Characterization of Emissions from Malfunctioning Vehicles Fueled with Oxygenated Gasoline-Ethanol (E-10) Fuel — Part III

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ABSTRACT

Five vehicles (a 1987 Ford Taurus, a 1996 Chrysler Concord, a 2001 Ford Focus (Low Emission Vehicle (LEV)), a 1993 Buick Regal, and a 2001 Dodge Intrepid (LEV)) were tested using three different fuels: (1) winter grade (E-10) fuel containing 10% (vol.) 200 proof ethanol, (2) winter grade (WG) fuel without any ethanol or oxygen containing compounds, and (3) summer grade (SG) fuel without oxygenates. Vehicle emissions were characterized at test temperatures of 75 (SG fuel only), 40, 20, 0, and -20 ^{o}F. The vehicles were tested in the conditions in which they were obtained from either a private individual or a vehicle rental service. They were also tested in a simulated malfunction mode in which the oxygen sensor was disconnected (O2 mode). The vehicles were tested using the Urban Dynamometer Driving Schedule (UDDS) of the Federal Test Procedure (FTP). Four IM240 test cycles were run after each of the UDDS tests and the exhaust particulate matter (PM2.5 and PM10), from the four IM240 driving cycles were collected on single filters. The gaseous emissions were collected and analyzed for total hydrocarbons (THC), carbon monoxide (CO), oxides of nitrogen (NOx), speciated hydrocarbons, speciated aldehydes, ethanol, methanol, 2-propanol, methyltertiarybutyl ether (MTBE), and ethyltertiarybutyl ether (ETBE).

Hydrocarbon emissions generally increased as test temperature decreased for all vehicles, fuels, and test modes. The E-10 fuel generally reduced vehicular CO emissions. The trend for carbon monoxide and oxides of nitrogen emissions showed a general increase in emission rates as the testing temperatures decreased. When the O2 sensor was disabled (O2 mode), the trend showed increasing carbon monoxide and oxides of nitrogen emissions.

The emissions of such toxic compounds as benzene and 1,3-butadiene tended to increase as the testing temperatures decreased. Disconnecting the O2 sensor generally increased the emissions of these toxic compounds when compared with the no malfunction (NM) mode emissions. The E-10 fuel generally reduced 1,3-butadiene emissions. The measured emissions of formaldehyde and acetaldehyde from the test vehicles showed a general increase in emissions as test temperature decreased, when operating in the malfunction mode, and when testing with E-10 fuel.

The PM2.5 and PM10 particulate emission rates were comparable at all test conditions. The particulate emissions from both vehicles followed the HC emission trend and increased as the test temperature decreased. The E-10 fuel generally reduced particulate emissions from the test vehicles. Disconnecting the oxygen sensor generally increased particulate emissions.

Generally, of the five vehicles tested, the LEV's had the lowest regulated, toxics, and particulate emissions.

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Abbreviations and Symbols

°F	degrees Fahrenheit
CFR	Code of Federal Regulation
CO	Carbon monoxide
CVS	Constant Volume Sampler
E-10	10 % ethanol, 90 % gasoline blend (v/v)
EGR	Exhaust Gas Recirculation
ETBE	Ethyltertiarybutylether
g/cm3	grams per cubic centimeter
HC	Hydrocarbon
i.d.	inside diameter
IBP	Initial Boiling Point
IM240	Inspection and Maintenance test cycle, 240 seconds
L/min	Liters per minute
mg/mi	milligrams per mile
MTBE	Methylteriarybutylether
NC	North Carolina
NM	Normal Mode
NOx	Oxides of nitrogen
O2	Oxygen
O2S	Oxygen sensor
PM10	Particulate matter <= 10 mm
PM2.5	Particulate matter <= 2.5 mm
R2	Correlation coefficient
RVP	Reid Vapor Pressure
SFI	Sequential Fuel Injection
SG	Summer grade fuel
THC	Total Hydrocarbon
TWC	Three Way Catalyst
UDDS	Urban Dynamometer Driving Schedule
WG	Winter grade fuel

INTRODUCTION

Motor vehicles emit large quantities of hydrocarbons (HCs), carbon monoxide (CO), and oxides of nitrogen (NOx). These emissions react in the atmospheric photochemical processes to form ozone and other oxidants. Motor vehicles also emit compounds such as formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and particulate matter (PM2.5 and PM10), all of which are of major health concern. The 1990 Clean Air Act Amendment specifies a reduction in these toxic emissions.[1] This study characterized the emissions from five light duty gasoline powered vehicles tested at ambient temperatures of 75, 40, 20, 0, and -20 °F. The test vehicles were operated on commercially available winter grade fuels (with and without ethanol) and on a commercially available summer grade fuel. The winter and summer grade fuels were purchased without any oxygenate (MTBE or ethanol) content. A portion of the winter fuel was blended with 200 proof ethanol to contain 10% ethanol by volume. In addition, the vehicles were tested using the different fuels at temperatures of 75 (summer grade fuel only), 40, 20, 0, and -20 °F (winter grade and the ethanol blended winter grade fuels). The vehicles were tested "as received" (no engine tuning, etc.) only the belts, hoses, and fluids were checked and replaced if necessary. The vehicles were then tested in a simulated malfunction mode (the oxygen sensor was disconnected).

Particulate emissions from vehicles are becoming of major concern due to their adverse effects on materials, visibility reduction, atmospheric reactivity, and human health. Recent epidemiological studies have indicated health concerns for particulate matter with an aerodynamic diameter of 10 μm or less.[2,3] In this study, individual PM2.5 and PM10 filters were taken from each of the UDDS tests. After the completion of each UDDS test, the particulate emissions from four IM240 driving cycles were collected on individual PM2.5 and PM10 filters. Currently there is little information regarding particulate emission rates from newer in-use light-duty gasoline vehicles [4] and very few studies done on vehicles tested at malfunction conditions (oxygen sensor disconnected), at ambient temperatures.

EXPERIMENTAL METHODS AND MATERIALS

The test fuels, vehicles, facilities, and procedures are described in this section.

Test Fuels

The fuels used in this study were a summer grade fuel (SG) and two winter grade fuels (WG-01 and WG-02) containing no ethanol. Portions of the winter grade fuels were mixed with ethanol to produce a 10 % ethanol by volume (E-10) fuel. The WG-01 was used in the Taurus, Concord, Regal, and Focus, and the WG-02 fuel was used only in the Intrepid. The WG-01 fuel was purchased in sufficient quantity to test the four scheduled vehicles. A delay in physically moving the test equipment to the New EPA Campus testing facilities allowed time to test a fifth vehicle (Intrepid); thus a second winter grade fuel (WG-02) was purchased. Fuels were purchased locally and are representative of the fuels used by consumers. The characteristics of the test fuels are listed in Table 1.

