CO_2 Sorption/Reduction Systems for Direct Air Capture/Utilization

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Carbon dioxide removal (CDR) is a new concept for removing CO_2 from the atmosphere. Direct air capture (DAC) is an important CDR technology which removes ultralow concentrations of CO_2 (~ 400 ppm) from the air. On the other hand, CO_2 capture and reduction with H_2 (CCR), which has been recently studied in catalysis community, targets at capturing high concentration CO_2 from combustion exhaust gas and then converting it to CO or CH_4. Several dual functional materials (DFMs) for CCR have been reported, but to the best of our knowledge, the CCR of CO_2 from the air has not yet been reported. In this study, the CCR system and a membrane DAC were combined to demonstrate the first example of direct air capture and utilization (DAC-U) for continuous production of CH_4 or CO from the air.

The screening tests for model CCR system showed that Ni nanoparticle (NP) on Ca-loaded Al_2O_3 (Ni-Ca/Al_2O_3) was the best DFM for methanation. Pt NPs on Na-loaded Al_2O_3 (Pt-Na/Al_2O_3) was the best DFM for CO formation. In the DAC-U system, a membrane DAC module was connected to a vacuum pump, and the outlet of the pump was connected to the CCR system via a water trap. The DAC unit feeds approximately 2000 ppm CO_2 to the CCR unit. The CCR system consists of parallel double fixed-bed flow reactors (A and B) at 350 °C and timer-controlled 4-way valves. Each reactor contains 0.5 g Ni-Ca/Al_2O_3. CO_2 (2000ppm)/air mixture was fed to the reactor A for 60 s, while H_2 was fed to the reactor B for 60 s. Then, the inverse gas was fed to each reactor by simultaneously switching the two 4-way valves. During a long-term (6000 min) DAC-U operation, the system continuously captured CO_2 in the air and converted it to CH_4 with the repetition of a few thousand cycles of CCR operation. Continuous and selective production of ca 2000 ppm CO from the air was demonstrated using a similar DAC-U system with a Pt-Na/Al_2O_3 catalyst.

Similar sorption/reduction systems for CH_4 production from 10% CO_2/10% O_2 mixture and NH_3 production from 0.1% NO/10% O_2 mixture will be introduced.