The Fuel Additive MMT®

Methylcyclopentadienyl Manganese Tricarbonyl
Contents

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- Use of MMT®

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- Objective
- Durability
- Accelerated Aging Procedures
- Summary

Summary
What is MMT®
What is MMT®?

**MMT®** - Methylcyclopentadienyl Manganese Tricarbonyl

- Pure, organo-metallic liquid containing 24.4% Manganese
- Trace level treat rate: typically 24-ppm Mn
- Very low vapor pressure
  - easy & safe to handle/transport
- Thermally stable at elevated temperatures
  - safe to store
- Relatively high freezing point (dilutions)
- Very stable for long periods of time
- Chemically compatible with all fuels and components
- Sensitive to light - quickly biodegrades
- Not soluble in water
Properties of MMT®

HiTEC® 3000

- Clear, Orange Coloured Liquid
- Manganese Content: 24.4 % wt.
- Freezing Point: -1°C
- Density: 1.38 g/ml @ 20°C
- Vapour Pressure: 0.05 mmHg @ 20°C
- Boiling Point: 232°C @ 760 mmHg
- Flash Point (TCC): 82°C (Minimum)

HiTEC® 3062

- Clear, Orange Coloured Liquid
- Manganese Content: 15.1 % wt.
- Freezing Point: -30°C
- Density: 1.11 g/ml @ 20°C
- Vapour Pressure: 1.8 mmHg @ 20°C
- Boiling Range: 179/212°C @ 760 mmHg
- Flash Point (TCC): 42°C (Minimum)
### “Near Zero” treat rate

<table>
<thead>
<tr>
<th></th>
<th>RON</th>
<th>MON</th>
<th>Lead Content g/litre</th>
<th>Sulphur Content g/kg</th>
<th>Manganese Content g/litre</th>
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<tbody>
<tr>
<td><strong>MMT® Performance Gasoline</strong></td>
<td>95</td>
<td>85</td>
<td>0.005</td>
<td>-</td>
<td>&lt;0.018</td>
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<tr>
<td><strong>“Zero” sulphur Gasoline</strong></td>
<td>95</td>
<td>85</td>
<td>0.005</td>
<td>0.010</td>
<td>-</td>
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<tr>
<td><strong>Unleaded Gasoline EN228:2005</strong></td>
<td>95</td>
<td>85</td>
<td>0.005</td>
<td>0.050</td>
<td>-</td>
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</tbody>
</table>
MMT® - Combustion & Interaction with Exhaust Systems
MMT® can help maintain catalyst efficiency

“Use of MMT significantly reduces phosphorus and zinc retention levels at catalyst inlets…

...while the TWCs (three way catalysts) maintained significantly higher 3-way conversions than in the absence of MMT.”

Ford Motor Co.
SAE Paper 821193
1982
Characterization of Exhaust Species

- Objective: Identify manganese species in exhaust
- Collected samples under various conditions (SWRI)
  - vehicles
  - accumulated mileage
  - driving cycle
  - fuels
  - engine out, tailpipe, w/ and w/o catalysts
- Sample following procedures in 40 CFR 86
- Use analytical techniques that provide chemical state information (ESCA, Auger, XRD, K edge and L edge XAS)
- Analysis performed by Lawrence Livermore National Laboratory (LLNL)
Typical Gasoline Particulate

C, N, H, O and trace amounts of S, Mn, P, Zn, Fe, Cu, Al, Si and others

~ 1.5 µm
**K-edge Spectra For Sample**

**Vehicle Sample**

- **Sample**: 96050311
- **Normalized Absorption Derivative**
  - **Photon energy**: 6539 eV

**Mn Phosphate**

- **Mn₃(PO₄)₂**
- **Normalized Absorption Derivative**
  - **Photon energy**: 6539 eV

**Mn₃O₄**

- **Mn₃O₄**
- **Normalized Absorption Derivative**
  - **Photon energy**: 6539 eV

**Vehicle Sample Mn₃O₄ Mn Phosphate**
Divalent Manganese

- MnO
- MnO₂
- Mn₂O₃
- Mn₃O₄

Mn filter samples

Mn K edge energy (E - 6539), (eV)

Mn valence
Manganese Oxides are initially formed in the combustion chamber. Phosphates form quickly as the exhaust cools. As the exhaust cools further, Manganese Sulfates form and become stable. Extensive testing has shown the predominant Manganese species emitted at the tailpipe are Phosphates and Sulfates.