Table 1. Characteristics of test fuels.[a]

Fuel Property	Summer	WG-01	WG-01-E10	WG-02	WG-02-E-10
Specific gravity, g/cm^3	0.75	0.72	0.75	0.74	NA
RVP[a]	8.30	10.33	11.14	12.28	13.30
Distillation, °F					
IBP[b]	93.20	86.00	95.00	87.80	82.40
10 %	138.20	113.00	118.40	111.20	109.40
50 %	223.70	205.70	167.00	212.00	163.40
90 %	311.90	327.20	320.90	338.90	333.50
End Point	410.00	410.00	402.80	417.20	420.80
Paraffins, %	54.07	50.34	45.31	51.32	46.19
Olefins, %	6.95	12.71	11.44	12.11	10.90
Aromatics, %	38.62	36.61	32.95	36.15	32.54
Benzene, %	1.20	1.27	1.14	1.72	1.55
Ethanol, %	0.00	0.00	10.00	0.00	10.00

[a] Reid vapor pressure.

[b] Initial Boiling Point.

NA-Data not available.

Test Schedule/Conditions

A single UDDS test was performed on each vehicle at 75 °F. Duplicate UDDS tests were performed on each vehicle at each of the four lower test temperatures and test conditions (Table 2). The vehicles were conditioned using the LA-4 cycle (bag1 and bag 2 of the UDDS driving cycle) with each test fuel, at each test condition, before actually testing the vehicle for data collection.

Table 2. Test Schedule/Conditions for 1987 Ford Taurus, 1996 Chrysler Concord, 2001 Ford Focus Low Emission Vehicle (LEV), 1993 Buick Regal, and 2001 Dodge Intrepid (LEV).

Description	**Summer Test Conditions**	**Winter Test Conditions**
Driving Cycles:	UDDS + 4 IM240's	UDDS + 4 IM240's
Test Temperatures:	75 (+/- 3)°F	40, 20, 0, -20 (+/- 3)°F
Duplicate Runs:	Single test only	Duplicate runs
Fuel Type:	Summer Fuel	Winter Fuel
Ethanol:	No Ethanol	With/Without Ethanol
Malfunction Mode:	O2 Sensor Disconnected	O2 Sensor Disconnected
Emissions Measured:	Gaseous Emissions Particles Measured PM2.5 and PM10	Gaseous Emissions Particles Measured PM2.5 and PM10

Test Vehicles

The vehicles used in this study are described below.

Table 2a. Vehicles tested.[a]

Vehicle	Cyl.	Vehicle Miles	Displaced Liters	Fuel System	Emission System [a]
1987 Ford Taurus	6	110,331	3.0	MFI	TWC/O2S
1996 Chrysler Concord	6	38,934	3.3	SFI	EGR/TWC/O2S
2001 Ford Focus	4	8,832	2.0	SFI	EGR/TWC/O2S
1993 Buick Regal	6	141,881	3.8	TPI	EGR/TWC/O2S
2001 Dodge Intrepid	6	23,495	2.7	SFI	EGR/TWC/O2S

[a] MFI=Multipoint Fuel Injection
EGR=Exhaust Gas Recirculation
TWC=Three Way Catalyst
O2S=Oxygen Sensor
SFI=Sequential Fuel Injection
TPI=Tuned Port Injection

Test Facilities

Vehicle road simulations were conducted on a Horiba Model CDC800/DMA915 computerized DC electric chassis dynamometer. The dynamometer was housed in a temperature controlled chamber capable of maintaining vehicle test temperatures from -20 to 110 °F (+/- 3 °F). Vehicle emissions were transferred from the vehicle tailpipe to a constant volume sampling (CVS) system through a 7.62-cm i.d. (3 inch) section of flexible stainless steel tubing heated to 230 °F. The CVS system, which dilutes the tailpipe emissions with charcoal-filtered room air, has been described previously.[5] A heater has been added behind the dilution air filter to raise the tunnel dilution air temperature to 150 °F to prevent formaldehyde and other compound losses in the system.[6]

Test Procedures

Testing was conducted as described in the *Code of Federal Regulations* (CFR) Title 40[7] using the Urban Dynamometer Driving Schedule of the Federal Test Procedure (FTP). The Inspection/Maintenance (IM240) test was designed to detect malfunctioning vehicles with advanced (computer-controlled) emission systems. The test was patterned after the first two major accelerations and decelerations of the FTP and has a maximum speed of 56.7 miles per hour and test duration of 240 seconds. At the beginning of the test week, the vehicle to be tested

was pre-conditioned by driving the vehicle over the UDDS cycle with the test fuel, in the test mode, and at the test temperature to be used for data collection. The daily UDDS test served (as duplicates were run at all temperatures except 75 °F) as the pre-conditioning for the following days test. During the test week when the vehicle, fuel, temperature, or mode were to be changed, the vehicle would be conditioned in the afternoon after the daily test was over, by running a LA-4 cycle at the test conditions to be used the following day. After each UDDS test cycle was run, four IM240s were run and the PM2.5 and PM10 particles and the gaseous emissions were collected. All four IM240 cycle particulate emissions were collected on single filters using both PM2.5 and PM10 cyclones (University Research Glassware, Carrboro, NC) system. Vehicle emissions were measured at 75, 40, 20, 0, and -20 °F for each of the UDDS driving cycles and IM240 cycles. The gaseous regulated emissions and particle data shown (Tables 8-12a) for the IM240 cycles are an average of the four tests.

An integrated emissions sample was collected from the CVS system in a Tedlar bag for each UDDS test phase, which included an initial 124 second sample. Also, a background air sample was taken after the charcoal dilution air filter. The regulated emissions (THC, CO, and NOx) were measured with instruments interfaced to the CVS system and used for real-time sampling during the testing.

Vehicle emissions were characterized by measurement of speciated (individual) hydrocarbons (more than 250 compounds), speciated aldehydes (12 compounds), regulated gaseous emissions (THC, CO, and NOx), 3 alcohols, and 2 ethers. Identifications or structural formulas for more than 95% of the emitted HCs have been determined by established gas chromatographic-mass spectrometric (GC-MS) techniques.[8] Supplementary regulated, speciated HCs, speciated aldehydes, ethanol, methanol, 2-propanol, methyltertiarybutyl ether (MTBE), and ethyltertiarybutyl ether (ETBE) data are available from the authors.

Tailpipe Emissions

The vehicle UDDS bag samples were analyzed for speciated hydrocarbons, alcohols, and ethers by gas chromatography.[9] The data were manually transferred to a PC where peak assignments were made and then the results were electronically transferred to the Archived Mobile Source Emissions Data Base (AME) . The individual hydrocarbons were identified using a Lotus 1-2-3 program developed for identifying these compounds in complex chromatograms.[10] The concentrations of the regulated emissions were reported as g/mi and mg/mi for individual HCs, aldehydes, alcohols, and ethers.

Aldehyde emissions were sampled from the CVS system through a heated (212 °F) stainless steel line and collected on silica gel cartridges coated with acidified 2,4-dinitrophenylhydrazine. A mass flow controller was used to regulate the sampling rate of the aldehydes in the exhaust stream at 1 L/min. The aldehydes were analyzed by the previously described liquid chromatographic procedure.[11]

Table 3. Vehicle UDDS tailpipe emission rates at 75 °F.

