The Potential of Thermal Plasma Pyrolysis for Clean Hydrogen Gas and High-Quality Solid Carbon Production from Methane

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Introduction

Hydrogen can be considered a key component in developing a clean and sustainable energy system. However, to reach a carbon-neutral energy source, the efficiency of hydrogen production technology and economic feasibility are to be overcome. Pyrolysis or decomposition by providing heat is an alternative to turning methane into hydrogen. In contrast to steam reforming, which consumes water and generates CO_2 emissions, plasma pyrolysis produces solid carbon, a valuable by-product. The use of plasma in the production of carbon black (CB) is relatively new and allows to obtain new grades of CB, such as carbon nanotubes, graphene nanosheets, and other carbon structures of high quality [1]. Another remarkable point is that thermal plasma with high-temperature ranges does not require expensive catalysts [2]. Adding to these features, if the electricity for plasma is supplied by renewable sources and the produced carbon will be used entirely in other sectors, the process achieves the goal of zero carbon footprint.

Experimental

The thermal plasma lab facility with a DC transferred arc is used. Various gas components such as Ar and CH_4 can be introduced to the reactor from the top through the hallow cathode. The electric discharge occur between the cathode and the anode pin, both made of graphite. With a flexible arc distance in a range of 1 to 6 cm, a power supply of 3.5 up to 16 kW is possible. Figure 1 shows the actual facility and the process layout.

