AVECC 2004 Beijing, China

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Motorcycle Catalyst Presentation: Meeting the Euro-3 Challenge for 4-Stroke Motorcycles

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Meeting the Euro-3 Challenge for 4-Stroke Motorcycles: Background

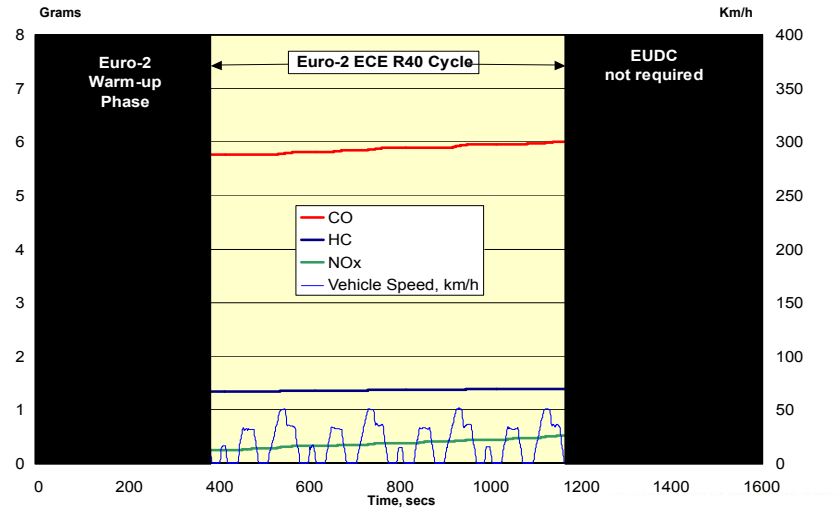
- China is following the European pattern for regulating emissions from on-road motorcycles
- Euro-2 level emissions regulations have been in force for new motorcycles in Europe since 2003, China is now beginning implementation of Euro-2 regulations
- Euro-3 will come into force in Europe in 2006, China in the future (?)
- Euro-2 is relatively easy to meet for 4-stroke motorcycles
  - Improvements in engine design, tuning and performance such as EFI
  - Secondary air injection (SAI) to target CO emissions
  - Simple oxidation catalysts in either heat tube or monolith form sometimes with SAI
- However, meeting Euro-3 is a difficult, but attainable, technological leap

Meeting Euro-3 Emission Regulations Will Become More Difficult Due to Significant Changes From Current Euro-2 Standards

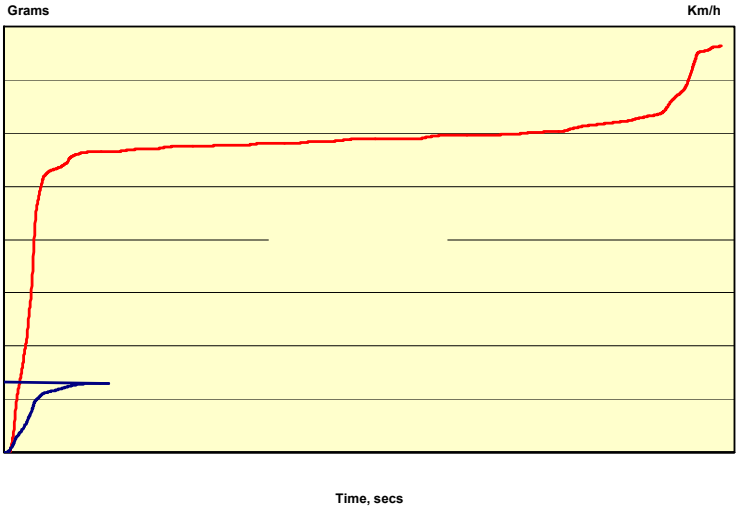
Vehicle	Homologation/Production (COP) Mass Emissions(g/km)				Durability	Remarks
	HC	CO	NOX	Test Cycle	Test	
All 4-stroke	3	13	0.3	ECE R40		Stage 1
2,4-S,150cc	1.2	5.5	0.3	ECE R40		Stage 2 for new models as of 1/1/2003
2,4-S >150cc	1	5.5	0.3	ECE R40		Stage 2 for new models as of 1/1/2003
2,4-S <150cc	0.8	2	0.15	Cold Start ECE R40	12K km	Stage 2 Tax Incentive/Proposed 2006 Stage 3
2,4-S >150cc	0.3	2	0.15	Cold Start ECE R40+EUDC	18K &30K km	Stage 2 Tax Incentive/Proposed 2006 Stage 3