Vehicle	**Taurus**		**Concord**	
Mode	**No Malfunction**	**O2 Sensor Disconnected**	**No Malfunction**	**O2 Sensor Disconnected**
Fuel	**Summer Grade**		**Summer Grade**	
THC, g/mi	0.34	1.67	0.18	0.35
CO, g/mi	5.02	23.84	1.35	5.05
NOx, g/mi	0.75	0.44	0.37	2.90
Fuel Economy, mpg	20.85	21.03	20.50	20.26
Ethanol, mg/mi	0.08	<0.01	<0.01	<0.01
Formaldehyde, mg/mi	5.04	6.05	3.82	3.52
Acetaldehyde, mg/mi	1.19	4.38	0.99	1.89
Total Aldehydes, mg/mi	8.68	15.12	6.83	9.20
Benzene, mg/mi	13.00	98.60	5.38	12.72
1,3-Butadiene, mg/mi	1.18	5.25	0.51	1.19
PM2.5, mg/mi	6.80	5.49	4.05	2.27
PM10, mg/mi	8.58	7.75	7.95	3.40

Table 3a. Vehicle UDDS tailpipe emission rates at 75 °F.

Vehicle	**Focus**		**Regal**	
Mode	**No Malfunction**	**O2 Sensor Disconnected**	**No Malfunction**	**O2 Sensor Disconnected**
Fuel	**Summer Grade**		**Summer Grade**	
THC, g/mi	0.07	0.40	0.26	0.66
CO, g/mi	0.56	9.38	2.98	6.82
NOx, g/mi	0.06	0.12	0.73	4.05
Fuel Economy, mpg	24.97	25.42	20.32	20.52
Ethanol, mg/mi	<0.01	0.72	<0.01	<0.01
Formaldehyde, mg/mi	1.04	0.65	4.64	4.80
Acetaldehyde, mg/mi	0.38	0.28	1.16	2.54
Total Aldehydes, mg/mi	2.50	2.09	9.03	11.54
Benzene, mg/mi	2.13	50.95	8.91	40.00
1,3-Butadiene, mg/mi	0.41	8.35	0.87	1.81
PM2.5, mg/mi	2.00	4.60	4.80	3.20
PM10, mg/mi	4.50	4.50	6.10	3.70

Table 3b. Vehicle UDDS tailpipe emission rates at 75 °F.

Vehicle	**Intrepid**	
Mode	**No Malfunction**	**O2 Sensor Disconnected**
Fuel	**Summer Grade**	
THC, g/mi	0.16	0.31
CO, g/mi	0.74	4.74
NOx, g/mi	0.10	0.81
Fuel Economy, mpg	21.24	21.46
Ethanol, mg/mi	<0.01	<0.01
Formaldehyde, mg/mi	1.32	1.15
Acetaldehyde, mg/mi	0.36	0.39
Total Aldehydes, mg/mi	2.42	2.26
Benzene, mg/mi	4.81	27.41
1,3-Butadiene, mg/mi	0.11	0.35
PM2.5, mg/mi	2.50	2.80
PM10, mg/mi	3.30	3.00

Table 4. Vehicle UDDS tailpipe emission rates at 40 °F.

Vehicle	**Taurus**				**Concord**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**		**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.81	0.76	3.43	2.06	0.44	0.42	0.69	0.34
CO, g/mi	10.49	8.49	51.20	27.01	3.37	3.40	7.63	3.31
NOx, g/mi	0.70	0.90	0.53	0.56	0.35	0.38	3.27	3.77
Fuel Economy, mpg	18.79	18.69	17.43	18.14	18.48	18.03	18.27	18.55
Ethanol, mg/mi	<0.01	0.02	<0.01	0.41	<0.01	4.24	<0.01	<0.01
Formaldehyde, mg/mi	5.46	9.56	13.35	9.09	3.88	3.69	4.49	3.98
Acetaldehyde, mg/mi	2.20	7.42	13.48	22.23	1.68	6.28	3.24	5.57
Total Aldehydes, mg/mi	12.34	21.46	42.33	38.31	9.53	14.03	14.16	13.73
Benzene, mg/mi	35.98	31.69	167.92	114.45	14.47	11.04	29.34	13.43
1,3-Butadiene, mg/mi	4.12	3.40	26.05	9.84	1.80	1.47	1.98	1.61
PM2.5, mg/mi	13.71	13.28	19.48	15.64	9.19	6.09	9.85	4.03
PM10, mg/mi	15.09	18.13	20.93	17.81	11.62	9.24	8.54	10.41

Table 4a. Vehicle UDDS tailpipe emission rates at 40 °F.

Vehicle	**Focus**				**Regal**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**		**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.19	0.20	0.42	0.21	0.47	0.46	0.93	1.31
CO, g/mi	1.65	1.54	5.73	2.07	4.85	4.24	9.80	17.54
NOx, g/mi	0.08	0.13	0.82	3.00	1.06	0.71	4.56	2.70
Fuel Economy, mpg	24.00	23.35	22.94	23.89	19.23	19.30	19.02	18.81
Ethanol, mg/mi	<0.01	2.22	<0.01	<0.01	0.10	<0.01	<0.01	1.79
Formaldehyde, mg/mi	0.90	0.80	1.28	0.95	9.39	8.09	10.42	18.81
Acetaldehyde, mg/mi	0.43	2.01	0.95	1.99	2.65	4.05	4.69	12.45
Total Aldehydes, mg/mi	2.35	4.09	4.07	4.15	20.36	16.08	24.84	41.40
Benzene, mg/mi	6.37	8.17	36.58	12.34	17.56	14.58	52.47	75.07
1,3-Butadiene, mg/mi	0.25	0.52	1.64	0.37	2.92	1.36	3.90	4.69
PM2.5, mg/mi	4.05	8.40	10.4	6.05	7.13	7.65	6.30	6.70
PM10, mg/mi	5.40	7.50	9.8	6.15	9.50	9.05	6.30	10.97

Table 4b. Vehicle UDDS tailpipe emission rates at 40 °F.

Vehicle	**Intrepid**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.57	0.44	0.87	0.41
CO, g/mi	1.56	1.05	8.36	0.56
NOx, g/mi	0.16	0.12	0.79	2.91
Fuel Economy, mpg	19.75	19.40	19.81	19.48
Ethanol, mg/mi	<0.01	1.08	<0.01	0.44
Formaldehyde, mg/mi	1.36	1.79	0.77	1.83
Acetaldehyde, mg/mi	0.69	2.72	1.07	2.17
Total Aldehydes, mg/mi	3.84	6.27	4.32	5.23
Benzene, mg/mi	17.57	14.77	71.80	10.40
1,3-Butadiene, mg/mi	1.42	1.71	1.43	0.63
PM2.5, mg/mi	9.95	9.10	12.27	6.80
PM10, mg/mi	10.05	10.00	12.17	8.10

Table 5. Vehicle UDDS tailpipe emission rates at 20 °F.

