
Identification and Control of Factors that Affect EGR Cooler Fouling August, 2008

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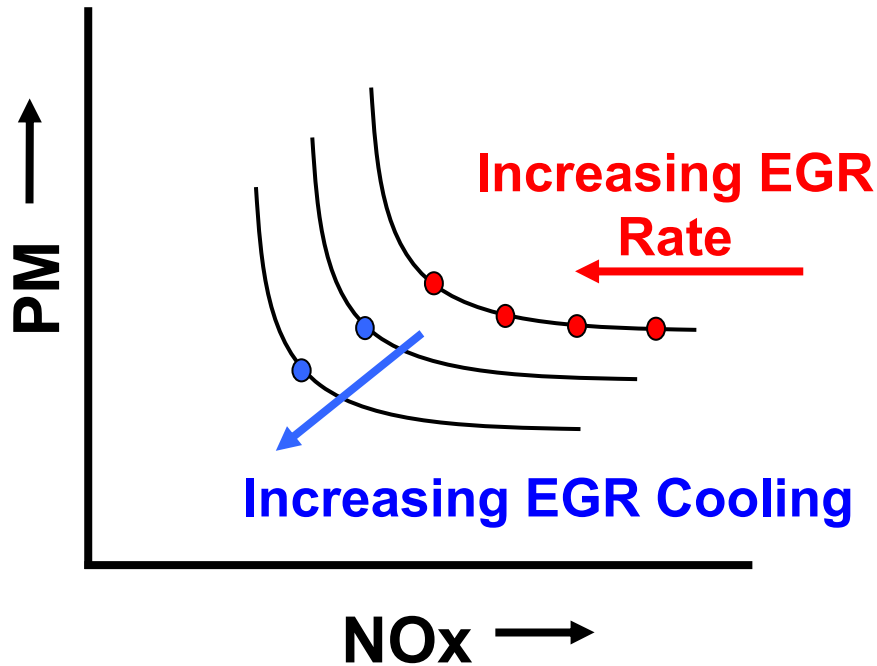
Oakridge National Laboratory



Benefits and Challenges of Cooled EGR

- Benefits

- ❖ Enables more EGR flow
- ❖ Cooler intake charge temp
- ❖ Reduces engine out NOx by reduced peak in-cylinder temps