- HC will be 33% to 70% lower than Euro-2
- CO will be 65% lower than Euro-2
- NOx will be 50% lower than Euro-2
- Cold start requirement will be added (increases HC & CO)
- High speed EUDC added for engines >150cc (increases NOx and CO)
- 30K km durability added for engines >270cc
- 18K km durability added for engines 170 to 269cc
- 12K km durability added for engines 51cc to 168cc

Cumulative Emissions Trace for a Typical Current 4-S EFI Motorcycle with Catalyst for the current ECE R40 Test (Euro-2)



Cumulative Emissions Trace for a Typical Current 4-S EFI Motorcycle with Catalyst for Cold Start ECE R40 + EUDC (Euro-3)



Elimination of Warm-up Phase and Addition of EUDC Causes Significant Changes to Final Emissions

- **HC and CO**
  - Most HC and CO are produced in the warm-up phase
  - Elimination of warm-up will result in significantly higher HC and CO
  - Catalyst light-off is a factor and must be improved to minimize HC and CO
- **NOx**
  - Most NOx is produced in EUDC portion of test
  - Addition of EUDC will result in much higher NOx unless NOx performance of catalyst is improved

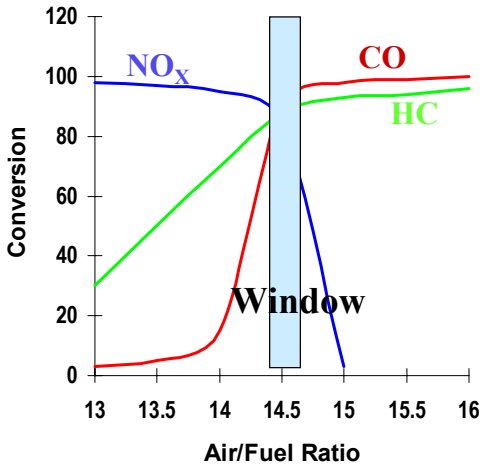
Ways to Improve Catalyst Light-off for Better HC and CO Performance

- Higher PM loading (increases active PM sites)
- Higher dispersion of PM to create more actives sites and reduce the effects of sintering and poisoning (also improves durability)
- Higher cell density substrates (increase surface area = better PM dispersion)
- Optimum positioning of catalyst higher temperature location (but not too hot to cause damage to catalyst)
- Use of close-mounted “light-off” catalysts using specially designed washcoat components that are high temperature resistant (can survive closer to engine)
- Lighter weight substrate (thinner foils have less thermal mass to overcome)

Ways to Improve NOx Performance

- Higher PM (Rh) loading
- Better utilization of Rh
  - Segregated washcoat (minimize potential alloying problems with other PMs)
  - Layering of washcoat
- NOx is space velocity (catalyst volume/ exhaust flow rate) sensitive
  - Larger substrate
  - Higher cell density
- Use of closed-loop engine control with three-way catalyst technology (TWC)

Three-Way Catalysts (TWC) Are Only Effective Close to Stoichiometry



- **Too "Rich": Insufficient O_2 to convert CO & HCs**
- **Too "Lean": Excess O_2 makes it hard for the NO_X molecules to compete for catalytic sites**
- **Stoichiometry: Just enough oxidants (O_2 & NO_X) to react with the reductants (CO & HCs) for optimum HC, CO, & NOx conversions**

"Perturbated" Flow is an Important Factor in TWC Design

- To maintain stoichiometric engine-out gas composition, we use an oxygen sensor in a feedback loop which controls engine fueling
- Just like a thermostat, the composition fluctuates around the desired value
- This "perturbation" causes a problem
  - Half the time, there's more oxygen than can be used
  - Half the time there's not enough oxygen

Ceria Solves this Problem by Switching Valences and "Storing Oxygen"

