3D printed reactors for direct CO_2 hydrogenation to DME

Vesna Middelkoop[1]*, Susana Pérez Gil[2], Yoran de Vos[1], Farnaz Sotoodeh[3], Erik Abbenhuis[4], Giuseppe Bonura[5]

1 Vlaamse Instelling voor Technologisch Onderzoek - VITO, Boeretang 200, 2400, Mol, Belgium;
2 TECNALIA, Parque Científico y Tecnológico de Gipuzkoa Mikeletegi Pasalekua 2, 20009 San Sebastián, Spain;
3 Feyecon Development & Implementation BV, Rijnkade 17A, 1382 GS Weesp, The Netherlands;
4 Hybrid Catalysis BV, Den Dolech 2, 5612 AZ, Eindhoven, The Netherlands;
5 Consiglio Nazionale delle Ricerche, Istituto di Tecnologie Avanzate per L'energia – CNR-ITAE, Via Salita Santa Lucia Sopra Contesse 5, 98126 Messina, Italy
**Corresponding author E-Mail: vesna.middelkoop@vito.be*

1. Introduction

This presentation will showcase our work on 3D printed reactors and catalysts within the CO2Fokus project (www.CO2Fokus.eu), that brings together six research organisations and six industrial partners. The goal of the project is to develop cutting-edge technology able to directly convert industrial CO_2 into DME, a valuable gas extensively used in the chemical and energy sectors fostering an alternative to fossil fuel derived feedstock (see the overall process concept presented in Figure 1). Currently, DME is commercially produced through an indirect, two-step process involving the production of methanol and its subsequent dehydration. This process is energy intensive and requires substantial capital and infrastructure investments. The project will contribute towards the transition to a low-carbon society by demonstrating that DME can directly be produced in an efficient way from CO_2 captured at large industrial point sources, such as energy intensive processes in the petrochemical sector.

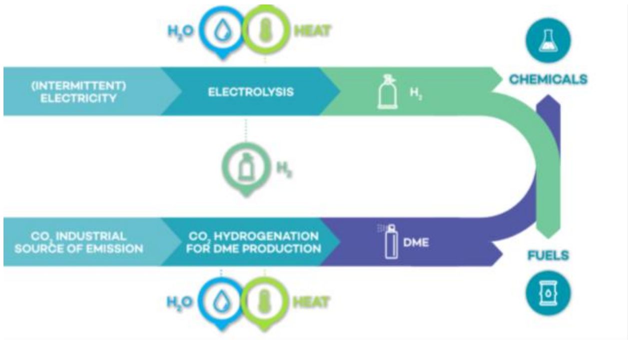

Figure 1. Flow diagram illustrating approach and methodology for carbon dioxide hydrogenation to DME

2. Methods

To this end, innovative 3D printed multi-channel catalyst were developed and tested at lab scale and are being scaled up for pilot scale multi-tubular reactors that will be commissioned in an industrial environment of large CO_2 point sources. Key considerations taken into account: tuning the material formulation as well as the thermodynamic aspects controlling the reaction underpinned by innovative reactor and solid oxide electrolyte systems (the latter are providing H_2 to the reaction) [1] Structured multi-channel reactors (Figure 2) are designed to accommodate the DME production process and provide tailored heat and mass transfer to the catalytic reaction zone. Their design can be realised using emerging 3D printing technologies to lay down functional material with high fidelity and near exact repeatability.[2] The use of finessed catalyst materials within bespoke reactors represents a step change in chemical engineering.

3. Results and discussion

Active catalyst materials (such as Cu-ZnO-Al_2O_3 and similar, novel composites) are 3D printed by Direct Ink Write (DIW) and integrated within structured supports and the internal engineering of multi-channel catalytic reactors to produce DME in an efficient way.[3-5] A highly defined three-dimensional network is designed to offer an exact control of flow dynamics and mixing.

