Conversion of CH_4 and CO_2 to value-added products

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Abstract: This study investigates the decomposition of CH_4 and CO_2 using a 30 kW triple thermal plasma system, producing hydrogen and high-value solid carbon. At the lowest CH_4 flow rate, CH_4 and CO_2 conversion rates were highest at 98% and 71%, respectively, graphene-like carbon synthesized. However, hydrogen selectivity was highest at 82% under the highest CH_4 flow rate.

1. Introduction

CO_2 and CH_4 are major greenhouse gases contributing to climate change. This study uses thermal plasma to convert CH_4 and CO_2 into H_2 and solid carbon[1]. Hydrogen offers zero-emission energy potential, while solid carbon materials like carbon black and graphene have industrial applications. This approach simultaneously reduces greenhouse gases and produces valuable materials[2].

2. Methods

In this study, a 30 kW triple thermal plasma system with three DC torches, a dual injection nozzle, a reactor, and a filter were used. In particular, we designed the injection nozzle separately to control the characteristics of solid carbon. CH_4 was injected through the co-flow injection nozzle. And CO_2 was injected through the counter-flow injection nozzle. The CO_2 flow rate was fixed at 20 L/min, while CH_4 flow rates ranged from 20 to 60 L/min. Gas Chromatography (GC) measured product gas ratios, determining CH4 and CO_2 conversion rates, H2 selectivity, and CO selectivity. Solid carbon produced during the process was analyzed using Field Emission Transmission Electron Microscopy to examine its morphology.

3. Results and Discussion

Based on Gas Chromatography (GC) data, the CH4 and CO_2 conversion rates, as well as H_2 and CO selectivity, were analyzed. As the methane flow rate increased threefold from 20 to 60 L/min, the CH_4 conversion rate remained above 90%. This suggests that the energy density of the thermal plasma was sufficient for CH_4 conversion at 60 L/min of CH_4 flow rate. However, although the CO_2 flow rate was fixed, its conversion decreased by approximately 60%, reaching 11% as the CH4 flow rate increased. The high CH_4 conversion rate indicates that the energy density of thermal plasma was sufficient for CO2 conversion. However, the low CO_2 conversion is presumed to be due to the secondary reactions between CO and C at the reactor of the lower part, leading to the formation of CO_2. The H_2 selectivity increased with the rise in CH_4 flow rate, exhibiting a trend opposite that of CO selectivity. It is presumed that the lower CO selectivity can be attributed to the same reason as the lower CO2 conversion rate.

Additionally, the characteristics of the synthesized solid carbon varied with the CH_4 flow rate. A multilayered, sheet-like carbon structure was formed at the lowest flow rate. In contrast, solid carbon with a vortex-layered structure characteristic of carbon black was synthesized at the highest flow rate.

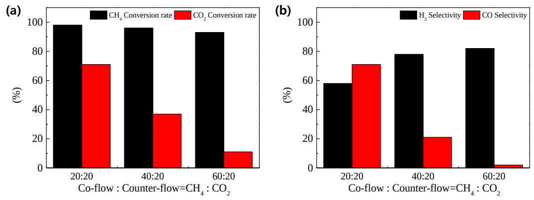

Fig. 1. According to CH_4 flow rate (a) CH_4, CO_2 conversion rate, (b) H_2, CO selectivity.

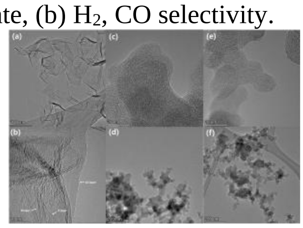

Fig. 2. TEM image of synthesized solid carbon according to CH_4 flow rate: CO_2 flow rate (a,b) 20:20, (c,d)40:20, (e,f) 60:20.

4. Conclusion

This study demonstrated the simultaneous conversion of CH_4 and CO_2 using a triple thermal plasma system, producing hydrogen and high-value solid carbon. Hydrogen selectivity increased with higher CH_4 flow rates, while CO_2 conversion and carbon monoxide selectivity decreased. Solid carbon with varying morphologies, including vortex-layered carbon black, was synthesized. Future work will aim to identify optimal conditions for maximizing both hydrogen production and solid carbon synthesis simultaneously.

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References

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