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Approaches to Integrating Catalytic Aerogel Materials into Three-way Catalytic Converters

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Aerogels have many unique physical properties:

- Very Low Thermal Conductivity
- Very Low Density
- Low Thermal Inertia
- Very High Surface Area
- High Temperature Stability
- Chemically Tailorable

https://www.aerogel.org/wp-content/uploads/2009/02/theflowerlow-lbl.jpg

All of which make them potentially attractive for use in TWC applications … BUT to bring aerogels' potential benefits to TWCs several prerequisites must be met. Can they be?

Abstract

Here we summarize findings from our group's investigations into the opportunities and challenges associated with incorporating catalytic aerogel materials (CAMs) into three-way catalytic converters (TWCs). We have demonstrated the ability to synthesize several candidate CAMs, including copper-alumina, copper-silica, ceria-alumina and platinum-alumina, via a novel rapid supercritical extraction (RSCE) process and using several distinct synthetic approaches to introduce the catalytically active species into the aerogel matrix[1-3]. The synthetic approaches include impregnating sol-gels with solutions of metal salts via solvent exchanges, forming sol-gels from "co-precursor" solutions containing salts of the active metal species, and incorporating commercially available metal nanoparticles into the aerogel precursor recipe. The resulting CAMs have been characterized (surface area, SEM/EDX, X-ray diffraction) and tested for TWC activity under conditions representative of use in automotive gasoline engines. Several recipes, including some that do not contain platinum group metals, show promising levels of catalytic activity. In addition to verifying that CAMs show TWC activity we have evaluated important performance aspects including demonstrations of high temperature stability and numerical studies that indicate that CAMs' low mass can reduce time to light-off. We have demonstrated that CAMs can be slurried and that they can be exposed to actual (humid) exhaust environments and retain their catalytic activity. We have also developed several methods for ruggedizing the aerogels, including laser-machining of CAM monoliths, offering a potential alternative to the standard cordierite/washcoating approach. These findings point to the promise of aerogel catalysts.

Catalytically Active Candidate Aerogels

We have demonstrated the ability to synthesize ***several*** candidate catalytic aerogel materials (Table 1) using the RSCE method[4-8] and various synthetic approaches.

These materials are active for TWC reactions (Figure 1) under realistic conditions[3,9] for at least several cycles.

Table 1: Catalytic aerogels: types and performance.

Aerogel Type	Simulated Gas	Light-Off Temperature (° C)			Reference
		HC	CO	NO	
Cu Si	BAR 97	800	275	350	10
Cu Si (NP)	BAR 97	800	375	400	11
Ce Si	BAR 97	800	450	500	12
Ni Al	BAR 97	540	460	800	9
Co Al	BAR 97	500	550	550	9, 13
Ce Al	BAR 97	500	275	425	12
Cu Al	BAR 97	450	210	310	3
Cr Al	CLEERS	290	310	350	14
Cu Al (Slurry)	CLEERS	260	220	350	15
Cu Al	CLEERS	250	220	260	15
RhPd Al (NP)	CLEERS	235	210	255	16

