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Short Communication

Performance evaluation of a high-throughput microchannel reactor for ammonia decomposition over a commercial Ru-based catalyst

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ABSTRACT

In this work, the prospect of producing hydrogen (H_2) via ammonia (NH_3) decomposition was evaluated in an experimental stand-alone microchannel reactor wash-coated with a commercial Ruthenium-based catalyst. The reactor performance was investigated under atmospheric pressure as a function of reaction temperature (723–873 K) and gas-hourly-space-velocity (65.2–326.1 Nl g_{cat}^{-1} h^{-1}). Ammonia conversion of 99.8% was demonstrated at 326.1 Nl g_{cat}^{-1} h^{-1} and 873 K. The H_2 produced at this operating condition was sufficient to yield an estimated fuel cell power output of 60 W_e and power density of 164 kW_e L^{-1}. Overall, the microchannel reactor considered here outperformed the Ni-based micro-structured system used in our previous work.

Introduction

The low volumetric energy density of hydrogen (H_2) fuel is widely considered the primary constraint in deploying fuel cell technology at a large scale. At present, there exists a wide gap in the H_2 supply chain to advance fuel cells to extensive commercialisation. Hardman and Steinberger-Wilckens [1] mention that successful infrastructural pre-development is essential in attaining a viable H_2 economy. On the foregoing, the existing lack of an adequate infrastructure motivates the need for on-site generation of H_2 via reforming of alternative H_2 carriers in fuel processors [2]. Among the various options, ammonia (NH_3) decomposition has lately been receiving

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Nomenclature

H_c	channel height, μm
L_c	channel length, mm
m_{cat}	mass of catalyst in reactor, mg
$\dot{m}_{H_2}$	mass flow rate of hydrogen, kg s^{-1}
$\dot{m}_{NH_3,out}$	mass flow rate of residual ammonia, kg s^{-1}
$\dot{m}_{NH_3,in}$	mass flow rate of ammonia at inlet, kg s^{-1}
$n_{T,in}$	total molar flow rate at reactor inlet, mol s^{-1}
$n_{T,out}$	total molar flow rate at reactor outlet, mol s^{-1}
P	pressure, Pa
P_{eq}	fuel cell power output equivalent, W_e
Q_e	cartridge heater power requirement, kJ s^{-1}
Q_{H_2}	molar hydrogen production rate, mol h^{-1}
R	ideal gas constant, 82.057 cm^3 atm K^{-1} mol^{-1}
T	temperature, K
T_r	reactor operating temperature, K
υ_{H_2}	volumetric hydrogen production rate at outlet, cm^3 h^{-1}
W_c	channel width, μm
W_f	fin width, μm
X_{NH_3}	ammonia conversion, %
$y_{NH_3,in}$	ammonia mole fraction at reactor inlet
$y_{NH_3,out}$	residual ammonia mole fraction at reactor outlet
Y_{H_2}	specific hydrogen production rate, mol g_{cat}^{-1} h^{-1}

Greek symbols

η	reformer energy efficiency, %
η_{PEM}	PEM fuel cell energy efficiency, %
Θ_{PEM}	PEM fuel cell hydrogen utilization, %

Sub- or superscripts

c	channel
cat	catalyst
e	electric
eq	equivalent
f	fin
in	inlet
out	Outlet
r	reactor
T	Total

Abbreviations

AFC	alkaline fuel cell
DSS	daily start-up and shut-down
GC	gas chromatograph
GHSV	gas-hourly-space-velocity, Nl g_{cat}^{-1} h^{-1}
HID	helium ionization detector
LHV	low heating value, kJ kg^{-1}
PEM	polymer electrolyte membrane
ppbv	parts per billion volume
ppmv	parts per million volume
TCD	thermal conductivity detector

increasing attention for various desirable reasons. Most importantly, NH_3 is a carbon-free H_2 carrier that has superior H_2 content and gravimetric energy density compared to alternative carriers [3–7]. Microchannel reactors are a transformative technology for realizing ammonia-fuelled reformers for portable and distributed H_2 generation. This reactor technology enables on the one hand to reduce substantially the size footprint of the overall system and on the other hand enhance the heat and mass transfer rates [5–10].

The literature reporting on experimental investigation of microchannel fuel processors for NH_3 decomposition is sparse. Only five experimental studies using microchannel reactors [5] have been reported in the past decade. The details of these respective studies are provided in our earlier communications [5,6]. Lately, Chiuta et al. [6] evaluated, characterized, and demonstrated miniaturized H_2 production in an ammonia-fuelled microchannel reactor washcoated with a Ni-based catalyst. Their reformer yielded exceptional performance only for low ammonia flows (<50 Nml min^{-1}), producing an estimated fuel cell power density of 15.8 kW_e L^{-1}. The present paper seeks to evaluate a Ru-based microchannel reactor for pure NH_3 decomposition, and compare its global performance against that attained in our previous work [6] using a Ni-based catalyst. In this assessment, the improved performance vis-à-vis the Ru-based catalyst is articulated.

Experimental

Microchannel reactor design

The microchannel reactor (Fig. 1) used for this work was designed and constructed in collaboration with Fraunhofer-ICT-IMM (Mainz, Germany). The reactor geometry was identical to that used in our previous study [6] for the Ni-catalyzed reaction system. The microchannels were fabricated on a SS314 stainless steel (German steel classification 1.4841) plate having a thickness of 2 mm. The plate consisted of 80 microchannels (H_c = 150 μm, W_c = 450 μm, W_f = 250 μm, and L_c = 50 mm), along with right-angled triangular header and

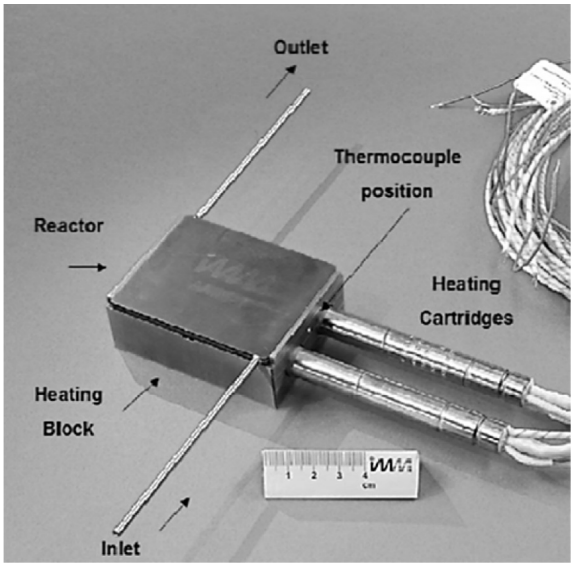

Fig. 1 – Depictions of the reactor with laser-welded inlet/outlet tubes, heating block and electric heater cartridges.