NREL
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# Effect of Gasoline Properties on Exhaust Emissions from Tier 2 Light-Duty Vehicles—Final Report: Phase 3

## July 28, 2008 – July 27, 2013

K. Whitney
*Southwest Research Institute*
*San Antonio, Texas*

NREL Technical Monitor: Matthew Thornton

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**Subcontract Report**
NREL/SR-5400-61098
May 2014

Contract No. DE-AC36-08GO28308

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Prepared under Subcontract Nos. ACI-8-88613-01, AFT-9-99319-01, and AFT-9-99155-01



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## FOREWORD

This report covers work the Southwest Research Institute (SwRI®) Office of Automotive Engineering has conducted for the U.S. Environmental Protection Agency (EPA), the National Renewable Energy Laboratory (NREL), and the Coordinating Research Council (CRC) in support of the Energy Policy Act of 2005 (EPAct). Section 1506 of EPAct requires EPA to produce an updated fuel effects model representing the 2007 light-duty gasoline fleet, including determination of the emissions impacts of increased renewable fuel use.

This report covers the exhaust emissions testing of fifteen light-duty vehicles with twenty-seven E0 through E20 test fuels, and four light-duty flexible fuel vehicles (FFVs) on an E85 fuel, as part of the EPAct Gasoline Light-Duty Exhaust Fuel Effects Test Program. This program will also be referred to as the EPAct/V2/E-89 Program based on the designations used for it by the EPA, NREL and CRC, respectively.

It is expected that this report will be an attachment or a chapter in the overall EPAct/V2/E-89 Program report prepared by EPA and NREL. Other EPAct/V2/E-89 reports are expected to cover the following:

- Fuel formulation, analysis, and procurement.
- Room temperature and 50°F emissions testing of three fuels using nineteen Tier 2 vehicles (known as Phases 1, 2, and FTP).
- Room temperature, 95°F, and 20°F testing of three fuels using six Tier 2 vehicles (Phase 4).
- Room temperature, 95°F, and 20°F testing of three fuels using three high-emitting vehicles (Phase 5).

This effort was authorized by EPA Contract EP-C-07-028, Work Assignments (WA) 1-03, 2-03, and 3-01 as well as NREL Subcontract Nos. ACI-8-88613-01, AFT-9-99319-01 and AFT-9-99155-01. The project was based on SwRI Proposal Nos. 03-55287 versions A through E to NREL, and SwRI Proposal Nos. 03-55242, 03-55242A, and 03-56310 versions A through G to EPA. The overall program was identified within SwRI under Project Nos. 03.14175.03, 03.14936.03, 03.14993, and 03.15777.01.

The project technical monitors were Dr. Rafal Sobotowski of EPA, Dr. Douglas Lawson of NREL, and Messrs. Jim Uihlein of Chevron and Dominic DiCicco of Ford on behalf of CRC. The SwRI Program Manager was Kevin Whitney, while Eugene Jimenez oversaw day-to-day operations. Testing occurred between March 2009 and June 2010.

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## ACKNOWLEDGEMENTS

SwRI acknowledges the following:

- The Environmental Protection Agency for their financial support
- The Department of Energy Office of Biomass Programs and Office of Vehicle Technologies for their financial support provided through the National Renewable Energy Laboratory
- The Coordinating Research Council for technical support and for providing the test vehicles following the expiration of their leases
- The Lubrizol Corporation for supplying all crankcase lubricants used in this program

## ACRONYMS AND ABBREVIATIONS

°F.....degrees Fahrenheit
IBP .....initial boiling point
API.....American Petroleum Institute
ASTM .....American Society for Testing and Materials
Btu.....British thermal unit
CARB .....California Air Resources Board
$CH_4$ .....methane
CO.....carbon monoxide
$CO_2$ .....carbon dioxide
CRC .....Coordinating Research Council
DTC .....diagnostic trouble code
DVPE.....dry vapor pressure equivalent
EPA.....U.S. Environmental Protection Agency
EPAct.....2005 Energy Policy Act
E0.....gasoline with no ethanol
E10.....gasoline nominally containing 10 percent volume of ethanol
E15.....gasoline nominally containing 15 percent volume of ethanol
E20.....gasoline nominally containing 20 percent volume of ethanol
E85……gasoline nominally containing 85 percent volume of ethanol
FBP .....final boiling point
FTP .....Federal Test Procedure
g .....gram
$H_2O$.....water
HP .....horsepower
HPLC .....high performance liquid chromatography
IBP .....initial boiling point
kg .....kilogram
kPa .....kilopascal
lb .....pound mass
LOD .....limit of detection
LOQ .....limit of quantification
LTFT.....long-term fuel trim
mg .....milligram
MIL .....malfunction indicator light

## ACRONYMS AND ABBREVIATIONS (CONT'D)

MJ .....megajoule
ml .....milliliter
MON .....motor octane number
mph .....miles per hour
$NH_3$ .....ammonia
NMHC .....non-methane hydrocarbons
NMOG .....non-methane organic gases
NO.....nitric oxide
$NO_2$ .....nitrogen dioxide
$NO_X$ .....oxides of nitrogen
NREL.....National Renewable Energy Laboratory
$O_2$ .....oxygen
OBD .....on-board diagnostics
PM.....particulate matter
ppm .....parts per million
psi.....pounds per square inch
RON .....research octane number
RPM.....revolutions per minute
RUL .....regular unleaded
RVP.....Reid vapor pressure
STFT .....short-term fuel trim
SwRI .....Southwest Research Institute
THC .....total hydrocarbons
VOC……...volatile organic compounds
vol... .....volume
WA.....work assignment
WAM .....work assignment manager

# 1.0 INTRODUCTION

Since September 2007, Southwest Research Institute (SwRI) has been conducting work on a series of tasks and assignments, the results of which are now collectively known as the EPAct/V2/E-89 emissions test program. The work began under the direction of the U.S. Environmental Protection Agency (EPA) to fulfill requirements for emissions modeling outlined in the Energy Policy Act of 2005 (EPAct). Section 1506 of the EPAct requires the production of an updated fuel effects model representing the 2007 light-duty gasoline fleet, including assessment of the emissions impacts of increased renewable fuel use. By January 2009, SwRI had completed Phases 1 and 2 of the EPAct/V2/E-89 program. These phases, described in a separate report, involved testing of 19 light duty cars and trucks (subsequently referred to as the "EPAct fleet") on three fuels, at two temperatures.

In March 2009, SwRI began work on Phase 3, which was jointly supported by EPA, the U.S. Department of Energy through the National Renewable Energy Laboratory (NREL), and the Coordinating Research Council (CRC). This report covers work conducted for Phase 3, which involved the testing of fifteen vehicles from the EPAct fleet using twenty-seven test fuels with ethanol content ranging from 0 to 20 percent by volume, and testing of four flexible-fuel vehicles (FFVs) from the EPAct fleet on an E85 fuel. Phase 3 testing was completed in June 2010.

# 2.0 TECHNICAL APPROACH

## 2.1 Test Fuels

Twenty-eight test fuels were evaluated in Phase 3 of the EPAct/V2/E-89 Program. Fuel procurement is detailed in SwRI Final Report 03.14295/03-51563E "*V2/EPAct/E-89 Fuel Blending,*" which has been submitted separately. Target fuel specifications are given in Table 1. The actual properties of test fuel as determined from the EPAct/V2/E-89 Fuels Round Robin are listed in Table 2.

Twenty-seven of the twenty-eight test fuels were procured by SwRI from Haltermann Products. EPA established a fuel development protocol for this program. Using this protocol, all test fuels were formulated by Rafal Sobotowski of the EPA in conjunction with Haltermann, who provided EPA with data for all their blendstock components. The procurement of Fuels 1 through 16, Fuel 30, and Fuel 31 was funded by EPA Contract No. EP-C-07-028, while NREL Subcontract No. ACI-8-88612-01 funded the procurement of Fuels 20 through 28. The E85 Fuel 29 was provided to the program by the CRC.

## TABLE 1. TEST FUEL SPECIFICATION

Test Fuel Specification

| PROPERTY | UNIT | METHOD | BLENDING TOLERANCE | E0/E10 Fuels | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | TEST FUELS | | | | | | | | | | | | | | | |
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Density, 60°F | $g/cm^3$ | D4052 | NA | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| API Gravity, 60°F | °API | D4052 | NA | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| **Ethanol Content** | **vol. %** | **D5599** | **E0: < 0.1; E10: ± 0.5; E15: ± 0.5; E20: ±0.5; E85: ±2** | **10** | **0** | **10** | **10** | **0** | **10** | **0** | **0** | **0** | **10** | **10** | **10** | **0** | **0** | **0** | **10** |
| Total Content of Oxygenates Other than Ethanol | vol. % | D5599 | - | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| T10 | °F | D86 | - | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 |
| **T50** | **°F** | **D86** | **± 4** | **150** | **240** | **220** | **220** | **240** | **190** | **190** | **220** | **190** | **220** | **190** | **150** | **220** | **190** | **190** | **220** |
| **T90** | **°F** | **D86** | **± 5** | **300** | **340** | **300** | **340** | **300** | **340** | **300** | **300** | **340** | **340** | **300** | **340** | **340** | **340** | **300** | **300** |
| FBP | °F | D86 | - | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 |
| **DVPE** | **psi** | **D5191** | **± 0.25** | **10.0** | **10.0** | **7.0** | **10.0** | **7.0** | **7.0** | **7.0** | **10.0** | **10.0** | **7.0** | **10.0** | **10.0** | **7.0** | **7.0** | **10.0** | **7.0** |
| **Aromatics** | **vol. %** | **D1319** | **± 1.5** | **15.0** | **15.0** | **15.0** | **15.0** | **35.0** | **15.0** | **15.0** | **15.0** | **35.0** | **35.0** | **35.0** | **35.0** | **35.0** | **15.0** | **35.0** | **35.0** |
| Olefins | vol. % | D1319 | ± 1.5 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Benzene | vol. % | D3606 | ± 0.15 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 |
| S | mg/kg | D5453 | ± 5 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| (R + M)/2 | - | Calc. | - | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 |
| C | mass % | Calc. | - | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| H | mass % | D4808 Method A | - | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| O | mass % | D5599 | - | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| Gross Heat of Combustion | Btu/lb | D4809 | - | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| Water Content | mg/kg | E1064 | - | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| Copper Strip Corrosion, 3h at 122°F | - | D130 | - | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 |
| Solvent-Washed Gum Content | mg/100 ml | D381 | - | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 |
| Oxidation Stability | minute | D525 | - | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 |

NOTE: Properties in bold were varied within the fuel matrix

## TABLE 1 (CONT'D). TEST FUEL SPECIFICATION

Test Fuel Specification

| PROPERTY | UNIT | METHOD | BLENDING TOLERANCE | E15/E20 Fuels | | | | | | | | | E85 | CRC Fuels | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | TEST FUELS | | | | | | | | | | | |
| | | | | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29[a] | 30 | 31 |
| Density, 60°F | $g/cm^3$ | D4052 | NA | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| API Gravity, 60°F | °API | D4052 | NA | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| **Ethanol Content** | **vol. %** | **D5599** | **E0: < 0.1; E10: ± 0.5; E15: ± 0.5; E20: ±0.5; E85: ±2** | **20** | **20** | **20** | **20** | **20** | **20** | **15** | **15** | **15** | **81** | **10** | **20** |
| Total Content of Oxygenates Other than Ethanol | vol. % | D5599 | - | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.15 | <0.15 | <0.15 | <2.0 | <0.1 | <0.2 |
| T10 | °F | D86 | - | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 | <158 | Report | <158 | <158 |
| **T50** | **°F** | **D86** | **± 4** | **165** | **165** | **165** | **165** | **165** | **165** | **160** | **220** | **220** | **Report** | **150** | **165** |
| **T90** | **°F** | **D86** | **± 5** | **300** | **300** | **300** | **340** | **340** | **340** | **340** | **340** | **300** | **Report** | **325** | **325** |
| FBP | °F | D86 | - | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 | <437 | Report | <437 | <437 |
| **DVPE** | **psi** | **D5191** | **± 0.25** | **7.0** | **7.0** | **10.0** | **7.0** | **10.0** | **10.0** | **10.0** | **7.0** | **7.0** | **6.9** | **10.0** | **7.0** |
| **Aromatics** | **vol. %** | **D1319** | **± 1.5** | **15.0** | **35.0** | **15.0** | **15.0** | **15.0** | **35.0** | **35.0** | **15.0** | **35.0** | **Report** | **35.0** | **35.0** |
| Olefins | vol. % | D1319 | ± 1.5 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | Report | 7 | 7 |
| Benzene | vol. % | D3606 | ± 0.15 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | Report | 0.62 | 0.62 |
| S | mg/kg | D5453 | ± 5 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 15 | 25 | 25 |
| (R + M)/2 | - | Calc. | - | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | ≥ 87.0 | Report | ≥ 87.0 | ≥ 87.0 |
| C | mass % | Calc. | - | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| H | mass % | D4808 Method A | - | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| O | mass % | D5599 | - | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| Gross Heat of Combustion | Btu/lb | D4809 | - | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report | Report |
| Water Content | mg/kg | E1064 | - | Report | Report | Report | Report | Report | Report | Report | Report | Report | <10,000 | Report | Report |
| Copper Strip Corrosion, 3h at 122°F | - | D130 | - | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | <No. 1 | na | <No. 1 | <No. 1 |
| Solvent-Washed Gum Content | mg/100 ml | D381 | - | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 |
| Oxidation Stability | minute | D525 | - | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | na | >240 | >240 |

[a] – fuel provided by CRC

NOTE: Properties in bold were varied within the fuel matrix

## TABLE 2. TEST FUEL PROPERTIES DETERMINED FROM THE EPACT/V2/E-89 FUELS ROUND ROBIN

| PROPERTY | UNIT | TEST METHOD | FUEL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Density, 60°F | g/cm$^3$ | D4052 | 0.7211 | 0.7220 | 0.7350 | 0.7346 | 0.7573 | 0.7342 | 0.7208 | 0.7191 | 0.7454 |
| API Gravity, 60°F | °API | D4052 | 64.6 | 64.3 | 60.8 | 60.9 | 55.2 | 61.1 | 64.6 | 65.1 | 58.2 |
| **Ethanol** | **vol. %** | **D5599** | **10.03** | **<0.10** | **10.36** | **9.94** | **<0.10** | **10.56** | **<0.10** | **<0.10** | **<0.10** |
| Total Content of Oxygenates Other Than Ethanol | vol. % | D5599 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Distillation IBP | °F | D86 (**OptiDist** or equivalent for E10, E15 and E20 fuels) | 92.9 | 83.5 | 106.4 | 89.9 | 94.1 | 106.7 | 100.1 | 83.7 | 85.3 |
| 5% evap | °F | | 112.5 | 105.4 | 136.0 | 115.9 | 128.6 | 130.4 | 127.6 | 108.1 | 105.1 |
| 10% evap | °F | | 117.3 | 121.7 | 141.7 | 126.3 | 145.4 | 135.9 | 137.0 | 123.4 | 115.1 |
| 20% evap | °F | | 123.9 | 154.4 | 148.9 | 140.9 | 172.6 | 142.6 | 149.0 | 151.6 | 130.3 |
| 30% evap | °F | | 131.2 | 190.6 | 155.0 | 151.7 | 199.4 | 148.3 | 161.7 | 185.1 | 147.2 |
| 40% evap | °F | | 139.9 | 218.5 | 175.1 | 161.2 | 222.1 | 153.4 | 176.6 | 204.4 | 167.7 |
| **50% evap** | °F | | **148.9** | **236.7** | **217.5** | **221.9** | **237.0** | **188.5** | **193.1** | **221.1** | **192.8** |
| 60% evap | °F | | 172.3 | 252.7 | 230.2 | 245.9 | 247.2 | 228.2 | 210.2 | 233.5 | 224.7 |
| 70% evap | °F | | 224.1 | 271.7 | 243.6 | 270.0 | 258.5 | 267.7 | 228.6 | 246.4 | 260.3 |
| 80% evap | °F | | 254.6 | 305.9 | 257.1 | 303.5 | 273.1 | 310.1 | 251.5 | 264.0 | 292.2 |
| **90% evap** | °F | | **300.2** | **340.1** | **295.9** | **337.5** | **300.0** | **340.4** | **298.4** | **303.1** | **341.8** |
| 95% evap | °F | | 334.5 | 353.0 | 334.4 | 352.0 | 323.5 | 352.7 | 329.3 | 330.5 | 363.5 |
| FBP | °F | | 368.0 | 375.3 | 368.9 | 369.8 | 357.8 | 369.2 | 361.8 | 360.9 | 384.7 |
| **DVPE (EPA equation)** | **psi** | **D5191** | **10.07** | **10.20** | **6.93** | **10.01** | **6.95** | **7.24** | **7.15** | **10.20** | **10.30** |
| **Aromatics** | **vol. %** | **D1319** | **15.4** | **14.1** | **15.0** | **15.5** | **34.7** | **15.0** | **17.0** | **15.7** | **35.8** |
| Olefins | vol. % | D1319 | 7.6 | 6.8 | 7.6 | 6.8 | 6.9 | 8.8 | 7.5 | 6.4 | 6.2 |
| Saturates | vol. % | calculated[a] | 67.0 | 79.1 | 67.0 | 67.8 | 58.4 | 65.6 | 75.5 | 78.0 | 58.0 |
| Benzene | vol. % | D3606 | 0.62 | 0.51 | 0.61 | 0.54 | 0.51 | 0.68 | 0.55 | 0.50 | 0.54 |
| Sulfur | mg/kg | D5453 | 30 | 23 | 22 | 21 | 24 | 23 | 23 | 23 | 23 |
| RON | - | D2699 | 94.8 | 96.0 | 98.0 | 97.1 | 96.7 | 96.3 | 91.2 | 95.5 | 94.5 |
| MON | - | D2700 | 86.3 | 88.6 | 87.6 | 87.6 | 86.3 | 86.6 | 84.2 | 87.8 | 84.8 |
| (RON+MON)/2 | - | calculated | 90.6 | 92.3 | 92.8 | 92.4 | 91.5 | 91.5 | 87.7 | 91.7 | 89.7 |
| C | mass % | D5291 mod. | 81.70 | 85.12 | 81.61 | 82.21 | 86.58 | 81.52 | 85.16 | 85.12 | 87.03 |
| H | mass % | D5291 mod. | 14.02 | 14.43 | 14.17 | 14.12 | 12.92 | 14.21 | 14.25 | 14.32 | 12.82 |
| O | mass % | D5599 | 3.9 | <0.1 | 3.9 | 3.7 | <0.1 | 4.0 | <0.1 | <0.1 | <0.1 |
| Net Heat of Combustion | MJ/kg | D4809 | 41.950 | 43.960 | 41.536 | 41.952 | 42.948 | 41.785 | 43.735 | 44.037 | 43.209 |
| Water | mass % | E-1064 | 0.071 | 0.010 | 0.059 | 0.077 | 0.014 | 0.073 | 0.019 | 0.020 | 0.009 |
| Lead | g/l | D3237 | - | <0.001 | - | - | <0.003 | - | <0.001 | 0.001 | <0.001 |
| Copper Strip Corrosion | - | D130 | 1A | 1A | 1A | 1A | 1A | 1A | 1A | 1A | 1A |
| Solvent Washed Gum Content | mg/100ml | D381 | <0.5 | <0.5 | <0.5 | 1.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Oxidation Stability | min. | D525 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 |

[a] Saturates = 100 - D1319 Aromatics - D1319 Olefins - D5599 Ethanol

NOTE: Properties in bold were varied within the fuel matrix.

## TABLE 2 (CONT'D). TEST FUEL PROPERTIES DETERMINED FROM THE EPACT/V2/E-89 FUELS ROUND ROBIN

| PROPERTY | UNIT | TEST METHOD | FUEL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **20** | **21** |
| Density, 60°F | g/cm$^3$ | D4052 | 0.7644 | 0.7596 | 0.7517 | 0.7540 | 0.7223 | 0.7428 | 0.7636 | 0.7425 | 0.7754 |
| API Gravity, 60°F | °API | D4052 | 53.4 | 54.6 | 56.5 | 56.0 | 64.2 | 58.8 | 53.6 | 58.9 | 50.8 |
| **Ethanol** | **vol. %** | **D5599** | **9.82** | **10.30** | **9.83** | **<0.10** | **<0.10** | **<0.10** | **10.76** | **20.31** | **20.14** |
| Total Content of Oxygenates Other Than Ethanol | vol. % | D5599 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Distillation IBP | °F | D86 (**OptiDist** or equivalent for E10, E15 and E20 fuels) | 104.7 | 92.0 | 91.3 | 96.6 | 100.4 | 84.7 | 104.5 | 107.9 | 106.3 |
| 5% evap | °F | | 130.0 | 115.4 | 110.7 | 127.0 | 126.5 | 105.5 | 133.0 | 137.3 | 134.7 |
| 10% evap | °F | | 136.3 | 124.4 | 116.9 | 139.8 | 135.5 | 115.6 | 139.2 | 142.6 | 141.3 |
| 20% evap | °F | | 144.3 | 137.6 | 125.0 | 158.7 | 147.3 | 130.5 | 147.8 | 149.7 | 150.3 |
| 30% evap | °F | | 151.0 | 148.1 | 133.8 | 178.2 | 160.0 | 146.6 | 155.1 | 155.3 | 157.1 |
| 40% evap | °F | | 161.6 | 156.5 | 142.8 | 199.9 | 175.1 | 166.3 | 172.1 | 159.6 | 162.6 |
| **50% evap** | °F | | **217.1** | **189.3** | **152.2** | **222.5** | **192.8** | **189.7** | **218.8** | **162.7** | **167.6** |
| 60% evap | °F | | 261.5 | 231.1 | 198.5 | 245.2 | 212.0 | 216.2 | 237.5 | 179.9 | 217.3 |
| 70% evap | °F | | 290.4 | 251.4 | 275.1 | 269.8 | 237.3 | 243.0 | 251.9 | 234.8 | 255.2 |
| 80% evap | °F | | 317.5 | 270.0 | 307.9 | 303.5 | 280.1 | 265.9 | 268.6 | 253.1 | 275.3 |
| **90% evap** | °F | | **340.2** | **298.6** | **339.8** | **337.9** | **338.5** | **299.4** | **300.6** | **298.7** | **305.0** |
| 95% evap | °F | | 354.3 | 325.0 | 357.7 | 354.4 | 354.5 | 329.3 | 330.8 | 336.6 | 331.3 |
| FBP | °F | | 372.4 | 360.8 | 375.9 | 377.5 | 377.5 | 363.7 | 365.6 | 371.9 | 360.5 |
| **DVPE (EPA equation)** | **psi** | **D5191** | **7.11** | **9.93** | **10.13** | **6.92** | **7.14** | **10.23** | **7.12** | **6.70** | **7.06** |
| **Aromatics** | **vol. %** | **D1319** | **34.0** | **35.0** | **34.8** | **34.1** | **16.9** | **35.3** | **35.6** | **15.2** | **35.5** |
| Olefins | vol. % | D1319 | 6.1 | 6.9 | 6.9 | 6.3 | 8.5 | 7.2 | 6.8 | 7.4 | 7.1 |
| Saturates | vol. % | calculated[a] | 50.1 | 47.8 | 48.5 | 59.6 | 74.6 | 57.4 | 46.9 | 57.1 | 37.3 |
| Benzene | vol. % | D3606 | 0.52 | 0.54 | 0.57 | 0.51 | 0.52 | 0.54 | 0.62 | 0.61 | 0.61 |
| Sulfur | mg/kg | D5453 | 25 | 24 | 19 | 23 | 24 | 24 | 23 | 22 | 22 |
| RON | - | D2699 | 98.5 | 97.8 | 100.4 | 95.8 | 91.5 | 95.0 | 101.0 | 101.9 | 101.4 |
| MON | - | D2700 | 87.2 | 85.6 | 88.0 | 85.8 | 84.6 | 84.9 | 88.3 | 89.3 | 87.5 |
| (RON+MON)/2 | - | calculated | 92.9 | 91.7 | 94.2 | 90.8 | 88.1 | 90.0 | 94.7 | 95.6 | 94.5 |
| C | mass % | D5291 mod. | 83.47 | 83.68 | 83.32 | 86.76 | 85.28 | 86.88 | 83.40 | 78.06 | 79.90 |
| H | mass % | D5291 mod. | 12.83 | 12.61 | 12.68 | 13.15 | 14.29 | 12.79 | 12.66 | 14.01 | 12.43 |
| O | mass % | D5599 | 3.6 | 3.7 | 3.6 | <0.1 | <0.1 | <0.1 | 3.9 | 7.6 | 7.1 |
| Net Heat of Combustion | MJ/kg | D4809 | 41.210 | 41.175 | 41.373 | 43.171 | 43.519 | 43.108 | 41.013 | 40.057 | 39.285 |
| Water | mass % | E-1064 | 0.067 | 0.066 | 0.066 | 0.014 | 0.015 | 0.012 | 0.066 | 0.138 | 0.128 |
| Lead | g/l | D3237 | <0.003 | - | <0.003 | <0.001 | <0.001 | <0.001 | - | <0.003 | 0.009 |
| Copper Strip Corrosion | - | D130 | 1A | 1A | 1A | 1A | 1A | 1A | 1A | 1A | 1A |
| Solvent Washed Gum Content | mg/100ml | D381 | <0.5 | 0.5 | <0.5 | 1.5 | <0.5 | 0.5 | 1 | <0.5 | 0.5 |
| Oxidation Stability | min. | D525 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 |

[a] Saturates = 100 - D1319 Aromatics - D1319 Olefins - D5599 Ethanol

NOTE: Properties in bold were varied within the fuel matrix.