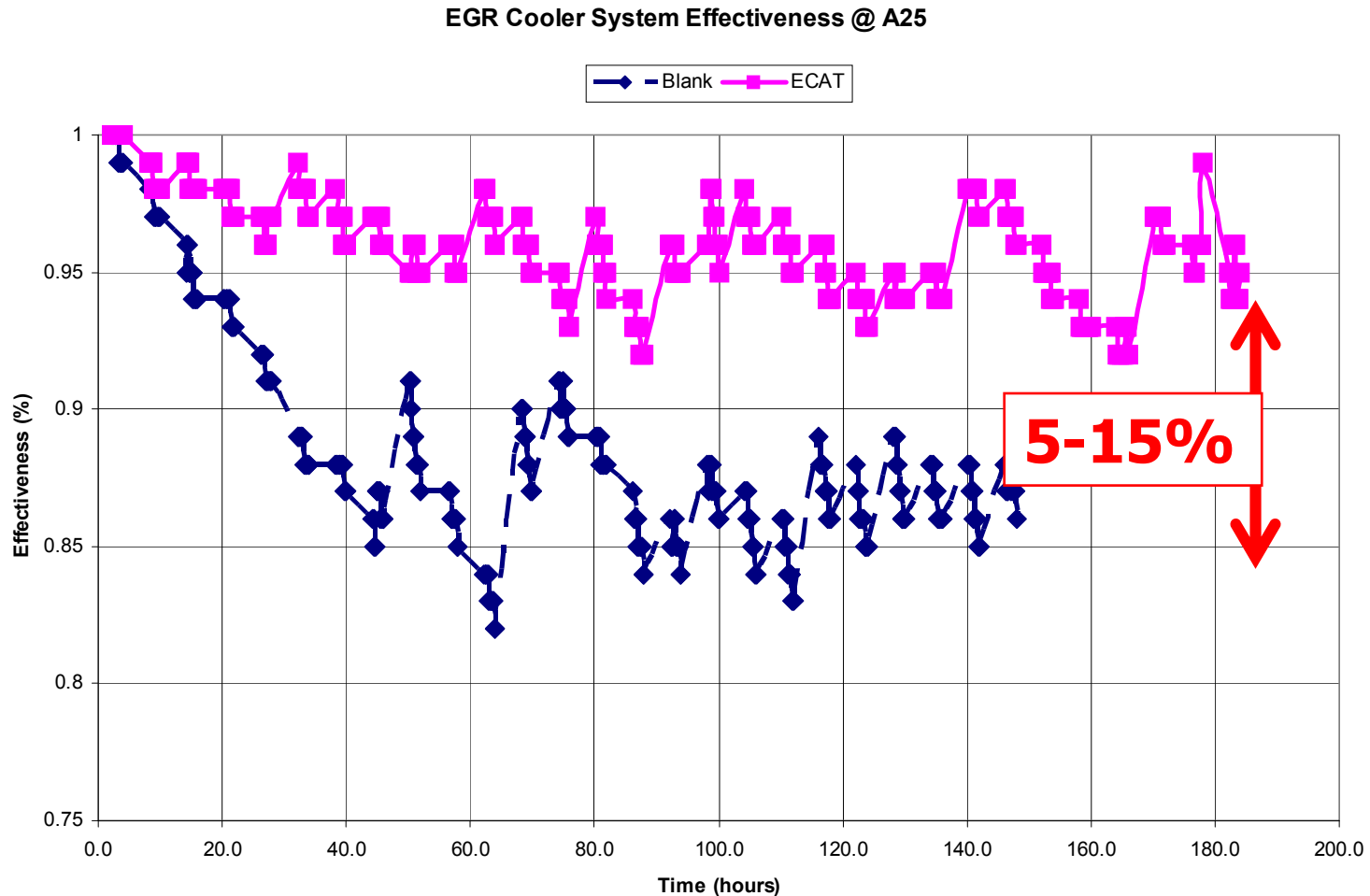
- Challenges

- ❖ More HC's/SOF
- ❖ More PM
- ❖ More heat rejection
- ❖ More condensation
- ❖ HC/PM deposition in cooler (fouling) → degraded heat transfer and higher flow resistance



