Arc plasma for CO_2 conversion: Comparing various quenching methods

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Abstract: In this contribution, we compare four different post-plasma quenching methods to improve CO_2 conversion in an arc plasma, and we try to reveal the underlying mechanisms by computer modeling. We obtained the best performance with a heat exchanger, which enhances the CO_2 conversion by a factor three (from 6 to above 18 %) and the energy efficiency by a factor 1.5 (from 20 to 30 %) compared to no quenching.

1. Introduction

Warm plasmas are very promising for CO_2 conversion, but the overall performance is often limited by post-plasma recombination of the products. A solution to overcome this problem is by post-plasma quenching, as successfully demonstrated e.g., for microwave plasmas [1]. In this contribution, we compare four different quenching methods for arc plasma, and we try to understand the differences and underlying mechanisms by modeling.

2. Methods

A dc arc plasma is created between a stainless-steel pin electrode (0.8 cm diameter, surrounded by a Teflon insulator) and a grounded stainless-steel tube (1.6 cm inner diameter and 2.0 cm outer diameter). A swirling flow stabilizes the plasma and allows operation in a large current range. We investigated four different quenching designs, i.e., (i) a nozzle (with diameter of 0.6 cm and thickness of 1.5 cm), (ii) wall cooling (double wall, with cooling water connected to a chiller), (iii) combined nozzle + cooling, and (iv) (shell-and-tube) heat exchanger (with seven effluent channels with outer diameter of 0.32 cm and inner diameter of 0.18 cm, in a tube with 4.2 cm outer diameter), and we compared them with the benchmark (no quenching). We recorded the CO_2 conversion and energy efficiency, as well as the electrical characteristics, and also measured the gas temperature at the outlet, using K-type thermocouples.

3. Results and Discussion

Figure 1 illustrates the CO_2 conversion (a) and energy efficiency (b) for the various quenching methods, compared to the benchmark, as function of SEI. Wall cooling is not presented, as it gave no improvement. The heat exchanger shows the best performance, with a CO_2 conversion up to above 18 % (i.e., 3 times higher than the maximum for the benchmark), and energy efficiency of 30 % (factor 1.5 higher than the benchmark). Our temperature measurements indeed reveal that it provides the most effective cooling.

In addition, electrical characterization demonstrates that the heat exchanger ensures a more stable and elongated plasma. This allows a higher voltage and power, which also explains its superior performance.

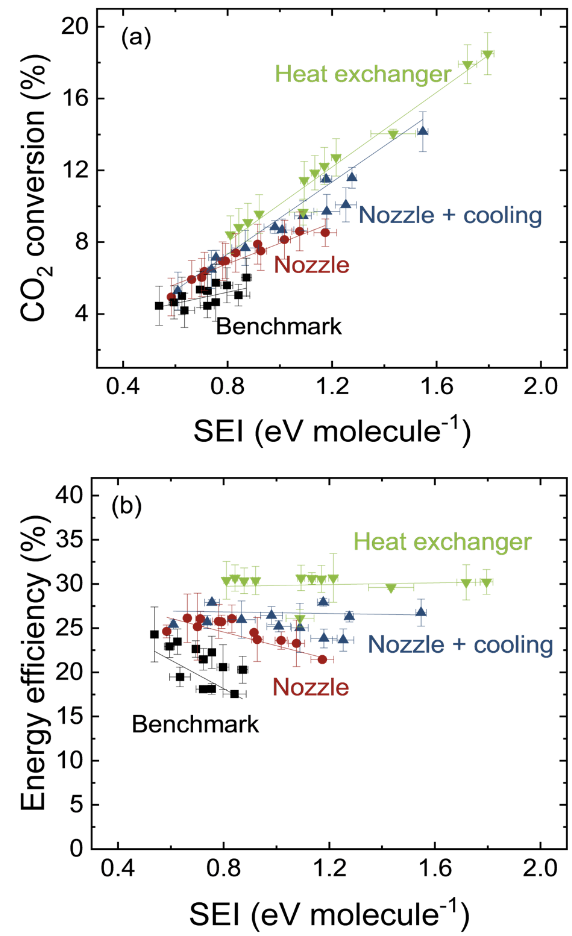

Fig. 1. Effect of three quenching methods on CO_2 conversion (a) and energy efficiency (b), compared to the benchmark, as a function of SEI.

4. Conclusion

Our results indicate how post-plasma quenching, especially with a heat exchanger, can improve the CO_2 conversion and energy efficiency of an arc plasma. The heat exchanger has a simple design, and we see room for further improvements by more sophisticated designs.

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References

[1] A. Hecimovic et al., J. CO_2 Utiliz, **71**, 102473 (2023).