## TABLE 2 (CONT'D). TEST FUEL PROPERTIES DETERMINED FROM THE EPACT/V2/E-89 FUELS ROUND ROBIN

| PROPERTY | UNIT | TEST METHOD | FUEL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **30** | **31** |
| Density, 60°F | g/cm$^3$ | D4052 | 0.7371 | 0.7476 | 0.7422 | 0.7702 | 0.7593 | 0.7434 | 0.7699 | 0.7508 | 0.7742 |
| API Gravity, 60°F | °API | D4052 | 60.3 | 57.6 | 58.9 | 52.0 | 54.6 | 58.6 | 52.1 | 56.8 | 51.1 |
| **Ethanol** | **vol. %** | **D5599** | **20.51** | **20.32** | **20.51** | **20.03** | **15.24** | **14.91** | **14.98** | **9.81** | **20.11** |
| Total Content of Oxygenates Other Than Ethanol | vol. % | D5599 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Distillation IBP | °F | D86 (**OptiDist** or equivalent for E10, E15 and E20 fuels) | 89.8 | 109.0 | 89.7 | 89.0 | 88.7 | 104.8 | 103.9 | 90.9 | 105.8 |
| 5% evap | °F | | 118.8 | 133.3 | 115.9 | 113.7 | 109.6 | 135.3 | 136.3 | 110.3 | 132.5 |
| 10% evap | °F | | 129.6 | 138.9 | 126.9 | 125.5 | 117.1 | 142.3 | 144.2 | 116.7 | 139.1 |
| 20% evap | °F | | 144.3 | 146.2 | 142.8 | 142.1 | 127.8 | 152.0 | 154.0 | 125.4 | 147.7 |
| 30% evap | °F | | 153.7 | 152.3 | 153.2 | 153.3 | 138.6 | 158.0 | 160.2 | 133.9 | 155.1 |
| 40% evap | °F | | 159.5 | 157.8 | 160.4 | 160.9 | 149.8 | 163.8 | 165.8 | 143.1 | 161.3 |
| **50% evap** | °F | | **163.2** | **162.5** | **165.1** | **166.9** | **160.3** | **221.5** | **216.6** | **152.9** | **167.3** |
| 60% evap | °F | | 167.2 | 171.6 | 172.9 | 191.3 | 174.7 | 265.1 | 240.2 | 197.2 | 214.0 |
| 70% evap | °F | | 233.9 | 270.9 | 266.1 | 281.6 | 277.0 | 274.9 | 251.6 | 267.3 | 271.6 |
| 80% evap | °F | | 253.6 | 311.4 | 305.5 | 310.3 | 306.5 | 311.3 | 268.4 | 294.6 | 297.0 |
| **90% evap** | °F | | **297.3** | **338.2** | **338.1** | **337.9** | **338.7** | **340.3** | **298.8** | **323.8** | **325.2** |
| 95% evap | °F | | 334.5 | 350.0 | 350.3 | 352.7 | 356.7 | 351.9 | 327.3 | 341.8 | 342.1 |
| FBP | °F | | 369.9 | 364.6 | 368.2 | 371.8 | 377.3 | 372.2 | 363.2 | 366.1 | 365.6 |
| **DVPE (EPA equation)** | **psi** | **D5191** | **10.21** | **6.84** | **10.12** | **10.16** | **10.21** | **6.97** | **6.87** | **10.23** | **6.98** |
| **Aromatics** | **vol. %** | **D1319** | **15.0** | **15.9** | **15.3** | **35.2** | **35.6** | **14.9** | **34.5** | **35.5** | **35.5** |
| Olefins | vol. % | D1319 | 6.9 | 7.5 | 7.3 | 6.6 | 6.5 | 7.4 | 7.0 | 6.5 | 6.8 |
| Saturates | vol. % | calculated[a] | 57.6 | 56.4 | 56.9 | 38.1 | 42.7 | 62.9 | 43.5 | 48.2 | 37.6 |
| Benzene | vol. % | D3606 | 0.59 | 0.63 | 0.62 | 0.65 | 0.62 | 0.56 | 0.59 | 0.58 | 0.60 |
| Sulfur | mg/kg | D5453 | 21 | 21 | 21 | 26 | 23 | 26 | 24 | 23 | 25 |
| RON | - | D2699 | 101.8 | 97.4 | 100.8 | 102.2 | 101.7 | 100.8 | 102.7 | 100.5 | 101.7 |
| MON | - | D2700 | 89.3 | 86.8 | 88.6 | 88.3 | 88.5 | 89.2 | 89.4 | 88.1 | 88.2 |
| (RON+MON)/2 | - | calculated | 95.6 | 92.1 | 94.7 | 95.3 | 95.1 | 95.0 | 96.1 | 94.3 | 95.0 |
| C | mass % | D5291 mod. | 78.24 | 78.34 | 78.47 | 80.62 | 81.48 | 80.27 | 81.78 | 83.17 | 79.90 |
| H | mass % | D5291 mod. | 13.85 | 13.86 | 13.86 | 12.38 | 12.45 | 14.01 | 12.62 | 13.00 | 12.49 |
| O | mass % | D5599 | 7.7 | 7.5 | 7.6 | 7.2 | 5.6 | 5.5 | 5.4 | 3.6 | 7.2 |
| Net Heat of Combustion | MJ/kg | D4809 | 40.031 | 39.915 | 40.114 | 38.855 | 40.384 | 41.062 | 40.383 | 41.304 | 39.391 |
| Water | mass % | E-1064 | 0.113 | 0.112 | 0.108 | 0.117 | 0.088 | 0.090 | 0.091 | 0.086 | 0.143 |
| Lead | g/l | D3237 | 0.004 | <0.003 | 0.005 | 0.001 | <0.003 | <0.003 | <0.003 | - | <0.003 |
| Copper Strip Corrosion | - | D130 | 1A | 1A | 1A | 1A | 1A | 1A | 1A | 1A | 1A |
| Solvent Washed Gum Content | mg/100ml | D381 | <0.5 | 0.5 | 0.5 | <0.5 | <0.5 | 0.5 | <0.5 | <0.5 | 0.5 |
| Oxidation Stability | min. | D525 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 | >240 |

[a] Saturates = 100 - D1319 Aromatics - D1319 Olefins - D5599 Ethanol

NOTE: Properties in bold were varied within the fuel matrix.

## TABLE 2 (CONT'D). TEST FUEL PROPERTIES DETERMINED FROM THE EPACT/V2/E-89 FUELS ROUND ROBIN

| PROPERTY | UNIT | TEST METHOD | FUEL 29 |
|---|---|---|---|
| Density, 60°F | $g/cm^3$ | D4052 | 0.7797 |
| API Gravity, 60°F | °API | D4052 | 49.8 |
| Uncorrected Ethanol | mass % | D5501 mod. | 79.59 |
| Uncorrected Methanol | mass % | D5501 mod. | 0.01 |
| Ethanol | vol. % | D5501 mod. | 77.15 |
| Methanol | vol. % | D5501 mod. | <0.01 |
| Estimated Hydrocarbon Content | vol. % | calculated[a] | 22.14 |
| Distillation IBP | °F | D86 | 99.0 |
| 5% evap | °F | | 132.9 |
| 10% evap | °F | | 154.3 |
| 20% evap | °F | | 167.6 |
| 30% evap | °F | | 170.3 |
| 40% evap | °F | | 171.2 |
| 50% evap | °F | | 171.8 |
| 60% evap | °F | | 172.1 |
| 70% evap | °F | | 172.5 |
| 80% evap | °F | | 172.9 |
| 90% evap | °F | | 173.9 |
| 95% evap | °F | | 176.2 |
| FBP | °F | | 265.8 |
| DVPE (EPA equation) | psi | D5191 | 8.92 |
| Benzene | vol. % | D5580 | 0.12 |
| S | mg/kg | D5453 | 16 |
| C | mass % | D5291 mod. | 57.74 |
| H | mass % | D5291 mod. | 12.80 |
| O | mass % | D5501 mod. | 27.19 |
| Water | mass % | E203 | 0.93 |
| | vol. % | E203 | 0.72 |
| Net Heat of Combustion | MJ/kg | D4809 | 30.058 |
| Solvent Washed Gum | mg/100 ml | D381 | 1.9 |
| Unwashed Gum | mg/100 ml | D381 | 1.8 |
| Acidity (as acetic acid) | mass % | D1613 | 0.0021 |
| pHe | - | D6423 | 8.08 |
| Inorganic Chloride | mg/kg | D7319 | nd |
| Copper | mg/l | D1688[b] | 0.02 |

[a] Estimated hydrocabon contenet = 100 - D5501 Ethanol - E203 Water

[b] D1688 modified as outlined in D4806

NOTE: Fuel provided by CRC

All fuels were maintained in sealed epoxy-lined 5B drums. All unopened drums were kept in a temperature-controlled facility (SwRI Building 205, Figure 1). The storage temperature for unopened drums was 70°F ± 5°F. Once a week, necessary unopened fuel drums were transported from Building 205 to a dedicated cold-storage facility located behind the emissions laboratory. Prior to opening a drum, it was conditioned to a temperature of less than 50°F. Once a drum of fuel was opened, it continued to be stored at 45°F ± 5°F. The temperature of both fuel storage facilities was continuously recorded, and was verified at least once a day.


**FIGURE 1. CONSTANT-TEMPERATURE STORAGE OF UNOPENED FUEL DRUMS**

All fuels received independent identifiers which included the EPAct fuel number, an SwRI fuel code, and a project-specific supplementary three-letter code (Table 3). All fuel drums and corresponding work requests included all three designators in an effort to assure the correct fuel was being used at any point in the test program. Additionally, each individual drum was labeled numerically.

## TABLE 3. SWRI FUEL CODES

| Test Fuel | SwRI Fuel Code | SwRI Fuel Name |
|---|---|---|
| Fuel 1 | EM-6995-F | SAT |
| Fuel 2 | EM-6953-F | ELP |
| Fuel 3 | EM-7053-F | FLG |
| Fuel 4 | EM-6996-F | HOU |
| Fuel 5R[a] | EM-7061-F | MCI |
| Fuel 6 | EM-7092-F | IND |
| Fuel 7 | EM-6954-F | JNU |
| Fuel 8 | GB-6936-F | BWI |
| Fuel 9 | EM-6955-F | KAW |
| Fuel 10 | EM-7093-F | LNK |
| Fuel 11 | EM-7055-F | MIA |
| Fuel 12 | EM-6997-F | MLS |
| Fuel 13 | EM-6965-F | CLF |
| Fuel 14 | EM-6956-F | BNA |
| Fuel 15 | EM-6957-F | OAK |
| Fuel 16 | EM-7056-F | OSH |
| Fuel 20 | EM-7057-F | PHX |
| Fuel 21 | EM-7058-F | RNO |
| Fuel 22 | EM-7001-F | SLC |
| Fuel 23 | EM-7059-F | SFO |
| Fuel 24 | EM-6998-F | TEX |
| Fuel 25 | EM-7073-F | TUL |
| Fuel 26 | EM-7094-F | YAK |
| Fuel 27 | EM-7095-F | BOS |
| Fuel 28 | EM-7096-F | NBA |
| Fuel 29 | EM-9675-F | E85 |
| Fuel 30 | EM-7060-F | BUF |
| Fuel 31 | EM-7074-F | GPZ |

[a] Fuel 5 was reblended prior to being used in the test program. 5R refers to the reblended version of the fuel.

When a vehicle received a fuel change, the appropriate fuel drum was removed from the cold box. The SwRI fuel code and supplemental three-letter fuel name were verified by two individuals prior to a refueling event (see fuel change procedure in Appendix A), and the individual fuel drum number was recorded. In an effort to ensure correct drum labeling, when each new drum of fuel was opened, a sample was collected in order to verify select fuel properties with a PetroSpec portable gasoline analyzer. The results of these analyses are given in Appendix B. Based on these results, SwRI did not observe any fuel drum mislabeling during this program.

There was one confirmed case of vehicle misfueling, which occurred with the Ford F-150. In the 45th week of testing, the F-150 was apparently refueled from an improperly-labeled drum of slop fuel, which contained a mixture of both gasoline and diesel fuel. Immediately following the misfueling, the vehicle had a rough idle. After the improper fuel was discovered, the fuel tank of the vehicle was cleaned, the fuel filter was replaced, and the fuel system was flushed. Additional exhaust emission tests were conducted with the fuel that was in the tank prior to the misfueling event, which showed emissions results similar to previous tests. EPA and NREL approved these results, and testing of this vehicle resumed. A more detailed description of this incident is given in Appendix C.

## 2.2 Test Vehicles

As specified by EPA and NREL, sixteen vehicles were utilized in the Phase 3 test program (Table 4). Fifteen of these vehicles were used to test the twenty-seven E0, E10, E15 and E20 fuels. Three of these fifteen vehicles (Chevrolet Impala FFV, Chevrolet Silverado FFV, Ford F-150 FFV) and one additional flexible fuel vehicle (Dodge Caravan FFV) were used to test the E85 Fuel 29. All vehicles were leased by SwRI for two years at the initiation of Phase 1 of the V2/EPAct/E-89 program. Due to changes and additions to the overall program, the term of the two-year leases expired prior to the completion of all Phase 3 testing. The Coordinating Research Council then purchased the test vehicles and made them available to the test program for the remainder of its duration.

**TABLE 4. PHASE 3 TEST VEHICLES**

| MAKE | MODEL YEAR | BRAND | MODEL | VEHICLE NAME | ENGINE | ENGINE FAMILY | EPA T2 BIN | CA CERT | PHASE 3 STARTING ODOMETER |
|---|---|---|---|---|---|---|---|---|---|
| GM | 2008 | Chevrolet | Cobalt | CCOB | 2.4L I4 | 8GMXV02.4025 | 5 | NA | 4,841 |
| GM | 2008 | Chevrolet | Impala FFV | CIMP | 3.5L V6 | 8GMXV03.9052 | 5 | L2 | 5,048[a] |
| GM | 2008 | Saturn | Outlook | SOUT | 3.6L V6 | 8GMXT03.6151 | 5 | L2 | 5,212[a] |
| GM | 2008 | Chevrolet | Silverado FFV | CSIL | 5.3L V8 | 8GMXT05.3373 | 5 | NA | 5,347[b] |
| Toyota | 2008 | Toyota | Corolla | TCOR | 1.8L I4 | 8TYXV01.8BEA | 5 | U2 | 5,019[a] |
| Toyota | 2008 | Toyota | Camry | TCAM | 2.4L I4 | 8TYXV02.4BEA | 5 | U2 | 4,974[b] |
| Toyota | 2008 | Toyota | Sienna | TSIE | 3.5L V6 | 8TYXT03.5BEM | 5 | U2 | 4,997 |
| Ford | 2008 | Ford | Focus | FFOC | 2.0L I4 | 8FMXV02.0VD4 | 4 | U2 | 5,150[a,b] |
| Ford | 2008 | Ford | Explorer | FEXP | 4.0L V6 | 8FMXT04.03DB | 4 | NA | 6,799[c] |
| Ford | 2008 | Ford | F-150 FFV | F150 | 5.4L V8 | 8FMXT05.44HF | 8 | NA | 5,523[a] |
| Chrysler | 2008 | Dodge | Caliber | DCAL | 2.4L I4 | 8CRXB02.4MEO | 5 | NA | 4,959 |
| Chrysler | 2008 | Dodge | Caravan FFV[d] | DCAR | 3.3L V6 | 8CRXT03.3NEP | 8 | NA | 5,282 |
| Chrysler | 2008 | Jeep | Liberty | JLIB | 3.7L V6 | 8CRXT03.7NE0 | 5 | NA | 4,785 |
| Honda | 2008 | Honda | Civic | HCIV | 1.8L I4 | 8HNXV01.8LKR | 5 | U2 | 4,765 |
| Honda | 2008 | Honda | Odyssey | HODY | 3.5L V6 | 8HNXT03.54KR | 5 | U2 | 4,850 |
| Nissan | 2008 | Nissan | Altima | NALT | 2.5L I4 | 8NSXV02.5G5A | 5 | L2 | 5,211[b] |

[a] – These vehicles were added to the Phase 3 test matrix at a later date. Prior to their inclusion in the matrix, they received on-road miles every other week.

[b] – These vehicles were included in an FTP interim test program (EPA WA 1-09) conducted between Phases 1 and 2.

[c] – During Phase 1, the initial 4,000 miles of vehicle break-in was conducted with the wrong crankcase lubricant viscosity grade. An additional 2,000-mile break-in was conducted with the correct lubricant viscosity grade.

[d] – Dodge Caravan FFV was only tested with E85

Prior to the initiation of Phase 1 of the program, each vehicle was brought up to 4,000 odometer miles to eliminate any engine break-in issues. This was accomplished by operating the vehicles on mileage accumulation dynamometers over the Standard Road Cycle using a non-oxygenated, commercial, 87 octane gasoline (Table 5). The engine crankcase lubricant was drained and replaced with the appropriate manufacturer-recommended viscosity grade at the start of mileage accumulation, and at 2,000 miles. The 2,000-mile fill of oil remained in the test vehicles throughout the conduct of Phases 1, 2, and 3 of the EPAct program. The vehicle odometer readings at the start of Phase 3 are included in Table 4.

**TABLE 5. MILEAGE ACCUMULATION FUEL PROPERTIES**

| PROPERTY | UNIT | METHOD | Valero RUL |
|---|---|---|---|
| Density, 60°F | $g/cm^3$ | D4052 | 0.7329 |
| API Gravity, 60°F | °API | D4052 | 61.5 |
| Ethanol Content | vol. % | D5599 | <0.1 |
| IBP | °F | D86 | 82 |
| T10 | °F | D86 | 109 |
| T50 | °F | D86 | 194 |
| T90 | °F | D86 | 342 |
| FBP | °F | D86 | 416 |
| DVPE | psi | D5191 | 11.1 |
| Aromatics | vol. % | D1319 | 26.2 |
| Olefins | vol. % | D1319 | 7.7 |
| Benzene | vol. % | D3606 | 0.95 |
| S | mg/kg | D5453 | 15.9 |
| (R + M)/2 | - | Calc. | 87.5 |
| Net Heat of Combustion | Btu/lb | D4809 | 18,734 |

Due to the nature of the randomized test matrix, as well as the incremental addition of test vehicles to the program, there were periods of time when vehicles were not involved in active testing. In an attempt to minimize vehicle maintenance issues due to extended inactivity, those vehicles were operated by an experienced driver once every two weeks over an on-road course around the perimeter of the SwRI campus (Appendix D). Prior to each drive, each vehicle received a brief visual inspection to ensure proper tire inflation and fluid levels. One "lap" was completed, which was approximately 8 miles in length and about 20 minutes in duration. Speed limits ranged from 35 to 45 mph, and the drive included six traffic signals and two stop signs. This task was conducted using an early discarded version of E0 Fuel 5, which was procured prior to use of the EPA-specified fuel development protocol. Properties of this fuel are included in Appendix E.

## 2.3 Crankcase Lubricants

GF-4 category crankcase lubricants of two viscosity grades (5W20 and 5W30) were provided by the Lubrizol Corporation. As mentioned in Section 2.2, lubricants were broken in for 2,000 miles prior to the initiation of Phase 1 of the program. The lubricants remained unchanged throughout the conduct of program Phases 1, 2, and 3. Four-ounce engine oil samples were taken from each vehicle at the start and end of the 2,000-mile lubricant break-in (at the 2,000- and 4,000-mile vehicle break-in intervals), and following emissions testing of the 3rd, 15th, and 27th fuels in the Phase 3 test sequence. The oil samples were shipped in batches to Dr. Ewa Bardasz of Lubrizol for analysis. To accommodate for the oil samples taken over the course of the program, each vehicle's sump was overfilled by 12 ounces during the oil change at the mid-point of the 4,000-mile vehicle break-in. A summary of the oil samples collected and shipped to Lubrizol is given in Appendix F.

### *2.3.1 Ford Explorer Crankcase Lubricant Issues*

An incorrect oil viscosity was used in the Ford Explorer during break-in. Ford specifies 5W-30 grade for the 4.0L V-6 engine and 5W-20 for the 4.6L V-8. The test vehicle was equipped with the 4.0L V-6, and was incorrectly filled with the 5W-20 oil at both the start of mileage accumulation and at the 2,000-mile oil change. The vehicle had accumulated 4,000 miles when this error was discovered. After discussing this situation with all involved parties, the vehicle received a single flush with 5W-30 oil (2 drains and 2 fills with oil filter changes) and an additional 2,000 miles were accumulated on the Ford Explorer to break-in the correct oil.

There also appeared to be an oil level issue with the Explorer. When the oil sample was collected following testing of the 15th fuel, the technician noticed that the oil level was below the minimum oil level on the dip stick. Following extensive discussions with all sponsors, an additional 20 ounces of fresh crankcase lubricant were added to the Ford Explorer before resuming testing. Details of this incident are given in Appendix G.

As a result of this situation, starting in the 22nd week of Phase 3, the oil level on all vehicles was checked monthly. These checks were taken on a level floor inside the emissions lab following a minimum 12-hour soak at room temperature (72°F ± 2°F). Initial results showed the Toyota Camry oil level was between 1/4 and 1/8 of the distance from the fill level to the full level on the dipstick. The oil level of this vehicle was monitored weekly, but did not change during the rest of the program. No other vehicles had oil level issues.

## 2.4 Test Procedure

All vehicle/fuel combinations were tested using the California Unified Cycle, also known as the LA92. For this program, the LA92 was conducted as a three-phase, cold-start test in a manner similar to the FTP, and FTP weighting factors were used to calculate composite emission rates. In order to supplement data being collected during Phase 4 of this test program, the four FFVs were also tested over the FTP cycle, only when operating on E85.

Testing was conducted during the day shift while vehicle preparation, fuel changes, sulfur purges, and conditioning were conducted during a second shift. All vehicle soaks and tests were

conducted at a nominal temperature of 72°F. The representative bulk oil temperature of a vehicle's sump was stabilized to 72°F ± 3°F prior to conducting any emission test.

SwRI made a good faith effort to maintain intake air humidity during testing at 75 ± 5 grains $H_2O$/lb dry air. However, despite substantial time and effort in upgrading and refining our test cell facilities to meet the requested humidity requirements, the system was incapable of maintaining these conditions 100 percent of the time. SwRI was typically able to maintain absolute humidity during testing within the desired range 95 percent of the time. It should be noted that in cases where outdoor ambient conditions were rapidly changing, the system was not able to meet the 95-percent target. SwRI flagged these tests in the test log and provided a humidity quality check metric within each individual test file. Tests where humidity was outside the desired range for more than five percent of the time were reviewed with EPA and NREL, who provided guidance to SwRI regarding whether or not an individual test should be repeated.

Under Phase 1 of the program, SwRI determined and verified PM sample flow rates that provided proportionality. Those same flow rates were used for Phase 3. The CVS blower was kept on for approximately 20 minutes before each emission test in an effort to ensure tunnel stability.

### *2.4.1 Test Matrix*

The test matrix was designed to be randomized for each vehicle/fuel combination. Duplicate tests were conducted "back-to-back", with the option for a third test based on repeatability criteria as detailed below. During the first nine weeks of testing, EPA specified vehicle/fuel assignments in an effort to determine the necessary amount of conditioning to allow a vehicle's fuel control system to adapt to a new ethanol concentration. This involved switching vehicles back and forth between E0 and higher ethanol concentration blends. Development of the vehicle conditioning procedure is discussed in further detail in Section 2.4.3. Once this issue was resolved, vehicle/fuel assignments were made randomly using an EPA-provided algorithm.

Testing started with five E0 fuels as shown in Table 6. Additional fuels were added to the test matrix based on both the requirements of the vehicle conditioning study and on fuel availability. All fuels were available and included in the random matrix starting in the 12$^{th}$ week of testing. Due to funding constraints, only ten vehicles were included in the original test matrix. Two additional vehicles were added to the matrix in the 25$^{th}$ week of testing, and three additional vehicles were added in the 37$^{th}$ week of testing.

## TABLE 6. INCREMENTAL ADDITION OF FUELS AND VEHICLES TO THE TEST MATRIX

| PHASE 3 WEEK | FUELS ADDED | VEHICLES[a] ADDED | VEHICLE/FUEL ASSIGNMENTS |
|---|---|---|---|
| Week 1 | 2, 7, 8, 9 and 15 | CCOB, TCAM, FEXP, DCAL, HODY | EPA |
| Week 2 | None | CSIL, TSIE, DLIB, HCIV, NALT | |
| Week 3 | None | None | |
| Week 4 | 1, 12, 13 | None | |
| Week 5 | None | None | |
| Week 6 | 22, 24 | None | |
| Week 7 | None | None | |
| Week 8 | 3, 4, 5, 11, 14, 16, 20, 21, 23, 30 | None | |
| Week 9 | None | None | |
| Week 10 | None | None | Random for rest of program, except for E85 |
| Week 12 | 6, 10, 25, 26, 27, 28, 31 | None | |
| Week 25 | None | FFOC, SOUT | |
| Week 37 | None | CIMP, F150, TCOR | |
| Week 55 | 29 (E85) | DCAR | Last fuel tested |
| Week 60 | End of Phase 3 testing | | |

[a] - Vehicle designations are explained in Table 3

Each vehicle/fuel combination was tested at least twice. After two tests were completed and the acquired data passed all quality control verifications, the need for a third test was determined by following the variability criteria shown in Table 7. If the ratio of any of the criteria pollutants (THC, $NO_X$, or $CO_2$) on a pair of tests for a given vehicle/fuel combination exceeded the levels shown in Table 7, a third test was conducted. The need for a third test was flagged in the daily test log.

## TABLE 7. REPEATABILITY CRITERIA FOR TRIPLICATE TESTING

| DILUTE GASEOUS EMISSION | CRITERIA FOR REQUIRING A THIRD TEST (COMPOSITE CYCLE EMISSIONS) |
|---|---|
| $CO_2$ | Ratio of higher / lower > 1.03 |
| $NO_X$ | Ratio of higher / lower > 2.7 |
| THC | Ratio of higher / lower > 2.0 |

In addition to emissions repeatability criteria, the following criterion was used to trigger a review of the information related to the cranking events to determine if an additional replicate test was necessary for a given vehicle/fuel combination:

abs(cranking time in test 1 - cranking time in test 2) > 1 sec

These flagged tests were reviewed with EPA and NREL, who provided guidance on the need for additional tests.

### *2.4.2 Drift Checks*

The test program included drift checks that were conducted at the beginning, midpoint, and end of the Phase 3 test matrix. Due to concerns at the beginning of Phase 3 about vehicles properly adapting to different ethanol contents, the drift check procedure was modified. In a best attempt to ensure that the test vehicles were similarly adapted during start-, mid-, and end-point testing, the test matrix was manipulated so the immediate history prior to mid- and end-point testing was substantially similar to that at the beginning of Phase 3.

Specifically, all vehicles were operated on two successive E0 fuels for the first three weeks of testing, which had been immediately preceded by operation on an E20 fuel at the end of Phase 2 of the program. The second E0 fuel for each vehicle was designated as the drift check fuel. With the assistance of EPA, SwRI scheduled mid- and end-point testing to be immediately preceded by an E20 or E15 fuel and then an E0 fuel with properties substantially similar to the first Phase 3 fuel on which each vehicle was tested.

Due to the scheduling of end-point drift checks, five of the original ten vehicles completed testing during Week 34, while the remainder of the original ten vehicles completed testing during Week 37. (Note that the Ford Explorer did not complete end-point testing until much later in the program due to a MIL issue described in Section 3.2.)

### *2.4.3 Vehicle Conditioning*

The vehicle fuel change and conditioning procedure used at the beginning of the program had been developed during the conduct of Phases 1 and 2. However, as EPA analyzed the data from Phases 1 and 2, they determined that the conditioning sequence was not sufficient for one of the vehicles to fully adapt to a new ethanol concentration following a switch from an E20 fuel to an E0 fuel. Therefore, the beginning of Phase 3 included a study to reassess the vehicle conditioning procedure. Long-term fuel trim (LTFT) and short-term fuel trim (STFT) were monitored during the conduct of successive two-phase LA-92 test cycles and were analyzed by EPA for stabilization. Based on the results of this study, all vehicles were conditioned with three successive two-phase LA92s except for the CCOB, NALT, HCIV, HODY, and TCAM, which were all conditioned with five successive two-phase LA92s starting in the third week of testing. Prior to the third week, all vehicles were conditioned with three LA92s. The final vehicle fuel change and conditioning sequence is given in Table 8. OBD data, including LTFT and STFT, were collected during all conditioning runs and were loaded onto the program file transfer site on a daily basis so that they could be accessed and reviewed by EPA and NREL. Example test requests for vehicle conditioning and testing are given in Appendix H.