After 200 hr. Fouling Test

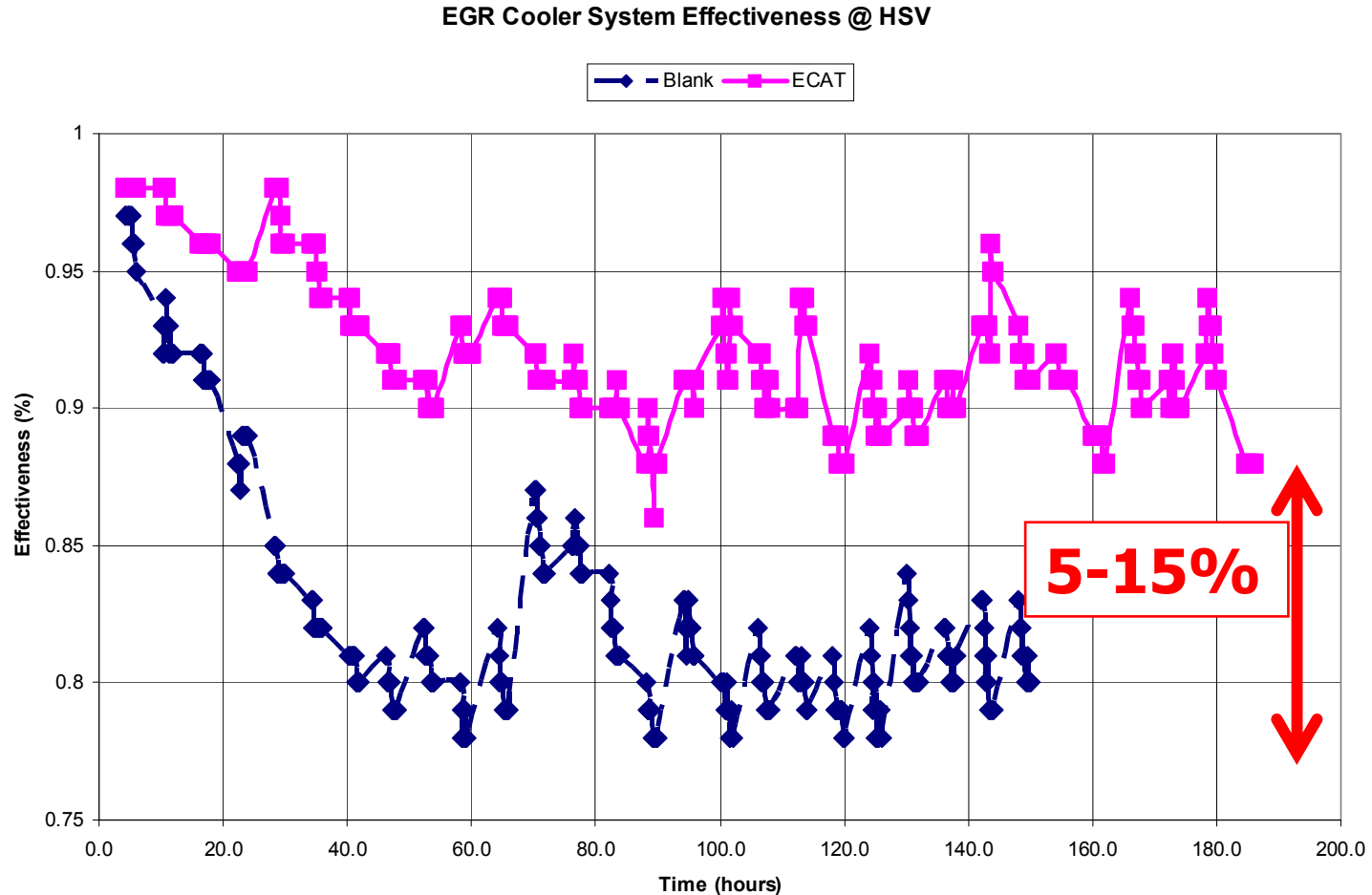
ECAT Effect on Effectiveness – A25



From “EGR Catalyst for Cooler Fouling Reduction” – Hoard et al, DEER 2007



ECAT Effect on Effectiveness - HSV



From “EGR Catalyst for Cooler Fouling Reduction” – Hoard et al, DEER 2007

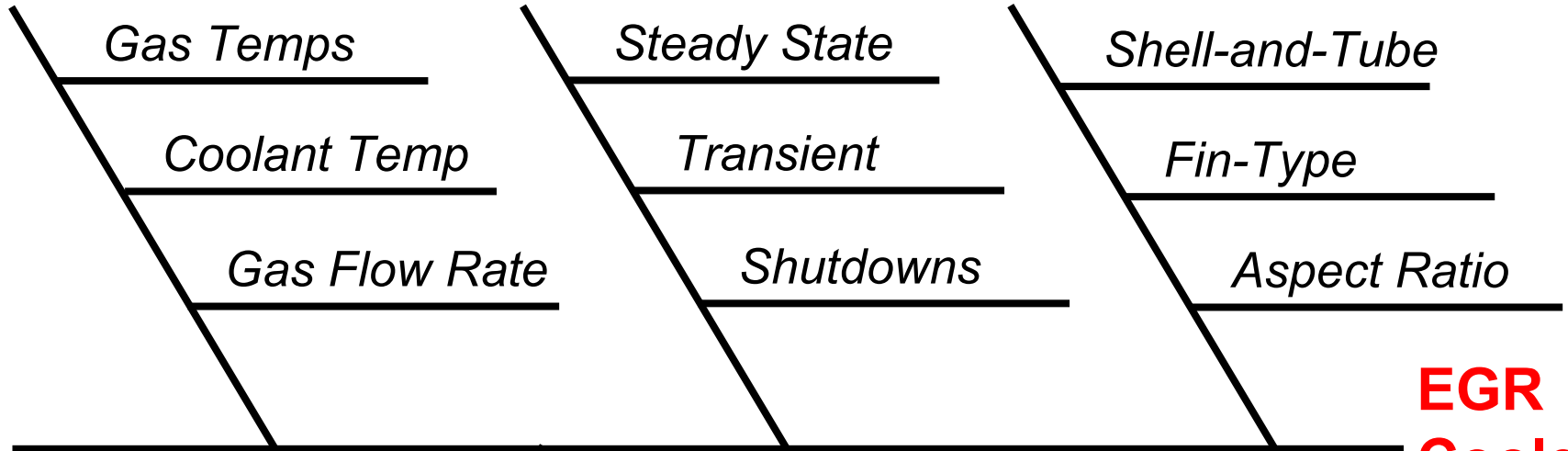


What Causes EGR Cooler Fouling?