- During the lean half-cycle, ceria adsorbs excess O_2 that would otherwise escape

$$Ce^{III}_2O_3 + 1/2\ O_2 \longrightarrow 2\ Ce^{IV}O_2$$

- During the rich half-cycle, CO reacts with this adsorbed O_2 forming CO_2

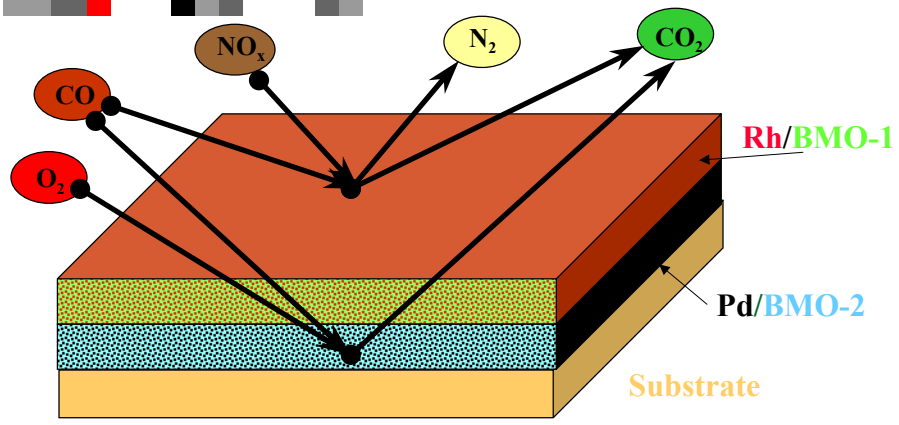
$$2\ Ce^{IV}O_2 + CO \longrightarrow Ce^{III}_2O_3 + CO_2$$

Proprietary Segregated Washcoat Process Allows Atomic Scale Engineering of Catalyst to Enhance PM Performance

- Precious Metals (Pt, Pd, Rh) Can be Atomically Dispersed on Specific Base Metal Supports (Alumina, Ceria)

- Allows Specific Promotion of Precious Metal Function
- Avoids Formation of Poorer Performing Alloys and PM/BMO Compounds

Segregated Materials Can Be Layered Giving Engineered Architecture



Enhances NOx Conversion by Localizing Rh in Region Exposed to High Reductant (CO) Concentration

Meeting Euro-3 Will Require a "Team Approach"

- **Engine Manufacturer**
  - To design the cleanest possible engine (within reasonable cost and performance constraints)
  - EFI, closed-loop system, electronic engine management system
- **Exhaust System Supplier**
  - Muffler design (sound, styling, backpressure)
  - Optimum catalyst positioning
- **Catalyst and Substrate Suppliers**
  - Cost effective catalyst technology for specified operating conditions
  - Proper selection of substrate (size, materials, cell density, etc.)
  - Excellent light-off, high conversion, excellent durability

Comments on Meeting 30K km Durability Requirement

- Required 30K km durability is new for motorcycles
- Automobiles have long had durability requirements in excess of 80K km
- Catalyst development has for over 30 years has focused on improving both the performance and durability of automotive catalysts
- Engelhard leverages advanced automotive catalyst experience and expertise into catalysts for motorcycle applications
- Therefore, meeting a 30k km durability requirement should not be an insurmountable technical problem

Euro-3 Program Results Update

- Euro-3 has been achieved at a number of OEMs
  - Closed-loop engine management systems have been required
  - Higher substrate cell densities have been required, at least 200cpsi and up to 400cpsi, up from typical 100cpsi for Euro-2
  - Larger catalyst volumes have sometimes been needed, up to double that required for Euro-2
  - Higher PM loadings have been required, often more than twice as much as for Euro-2 but increased use of currently lower cost palladium has minimized the cost impact
  - So far there has been no need for extra catalysts to be mounted close to the engine to improve light-off

Conclusion

While requiring technological upgrades in engine and catalyst design, meeting Euro-3 is proving to be achievable using available technology.

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Small Engine Catalyst Presentation : Duracat™ Screen Catalyst System

