Pyrolysis of methane by thermal plasma: a 25-year journey and start of an industrial transition

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Abstract: In this contribution, we report a 25-year research journey on thermal plasma pyrolysis of methane which has led to the emergence of a new, environmentally-friendly, and disruptive process to produce decarbonized hydrogen and carbon black. After a brief introduction stating the benefits of plasma methane pyrolysis in the energy transition context and history, a discussion on the state of the art, scientific challenges and main achievements is given.

1. Introduction

The most common current method of hydrogen production on an industrial scale (SMR) is accompanied by more than 10 tons of CO_2eq per ton of hydrogen. Water electrolysis holds promise as a source of "decarbonized" hydrogen. Now, water dissociation is extremely energy-intensive, and the cost of H_2 from electrolysis remains very high.

An emerging pathway for H_2 production is based on the pyrolysis of methane to produce solid carbon and H_2

$$CH_4 \rightarrow C + 2\,H_2$$

The main advantage of this method is that it allows low CO_2 production of hydrogen and solid carbon while being thermodynamically much less energy-intensive than water electrolysis for H_2 production, requiring about seven times less energy per mass (or mole) of hydrogen (38 kJ vs 285 kJ per mole H_2). Additionally, this process can co-produce two valuable products: hydrogen and high-value carbon. The principle of this process is illustrated on Figure 1.

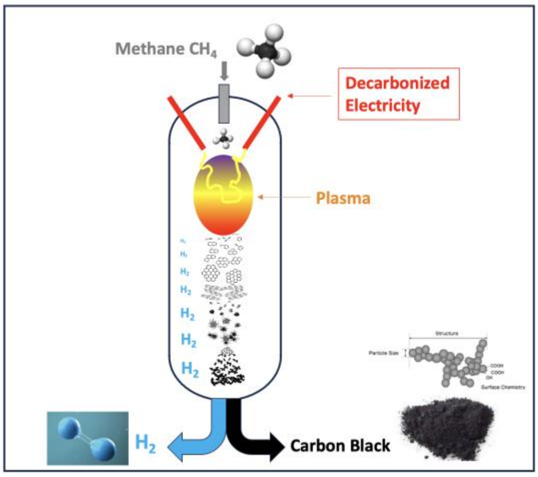

Fig. 1. Schematic of the plasma methane pyrolysis

2. History

Commercialization of thermal plasma for hydrocarbon processing has been attempted for over 100 years (Rose 1920). From 1920 to 1990, many carbon black companies followed in the footsteps of the original thermal plasma process patent. From 1993 onwards, our group initiated research based on a three-phase AC plasma technology [1]. Since 2012, research continued with MONOLITH Materials, who in parallel constructed a pilot plant in California. After using this pilot facility to demonstrate technical feasibility and economic viability, MONOLITH then constructed a commercial scale facility in Nebraska (termed OC1) which began construction in 2016 and was complete and operational in 2020.

3. Results and Discussion

This presentation gives an overview of plasma processing of hydrocarbons through different experimental and modeling conditions and approaches carried out over decades with a special focus on: (i) gas phase chemistry of methane pyrolysis, solid carbon nucleation and growth; (ii) technology and modelling challenges; life cycle analysis ; and (iii) future challenges and opportunities for the plasma scientific community [2].

4. Conclusion

After a long journey, thermal plasma methane pyrolysis technology is now mature and can offer a new, economically viable, environmental-friendly, and disruptive process to produce decarbonized hydrogen and carbon black that may have a huge impact in the context of decarbonization.

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References

[1] L. Fulcheri et al. Int. J. H. E. Vol. 20. No. 3, pp. 197-202, (1995).
[2] E. Dames et al Ad. in Chem. Eng. Vol. 61, pp 253-317 (2023).