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Study on On-Board Carbon Recycling Technology (Part II) -Effect of Secondary Particle Size on Reverse Water–Gas Shift Activity under an Electric Field-

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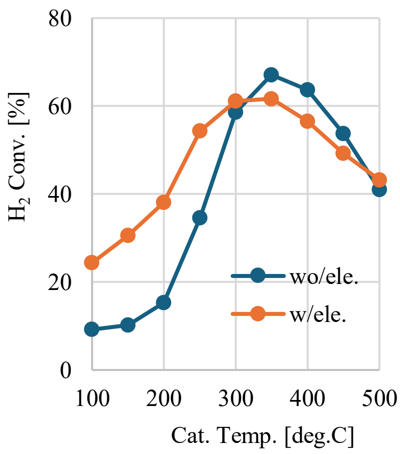
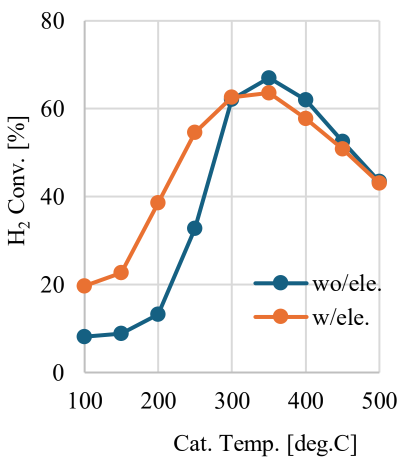
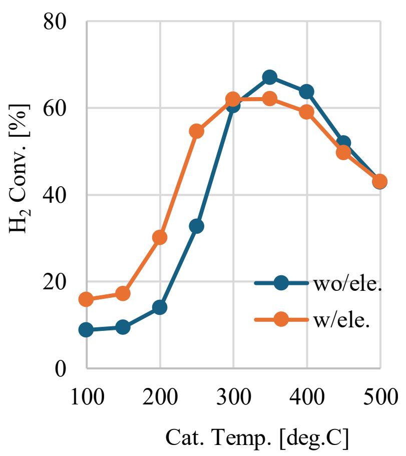
This study investigates the effect of secondary particle size (micro-pellet size) on the activity of the reverse water–gas shift (RWGS) reaction under an applied electric field, with the aim of developing an on-board carbon recycling system for automotive exhaust gases. Reducing CO_2 emissions from the transportation sector is a critical global challenge. While improvements in engine efficiency have reached their limits, alternative approaches such as direct CO_2 capture and conversion are gaining attention. However, for on-board applications, storage of captured CO_2 is impractical, making in-situ conversion technologies such as RWGS particularly attractive. Conventional thermal RWGS requires high temperatures due to the stability of CO_2 , but recent studies have shown that applying an electric field can significantly enhance catalytic activity even at low temperatures by promoting surface protonics. In this work, Ni/CeO_2 - ZrO_2 catalysts were prepared and formed into micro-pellets with controlled size ranges (150‐355 µm, 355‐500 µm, and 500‐850 µm). Catalytic performance was evaluated using a fixed-bed flow reactor under both thermal and electric-field conditions, and electrochemical impedance spectroscopy (EIS) was conducted to analyze ionic conduction behavior within the catalyst bed. Under thermal (no electric field) conditions, the hydrogen conversion showed strong temperature dependence, decreasing sharply at lower temperatures(Fig. 1). Importantly, no significant difference in activity was observed among different pellet sizes, indicating that internal diffusion limitations were negligible in the studied size range. In contrast, when a constant electric field (3 mA) was applied, significant enhancement in catalytic activity was observed, particularly in the low-temperature range (200–300°C). The smallest pellet size (150–355 µm) exhibited the highest activity. Since diffusion effects were ruled out, this improvement was attributed to electrical factors. Smaller particles increased the number of contact points between pellets, forming dense, parallel ionic conduction pathways across the catalyst bed. EIS analysis supported this interpretation. At high temperature (500°C), smaller pellets exhibited lower overall resistance due to increased parallel conduction paths. At low temperature (200°C), large pellets showed extremely high resistance (on the order of GΩ), indicating that ionic conduction pathways were effectively blocked. Although smaller pellets had more interfaces (which could increase resistance under small perturbations), the applied strong electric field in actual operation enabled breakdown of interfacial barriers, allowing efficient long-range ion transport. Finally, the study highlights a key design trade-off for practical automotive applications: while smaller particles improve ionic conduction and catalytic activity, they also increase pressure drop in exhaust systems. Therefore, future reactor designs must balance electrical performance and fluid dynamics, potentially through structured supports such as honeycomb substrates with engineered conductive pathways. Overall, this work provides fundamental design guidelines emphasizing the importance of constructing dense, parallel ionic conduction networks for efficient electric-field-assisted catalytic systems in on-board carbon recycling.



(a) 150～355 µm



(b) 355～500 µm



(c) 500～850 µm

Fig.1 Experimental results of the effect of the pellet diameter of carbon dioxide and the electric field on the CO_2 reduction.

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