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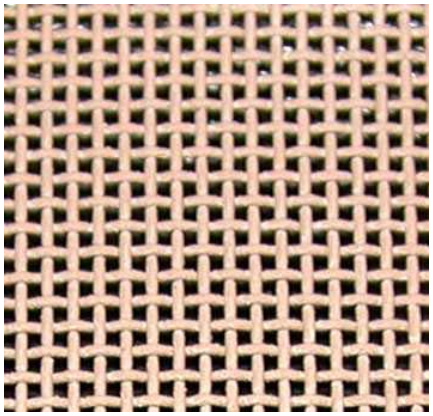
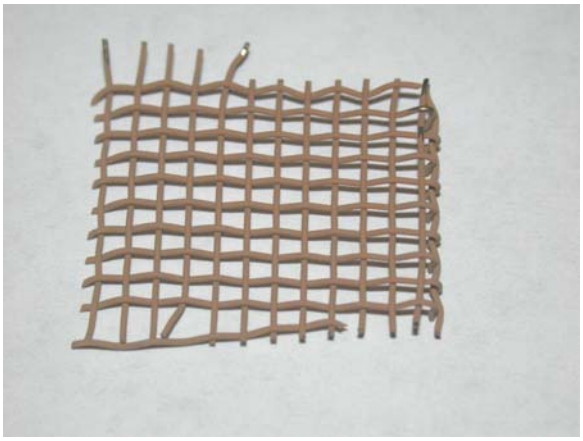
Proprietary Duracat™ Screen Catalyst System



- Low cost, ideal for utility engine applications
- Light weight, fast light-off
- Coated on large, flat sheets which can be cut to desired shape
- Excellent adherence of catalyst allows screen to be rolled (shown), bent, or folded without significant catalyst loss
- Has demonstrated excellent customer durability in consumer applications for 125hrs. Recently achieved 300hrs in a professional application
- HC conversion efficiencies demonstrated to over 50%
- Screen geometries and PM loadings can adjusted to achieve desired performance

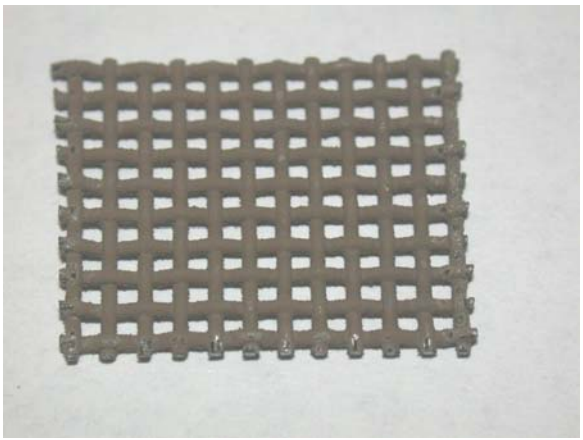
Conventionally Coated Stainless Steel Screen Prior to Thermal Shock Treatment



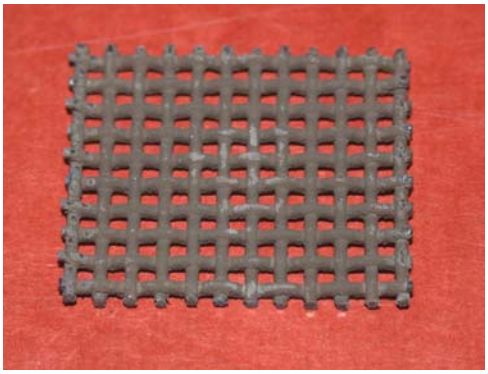
Non-Duracat™ Catalyzed Stainless Steel Mesh Shows Considerable Coating Loss after only 10 Minutes Thermal Shock Treatment

Thermal Shock Procedure: **20 cycles** (30 second cycles; 10 total minutes): insert sample into Bunsen Burner flame (ca. 60°C to 900°C); 900°C for 2-3 seconds/cycle; remove from flame and cool with DI water spray; blow with hair dryer