Manganese Species Present

- Oxides
- Phosphates
- Phosphates & Sulfates

Decreasing Temperature
Other than color, there are no visual differences between Base Fuel and MMT® Fuel Catalysts.
Close-Coupled High-Density Catalysts

Theory and practice show no-issue for MMT®

Close-coupled catalysts

- Analysis shows:
  - Tier II operating temperatures are reached quicker but are not higher than previous systems

High-cell density catalysts

- Use thin wall techniques
  - Reduces thermal mass
  - Increases surface area
- Less area for deposition

Tested without issue in:
- 1992/93 EPA fleet test
- AAM fleet test (no failures)
- Afton EURO IV testing

400-cpi 900-cpi
Plugged Catalysts - No MMT®

Catalysts fail and plug during normal consumer use for many reasons.

If the fuel had contained MMT®, they would be red.
Colour does not identify why they failed.
In-use Catalyst

U.S. Vehicle

Canadian Vehicle
**In-use Catalyst**

U.S. Vehicle

Canadian Vehicle
Use of MMT®

**MMT® - The most cost effective octane improver**

- 2 to 3 octane number increase
- Allows grade rationalisation
- Lower emissions & energy use
  - Less Greenhouse gas emissions
  - Reduced crude use (3%)
- Essential component to many refiners
- Important part of Afton’s worldwide business
History of Success

1953  MMT developed

1970  MMT first used in leaded gasoline

1975  MMT first used in unleaded gasoline

1995  US EPA Waiver

1997  Canadian review confirmed in 2002

Application as combustion improver in road diesel, heating oil and fuel oil

2005 - Importance of MMT® increases as specifications tighten and crude oil demand increases
MMT® – The best choice

- Provides essential octane for refineries
  - Blend component or trimming agent
  - Easy adjustment of octane
  - Reduces high-risk gasoline components (reformate)
  - Compliments future refinery investment
- Reduces imports of MTBE, reformate and crude
- Reduces energy consumption and emissions
  - Lower reformer severity
  - Lowers Benzene and Aromatic levels
- MMT® is a critical gasoline component

Allows optimum refinery flexibility
Growing use of MMT® Worldwide

Currently used in over 45 countries around the world

Number of Countries using MMT

U.S. Waiver application based on extensive fleet test
EPA waiver
Canadian Review
First WWFC
Europe LRP
Canada Reconfirms

Years

1988 2004

45

EPA Tier II
Canadian & European Review

EPA Tier II
Canadian & European Review
European Fuels Review Implications

- European specifications are regarded by many nations as standard setters for good, sound science based decisions
- This review will render an opinion on whether or not MMT® causes harm
- The outcome has worldwide implications
  - for the sale of our product
  - for our company’s reputation
MMT® Testing & Reviews
1977... Auto Industry Concerns

Manganese Fuel Additive (MMT) Can Cause Vehicle Problems

Jack D. Benson
Fuels and Lubricants Dept., General Motors Research Laboratories

Society of Automotive Engineers

Fuels and Lubricants Meeting
Mayo Hotel, Tulsa
June 7-9, 1977

770666
Concerns About Use of MMT®

“Therefore, the introduction of MMT into future fuels could either cause vehicles to fail the more stringent emissions standards or prevent the use of close-coupled catalyst which may be required to comply with future emission standards.” Chrysler Corporation, 1993.

“MVMA suspect that there are many “current’ and “future” technology vehicle which will be adversely affected by MMT.” Motor Vehicle Manufacturers Association, 1992.

The allowance of an MMT additive may have an adverse affect on manufacturers ability to comply with more stringent emission standards in the future” Toyota, 1991.
Concerns About Use of MMT®

“These preliminary data suggest that use of MMT in commercial gasoline may cause problems with exhaust emission control systems now in use” Benson, J.D. SAE 770655 (1977).

“These findings greatly increase the concern of automobile manufacturers about in-use emissions compliance of LEV and later technology vehicles if MMT is used in gasoline” Benson, J.D. SAE 2002-01-2894 (2002).
Extensive Experience with MMT®

- 1988-93 US EPA Waiver fleet
- 1994-1997 Afton OBD/LEV Technology Fleet
- 1996-1999 AAM MMT Evaluation Program
- 2003 Euro IV Advanced Technology Fleet
- 2003 US EPA Alt Tier II Emission Speciation Program

- Vehicle testing has demonstrated MMT® compatibility
- Mechanistic investigations enables understanding of MMT® behavior in vehicle systems
EPA Waiver
EPA Waiver Test Fleets

