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Direct Electrification of Dry Methane Reforming in Additively Manufactured Monolithic and Foam Reactors via Joule Heating

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ABSTRACT

Dry methane reforming (DRM) represents a strategically important pathway for the simultaneous valorisation of methane (CH_4) and carbon dioxide (CO_2), two of the most significant anthropogenic greenhouse gases. Through catalytic reforming, these molecules are converted into synthesis gas (syngas), a versatile intermediate for the production of value-added chemicals and fuels including methanol, dimethyl ether, and Fischer–Tropsch hydrocarbons. Despite its environmental and industrial relevance, DRM is a strongly endothermic reaction requiring temperatures typically exceeding 800–900 °C, which imposes severe constraints on conventional furnace-heated reactor systems due to inefficient heat transfer, thermal gradients, and high energy demand. Electrified reactor technologies powered by renewable electricity offer a transformative alternative for delivering reaction heat with improved efficiency and controllability.

This work investigates direct Joule (ohmic) heating of structured catalytic reactors as an intensified platform for DRM. Additive manufacturing is employed to fabricate 3D-printed Inconel monolithic reactors with engineered internal architectures that enhance surface-area-to-volume ratio, promote uniform current distribution, and improve heat and mass transfer within the catalytic bed [1]. In this configuration, the electrically conductive monolith functions simultaneously as a resistive heating element and catalyst support, enabling rapid, localized heating directly within the reactive domain.

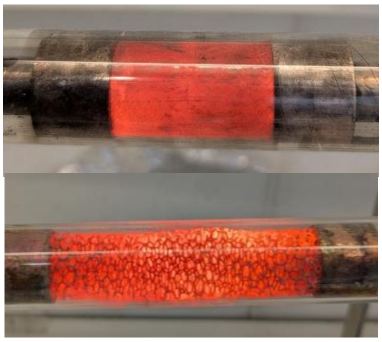

Fig 1. Top: Inconel 3D-printed monolithic reactor; Bottom: foam-based monolith during the dry methane reforming (DRM) reaction.

The relatively low electrical resistivity of Inconel results in low resistance across the monolithic structure, necessitating high-current operation at low applied voltage. Tailored electrode architectures and a dedicated low-voltage, high-current power supply enable stable Joule heating of the monolith to temperatures exceeding 900 °C under continuous operation.

Catalytic activity is introduced via thin-layer dip-coating of Ni-based perovskite catalysts ($LaNiO_3$) onto the structured substrates. To enhance catalyst stability and dispersion, the active phase is incorporated within an MCM-41 mesoporous silica matrix, which promotes improved metal dispersion, enhanced thermal stability, and resistance to carbon deposition under DRM conditions. Perovskite-derived catalysts exhibit favorable redox properties, structural stability, and resistance to carbon deposition, making them promising candidates for sustained DRM operation [2].

In addition to additively manufactured monoliths, this study systematically evaluates metallic and ceramic foam reactor architectures, including NiCr alloy and silicon carbide (SiC) foams, as scalable and economically attractive alternatives for electrified DRM. The highly interconnected pore networks of these foams facilitate efficient electrical conduction, enhanced heat dissipation, and improved reactant accessibility to active catalytic sites [3].

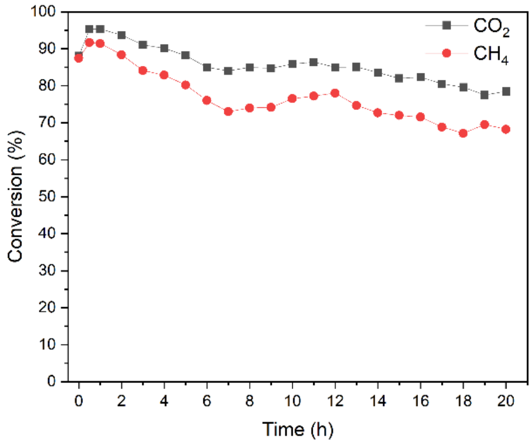

Fig 2. CO_2 and CH_4 conversion over a $LaNiO_3$ perovskite catalyst in an Inconel-based 3D printed reactor operated under Joule heating conditions.

By integrating advanced catalyst design, additive manufacturing, and electrified reactor engineering, this work establishes a platform for intensified DRM processes capable of converting greenhouse gases into valuable chemical feedstocks with improved thermal efficiency. The findings provide critical insights into the design of next-generation electrified catalytic reactors for sustainable and low-carbon chemical manufacturing.

KEY WORDS

Dry Methane Reforming; Joule Heating; Electrified Catalysis; Additive Manufacturing; Structured Reactors; Inconel Monolith; Silicon Carbide Foam; Perovskite Catalyst

BIOGRAPHY

Ashwin Kishor Hatwar is a PhD candidate in the Department of Chemical Engineering at Monash University, Australia. His research focuses on electrified catalytic reactors for greenhouse gas valorisation, particularly dry methane reforming using Joule-heated structured reactors. His work integrates additive manufacturing, catalyst development, and reactor engineering to develop scalable technologies for sustainable syngas production and electrified chemical processing.

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