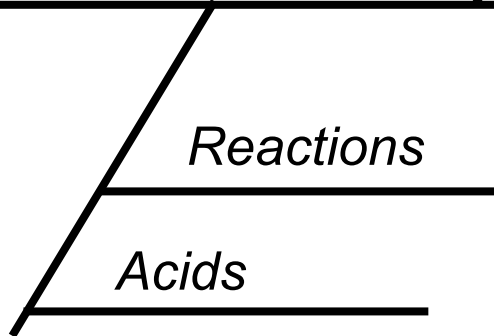
Boundary Conditions

Operating Mode

Cooler Design



**EGR
Cooler
Fouling**



Chemistry

Constituents



Literature Search Key Findings

- Literature search performed by John Hoard Paper planned for SAE Powertrain, Fuels and Lubricants Meeting – October, 2008.
- EGR cooler deposits degrade heat transfer effectiveness by as much as 25-30% and significantly increase pressure drop.
- EGR cooler deposits are a combination of carbonaceous soot particles, condensed HC (C10-C25 alkanes and aromatics), and acids.
- Deposits build rapidly but eventually stabilize after 50-200 hours of test cycle operation.
- An oxidation catalyst in the EGR line can reduce the amount of deposits. A catalyst and wall flow particulate filter in the EGR line eliminates fouling.
- Lower coolant temperature greatly increases deposit mass.
- Pulsations in the gas flow can have large impacts on heat transfer and deposits.



Literature Search Key Findings, continued

- Deposit accumulation is generally worst where flow rate and gas/coolant temperatures are low and HC and/or PM levels are high.
- Deposits form due to thermophoretic soot deposition, and condensation of HC and acid.
- Coolers experience “recoveries”, frequently associated with shutdowns and restarts, but the physics are not well understood.
- Little data exists on properties of cooler deposit layers such as thermal conductivity, density and heat capacity.
- Chemical reactions in the deposit layers should be expected as conditions can be similar to intake systems where varnishes are known to occur.
- Advanced combustion modes or alternate fuels which produce different levels or types of exhaust gas constituents are of concern.
- EGR cooler design is an important factor and coolers that perform the best “clean” may not perform the best “fouled”.



Initial Experiment.....

- Evaluate three key factors ...
 - ❖ Coolant temperature: 40, 70, 85°C
 - ❖ Gas Flow rate: 5, 15, 30 SLPM
 - ❖ HC's: w/ & w/o small oxidation catalyst
- Use simplified single tube EGR cooler
- 2 hour exposures
- Experiment designed for easy separation of variables – no confounding – replicates included to ensure repeatability
- Heated tubes included as reference