Vehicle	**Taurus**				**Concord**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**		**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	1.25	1.20	4.63	2.78	0.66	0.69	1.02	0.47
CO, g/mi	13.36	11.93	69.50	35.07	6.00	6.24	10.61	4.84
NOx, g/mi	0.86	0.81	0.84	0.53	0.46	0.50	3.41	3.69
Fuel Economy, mpg	17.45	17.71	16.12	17.07	17.00	17.25	17.26	17.61
Ethanol, mg/mi	<0.01	0.77	5.30	7.62	<0.01	0.07	<0.01	<0.01
Formaldehyde, mg/mi	4.91	3.10	13.86	5.17	3.78	4.07	4.52	4.46
Acetaldehyde, mg/mi	2.78	11.39	22.74	33.82	1.99	8.89	3.48	7.31
Total Aldehydes, mg/mi	14.51	20.18	63.11	48.32	10.74	18.44	15.02	16.78
Benzene, mg/mi	54.47	49.36	198.27	141.39	21.99	17.57	40.05	18.91
1,3-Butadiene, mg/mi	6.64	6.14	41.10	14.93	3.42	2.57	2.84	2.66
PM2.5, mg/mi	35.96	27.90	43.24	27.56	22.11	13.69	25.82	12.89
PM10, mg/mi	40.44	30.67	48.33	28.61	22.21	21.89	26.13	13.93

Table 5a. Vehicle UDDS tailpipe emission rates at 20 °F.

Vehicle	**Focus**				**Regal**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**		**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.52	0.49	0.69	0.48	0.68	0.65	1.24	1.58
CO, g/mi	4.64	3.57	8.74	4.20	5.74	5.64	13.85	21.54
NOx, g/mi	0.14	0.16	0.50	3.32	1.19	0.89	4.16	2.48
Fuel Economy, mpg	21.91	21.38	21.24	21.98	17.83	18.25	17.77	17.73
Ethanol, mg/mi	<0.01	4.73	0.02	0.77	1.01	0.07	<0.01	0.96
Formaldehyde, mg/mi	0.85	1.06	0.80	1.15	8.54	5.32	11.32	11.91
Acetaldehyde, mg/mi	0.78	4.29	0.66	3.23	2.52	4.73	5.16	21.42
Total Aldehydes, mg/mi	3.10	7.48	3.30	6.48	19.04	14.04	28.02	42.44
Benzene, mg/mi	21.16	17.77	57.54	34.12	26.10	23.51	66.55	84.22
1,3-Butadiene, mg/mi	1.57	1.65	2.19	1.55	4.01	1.99	4.80	6.09
PM2.5, mg/mi	NA*	21.90	25.35	18.60	16.65	17.45	14.20	12.20
PM10, mg/mi	27.75	19.70	18.30	18.90	16.20	16.85	15.90	14.25

NA*-Data not available.

Table 5b. Vehicle UDDS tailpipe emission rates at 20 °F.

Vehicle	**Intrepid**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	1.09	0.96	1.42	0.85
CO, g/mi	2.57	2.49	7.01	1.75
NOx, g/mi	0.20	0.12	1.32	2.93
Fuel Economy, mpg	18.97	18.42	18.80	18.38
Ethanol, mg/mi	<0.01	6.27	<0.01	<0.01
Formaldehyde, mg/mi	0.79	1.08	0.75	1.53
Acetaldehyde, mg/mi	1.20	4.43	1.33	4.62
Total Aldehydes, mg/mi	5.37	7.40	5.57	8.08
Benzene, mg/mi	32.92	29.42	72.96	27.74
1,3-Butadiene, mg/mi	2.41	2.95	2.15	0.99
PM2.5, mg/mi	20.75	19.30	28.10	21.10
PM10, mg/mi	21.25	19.30	28.05	22.20

Table 6. Vehicle UDDS tailpipe emission rates at 0 °F.

Vehicle	**Taurus**				**Concord**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**		**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	2.03	2.20	5.70	4.29	1.19	1.22	1.58	1.12
CO, g/mi	16.76	16.88	91.55	53.70	9.97	9.34	15.09	8.05
NOx, g/mi	0.86	1.02	0.84	0.53	0.54	0.64	2.42	3.38
Fuel Economy, mpg	16.31	16.36	14.84	15.63	16.13	15.48	16.03	15.80
Ethanol, mg/mi	<0.01	28.55	<0.01	34.60	<0.01	10.58	<0.01	2.69
Formaldehyde, mg/mi	5.31	7.33	15.92	7.34	4.41	4.51	4.73	4.61
Acetaldehyde, mg/mi	3.78	18.28	30.11	60.75	2.91	11.33	3.80	10.06
Total Aldehydes, mg/mi	18.36	34.49	80.80	83.22	14.33	21.01	16.92	20.59
Benzene, mg/mi	84.00	85.42	226.29	195.34	39.97	34.38	66.37	42.47
1,3-Butadiene, mg/mi	11.13	11.57	48.97	26.65	6.69	5.41	5.09	5.64
PM2.5, mg/mi	64.61	69.17	71.84	60.34	41.99	NA*	41.24	40.98
PM10, mg/mi	64.04	70.14	72.82	64.05	43.87	51.15	41.88	42.03

NA*-Data not available.

Table 6a. Vehicle UDDS tailpipe emission rates at 0 °F.

Vehicle	**Focus**				**Regal**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**		**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.91	0.88	1.27	0.81	1.09	1.00	1.86	2.48
CO, g/mi	5.94	4.91	13.36	5.20	7.26	5.94	19.71	35.24
NOx, g/mi	0.17	0.20	0.50	3.52	1.40	1.23	3.82	2.18
Fuel Economy, mpg	19.93	19.86	19.57	20.48	16.83	16.61	17.03	16.72
Ethanol, mg/mi	<0.01	12.17	0.40	0.73	<0.01	0.84	<0.01	2.59
Formaldehyde, mg/mi	0.90	1.26	0.97	1.43	9.00	6.31	13.32	22.12
Acetaldehyde, mg/mi	1.19	7.57	0.92	6.07	2.76	6.93	6.17	45.79
Total Aldehydes, mg/mi	4.55	12.39	5.48	11.31	20.87	19.13	33.74	81.43
Benzene, mg/mi	38.10	32.95	106.58	40.53	40.95	37.66	90.92	123.28
1,3-Butadiene, mg/mi	3.70	3.81	5.72	1.92	4.53	3.13	6.65	9.61
PM2.5, mg/mi	NA*	41.35	70.83	34.45	28.95	34.55	38.10	27.65
PM10, mg/mi	46.75	42.10	48.3	36.15	36.35	34.00	38.15	30.45

NA*-Data not available.

Table 6b. Vehicle UDDS tailpipe emission rates at 0 °F.

Vehicle	**Intrepid**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	1.81	1.49	2.43	1.47
CO, g/mi	3.27	3.01	11.52	3.06
NOx, g/mi	0.19	0.14	0.78	3.50
Fuel Economy, mpg	17.25	17.02	16.81	17.23
Ethanol, mg/mi	<0.01	42.91	<0.01	<0.01
Formaldehyde, mg/mi	1.00	1.30	0.70	1.64
Acetaldehyde, mg/mi	1.26	8.09	1.67	7.46
Total Aldehydes, mg/mi	6.09	12.78	6.49	11.88
Benzene, mg/mi	69.34	51.40	156.14	82.82
1,3-Butadiene, mg/mi	4.85	4.68	5.84	1.93
PM2.5, mg/mi	43.15	33.70	45.50	46.30
PM10, mg/mi	43.55	34.90	46.47	47.10

Table 7. Vehicle UDDS tailpipe emission rates at -20 °F.