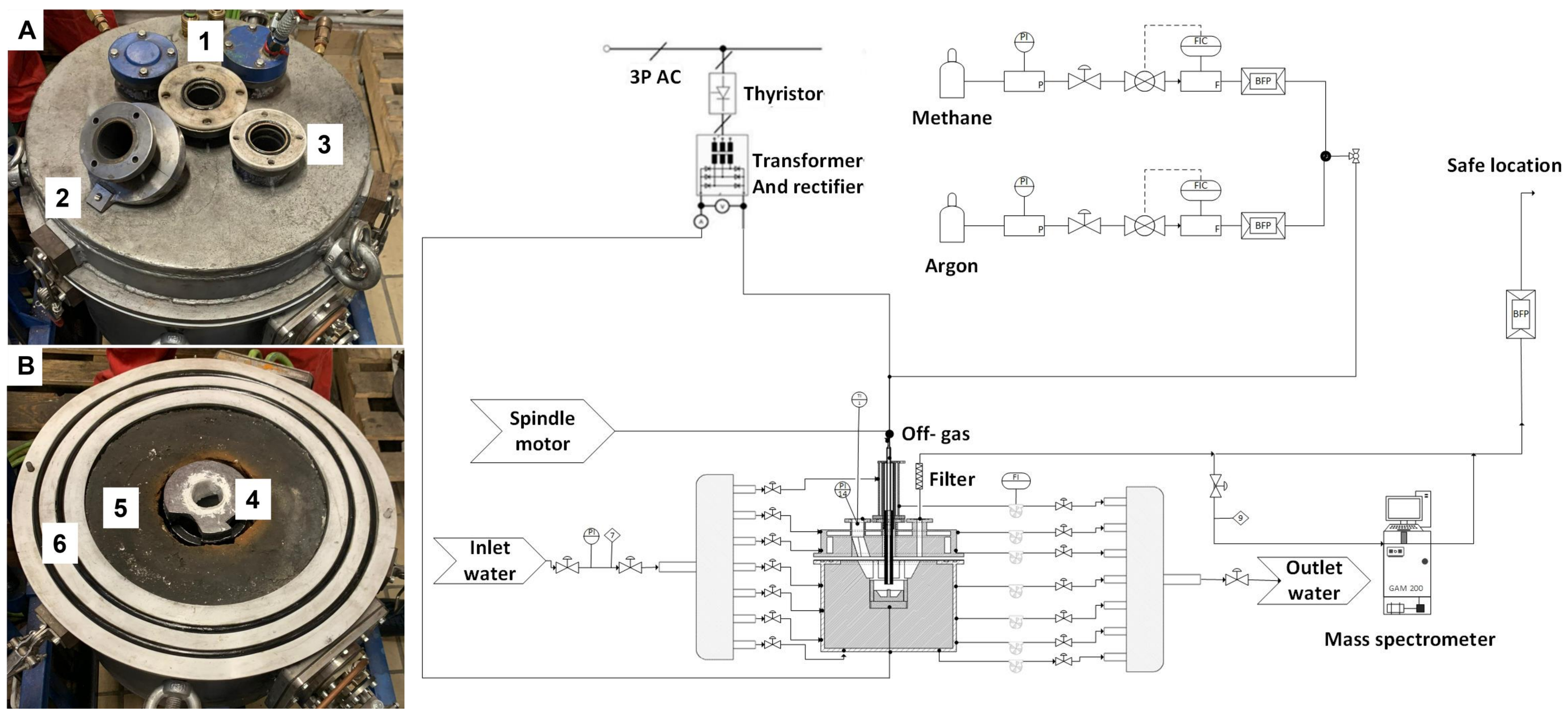


Figure 1. Process layout with different units of the thermal plasma facility (right side) and the reactor's installation consisting A. The lid with three openings: 1. Cathode inlet, 2. Camera window, 3. Off-gas outlet. And B. The reactor: 4. The graphite reaction chamber, 5. The lining, 6. The sealings (left side).

Results

Various tests were carried out to investigate the feasibility of the process, in respect to different variables. For instance, Figure 2 shows the current level, corresponding to the H_2 outcome. An increase in the current from 85 to 135 A (left) improves the H_2 outcome by about 10% (right). This is due to higher energy input for the pyrolysis reaction. The collected carbon samples were investigated using morphological and chemical analysis via scanning electron microscope (SEM) and energy dispersive X-Ray (EDX) analysis. Figure 3 shows the reaction chamber after the test. The carbon particles are attached and grown on the inner surface of that.

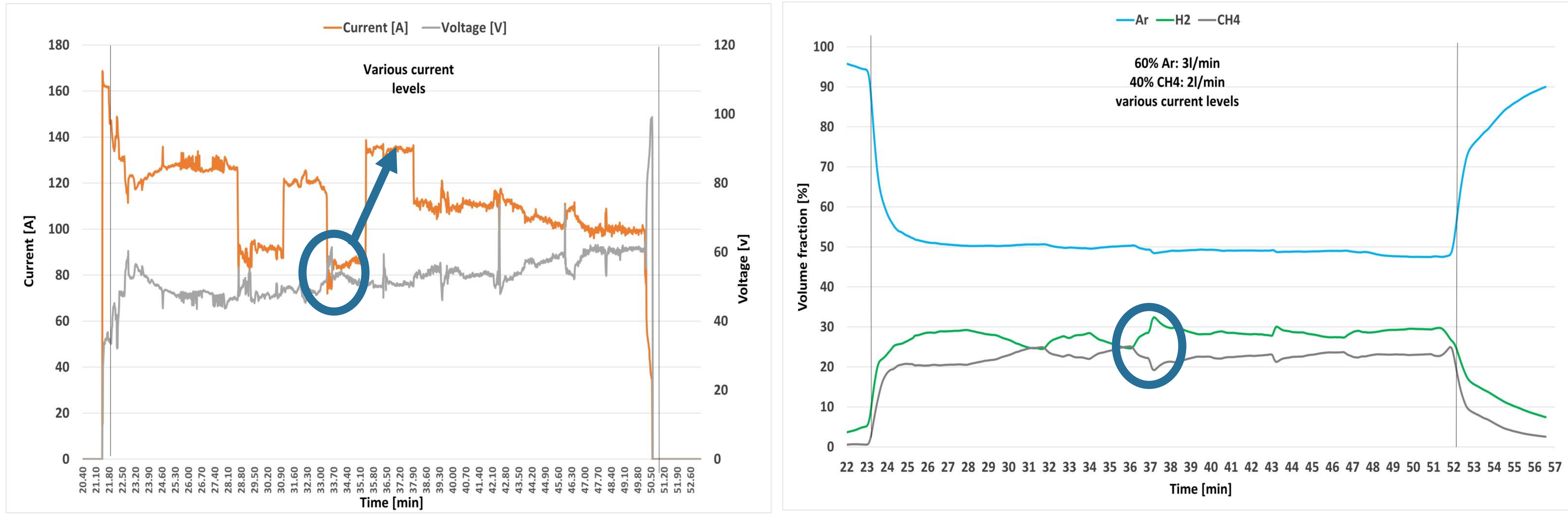


Figure 2. The current level change during the test (left) corresponding to the H_2 outcome of the process (right).

The SEM images in Figure 3 show the dendritic morphology of the carbon agglomerates. These agglomerates consist of many smaller primary particles and aggregates.