## TABLE 8. FUEL CHANGE, CONDITIONING, AND TEST EXECUTION SEQUENCE

| STEP | DESCRIPTION |
|---|---|
| 1 | Drain vehicle fuel completely via fuel rail whenever possible. When switching to E85 only, drive vehicle to fully warm up engine. |
| 2 | Turn vehicle ignition to RUN position for 30 seconds (60 seconds when switching to E85) to allow controls to allow fuel level reading to stabilize. Confirm the return of fuel gauge reading to zero. |
| 3 | Turn ignition off. Fill fuel tank to 40% with next test fuel in sequence. Fill-up fuel temperature must be less than 50°F. |
| 4 | Start vehicle and execute catalyst sulfur removal procedure described in Appendix C of CRC E-60 Program report. Apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system. Engine oil temperature in the sump will be measured and recorded during the sulfur removal cycle. |
| 5[a] | Perform four vehicle coast downs from 70 to 30 mph, with the last two measured. If the individual run fails to meet the repeatability criteria established in Phases 1 and 2 of the program, the vehicle will be checked for any obvious and gross source of change in the vehicle's mechanical friction. |
| 6 | Drain fuel and refill to 40% with test fuel. Fill-up fuel must be less than 50°F. |
| 7[b] | Drain fuel again and refill to 40% with test fuel. Fill-up fuel must be less than 50°F. |
| 8 | Soak vehicle for at least 12 hours to allow fuel temperature to stabilize to the test temperature. |
| 9[c] | Move vehicle to test area without starting engine. Start vehicle and perform three 2-phase (bags 1 and 2) LA92 cycles. During these prep cycles, apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system. Following the first two prep cycles, allow vehicle to idle in park for two minutes, then shut-down the engine for 2-5 minutes. Following the last prep cycle, allow the vehicle to idle for two minutes, then shut down the engine in preparation for the soak. |
| 10 | Move vehicle to soak area without starting the engine. |
| 11 | Park vehicle in soak area at proper temperature (75 °F) for 12-36 hours. During the soak period, maintain the nominal charge of the vehicle's battery using an appropriate charging device. |
| 12 | Move vehicle to test area without starting engine. |
| 13 | Perform LA92 cycle emissions test. |
| 14 | Move vehicle to soak area without starting the engine. |
| 15 | Park vehicle in soak area of proper temperature for 12-36 hours. During the soak period, maintain the nominal charge of the vehicle's battery using an appropriate charging device. |
| 16 | Move vehicle to test area without starting the engine. |
| 17 | Perform LA92 emissions test. |
| 18 | Determine whether third replicate is necessary, based on data variability criteria (see Table 6). |
| 19 | If a third replicate is required, repeat steps 14, 15, 16 and 17. |
| 20 | If third replicate is not required, return to step 1 and proceed with next vehicle in test sequence. |

a – Vehicle coastdown repeatability criteria referred to in Step 5 were provided by EPA as follows:

- maximum difference of 0.5 seconds between back-to-back coastdown runs from 70 to 30 mph
- maximum ±7 percent difference in average 70 to 30 mph coastdown time from the running average for a given vehicle

b – Some vehicles received only two fuel drains and fills, i.e. Step 7 was skipped. See section 3.4 for details.

c – Conduct five 2-phase LA92 test cycles for the following vehicles: CCOB, NALT, HCIV, HODY, and TCAM.

### *2.4.4 Chassis Dynamometer*

All tests were conducted using a Horiba 48-inch single-roll electric chassis dynamometer. A single test site and a single test driver were used for this entire program. Different drivers were used for sulfur purges and vehicle conditioning. The dynamometer electrically simulates inertia weights up to 12,000 lb over the FTP test cycle, and provides programmable road load simulation of up to 150 hp continuous at 65 mph.

Chassis dynamometer settings were derived from target road load coefficients as reported in EPA's on-line Test Car List Data Files. Target road load coefficients and subsequently-derived chassis dynamometer settings were approved by EPA prior to the initiation of testing (Table 9).

**TABLE 9. VEHICLE CHASSIS DYNAMOMETER SETTINGS**

| MODEL YEAR | MAKE | BRAND | MODEL | NAME | ETW, lbs | TARGET COEFFICIENTS | | | SET COEFFICIENTS | | | ROAD LOAD HP @ 50 mph |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | A, lbs | B, lbs/mph | C lbs/mph$^2$ | A, lbs | B, lbs/mph | C lbs/mph$^2$ | |
| 2008 | GM | Chevrolet | Cobalt | CCOB | 3,125 | 21.51 | 0.5409 | 0.01521 | 4.22 | 0.20100 | 0.017055 | 11.5 |
| 2008 | GM | Chevrolet | Impala FFV | CIMP | 3,875 | 19.87 | 0.4397 | 0.01752 | 8.320 | 0.11210 | 0.018601 | 11.4 |
| 2008 | GM | Saturn | Outlook | SOUT | 5,000 | 38.61 | 0.3921 | 0.02818 | 19.860 | 0.07430 | 0.030294 | 17.2 |
| 2008 | GM | Chevrolet | C1500 Silverado FFV | CSIL | 5,500 | 28.80 | 0.8005 | 0.03219 | 18.130 | 0.31630 | 0.035662 | 19.9 |
| 2008 | Toyota | Toyota | Corolla | TCOR | 2,875 | 22.10 | 0.1500 | 0.01886 | 8.080 | -0.02580 | 0.020902 | 10.2 |
| 2008 | Toyota | Toyota | Camry | TCAM | 3,625 | 29.16 | 0.1659 | 0.01844 | 10.110 | -0.15630 | 0.019592 | 11.1 |
| 2008 | Toyota | Toyota | Sienna | TSIE | 4,500 | 38.41 | 0.0249 | 0.02946 | 16.270 | -0.12110 | 0.029718 | 15.1 |
| 2008 | Ford | Ford | Focus | FFOC | 3,000 | 27.66 | 0.2892 | 0.01697 | 15.240 | 0.07660 | 0.018743 | 11.3 |
| 2008 | Ford | Ford | Explorer | FEXP | 4,750 | 32.35 | 0.6076 | 0.02716 | 14.350 | 0.43360 | 0.028153 | 17.4 |
| 2008 | Ford | Ford | F150 FFV | F150 | 5,250 | 27.26 | 0.9495 | 0.02932 | 4.300 | 0.83540 | 0.029383 | 19.7 |
| 2008 | Chrysler | Dodge | Caliber | DCAL | 3,500 | 52.75 | -0.3153 | 0.02826 | 15.990 | -0.20400 | 0.025692 | 14.4 |
| 2008 | Chrysler | Dodge | Caravan FFV | DCAR | 4,750 | 35.94 | 0.6505 | 0.02155 | 18.470 | 0.30710 | 0.023981 | 16.3 |
| 2008 | Chrysler | Jeep | Liberty | JLIB | 4,250 | 29.53 | 0.4040 | 0.02955 | 9.410 | 0.13330 | 0.031781 | 16.5 |
| 2008 | Honda | Honda | Civic | HCIV | 3,000 | 23.18 | 0.1904 | 0.01699 | 8.120 | 0.05150 | 0.017724 | 10.0 |
| 2008 | Honda | Honda | Odyssey | HODY | 4,750 | 28.70 | 0.6915 | 0.02167 | 11.170 | 0.24850 | 0.024710 | 15.7 |
| 2008 | Nissan | Nissan | Altima | NALT | 3,500 | 47.47 | -0.4531 | 0.02414 | 19.710 | -0.30660 | 0.021358 | 11.4 |

## 2.5 Regulated and Unregulated Emissions

The emissions measured and reported were THC, NMHC (by FID), NMOG, $NO_X$, $NO_2$, CO, $CO_2$, PM, alcohols, carbonyl compounds, and speciated hydrocarbons. Details on measurement accuracy and precision, sampling and analytical methods, sample handling and custody, equipment, calibrations, and quality control are provided in Appendix I.

Gaseous emissions were determined in a manner consistent with EPA protocols for light-duty emission testing as given in the CFR, Title 40, Part 86. A constant volume sampler was used to collect proportional dilute exhaust in Kynar bags for analysis of carbon monoxide (CO), carbon dioxide ($CO_2$), total hydrocarbons (THC), methane ($CH_4$), and oxides of nitrogen ($NO_X$). For the determination of particulate matter (PM) mass emissions, a proportional sample of dilute exhaust was drawn through Whatman Teflon membrane filters. The PM sampling method was compliant to CFR, Title 40, Part 1065.

In addition to the dilute, bagged exhaust samples, continuous raw exhaust mass emissions rates were measured on a second-by-second basis for THC, $CH_4$, CO, $NO_X$, $CO_2$ and $O_2$ at the tailpipe. These measurements were performed during the first test of each vehicle/fuel combination at a sampling frequency of 1 Hz. Dilution air flow was measured with a smooth approach orifice, and a critical flow venturi measured bulkstream dilute exhaust flow. Measured dilution air flow was subtracted from the bulkstream flow to calculate raw exhaust flow to determine continuous raw mass emission rates.

Additionally, select alcohols and carbonyls were measured during emission tests. The measurement of alcohols in exhaust was accomplished by bubbling the exhaust through glass impingers containing deionized water after which samples were analyzed by gas chromatography. An HPLC procedure was utilized for the analysis of carbonyls. Samples were collected using DNPH cartridges and were extracted with acetonitrile. Speciated hydrocarbons were determined by gas chromatography.

Exhaust emissions were measured as shown below.

| **CONSTITUENT** | **ANALYSIS METHOD** |
|---|---|
| Total Hydrocarbon | Heated Flame Ionization Detector (bag, modal) |
| Methane | Gas Chromatography (bag, modal) |
| Carbon Monoxide | Non-Dispersive Infrared Analysis (bag, modal) |
| Carbon Dioxide | Non-Dispersive Infrared Analysis (bag, modal) |
| Oxides of Nitrogen | Chemiluminescence Analysis (bag, modal) |
| Nitric Oxide | Chemiluminescence Analysis (bag only) |
| Oxygen | Magnetopneumatic Detector (modal only) |
| Particulate Matter | Part 1065 Gravimetric Measurement (bag only) |
| Non-methane Hydrocarbons | Calculated from THC and $CH_4$ (bag, modal) |
| Non-methane Organic Gases | Calculated as specified in Section 2.5.2 (bag only) |
| Nitrogen Dioxide | Calculated from difference of $NO_X$ and NO (bag only) |
| $C_1 - C_{12}$ HC Speciation | Gas Chromatography (bag only) |
| Alcohols | Gas Chromatography (bag only) |
| Carbonyls | Liquid Chromatography (bag only) |

During Phases 1 and 2 of the test program, continuous raw $NH_3$ measurements were made. Results showed $NH_3$ spikes of several hundred ppm during testing of many vehicles. These concentrations were sufficient to cause poising of the $NO_2$-to-NO converter in the continuous raw $NO_X$ analyzer. In an attempt to minimize this problem, prior to the start of Phase 3 SwRI installed two $NH_3$ adsorbers in series upstream of the continuous raw emission measurement sample train. These adsorbers were changed daily. Additionally, the $NO_2$-to-NO converter was purged with 5,000-ppm (nominal) $NO_X$ for five minutes following every test in an effort to reverse any $NH_3$ poising of the converter that may have occurred during testing. The $NO_X$ analyzer was then purged for another three minutes with zero nitrogen prior to initiating the normal pre-test zero-span sequence.

### *2.5.1 Speciation of Volatile Organic Compounds*

Phase-level (bag-by-bag) speciated volatile organic compounds (VOCs) included $C_1$ - $C_{12}$ hydrocarbons, light alcohols, aldehydes, and ketones. Sampling and analysis of $C_2$-$C_{12}$ hydrocarbons was conducted in a manner similar to CARB method 1002/1003, "Procedure for the Determination of $C_2$-$C_{12}$ Hydrocarbons in Automotive Exhaust Samples by Gas Chromatography". Sampling and analysis of alcohols was done in a manner similar to CARB method 1001, "Determination of Alcohols in Automotive Source Samples by Gas Chromatography". Sampling and analysis of carbonyl compounds was conducted in a manner similar to CARB method 1004, "Determination of Aldehyde and Ketone compounds in Automotive Source Samples by High Performance Liquid Chromatography". Analysis of $C_2$ - $C_4$ HC samples was conducted within one hour of completion of an emissions test. Subsequent analysis of the additional compounds of interest was done within 4 hours of emission test completion.

During the analysis of $C_2$ - $C_4$ hydrocarbons, special consideration was given to 1,3-butadiene. Because of the instability of 1,3-butadiene, the analysis of $C_2$ - $C_4$ hydrocarbon samples collected during Bag 1 of a test cycle was initiated within one hour of collection. The speciation of $C_5$ - $C_{12}$ hydrocarbon samples collected in Bag 1 of the test cycle was completed within 4 hours of collection.

Sampling and analysis of light alcohols was accomplished by bubbling exhaust through glass impingers containing deionized water, and samples were analyzed with a gas chromatograph. Analysis included the following compounds: methanol, ethanol, isopropanol, and n-propanol. Alcohol samples were sealed and stored at a temperature below 40°F immediately following collection. Most of these samples were analyzed on the day they were collected, but no later than within six calendar days.

Samples of carbonyl compounds were collected in cartridge type samplers. These samples were extracted immediately following collection (within 15 minutes) and the extracts sealed and stored immediately at a temperature below 40°F. Most of these extracts were analyzed on the day they were collected, but no later than within three calendar days. An effort was made to detect the presence of a tautomer of acrolein, acrolein-x, which can be a measurement artifact. No acrolein-x was found in any exhaust sample.

Storage of alcohol and carbonyl samples was segregated to prevent any cross-contamination of samples.

The speciation schedule was conducted as shown in Table 10. Alcohols and carbonyls were determined during Bag 1 for all tests. In addition, Bag 1 $C_1$-$C_{12}$ speciation was performed on the first test of all vehicles while operating on Fuels 3, 4, 6, 7, 10, 13, 14, 21, 23, 27, 28, and 31. For the Honda Civic, Toyota Corolla, Chevrolet Impala, Ford F150, and Chevrolet Silverado, three-bag speciation was conducted with these fuels on the first test. Three-bag speciation was also conducted on all E85 tests.

## TABLE 10. VOC SPECIATION SCHEDULE

| Test Phase (Bag) | Test Repeat | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Test 1 | | | Test 2 | | | Test 3 (If Needed) | | |
| | Fuel Set A[a] | Fuel Set B[b] | E85 Fuel[c] | Fuel Set A[a] | Fuel Set B[b] | E85 Fuel[c] | Fuel Set A[a] | Fuel Set B[b] | E85 Fuel[c] |
| 1 | Alcohols Carbonyls | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls | Alcohols Carbonyls | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls | Alcohols Carbonyls | $C_1$-$C_{12}$ Speciation[d] Alcohols Carbonyls | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls |
| 2 | none | $C_1$-$C_{12}$ Speciatione[e] Alcohols[e] Carbonyls[e] | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls | none | $C_1$-$C_{12}$ Speciation[d,e] Alcohols[d,e] Carbonyls[d,e] | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls | none | $C_1$-$C_{12}$ Speciation[d,e] Alcohols[d,e] Carbonyls[d,e] | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls |
| 3 | none | $C_1$-$C_{12}$ Speciatione[e] Alcohols[e] Carbonyls[e] | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls | none | $C_1$-$C_{12}$ Speciation[d,e] Alcohols[d,e] Carbonyls[d,e] | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls | none | $C_1$-$C_{12}$ Speciation[d,e] Alcohols[d,e] Carbonyls[d,e] | $C_1$-$C_{12}$ Speciation Alcohols Carbonyls |

[a] – Fuel Set A: Fuels 1, 2, 5, 8, 9, 11, 12, 15, 16, 20, 22, 24, 25, 26, & 30
[b] – Fuel Set B: Fuels 3, 4, 6, 7, 10, 13, 14, 21, 23, 27, 28, & 31
[c] – Three-bag speciation conducted on all E85 tests
[d] – $C_1$-$C_{12}$ speciation conducted only if results from Test 1 were void
[e] – Only the Honda Civic, Toyota Corolla, Chevrolet Impala, Ford F150, and Chevrolet Silverado received three-bag speciation

The following daily sequence was used for the analysis of VOC samples:

- VOC samples collected during Bag 1 of the test cycle were analyzed first, in the sequence of vehicle tests.
- If a vehicle requiring VOC sampling during all three bags of the test cycle was tested, the Bag 1 was analyzed first, followed immediately by the Bag 3 sample and finally by the Bag 2 sample.
- Background samples were analyzed last, in the sequence of vehicle tests.

### *2.5.2 Determination of NMOG*

An EPA-provided protocol for calculating NMHC and NMOG (Appendix J) was followed. Bag-level NMHC and NMOG were calculated for all bags where the required measurements were available. In cases where one or more components of the bag-level NMHC and NMOG calculation were not measured (for example, when alcohols and carbonyls were not measured in Bags 2 and 3), bag-level NMHC and NMOG mass emissions were calculated assuming the missing measurements were below method detection limits. These bag-level NMHC and NMOG calculations were then used to calculate composite weighted NMHC and NMOG mass emissions.

During the early conduct of Phase 3, SwRI observed media interferences that impacted our limits of detection (LOD) and limits of quantification (LOQ) for alcohols and carbonyls. In conjunction with EPA and NREL, SwRI developed an LOD/LOQ determination method which accounted for these media interferences (Appendix K).

## 2.6 OBD Data

Additional available data were acquired at 1 Hz from each vehicle's onboard diagnostic (OBD) system during all emissions tests using a DBK70 data acquisition system. The data, when available, included:

- RPM
- Vehicle speed
- Engine load
- Short term fuel trim-bank 1
- Long term fuel trim-bank 1
- MIL status
- Absolute throttle position
- Engine coolant temperature
- Short term fuel trim-bank 2
- Long term fuel trim-bank 2
- Fuel/air commanded equivalence ratio
- Alcohol fuel percent (if available)
- Manifold absolute pressure
- Spark advance
- PID $42 Control Module Voltage
- Air flow rate from mass air flow sensor

# 3.0 ISSUES ENCOUNTERED WHILE TESTING

## 3.1 Ford Explorer Low Oil Level

At one point during the course of the program, 20 ounces of crankcase lubricant had to be added to the sump. This issue is detailed in Section 2.3.1.

## 3.2 Ford Explorer Evaporative System MIL

During the 27th week of testing, the Ford Explorer illuminated a malfunction indicator light (MIL – a.k.a. "check engine light") for diagnostic trouble code (DTC) P0455-Evaporative Emission System Leak Detected (Gross Leak/No flow). This started a series of troubleshooting events that are summarized in Table 11. On-road testing seemed to indicate that code was not due to the fuel change procedure or operation of the vehicle on the chassis dynamometer. Following extensive discussions that included Dominic DiCicco of Ford, the team decided that the MIL would not have an adverse affect on emissions testing, and the vehicle was placed back into the test matrix.

**TABLE 11. TROUBLESHOOTING OF THE FORD EXPLORER EVAPORATIVE SYSTEM MIL**

| DATE | ACTION |
|---|---|
| 9/16/2009 | Fuel change to E20 Fuel 31; key off |
| 9/17/2009 | MIL light during vehicle conditioning, E20 Fuel 31; PO455-Evaporative Emission System Leak Detected (Gross Leak/ No Flow) |
| 9/23/2009 | Vehicle sent to dealer; performed a smoke test; Canister vent solenoid replaced |
| 9/26/2009 | Fuel change to E20 Fuel 21; key off |
| 9/27/2009 | MIL light during vehicle conditioning, E20 Fuel 21; PO455-Evaporative Emission System Leak Detected (Gross Leak/ No Flow) |
| 10/5/2009 | Vehicle sent to dealer; performed a smoke test; capless fuel filler door was cleaned as it had dirt and grime |
| 10/12/2009 | Fuel change to E20 Fuel 21; key off |
| 10/13/2009 | MIL light during vehicle conditioning, E10 Fuel 12; PO455-Evaporative Emission System Leak Detected (Gross Leak/ No Flow) |
| 10/16/2009 | SwRI performed an IDS test and a smoke test and a leak test by pressurizing the evap system and found no leaks. |
| 10/26/2009 | FEXP was taken to the test track where we ran 9 WOT up to 70 mph. The MIL did not light. The next day we ran through the three LA 92 (2-bag) prep sequence on the dyno. The MIL did light approximately 500 seconds (~24 miles) into the third LA 92. This means the fuel change procedure is probably not the cause for the MIL. |
| 10/28/2009 | Vehicle was driven on road approximately 50 miles. Pending code P0422, but no MIL light |
| 11/20/2009 | Vehicle sent to the dealer; The EVAP system was smoke tested and the capless fuel assembly was replaced. I was told that the technician drove the vehicle for more than 10 miles to confirm that the code did not reappear. |
| 11/21/2009 | Fuel change to E15 Fuel 28; key off |
| 11/22/2009 | MIL light during vehicle conditioning, E15 Fuel 28; PO455-Evaporative Emission System Leak Detected (Gross Leak/ No Flow) |
| 12/1/2009 | Dealership performed IDS Diagnosis, PO455 code. EVAP test found capless retainer broken. Replaced retainer and retested ok. |
| 12/8/2009 | MIL light during vehicle conditioning, E15 Fuel 28; PO455-Evaporative Emission System Leak Detected (Gross Leak/ No Flow) |

Following Phase 3 testing, SwRI performed additional evaporative system leak checks with an IDS scan tool per instructions given by Ford, and the data files were forwarded to Ford for review. Subsequent coordination among SwRI, Ford, and our local Ford dealership allowed us to determine that the FTP sensor had an internal fault causing the signal to become erratic during vehicle operation, after which the vehicle was repaired.

### 3.3 Saturn Outlook Transmission Module Malfunction

A MIL illuminated during the second test of Fuel 16 with the Saturn Outlook. The diagnostic trouble codes (DTCs) were Tran Control Sys Malfunction and U0073 - Control Module Comm. Bus Off. The same codes illuminated while operating the vehicle on the mileage accumulation dynamometer during the initial vehicle break-in. At that time, the vehicle was taken to the dealership where the codes were cleared. The vehicle was driven 10 miles but the codes did not reappear. The Saturn Outlook then completed mileage accumulation and was tested on six fuels in Phases 1 and 2.

Review of the emissions results from the two tests on Fuel 16 did not show a significant difference. With EPA's and NREL's approval, the codes were cleared and the vehicle was placed back into the test program. Four days later, the MIL came on again during testing, with the same DTCs. This time the driver noticed that the vehicle's engine was revving higher than usual at cruising speeds and shifting hard during the first two bags. Bag 3 did not have the same issues. With EPA's and NREL's approval, the vehicle was taken to the dealer for diagnosis, but they were not able to find any problems. There was concern that the DBK system used to collect OBD data may have somehow been interfering with proper vehicle operation. The next set of tests was conducted without OBD data acquisition, and the MIL did not illuminate. All subsequent tests were conducted without OBD data acquisition, and the MIL did not illuminate.

### 3.4 Fuel Carryover

On May 27, 2009, SwRI noticed an issue with results for the Nissan Altima tested on Fuel 13. Fuel 13 was an E0 fuel, yet we found low levels of ethanol in exhaust samples from both tests. We checked the original fuel sample from the drum used to fuel the vehicle, and also pulled a sample from the vehicle. Both samples were tested with the PetroSpec portable gasoline analyzer. The drum sample showed no ethanol and the vehicle's fuel tank showed 1.5 wt% ethanol. This suggested fuel carryover in the Altima. This sample was sent to EPA for analysis by ASTM D5599 method and was found to contain 1.44 vol% of ethanol, equivalent to a fuel carryover rate of 7.2% following two drains and 40% fills. This ethanol concentration indicated that approximately 3 gallons of the previous fuel remained in Altima's tank after it has been drained via the fuel rail. From this point forward, except for mid- and end-point tests, the Altima received three fuel flushes during the fuel change sequence.

SwRI checked the rest of the Phase 3 results for the Altima, Camry, Odyssey, and Civic. All vehicles showed measurable levels of ethanol when testing with an E0 fuel that was immediately preceded by an E20 fuel.

To better understand this situation, SwRI collected fuel samples during tests leading up to mid-point testing, when all vehicles changed from an E15/E20 fuel to an E0 fuel. SwRI's and EPA's analyses of ethanol content in the samples by D5599 indicated that the following percentages of the previous fuel were retained in the tanks of the test vehicles following fuel changes which included two drains and 40% fills:

- Honda Odyssey: 8.8 vol%
- Toyota Sienna: 5.0 vol%
- Honda Civic: 4.2 vol%
- Nissan Altima: 6.1 vol%
- Toyota Camry: 5.3 vol%
- All remaining vehicles: 2.1 vol% to 3.2 vol%

Based on these results, EPA and NREL directed SwRI to prepare several 95%/5% and 5%/95% blends of the test fuels with the most extreme combinations of distillation properties and ethanol content to determine the effect of 5% fuel carryover on T50, T90 and RVP. The fuel sampling procedure used during these experiments is given in Appendix L, while the test matrix is given in Appendix M.

Because the two results from the Altima had such a wide spread (3.7% vs. 7.2%), SwRI performed additional refueling experiments with the Altima, Odyssey, Camry, Civic, and Sienna to determine the variability of fuel carryover measurements. These experiments showed that a third fuel flush was effective in reducing fuel carryover to less than one percent. The procedure and results are given in Appendix N. Based on these results, starting on August 1, 2010, SwRI incorporated a third fuel drain and fill into the vehicle change procedure for the Altima, Odyssey, Sienna, Civic, and Camry.

Fuel carryover was characterized for the Focus, Outlook, Impala, F-150, and Corolla before they were added to the test matrix. Based on results, these five vehicles received triple drains and fills during fuel changes.

As part of the investigation into fuel carryover, EPA was interested in the impact of different refueling locations on in-tank fuel carryover. Starting in August 2009, all vehicles were refueled in an assigned location. However, early in the conduct of Phase 3, refueling of a test vehicle may have occurred in one of two locations. Each location was sloped in a different direction, which may have affected the amount of fuel remaining in a vehicle's tank after being drained. These additional refueling experiments were conducted with the Silverado, Camry, Sienna, Caliber, Civic, Odyssey, and Altima. They involved collecting fuel samples at the two different refueling locations while changing between and E0 and an E20 fuel. The test procedure is given in Appendix O. The results of these experiments were provided to EPA for further analysis.

# 4.0 CLOSURE

SwRI conducted exhaust emission testing of fifteen light-duty vehicles operating on twenty-seven test fuels with ethanol contents ranging from 0 to 20 percent by volume and four light-duty flexible fuel vehicles (FFVs) operating on an E85 fuel, as part of Phase 3 of the EPAct/V2/E-89 test program. Vehicle testing for this phase of the program was carried out between March 2009 and June 2010. This work was conducted for the Environmental Protection Agency (EPA), the National Renewable Energy Laboratory (NREL) and the Coordinating Research Council (CRC) and was authorized by EPA Contract EP-C-07-028, Work Assignments 1-03, 2-03 and 3-01, and NREL Subcontract Nos. ACI-8-88613-01, AFT-9-99319-01 and AFT-9-99155-01.

All test results have been posted on SwRI's secure file transfer site to which both EPA and NREL have access.

# APPENDIX A

# FUEL CHANGE PROCEDURE

# Fuel Change Procedure / Coastdown Sequence
# EPAct Test Fleet
# 03.14936.03.202

**Date: Tuesday, January 19, 2010** **Vehicle: Chevrolet Impala FFV : EPA-CIMP**

**Test #: EPA-CIMP-P3-27-3FC** **Fuel #: 27**

**First Fuel Change**

□ With key off, drain fuel from vehicle

□ drain until fuel flow drops off. Stop drain immediately. **DO NOT OVERDRAIN.**
Turn ignition to run position for 30 seconds allowing fuel gauge level to stabilize.

□ Confirm fuel level reads zero. If gage does not read zero, use the Bosch scan tool to verify fuel level.

□ Turn ignition key off.

□ Locate fuel drum:

| | |
|---|---|
| **EPA Fuel No.** | **27** |
| **SwRI Fuel Name** | **BOS** |
| **SwRI Fuel Code** | **EM-7095-F** |
| **Drum No.** | |

(Record Drum Number)

Verify fuel fill drum matches using "2-person rule"

Initials: _____, _____

Verify fuel temperature: _____ should be 45 ± 2 °F

□ Fill tank with **6.8** gallons of fuel. Record time _____.

□ Record fuel information from box above on vehicle windshield.

□ Place fuel drum back into cold box.

□ PUSH vehicle into lab within 10 minutes of refueling. Record time _____.

□ Install vehicle on Dyno. Record drive wheel tire pressures. RT_____ LF_____.

□ Connect the correct transfer pipe to the vehicle and run out the roof with flex pipe.