Duracat™ Screen Prior to Thermal Shock Treatment



Duracat™ Screen Shows Excellent Durability after 5 Hours Thermal Shock Treatment

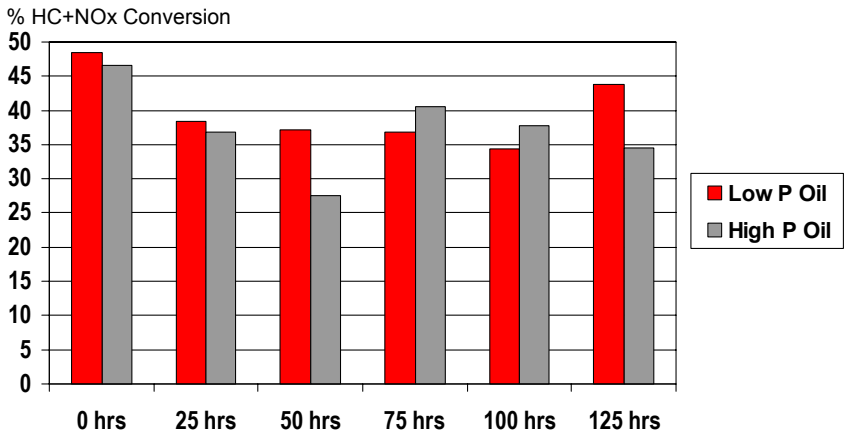


Thermal Shock Procedure: **600 cycles** (30 second cycles; 5 total hours): insert sample into Bunsen Burner flame (ca. 60°C to 900°C); 900°C for 2-3 seconds/cycle; remove from flame and cool with DI water spray; blow with hair dryer

Durability Testing of Duracat™ Screen Catalyst

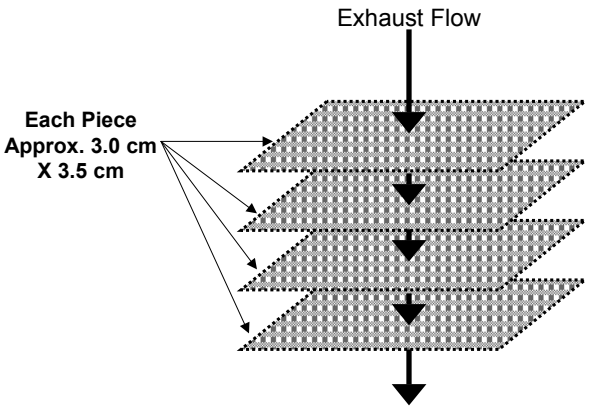
- **Screen specs:**
  36mm W x 175 mm L, 12 mesh (2.1mm pitch), 0.71mmD 304SS wire
- **Catalyst:**
  0.0234 gPM/part, 2.47Pt/1.33Pd/1Rh
- **Geometry:**
  Screen formed into 33mm H x 58mm D radial-flow cylinder

Duracat™ Screen Shows Excellent Durability When Aged for 125 hrs on a Consumer Chainsaw Engine Even With High P Oil

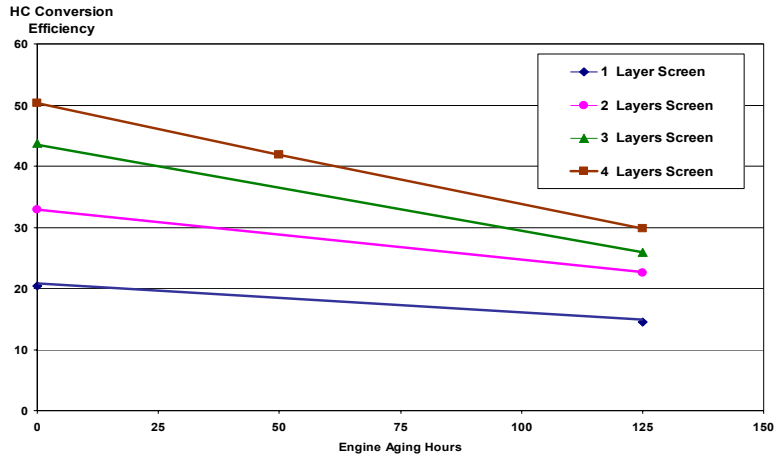


•Tested on 2-S 42cc consumer chainsaw @ wide-open-throttle and full load

Duracat™Screen Can Be Cut and Stacked in Modular Fashion to Achieve Desired Conversion Efficiency



Duracat™ Screen Can Be Cut and Stacked in Modular Fashion to Achieve Desired Conversion Efficiency: Test Results



- **Aged on 2-S 50cc blower engine**
- **Evaluated on 2-S 32cc trimmer engine @ WOT**

Duracat™ Screen Catalyst System: Summary

- Demonstrates superior coating adhesion after thermal shock aging when compared to conventionally coated screens
- Has demonstrated up to 300hrs of acceptable catalyst durability in a professional utility engine application
- Experience has shown that screen can be cut to desired shapes, stacked, or rolled into radial flow or heat tube configurations without significant washcoat loss or damage
- Many of the world's utilty engines and mufflers are produced in China and today more than one million small engine mufflers are manufactured annually using Duracat™ screens
- Applications include emission control strategies for small utility engines and heat tubes for 2-wheelers