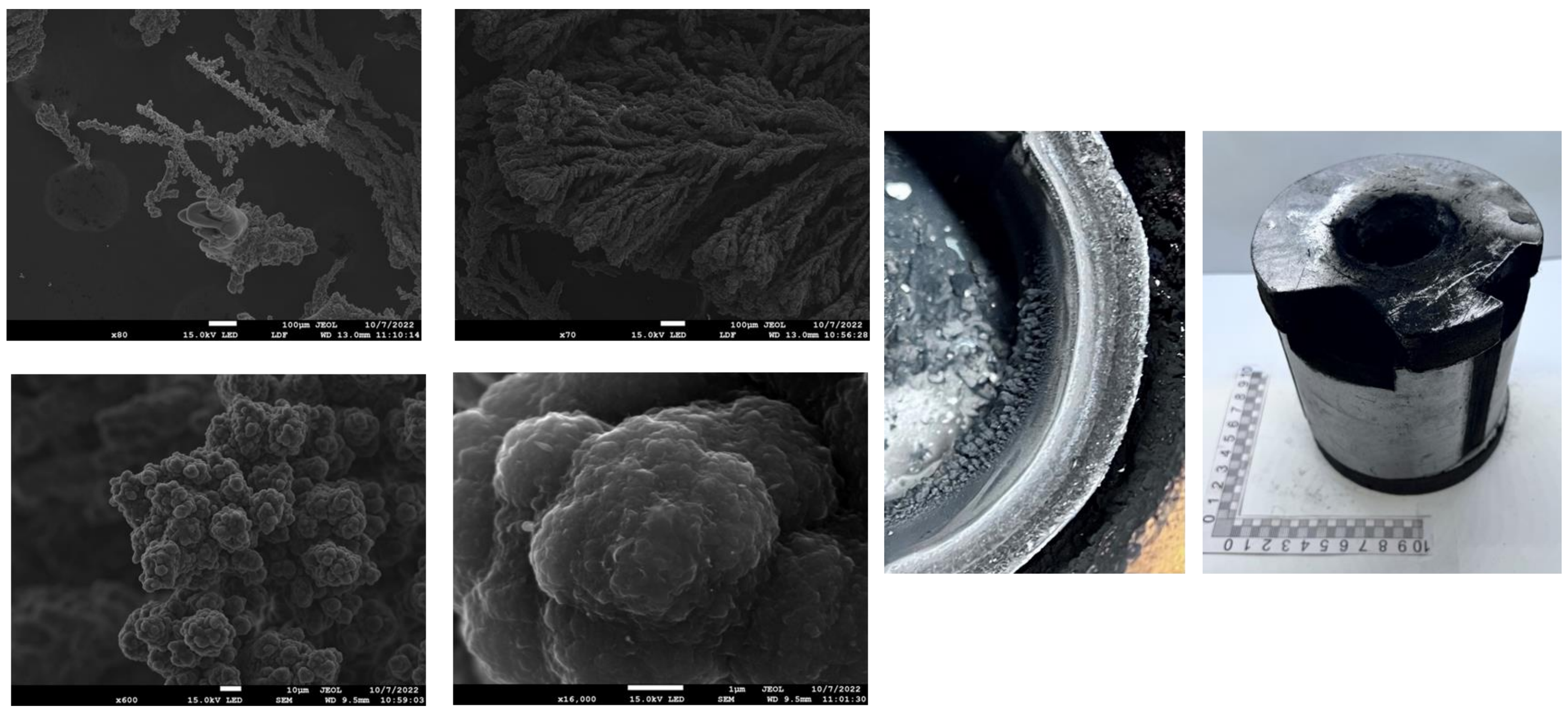
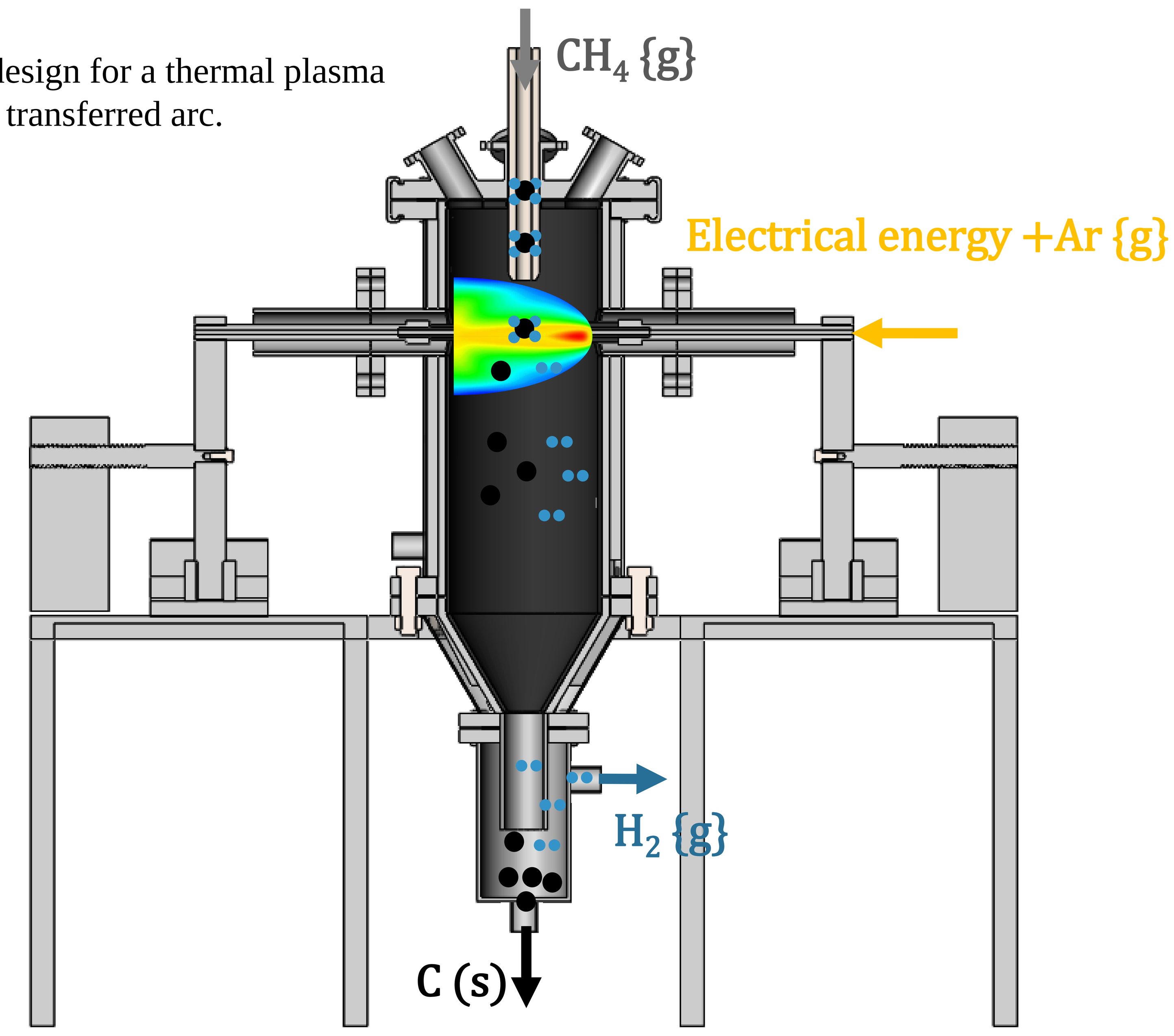


Figure 3. SEM images of the produced carbon (left) and the reaction chamber after the test (right).

Outlook: A noble concept for H_2 production

Figure 4. A new design for a thermal plasma facility with a DC transferred arc.



- A vertical design → Clean reaction zone
- Water-cooled reactor → Zero refractory contamination
- External CH_4 inlet → Extended electrode's life
- Adjustable electrodes → Different electrode materials
- Moving electrodes → In situ shifting
- Various gas components → Different trials
- High power input → Higher production rate

References

[1] A. Mašláni, M. Hrabovský, P. Křenek, M. Hlína, S. Raman, V.S. Sikarwar and M. Jeremiáš, Pyrolysis of methane via thermal steam plasma for the production of hydrogen and carbon black. International Journal of Hydrogen Energy 46 (2021), 2, pp. 1605–1614. doi:10.1016/j.ijhydene.2020.10.105.

[2] A.R. Da Costa Labanca, Carbon black and hydrogen production process analysis. International Journal of Hydrogen Energy 45 (2020), 47, pp. 25698–25707. doi:10.1016/j.ijhydene.2020.03.081

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