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Microwave Heated, Additive Manufactured Catalyst Converters for Zero Impact Emission Powertrains

Polyhedral open lattice catalyst converters have the potential to achieve higher conversion performance with lower precious metals content. Numerical simulations confirmed the advantages and led to optimal geometrical configuration. Additive Manufacturing (AM) techniques have been employed for the realization of real vehicle catalyst converters. What's more, a microwave heating system of the catalyst converter has been designed in order to reduce Cold Start emissions. Testing results are very encouraging so far. A combined approach, microwave heated polyhedral catalyst converter is promising for achieving very low pollution powertrains.

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Introduction

Currently, major challenges for Exhaust After-treatment at real driving conditions are:

- Cold Starts, and
- High Exhaust Mass Flow

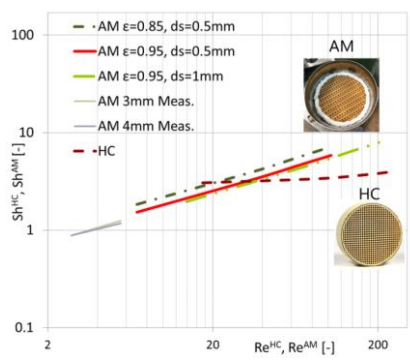
Decreasing emissions in both conditions result in contradictory requirements, lower catalyst thermal inertial for the former, while bigger catalyst converter for the latter.

In addition, it is important to prevent:

- catalyst converter cooling during longer low load operation (particularly for hybrid powertrain systems)

In order to address these issues, research focuses in identifying catalyst supports structures with high heat and mass transfer characteristics, as well as low flow through resistance.

Additive Manufactured Polyhedral Catalyst Substrates

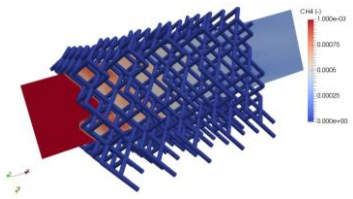


CFD simulations show significantly higher heat and mass transfer (higher Sh^{AM}) of polyhedral lattices in respect to state-of-the-art honeycombs (HC).

- Polyhedral lattices require less surface, thus less precious metals for identical conversion
- Polyhedral lattice catalyst substrates have been realized with additive manufacturing (AM) techniques.

Numerical Simulations for Fluid Dynamic Optimization

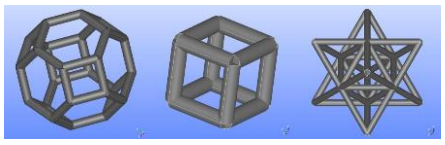
A numerical code in OpenFOAM has been developed for solving the mass, momentum, heat transfer with catalytic surface reaction.



$$\frac{\partial X_i}{\partial n} = \alpha_i \frac{MM_i}{MM_{CH4}} \frac{\partial X_{CH4}}{\partial n}$$

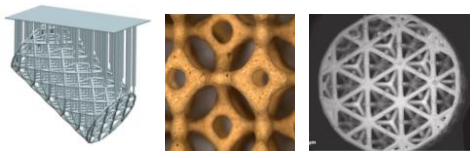
$$K = \frac{-\ln(1-\eta_{CH4})S_V}{\dot{Q}_{in}} = \frac{Sh\,L}{D}$$

Systematic variation of the elementary cell and dimensions has been conducted.



Rotated Cubic cell (45° in respect to all the 3 spatial directions) with highest porosity and thinnest struts possible shows the best reactivity to pressure drop ratio.

Stereolithography of Ceramic Materials

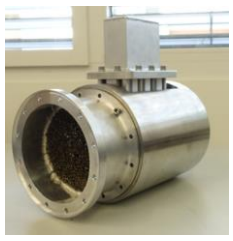


Realization of polyhedral lattices has been achieved by AM techniques.

Systematic optimization of the process material (photoinitiator, photo sensitive resin) and parameters (T, slurry) has led to the first worldwide Cordierite polyhedral catalysts (small dimensions).

Upscaling to vehicle dimensions has required the development of a hybrid method (polymer additive manufactured stamp and replica method for ceramization.

Heating the Catalyst Substrate with Microwaves

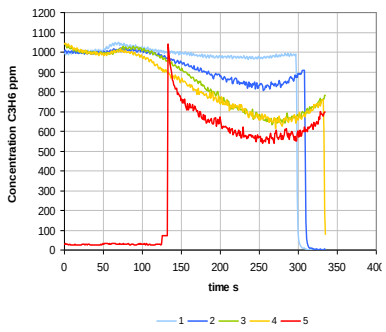


Layout design and manufacturing of the waveguide, cavity and catalyst system

The catalyst comprising of SiC and Cordierite slices.

Microwave source: household magnetron with P=1.3 kW, preheating for 100s .

Depending on the catalyst configuration, up to 40% Cold Start emission reduction with synthetic exhaust, while 20% on real vehicle.



Achieved Objectives and Next Steps

- Measurements confirm Cold Start emission reduction on vehicle tailpipe
- AM catalysts achieve the same conversion of HC with 50% less precious metal content
- Currently, the first detailed real vehicle tests are performed on the chassis dynamometer
- Further optimizations through experiments and numerical simulations are required.

References

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