Comprehensive fleet tests cover current vehicle technologies

- **1988 EPA Fleet - 120,000 kilometer test**
  - 48 vehicles from GM, Ford and Chrysler.
  - Selected to represent the mainstream US market

- **1992/93 EPA Fleet - 160,000 kilometer test**
  - 22 vehicles from Ford, Toyota and Honda.
  - Featured close-coupled catalysts, OBD systems, high-output engines, high-speed engines
1988 Model Year EPA Waiver Fleet

Cars using fuel with MMT® produced lower NOx emissions

120,000 Kilometer Test

- 48 vehicles (paired)
- 2.5, 2.6 & 3.8 liter Buick Century, 2.0 liter Chevy Cavalier, 1.9 liter Ford Escort, 3.0 liter Ford Taurus, 5.0 liter Ford Crown-Victoria, 3.0 liter Dodge Dynasty
- Mileage accumulation fuel - 50 ppm S; no detergent; MMT splash blended
- Emissions testing on all vehicles completed with the same certification fuel

End Of Test Emissions

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

<table>
<thead>
<tr>
<th></th>
<th>MMT Fuel</th>
<th>Base Fuel</th>
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<tbody>
<tr>
<td>HC</td>
<td>0.326</td>
<td>0.356</td>
</tr>
<tr>
<td>CO/10</td>
<td>0.3772</td>
<td>0.3987</td>
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<tr>
<td>NOx</td>
<td>0.482</td>
<td>0.682</td>
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</table>

29% NOx Reduction
1992/1993 Model Year EPA Fleet

Cars using fuel with MMT® produced lower CO and NOx emissions

- 22 vehicles (paired)
- Vehicle selection based on Automotive Company and EPA comments, Public Docket A-92 41, November 9, 1992
- Mileage acc. fuel - 300 ppm S; gasoline detergent used; MMT splash blended
- Emissions testing on all vehicles completed with the same certification fuel

160,000 Kilometer Test

<table>
<thead>
<tr>
<th></th>
<th>MMT Fuel</th>
<th>Base Fuel</th>
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<tbody>
<tr>
<td>HC</td>
<td>0.179</td>
<td>0.171</td>
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<td>CO/10</td>
<td>0.224</td>
<td>0.2016</td>
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<tr>
<td>NOx</td>
<td>0.572</td>
<td>0.375</td>
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</table>

34% NOx Reduction
10% CO Reduction
EPA Waiver Testing of MMT®

Afton’s statements are based on comprehensive, scientific data.

The US EPA and US car-makers specified the vehicle test programs to assess MMT’s real impact on automotive emission systems.

Vehicle fleets encompassed many available engine and emission technologies.

Significant statistical analysis was used to separate the fuel additive effects from the vehicle to vehicle variations.
**MMT® - Data Differences**

1991 Escort/Explorer Fleet

- No MMT
- MMT

<table>
<thead>
<tr>
<th></th>
<th>HC</th>
<th>CO/10</th>
<th>NOx</th>
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<td>No MMT</td>
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<tr>
<td>MMT</td>
<td>0.5</td>
<td>0.6</td>
<td>0.5</td>
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</table>

6 cars (100,000 MILES)

1993 MMT Fleet Study

- No MMT
- MMT

<table>
<thead>
<tr>
<th></th>
<th>HC</th>
<th>CO/10</th>
<th>NOx</th>
</tr>
</thead>
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<td>0.2</td>
</tr>
<tr>
<td>MMT</td>
<td>0.4</td>
<td>0.5</td>
<td>0.4</td>
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</tbody>
</table>

48 cars tested 22 completed 100,000 miles
Serious Irregularities Revealed During U.S. EPA Led Review

...did not support automakers’ conclusions
Irregularities revealed through:
- disclosure of all information
- questioning by stakeholders
- additional verification testing
- in-depth scrutiny of all data

Yet, auto’s data continued to be used in WWFC until December 2002

1991 Escort/Explorer Fleet

6 cars

<table>
<thead>
<tr>
<th>HC (g/mile)</th>
<th>CO/NOx (100,000 MILES)</th>
<th>MMT</th>
<th>No MMT</th>
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<tr>
<td>0.1</td>
<td>0.2</td>
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<td>0.4</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
EPA Conclusions

Analysis: CO and NOx emissions are decreased with presence of MMT®

- Reduction in CO emissions with use of MMT®
  “Examination of all the available test data on the CO effects of MMT shows a small decrease attributable to the additive.”

