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Liquid Metal Bubble Column Reactor for Methane Pyrolysis

Scale-Up: Opportunities and Research Questions

Methane pyrolysis is the dissociation of CH_4 in an oxygen-free environment. The products are solid carbon and gaseous hydrogen. With 38 kJ/mol H_2, the standard reaction enthalpy is lower compared to alternative hydrogen production routes, such as steam reforming of methane (41 kJ/mol H_2) and water electrolysis (286 kJ/mol H_2; thermodynamic values calculated using FactSage™ 8.3).

One possible approach for practical implementation is methane pyrolysis in liquid metals: Input gas is injected into a metallic melt, e.g., via lances, impellers, or bottom spargers. The melt provides the heat required for dissociation and, in the best case, acts as a catalyst. Gaseous products leave the reactor through designated openings. Carbon particles float to the melt surface due to density differences and can be removed continuously. The basic principle is depicted in Figure 1. [1, 2]

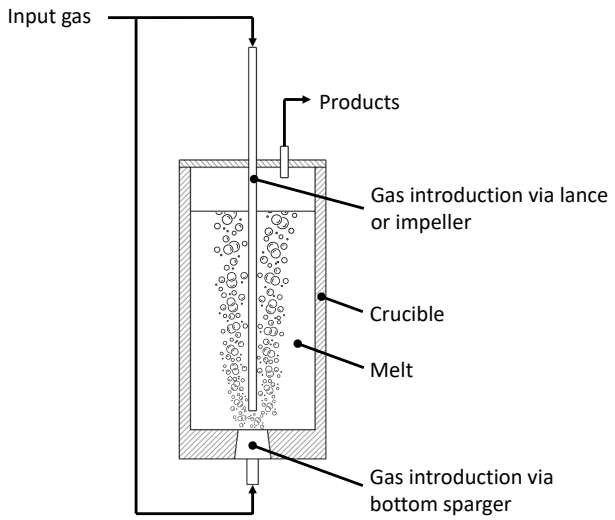

Figure 1: Possible reactor concept for methane pyrolysis in liquid melts [2]

With the commissioning of a methane pyrolysis pilot plant at the Research Center for Hydrogen and Carbon at the Montanuniversität Leoben, new opportunities were unlocked for scale-up research. The plant consists of an inductively heated reactor insert which is placed in a gas-tight vessel. Side and interior views of the pilot plant are shown in Figure 2.

Figure 2: Pilot plant for methane pyrolysis in metallic melts in the Research Center for Hydrogen and Carbon

Key facts and research questions in the pilot plant:

- The **maximum process pressure is 10 bar**, facilitating an investigation of pressure effects on reactor performance.
- Aiming to determine optimum aspect ratios, different reactor inserts can be used, with a **maximum diameter of 600 mm** and a **maximum height of 1500 mm**.
- Gas can be introduced from the top via **lances** or **impellers**, and from the bottom via **spargers** (up to **12 m³/h**). Here, one essential focus is on bubble size and residence time.
- Inductive heating is realized by two coils with a total power of **160 kW**. Separate control of those coils facilitates the investigation of electromagnetic stirring in the melt and the effects on hydrodynamics.

The methane pyrolysis plant is implemented in a process route comprising separation of solid particles from the product gas in a hot gas filter including a system for continuous carbon discharge, condensation of potentially formed longer-chain hydrocarbons in a heat exchanger, further purification of the product gas via membrane separation, and post-combustion (see process scheme in Figure 3). Research at this facility, conducted in cooperation with industrial partners, can significantly advance the large-scale implementation of methane pyrolysis.

Figure 3: Process flow in the Research Center for Hydrogen and Carbon

Dipl.-Ing. Dr.mont.
David Scheiblehner
Research Center for Hydrogen and Carbon
david.scheiblehner @unileoben.ac.at

Sources:
[1] Patlolla SR, Katsu K, Sharafian A, Wei K, Herrera OE, Mérida W. A review of methane pyrolysis technologies for hydrogen production. Renewable and Sustainable Energy Reviews 2023;181:113323. doi:10.1016/j.rser.2023.113323
[2] Scheiblehner D.: Investigation of Molten Metals and Alloys asCatalysts for Methane Pyrolysis. Doctoral Thesis, Montanuniversität Leoben, Leoben (2025)