□ Place cooling fans to cool the exhaust.

# Fuel Change Procedure / Coastdown Sequence
## EPAct Test Fleet
## 03.14936.03.202

**Date: Tuesday, January 19, 2010** **Vehicle: Chevrolet Impala FFV : EPA-CIMP**

**Test #: EPA-CIMP-P3-27-3FC** **Fuel #: 27**

- □ Dyno computer setup procedure
- □ Horiba trace setup procedure
- □ Connect thermocouple #1 to record oil temperature.
- □ Start the vehicle. Idle in neutral. Using the OBD scan tool, read and record the long term fuel trim
- □ Run the sulfur purge procedure described on the last page.
- □ Record sulfur purge completion time. _____
- □ Place vehicle in neutral with engine idling. Using the OBD scan tool, read and record the long term fuel trim
- □ Within 5 minutes of completing the sulfur purge procedure begin coast downs. Use the speed range from 70 - 10 mph and record in 5 mph increments.
- □ Coast down 1.
- □ Coast down 2.
- □ Coast down 3, print.
- □ Coast down 4, print.
- □ Type the coastdown data from runs 3 and 4 into the coastdown analysis Excel program. If the program notes a repeatability failure, check for incorrect inputs. **If repeatability cannot be accomplished, remove vehicle and begin fuel change procedure on backup vehicle** and notify supervisor. If test repeatability is indicated OK, continue with this procedure.
- □ Remove vehicle from dyno and move to the fuel drain area.

# Fuel Change Procedure / Coastdown Sequence
## EPAct Test Fleet
## 03.14936.03.202

**Date:** Tuesday, January 19, 2010 **Vehicle#:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-27-3FC **Fuel #:** 27

**Second Fuel Change**

□ Drain fuel from vehicle until flow drops off. Stop drain immediately.
**DO NOT OVERDRAIN.**

Turn ignition to run position for 30 seconds allowing fuel gauge level to stabilize.

□ Confirm fuel level reads zero. If gage does not read zero, use the Bosch scan tool to verify fuel level.

□ Locate fuel drum:

| | |
|---|---|
| EPA Fuel No. | 27 |
| SwRI Fuel Name | BOS |
| SwRI Fuel Code | EM-7095-F |
| Drum No. | |

(Record Drum Number)

Verify fuel fill drum matches using "2-person rule"

Initials: _____, _____

Verify fuel temperature: _____ should be 45 ± 2 °F

□ Fill tank with 6.8 gallons of fuel. Record time _____.

Note: **For vehicles HODY, NALT, TSIE, HCIV, TCAM**

These vehicles (only) require a third fuel change. If you are not working on one of these five vehicles, skip the third fuel change and return fuel drum to the cold box.

# Fuel Change Procedure / Coastdown Sequence
## EPAct Test Fleet
## 03.14936.03.202

**Date: Tuesday, January 19, 2010** **Vehicle#: Chevrolet Impala FFV : EPA-CIMP**

**Test #: EPA-CIMP-P3-27-3FC** **Fuel #: 27**

**Third Fuel Change For Odyssey, Altima, Sienna, Civic, and Camry only.**

☐ Drain fuel from vehicle until flow drops off. Stop drain immediately.
**DO NOT OVERDRAIN.**

☐ Turn ignition to run position for 30 seconds allowing fuel gauge level to stabilize.

☐ Locate fuel drum:

| | |
|---|---|
| **EPA Fuel No.** | **27** |
| **SwRI Fuel Name** | **BOS** |
| **SwRI Fuel Code** | **EM-7095-F** |
| **Drum No.** | |

(Record Drum Number)

Verify fuel fill drum matches using "2-person rule"

Initials: _____, _____

Verify fuel temperature: _____ should be 45 ± 2 °F

☐ Fill tank with **6.8** gallons of fuel. Record time _____.

☐ Place fuel drum back into cold box.

☐ PUSH vehicle into lab and park in 75° F soak area for at least 12 hours..

Lead Technician's Signature:_____

# Fuel Change Procedure / Coastdown Sequence
## EPAct Test Fleet
## 03.14936.03.202

**Date:** Tuesday, January 19, 2010 **Vehicle#:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-27-3FC **Fuel #:** 27

| SULFUR PURGE PROCEDURE | | |
|---|---|---|
| □ idle | 30 seconds | |
| □ 55 mph | 5 minutes | |
| □ 30 mph | 1 minute | |
| □ WOT acceleration | >5 seconds | >70 mph |
| □ hold speed | 15 seconds | |
| □ 30 mph | 1 minute | |
| □ WOT acceleration | >5 seconds | >70 mph |
| □ hold speed | 15 seconds | |
| □ 30 mph | 1 minute | |
| □ WOT acceleration | >5 seconds | >70 mph |
| □ hold speed | 15 seconds | |
| □ 30 mph | 1 minute | |
| □ WOT acceleration | >5 seconds | >70 mph |
| □ hold speed | 15 seconds | |
| □ 30 mph | 1 minute | |
| □ WOT acceleration | >5 seconds | >70 mph |
| □ hold speed | 15 seconds | |
| □ 30 mph | 1 minute | |
| □ idle | 30 seconds | |
| □ 55 mph | 5 minutes | |
| □ 30 mph | 1 minute | |
| □ WOT acceleration | >5 seconds | >70 mph |
| □ hold speed | 15 seconds | |
| □ 30 mph | 1 minute | |
| □ WOT acceleration | > 5 seconds | >70 mph |
| □ hold speed | 15 seconds | |
| □ 30 mph | 1 minute | |
| □ WOT acceleration | >5 seconds | >70 mph |
| □ hold speed | 15 seconds | |
| □ 30 mph | 1 minute | |
| □ WOT acceleration | >5 seconds | >70 mph |
| □ hold speed | 15 seconds | |
| □ 30 mph | 1 minute | |
| □ WOT acceleration | >5 seconds | >70 mph |
| □ hold speed | 15 seconds | |
| □ 30 mph | 1 minute | |
| □ idle | 30 seconds | |


R:\03Projects\DEER\03-13363_EPA\Forms (Lab Check Lists)\2010 01-29\Fuel Change 2.xls
Revised 12/01/2009. Julia DeGrace

# APPENDIX B

# PETROSPEC RESULTS FOR INDIVIDUAL FUEL DRUMS

## Petrospec Analysis on EPAct Fuels

| Updated 6/22/10 | Top/Bottom | Drum No. | Ethanol content (% vol) | Aromatic content (% vol) | T90 (°F) |
|---|---|---|---|---|---|
| **Fuel 1** | Top | 2 | 11.7 | 15.3 | 307 |
| | Top | 3 | 11.6 | 15.6 | 308 |
| | Bottom | 6 | 11.7 | 15.9 | 319 |
| | Top | 7 | 11.7 | 15.8 | 321 |
| **Fuel 2** | Top | 3 | 0.0 | 15.4 | 294 |
| | Bottom | 4 | 0.0 | 14.9 | 322 |
| | Top | 5 | 0.0 | 15.1 | 325 |
| | Top | 6 | 0.0 | 15.9 | 332 |
| | Top | 7 | 0.0 | 15.3 | 327 |
| | Top | 2 | 0.0 | 14.8 | 333 |
| | Top | 8 | 0.0 | 16.7 | 332 |
| **Fuel 3** | Top | 4 | 12.0 | 15.6 | 314 |
| | Top | 5 | 12.0 | 15.7 | 319 |
| | Bottom | 6 | 12.0 | 15.8 | 324 |
| | Bottom | 7 | 12.1 | 11.1 | 323 |
| | Top | 2 | 12.0 | 15.6 | 315 |
| | Top | 3 | 11.9 | 18.5 | 314 |
| **Fuel 4** | Top | 2 | 11.4 | 16.8 | 323 |
| | Top | 3 | 11.3 | 16.7 | 326 |
| | Top | 7 | 11.4 | 16.8 | 336 |
| | Top | 5 | 11.4 | 17.1 | 332 |
| | Top | 8 | 11.4 | 17.3 | 335 |
| **Fuel 5B** | Top | 1 | 0.0 | 37.2 | 323 |
| **Fuel 5** | Top | 3 | 0.0 | 37.3 | 323 |
| | Bottom | 5 | 0.0 | 42.0 | 307 |
| | Bottom | 5 | 0.0 | 37.5 | 329 |
| | Top | 4 | 0.0 | 41.8 | 304 |
| | Top | 8 | 0.0 | 37.3 | 340 |
| | Bottom | 7 | 0.0 | 37.6 | 332 |
| **Fuel 6** | Top | 4 | 12.3 | 16.7 | 323 |
| | Bottom | 5 | 12.2 | 16.8 | 320 |
| | Top | 3 | 12.3 | 16.3 | 315 |
| | Top | 6 | 12.4 | 16.7 | 317 |
| **Fuel 7** | Top | 2 | 0.0 | 18.0 | 321 |
| | Top | 3 | 0.0 | 18.2 | 321 |
| | Top | 4 | 0.0 | 18.0 | 319 |
| | Top | 1 | 0.0 | 16.7 | 321 |
| | Top | 9 | 0.0 | 18.5 | 328 |
| | Top | 7 | 0.0 | 18.2 | 328 |
| | Bottom | 8 | 0.0 | 18.7 | 341 |
| | Top | 5 | 0.0 | 18.8 | 323 |
| **Fuel 8** | Top | 2 | 0.0 | 17.0 | 320 |
| | Top | 3 | 0.0 | 16.8 | 321 |
| | Top | 4 | 0.0 | 16.7 | 326 |
| | Top | 1 | 0.0 | 16.7 | 321 |
| | Top | 7 | 0.0 | 17.0 | 331 |
| **Fuel 9** | Top | 2 | 0.0 | 35.8 | 327 |
| | Top | 4 | 0.0 | 36.3 | 329 |
| | Top | 3 | 0.0 | 36.0 | 333 |
| | Top | 5 | 0.0 | 36.2 | 328 |
| | Top | 1 | 0.0 | 34.9 | 331 |
| | Top | 7 | 0.0 | 36.5 | 340 |
| | Top | 8 | 0.0 | 36.5 | 344 |
| | Bottom | 7 | 0.0 | 36.8 | 338 |

## Petrospec Analysis on EPAct Fuels

| Updated 6/22/10 | Top/Bottom | Drum No. | Ethanol content (% vol) | Aromatic content (% vol) | T90 (°F) |
|---|---|---|---|---|---|
| **Fuel 10** | Bottom | 1 | 11.3 | 36.9 | 304 |
| | Top | 1 | 11.2 | 34.9 | 331 |
| | Top | 2 | 11.2 | 35.1 | 330 |
| | Bottom | 3 | 11.2 | 35.0 | 331 |
| | Bottom | 6 | 11.2 | 34.9 | 343 |
| | Bottom | 7 | 11.2 | 35.1 | 337 |
| | Top | 4 | 11.2 | 35.1 | 334 |
| **Fuel 11** | Top | 3 | 11.4 | 37.1 | 312 |
| | Top | 1 | 11.3 | 36.9 | 304 |
| | Top | 2 | 11.2 | 35.4 | 331 |
| | Top | 6 | 11.4 | 37.4 | 315 |
| | Top | 7 | 11.5 | 37.5 | 316 |
| **Fuel 12** | Top | 1 | 11.3 | 36.4 | 363 |
| | Top | 7 | 11.3 | 35.6 | 348 |
| | Bottom | 6 | 11.2 | 35.7 | 342 |
| | Top | 4 | 11.3 | 36.1 | 331 |
| **Fuel 13** | Top | 2 | 0.0 | 36.5 | 354 |
| | Top | 1 | 0.0 | 36.4 | 363 |
| | Top | 3 | 0.0 | 37.0 | 354 |
| | Top | 7 | 0.0 | 36.9 | 366 |
| | Top | 4 | 0.0 | 37.0 | 351 |
| | Top | 6 | 0.0 | 36.8 | 367 |
| **Fuel 14** | Top | 1 | 0.0 | 38.0 | 321 |
| | Top | 2 | 0.0 | 18.2 | 324 |
| | Bottom | 6 | 0.6 | 19.1 | 331 |
| | Bottom | 7 | 0.0 | 17.7 | 332 |
| | Top | 8 | 0.0 | 17.6 | 329 |
| | Bottom | 4 | 0.0 | 18.2 | 336 |
| | Top | 3 | 0.0 | 17.8 | 327 |
| | Top | 7 | 0.0 | 18.5 | 331 |
| **Fuel 15** | Top | 2 | 0.0 | 38.0 | 334 |
| | Top | 3 | 0.0 | 38.5 | 319 |
| | Bottom | 4 | 0.0 | 37.9 | 324 |
| | Top | 1 | 0.0 | 36.6 | 299 |
| | Top | 8 | 0.0 | 36.4 | 336 |
| | Bottom | 7 | 0.0 | 38.4 | 343 |
| | Top | 9 | 0.0 | 38.6 | 337 |
| **Fuel 16** | Top | 2 | 11.8 | 36.8 | 295 |
| | Top | 3 | 11.8 | 36.8 | 303 |
| | Top | 1 | 11.8 | 36.6 | 299 |
| | Top | 3 | 11.8 | 36.7 | 301 |
| | Top | 5 | 11.8 | 36.8 | 307 |
| **Fuel 20** | Top | 2 | 19.4 | 17.0 | 320 |
| | Top | 1 | 19.3 | 17.0 | 316 |
| | Top | 4 | 19.5 | 17.4 | 324 |
| | Top | 5 | 19.4 | 7.5 | 325 |
| **Fuel 21** | Top | 2 | 19.0 | 38.0 | 289 |
| | Top | 1 | 19.0 | 37.8 | 289 |
| | Top | 3 | 18.9 | 38.0 | 290 |
| | Top | 5 | 19.0 | 38.3 | 303 |
| | Top | 6 | 19.1 | 38.1 | 296 |
| | Top | 8 | 19.0 | 38.1 | 305 |
| | Top | 4 | 19.0 | 38.4 | 296 |
| | Top | 9 | 18.9 | 38.2 | 300 |

## Petrospec Analysis on EPAct Fuels

| Updated 6/22/10 | Top/Bottom | Drum No. | Ethanol content (% vol) | Aromatic content (% vol) | T90 (°F) |
|---|---|---|---|---|---|
| **Fuel 22** | Bottom | 1 | 19.3 | 17.4 | 329 |
| | Top | 1 | 19.3 | 17.0 | 329 |
| | Top | 2 | 19.5 | 17.0 | 322 |
| | Top | 3 | 19.4 | 16.9 | 321 |
| | Top | 4 | 19.4 | 17.0 | 325 |
| | Bottom | 7 | 19.2 | 17.7 | 322 |
| | Top | 6 | 19.4 | 17.1 | 322 |
| | Top | 8 | 19.4 | 17.4 | 333 |
| **Fuel 23** | Top | 2 | 19.5 | 17.5 | 325 |
| | Top | 1 | 19.5 | 16.1 | 320 |
| | Bottom | 6 | 19.3 | 18.7 | 341 |
| | Top | 3 | 19.6 | 18.6 | 329 |
| | Top | 2 | 19.5 | 18.5 | 329 |
| | Top | 7 | 19.5 | 18.7 | 330 |
| **Fuel 24** | Top | 1 | 19.3 | 17.4 | 329 |
| | Top | 2 | 19.5 | 17.5 | 325 |
| | Top | 3 | 19.4 | 17.7 | 327 |
| | Bottom | 4 | 19.5 | 17.7 | 324 |
| | Top | 5 | 19.4 | 17.7 | 327 |
| | Top | 8 | 19.3 | 18.1 | 337 |
| | Top | 8 | 19.5 | 18.0 | 333 |
| **Fuel 25** | Top | 2 | 19.0 | 37.1 | 320 |
| | Bottom | 3 | 19.2 | 37.0 | 321 |
| | Bottom | 4 | 19.1 | 37.4 | 321 |
| | Top | 5 | 19.0 | 37.4 | 323 |
| | Bottom | 8 | 19.1 | 37.6 | 339 |
| | Bottom | 9 | 19.1 | 37.4 | 325 |
| | Top | 10 | 19.2 | 37.6 | 336 |
| **Fuel 26** | Top | 2 | 15.8 | 35.6 | 326 |
| | Top | 3 | 15.8 | 35.4 | 323 |
| | Top | 4 | 15.8 | 35.7 | 323 |
| | Top | 7 | 15.8 | 36.0 | 339 |
| | Top | 9 | 16.0 | 36.6 | 328 |
| **Fuel 27** | Top | 2 | 15.8 | 34.8 | 323 |
| | Top | 3 | 15.8 | 16.1 | 319 |
| | Top | 4 | 15.9 | 16.3 | 318 |
| | Bottom | 6 | 16.0 | 16.6 | 320 |
| | Top | 7 | 15.9 | 16.3 | 326 |
| **Fuel 28** | Top | 2 | 15.6 | 36.5 | 289 |
| | Top | 3 | 15.8 | 36.2 | 293 |
| | Bottom | 4 | 15.7 | 36.6 | 296 |
| | Top | 6 | 15.7 | 36.5 | 307 |
| | Bottom | 7 | 15.7 | 36.5 | 298 |
| | Bottom | 8 | 15.7 | 36.5 | 309 |
| | Top | 8 | 15.9 | 36.1 | 330 |
| | Top | 9 | 15.6 | 36.4 | 300 |
| **Fuel 30** | Top | 1 | 11.2 | 37.2 | 329 |
| | Top | 2 | 11.0 | 37.3 | 329 |
| | Top | 3 | 11.2 | 37.2 | 330 |
| | Top | 4 | 11.2 | 37.3 | 332 |
| | Top | 5 | 11.2 | 37.7 | 332 |
| | Top | 7 | 11.3 | 37.7 | 336 |
| **Fuel 31** | Top | 2 | 19.1 | 38.2 | 321 |
| | Top | 3 | 19.2 | 38.6 | 324 |
| | Top | 5 | 19.0 | 38.4 | 320 |
| | Bottom | 6 | 19.1 | 38.5 | 322 |
| | Top | 8 | 19.2 | 38.4 | 332 |

# APPENDIX C

# DETAILS OF FORD F-150 MISFUELING EVENT

Tuesday, March 9, 2010
The day-shift ran the F150 on test F150-P3-5-T2. The night-shift crew then performed a fuel change on the F150 during which the tank was drained and 10.6 gallons of Fuel 26 (Drum #5) were added. The vehicle was pushed onto the dynamometer where it was started and it idled very rough for 2 minutes before it was turned off and pushed off the dynamometer.

Wednesday, March 10, 2010
Five gallons of Fuel 26 (Drum #6) were put into the F150. To verify the fuel pump was working, the fuel line was removed from the fuel rail and a small amount of fuel was drained by energizing the fuel pump manually. The fuel pump worked correctly.

Friday, March 12, 2010
A fuel sample was pulled from the F150 and had the smell of gasoline and diesel. A PetroSpec analysis confirmed the fuel contained some diesel. The fuel tank was drained and "extra Fuel 5" was added. The vehicle started after a few cranks and ran normally.

Wednesday, March 17, 2010
The fuel tank was removed from the F150 and it was wiped clean by removing the fuel sending unit. The external fuel filter was also replaced.

Thursday, March 18, 2010
Everything was put back together and it was filled with three gallons of "extra Fuel 5". The vehicle appeared to operate normally.

Saturday, March 20, 2010
The fuel used prior to the misfueling event, Fuel 5, was installed in the vehicle and a sulfur purge was conducted.

Sunday, March 21, 2010
The vehicle was conditioned without incident.

Tuesday, March 23, 2010
Results from additional test conducted on Fuel 5 on Monday and Tuesday were submitted to EPA and NREL for review. Results looked very similar to Fuel 5 tests conducted prior to the misfueling event. The vehicle was approved to continue testing with the next fuel.

# APPENDIX D

# ON-ROAD OPERATION FOR INACTIVE TEST VEHICLES

**1.** _____ Verify that the fuel gage level before driving.

- ☐ Gage reads more than ½ a tank. Continue to step 4.
- ☐ Gage reads less than ½ a tank
  - Top off fuel tank
  - Added _____ gallons of Fuel 5.

**2.** _____ Locate fuel drum:

| | |
|---|---|
| **EPA Fuel No.** | 5 |
| **SwRI Fuel Code** | GA-6759-F |
| **Drum No.** | |

Verify fuel fill drum matches using "2-person rule"

Initials: _____, _____

**3.** _____ Place fuel drum back into cold box.

**4.** _____ Verify all four tires are at proper pressures.

**5.** _____ Verify proper engine oil and coolant levels.

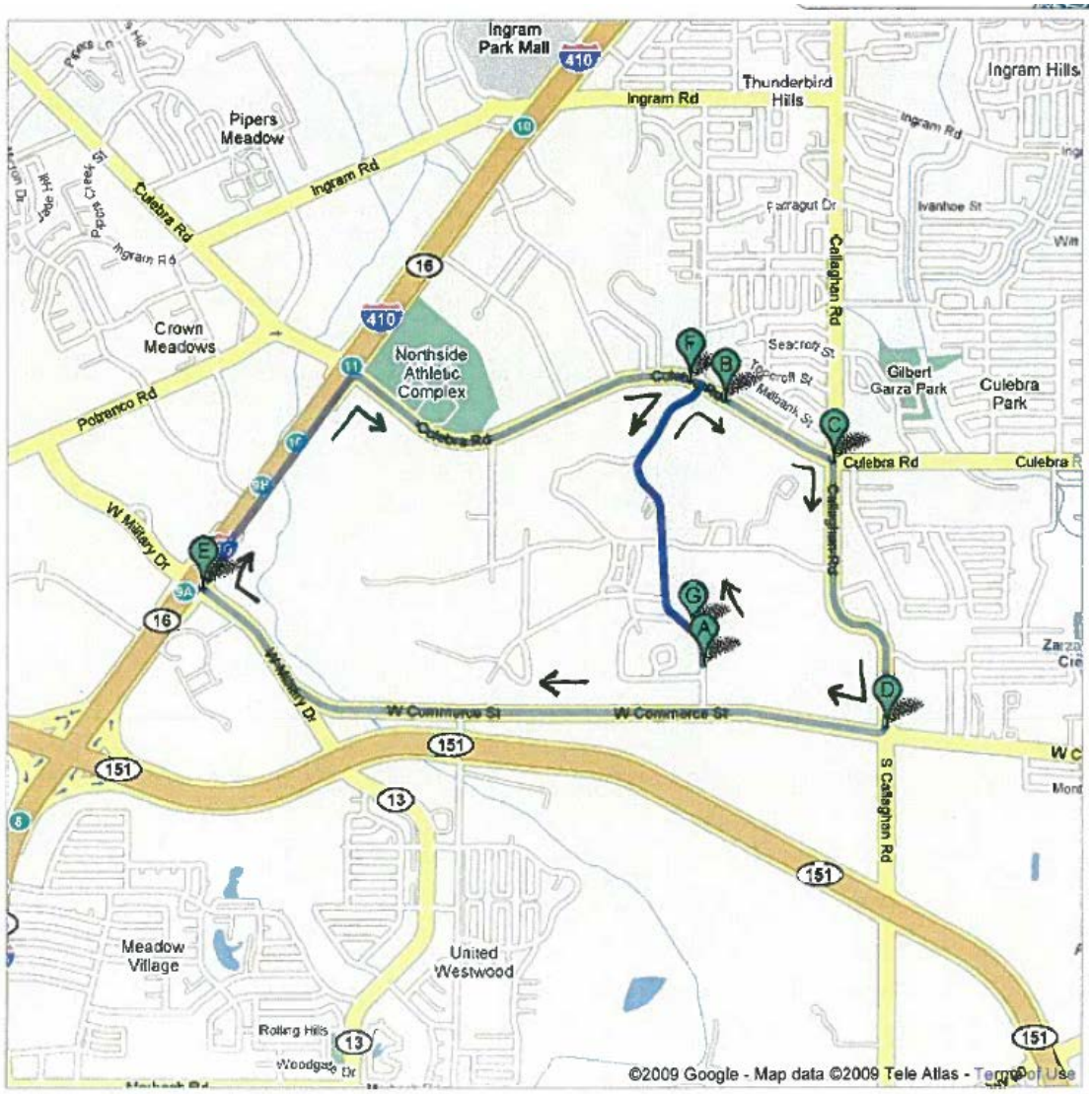
**6.** _____ Record the odometer reading _____.

**7.** _____ Drive the vehicle using attached driving instructions.

**8.** _____ Record the odometer reading _____.

**9.** _____ Record the time of completion _____.

Lead Technician's Signature:_____


Ingram Park Mall
410
Thunderbird Hills
Ingram Hills
Ingram Rd
Pipers Meadow
Culebra Rd
Ingram Rd
Ivanhoe St
Callaghan Rd
16
410
Crown Meadows
Northside Athletic Complex
11
Seacroft St
Gilbert Garza Park
Culebra Park
Pobranco Rd
Culebra Rd
Culebra Rd
W Military Dr
16
W Military Dr
W Commerce St
W Commerce St
151
151
13
S Callaghan Rd
151
Meadow Village
United Westwood
Rolling Hills
13
151
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# APPENDIX E

# FUEL USED IN ON-ROAD OPERATION FOR INACTIVE TEST VEHICLES

**PRODUCT:** **EPA Matrix Fuel 5**

**PRODUCT CODE:** **HF0678-5**

**Batch No.:** WC1121GP02
**TMO No.:** MTS
**Tank No.:** Gage
**Analysis Date:** 5/23/2008
**Shipment Date:**

| TEST | METHOD | UNITS | SPECIFICATIONS | | | RESULTS |
|---|---|---|---|---|---|---|
| | | | MIN | TARGET | MAX | |
| Distillation - IBP | ASTM D86 | °F | | | | 95 |
| 5% | | °F | | | | 125 |
| 10% | | °F | | | 158 | 144 |
| 20% | | °F | | | | 172 |
| 30% | | °F | | | | 200 |
| 40% | | °F | | | | 227 |
| 50% | | °F | 236 | | 244 | 244 |
| 60% | | °F | | | | 254 |
| 70% | | °F | | | | 266 |
| 80% | | °F | | | | 278 |
| 90% | | °F | 295 | | 305 | 298 |
| 95% | | °F | | | | 316 |
| Distillation - EP | | °F | | | | 373 |
| Recovery | | vol % | | Report | | 99 |
| Residue | | vol % | | Report | | 0.8 |
| Loss | | vol % | | Report | | 0.2 |
| Gravity | ASTM D4052 | °API | | Report | | 53.4 |
| Specific Gravity | ASTM D4052 | - | | Report | | 0.7672 |
| Reid Vapor Pressure | ASTM D5191 | psi | 6.50 | | 6.80 | 6.79 |
| Carbon | ASTM D5291 | wt fraction | | Report | | 86.9 |
| Hydrogen | ASTM D4808-A | wt fraction | | Report | | TBD |
| Hydrogen | ASTM D5291 | wt fraction | | Report | | 12.7 |
| Oxygen | ASTM D5599 | wt fraction | | Report | | <0.1 |
| Oxygen, other then ETOH | ASTM D5599 | wt fraction | | | 0.10 | 0.01 |
| Ethanol content | ASTM D5599 | wt % | | | 0.05 | <0.01 |
| Water content | ASTM E1064 | mg/kg | | Report | | 52 |
| Sulfur | ASTM D5453 | ppm wt | 20 | | 30 | 23 |
| Lead | ASTM D3237 | g/l | | | 0.01 | <0.01 |
| Composition, aromatics | ASTM D1319 | vol % | 38.5 | | 41.5 | 38.6 |
| Composition, olefins | ASTM D1319 | vol % | 5.5 | | 8.5 | 5.7 |
| Composition, saturates | ASTM D1319 | vol % | | Report | | 56.0 |
| Benzene | ASTM D3606 | vol % | 0.47 | | 0.77 | 0.54 |
| Existent gum, washed | ASTM D381 | mg/100mls | | | 5.0 | <0.5 |
| Research Octane Number | ASTM D2699 | | 91.0 | | 95.0 | 94.0 |
| Motor Octane Number | ASTM D2700 | | 83.0 | | 87.0 | 84.7 |
| R+M | D2699/2700 | | 87.0 | | 91.0 | 89.4 |
| Corrosion, Copper | ASTM D130 | | | | 1 | 1a |
| Oxidation stability | ASTM D525 | minutes | 240 | | | >240 |
| Net Heat of Combustion | ASTM D4809-A | BTU/lb | | Report | | 18417 |

APPROVED BY: _____ ANALYST DSL

# APPENDIX F

# OIL SAMPLE SUMMARY

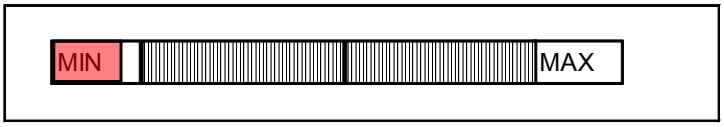
| Vehicles | Sample Interval | Date of Sample | Date Shipped to Lubrizol | Vehicle Odometer |
|---|---|---|---|---|
| EPA-CCOB - 2008 Chevrolet Cobalt | start of oil break-in | 3/21/2008 | 4/2/2008 | 2,139 |
| | end of oil break-in | 3/27/2008 | 4/2/2008 | 4,142 |
| | after 3rd Phase 3 fuel | 4/3/2009 | 4/5/2009 | 5,098 |
| | after 15th Phase 3 fuel | 7/17/2009 | 8/4/2009 | 6,574 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 7,636 |
| EPA-CIMP - 2008 Chevrolet Impala FFV | start of oil break-in | 4/4/2008 | 4/18/2008 | 2,315 |
| | end of oil break-in | 4/7/2008 | 4/18/2008 | 4,318 |
| | after 3rd Phase 3 fuel | 12/17/2009 | 2/2/2010 | 5,280 |
| | after 15th Phase 3 fuel | 3/25/2010 | 4/7/2010 | 7,139 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 7,712 |
| EPA-SOUT - 2008 Saturn Outlook | start of oil break-in | 4/4/2008 | 4/18/2008 | 2,240 |
| | end of oil break-in | 4/8/2008 | 4/18/2008 | 4,241 |
| | after 3rd Phase 3 fuel | 10/1/2009 | 2/2/2010 | 5,552 |
| | after 15th Phase 3 fuel | 12/15/2009 | 2/2/2010 | 6,649 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 7,779 |
| EPA-CSIL - 2008 Chevrolet Silverado FFV | start of oil break-in | 3/31/2008 | 4/2/2008 | 2,151 |
| | end of oil break-in | 4/4/2008 | 4/18/2008 | 4,152 |
| | after 3rd Phase 3 fuel | 4/7/2009 | 4/5/2009 | 5,586 |
| | after 15th Phase 3 fuel | 7/24/2009 | 8/4/2009 | 6,795 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 8,778 |
| EPA-TCOR - 2008 Toyota Corolla | start of oil break-in | 3/10/2008 | 3/20/2008 | 2,064 |
| | end of oil break-in | 3/18/2008 | 3/20/2008 | 4,064 |
| | after 3rd Phase 3 fuel | 12/17/2009 | 2/2/2010 | 5,222 |
| | after 15th Phase 3 fuel | 3/25/2010 | 4/7/2010 | 7,055 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 7,860 |
| EPA-TCAM - 2008 Toyota Camry | start of oil break-in | 3/6/2008 | 3/20/2008 | 2,068 |
| | end of oil break-in | 3/12/2008 | 3/20/2008 | 4,072 |
| | after 3rd Phase 3 fuel | 4/3/2009 | 4/5/2009 | 5,149 |
| | after 15th Phase 3 fuel | 7/17/2009 | 8/4/2009 | 6,366 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 7,901 |
| EPA-TSIE - 2008 Toyota Sienna | start of oil break-in | 3/11/2008 | 3/20/2008 | 2,251 |
| | end of oil break-in | 3/18/2008 | 3/20/2008 | 4,253 |
| | after 3rd Phase 3 fuel | 4/8/2009 | 4/5/2009 | 5,209 |
| | after 15th Phase 3 fuel | 7/24/2009 | 8/4/2009 | 6,327 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 7,901 |
| EPA-FFOC - 2008 Ford Focus | start of oil break-in | 3/21/2008 | 4/2/2008 | 2,094 |
| | end of oil break-in | 3/27/2008 | 4/2/2008 | 4,095 |
| | after 3rd Phase 3 fuel | 9/17/2009 | 2/2/2010 | 5,449 |
| | after 15th Phase 3 fuel | 11/13/2009 | 2/2/2010 | 6,493 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 7,901 |
| EPA-FEXP - 2008 Ford Explorer | start of oil break-in | 4/9/2008 | 4/18/2008 | 39,556 |
| | end of oil break-in | 4/14/2008 | 4/18/2008 | 39,556 |
| | after 3rd Phase 3 fuel | 4/3/2009 | 4/5/2009 | 6,989 |
| | after 15th Phase 3 fuel | 7/17/2009 | 8/4/2009 | 8,300 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 10,091 |
| EPA-F150 - 2008 Ford F150 FFV | start of oil break-in | 3/20/2008 | 4/2/2008 | 2,162 |
| | end of oil break-in | 3/28/2008 | 4/2/2008 | 4,167 |
| | after 3rd Phase 3 fuel | 12/17/2009 | 2/2/2010 | 5,708 |
| | after 15th Phase 3 fuel | 3/25/2010 | 4/7/2010 | 7,189 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 8,002 |
| EPA-DCAL - 2008 Dodge Caliber | start of oil break-in | 3/25/2008 | 4/2/2008 | 2,119 |
| | end of oil break-in | 4/3/2008 | 4/18/2008 | 4,121 |
| | after 3rd Phase 3 fuel | 4/3/2009 | 4/5/2009 | 5,143 |
| | after 15th Phase 3 fuel | 7/17/2009 | 8/4/2009 | 6,484 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 7,804 |
| EPA-JLIB - 2008 Jeep Liberty | start of oil break-in | 3/25/2008 | 4/2/2008 | 2,041 |
| | end of oil break-in | 4/3/2008 | 4/18/2008 | 4,044 |
| | after 3rd Phase 3 fuel | 4/9/2009 | 4/5/2009 | 4,972 |
| | after 15th Phase 3 fuel | 7/17/2009 | 8/4/2009 | 6,165 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 7,236 |
| EPA-HCIV - 2008 Honda Civic | start of oil break-in | 3/10/2008 | 3/20/2008 | 2,080 |
| | end of oil break-in | 3/14/2008 | 3/20/2008 | 4,081 |
| | after 3rd Phase 3 fuel | 4/9/2009 | 4/5/2009 | 4,983 |
| | after 15th Phase 3 fuel | 7/24/2009 | 8/4/2009 | 6,304 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 8,214 |
| EPA-HODY - 2008 Honda Odyssey | start of oil break-in | 3/14/2008 | 3/20/2008 | 2,050 |
| | end of oil break-in | 3/18/2008 | 3/20/2008 | 4,055 |
| | after 3rd Phase 3 fuel | 3/31/2009 | 4/5/2009 | 5,074 |
| | after 15th Phase 3 fuel | 7/10/2009 | 8/4/2009 | 6,515 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 8,070 |
| EPA-NALT - 2008 Nissan Altima | start of oil break-in | 3/28/2008 | 4/2/2008 | 2,151 |
| | end of oil break-in | 4/2/2008 | 4/2/2008 | 4,152 |
| | after 3rd Phase 3 fuel | 4/3/2009 | 4/5/2009 | 5,431 |
| | after 15th Phase 3 fuel | 7/10/2009 | 8/4/2009 | 6,786 |
| | after 27th Phase 3 fuel | 4/28/2010 | 7/19/2010 | 8,405 |

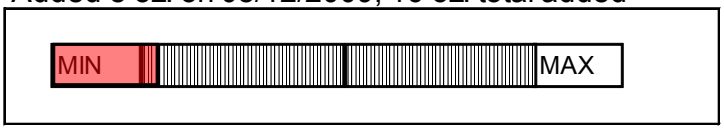
# APPENDIX G

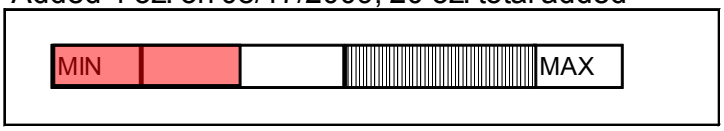
# FORD EXPLORER OIL LEVEL INCIDENT

Oil Level Check Procedure

1. Drive vehicle for 10 minutes.
2. Allow vehicle to sit for 10 minutes in a designated level space.
3. Take dipstick reading.
4. Confirm dipstick reading.
5. Immediately after dipstick reading add 8 oz. of specified 5W-30 engine oil.
6. Idle vehicle 2 minutes.
7. Allow vehicle to sit for 10 minutes in a designated level space.
8. Take dipstick reading.
9. Confirm dipstick reading.
10. Email oil level information to team along with a recommendation for possible additional fill.
11. If necessary, add oil based on team feedback.
    a. Drive vehicle for 10 minutes.
    b. Allow vehicle to sit for 10 minutes in a designated level space.
    c. Take dipstick reading.
    d. Confirm dipstick reading.
    e. Email oil level information to team.
12. Release vehicle back into test program.
13. Record oil level on dipstick for all tests vehicles monthly.

To minimize logistics and effort in monthly oil level readings, SwRI changed the measurement procedure so that all readings for all vehicles were taken inside the shop following an overnight soak. To correlate the two conditions, SwRI checked all oil levels following engine operation, then following an overnight soak:

1. Drive vehicle for 10 minutes.
2. Allow vehicle to sit for 10 minutes in a designated level space.
3. Take dipstick reading.
4. Confirm dipstick reading.
5. Allow vehicle to soak overnight in designated soak area.
6. Confirm that engine oil sump temperature is 72 +/- 2F.
7. Take dipstick reading.
8. Confirm dipstick reading.
9. Repeat steps 5 through 8 monthly

# APPENDIX H

# VEHICLE CONDITIONING AND TEST EXECUTION REQUESTS

# Fuel Change Procedure / Coastdown Sequence
## EPAct Test Fleet
## 03.14936.03.202

**Date:** Tuesday, April 13, 2010 **Vehicle:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-23-3FC T3 **Fuel #:** 23

**First Fuel Change**

- ☑ With key off, drain fuel from vehicle
- ☑ drain until fuel flow drops off. Stop drain immediately. **DO NOT OVERDRAIN.**
- ☑ Turn ignition to run position for 30 seconds allowing fuel gauge level to stabilize.
- ☑ Confirm fuel level reads zero. If gage does not read zero, use the Bosch scan tool to verify fuel level.
- ☑ Turn ignition key off.
- ☑ Locate fuel drum:

| | |
|---|---|
| **EPA Fuel No.** | **23** |
| **SwRI Fuel Name** | **SFO** |
| **SwRI Fuel Code** | **EM-7059-F** |
| **Drum No.** | 6 |

(Record Drum Number)

Verify fuel fill drum matches using "2-person rule"

Initials: H.V., AGW

Verify fuel temperature: 45 should be 45 ± 2 °F

- ☑ Fill tank with **6.8** gallons of fuel. Record time 4:48.
- ☑ Record fuel information from box above on vehicle windshield.
- ☑ Place fuel drum back into cold box.
- ☑ PUSH vehicle into lab within 10 minutes of refueling. Record time 4:50.
- ☑ Install vehicle on Dyno. Record drive wheel tire pressures. RT 30 LF 30.
- ☑ Connect the correct transfer pipe to the vehicle and run out the roof with flex pipe.
- ☑ Place cooling fans to cool the exhaust.

# Fuel Change Procedure / Coastdown Sequence
## EPAct Test Fleet
## 03.14936.03.202

**Date:** Tuesday, April 13, 2010 **Vehicle:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-23-3FC **Fuel #:** 23 ~~35~~ odo 7565 Run 8115

- [x] Dyno computer setup procedure
- [x] Horiba trace setup procedure
- [x] Connect thermocouple #1 to record oil temperature.
- [x] Start the vehicle. Idle in neutral. Using the OBD scan tool, read and record the long term fuel trim LTFT: -6.9%
- [x] Run the sulfur purge procedure described on the last page.
- [x] Record sulfur purge completion time. 8:11
- [x] Place vehicle in neutral with engine idling. Using the OBD scan tool, read and record the long term fuel trim LTFT -10.2%
- [x] Within 5 minutes of completing the sulfur purge procedure begin coast downs. Use the speed range from 70 - 10 mph and record in 5 mph increments.
- [x] Coast down 1.
- [x] Coast down 2.
- [x] Coast down 3, print.
- [x] Coast down 4, print.

Type the coastdown data from runs 3 and 4 into the coastdown analysis Excel program. If the program notes a repeatability failure, check for incorrect inputs. **If repeatability cannot be accomplished, remove vehicle and begin fuel change procedure on backup vehicle** and notify supervisor. If test repeatability is indicated OK, continue with this procedure.

- [x] Remove vehicle from dyno and move to the fuel drain area.

## EPAct Test Fleet
## 03.14936.03.202

**Date:** Tuesday, April 13, 2010 **Vehicle#:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-23-3FC **Fuel #:** 23

**Second Fuel Change**

☑ Drain fuel from vehicle until flow drops off. Stop drain immediately.
**DO NOT OVERDRAIN.**

☑ Turn ignition to run position for 30 seconds allowing fuel gauge level to stabilize.
☐ Confirm fuel level reads zero. If gage does not read zero, use the Bosch scan tool to verify fuel level.

☑ Locate fuel drum:

| | |
|---|---|
| EPA Fuel No. | 23 |
| SwRI Fuel Name | SFO |
| SwRI Fuel Code | EM-7059-F |
| Drum No. | 6 |

(Record Drum Number)

Verify fuel fill drum matches using "2-person rule"

Initials: DA, AMS

Verify fuel temperature: 45 should be 45 ± 2 °F

☑ Fill tank with 6.8 gallons of fuel. Record time 11:07.

Note: **For vehicles HODY, NALT, TSIE, HCIV, TCAM**

These vehicles (only) require a third fuel change. If you are not working on one of these five vehicles, skip the third fuel change and return fuel drum to the cold box.

#N/A

**3 of 3** Fuel Change Procedure / Coastdown Sequence

**Date:** Tuesday, April 13, 2010 **Vehicle#:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-23-3FC **Fuel #:** 23

**Third Fuel Change For Odyssey, Altima, Sienna, Civic, and Camry only.**

☑ Drain fuel from vehicle until flow drops off. Stop drain immediately.
**DO NOT OVERDRAIN.**

☑ Turn ignition to run position for 30 seconds allowing fuel gauge level to stabilize.

☑ Locate fuel drum:

| | |
|---|---|
| EPA Fuel No. | 23 |
| SwRI Fuel Name | SFO |
| SwRI Fuel Code | EM-7059-F |
| Drum No. | 6 |

(Record Drum Number)

Verify fuel fill drum matches using "2-person rule"

Initials: RA, MS

Verify fuel temperature: 45 should be 45 ± 2 °F

☑ Fill tank with 6.8 gallons of fuel. Record time 11:16.

☑ Place fuel drum back into cold box.

☑ PUSH vehicle into lab and park in 75° F soak area for at least 12 hours..

Lead Technician's Signature: [signature]

**Date:** Tuesday, April 13, 2010 **Vehicle#:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-23-3FC **Fuel #:** 23

| | | SULFUR PURGE PROCEDURE | | |
|---|---|---|---|---|
| 0 | ☐ idle | 30 seconds | | |
| 90 | ☑ 55 mph | 5 minutes | | |
| 03 | ☑ 30 mph | 1 minute | | |
| 26 | ☑ WOT acceleration | >5 seconds | >70 mph | |
| 41 | ☑ hold speed | 15 seconds | | |
| 48 | ☑ 30 mph | 1 minute | | |
| 11 | ☑ WOT acceleration | >5 seconds | >70 mph | |
| 26 | ☑ hold speed | 15 seconds | | |
| 30 | ☑ 30 mph | 1 minute | | |
| 45 | ☑ WOT acceleration | >5 seconds | >70 mph | |
| 00 | ☑ hold speed | 15 seconds | | |
| 05 | ☑ 30 mph | 1 minute | | |
| 22 | ☑ WOT acceleration | >5 seconds | >70 mph | |
| 37 | ☑ hold speed | 15 seconds | | |
| 42 | ☑ 30 mph | 1 minute | | |
| 58 | ☑ WOT acceleration | >5 seconds | >70 mph | |
| 13 | ☑ hold speed | 15 seconds | | |
| 17 | ☑ 30 mph | 1 minute | | |
| 20 | ☑ idle | 30 seconds | | |
| 59 | ☑ 55 mph | 5 minutes | | |
| 05 | ☑ 30 mph | 1 minute | | |
| 20 | ☑ WOT acceleration | >5 seconds | >70 mph | |
| 35 | ☑ hold speed | 15 seconds | | |
| 41 | ☑ 30 mph | 1 minute | | |
| 10 | ☑ WOT acceleration | > 5 seconds | >70 mph | |
| 25 | ☑ hold speed | 15 seconds | | |
| 31 | ☑ 30 mph | 1 minute | | |
| 46 | ☑ WOT acceleration | >5 seconds | >70 mph | |
| 01 | ☑ hold speed | 15 seconds | | |
| 05 | ☑ 30 mph | 1 minute | | |
| 18 | ☑ WOT acceleration | >5 seconds | >70 mph | |
| 33 | ☑ hold speed | 15 seconds | | |
| 39 | ☑ 30 mph | 1 minute | | |
| 55 | ☑ WOT acceleration | >5 seconds | >70 mph | |
| 10 | ☑ hold speed | 15 seconds | | |
| 16 | ☑ 30 mph | 1 minute | | |
| 23 | ☑ idle | 30 seconds | | |

# Precondition Sequence
## EPAct Test Fleet
## 03.14936.03.202

**Date:** Wednesday, April 14, 2010 **Vehicle#:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-23-3P **Fuel #:** 23

- ☑ PUSH the vehicle to the dyno.
- ☑ Place cooling fans to cool exhaust.
- ☑ Connect DBK 70 cable to vehicle OBDII connector. ODO: 7597
- ☑ **PC Host:** Open DBK 70 PidPro. Select "Connect". Select "Load config file". Select "Obdcan-EPA". Select "Display current channel values".
- ☑ Dyno Computer setup procedure:

| | | |
|---|---|---|
| Set Coefficients: **A:** | **8.32** | lb. |
| **B:** | **0.1121** | lb/mph. |
| **C:** | **0.018601** | lb/mph2/ |
| **ETW:** | **3875** | lbs. |

- ☑ Horiba trace setup procedure
- ☑ Run the number of LA92 precondition cycles as indicated by the test number.
  - ☑ LA92 Run # 8124
    - After each LA92 sequence, idle in neutral for two minutes before shutdown
    - Shut down engine for a min of 2 minutes and 5 minutes (max) between precondition cyc
  - ☑ LA92 Run # 8125
    - After each LA92 sequence, idle in neutral for two minutes before shutdown
    - Shut down engine for a min of 2 minutes and 5 minutes (max) between precondition cyc
  - ☑ LA92 Run # 8126
    - After each LA92 sequence, idle in neutral for two minutes before shutdown
    - Shut down engine for a min of 2 minutes and 5 minutes (max) between precondition cyc
  - ☐ LA92
    - After each LA92 sequence, idle in neutral for two minutes before shutdown
    - Shut down engine for a min of 2 minutes and 5 minutes (max) between precondition cyc
  - ☐ LA92
    - After each LA92 sequence, idle in neutral for two minutes before shutdown

-5P = five 2-bag LA92 -3P = three 2-bag LA92 -1P = single LA92

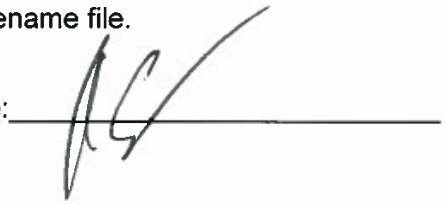

R:\03Projects\DEER\03-13363_EPA\Forms (Lab Check Lists)\Kent's Master EPA Forms Generator LA92 (Phase-3) with NREL Filters & charge numbers 4-2010.xlsm
Revised 12/01/2009. Julia DeGrace

## Precondition Sequence
## EPAct Test Fleet
## 03.14936.03.202

**Date: Wednesday, April 14, 2010** **Vehicle#: Chevrolet Impala FFV : EPA-CIMP**

**Test #: EPA-CIMP-P3-23-3P** **Fuel #: 23**

- [x] Select "Disconnect" on the DBK70 PidPro.
- [x] Remove the vehicle from the dyno and PUSH to a 75°F soak area for 12 - 36 hrs. Time: 1:34
- [x] Place a battery charger on vehicle and set to trickle charge at 2 amps.
- [x] Transfer data and rename file.

Lead Technician's Signature: 

# Driver Test Sheet
## EPAct Test Fleet
## 03.14936.03.202

**Date:** Thursday, April 15, 2010 **Vehicle:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-23-T3 **Fuel #:** 23

- ☑ **Dyno RTM**: Perform 30 min. Dyno warm-up against Loss No. 106.
  Enter Record No. : 903 and Loss Record No.: 106.
- ☑ **Dyno RTM**: Perform parasitic friction curve against Loss No. 106.
  **(Save this record - Do Not make it the current record).** Enter Record No. 1495 and Loss Record No. 106.
- ☑ **Dyno RTM**: Select "Road Load Simulation".
- ☑ **Dyno RTM**: Select "Vehicle Database". Select " **EPA-CIMP**
- ☑ **Dyno RTM**: Select "Set Up" and select "Aug Braking **off**
- ☑ **Dyno RTM**: Select "**Host Mode**".
- ☑ Check oil sump temperature and record : 70.7 should be 72 ± 3°F
- ☑ Install vehicle on chassis dyno. Align vehicle using laser level.
- ☑ Tie down vehicle. Adjust tie down straps at 150 to 200 lbs/ft.
- ☑ Connect RMT to vehicle.
- ☑ Record front tire pressures; (Veh. Spec = **30** psi).
  LR: 30.0 RR: 30.0.
- ☑ Record vehicle odometer: 7627.
- ☑ Connect DBK 70 cable to vehicle OBDII connector.
- ☑ Verify correct bags installed at CVS.
- ☑ **PC Host:** Open DBK 70 PidPro. Select "Connect". Select "Load config file". Select "Obdcan-EPA". Select "Display current channel values".
- ☑ **Dyno RTM:** Enter test number in comment box on "Road Load Simulation" screen.
- ☑ **MEXA:** Turn off blower.
- ☑ **Dyno RTM:** Enter Record No. 4087 and Loss Record No. 106.
- ☑ **MEXA:** Select "Online".

- ☑ **Verify** that humidity is between **9.9 and 11.4** on the Multi Signal Chart
  If not, notify Supervisor or Project Leader

# Driver Test Sheet
## EPAct Test Fleet
## 03.14936.03.202

**Date:** Thursday, April 15, 2010 **Vehicle:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-23-T3 **Fuel #:** 23

- ☑ **CDTCS:** Select "Run". Select "Test Schedule". Select "Emissions Test".
- ☑ **CDTCS:** Select "File". Select "Open Answer File. Select file " EPA-CIMP
- ☑ **CDTCS:** Select "File". Select "ID/Preferences" and make correct entries.

- ☑ **CDTCS:** Select "Test Options".
  - ☑ Select "Measure Emissions".
  - ☑ Select "PostCat" sample. Check applicable ranges for AUTO mode.
  - ☑ Select "Bags".
  - ☑ Select "Clean" Bagline.
- ■ Select Shift Schedule
  - ☑ Select "LA92".
  - ☑ Turn on Dilution Heat.
  - ☑ Shift 1: LA92 phase 1 & 2
  - ☑ Shift 2: LA92 phase 3
  - ☐ Shift 3: None.
- ■ Select CVS flow rates:
  - ☑ Select "Do Cert Z/S/Z" in "Zero Span Options".
    - ☑ Bag 1: **390** cfm.
    - ☑ Bag 2: **390** cfm.
    - ☑ Bag 3: **390** cfm.
- ☑ **CDTCS:** Select "Vehicle Data" and make correct entries.
- ☑ **CDTCS:** Select "Fuel Table". **EM-7059-F** **Fuel** **23** **SFO**
- ☑ **CDTCS:** Select "Dyno Data" and verify coeff. with RTM values:
  - ☑ a= **8.32** lb.
  - ☑ b= **0.1121** lb/mph.
  - ☑ c= **0.018601** lb/mph2/

# Driver Test Sheet
# EPAct Test Fleet
# 03.14936.03.202

**Date:** Thursday, April 15, 2010 **Vehicle:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-23-T3 **Fuel #:** 23

- ☑ **CDTCS:** Select "File". Select "Save Answer File". Select "OK".
- ☑ Select "Overwrite" EPA file.
- ☑ **CDTCS:** Record Horiba Run No. 8133.
- ☑ **CDTCS:** Select "File". Select "Run Test".

- ☑ **Dyno RTM:** Select "Start Test" when CDTCS is ready to start test.
  - ☑ Verify green dyno light in test cell is on.
  - ☑ Verify chemistry ready
  - ☑ Verify PM ready
- ☑ **Start of Test.** Turn vehicle Traction Control (T/C) to OFF.
- ☑ **PC Host:** DBK70 PidPro: Select "Disconnect".
- ☑ **MEXA:** Take MEXA offline.

- ☑ **TURN BLOWER ON AFTER IT SHUTS DOWN AUTOMATICALLY.**

**BAG 1** Start: (1), 2, 3 1: Good Start 2: Hesitate Start 3: Restart

**BAG 3** Start: (1), 2, 3 1: Good Start 2: Hesitate Start 3: Restart

- ☑ **CDTCS:** Run these reports: "Bag Data", "Bag-Model Summary", "Zero/Span Data", and "1 HZ Data", then select "Print".
- ☑ **PC Host:** Rename vertical reports in "Results on Workstation" folder, then copy reports to both "Results on PC Host" folder and "EPA" folder.
- ☑ Disconnect vehicle and push off dyno into designated soak space.
- ☐ Connect battery charger and set for 2 amp trickle charge.

Lead Technician's Signature: P Wyatt

Driver's Signature: P White


R:\03Projects\DEER\03-13363_EPA\Forms (Lab Check Lists)\Kent's Master EPA Forms Generator LA92 (Phase-3) with NREL Filters & charge numbers 4-2010.xlsm
Revised 12/01/2009 Julia DeGrace

# PM Sampling
# Daily Test Sheet
# EPAct Test Fleet
# 03.14936.03.202

**Date:** Thursday, April 15, 2010 **Vehicle: Chevrolet Impala FFV : EPA-CIMP**

**Test #: EPA-CIMP-P3-23-T3** **Fuel #: 23**

- [x] Perform a leak check on the PM Sampling system.

- [x] Make sure PM sample pumps are off.
- [x] Make sure ball valves on NREL composite filters are closed.
- [x] Make sure ball valves on RMT impinger cart and dilution air are closed (2)
- [x] Make sure impinger cart ball valve is closed.

- [x] Within 10 minutes of SOT, checkout filters for NREL positions 1-5 and EPA positions 1 and 2.

- [x] Record filter numbers for all positions on attached test form.

- [x] Install filters in appropriate holders.

- [x] Wait for driver's signal before proceeding.
  (approximately four minutes after start of CVS calibrations)

- [x] Verify the EPA cart is set to AUTO. Start sample pumps 1 & 2.
  - [x] Clear counters and timer.
  - [x] Verify flow setting on pumps: Dilution = 1.09 Sample = 1.90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Revised 12/01/2009. Julia DeGrace

# PM Sampling
# Daily Test Sheet
# EPAct Test Fleet
# 03.14936.03.202

**Date:** Thursday, April 15, 2010 **Vehicle:** Chevrolet Impala FFV : EPA-CIMP

**Test #:** EPA-CIMP-P3-23-T3 **Fuel #:** 23

- ☑ Open RMT ball valves (2 valves)
- ☑ Open impinger cart ball valve.
- ☑ After SOT, verify sample flow rates on all carts.
  EPA cart: Dilution = 1, Sample = 2
- ☑ Close ball valves
  - ☑ Impinger cart sample @ CVS
  - ☑ Impinger cart B6 @ RMT
  - ☑ Dilution air sample @ RMT
- ☑ Turn off all PM sample pumps.

Lead Technician's Signature _____


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Revised 12/01/2009. Julia DeGrace

# PM Filters
## Daily Test Sheet
## EPAct Test Fleet
## 03.14936.03.202

**Date:** Thursday, April 15, 2010 **Vehicle:** Chevrolet Impala FFV EPA-CIMP

**Test #:** EPA-CIMP-P3-23-T3 **Fuel #:** 23 **NREL Filter Set:** None

| GM | Sample Probe | Flow | Filter Description | Filter No. | GM Temp. (°F) | GM Press. (" $H_2O$) | GM Counts |
|---|---|---|---|---|---|---|---|
| 1 | Single | Dilute = 1<br>Sample = 2 | EPA PP47<br>Bag 1 | 21492 | | | Dilute 506<br>Sample 1346 |
| 2 | Single | Dilute = 1<br>Sample = 2 | EPA PP47<br>Bag 2 | 21493 | | | Dilute 1903<br>Sample 5215 |
| 1 | Single | Dilute = 1<br>Sample = 2 | EPA PP47<br>Bag 3 | 21494 | | | Dilute 511<br>Sample 1388 |
| 1 | 1 | 100 | DRI G47<br>Bag 1,2,3 | | Bag 1<br>Bag 2<br>Bag 3 | | |
| 2 | 2 | 100 | DRI Q47<br>Bag 1,2,3 | | Bag 1<br>Bag 2<br>Bag 3 | | |
| 3 | 3 | 100 | DRI T47<br>Bag 1,2,3 | | Bag 1<br>Bag 2<br>Bag 3 | | |
| 4 | RMT | 90 | SwRI RP47<br>Bags 1,2,3 | | Bag 1<br>Bag 2<br>Bag 3 | | |
| Puf | 5 | 2 | 100 mm XAD<br>Bags 1,2,3 | | Bag 1<br>Bag 2<br>Bag 3 | | |

Lead Technician's Signature: _____

Page 1 of 1

R:\03Projects\DEER\03-13363_EPA\Forms (Lab Check Lists)\Kent's Master EPA Forms Generator LA92 (Phase-3) with NREL Filters & charge numbers 4-2010.xlsm

Revised 12/01/2009. Julia DeGrace

# APPENDIX I

# DETAILED MEASUREMENT AND ANALYSIS METHODS

## A. QA OBJECTIVES FOR TESTING OF LIGHT-DUTY VEHICLES

The QA objectives for precision, accuracy, and completeness are presented in Table 1. All measurements will be representative of the fuels, vehicle engine exhaust, and conditions being measured. Completeness equals number of tests performed divided by number of tests proposed times 100.

**TABLE 1. PRECISION, ACCURACY, AND COMPLETENESS OBJECTIVES FOR LIGHT-DUTY ENGINES**

| Measurement Parameter (Method) | Reference | Experimental Conditions | Precision Std. Dev. | Accuracy,% | Completeness,% |
|---|---|---|---|---|---|
| HC (FID) | SwRI and SAE[a,b] | Dilute Exhaust | 0.04[a] | ±15[b] | >95 |
| CO (NDIR) | SwRI and SAE[a,b] | Dilute Exhaust | 0.06[b] | ±20[b] | >95 |
| $CO_2$ (NDIR) | SwRI and SAE[a,b] | Dilute Exhaust | 4[b] | ±5[b] | >95 |
| $NO_x$ (CL) | SwRI and SAE[a,b] | Dilute Exhaust | 0.08[a] | ±10[b] | >95 |
| Particulate, 47 mm (Gravimetric) | SwRI and SAE[a,b] | Dilute Exhaust | 0.05[a] | ±10[b] | >95 |
| Fuel Economy (Carbon Balance) | SwRI and SAE[a,b] | Dilute Exhaust | 1[a] | ±5[b] | >95 |
| Aldehydes (DNPH/HPLC) | EPA[1,2] CRC[3] | Dilute Exhaust | See Appendix K | | >95 |
| Alcohols (water impinger/GC-FID) | EPA[1,2] CRC[3] | Dilute Exhaust | See Appendix K | | >95 |

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[a] Precision experienced at SwRI, but precision is vehicle dependent.

[b] Accuracy goals were based on SwRI experience and SAE Technical Paper 790232, "Identification, Quantification and Reduction of Sources of Variability in Vehicle Emissions and Fuel Economy Measurements," N.J. Sheth and T.I. Rice, 1979.

[c] ±100% of defined detection limit; precision generally improves with increased sample concentration.

## B. SAMPLING METHODS

The sampling system is comprised primarily of the exhaust sampling system to which continuous measurement devices, a dilute exhaust bag sampler, impinger and cartridge samplers, and particle filters are attached. The sampling procedures employed for the determination of regulated and unregulated emissions for light-duty engines are identified below. In the event of errors, mishaps, or deviations from procedure, the project leader, Kevin Whitney is to be notified.

All procedures will be designed to maximize test-to-test repeatability. For example, the following steps will be taken:

- The position and angle of the vehicle cooling fan shall be consistent for each vehicle and each test.
- The airflow around the vehicle during tests shall be kept consistent.
- To the extent possible, the CARB laboratory correlation program will be used in support of this program's QA procedures.
- Sample side verification of exhaust analyzers will be performed monthly by sampling span gases from a sample bag.
- Sample flow proportionality will be verified after each emissions test. For PM samples, a proportionality statistic will be calculated. For other parameters, the constancy of tunnel flows will be verified.
- Duplicate vehicle coastdown checks from 70 to 30 mph will be performed following each sulfur purge procedure.
- A check will be performed before, during, and at the end of each test to assure than manually controlled parameters are set and adhered to during each test.
- Battery chargers will be utilized to maintain the state of battery charge of test vehicles between vehicle prep procedures and emissions tests.
- The LA92 driving cycle will be used for the vehicle prep procedures to match the driving cycle used in emissions tests.
- NOx analyzers will be equipped with NH3 traps to prevent contamination of NOx converters.

### B.1. Exhaust Gas Sampling System Description

A Horiba selectable flow CVS system will be used to sample exhaust emissions. Test technicians first connect the vehicle exhaust pipe to the CVS inlet. While the vehicle operates on the dynamometer, an adjustable-speed turbine blower dilutes the exhaust with ambient air. This dilution prevents the exhaust moisture from condensing and provides controllable sampling conditions. A sample pump and a control system transfers diluted exhaust aliquots to several different Kynar bags during specific phases of each test run. Regulating needle valves maintain constant sample flow rates for the alcohol impingers and DNPH cartridges, and mass flow controllers maintain proper flow into the bags. Exhaust backpressure will be recorded continuously at the tailpipe during emissions testing. Table 2 summarizes the CVS system specifications.

**TABLE 2. CVS SPECIFICATIONS**

| Measurement Variable | Operating Range Expected in Field | Instrument Description | Range | Accuracy | How Verified / Determined |
|---|---|---|---|---|---|
| Pressure | 950 to 1050 millibar | Horiba Variable-Flow Constant Volume Sampler | 0 to 1500 millibar | ± 2 % reading | Sensors calibrated and verified during installation. |
| Temperature | 20 to 45 °C | | 0 to 100 °C | ± 2 % reading | |
| Volumetric Flow Rate | 200 to 500 $ft^3$/min | | 150 to 1100 $ft^3$/min | ± 0.5 % reading | |

## B.2. Dilute Exhaust Bag Sampling

The Kynar bags (sample and background) specified for HC speciation analysis will be removed from the Horiba sampling system, marked with a sample ID/custody label, and transported to the GC laboratory. Analysis of sample Bag 1 will begin immediately (within one hour) for the $C_1$-$C_4$ analysis and within four hours for the benzene-toluene and $C_5$-$C_{12}$ analysis. Times that analyses are started will be reported. For tests in which multiple test phases will be analyzed for HC speciation, analysis order shall be: Bag 1, Bag 3, Bag 2, Background Bags.

## B.3. Carbonyl Compound Sampling

Heated (235 ±15˚F) sample lines from the dilution tunnel carry sample gas to a cart which holds the DNPH sampling cartridges. The cart includes controls for the flow rate and measures the volume sampled. Thermocouples with electronic readouts allow recording of the gas temperature sampled, so coupled with the recorded barometric pressure, the volume sampled can be corrected to standard temperature and pressure.

Immediately following the end of the sampled test phase (within 15 minutes), the DNPH cartridge will be extracted with 5.0 ml acetonitrile in accordance with the manufacturer's instructions. The extract will be promptly sealed and analyzed (within one hour), or stored at <40˚F for no longer than three calendar days until analysis. Every effort will be made to analyze the sample the same day. Samples and sampling media will be stored separately from calibration standards.

## B.4. Alcohol Sampling

Heated (235 ±15˚F) sample lines from the dilution tunnel carry sample gas to a cart which holds glass impingers filled with ultra-pure water. The cart includes controls for the flow rate and measures the volume sampled. Thermocouples with electronic readouts allow recording of gas temperature sampled, so coupled with the recorded barometric pressure, the volume sampled can be corrected to standard temperature and pressure. The impingers are maintained in an ice bath during sampling.

Immediately following the end of the sampled test phase, the impinger contents will be carefully transferred to sealed containers and stored at <40˚F for no longer than six calendar days until analysis. Every effort will be made to analyze the samples on the same day as collection. Samples and sampling media will be stored separately from calibration standards.

Ethanol recovery will be checked during every blank test conducted in this program. Recovery shall be ≥92 percent.

### B.5. Filter Sampling and Weighing

Whatman Teflo filters with polypropylene support rings will be used for particulate matter (PM) measurements. Particle filters are stored, conditioned, and weighed in a room at SwRI that strictly conforms to 40 CFR 86.1312 and Part 1065. A PM filter field blank will be tested daily. This field blank shall be a tared filter that is installed in a sample holder, then returned to the filter room for weighing by the same procedures as actual samples.

## C. SAMPLE HANDLING AND CUSTODY

Only PM filters, bag, impinger, and cartridge samples involve manual handling, because gaseous emission measurements are made and recorded by the computer-controlled data system associated with the continuous sampling system.

### C.1. Particle Filters

Particle filters are managed by a bar code tracking system. Test I.D., date, time, and technician name are tracked with this system. This procedure is compliant with 40 CFR 86.1312 and Part 1065.

### C.2. Bag Samples

Because bag samples may be handled by multiple analysts, a bag sample tag is affixed to each sample or background bag. With this tag, progress and times of analysis can be recorded. A bag sample tag is shown in Figure 1.

| BAG ANALYSIS | | |
|---|---|---|
| **S A M P L E** | | |
| **Project No. 13363.01.101**<br>**EPA Work Assignment 0-1** | | |
| **Test No.:** **Date:** / / | | |
| **Dyno 8** **Operator:** | | |
| **Bag Description** | | |
| LA-92 Unified Cycle<br>□ Bag 1 End of Test: :<br>□ Bag 2 End of Test: :<br>□ Bag 3 End of Test: : | | |
| Analysis Required | Analysis Start (Time) | Analyzed by: |
| □ $C_1$-$C_4$ speciation | : | |
| □ Benz-Tol speciation | : | |
| □ $C_5$-$C_{12}$ speciation | : | |

**FIGURE 1. BAG SAMPLE TAG**

## C.3. Cartridge and Impinger Samples

Sampling of carbonyl compounds is to be performed with DNPH cartridges, and alcohols, with liquid impingers, as described above. Tracking of sample times and extraction times will be made by recording times on the cartridge tag (Figure 2) and impinger data sheet (Figure 3).

| **ALDEHYDE DNPH CARTRIDGE** | | |
|---|---|---|
| **Project No. 13363.01.101**<br>**EPA Work Assignment 0-1** | | |
| **Test No.:** **Date: / /** | | |
| **Dyno 8** **Analyst:** | | |
| **Bag Description** | | |
| LA-92 Unified Cycle<br>□ Bag 1 End of Test: :<br>□ Bag 2 End of Test: :<br>□ Bag 3 End of Test: : | | |
| Cartridge Extraction Required within 15 min | **Extraction** (Time) | Analyst Initials: |
| □ Bag 1 | : | |
| □ Bag 2 | : | |
| □ Bag 3 | : | |
| □ Background | : | |

**FIGURE 2. DNPH CARTRIDGE TAG**

| Project 13363.01.101 Date: / / Dyno 8 Initials: | | | | |
|---|---|---|---|---|
| Test Number: | DNPH Cartridge | | Alcohol Impinger | |
| | Sample | Background | Sample | Background |
| Test Cycle: | Temp: | Temp: | Temp: | Temp: |
| Barameter, "Hg: | Counts: | Counts: | Counts: | Counts: |
| End Time: | Sx 1° | Sx 2° | Sx 1° | Sx 2° |
| Test Cycle: | Temp: | Temp: | Temp: | Temp: |
| Barameter, "Hg: | Counts: | Counts: | Counts: | Counts: |
| End Time: | Sx 1° | Sx 2° | Sx 1° | Sx 2° |
| Test Cycle: | Temp: | Temp: | Temp: | Temp: |
| Barameter, "Hg: | Counts: | Counts: | Counts: | Counts: |
| End Time: | Sx 1° | Sx 2° | Sx 1° | Sx 2° |

**FIGURE 3. IMPINGER AND CARTRIDGE SAMPLING DATA SHEET**

## D. ANALYTICAL METHODS

The analytical procedures employed for the determination of regulated and unregulated emissions for light-duty engines are given below. In the event of errors, mishaps, or deviations from procedure, the project leader, Kevin Whitney is to be notified.

### D.1. Filter Weighing

The chamber in which the PM filters are conditioned and weighed conforms to 40 CFR 86.1339 and Part 1065 without deviation.

### D.2. Gaseous Analyzers

Horiba analytical benches equipped with either MEXA 7000-Series analyzers are used to determine NMHC, CO, $NO_X$, and $CO_2$ concentrations in dilute exhaust. Sample pumps transfer the dilute exhaust from Kynar bags to each analyzer as commanded by the control system. Each analyzer used for these measurements is accurate to ±2 percent. Table 3 provides a summary of the emissions analyzers to be used.

## TABLE 3. EMISSION ANALYZER SPECIFICATIONS

| Measurement Variable | Expected Operating Range | Instrument Mfg., Model / Type | Instrument Range(s) | Accuracy[a] | How Verified / Determined |
|---|---|---|---|---|---|
| THC | 0 - 100 ppmC | Horiba FIA-220 or FIA-726LE / FID | 0 - 10 ppmC<br>0 - 50 ppmC<br>0 - 1000 ppmC | ± 1.0 % FS or ± 2.0 % of the calibration point[a] | Gas divider with protocol calibration gases at 11 points (minimum) spaced throughout span (including zero) |
| $NO_X$ | 0 - 100 ppm | Horiba CLA-220 or CLA-750LE / CL | 0 - 30 ppm<br>0 - 100 ppm<br>0 - 300 ppm | | |
| Low CO | 0 - 50 ppm | Horiba AIA-210 or AIA-721LE / NDIR | 0 - 10 ppm<br>0 - 50 ppm | | |
| CO | 0 - 1000 ppm | Horiba AIA-220 or AIA-721A / NDIR | 0 - 1000 ppm | | |
| $CO_2$ | 0 - 1.5 % | Horiba AIA-220 or AIA-722 / NDIR | 0 - 4 % | | |

[a]The most stringent accuracy specification applies for each calibration point.

## E. QUALITY CONTROL

SwRI verifies performance of each analyzer through a series of zero and calibration gas challenges. Each zero and calibration gas must conform to certain specifications and/or be NIST-traceable. Table 4 summarizes the applicable QA/QC checks. If all calibration gases and QA/QC checks meet their specifications, then SwRI will infer that the emissions analyzers meet Table 1 accuracy specifications.

SwRI verifies all new Standard Reference Material (SRM) or other NIST-traceable reference gas concentrations with an emissions analyzer that has been calibrated within the last 30 days. The operator will first zero the analyzer with a certified zero grade gas and then span it with a NIST SRM (or equivalent) three times to ensure stability and minimal analyzer drift.

The operator will then introduce the new reference gas into the analyzer and record the concentration, followed by reintroduction of the NIST SRM to ensure that the analyzer span point does not drift more than ±0.1 percent of span point. The operator will repeat these last two steps until three consistent values are obtained. The mean of these three determinations must be within one percent of its NIST SRM concentration. SwRI will then consider the reference gas as suitable for emissions analyzer calibrations.

For chemical evaluations, QC measures are generally specified in the analytical method. A summary of actions taken to ensure data quality for analytical procedures is presented in Table 5.

**TABLE 4. EMISSION ANALYZER QA/QC CHECKS**

| QA/QC Check | When Performed / Frequency | Expected or Allowable Result | Response to Check Failure or Out of Control Condition |
|---|---|---|---|
| NIST-traceable calibration gas verifications | Prior to being put into service | Average of three readings must be within ±1% of verified NIST SRM concentration | Identify cause of any problem and correct; discard bottle and replace if necessary |
| Zero-gas verification against NIST certified zero gases | Prior to being put into service | HC < 1 ppmC<br>CO < 1 ppm<br>$CO_2$ < 400 ppm<br>$NO_x$ < 0.1 ppm<br>$O_2$ between 18 and 21% | Discard bottle and replace |
| Gas divider linearity verification | Monthly | All points within ±2% of linear fit<br>FS within ±0.5% of known value | Identify cause of any problem and correct; replace gas divider if necessary |
| Analyzer calibrations | Monthly | All values within ±2% of point or ±1% of FS;<br>Zero point within ±0.2% of FS | Identify cause of any problem and correct; recalibrate analyzer |
| Wet $CO_2$ interference check | Monthly | CO 0 to 300 ppm, interference ≤ 3 ppm<br><br>CO > 300 ppm, interference ≤ 1% FS | |
| $NO_X$ analyzer interference check | Monthly | $CO_2$ interference ≤ 3% | |
| $NO_X$ analyzer water quench check | Once, before each phase of program | Proper opreration | |
| $NO_X$ analyzer converter efficiency check | Monthly | $NO_x$ converter efficiency > 95% | |

**TABLE 5. SUMMARY OF QA/QC CHECKS FOR ANALYTICAL PROCEDURES**

| Procedure | Type | Blank | Field Blank | Duplicate Analysis | Continuing Calibration Check | Holding Time | Preservation During Storage |
|---|---|---|---|---|---|---|---|
| Light Alcohols | GC-FID | 1 per batch | 1 per day | 1 per 10 samples | 1 per 10 samples | 6 days | Keep at <4˚F |
| Aldehydes and Ketones | HPLC-UV | 1 per batch | 1 per day | 1 per 10 samples | 1 per 10 samples | 15 minutes to extraction; 3 days | Keep at <4˚F |
| HC Speciation | GC-FID | 1 per day | n/a | no | end of day | 1 hour for C2-C4 Analysis | protect from UV light |
| Particulate Matter Mass | Gravimetric | Reference filter every 2 hours | n/a | At least three measurements on each filter | Monthly reference check | Filters may be out of chamber only ≤ 1 hr | Temperature and humidity control |

## F. INSTRUMENT/EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE

Gaseous analyzers conform to 40 CFR 86.1311 without deviation. Internal QC checks and corrective actions are summarized in Table 6.

### TABLE 6. INTERNAL QUALITY CONTROL CHECKS AND CORRECTIVE ACTION

| EQUIPMENT AND/OR MEASUREMENT | OPERATIONAL CHECK | CONTROL LIMIT(S) (reference no.) | CORRECTIVE ACTION |
|---|---|---|---|
| Driver's aid | Speed agreement[a] | EPA[29] | Repair and/or recalibrate |
| CVS | Propane recovery[b] | ±2%[25,29] | Check for leaks and by procedural assessment |
| | Speed, RPM[a] | ±5%[25,29] | Check speed sensor and recalibrate rpm |
| Engine Dynamometer | Load and Speed, RPM[a] | Federal Register[25] | Check and/or repair load cell and rpm indicator; recalibrate |
| CO bag analyzer | $CaSO_4$ and ascarite conditioning column | Blue indicator of $CaSO_4$[25,29] | Change $CaSO_4$ and ascarite column soon after $CaSO_4$ indicator turns color. Leak-check before continuing bag analysis. |
| $NO_X$ bag analyzer | Percent efficiency of $NO_2$ to NO converter[b] | Percent efficiency greater than 90%[25,29] | Repair analyzer |
| Sampling bags | Leak-check bags before and after each test | Bag holds gauge vacuum pressure of 27.6 in. Hg | Discard bag and note finding in test results. Repeat test as applicable. |
| HFID analyzer | Leak-check sampling system[a] | Flowmeter float is at zero position | Correct leak before sample analysis |
| | Sample gas temperature immediately before heated filter and before the HFID[a] | 375±10°F[25,29] | Locate sampling line heating problem and correct before conducting sample analysis |
| | Zero and span before each range[c] | Zero at 0.0 of full- scale and span to set value[25,29] | Determine problem and adjust zero and span accordingly |
| | Pre-analysis and post-analysis zero and span of each range[c] | Zero and span drift- limit of 2% of full- scale chart deflection[25,29] | Repeat test |
| | Pre-analysis and post-analysis tunnel HC back-grounds[c] | Continuous tunnel and bag HC backgrounds agree to within l% of full-scale chart deflection(25,29) | Determine cause for discrepancy and correct |

## TABLE 6. INTERNAL QUALITY CONTROL CHECKS AND CORRECTIVE ACTION

| EQUIPMENT AND/OR MEASUREMENT | OPERATIONAL CHECK | CONTROL LIMIT(S) (reference no.) | CORRECTIVE ACTION |
|---|---|---|---|
| 47 mm filter sampling system | Leak-check sampling system[a] | Flowmeter float is at zero position | Correct leak before particulate sampling |
| | Sampling rate[c] | Flowrate constant ±5% throughout test | Check for leaks or restrictions on sampling line and filter |
| 47 mm reference filters | Weight tolerance[c] | ±1% of the nominal filter loading[(27)] | Reweigh all filters being conditioned |
| Particle Dilution Tunnel | Particle sampling zone temperature[c] | 125°F or less | Increase level of sample dilution |
| Aldehydes and ketones | Leak-check sampling system[c] | Flowmeter float is at zero position | Correct leak before sample collection |
| | Sampling rate[c] | Flowrate constant ±5% throughout test | Check for leaks or restrictions on sampling line and filter |
| | Dry gas meter volume[d] | Compare to flowmeter estimate | Recalibrate or replace dry gas meter |
| Aldehydes and ketones | Sample identification[c] | Date, project, cycle, and test no. if designated | Correct labeling |
| | Sample preparation[c] | Within 15 minutes of end of sampled phase | Void sample |
| | Sample analysis[c] | Within 3 days of end of sampled date | Void sample |
| HC, CO, $NO_X$, and CO bag analyzers | Leak-check analyzer sampling system[a] | Flowmeter float at zero position | Correct leak before bag analysis |
| | Zero and span before each range[c] | Zero at 0.0 of full-scale and span to set value[(25,29)] | If not adjustable using analyzer zero and gain control within specified limits, repair analyzer |
| | Pre-analysis and post-analysis zero and span of each range[c] | Zero and span drift limit of 2% of full-scale meter reading[(25,29)] | Repeat bag analysis |

In the event of out of specification conditions, equipment should be repaired and recalibrated. If a significant delay will result, the project leader, Kevin Whitney is to be notified.

## G. INSTRUMENT/EQUIPMENT CALIBRATION AND FREQUENCY

Sampling and analytical methodologies and test procedures adhere to Title 40 CFR Parts 86 and 600 requirements. All equipment calibrations are conducted according to the schedules in 40 CFR § 86.116. Table 7 summarizes the relevant calibrations, Title 40 CFR citations, and their frequencies. Calibrations and QA/QC checks are discussed in more detail below.

**TABLE 7. EQUIPMENT CALIBRATIONS SUMMARY**

| Equipment Description | Title 40 CFR Procedure | Calibration Frequency |
|---|---|---|
| CO analyzer | § 86.121 | Monthly |
| $CO_2$ analyzer | § 86.122 | Monthly |
| HC analyzer | § 86.124 | Monthly |
| $NO_X$ analyzer | § 86.123 | Monthly |
| Chassis dynamometer | § 86.118 | Daily |
| CVS system | § 86.119 | Weekly |
| Speciated Hydrocarbons | EPA [41] | Each Sample Set |
| Alcohols | EPA [39] | Each Sample Set |
| Aldehydes and Ketones | EPA [1, 2, 3] | Each Sample Set |

Analytical equipment in the chemistry laboratories is calibrated at least once daily, with a calibration verification performed at the end of the batch.

### G.1. Gas Meter Calibrations

**A**ll gas meters, selected from the list of routinely used instruments given in the recall database, are calibrated to conform to 40 CFR 86.1320. Any necessary correction is made by mechanically adjusting the meter and recalibrating.

### G.2. Gaseous Analyzers

The gaseous analyzers to be utilized in this program are discussed in the following sections.

#### G.2.1. Hydrocarbon Analyzers

The HC analyzers used in this testing program are calibrated in conformance with 40 CFR 86.1321.

#### G.2.2. Carbon Monoxide Analyzers

The CO analyzers used in this testing program are calibrated in conformance with 40 CFR 86.1322 and 40 CFR 89.320.

#### G.2.3. Oxides of Nitrogen Analyzers

The $NO_x$ analyzers used in this testing program are calibrated in conformance with 40 CFR 86.1323 and 40 CFR 89.321.

### G.2.4. Carbon Dioxide Analyzers

The carbon dioxide ($CO_2$) analyzers used in this testing program are calibrated in conformance with 40 CFR 86.1324 and 40 CFR 89.322.

### G.2.5. Methane Analyzers

The methane analyzers used in this testing program are calibrated in conformance with 40 CFR 86.1325, without deviation.

### G.3. Analyzer Gases

The gases used for instrument calibration conform to 40 CFR 86.114 and 40 CFR 89.312 without deviation.

SwRI verifies each new working zero air (or $N_2$) cylinder's impurities to ensure that it is suitable for emissions analyzer zero checks. Comparisons between a certified Vehicle Emission Zero (VEZ) Gas (or equivalent) and the candidate zero gas will serve this purpose. SwRI will employ an emissions cart (or suite of instruments) that has been calibrated within the last 30 days for this procedure. The operator will zero the analyzers with certified VEZ gas and span them with NIST-traceable reference gases to ensure stability and minimal analyzer drift. The operator will then introduce the candidate cylinder's zero gas to the sample train and record the HC, CO, $CO_2$, and $NO_x$ values. The results must fall within specified ranges for the zero gas to be deemed suitable for instrumental analyzer calibrations.

Prior to the monthly exhaust emission analyzer calibrations, SwRI verifies the calibration gas divider linearity with an HC analyzer known to have a linear response and a HC span gas. The operator will first zero and then span the instrument such that the span occupies 100 meter or chart divisions. The operator will operate the divider in each of its settings in descending order and compare the observed results with a linear scale. The difference between the commanded and observed concentrations must be within ±2.0 percent of the commanded concentration. Also, this difference must be less than ±0.5 percent of the span value.

NIST-traceable calibration gases, in conjunction with a verified gas divider and zero gas, will create individual gas concentrations with which to challenge each instrumental analyzer. The gas divider will generate 11 concentrations in 10 percent increments from 0 to 100 percent of each analyzer's span. Analyzer response at each point must be within ±2.0 percent of the concentration or ±1.0 percent of span, whichever is more stringent. Zero gas response must be within ±0.2 percent of span (the CFR requires ±0.3 percent). If any point is outside these limits, operators will generate a new calibration curve.

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# APPENDIX J

# EPACT NMOG CALCULATION PROTOCOL

# EPAct NMOG Calculation Protocol

19-Feb-2009

The series of calculations shown here (Equations (1) through (6)) must be performed separately for each test phase (bag). The NMOG mass results can then be weighed in the usual way to form a test cycle composite emission rate.

First we calculate corrected NMHC concentration for dilute exhaust (subscript e) and dilution air (subscript d) as follows:

$$NMHC_e = FIDHC_e - r_{CH4} \cdot CH4_e - r_{MeOH} \cdot MeOH_e - r_{EtOH} \cdot EtOH_e - r_{Pr\,OH} \cdot Pr\,OH_e - r_{AcetHO} \cdot AcetHO_e \quad (1)$$

$$NMHC_d = FIDHC_d - r_{CH4} \cdot CH4_d - r_{MeOH} \cdot MeOH_d - r_{EtOH} \cdot EtOH_d - r_{Pr\,OH} \cdot Pr\,OH_d - r_{AcetHO} \cdot AcetHO_d \quad (2)$$

Note that these values are all as ppmC (so speciation results for EtOH, PrOH, and AcetHO reported in ppm of the particular chemical compound will need to be multiplied by 2 or 3 depending on the number of C atoms in the compound).

The following constant values shall be used for FID response factors:

$r_{CH4}$ = 1.15 ppmC/ppmC (this program)
$r_{MeOH}$ = 0.63 ppmC/ppmC (this program)
$r_{EtOH}$ = 0.74 ppmC/ppmC (this program)
$r_{PrOH}$ = 0.85 ppmC/ppmC (CARB)
$r_{FormHO}$ = 0.00 ppmC/ppmC (various sources)
$r_{AcetHO}$ = 0.51 ppmC/ppmC (this program)

Next, we must calculate the dilution factor to be used in generating the net NMHC concentration:

$$DF = \frac{100 \cdot \left[ \frac{x}{x + 0.5y + 3.76 \cdot (x + 0.25y - 0.5z)} \right]}{CO2_e + (NMHC_e + CH4_e + MeOH_e + Pr\,OH_e + EtOH_e + FormHO_e + AcetHO_e + CO_e) \cdot 10^{-4}} \quad (3)$$

The parameters x, y and z in Eq. (3) are coefficients taken from the chemical formula $C_xH_yO_z$ of a test fuel. The procedure to calculate their values is provided in Appendix 2.

Once the DF is determined, we calculate the net NMHC concentration as follows:

$$NMHC_{conc} = NMHC_e - NMHC_d \cdot \left(1 - \frac{1}{DF}\right) \quad (4)$$

Then we compute $NMHC_{mass}$:

$$NMHC_{mass} = V_{mix} \cdot Density_{NMHC} \cdot NMHC_{conc} \cdot 10^{-6} \quad (5)$$

Equations (4) and (5) must be repeated for each emission being considered. $V_{mix}$ is the volume of dilute exhaust collected during a given phase of the test cycle, measured in standard cubic feet. Density is the calculated gas phase density of a particular species treated as a $C_1H_yO_z$ ideal gas.

The following values of gas phase density shall be used:

$Density_{NMHC} = 16.334\ g/ft^3$
$Density_{MeOH} = 37.718\ g/ft^3$
$Density_{EtOH} = 27.115\ g/ft^3$
$Density_{PrOH} = 23.581\ g/ft^3$
$Density_{FormHO} = 35.345\ g/ft^3$
$Density_{AcetHO} = 25.929\ g/ft^3$

To generate the NMOG figure, we need methanol, ethanol, 2-propanol, formaldehyde and acetaldehyde mass emissions as computed using Eq. (4) and (5) based on measured concentration values form the speciation results (as in Eq. (1) and (2)).

Finally, then, NMOG mass emissions can be computed as follows:

$$NMOG_{mass} = NMHC_{mass} + MeOH_{mass} + EtOH_{mass} + PrOH_{mass} + FormHO_{mass} + AcetHO_{mass} \quad (6)$$

Once $NMOG_{mass}$ calculations have been completed for all three phases (cold transient (ct), stabilized (s) and hot transient (ht)) of the LA92 test cycle they, calculate the total weighted NMOG emissions using the following formula:

$$NMOG_{wm} = 0.43 \cdot \left( \frac{NMOG_{mass.ct} + NMOG_{mass.s}}{D_{ct} + D_s} \right) + 0.57 \cdot \left( \frac{NMOG_{mass.ht} + NMOG_{mass.s}}{D_{ht} + D_s} \right) \quad (7)$$

For tests where there is no bag 2 or 3 speciation data, NMOG shall be computed assuming emission levels for oxygenated species in bags 2 and 3 are zero.

## Attachment 1

Definitions

$NMHC_e$ – Concentration of NMHC in dilute exhaust sample, ppm C equivalent
$FIDHC_e$ - Uncorrected concentration of HC in dilute exhaust sample as measured by the FID, ppm C equivalent
$CH4_e$ – Concentration of methane in dilute exhaust sample as measured, ppm C equivalent
$MeOH_e$ - Concentration of methanol in dilute exhaust sample as measured, ppm C equivalent
$EtOH_e$ - Concentration of ethanol in dilute exhaust sample as measured, ppm C equivalent
$PrOH_e$ - Concentration of 2-propanol in dilute exhaust sample as measured, ppm C equivalent
$FormHO_e$ - Concentration of formaldehyde in dilute exhaust sample as measured, ppm C equivalent
$AcetHO_e$ - Concentration of acetaldehyde in dilute exhaust sample as measured, ppm C equivalent
$CO2_e$ - Concentration of carbon dioxide in dilute exhaust sample as measured, percent
$CO_e$ - Concentration of carbon monoxide in dilute exhaust sample as measured, ppm
$r_{CH4}$ - FID response to methane, ppmC/ppmC
$r_{MeOH}$ - FID response to methanol, ppmC/ppmC
$r_{EtOH}$ - FID response to ethanol, ppmC/ppmC
$r_{PrOH}$ - FID response to 2-propanol, ppmC/ppmC
$r_{FormHO}$ - FID response to formaldehyde, ppmC/ppmC
$r_{AcetHO}$ - FID response to acetaldehyde, ppmC/ppmC
$NMHC_d$ - NMHC concentration in dilution air, ppm C equivalent
$FIDHC_d$ - Uncorrected HC concentration in dilution air sample as measured by the FID, ppm C equivalent
$CH4_d$ - Concentration of methane in dilution air sample as measured, ppm C equivalent
$MeOH_d$ - Concentration of methanol in dilution air sample as measured, ppm C equivalent
$EtOH_d$ - Concentration of ethanol in dilution air sample as measured, ppm C equivalent
$PrOH_d$ - Concentration of 2-propanol in dilution air sample as measured, ppm C equivalent
$FormHO_d$ - Concentration of formaldehyde in dilution air sample as measured, ppm C equivalent
$AcetHO_d$ - Concentration of acetaldehyde in dilution air sample as measured, ppm C equivalent
$_{DF}$ - Dilution factor
$_x$ - Carbon-to-carbon ratio in formula $C_xH_yO_z$ determined as in Appendix 2 for the fuel used (by definition x=1)
$_y$ - Hydrogen-to-carbon ratio in formula $C_xH_yO_z$ determined as in Appendix 2 for the fuel used
$_z$ - Oxygen-to-carbon ratio in formula $C_xH_yO_z$ determined as in Appendix 2 for the fuel used
X – Carbon mass fraction of the fuel
Y – Hydrogen mass fraction of the fuel
Z – Oxygen mass fraction of the fuel
$NMHC_{conc}$ – Concentration of NMHC in dilute exhaust sample corrected for background, ppm C equivalent
$MeOH_{conc}$ - Concentration of methanol in dilute exhaust sample corrected for background, ppm C equivalent

$EtOH_{conc}$ - Concentration of ethanol in dilute exhaust sample corrected for background, ppm C equivalent
$PrOH_{conc}$ - Concentration of 2-propanol in dilute exhaust sample corrected for background, ppm C equivalent
$FormHO_{conc}$ - Concentration of formaldehyde in dilute exhaust sample corrected for background, ppm C equivalent
$AcetHO_{conc}$ - Concentration of acetaldehyde in dilute exhaust sample corrected for background, ppm C equivalent
$V_{mix}$ - Volume of dilute exhaust collected during a given phase of the test cycle, scf
$Density_{NMHC}$ – Density of NMHC treated as a $C_1H_y$ ideal gas at standard conditions of 293.16°K and 760 mm Hg, $g/ft^3$
$Density_{MeOH}$ - Density of methanol treated as a $C_1H_yO_z$ ideal gas at standard conditions of 293.16°K and 760 mm Hg, $g/ft^3$
$Density_{EtOH}$ - Density of ethanol treated as a $C_1H_yO_z$ ideal gas at standard conditions of 293.16°K and 760 mm Hg, $g/ft^3$
$Density_{PrOH}$ - Density of 2-propanol treated as a $C_1H_yO_z$ ideal gas at standard conditions of 293.16°K and 760 mm Hg, $g/ft^3$
$Density_{FormHO}$ - Density of formaldehyde treated as a $C_1H_yO_z$ ideal gas at standard conditions of 293.16°K and 760 mm Hg,$ft^3$
$Density_{AcetHO}$ - Density of acetaldehyde treated as a $C_1H_yO_z$ ideal gas at standard conditions of 293.16°K and 760 mm Hg, $g/ft^3$
$M_{NMHC}$ - Molecular mass of NMHC treated as a $C_1H_y$, g/mole, calculated according to the formula provided in Appendix 3
$NMOG_{mass}$ - NMOG mass, g/test phase
$NMHC_{mass}$ - NMHC mass, g/test phase
$MeOH_{mass}$ - Methanol mass, g/test phase
$EtOH_{mass}$ - Ethanol mass, g/test phase
$PrOH_{mass}$ - 2-propanol mass, g/test phase
$FormHO_{mass}$ - Formaldehyde mass, g/test phase
$AcetHO_{mass}$ - Acetaldehyde mass, g/test phase
$NMOG_{wm}$ – Weighted NMOG emissions, g/mile
$NMOG_{mass.ct}$ - NMOG mass emitted during the cold transient phase of the test cycle, g/test phase
$NMOG_{mass.s}$ - NMOG mass emitted during the stabilized phase of the test cycle, g/test phase
$NMOG_{mass.ht}$ - NMOG mass emitted during the hot transient phase of the test cycle, g/test phase
$D_{ct}$ - Distance driven by the test vehicle on a chassis dynamometer during the cold transient phase of the LA92 test cycle, miles
$D_s$ - Distance driven by the test vehicle on a chassis dynamometer during the stabilized phase of the LA92 test cycle, miles
$D_{ht}$ - Distance driven by the test vehicle on a chassis dynamometer during the hot transient phase of the LA92 test cycle, miles

## Attachment 2

Calculation of x, y and z Coefficients in Formula $C_xH_yO_z$ Using Fuel C, H and O Content Data

The carbon-to-carbon ratio x in formula $C_xH_yO_z$ by definition equals 1. The hydrogen-to-carbon and oxygen-to-carbon ratios y and z, respectively, can be calculated using the following equations:

$$y = \frac{\frac{Y}{1.008}}{\frac{X}{12.011}} \quad \text{(A2.1)} \qquad \text{and} \qquad z = \frac{\frac{Z}{15.999}}{\frac{X}{12.011}} \quad \text{(A2.2)}$$

where:

X – Carbon mass fraction of the fuel
Y – Hydrogen mass fraction of the fuel
Z – Oxygen mass fraction of the fuel

The values of X, Y and Z will be provided by the EPA for all fuels tested in the EPAct Program.

# APPENDIX K

# LOD/LOQ METHOD

## LOD/LOQ Method for EPAct/V2/E-89 Program at SwRI®

This document is a description of the method that will be used for handling chemistry data in the EPAct/V2/E-89 Program, with respect to Limit of Detection (LOD) and Limit of Quantification (LOQ). In addition to describing the final method for processing the data, the methods used to determine and track LOD and LOQ are described, as well as the reasoning behind the method and the background and experiments which led to its development.

Most of this discussion is related specifically to the carbonyl and alcohol data, where potential interference from the sampling media is significant issue.

### Root Issue

The primary problem for which this method was developed is how to properly address media interference in the measurement process when the exhaust samples themselves are at levels similar to that interference. This problem arises because we are using methods and media which were developed for use at much higher measurement levels (and which are perfectly adequate for those higher levels).

For example, based on our experiments, most of the media interference for carbonyls is on the order of 0.5 mg/mile or less, which is similar to the levels were are trying to quantify in the exhaust samples. It is important to recognize that the traditional process has been developed to determine compliance with formaldehyde standards on the order of 4 to 18 mg/mile, and to quantify even higher values on pre-Tier 2 vehicles, where this level of blank interference represents at most 10% of the standard. We are trying to use the same process to quantify values an order of magnitude lower than that, and this has required some refinement of the process.

### Proposed QA Blank Tracking and Data Analysis Process

It should be noted that all of this tracking is done on a compound-by-compound basis, so that (for instance) an issue might be observed only on acrolein while all other compounds could still be within limits.

1. The laboratory and field blanks are analyzed in a daily basis to determine a daily average blank value ($blank_i$).
2. Data from these blanks are tracked over time, and are used to generate a **5-day moving average** ($\overline{blank}$), and an associated **standard deviation** ($\sigma_{blank}$)**.**
3. The daily blanks for a given test day ($blank_i$) are first evaluated in comparison to the previous 5-day average as follows:

   Is $\left|blank_i - \overline{blank}\right| \leq 3\sigma_{blank}$ ?

   a. If the above answer is **Yes,** update the 5-day $\overline{blank}$ and $\sigma_{blank}$, and proceed with data analysis. This indicates that the current blank falls within acceptable variation from the running average, and is described in Step 4 below.

b. If the above answer is **No**, then the current blank is outside the normal range of variation and is flagged for review. This process is described further below in Step 5.

4. Data analysis for "normal" blanks (Case 3a, answer to 3 is **Yes)**. Each analyzed sample (which is either a dilution air background or a dilute exhaust sample) is compared individually to the 5-day $\overline{blank}$ and $\sigma_{blank}$.

a. Is $sample_{uncorrected} - \overline{blank} \leq 3\sigma_{blank}$ ?

b. If the answer to 4a is **No**, then calculate the blank corrected sample as follows:

$$sample_{corrected} = sample_{uncorrected} - \overline{blank}$$

c. If the answer to 4a is **Yes**, then report $sample_{corrected} = 0$ for that given sample. The means that the difference between the sample and the blank does not rise above the level of noise in the blanks (i.e., we cannot tell the difference between the sample and a media blank).

d. Analysis then proceeds normally with background correction (using the dilution factor) and mass calculations. The final analyzed mass is always reported. Negative masses are reported as zero and set to zero on a bag-by-bag basis prior to composite calculations.

**e. Analysis Complete, Proceed to Reporting.**

5. Review of and processing "outlier" blanks (Case 3b, answer to 3 is **No**).

a. Manual review of blank data chromatograms to determine if an analytical problem is at fault, and correct if possible.
b. Manual review of blank data and association with sample/background samples to determine if the blank itself is an outlier or if there is a shift observed for all samples and blanks on that day.
c. If blank itself is an outlier, discard and process test data (as described in Step 4) using the **previous 5-day average. Do not update** $\overline{blank}$ **and** $\sigma_{blank}$.
d. If the shift is consistent for all samples, backgrounds, and blanks on that day, process test data (as described in Step 4) BUT **use the daily average blank value** $blank_i$ **in place of** $\overline{blank}$ **for that day only. Do not update** $\overline{blank}$ **and** $\sigma_{blank}$.

6. Media Shift.

a. If outlier behavior is consistent for three days running, blanks may have shifted. In other words, if a blank value shifts from low to high, but then stays high for

three days, this may indicate a shift in the media, rather just an outlier. If this is the case, data will be reviewed.

b. If it is determined to be appropriate, $\overline{blank}$ **and** $\sigma_{blank}$ will be **reset** (initially with values from the three days of question). Note this will be done on a compound-by-compound basis.

It should be noted that there are multiple review steps throughout this process in the event of outliers. It is hoped that over the course of these review steps, any process issues which may have contributed to either an increase in the frequency of outliers or a shift in blank values can be identified and corrected.

**Background on Process Development**

To establish an appropriate method for determination of the LOQ for a given measurement, it is necessary to understand the key factors driving measurement variability. These factors will vary depending in the measurement in question.

In the case of gaseous HC speciation measurements, the primary driver is analytical variability. Experiments have indicated that the bag media do not contribute in a significant manner to the measurement, which is not unexpected given the requirements on the media with respect to HC off-gassing, as well as the multiple purge-evacuation processes designed to eliminate carryover. Therefore, the repeatability of the GC instrument was quantified and an LOQ was established in terms of raw area counts at 200 counts. This analytical LOQ was determined by examining repeat measurements of low-level standards. LOD and LOQ are then determined by examining the ratio between the standard peak height and the noise response. The LOD is the lowest concentration where the standard-to-noise ratio is 3 to 1, while the LOQ is defined as the lowest concentration where the standard-to-noise ratio is 10 to 1. These ratios follow standard good laboratory practice for GC analysis. Any analyzer response below this LOQ in terms of area counts is reported as a zero, because we cannot reliably quantify a number below this threshold. Note that this process is done on every individual measurement, including samples and backgrounds, before the numbers are fed into calculations to determine mass.

For the carbonyls, and to a lesser extent alcohols, the sample media have a much higher potential for interference. Table 1 shows a comparison of analytical instrument LOD versus the average blank levels, with the data given as raw area counts. The values in the table compare $3\sigma$ for the instrument (as quantified by multiple analyses of a standard of 0.0003 ug/ml) against $3\sigma$ for the blanks (as quantified by examining multiple blanks). This comparison demonstrates that the variation in blank area counts is at a much higher level than the instrument LOD, which indicates that blank variation is the dominant source of variability in the measurement.

**TABLE 1. COMPARISON OF INSTRUMENT AND BLANK VARIABILITY FOR CARBONYLS (AREA COUNTS)**

| Compound | Instrument LOD | Blank Average |
|---|---|---|
| FORMALDEHYDE | 984 | 2823 |
| ACETALDEHYDE | 1285 | 9217 |
| ACROLEIN | 757 | 1115 |
| ACETONE | 661 | 39183 |
| PROPIONALDEHYDE | 850 | 1070 |
| CROTONALDEHYDE | 392 | 1605 |
| N-BUTYRALDEHYDE + MEK | 785 | 6002 |
| BENZALDEHYDE | 437 | 1707 |
| HEXANALDEHYDE | 326 | 1154 |
| ISOVALERALDEHYDE | 371 | 4155 |
| VALERALDEHYDE | 716 | 976 |
| O-TOLUALDEHYDE | 389 | 1659 |
| M/P-TOLUALDEHYDE | 383 | 1762 |
| DIMETHYLBENZALDEHYDE | 496 | 1291 |

To determine an appropriate method to deal with this variation, it was also necessary to determine if this variation is present on a day-to-day basis, a batch-to-batch basis (i.e., different batches or lots of cartridges), or on the basis of individual blanks. Two data sets were used for this analysis. One data set is similar to the set shown above which includes area count values for blanks determined over a period of three months' time, including about 60 days of data and covering more than one batch. The second data set was generated but taking 10 blanks from a single batch and analyzing all of them in a single analytical run on the same day. The results are summarized below in Table 2, with the data given as raw area counts.

**TABLE 2. COMPARISON OF LONG-TERM AND SHORT-TERM CARBONYL COMPOUND BLANK VARIABILITY**

| | Average | | Standard Deviation | |
|---|---|---|---|---|
| Compound | 90-day | Single batch | 90-day | Single batch |
| Formaldehyde | 3460 | 3647 | 941 | 1070 |
| Acetaldehyde | 7858 | 6791 | 3072 | 2677 |
| Acrolein | 253 | 354 | 372 | 389 |
| Acetone | 21482 | 20767 | **13061** | **5020** |
| Propionaldehyde | 256 | 389 | 357 | 409 |
| Crotonaldehyde | 432 | 430 | 535 | 465 |
| N-butyraldehyde & MEK | 2172 | 1722 | 2001 | 2303 |
| Benzaldehyde | 783 | 593 | 569 | 316 |
| Isovaleraldehyde | 262 | 381 | 385 | 486 |
| Valeraldehyde | 1787 | 1733 | 1385 | 1283 |
| o-Tolualdehyde | 128 | 43 | **325** | **108** |
| m/p-Tolualdehyde | 437 | 255 | **553** | **149** |
| Hexanaldehyde | 1512 | 1898 | 587 | 746 |
| Dimethylbenzaldehyde | 267 | 8 | **430** | **25** |

In most cases the average and standard deviations for both data sets were very similar. This indicates that the variation exists on a cartridge-to-cartridge basis, even within a single batch, and that this short-term media variation cannot be distinguished from any longer term factors. There are a few compounds that do not follow this trend such as acetone, wherein the variations are likely also driven by daily variations in the laboratory environment.

As a result of this determination, the practice of using a daily blank for correction of samples for that given day is problematic, because the cartridge-to-cartridge variability means that a daily blank set may not necessarily represent the sample cartridges. Therefore, it is necessary to average a number of blanks over time to represent the media correctly. However, any method must also track sudden shifts in media which do occur from time to time, as well as dealing with individual outliers.

Blank data for both formaldehyde and acetaldehyde are given in Figure 1 and Figure 2, respectively, showing different kinds of behavior that need to be addressed. In the case of formaldehyde, the blanks are generally well behaved, with some slow movement over time indicated. However, there are also individual outliers that need to be dealt with. On the other hand, the acetaldehyde blanks show periodic and significant shifts, such as a shift which occurs at about Blank 59 from a low level to a higher level. On review this shift is also present in actual test samples and backgrounds from that day, indicating a real shift in the media or process.

Similar data were examined for the heavier carbonyls, and a similar analysis was also performed for the alcohols (although in the case of alcohols only the methanol data showed evidence of variability). Based on all of these data, it was determined that a 5-day moving window for would be appropriate to properly characterize media blank variation, while also being short enough to detect movement of the blanks. In addition, the inclusion of a 3-sigma outlier test to trigger manual data review accounts for detection of outlier days, which might result from either an individual blank issue or a shift which affects an entire test day. Finally, a provision is included to reset the daily average, in the event that a real long-term shift is observed over several days, such as observed from time to time in the acetaldehyde data.

Figure 3 shows acetone blanks over the same time window. In this case there are several outlier days, which upon analysis were reflected in the data for that day, but then the blank levels returned to normal. Thus far, we believe that acetone is uniquely affected by laboratory environment given the presence of acetone in many places. In these cases, the blanks for that day should be used to process that data for that day, but the running average should not be disturbed for an outlier day.

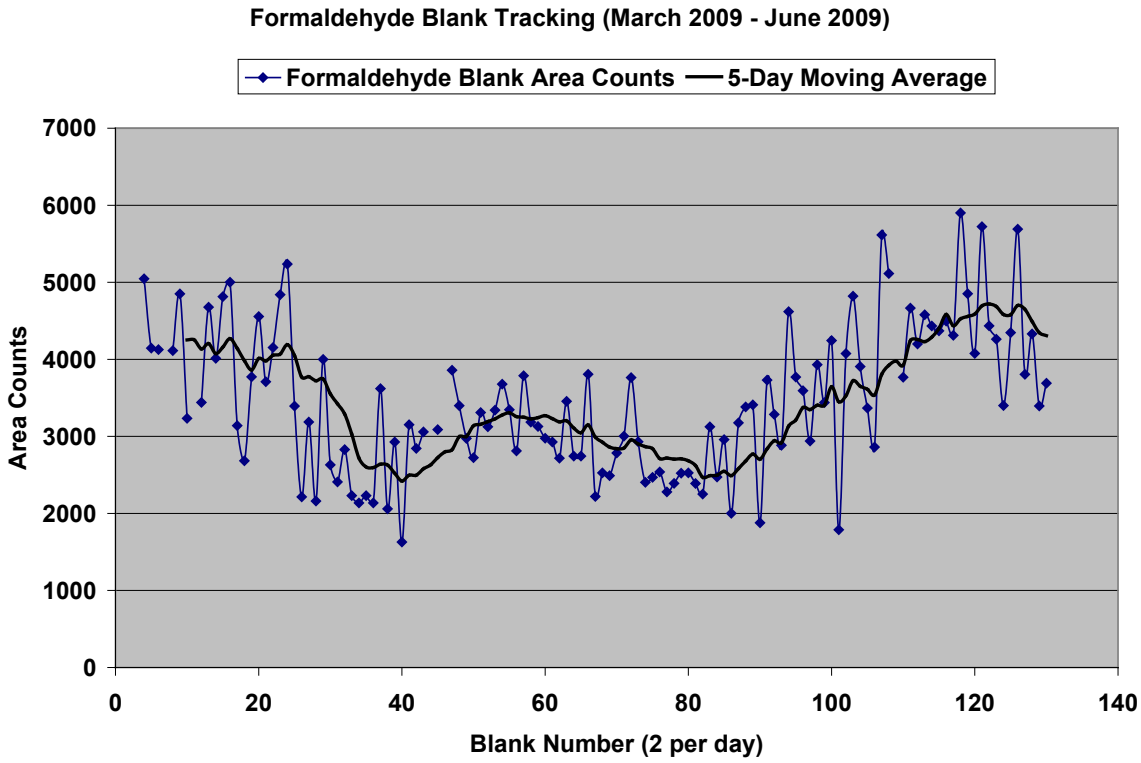


FIGURE 1. FORMALDEHYDE BLANK TRACKING

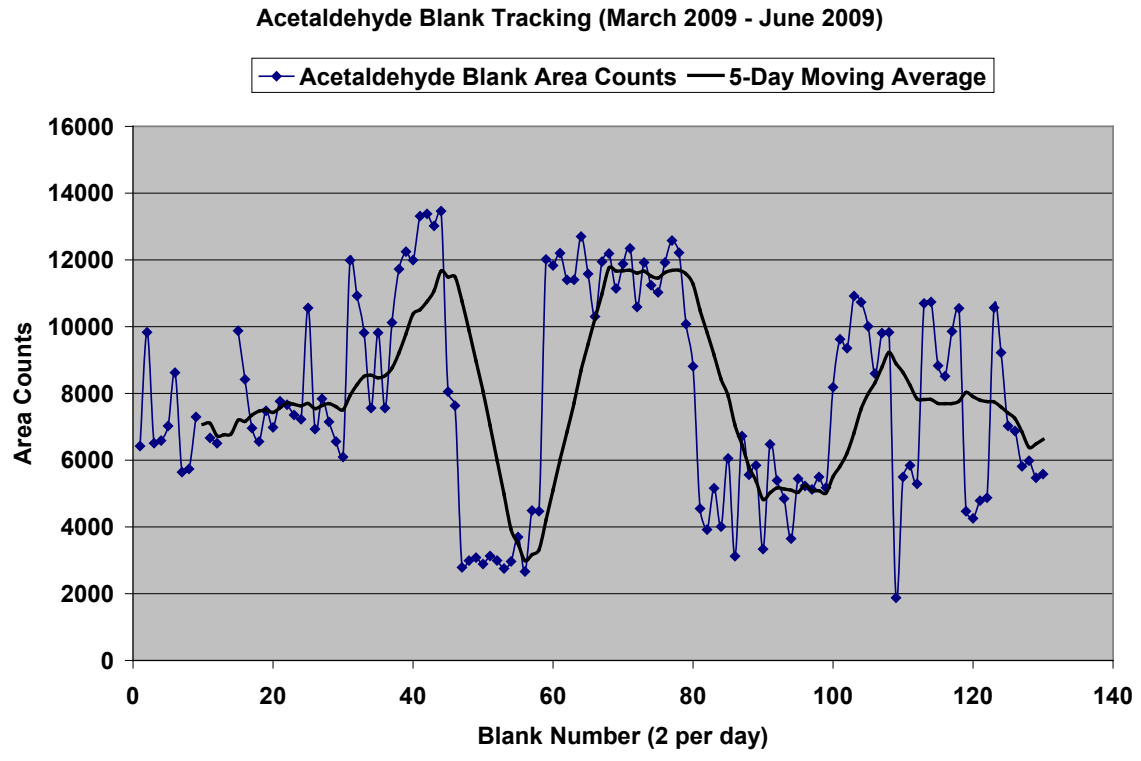


FIGURE 2. ACETALDEHYDE BLANK TRACKING

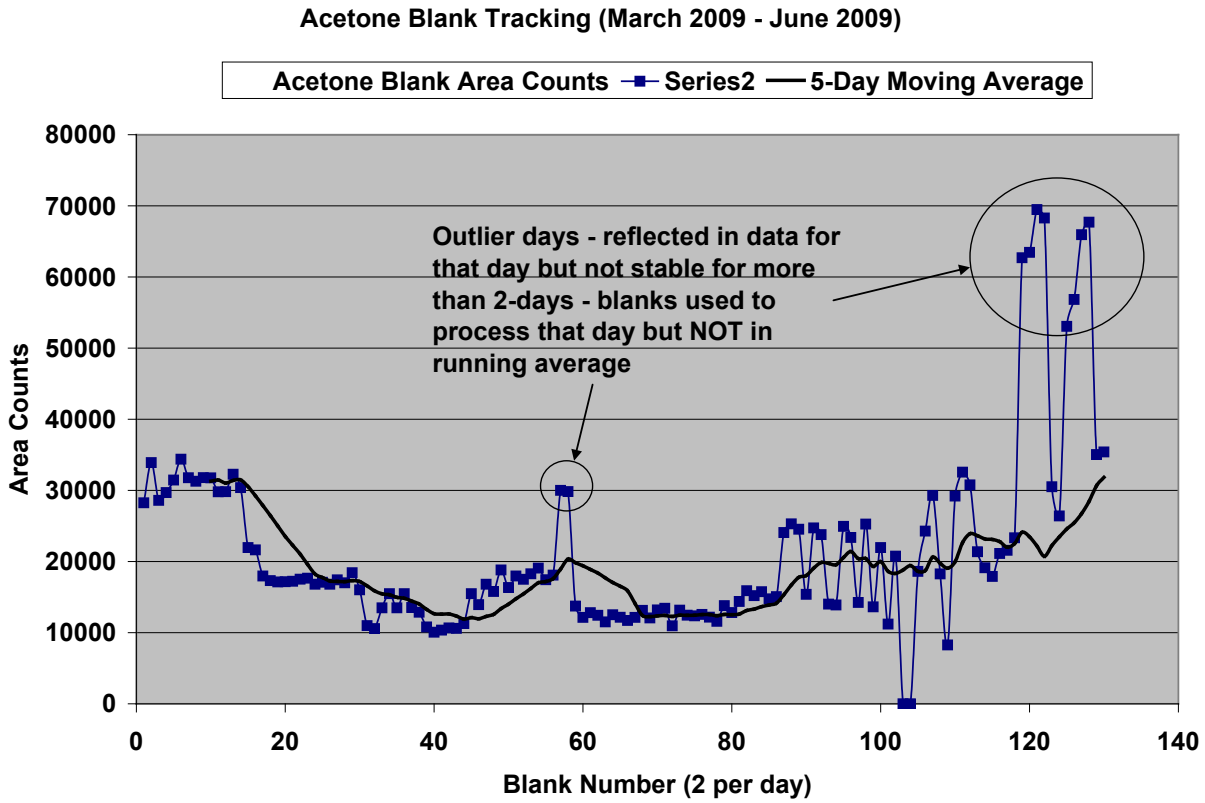


**FIGURE 3. ACETONE BLANK TRACKING**

Figure 4 illustrates a running example of the final blank process that was developed using formaldehyde as an example. The figure shows the five-day running average blank value (note that there are two blanks analyzed per day, as well as the five-day running 3σ upper and lower control limits. As noted there are occasional single blanks which rise above those limits, which would trigger review. In these cases, the review indicates that these were outliers that were not represented in the data, and therefore, these measurements were not used to modify the running average or control limits. In one case, near Run 45 the control limits are very tight due to a period of time when the variation was small. In this case, although the blanks shown are slightly above the 3σ limit, the movement is small and still well within the historical norm, and in that case the judgment is made to utilize the data. This example also underscores the fact that a set of process rules are not a complete replacement for good engineering judgment.

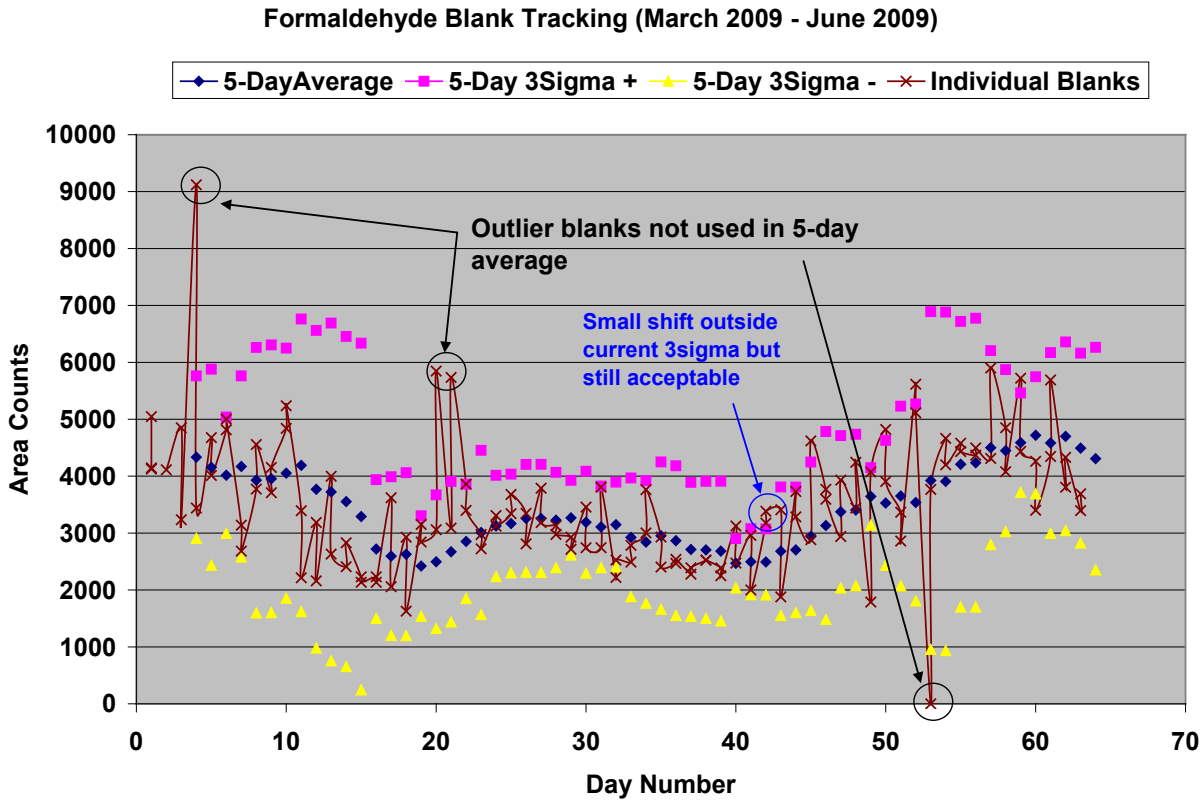


**FIGURE 4. FINAL BLANK PROCESS EXAMPLE WITH FORMALDEHYDE**

Figure 5 illustrates a similar example for methanol tracking. Methanol appears to be affected by periodic issues which generate a low level noise in both blanks and samples, which could result in erroneous reporting of methanol and therefore affect NMOG calculation. This is confirmed by the fact that when the blanks are clean there is also no methanol detected in exhaust samples. The developed QA process is able to detect this noise and account for its effect on the data, so that only a significant quantity of real methanol emission would be reported, and the data are not disturbed by this process noise. In areas of media/process variability, the 3-sigma screening value (yellow triangles) rises, as shown in Figure 5. Therefore, the LOQ screening process outlined earlier of checking the different between sample and blanks against the five-day 3-sigma would be an effective screening for this issue.

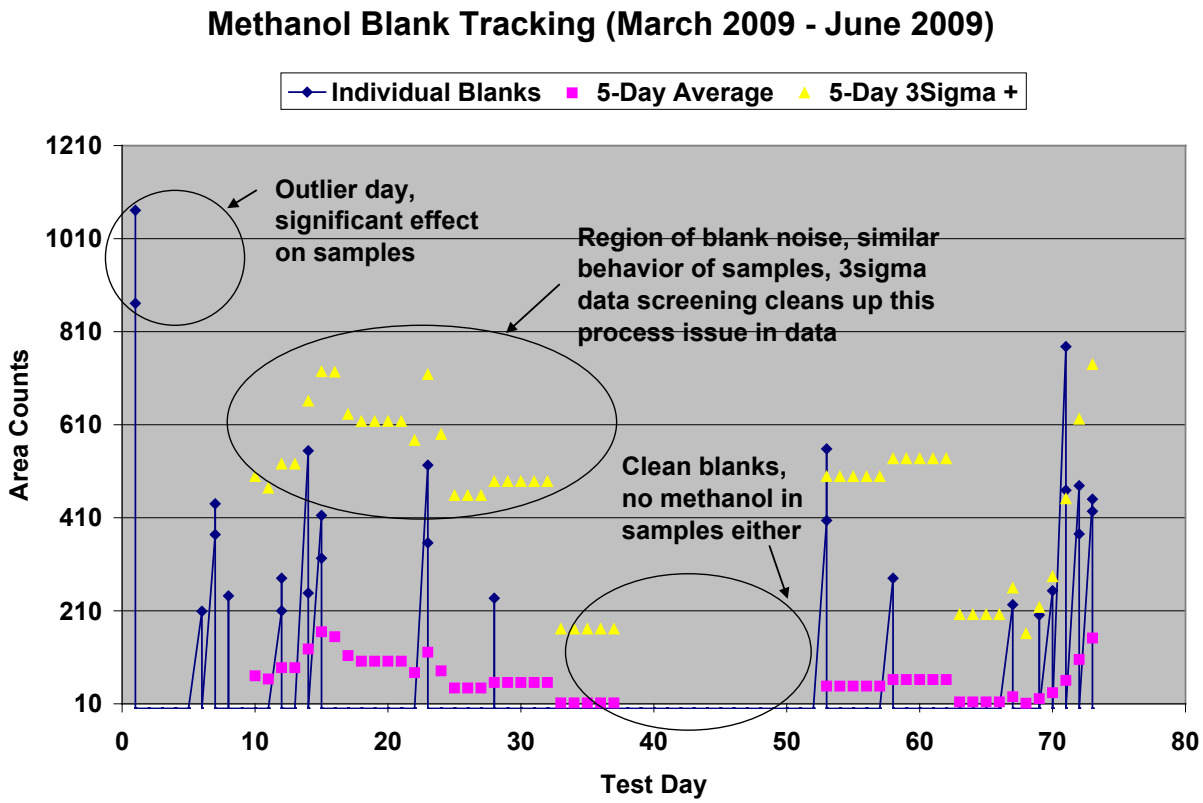


**FIGURE 5. FINAL BLANK PROCESS EXAMPLE WITH METHANOL**

# APPENDIX L

# EPA FUEL SAMPLING PROCEDURE FOR CARRYOVER EXPERIMENTS

November 12, 2008

Procedure for Sampling and Handling of Gasoline Samples

1. Make sure that the fuel in drum, sampling equipment and sample container are at 50$^{o}$F max

    - It is strongly advisable that the sample container be cooled in an ice chest
    - Use a hand transfer pump
    - The glass sampling container must meet the following requirements:

        i. At least 1 qt. capacity
        ii. Amber colored.
        iii. Its cap must be equipped with a neoprene seal

2. Position the sampling tube to take the fuel sample from the mid level of whatever fuel quantity is left in the drum

    - It is recommended that a separate rigid tube of required length be used to sample fuel from a full drum and from a nearly empty (~ 15% full) drum

3. Using the hand transfer pump, activate the flow of fuel from the drum into a slop container and slop at least 1 qt. of fuel

4. Fill the sample container to 75-80% of capacity and seal tightly to prevent sample losses

    - Make sure that during sampling the fuel flows gently (w/o splashing) into the sampling container. Use a filling tube that reaches to the bottom of the container

5. Store the sample at 0 to 1$^{o}$C in a cooling bath or a refrigerator prior to opening the sample container for RVP measurement

6. Have the sample analyzed as quickly as possible

# APPENDIX M

# FUEL BLENDING EXPERIMENT TO CHARACTERIZE CARRYOVER EFFECTS

## Investigation of Fuel Carryover Effects on Distillation Parameters

July 27, 2009

| PROPERTY | UNIT | Fuel Pair A | | Fuel Pair B | | Fuel Pair C | | Fuel Pair D | | Fuel Pair E | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fuel 1 | Fuel 2 | Fuel 1 | Fuel 27 | Fuel 1 | Fuel 6 | Fuel 2 | Fuel 21 | Fuel 27 | Fuel 21 |
| **Ethanol Content** | **vol. %** | **10** | **0** | **10** | **15** | **10** | **10** | **0** | **20** | **15** | **20** |
| **T50** | **°F** | **150** | **240** | **150** | **220** | **150** | **190** | **240** | **160** | **220** | **160** |
| **T90** | **°F** | **300** | **340** | **300** | **340** | **300** | **340** | **340** | **300** | **340** | **300** |
| **DVPE** | **psi** | **10.0** | **10.0** | **10.0** | **6.65** | **10.0** | **6.65** | **10.0** | **6.65** | **6.65** | **6.65** |
| **Aromatics** | **vol. %** | **15** | **15** | **15** | **15** | **15** | **15** | **15** | **40** | **15** | **40** |

## Test Fuel Sets

| EtOH | Fuel Set A | | | RVP | | T50 | | T90 | |
|---|---|---|---|---|---|---|---|---|---|
| | Test Fuel | Components | | Target | Meas. | Target | Meas. | Target | Meas. |
| | | Fuel 1 | Fuel 2 | | | | | | |
| 10 | 1 | 100 | 0 | 10 | 9.93 | 150 | 149.8 | 300 | 297.2 |
| 0 | 2 | 0 | 100 | 10 | 10.22 | 240 | 237.9 | 340 | 339 |
| | A3 | 5 | 95 | | 10.64 | | 236 | | 338.8 |
| | A4 | 95 | 5 | | 10.05 | | 150.6 | | 301.7 |

| | Fuel Set B | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Test Fuel | Components | | | | | | | |
| | | Fuel 1 | Fuel 27 | | | | | | |
| 10 | 1 | 100 | 0 | 10 | 9.93 | 150 | 149.8 | 300 | 297.2 |
| 15 | 27 | 0 | 100 | 6.65 | 6.87 | 220 | 221.7 | 340 | 339.3 |
| | B3 | 5 | 95 | | 7.01 | | 216.1 | | 339.2 |
| | B4 | 95 | 5 | | 9.81 | | 150.9 | | 301.9 |

| | Fuel Set C | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Test Fuel | Components | | | | | | | |
| | | Fuel 1 | Fuel 6 | | | | | | |
| 10 | 1 | 100 | 0 | 10 | 9.93 | 150 | 149.8 | 300 | 297.2 |
| 10 | 6 | 0 | 100 | 6.65 | 7.21 | 190 | 189.4 | 340 | 340.3 |
| | C3 | 5 | 95 | | 7.23 | | 186 | | 339.2 |
| | C4 | 95 | 5 | | 9.72 | | 150.4 | | 301.7 |

| | Fuel Set D | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Test Fuel | Components | | | | | | | |
| | | Fuel 2 | Fuel 21 | | | | | | |
| 0 | 2 | 100 | 0 | 10 | 10.22 | 240 | 237.9 | 340 | 339 |
| 20 | 21 | 0 | 100 | 6.65 | 6.98 | 160 | 168.8 | 300 | 304.8 |
| | D3 | 5 | 95 | | 7.27 | | 169.2 | | 305.9 |
| | D4 | 95 | 5 | | 10.75 | | 235.8 | | 336.4 |

| | Fuel Set E | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Test Fuel | Components | | | | | | | |
| | | Fuel 27 | Fuel 21 | | | | | | |
| 15 | 27 | 100 | 0 | 6.65 | 6.87 | 220 | 221.7 | 340 | 339.3 |
| 20 | 21 | 0 | 100 | 6.65 | 6.98 | 160 | 168.8 | 300 | 304.8 |
| | E3 | 5 | 95 | | 6.95 | | 168.6 | | 305.2 |
| | E4 | 95 | 5 | | 6.83 | | 217.8 | | 338.9 |

**Scope of Work:**

- ▶ Obtain samples of fuels 1,2,6,21 and 27
  Sample sizes (~2X needed volume):
  Fuel 1: 1 gal
  Fuel 2: 1/2 gal
  Fuel 6: 1 qt
  Fuel 21: 1/2 gal
  Fuel 27: 1/2 gal
- ▶ Follow EPAct Fuel Sampling Procedure
- ▶ Blend fuels A3, A4, B3, B4, C3, C4, D3, D4, E3 and E4
- ▶ Perform D86 test on the fuels of each set in the course of a single day
  - Use exclusively OptiDist equipment
  - Use the same distillation still for all tests
- ▶ Note: The same fuel need not be tested twice on a given day, if it belongs to two different fuel sets which are being tested on that day

# APPENDIX N

# ADDITIONAL FUEL CARRYOVER EXPERIMENTS

## Procedure

1. collect fuel sample
2. drain and flush to E20
3. run sulfur purge
4. collect fuel sample
5. drain and refill with E20
6. run single LA92 prep
7. collect fuel sample
8. drain and flush to E0
9. run sulfur purge
10. collect fuel sample
11. drain and refill with E0
12. run single LA92 prep
13. collect fuel sample
14. drain and refill with E0
15. run single LA92 prep
16. collect fuel sample

# Results

| Vehicle | Sample Description | Ethanol SwRI D5599 Vol% | Ethanol SwRI Petrospec Wt% |
|---|---|---|---|
| EPA-HODY | original fuel in tank | 10.4 | 11.9 |
| EPA-HODY | first flush to E20 | 18.0 | 17.5 |
| EPA-HODY | 2nd flush to E20 | 20.1 | 18.8 |
| EPA-HODY | first flush to E0 | 7.4 | 7.8 |
| EPA-HODY | 2nd flush to E0 | 1.6 | 1.5 |
| EPA-HODY | 3rd flush to E0 | 0.2 | 0.2 |
| EPA-NALT | original fuel in tank | 10.9 | 11.3 |
| EPA-NALT | first flush to E20 | 19.3 | 18.0 |
| EPA-NALT | 2nd flush to E20 | 20.7 | 18.6 |
| EPA-NALT | first flush to E0 | 4.9 | 5.0 |
| EPA-NALT | 2nd flush to E0 | 1.4 | 1.3 |
| EPA-NALT | 3rd flush to E0 | 0.2 | 0.2 |
| EPA-TSIE | original fuel in tank | 19.4 | 19.1 |
| EPA-TSIE | first flush to E20 | 21.5 | 19.6 |
| EPA-TSIE | 2nd flush to E20 | 21.0 | 19.2 |
| EPA-TSIE | first flush to E0 | 5.0 | 5.0 |
| EPA-TSIE | 2nd flush to E0 | 1.1 | 1.1 |
| EPA-TSIE | 3rd flush to E0 | 0.2 | 0.0 |
| EPA-HCIV | original fuel in tank | 13.9 | 14.9 |
| EPA-HCIV | first flush to E20 | 20.4 | 18.8 |
| EPA-HCIV | 2nd flush to E20 | 21.1 | 19.4 |
| EPA-HCIV | first flush to E0 | 5.2 | 5.2 |
| EPA-HCIV | 2nd flush to E0 | 0.9 | 0.7 |
| EPA-HCIV | 3rd flush to E0 | 0.1 | 0.0 |
| EPA-TCAM | original fuel in tank | 10.2 | 11.2 |
| EPA-TCAM | first flush to E20 | 19.1 | 18.2 |
| EPA-TCAM | 2nd flush to E20 | 20.7 | 18.9 |
| EPA-TCAM | first flush to E0 | 3.2 | 3.2 |
| EPA-TCAM | 2nd flush to E0 | 0.5 | 0.4 |
| EPA-TCAM | 3rd flush to E0 | <0.1 | 0.0 |

Note: 2nd flush to E0 (color-shaded above), should be roughly equivalent to color-shaded samples listed below. The entries with the same color-shaded areas from above and below can be compared.

| previous results | | EPA D5599 Vol% | SwRI Petrospec Wt% |
|---|---|---|---|
| EPA-HODY | MP-1 fuel sample | 2.0 | 1.9 |
| EPA-NALT | MP-1 fuel sample | 0.6 | 0.2 |
| EPA-NALT | 05/29 fuel sample | 1.4 | 1.5 |
| EPA-TSIE | MP-1 fuel sample | 0.7 | 0.4 |
| EPA-HCIV | MP-1 fuel sample | 0.6 | 0.3 |
| EPA-TCAM | MP-1 fuel sample | 1.6 | 1.5 |

# APPENDIX O

# REFUELING LOCATION EXPERIMENTS

For each chosen vehicle SwRI conducted the fuel change sequence given in Table O-1. This sequence was based on what was used during the conduct of Phase 3 testing, and should be representative of the actual Phase 3 test procedure. For each vehicle, the sequence was conducted at each of two refueling locations using the same pair of E20 and E0 fuels. The refueling locations used for each chosen vehicle are given in Table O-2. A schematic of the refueling locations is given in Figure O-1. All fuel samples were collected approximately half way through each drain

## TABLE O-1. FUEL CHANGE SEQUENCE

| STEP | DESCRIPTION | REQUIRED SAMPLE ANALYSES |
|---|---|---|
| 1 | Collect fuel sample from vehicle while draining fuel via fuel rail. | Density @ 60°F by D4052<br>Ethanol concentration by D5599<br>Ethanol concentration by Petrospec |
| 2 | Fill fuel tank to 40% with designated E20 Group 1 fuel. Fill-up fuel temperature must be less than 50°F. | |
| 3 | Start vehicle and execute catalyst sulfur removal procedure described in Appendix C of CRC E-60 Program report. Apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system. | |
| 4 | Collect fuel sample from vehicle while draining fuel via fuel rail. | Density @ 60°F by D4052<br>Ethanol concentration by D5599<br>Ethanol concentration by Petrospec |
| 5 | Fill fuel tank to 40% with designated E20 Group 1 fuel. Fill-up fuel temperature must be less than 50°F. | |
| 6 | Perform three 2-phase (bags 1 and 2) LA92 cycles. During these prep cycles, apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system. | |
| 7 | Collect fuel sample from vehicle while draining fuel via fuel rail. | Density @ 60°F by D4052<br>Ethanol concentration by D5599<br>Ethanol concentration by Petrospec |
| 8 | Fill fuel tank to 40% with designated E0 Group 2 fuel. Fill-up fuel temperature must be less than 50°F. | |
| 9 | Start vehicle and execute catalyst sulfur removal procedure described in Appendix C of CRC E-60 Program report. Apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system. | |
| 10 | Collect fuel sample from vehicle while draining fuel via fuel rail. | Density @ 60°F by D4052<br>Ethanol concentration by D5599<br>Ethanol concentration by Petrospec |
| 11 | Fill fuel tank to 40% with designated E20 Group 2 fuel. Fill-up fuel temperature must be less than 50°F. | |
| 12 | Perform three 2-phase (bags 1 and 2) LA92 cycles. During these prep cycles, apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system. | |
| 13 | Collect fuel sample from vehicle while draining fuel via fuel rail. | Density @ 60°F by D4052<br>Ethanol concentration by D5599<br>Ethanol concentration by Petrospec |

**TABLE O-2. REFUELING LOCATIONS**

| BRAND | MODEL | LOCATION A | LOCATION B |
|---|---|---|---|
| Chevrolet | C1500 Silverado | Containment Pad | South |
| Toyota | Camry | Containment Pad | South |
| Toyota | Sienna | Containment Pad | South |
| Dodge | Caliber | Containment Pad | South |
| Honda | Civic | Containment Pad | South |
| Honda | Odyssey | Containment Pad | South |
| Nissan | Altima | Containment Pad | South |

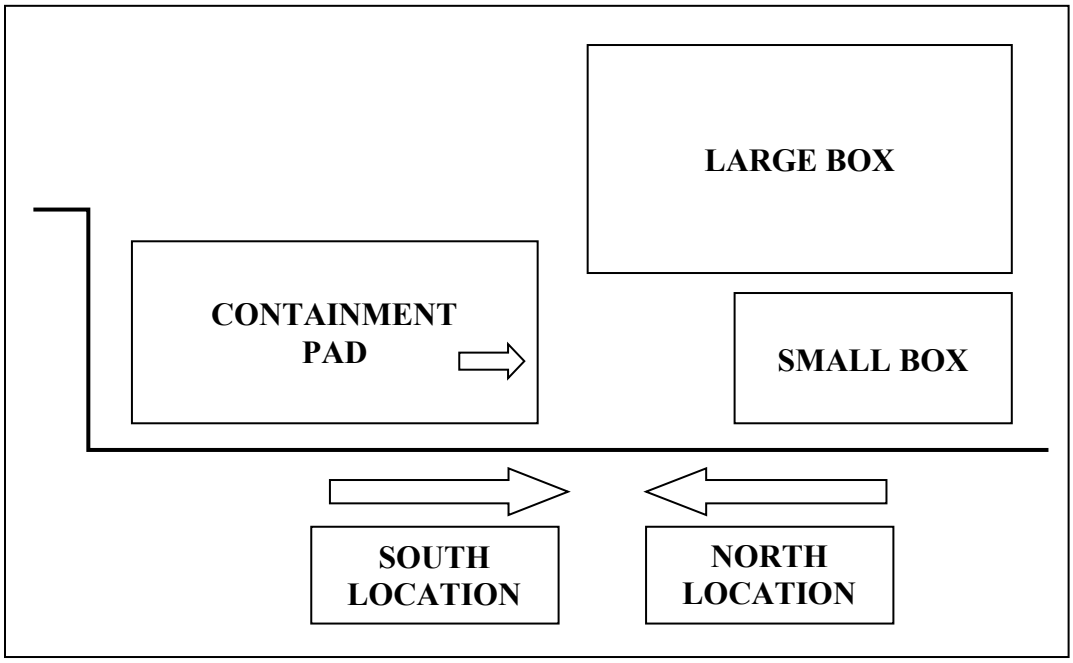


**FIGURE O-1. SCHEMATIC OF VEHICLE REFUELING LOCATIONS**