- MMT® use yields reduction in NOx emissions
  “The test data for NOx show a more substantial and more consistent decrease for this pollutant than was the case for CO.”

Canada

MMT® Approval & Review

1977 First Approved
25 years safe use

Despite this, automaker allegations persist . . .
Canadian review 1997/1998

- Brief history - to clarify misinformation and provide context to current situation

- Long history of past Auto predictions that catastrophic failures will occur due to MMT® (e.g. spark plugs, earlier generation catalysts, OBD II oxygen sensors etc.)

- These past claims have never been accepted when put to scientific scrutiny by a respected independent Third Party. (This position is supported “on record” by US EPA and Environment Canada.)

- 25+ years of widespread MMT® use in Canada clearly showed these predicted failures simply did NOT occur
"If MMT is not removed from Canadian gasoline, Canada will be faced with a serious embarrassment.

The proposed 1998 vehicle emission standards will be unachievable."

Testimony of Mark Nantais, President, CVMA, to the Standing Senate Committee on Energy, Environment and Natural Resources on Bill C-29 on February 4, 1997.
"MMT in fuel will prevent us from meeting current British Columbia emission standards and Transport Canada's proposed 1998 vehicle emission regulations."

"It is likely that we will be forced to remove the advanced emission control systems from 1998 cars."

Yves Landry, head of Chrysler Canada, to the Standing Senate Committee on Energy, Environment and Natural Resources, on Bill C-29, on February 4, 1997.
1997/1998 Experience

1997, the Canadian Government believed Auto statements that MMT® harmed “on board diagnostic systems” and this led to a temporary trade ban.

In 1998, this ban was removed, allowing full use of MMT® again.

A common “misunderstanding” is that Government did not want to remove the ban and only did so due to a NAFTA trade law “technicality”. This is NOT correct.

A provincial challenge and separate Afton challenge were actually the forum where the Government discovered the Auto claims against MMT® were not supported by any data.
“We also have warranty data. As we compare Northeastern U.S. with Canada, we see (on-board diagnostic system or OBD) failures that have taken place. Certainly it is a multiple cost in Canada versus the U.S., with regard to spark plug, sensors and converters. The only difference is fuels.”

Testimony of Mark Hutchins, then President of Ford Canada, to the Committee on Energy, Environment and Natural Resources, on Bill C-29, on February 4, 1997.

During questioning from attorneys representing Ethyl Canada in early 1998, Ron Bright, a technical manager at Ford Canada stated that he had no knowledge of any such warranty comparisons having been done by his company.
1997/1998 Experience

- Recognizing the expected data did not exist;
  - the Government saw there was no longer any reason to ban MMT®
  - and issued a statement saying, “Current scientific evidence fails to demonstrate that MMT® impairs the proper functioning of automotive on-board diagnostic systems”.

- Trade ban was immediately removed and MMT® returned to widespread use.
Current Canadian Review
Current MMT® Dispute?

Auto claims harm to a single specific new technology configuration (close coupled high density catalysts in Tier II vehicles).

- Primary controversy is with a single vehicle type (Honda Civics).
- However, consistent with their anti-MMT® position, Autos have claimed there will be problems with all Tier II close-coupled high density catalysts.

Auto data has not yet been peer reviewed or subjected to any independent scientific scrutiny.

Afton’s data analysis of Tier II vehicles strongly disagrees with the Auto position. (Extensive vehicle testing, numerous “real world” vehicle inspections, Provincial/State inspection/maintenance programs, modelling, theory, etc.)
Resolving the Current Dispute

Government’s Third Party Review process has been initiated to resolve the dispute. It will determine if the Auto claims against MMT® are justified.

Afton fully supports the Review as a means to resolve the dispute, eliminate the controversy, and bring independent scientific evaluation to the Auto claims.

Primary focus of the Review is whether or not MMT® harms new Tier II technology (close coupled high density catalysts).

Significant time has been spent developing the terms of reference to ensure a review that is based on the principles of transparency and sound science.
Criteria for “Harm”

- The task definition and wording **must** give a clear result
  - I.e. Require a response that is a clear Yes or No
  - E.g. Is MMT the root cause for a significant number of models and manufacturers failing “in-use” emission standards?

- “Harm” must be clearly defined
  - Comparison of photographs is not science!
  - Small variations in emissions similar to those seen with vehicles and other market place fuels are allowed for in current legislation
  - The criteria for harm should be:-
    “Does MMT cause failure vs. in-use specifications?”