Vehicle	**Taurus**				**Concord**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**		**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	2.42	4.94	9.59	8.30	2.76	2.17	4.75	1.98
CO, g/mi	25.01	28.44	134.26	89.90	15.54	13.31	33.94	10.33
NOx, g/mi	1.11	1.26	0.99	0.95	0.68	0.55	1.97	3.41
Fuel Economy, mpg	15.72	15.15	12.65	13.63	14.78	15.14	14.46	14.95
Ethanol, mg/mi	<0.01	187.34	<0.01	193.31	<0.01	13.70	<0.01	3.02
Formaldehyde, mg/mi	8.34	8.74	28.76	19.67	5.57	5.34	4.45	6.95
Acetaldehyde, mg/mi	5.68	37.73	38.11	131.51	4.58	19.61	6.14	16.01
Total Aldehydes, mg/mi	25.33	58.94	119.00	181.77	21.02	33.36	24.19	31.48
Benzene, mg/mi	144.78	155.35	346.42	303.64	93.29	64.31	181.45	76.78
1,3-Butadiene, mg/mi	20.44	18.42	72.09	55.43	13.49	10.05	21.28	8.11
PM2.5, mg/mi	112.33	118.70	155.49	157.53	77.24	NA*	123.10	76.73
PM10, mg/mi	113.31	131.57	159.71	160.69	104.44	81.77	124.35	77.38

NA*-Data not available.

Table 7a. Vehicle UDDS tailpipe emission rates at -20 °F.

Vehicle	**Focus**				**Regal**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**		**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	1.81	2.27	2.47	1.56	2.03	NA*	3.92	5.55
CO, g/mi	8.25	7.56	12.73	7.17	9.52	NA	35.02	73.33
NOx, g/mi	0.17	0.20	1.01	2.22	1.43	NA	3.13	1.85
Fuel Economy, mpg	18.66	18.20	17.97	19.17	15.84	NA	15.53	14.94
Ethanol, mg/mi	<0.01	72.36	0.80	2.19	<0.01	NA	<0.01	3.55
Formaldehyde, mg/mi	1.18	2.16	1.55	2.01	8.63	NA	20.76	51.37
Acetaldehyde, mg/mi	1.85	18.08	1.41	10.80	3.28	NA	10.81	97.54
Total Aldehydes, mg/mi	7.38	26.61	8.59	18.15	22.25	NA	50.96	197.74
Benzene, mg/mi	71.39	85.14	131.17	80.67	69.64	NA	156.58	236.24
1,3-Butadiene, mg/mi	8.13	8.58	11.21	4.70	9.35	NA	12.39	34.99
PM2.5, mg/mi	71.50	118.25	117.25	72.75	84.10	NA	74.30	57.30
PM10, mg/mi	92.00	120.75	119.2	76.75	89.05	NA	75.70	59.30

NA*- Data not available-Vehicle starting problem.

Table 7b. Vehicle UDDS tailpipe emission rates at -20 °F.

Vehicle	**Intrepid**			
Mode	**No Malfunction**		**O2 Sensor Disconnected**	
Fuel	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	4.03	3.19	4.03	3.48
CO, g/mi	5.73	4.83	11.46	4.93
NOx, g/mi	0.26	0.18	1.43	3.25
Fuel Economy, mpg	16.06	15.49	15.96	16.19
Ethanol, mg/mi	<0.01	187.96	<0.01	<0.01
Formaldehyde, mg/mi	1.01	1.31	0.71	NA*
Acetaldehyde, mg/mi	1.91	21.59	1.22	NA
Total Aldehydes, mg/mi	8.08	27.61	5.67	NA
Benzene, mg/mi	125.69	101.11	196.57	121.40
1,3-Butadiene, mg/mi	9.16	10.35	5.47	3.73
PM2.5, mg/mi	93.85	77.70	69.20	87.50
PM10, mg/mi	93.85	78.30	70.40	89.60

NA* - Data not available.

Table 8. Vehicle IM240 tailpipe emissions rates at 75 ºF.

Vehicle	**Taurus**		**Concord**	
Mode	**No Malfunction**	**O2 Sensor Disconnected**	**No Malfunction**	**O2 Sensor Disconnected**
Fuel	**Summer Grade**		**Summer Grade**	
THC, g/m	0.33	1.11	0.02	0.06
CO, g/mi	6.96	21.66	0.38	1.37
NOx, g/mi	1.30	0.50	0.36	2.74
PM2.5, mg/mi	5.26	5.71	2.74	1.83
PM10, mg/mi	8.70	8.22	4.57	2.74
Vehicle	**Focus**		**Regal**	
Mode	**No Malfunction**	**O2 Sensor Disconnected**	**No Malfunction**	**O2 Sensor Disconnected**
Fuel	**Summer Grade**		**Summer Grade**	
THC, g/m	0.03	0.21	0.24	0.12
CO, g/mi	1.11	8.77	2.38	0.98
NOx, g/mi	0.11	0.15	1.11	0.14
PM2.5, mg/mi	17.8	3.80	NA*	NA
PM10, mg/mi	20.7	4.20	NA	NA

NA*- Data not available.

Table 9. Vehicle IM240 tailpipe emission rates at 40 °F.

Vehicle	**Taurus**				**Concord**			
Mode	**No Malfunction**		**O2 Sensor Disc.**		**No Malfunction**		**O2 Sensor Disc.**	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.49	0.38	2.55	1.26	0.09	0.08	0.07	0.03
CO, g/mi	11.02	7.40	46.70	21.96	1.31	1.18	0.84	0.04
NOx, g/mi	1.07	1.18	0.62	0.58	0.30	0.28	3.86	5.02
PM2.5, mg/mi	3.90	6.98	6.98	4.77	4.58	2.88	2.64	2.27
PM10, mg/mi	6.44	13.52	8.47	8.62	4.82	3.07	2.07	7.96
Vehicle	**Focus**				**Regal**			
Mode	**No Malfunction**		**O2 Sensor Disc.**		**No Malfunction**		**O2 Sensor Disc.**	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.02	0.07	0.04	0.02	0.25	0.13	0.38	0.67
CO, g/mi	0.53	0.98	0.18	0.17	2.99	2.27	4.03	9.98
NOx, g/mi	0.28	0.15	2.13	4.32	0.98	0.66	5.86	3.60
PM2.5, mg/mi	1.30	4.45	2.20	5.65	6.27	4.25	2.45	3.55
PM10, mg/mi	2.10	3.45	2.35	3.05	7.07	5.4	2.00	4.00

[†] Winter grade, without ethanol
[‡] Winter grade, with ethanol

Table 9a. Vehicle IM240 tailpipe emission rates at 40 °F.

Vehicle	Intrepid			
Mode	**No Malfunction**		**O2 Sensor Disc.**	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**
THC, g/mi	0.05	0.06	0.39	0.05
CO, g/mi	0.27	0.27	10.94	0.08
NOx, g/mi	0.08	0.05	0.24	3.90
PM2.5, mg/mi	1.65	0.90	0.87	4.00
PM10, mg/mi	1.85	0.90	1.03	3.50

[†] Winter grade, without ethanol
[‡] Winter grade, with ethanol

Table 10. Vehicle IM240 tailpipe emission rates at 20 °F.

Vehicle	Taurus	Concord

Mode	No Malfunction		O2 Sensor Disc.		No Malfunction		O2 Sensor Disc.	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.58	0.38	3.38	1.76	0.11	0.10	0.10	0.03
CO, g/mi	13.16	7.54	62.86	30.86	1.36	0.93	0.76	0.10
NOx, g/mi	1.10	1.10	0.91	0.54	0.34	0.39	4.20	4.58
PM2.5, mg/mi	8.84	1.62	10.42	4.10	4.06	2.31	2.96	2.76
PM10, mg/mi	5.38	4.86	15.44	4.33	3.72	2.77	5.14	5.08
Vehicle	**Focus**				**Regal**			
Mode	**No Malfunction**		**O2 Sensor Disc.**		**No Malfunction**		**O2 Sensor Disc.**	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.02	0.03	0.05	0.02	0.31	0.22	0.51	0.72
CO, g/mi	1.22	0.90	0.99	0.02	2.82	3.24	6.40	9.86
NOx, g/mi	0.11	0.14	1.20	5.10	1.02	0.77	5.15	3.13
PM2.5, mg/mi	15.95	1.25	2.95	8.10	5.65	5.55	1.40	3.15
PM10, mg/mi	14.20	3.05	2.35	7.25	9.95	4.8	1.60	4.60

[†] Winter grade, without ethanol
[‡] Winter grade, with ethanol

Table 10a. Vehicle IM240 tailpipe emission rates at 20 °F.

Vehicle	Intrepid

Mode	No Malfunction		O2 Sensor Disc.	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**
THC, g/mi	0.06	0.05	0.50	0.04
CO, g/mi	0.23	0.19	10.88	0.08
NOx, g/mi	0.08	0.03	0.20	3.81
PM2.5, mg/mi	1.15	1.20	3.30	0.20
PM10, mg/mi	1.90	1.20	3.40	4.70

[†] Winter grade, without ethanol
[‡] Winter grade, with ethanol

Table 11. Vehicle IM240 tailpipe emission rates at 0 °F.

Vehicle	**Taurus**				**Concord**			
Mode	**No Malfunction**		**O2 Sensor Disc.**		**No Malfunction**		**O2 Sensor Disc.**	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.64	0.41	3.20	2.40	0.15	0.13	0.12	0.05
CO, g/mi	13.32	7.75	78.16	41.58	1.56	0.91	0.87	0.22
NOx, g/mi	1.13	1.16	0.87	0.54	0.34	0.37	4.74	4.60
PM2.5, mg/mi	14.32	4.72	15.00	8.30	7.28	1.75	6.56	3.79
PM10, mg/mi	18.88	5.30	20.10	9.91	8.55	5.15	7.38	6.08
Vehicle	**Focus**				**Regal**			
Mode	**No Malfunction**		**O2 Sensor Disc.**		**No Malfunction**		**O2 Sensor Disc.**	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.08	0.06	0.15	0.02	0.31	0.24	0.64	1.14
CO, g/mi	1.31	1.34	2.96	0.03	2.60	3.48	9.20	18.72
NOx, g/mi	0.15	0.15	0.65	5.22	1.10	0.88	4.74	1.76
PM2.5, mg/mi	0.70	2.70	5.47	7.70	2.65	4.70	4.00	3.05
PM10, mg/mi	3.00	4.80	4.47	10.35	2.55	4.85	4.70	4.85

[†] Winter grade, without ethanol
[‡] Winter grade, with ethanol

Table 11a. Vehicle IM240 tailpipe emission rates at 0 °F.

Vehicle	**Intrepid**			
Mode	**No Malfunction**		**O2 Sensor Disc.**	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**
THC, g/mi	0.07	0.05	0.37	0.08
CO, g/mi	0.32	0.21	6.23	0.12
NOx, g/mi	0.09	0.07	0.54	3.33
PM2.5, mg/mi	0.70	2.80	2.33	1.60
PM10, mg/mi	1.60	1.60	3.37	1.90

[†] Winter grade, without ethanol
[‡] Winter grade, with ethanol

Table 12. Vehicle IM240 tailpipe emission rates at -20 °F.

Vehicle	**Taurus**				**Concord**			
Mode	**No Malfunction**		**O2 Sensor Disc.**		**No Malfunction**		**O2 Sensor Disc.**	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.84	0.57	4.48	3.58	0.27	0.16	0.29	0.10
CO, g/mi	17.19	9.34	88.28	63.80	3.06	1.62	3.20	0.78
NOx, g/mi	1.32	1.16	1.23	0.82	0.62	0.34	4.88	5.18
PM2.5, mg/mi	9.21	6.40	13.58	12.56	7.06	4.67	7.38	5.02
PM10, mg/mi	13.31	9.72	13.92	16.70	12.15	9.23	11.83	5.02
Vehicle	**Focus**				**Regal**			
Mode	**No Malfunction**		**O2 Sensor Disc.**		**No Malfunction**		**O2 Sensor Disc.**	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**	**Base**	**E-10**	**Base**	**E-10**
THC, g/mi	0.14	0.16	0.37	0.04	0.29	NA*	0.96	3.03
CO, g/mi	1.76	2.34	11.06	0.16	3.48	NA	12.73	52.25
NOx, g/mi	0.12	0.15	0.20	2.87	1.13	NA	4.16	2.51
PM2.5, mg/mi	2.03	3.30	5.30	3.05	3.05	NA	4.15	7.85
PM10, mg/mi	2.43	11.75	5.95	4.25	6.2	NA	6.80	10.10

[†] Winter grade, without ethanol
[‡] Winter grade, with ethanol
NA*-Data not available

Table 12a. Vehicle IM240 tailpipe emission rates at -20 °F.

Vehicle	**Intrepid**			
Mode	**No Malfunction**		**O2 Sensor Disc.**	
Fuel	**Base**[†]	**E-10**[‡]	**Base**	**E-10**
THC, g/mi	0.11	0.06	0.32	0.09
CO, g/mi	0.35	0.29	3.03	0.18
NOx, g/mi	0.13	0.07	1.35	4.52
PM2.5, mg/mi	4.00	4.70	3.90	1.60
PM10, mg/mi	4.15	4.70	4.00	4.90

[†] Winter grade, without ethanol
[‡] Winter grade, with ethanol

RESULTS AND DISCUSSIONS

Vehicle tests were performed in duplicate for all temperatures except at 75 °F. At 75 °F only a single test with summer grade fuel was run. Empirical relationships could not be tested since only single and duplicate tests were made; rather the relationships are indicative of trends. The THC emission results reported were the values determined by a total hydrocarbon analyzer (using the flame ionization detector) rather than a summation of the individual hydrocarbons as determined by gas chromatographic analysis. Tables 3-7b contain the UDDS tailpipe regulated emissions (THC, CO, and NOx), fuel economy, toxic emissions (Formaldehyde, Acetaldehyde, Benzene, and 1,3-Butadiene), ethers/alcohols (MTBE, Ethanol, and Methanol), and particulate emissions (PM2.5 and PM10) data. Tables 8-12a contain the IM240 tailpipe gas phase (THC, CO, and NOx) and particulate emissions (PM2.5 and PM10) data. Detailed hydrocarbon, aldehyde and ketone tables are included showing the compounds determined from each bag sample taken from the three bag FTP test. Figures 1 through 190 show the relation of compound emission rates for the vehicles, fuels, test cycles, and test modes at the program test temperatures. Each point (symbol) on the plots is the data from an individual vehicle test run at the specified test temperature. Figures 191 and 192 are regression plots (individual vehicle tests) showing the relationship of PM2.5 vs PM10 and THC vs PM2.5 emissions, respectively.

