differ from SEG tests performed at pilot plant scale [1]. In particular, findings highlight that, at 1 bar, a fast segregation of biomass particles occurs, resulting in inadequate gas residence time within the bed, and reducing the effective CO_2 adsorption. Simulations at 8 bars show increased carbonation rates leading to H_2 content improvement.

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Keywords

Hydrogen; Sorption enhanced gasification; Pressurized gasifier; CPFD simulation