The terms of reference are not yet issued hence these views represent the opinion and interpretation of Afton Chemical
Data Disclosure

“Black Box” versus “Transparent Approach”

- Afton’s review and comment on Auto data is helpful because of:
  - Uniquely qualified people
  - Unique data bank
  - Unique ability to bring resource

- Afton’s access results in better Science and improved efficiency

- “Legitimate” Auto disclosure concerns can be addressed with confidentiality agreements

The terms of reference are not yet issued hence these views represent the opinion and interpretation of Afton Chemical
Current Canadian Government Review

- Timing not yet finalized by Government but Review expected to target completion in 2006

- Afton is fully confident the review will show that Auto assertions of harm to Tier II vehicles are not substantiated

- Afton therefore expects resolution of dispute in favour of MMT®
AAM Trial
Auto Industry (AAM) Test

“The purpose of this study is to resolve discrepancies reported to date about the effect of MMT on emissions and vehicle performance, focusing on latest technology vehicles with FTP-based OBD-II systems. Among the questions the program will seek to answer are the following:

1. Does MMT cause vehicle emissions to increase and/or impair the performance of any emission control device?  
   Results: NO

2. Does MMT impair OBD II catalyst monitor performance?  
   Results: NO

3. Does MMT cause spark plugs to misfire?  
   Results: NO

4. Does MMT degrade oxygen sensor performance?  
   Results: NO

Project Description, MMT Vehicle Test Program, Prepared by the AAMA/AIAM MMT Task Force, March 5, 1996, p. 2
Comparison of Compliance Margins

- Compliance margin provides measure of vehicles ability to meet standards over vehicles useful life
- Vehicle emissions below standard indicate properly operating emission system

\[ \text{% Compliance Margin} = \frac{\text{Compliance Level}}{\text{Emission Standard}} \times 100 \]
Every Vehicle Met Emission Standards

• Vehicles display greater compliance margins as standards move to lower emission levels

• No difference in compliance margins between MMT and Base vehicles

• No difference between base and MMT vehicles as vehicle technology advances
AAM Fleet Test Vehicle Emissions

- All vehicles in study met all in-use vehicle emission standards for HC, CO, & NOx even under the double aging factor.

- Difference in total emissions from clear-fuel vehicles ranged from 2 to 3 times greater than largest difference attributed to MMT.
Automakers’ Fleet Study

**OEMs’ own data shows that MMT® is problem free**

- **What AAM Press Release Says:**
  - Increases vehicle emissions
  - Impairs vehicle emissions controls
  - Increases fuel consumption

- **What AAM Data says:**
  - All vehicles met applicable emissions standards
  - No damage to OBD II or oxygen sensors, & no spark-plug misfire
  - Vehicle bias – all (LEV) cars selected to run on non-MMT fuel had lower CO₂ emissions at the outset

AAM = American Automobile Manufacturers
AAM/AIAM Fleet Test Results

- MMT® did not cause vehicle emissions to increase and/or impair the performance of any emission control device
- MMT® did not impair OBD II catalyst monitor performance
- MMT® did not cause spark plugs to misfire
- MMT® did not degrade oxygen sensor performance
- MMT® did not degrade fuel economy

Automobile industry test demonstrated that vehicles are compatible with MMT® containing fuel
EURO IV Trial
2003 Euro IV Vehicle Test

2003 VW Passat
2.0 liter Euro IV

2003 Opel Corsa
1.4 liter Euro IV
Euro IV Fleet Test

- Two models: 2003 VW Passat, 2003 Opel Corsa
  - 8 vehicles total
  - High cell density: 600cpi
  - Close coupled catalyst

- Commercial base fuel & base fuel + 18mg Mn/l

- Combination of normal and high speed track driving

- 100,000 km (Euro IV Standard)
Results

- MMT is compatible with vehicles designed to meet EURO IV emission standards.

