Rise time of Sabatier process using low pressure and low temperature plasma

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For reducing the loaded mass in rocket towards Mars, propellant production on Mars has attracted attention. Catalytic methanation of CO_2 is one way of production of the rocket propellant on Mars. Considering Mars environment of low temperature and low pressure, plasma process is superior to catalyst in the propellant production. Here, we carry out methanation of CO_2 using low pressure and low temperature plasma, and investigated dependence of rise time of CH_4 yield on H_2 flow rate. Based on the experimental results and rate equations, we discuss the methanation mechanism and deduce some key rate coefficients.

1. Introduction

Loaded propellant mass is important issue in planetary mission, because propellant mass accounts for 80% of total rocket mass. When return flights are required, loaded mass requirements are even more critical. Recently, in situ propellant production on Mars has attracted attention for returning journey from Mars to Earth. The Sabatier reaction is hydrogenation of CO_2 to CH_4.

$$CO_2+4H_2 \rightarrow CH_4+2H_2O,\ \Delta H = -165.0\ \text{kJ/mol.} \quad (1)$$

CO_2 is the dominant species in the atmosphere of Mars. H_2O could be electrolyzed to provide H_2 and O_2, with the O_2 acting as the oxidant for the rocket propellant and the H_2 being recycled [1].

Catalytic methanation is a major way of hydrogenation of CO_2 on Earth. However, Mars environment provides inappropriate conditions for catalytic methanation; catalytic methanation requires high temperature over 200°C and high pressure over 1.0×10^5 Pa, while the surface pressure on Mars is 750 Pa (135 times less than that on Earth) and the average temperature is very low of −63 °C [2]. Plasma process allows methanation under low pressure and low temperature conditions, employing high energy electrons in the nonequilibrium plasma ($T_e >> T_g$) to dissociate gas molecules and form reactive species [3]. Here, we carried out methanation of CO_2 using low pressure capacitive coupled plasma (CCP), and investigated dependence of rise time of CH_4 yield on H_2 flow rate FR_{H2}.

2. Experimental

Experiments were carried out using a low pressure CCP plasma reactor at ambient temperature. Plasmas were generated by applying 60 MHz RF power of 50 W. The electrode diameter was 34 mm and the distance between the electrodes was 10 mm. The pressure was 750 Pa. The CO_2 gas flow rate was 1 sccm and the H_2 gas flow rate was in the range of 6.0-21 sccm. The gas composition in the discharge plasma was measured with a quadrupole mass spectrometer (QMS, SRS QMS100).

3. Results and Discussion

Figure 1 shows time evolution of normalized CH_4 yield as a parameter of the H_2 flow rate. CH_4 yield rises more rapidly at higher H_2 flow rate. The rise time provides information of methanation mechanism. Using rate equations, we deduced the rate coefficients of decomposition reaction of CO_2 and H_2 and those of CH_4 generation reactions. I will discuss the methanation mechanism and will report some key rate coefficients.

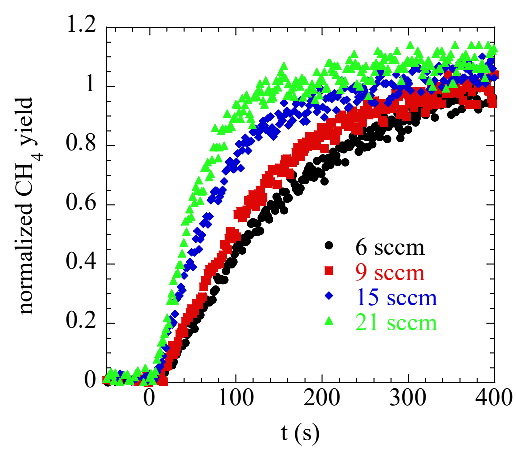

Fig. 1. Time evolution of normalized CH_4 yield as a parameter of H_2 flow rate.

This work was supported by JAXA and JSPS KAKENHI Grant Number 15J05441.

4. References

[1] K. P. Brooks, J. Hu, H. Zhu, and R.J. Kee, Chem Eng. Sci. 62 (2007) 1161.

[2] M. Kano, G. Satoh, and S. Iizuka, Plasma Chem. Plasma Process 32 (2012) 177.

[3] S. Toko, R. Katayama, K. Koga, E. Leal-Quiros, and M. Shiratani, to be published in Sci. Adv. Mater.