Microwave-enhanced fixed-bed flow reactions: Fundamental mechanism to applications

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Microwaves often exhibit enhanced reaction rate and product selectivity in heterogeneous reactions [1]. Microwaves directly heats solid catalysts and generate local thermal non-equilibrium at the vicinity of the catalyst particle [2]. To understand the effects of local thermal non-equilibrium on gas-solid reaction, we fabricated microwave reaction system equipped with semiconductor microwave generator and ellipsoidal applicator to obtain focused microwave irradiation at the catalyst bed (Fig. 1A).

Dehydration of 2-propanol was conducted as a model reaction to evaluate the effects of microwaves. Fe_3O_4 catalysts were used since they exhibit good microwave absorption. Microwaves gave higher acetone yield than conventional heating using electrical furnace at 250 °C (Fig. 1B). The activation energy was calculated as 90 kJ/mol and 118 kJ/mol for microwave and conventional heating, respectively. The results indicated that the microwave irradiation enhances dehydration reaction over Fe_3O_4 catalyst.

To understand the mechanism of effects of microwave irradiation, the distribution of microwave electric field in the catalyst bed was simulated by the finite element (FEM) method. The focused microwave electric field was particularly observed at the contact point of catalyst particles. As a result, the temperature of the contacting point became higher than the other points (Fig. 3B). The enhanced reaction under microwaves can be, therefore, attributed to the generation of local thermal non-equilibrium at the contact points of catalysts.

We also explored microwave susceptible metal oxide catalysts to use them for practical microwave reactions. We found that $LaCoO_3$ exhibit high microwave absorption and attained 800 °C even at low microwave power below 50 W (Fig. 1D). By measuring the dielectric property of $LaCoO_3$, the microwave absorption of $LaCoO_3$ was strongly dependent on the electrical conductivity of the catalyst. $LaCoO_3$ is, therefore, expected to exhibit enhanced catalysis under microwaves due to its strong microwave absorption.

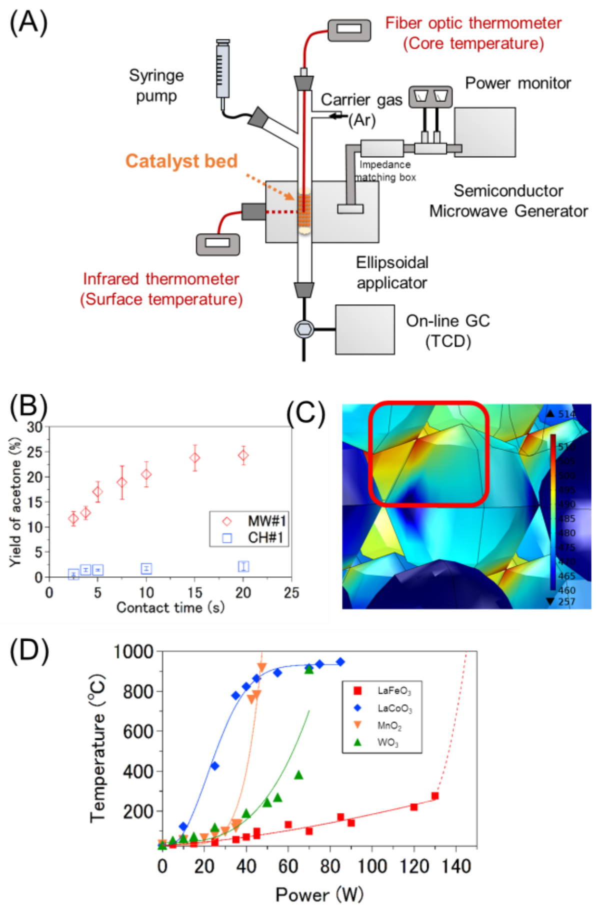

Fig.1 (A) Experimental set-up of fixed bed flow reactor equipped with microwaves. (B) Comparison of dehydrogenation of 2-propanol over Fe_3O_4 catalyst between microwaves (MW) and conventional heating (CH) at 250 °C. (C) Local thermal non-equilibrium generated at the contact point between catalysts. (D) Microwave heating behaviors of metal oxide catalysts.

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