Carbon beds in CO_2 conversion by plasma: Process enhancement via the reverse Boudouard reaction

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Abstract: We present a study of several types of carbon beds (varied in length and degree of thermal insulation) coupled with different plasma reactors (gliding arc and microwave). The best process metrics corresponded to the carbon bed with the longest residence time, while thermal insulation and the integrated silo removed the oscillations of the CO_2 conversion.

1. Introduction

The carbon capture and utilisation concept aims to convert the anthropogenic-originated CO_2 into value-added chemical building blocks. To remove the restrictions on the process efficiency associated with the recombination of CO and O produced via plasma splitting of CO_2 [1], post-plasma carbon (C) beds are often employed. C here acts as both the scavenger for O/O_2 to restrict recombination, and the source of solid C for the reverse Boudouard reaction [2]. To date, mostly the effects of the C pellets size and source/elemental content have been studied [3]. Here, we present a study on the C bed parameters such as the effective size and thermal insulation. Improved energy efficiency formulae were derived to correctly evaluate the process performance.

2. Methods

Three carbon beds with varied length and insulation were manufactured and coupled with two plasma reactors. A DC gliding arc plasmatron (GAP) operated at 10-20 L/min CO_2 was used to study the effects of the C bed length, and the thermal insulation effect. The C beds were equipped with a silo used for a continuous supply of C into the bed. A 2.4 GHz magnetron microwave plasma reactor was operated at 100-150 L/min CO_2 using a C bed with a heated silo. The carbonaceous residues were removed from the exhaust gas in a cyclone separator, after which the gas was analysed with NDIR and solid luminescence sensors.

3. Results and Discussion

Figure 1 shows the values of the energy efficiency (EE) and energy cost (EC) with three different carbon beds. Although all three C beds are effective in the removal of O_2 and hence in cost reduction for product separation, the optimal conversion of CO_2 and the associated high EE and low EC were obtained with the C bed with maximal gas residence time. The shorter and insulated C beds performed worse. However, with the latter the oscillations of CO_2 conversion observed with the two non-insulated beds were absent. The hypothesis of the temporal oscillations originating from C depletion in the bed and replenishment from the external silo was confirmed by pre-heating the silo of the long C bed. Optimisation of the process resulted in 41% CO_2 conversion, an EC of 0.41 MJ/mol CO_2, and 51% EE, close to the suggested target of 60% EE capable of making plasma technology for CO_2 splitting industrially viable [4]. We also note that instead of the EE metric used in most literature reports (and often ambiguous due to the inclusion of several reaction enthalpies), a clearer metric of EC should thus be used as a process performance indicator.

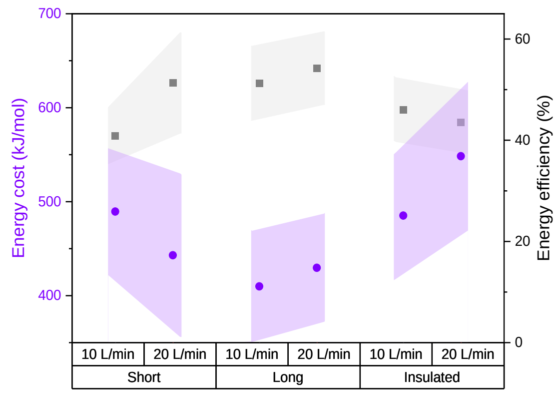

Fig. 1. Energy efficiency and energy cost metrics for CO_2 splitting using three types of C beds with GAP at SEI 3.7 (10 L/min) and 6.8 (20 L/min) kJ/L.

4. Conclusion

The study of post-plasma C beds of various design (length, thermal insulation, external/integrated silo) revealed that direct plasma contact and long residence time of the gas are paramount for process optimisation. Heat recovery either via integrating the silo in the bed or with a heat exchanger can prevent the detrimental conversion oscillations. Using post-plasma heterogeneous reactions aids in bringing the plasma-based CO_2 conversion closer to industrial milieu.

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