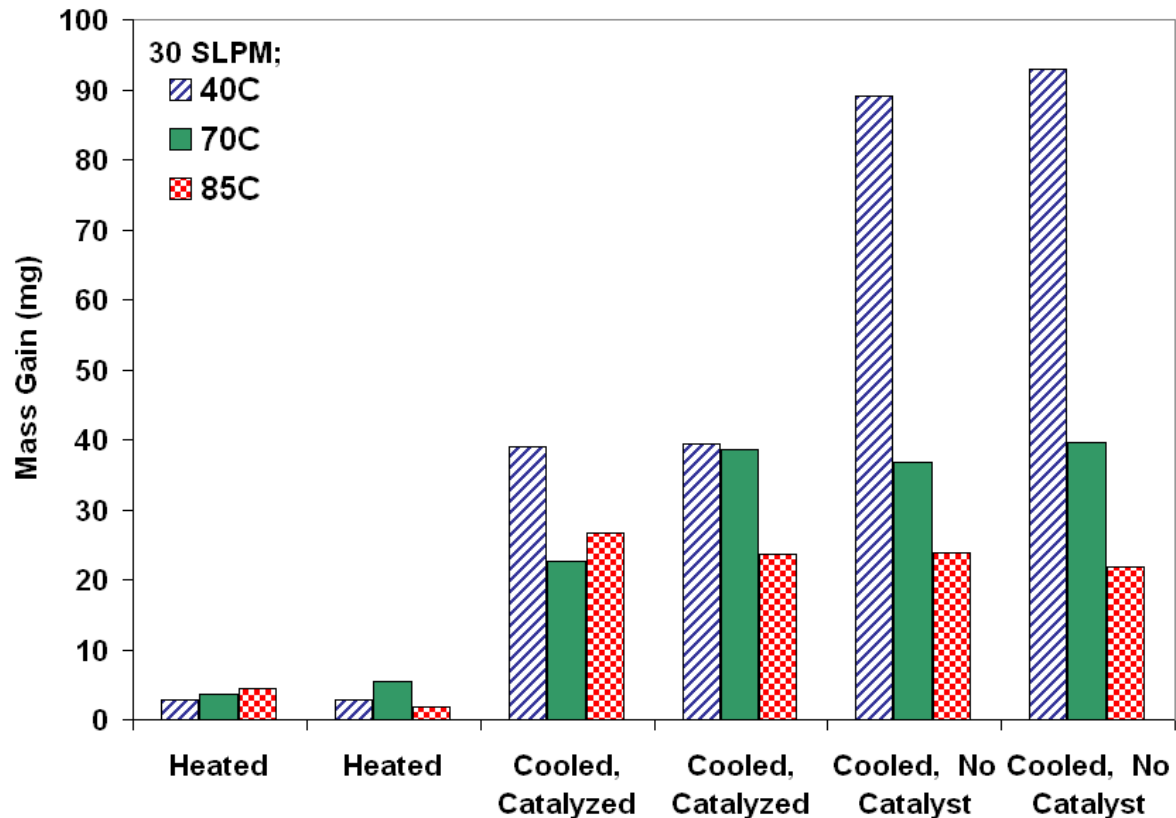
Initial Experiment, continued

- Mercedes 1.7L TDI engine – 2000 rpm, 16 ft-lb – 30% EGR
- Gas inlet is 250°C – 7 psig – 0.83/1.47 FSN – 416-648 ppm C₁ (HC)
- Mass gain and deposit chemical analysis are response variables
- Great job by ORNL colleagues!



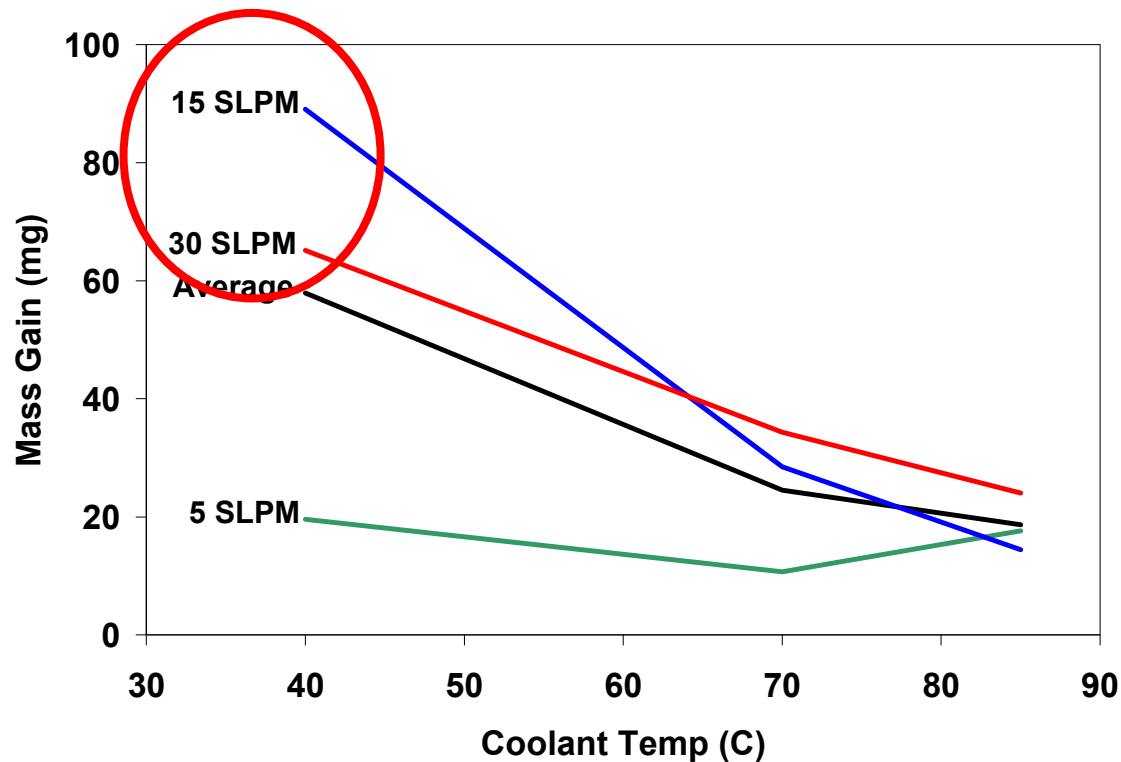
Experimental Results

- Deposits are due to cooling
- Lower coolant temperatures = more deposits
- Catalyst reduces deposit mass gain for 40°C coolant



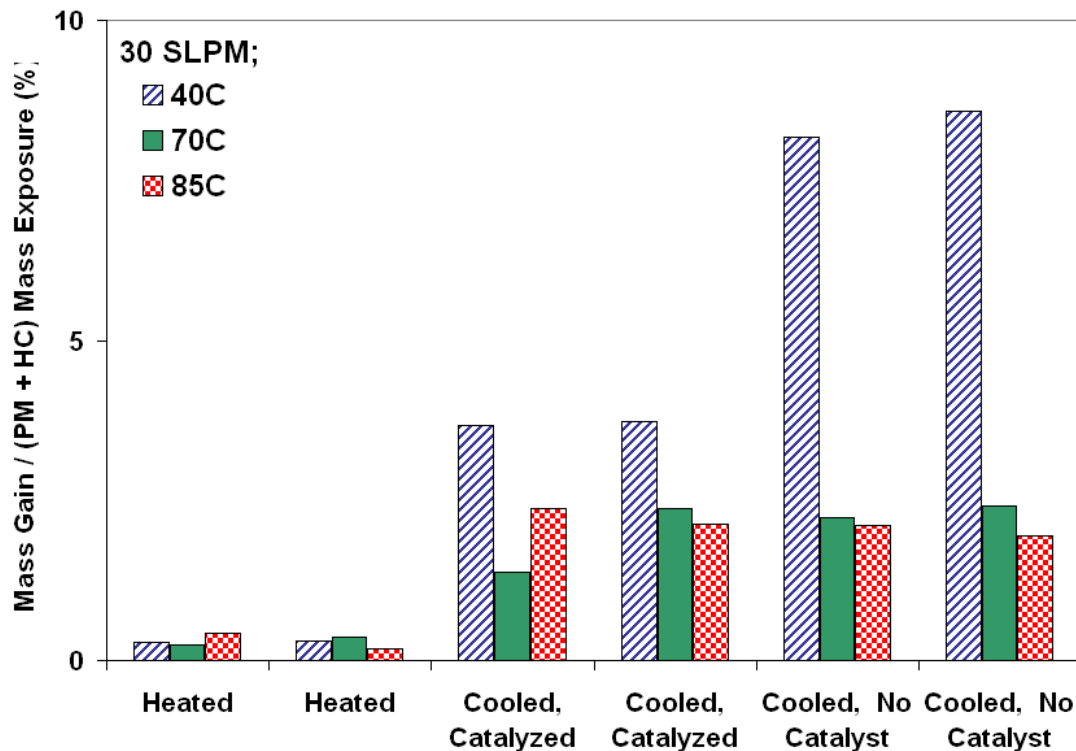
Experimental Results, continued

- Interesting interaction....
- At 40°C coolant, 30 SLPM gas flow gains less mass than 15 SLPM with double the mass exposure!



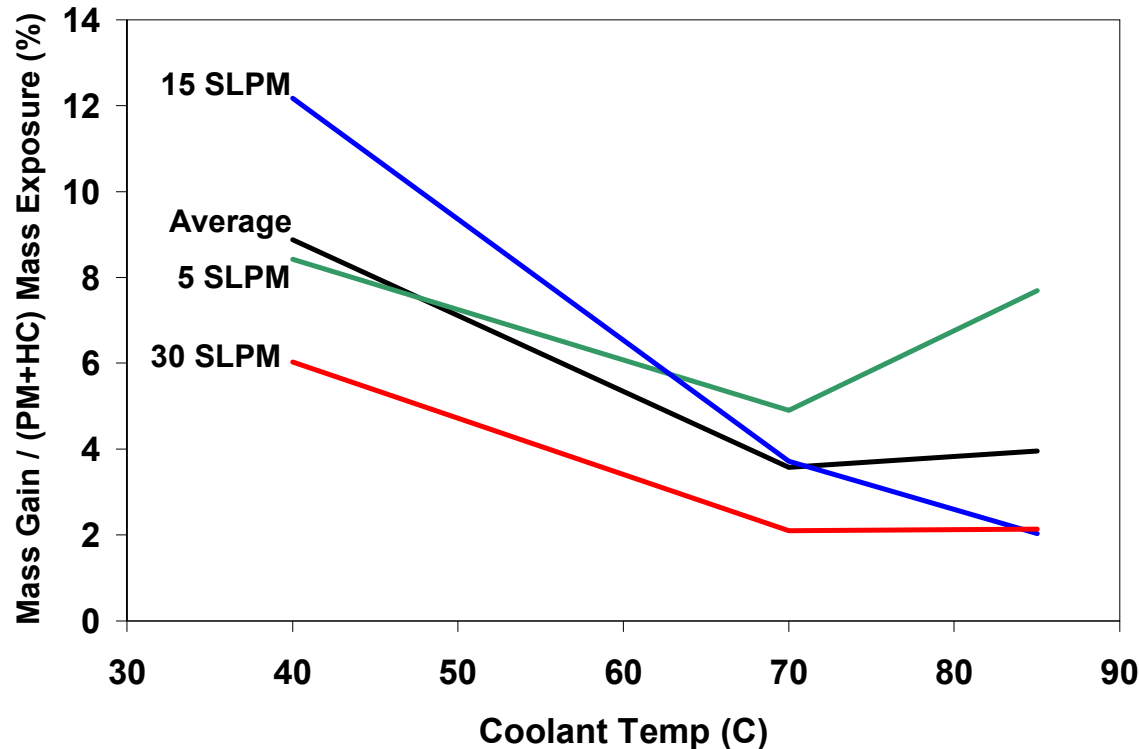
Experimental Results, continued

- Due to higher than desired variation in smoke measurement between experiments, mass gain normalized to HC/PM exposure – i.e., trapping efficiency
- Conclusions are the same....



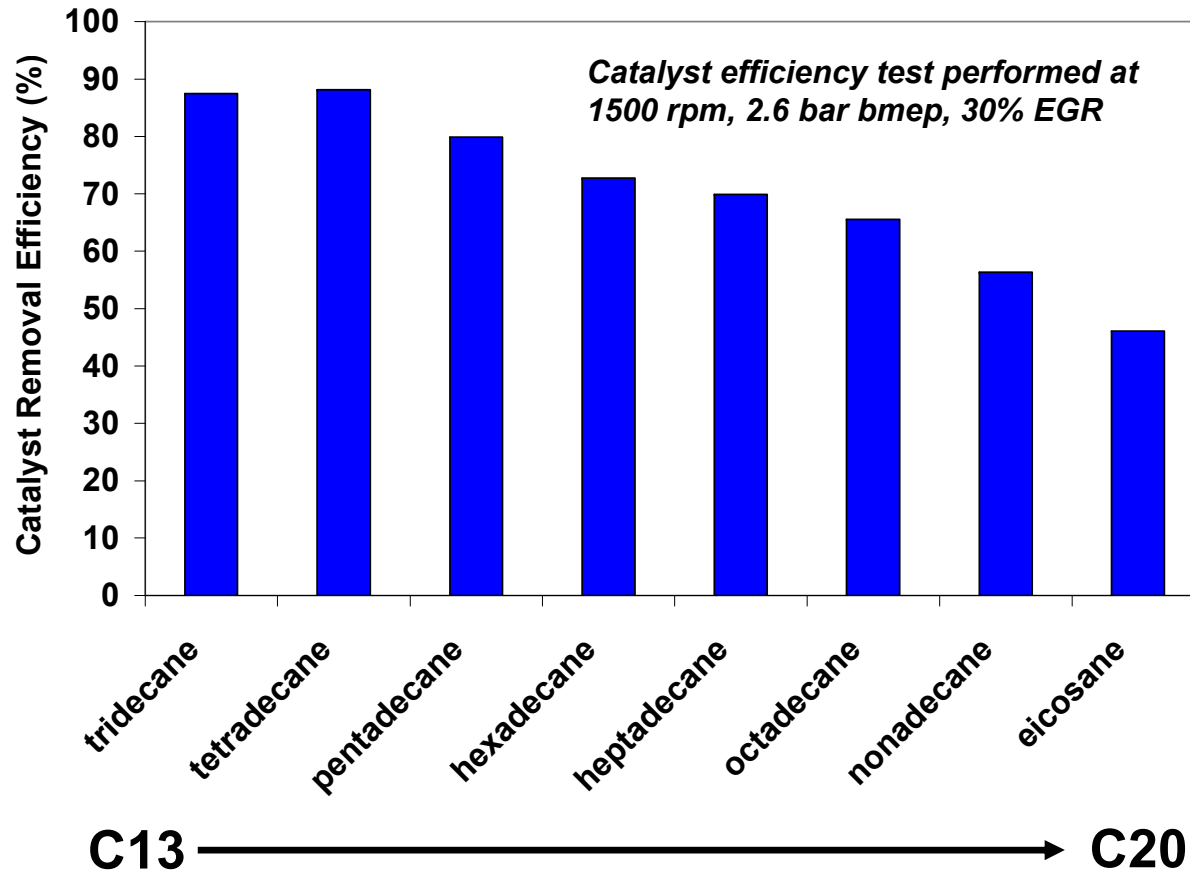
Experimental Results, continued

- Interaction plot with normalized mass gains...
- High gas flow rate has lower deposition rate than lower flow rates.



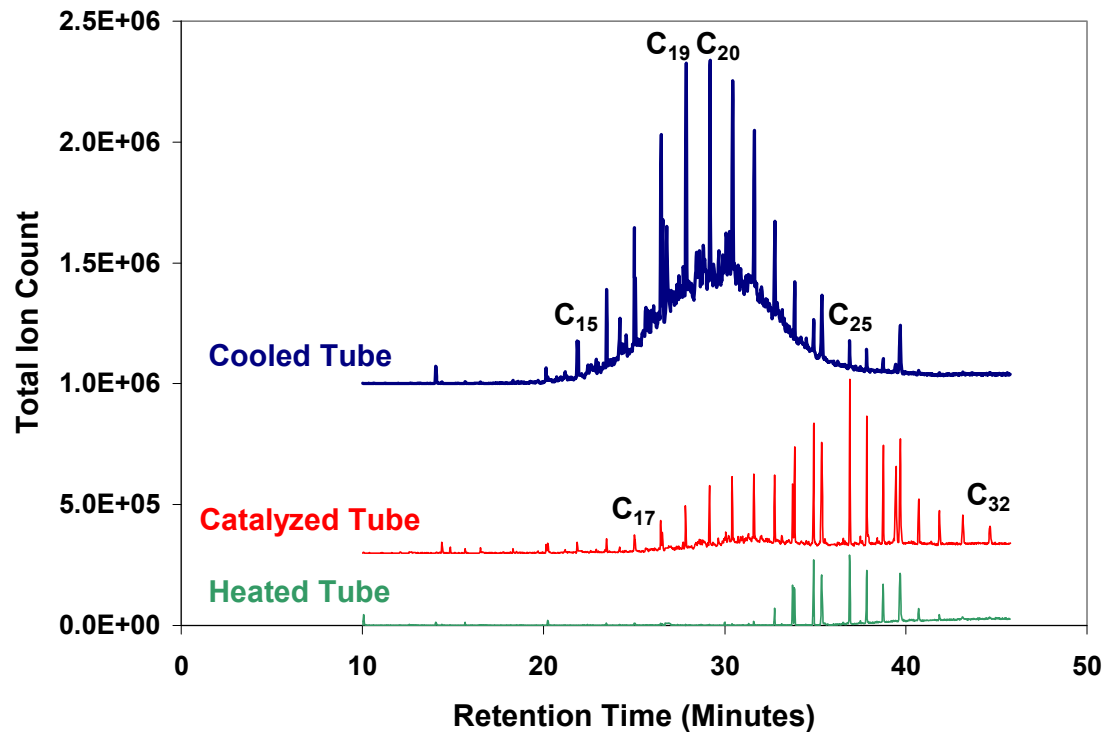
Experimental Results, continued

- Catalyst was more effective at oxidizing lighter HC's than heavier HC's:



Experimental Results, continued

- But the deposits in the tubes are “heavier” HC’s.....
- Fuel HC’s are C11-C23 centered at C16.



Experiment Key Conclusions

- High gas flow rates were beneficial at reducing trapping efficiency (decreased likelihood of deposits sticking to walls, residence time, deposit removal)
- Low coolant temperatures significantly increase deposit mass gain. This makes sense as an increasing number fuel HC's pass their dewpoints and condense from 85°C → 40°C.
- An oxidation catalyst can reduce but not eliminate deposit mass gain, especially at low coolant temperatures where catalyst's higher conversion efficiency of lighter HC's starts to overlap condensable species.
- Paper planned for SAE Powertrain, Fuels and Lubricants Meeting – October, 2008 ... more details on experimental results and deposit chemical analysis.



Thanks for Your Attention

- Questions?