- The overall emissions results are comparable with other fleet test programs conducted by Afton Chemical and automobile manufacturers.
Comparison of test results

Integrated Emissions Over Entire Test

(1) Euro IV vehicles; 100,000 km; (2) U.S. LEV; 160,000 km (AAM, 2002)
Evaluating Fuel/Fuel Additive Impact on Vehicle Emission System Durability

- **Objective**
- **Durability Requirements**
  - In-service conformity
  - Certification demonstration
- **Design of Accelerated Aging Procedures**
  - Accelerated bench aging
  - Whole vehicle aging
- **Summary**
Objective

To evaluate:

- fuel or fuel additive influence
- on long-term vehicle emission system durability

The requirements for vehicle emission system durability are already defined by European regulations.
Vehicle Emission System Performance

EC/98/69 “In-service conformity” defines checks for the durability of vehicle emission systems

Evaluation criteria

- Probability of a batch of vehicles passing the test with 40% of the production defective is 95% (producers risk 5%)
- Probability of batch being accepted with 75% of the production defective is 0.15 (consumer risk 15%)

Recent studies show that significant numbers of vehicles fail in-use conformity criteria.
Vehicles Selection Criteria

Prior to testing for durability conformance:

- Vehicles must have
  - experienced normal consumer use for between 15,000 km (or 6 months) and 80,000 km (or 5 years)
  - records to demonstrate proper maintenance

- Vehicles must **not** have
  - any indication of abuse including racing, overloading, misfueling, tampering, etc
  - operated with an OBD fault code
Vehicle Emission Certification

- OEMs demonstrate that vehicle emission systems are capable of meeting emission certification standards

- Criteria for evaluation of system hardware design
  - Gaseous emission levels
  - On-board diagnostic (OBD-II) system performance

*Demonstration of hardware design capabilities is often based on assumption that main source of emission system deterioration in current vehicle is loss of catalyst activity and A/F control*
Appropriate Methods

To evaluate fuel/fuel additive impact on vehicle emission system performance:

- Methods must be capable of simulating the interaction mechanism between additive and emission systems that occur in the majority of the on-road vehicles.

- They can be based on
  - Consumer use
  - Increase severity to accelerate testing

Properly designed accelerated durability tests can be used to evaluate vehicle long term durability.
Accelerated Aging Test

“It is always of great interest in the automotive industry to develop rapid or accelerated aging tests

.... which ideally, are representative of actual consumer use-otherwise the conclusion drawn can be quite erroneous”

Accelerated Aging Tests

“An aging cycle might represent the in-use deactivation for one vehicle or one type of catalyst technology, it may not necessarily be universal.”

Kumar et al SAE 2003-01-3735
Accelerated Aging Procedures Criteria

Can accelerated aging predict in-use behavior?

Can an accelerated aging procedure be applied to other applications?

Does a correlation built for certification extend to other catalyst response issues? (i.e. fuels, lubricants)
  - Mechanisms of potential fuel/lubricant effects are different from thermal catalyst deterioration
Certification Demonstrations

Simulation of In-use Deterioration with Accelerated Aging

Emission profile for a group of in-use vehicles of the same age

Thermal aging is frequently employed to rapidly deteriorate the exhaust catalysts and yield emissions similar to the highest emitting vehicles in-use.
# U.S. Certification Demonstration of Vehicle Emission System

<table>
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<tr>
<th>Manufacture</th>
<th>Approval</th>
<th>Type of Test</th>
<th>% of In-use Durability Distribution Covered</th>
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<tr>
<td>BMW</td>
<td>1993</td>
<td>Track – accel. Mi</td>
<td>&gt;75%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>75% + 10% to 30% safety factor</td>
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<tr>
<td>Chrysler</td>
<td>1996</td>
<td>Bench</td>
<td>75%</td>
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<tr>
<td>Ford</td>
<td>1995</td>
<td>Bench &amp; Track</td>
<td>95-98%</td>
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<tr>
<td>GM</td>
<td>1992-3</td>
<td>Bench</td>
<td>95-98%</td>
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<td>Honda</td>
<td>1996</td>
<td>Bench &amp; Track</td>
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<td>Mazda</td>
<td>1994</td>
<td>Track</td>
<td>99.9% in-use driving pattern</td>
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<td>Track</td>
<td>95%</td>
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<td>Nissan</td>
<td>1993 &amp; 1996</td>
<td>Track Bench</td>
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<td>1997</td>
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<td>Saab</td>
<td>1998</td>
<td>Bench</td>
<td>GM 95-98%</td>
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<tr>
<td>Suzuki</td>
<td>1996</td>
<td>Bench + Vehicle Aging</td>
<td>Driving exceeds all 113 in-use vehicles surveyed</td>
</tr>
<tr>
<td>Toyota</td>
<td>1993 &amp; 1995</td>
<td>Track &amp; Bench</td>
<td>Above 90%</td>
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</table>
Accelerated Thermal Catalyst Aging

- Method used to evaluate catalyst hardware and predict the capability of meeting in-use conformity
- Rapidly degrade catalyst to a predefined activity level
- Evaluate catalyst response to thermal stress
- The correlation is built for:
  - A specific procedure
  - A specific catalyst
  - A specific link to the degree of aging in consumer use
Accelerated Catalyst Durability Aging Processes for US Certification

- US EPA requires that durability process covers a “significant majority” of the in-use deterioration of the vehicle emissions.
  - Durability demonstration typically covers greater than 90% of the in-use deterioration

- All approved processes result in higher catalysts thermal exposure than observed under AMA cycle

- Vehicles in-use emission performance compared to certification prediction
  - Iterative process - accelerated aging method adjusted to meet consumer performance
Accelerated Aging Procedures Criteria

- Can accelerated aging predict in-use behavior?
- Can an accelerated aging procedure be applied to other applications?
- Does a correlation built for certification extend to other catalyst response issues? (i.e. fuels, lubricants)
  - Mechanisms of potential fuel/lubricant effects are different from thermal catalyst deterioration
Accelerated Aging Methods – Application to other Applications

- Certification correlations are engine family specific
- Accelerated aging methods often designed with singular purpose – not widely applicable
  - Failure modes may differ between catalyst applications
  - Catalyst technology can affect in-use deactivation
  - Hardware configuration alters catalyst operating conditions in-use
  - Engine control system design impacts catalyst deterioration
  - Catalyst aging procedure for emissions certification may not be appropriate for OBD-II certification

Examples: SAE972853, SAE980934, SAE2003-01-3735
Accelerated Aging Procedures Criteria

- Can accelerated aging predict in-use behavior?

- Can an accelerated aging procedure be applied to other applications?

- Does a correlation built for certification extend to other catalyst response issues? (i.e. fuels, lubricants)
  - Mechanisms of potential fuel/lubricant affects are different from thermal catalyst deterioration
Accelerated Aging Tests
For Evaluating Fuel and Lubricants

- Mechanisms of potential fuel/lubricant affects are different from thermal catalyst deterioration
- Accelerated emission system durability procedures should
  - Increase test severity without introducing failure modes not otherwise encountered in consumer vehicles
  - Rely on operating modes representative of consumer use
  - Employ conditions consistent with vehicle operating criteria for durability demonstrations
- Test results must be shown to correlate with findings from consumer durability evaluations
Vehicle Aged and Bench Aged Catalysts Display Different Response to Sulfur

Vehicle Aged 160,000 km catalysts and thermally aged catalysts
Steady state conversion 500 C, 120K 1/h
Accelerated Tests Failure Modes

- Accelerated test can introduce failure modes not otherwise encountered in consumer vehicles
- Example
  - Accelerated bench test predicts catalyst fouling within 80,000 km
  - Current technology emission systems
  - Commercial type fuel and lubricant
Catalyst Fouling in Accelerated Catalyst Bench Aging

Catalyst from Test with Modern Lubricating Oil

Catalyst from Test with Reformulated Lubricating Oil

L. Gotta et al JSAE 20030344
Accelerated Aging Test Conditions

- Bench accelerated aging tests can rely on conditions that violate vehicle selection criteria for durability demonstrations

- Example
  - ZADKW
Basis of Auto Testing Position
Afton question whether all designs will tolerate 920°C.
Driving Conditions - Speed Comparison

When it can be reached - most vehicles can’t!

Percentage Time vs Speed (MPH)

- ECE15 + EUDC
- UK Motorway Driving
- ZDAKW
Accelerated Aging - Bench Tests

- Test procedures are not robust
  - Require hardware and software specific modification and correlation

- Tests developed for certification demonstration of emission system durability are not appropriate for fuel/fuel additive evaluations
  - Mechanisms of potential fuel/fuel additive effects are expected to differ from thermal catalyst deterioration

- Conditions employed in accelerated bench may not be valid for evaluating emission system durability performance in consumer use
Accelerated Aging
- Whole Vehicle Tests

Whole vehicle operation criteria
- Incorporate consumer operation
- Account for factors encountered in-use that impact emissions system durability
- Consistent with and allow application of criteria for evaluation of emission system durability

Whole vehicle test procedure robust across vehicle technology
Whole Vehicle Test Cycle

- Cycle must be based on consumer driving habits
- Mechanisms of potential fuel/fuel additive effects differ from mechanism of catalyst deterioration
  - High and low temperature interactions
  - Reversible processes occur for fuels
- Cycle severity based on driving habits
  - Example – 90% percentile consumer operation
# Characteristics of Consumer Driving

- Speed
- Acceleration
- Trip length
- Trip time
- Distance between stops
- Idle operation
- Load
- Cold starts

<table>
<thead>
<tr>
<th>Driving Behavior</th>
<th>Exeter</th>
<th>Rossville</th>
<th>Spokane</th>
<th>Atlanta</th>
<th>Los Angeles</th>
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</thead>
<tbody>
<tr>
<td>Speed (km/h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>33.4</td>
<td>45.0</td>
<td>37.1</td>
<td>46.1</td>
<td>45.3</td>
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<td>Maximum</td>
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<td>151.2</td>
<td>124.0</td>
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<td>128.5</td>
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<tr>
<td>Acceleration (km/h/sec)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Minimum</td>
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<td>-31.2</td>
<td>-24.8</td>
<td>-29.8</td>
<td>-24.0</td>
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<tr>
<td>Maximum</td>
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<td>23.4</td>
<td>25.4</td>
<td>26.7</td>
<td>16.6</td>
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<tr>
<td>Average Trip Length (km)</td>
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<td>9.4</td>
<td>5.8</td>
<td>9.6</td>
<td>12.5</td>
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<tr>
<td>Average Trip Time (minutes)</td>
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<td>12.6</td>
<td>9.2</td>
<td>12.6</td>
<td>16.5</td>
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<tr>
<td>Average distance between stops (km)</td>
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<td>1.8</td>
<td>1.3</td>
<td>1.8</td>
<td>2.1</td>
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<tr>
<td>Percent Idle</td>
<td>23.9</td>
<td>18.3</td>
<td>17.9</td>
<td>17.4</td>
<td>11.8</td>
</tr>
</tbody>
</table>
Whole Vehicle Tests – Consumer Operation

- Operating cycles designed to evaluate emission system durability data may be different than emission test cycles

- Aggressive driving cycles are not generally appropriate
  - Higher speed, acceleration or loads
  - Accelerated mileage
  - 1 mile on cycle is equivalent to higher mileage in-use (2:1)

- ARTEMIS project provides basis for evaluating consumer operation
Correlation of Whole Vehicle Aging (WVA) Cycle with Consumer Operation

NOx Emissions

Emissions (g/mile)

Kilometer

0 20000 40000 60000 80000 100000

Base
MMT
CN In-Use
Evaluating Fuel/Fuel Additive Impact on Vehicle Emission System Durability

- Criteria for evaluating vehicle emission system durability are rigorously defined (EC/98/69)

- Mechanisms of potential fuel/fuel additive effects differ from mechanism of catalyst deterioration

- Whole vehicle accelerated aging tests may be required
  - Consistent with evaluation criteria
  - Accelerated bench tests are generally not appropriate
  - Whole vehicle aging has successfully been used

- Information readily available to develop/modify whole vehicle cycle
Summary
MMT® - The Product

- The chemical
  - Pure organo-metallic liquid
  - Easy to use

- Most effective gasoline octane improver
  - Used at “near-zero” treat level

- Known fate in the engine combustion process
  - Predominantly manganese phosphate

- Known interaction with exhaust system
  - Known from scientific study
  - Supported by extensive real world performance
30 Years of Testing and Real World Experience

*Independent transparent test procedures based on stakeholder input.*

- 30 years of continuous commercial use
- Over 3 trillion kilometres in catalyst cars
- Ongoing successful application in unleaded gasoline

- Controlled automotive testing
  - over 250 vehicles & 28 million kilometres
  - emissions testing
  - fundamental automotive technology studies
30 years successful use...

- Automakers have a long history of stating concerns against MMT®
- Actual evidence: -
  - Numerous vehicle performance tests
  - Fundamental science studies
  - 30 years of real-world, continuous, successful use.
- Subjected to independent, proper scientific review these allegations have been discredited every time

Allegations continually proved false
Methods to Assess Durability

- Criteria for evaluating vehicle emission system durability are rigorously defined (EC/98/69)

- Mechanisms of potential fuel/fuel additive effects differ from mechanism of catalyst deterioration

- Whole vehicle accelerated aging tests may be required
  - Consistent with evaluation criteria
  - Accelerated bench tests are generally not appropriate
  - Whole vehicle aging has successfully been used

- Information readily available to develop/modify whole vehicle cycle

Performance Fuels
Finally

- Further questions?
- Is there a need for further information?
- Can Afton provide more detail analysis or interpretation of data that would be valuable to JRC?

- How can Afton help move this forward?