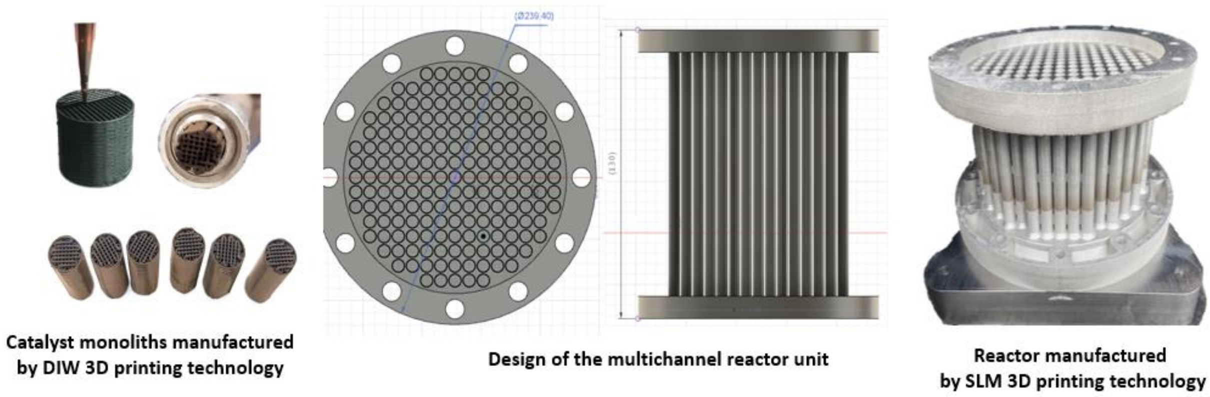

Figure 2. 3D co-printing of catalysts at VITO employed for manufacturing different formulations and architectures of pre-defined patterns and size, inserted in a single reactor tube and TECNALIA's multi-tubular reactor scaled from 16 to up 170 channels.

The multi-tubular reactor modules are developed by another 3D printing technique, Selective Laser Melting (SLM) which allows the flexibility in the design and scale of the reactor configurations. Each tube contains the 3D printed catalyst monoliths that the reaction gas mixture (H_2 and CO_2) flows through. The reactors can withstand 30 bar of pressure at up to 300ºC and at a total flow rates of 4-5 Nm3/h with the H_2:CO_2 ratio of 3:1. For innovative 3D printed multichannel catalytic reactors comprising 30 or more tubes and operating at 1500 N L/h CO_2/H_2 feed, at least 30 % CO_2 conversion is expected.

4. Conclusions

The production of DME in a single-step process by direct catalytic and electrochemical conversion of CO_2 and H_2 can offer to meet the ever-increasing demand for alternative, carbon-neutral, environmentally-friendly fuels and chemical and energy carriers.

References

[1] E. Catizzone, G. Bonura, M. Migliori, F. Frusteri, G. Giordano, CO_2 Recycling to dimethyl ether: state-of-the-art and perspectives, Molecules, 23 (2018) 31

[2] V. Middelkoop, A. Vamvakeros, D. De Wit, S. Jacques, S. Danaci, C. Jacquot, Y. De Vos, D. Matras, S. Price, A. Beale, 3D printed Ni/Al2O3 based catalysts for CO_2 methanation - a comparative and operando XRD-CT study, Journal of CO_2 Utilization, 33 (2019) 478-487

[3] G. Bonura, M. Migliori, L. Frusteri, C. Cannilla, E. Catizzone, G. Giordano, F. Frusteri, Acidity control of zeolite functionality on activity and stability of hybrid catalysts during DME production via CO_2 hydrogenation, Journal of CO_2 Utilization 24 (2018) 398-406

[4] G. Bonura, C. Cannilla, L. Frusteri, F. Frusteri, The influence of different promoter oxides on the functionality of hybrid CuZn-ferrierite systems for the production of DME from CO_2-H_2 mixtures. Applied Catalysis A: General 544C (2017) 21-29.

[5] G. Bonura, C. Cannilla, L. Frusteri, A. Mezzapica, F. Frusteri, DME production by CO2 hydrogenation: Key factors affecting the behaviour of CuZnZr/ferrierite catalysts. Catalysis Today 281 (2017) 337–344.

CO2FOKUS
ADVANCING CO2 CONVERSION

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061
This presentation reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein