Electrosynthesis of Ethylene from CO$_2$-derived Syngas Using Nanostructure Cu-based Catalysts

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Abstract

Increased atmospheric CO$_2$ levels have contributed to a global rise in temperatures, highlighting the need for carbon-neutral and carbon-negative processes. To combat this climate issue, extensive studies have been carried out on CO$_2$ reduction reaction via photo-, photovoltaic- and electrochemical conversion to produce syngas. Among these processes, the electroreduction of CO$_2$ (e.g., Fisher Tropsch) to produce CO has the potential to be economically viable.

To accelerate decarbonisation of the chemical industry, the development of sustainable production of commodity chemicals from non-petroleum feedstock, also known as Power-to-X, is critical. A recent study revealed that tandem electrosynthesis of ethylene products (i.e., CO$_2$-CO-C$_2$H$_4$) is more sustainable than the single-step process (i.e., CO$_2$-to-C$_2$H$_4$) because the former process shows less loss of CO$_2$-to-carbonate, lower overpotential, higher product selectivity and thus, higher overall efficiency than the latter.$^1$ However, the use of CO and H$_2$ to produce ethylene – the most important organic chemicals as the building block for a vast range of polymers, has not been studied extensively. Hence, this study focuses on the development of green synthetic ethylene from syngas in giga-tonne scale using electrochemical approach, which could achieve carbon neutral in terms of energy consumption if combined with a suitable solar powered energy source.

Abundantly available Cu is one of the few transition metals that can efficiently catalyse the electroreduction of CO or CO$_2$ into hydrocarbons. However, the efficiency of ethylene production from CO or CO$_2$ using Cu nanometal reported is still low for practical applications ($\leq40\%$ and 0.5 mA cm$^{-2}$).$^2$ To maximise conversion efficiency and selectivity, previous studies revealed that the morphology of the catalysts played an important role.$^2,3$ Various morphologies of Cu nanoparticles are synthesized herein using the versatile solvothermal synthesis prior to the deposition onto the gas diffusion layer as the cathodic material. The morphology of the catalysts is examined using electron microscopies (i.e., SEM and HRTEM equipped with EDX); crystal phase analysis is conducted using powder X-ray diffraction and Raman spectroscopy. The electro-production of ethylene under different flow of CO and H$_2$, which was monitored with mass flow controllers, is performed using the PECC-2 flow cell (from Zahner Ltd.) connected to the GC to analyse the gaseous products.

To further enhance the conversion efficiency of the Cu catalysts, recent studies revealed that amine-based polymers could be used to boost efficiency and selectivity towards ethylene production.$^4,5$ The amine-based polymers is then grafted onto the optimised Cu catalyst to perform the electrosynthesis of ethylene. To understand the reaction occurs at the electrode-liquid interface, operando ATR-FTIR is performed, and a reaction mechanism is proposed.

The results obtained in this study also provide a guideline to scale up and fabricate the self-standing electrodes using direct ink writing method on a 3D printer in the future, as well as showcasing the feasibility of the green process in commodity chemical production using CO$_2$-derived syngas.

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