NP - indicates that catalytic metal was introduced in nanoparticle form

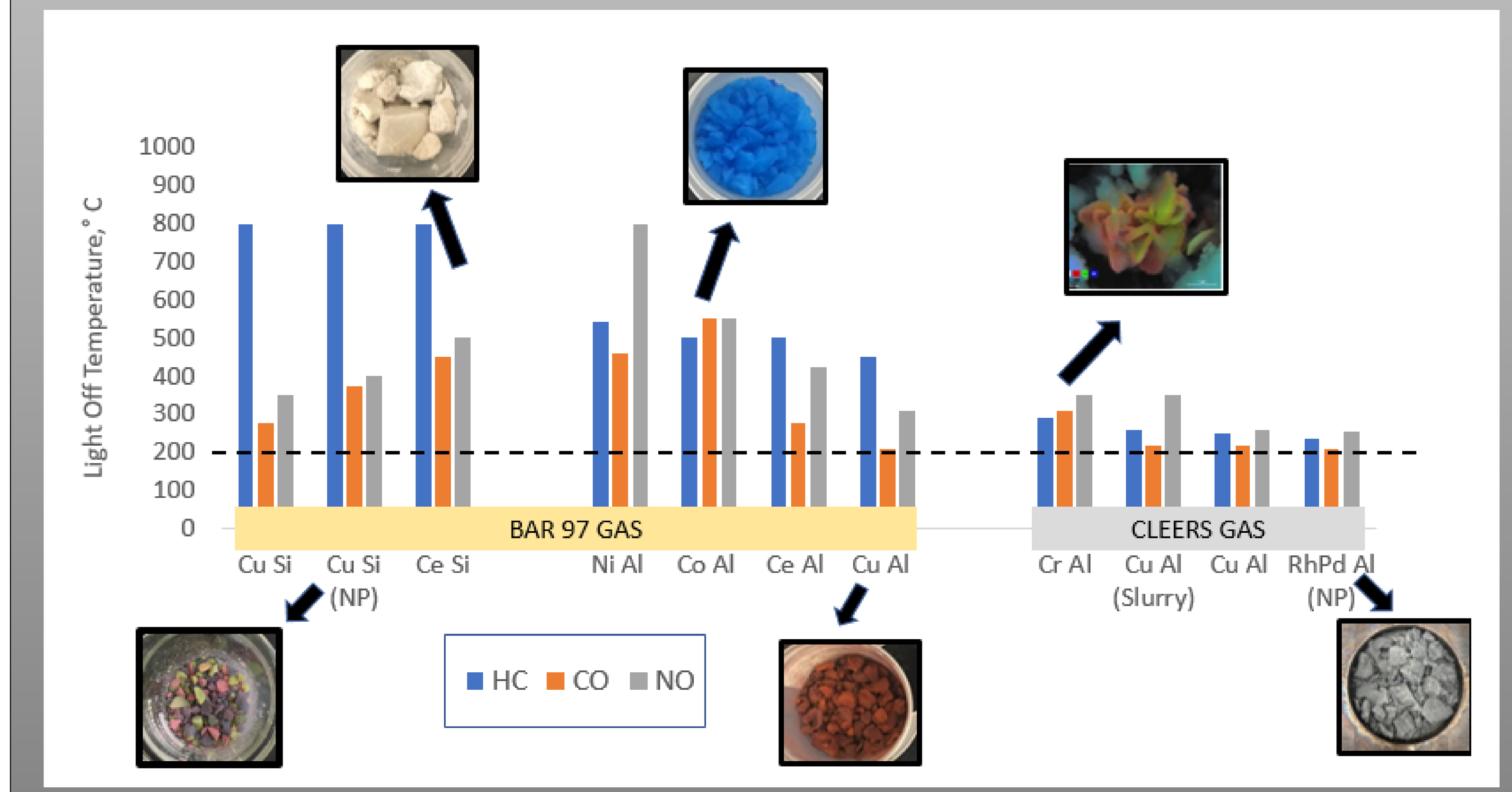


Figure 1: Visual depiction of catalytic aerogels and their light-off temperatures. Values above 700°C indicate light-off was not achieved under testing conditions. Dotted line shows target (200°C).

https://www.chicagotribune.com/autos/ct-chicago-catalytic-converter-theft-20160908-story.html

Some potential advantages of an aerogel-based catalyst include:

High Surface Area: More active sites, improved gas/solid interaction
High Thermal Stability: TWC close coupling, reduced active site diffusion/sintering
Chemically Tailorable: PGM reduction or elimination
Low Thermal Inertia: Reduced time to light-off temperature

Open Questions & Future Work

Survivability?

- Long term aging? Preliminary results show short term (several cycles) of survivability under dry and humid conditions[15,16].
- Vibration and physical loading?
- Poisoning?

Benefits?

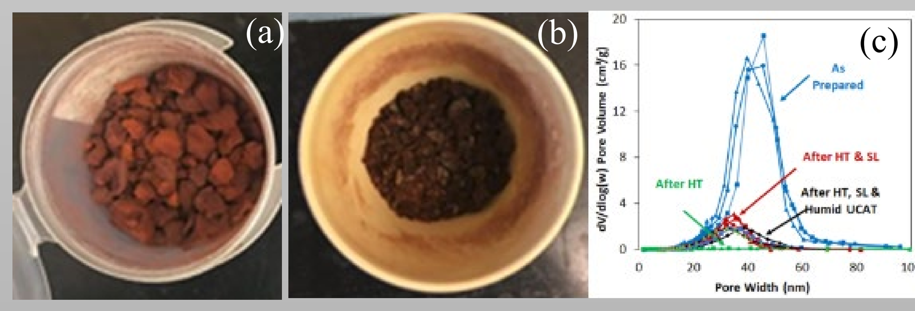
- Does increased thermal stability lead to decreased sintering aging and increased lifetime?
- Does increased surface area and accessibility of active sites lead to reduced metal usage?
- Can the lower thermal inertia of aerogels be translated into reduced light-off delays?