Regulated Emissions

Total Hydrocarbons-UDDS Cycle. Hydrocarbon emissions (Figures 1-2, 39-40, 77-78, 115-116, and 153-154) increased in the mode no malfunction) and generally increased in O2 mode (malfunction-oxygen sensor disconnected) as the test temperature decreased with all vehicles and fuels. The vehicle's engine air/fuel mixture is controlled by a feedback loop via the oxygen sensor, and when the sensor was disconnected, the vehicle operated in a slightly rich fuel condition throughout the test cycle. The greatest HC emitter was the Taurus when tested with the base fuel, at -20 ºF in the O2 mode, while the least HC emitter was the Intrepid when tested with the SG fuel, at 75 ºF in the NM mode (9.60 g/mile vs 0.16

g/mile, respectively). Taurus HC emissions ranged from a low of 0.34 g/mile (NM mode, 75 °F, SG fuel) to a high of 9.60 g/mile (O2 mode, -20 °F, E-10 fuel). Regal HC emissions ranged from a low of 0.26 g/mile (NM mode, 75 °F, SG fuel) to a high of 5.55 g/mile (O2 mode, -20 °F, E-10 fuel). Focus emissions ranged from a low of 0.07 g/mile (NM mode, 75 °F, SG fuel) to a high of 2.48 g/mile (O2 mode, -20 °F, base fuel). Concord emissions ranged from a low of 0.33 g/mile to a high of 4.75 g/mile (O2 mode, -20 °F, base fuel). Intrepid HC emissions ranged from a low of 0.06 g/mile (NM mode, 75 °F, SG fuel) to a high of 4.07 g/mile (O2 mode, -20 °F, base fuel). Disconnecting the oxygen sensor (O2 mode) increased emissions from all vehicles at every temperature with the base fuel and generally increased the emissions with the E-10 fuel. The E-10 fuel generally lowered HC emissions.

Total Hydrocarbons-IM240 Cycle. The hydrocarbon emissions (Tables 8-12a) in general showed a general increase with all the vehicles emissions as the test temperature decreased from 75 °F to -20 °F. When operating the vehicles on E-10 fuel, the emissions were generally decreased in both the NM and O2 modes.

Carbon Monoxide-UDDS Cycle. Carbon monoxide emissions (Figures 3-4, 41-42, 79-80, 117-118 and 155-156) increased as the test temperature decreased with all the vehicles, at all test modes and fuels with one exception; the Focus emissions were greater at 0 °F than at -20 °F (13.36 vs 12.73 g/mile respectively). The greatest CO emitter was the Taurus, (134.26 g/mile) when tested with base fuel, at -20 °F, in the O2 mode. The least emitters were the Focus, (0.56 g/mile) when tested with the SG fuel, at 75 °F, in the NM mode and the Intrepid, (0.56 g/mile) when tested with E-10 fuel, at 40 °F, in the O2 mode. Taurus emissions ranged from a low of 5.02 g/mile (NM mode, 75 °F, SG fuel) to a high of 134.26 g/mile (O2 mode, -20 °F, base fuel). Regal emissions ranged from a low of 2.98 g/mile (NM mode, 75 °F, SG fuel) to a high of 73.33 g/mile (O2 mode, -20 °F, E-10 fuel). Focus emissions ranged from a low of 0.56 g/mile (NM mode, 75 °F, SG fuel) to a high of 13.36 g/mile (O2 mode, 0 °F, base fuel). Concord emissions ranged from a low of 2.55 g/mile (NM mode, 75 °F, SG fuel) to a high of 33.94 g/mile (O2 mode, -20 °F, base fuel). Intrepid emissions ranged from a low of 0.56 g/mile (O2 mode, 40 °F, E-10 fuel) to a high of 11.62 g/mile (O2 mode, 0 °F, base fuel). Disconnecting the oxygen sensor increased the CO emissions from all vehicles when tested with base fuel and generally increased the CO emissions when the vehicles were tested with the E-10 fuel. The E-10 fuel generally reduced the CO emissions from the vehicles.

Carbon Monoxide-IM240 Cycle. The carbon monoxide emissions (Tables 8-12a) from the vehicles generally increased as the test temperature decreased. E-10 fuel generally decreased vehicle CO emissions. In the malfunction mode the emissions were generally increased for some vehicles and decreased for others.

Oxides of Nitrogen-UDDS. Oxides of nitrogen emissions (Figures 5-6, 43-44, 81-82, 119-120, and 157-158) show the vehicle emissions for all vehicles at all test conditions. The greatest emissions were produced by the Regal when tested with the base fuel, at 40 °F, in the O2 mode. The least emissions were produced by the Focus when tested with the SG fuel, at 75 °F, in the NM mode (4.56 vs 0.06 g/mile, respectively). Taurus emissions ranged from a low of 0.53 g/mile (O2 mode, 40 °F, base fuel and NM mode, at both 0 and 20 °F, E-10 fuel). Regal emissions ranged from a low of 0.73 g/mile (NM mode, 75 °F, SG fuel) to a high of 4.56 g/mile (O2 mode, 40 °F, base fuel). Focus emissions ranged from a low of 0.06 g/mile (NM mode, 75 °F, SG fuel) to a high of 3.52 g/mile (O2 mode, 0 °F, E-10 fuel). Concord emissions ranged from a low of 0.35 g/mile (NM mode, 40 °F, base fuel) to a high of 3.77 g/mile (O2 mode, 40 °F, E-10 fuel). Intrepid emissions ranged from a low of 0.10 g/mile (NM mode, 75 °F, SG fuel) to a high of 3.50 g/mile (O2 mode, 0 °F, E-10 fuel). Disconnecting the oxygen

sensor decreased the emissions from the Taurus but increased the emissions from the Focus, Regal, Concord, and Intrepid with both base and E-10 fuels. The E-10 fuel reduced the emissions from the Regal and generally from the Intrepid but increased emissions from the Focus and Concord and generally from the Taurus in the NM mode.

Oxides of Nitrogen-IM240. Tables 8-12a show vehicle IM240 data for both vehicles at all test conditions. The emissions generally increased as the test temperature decreased, when the vehicles were operated in the malfunction mode and when the vehicles were operated with the E-10 fuel.