Cost?

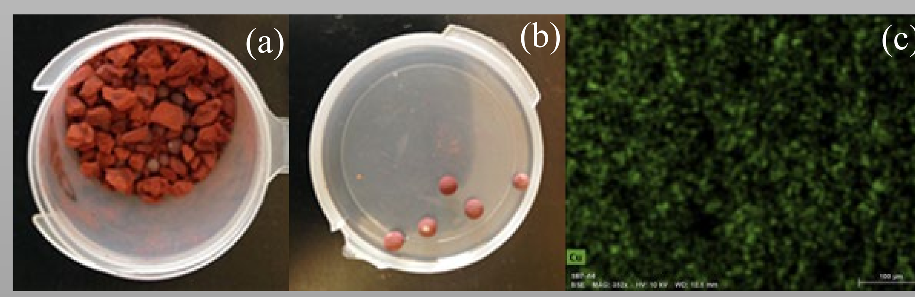
- Potentially reduced PGM loading?
- Use lower-cost aerogel manufacturing techniques?

Integrating Candidate Aerogels

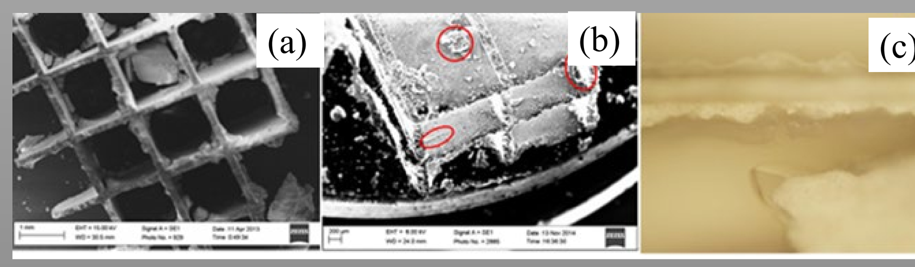
It is not enough to demonstrate catalytically active aerogels. They must also be in a form that can be integrated into robust, functional catalytic converters. We have demonstrated key steps for several possible pathways, from the lower-risk incumbent "slurry and washcoat" methods to more speculative: catalytic aerogel monoliths acting as both the catalyst and support structure.



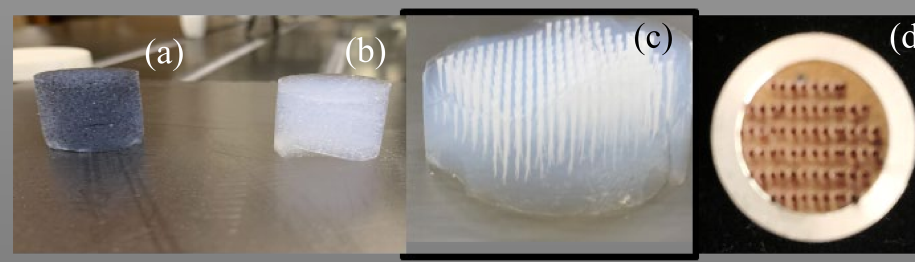
Slurried aerogel maintains performance - could be integrated into washcoating process.[15] (a) raw, (b) post slurry, (c) pore volume



Aerogel can be coated onto **alumina beads** in-situ during RSCE processing: (a) Cu-Al aerogel (b) resulting beads (c) EDX map of coated beads



Aerogel can be coated onto **cordierite** in-situ during RSCE processing: SEM (a) Si aerogel (b) & (c) Co-Al aerogel



Aerogel can form **the structure**: (a) activated carbon (b) subsequently burnt out (c) laser cut channels in Silica aerogel and (d) Cu-Al doped silica aerogel

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16. Manuscript in preparation.

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