Toxic Emissions

Benzene. Besides being present in the fuel itself, benzene is emitted from the tailpipe as a result of its formation during the combustion process involving other fuel components, such as cyclohexane and the alkylaromatics. [12,13] In one study, from 2 to 7 % of the benzene was determined to be the result of the rearrangement of these molecules during combustion.[14] Benzene emissions (Figures 11-12, 49-50, 87-88,125-126 and 163-164) increased as test temperatures decreased. The greatest benzene emitter was the Taurus when tested with base fuel, at -20 °F, in the O2 mode and the lowest benzene emitter was the Focus when tested with the SG fuel, at 75 °F, in the NM mode. Taurus benzene emissions ranged from a low of 13.00 mg/mile (NM mode, at 75 °F, SG fuel) to a high of 346.41 mg/mile (O2 mode, -20 °F, base fuel). Regal benzene emissions ranged from a low of 8.91 mg/mile (NM mode, 75 °F, SG fuel) to a high of 236.24 mg/mile (O2 mode, -20 °F, E-10 fuel). Focus benzene emissions ranged from a low of 2.13 mg/mile (NM mode, 75 °F, SG fuel) to a high of 131.17 mg/mile (O2 mode, -20 °F, base fuel). Concord benzene emissions ranged from a low of 8.00 mg/mile (NM mode, 75 °F , SG fuel) to a high of 181.45 mg/mile (O2 mode, -20 °F, base fuel). Intrepid emissions ranged from a low of 4.81 mg/mile (NM mode, 75 °F, SG fuel) to a high of 196.56 mg/mile (O2 mode, -20 °F, base fuel). Disconnecting the oxygen sensor almost doubled the emissions from all vehicles when tested with the base fuel and increased the emissions from all vehicles when tested with the E-10 fuel with the following exceptions: The Focus at -20 °F in which the emissions decreased from 85.14 mg/mile to 80.68 mg/mile and the Intrepid at 20 and 40 F °F when the emissions decreased from 29.42 mg/mile to 27.74 mg/mile and 14.77 mg/mile to 10.40 mg/mile, respectively. The E-10 fuel generally lowered benzene emissions from the vehicles when tested in the NM mode and in the O2 mode the E-10 fuel decreased the emissions from the Taurus, Focus, Concord, and Intrepid, but increased emissions from the Regal.

1,3-Butadiene. 1,3-Butadiene is not a gasoline component but a by-product of the combustion process. This compound was emitted primarily in the initial 2 minutes of vehicle start-up, when the air-to-fuel mixture was rich and the vehicle's emission control system was warming up. Figures 13-14, 51-52, 89-90, 127-128, and 165-166 show the emission rates for all vehicles at all test conditions. 1,3-Butadiene emissions increased as test temperature decreased with both fuels and in both test modes. The greatest emitter was the Taurus when tested with the base fuel, at -20 °F, in the O2 mode and the lowest emitter was the Intrepid when tested with the SG fuel, at 75 °F, in the NM mode. Taurus emissions ranged from a low of 1.18 mg/mile (NM mode, 75 °F , SG fuel) to a high of 72.09 mg/mile (O2 mode, -20 °F, base fuel). Regal emissions ranged from a low of 0.87 mg/mile (NM mode, 75 °F , SG fuel) to a high of 34.99 mg/mile (O2 mode, -20 °F, E-10 fuel). Focus emissions ranged from a low of 0.25 mg/mile (NM mode, 40 °F, base fuel) to a high of 11.21 mg/mile (O2 mode, -20 °F, base fuel). Concord emissions ranged from a low of 0.51 mg/mile (NM mode, 75 °F, SG fuel) to a high of 21.28 mg/mile (O2 mode, -20 °F, base fuel). Intrepid emissions ranged from a low of 0.11 mg/mile (NM mode, 75 °F, SG fuel) to a high

of 10.35 mg/mile (NM mode, -20 °F, E-10 fuel). Disconnecting the oxygen sensor increased the emissions from the Taurus, Regal, and Focus and generally from the Concord and Intrepid with the base fuel. With the E-10 fuel, Taurus emissions were increased, and Regal and Concord emissions generally increased, but Intrepid and Focus emissions decreased . The E-10 fuel reduced emissions from the Concord and generally from the Taurus, Regal, and Intrepid, but increased emissions from the Focus in the NM mode. The E-10 fuel decreased emissions from the Taurus, Focus, and Intrepid and generally from the Concord but increased emissions from the Regal.

Formaldehyde and Acetaldehyde. Formaldehyde (Figures 7-8, 45-46, 83-84, 121-122 and 159-160) and acetaldehyde (Figures 9-10, 47-48, 85-86, 123-124, and 161-162) were not present in the fuel but are by-products of the incomplete combustion of the fuel. These two aldehydes are usually the major aldehydes emitted, with formaldehyde generally the major emission product. Vehicle formaldehyde emissions generally increased as test temperature decreased. The greatest formaldehyde emitter was the Regal when tested with the E-10 fuel, at -20 F, in the O2 mode and the lowest emitter was the Focus when tested with SG fuel, at 75 F, in the O2 mode (51.37 mg/mile vs 0.65 mg/mile, respectively). Taurus formaldehyde emissions ranged from a low of 3.10 mg/mile (NM mode, 20 F, E-10 fuel) to a high of 28.77 mg/mile (O2 mode, -20 F, base fuel). Regal formaldehyde emissions ranged from a low of 4.64 mg/mile (NM mode, 75 F, SG fuel) to a high of 51.37 mg/mile (O2 mode, -20 F, E-10 fuel). Focus formaldehyde emissions ranged from a low of 0.65 mg/mile (O2 mode, 75 F, SG fuel) to a high of 2.16 mg/mile (NM mode, -20 F, E-10 fuel). Concord formaldehyde emissions ranged from a low of 3.52 mg/mile (O2 mode, 75 F, SG fuel) to a high of 6.95 mg/mile (O2 mode, -20 F, E-10 fuel). Intrepid formaldehyde emissions ranged from a low of 0.70 mg/mile (O2 mode, 0 °F, base fuel) to a high of 1.79 mg/mile (NM mode, 40 °F, base fuel). Disconnecting the oxygen sensor in the NM mode, with base fuel, increased the formaldehyde emissions from the Taurus and Regal and generally increased the emissions from the Focus and Concord but reduced emissions from the Intrepid. In the oxygen sensor disconnect mode with the E-10 fuel, Concord emissions were increased and generally increased with the Taurus, Regal, Focus, and Intrepid. With the E-10 fuel, increased Intrepid emissions and generally increased Taurus, Regal, Concord, and Focus emissions in the NM mode. In the O2 mode, the E-10 fuel increased Intrepid emissions and generally increased Regal and Focus emissions, but decreased Taurus emissions and generally decreased Concord emissions.

Vehicle acetaldehyde emissions generally increased as the test temperature decreased. The greatest acetaldehyde emitter was the Taurus when tested with the E-10 fuel, at -20 F, in the O2 mode and the lowest acetaldehyde emitter was the Focus when tested with the SG fuel, at 75 F, in the O2 mode (131.51 mg/mile and 0.28 mg/mile, respectively). Taurus acetaldehyde emissions ranged from a low of 1.19 mg/mile (NM mode, 75 F, SG fuel) to a high of 131.51 mg/mile (O2 mode, -20 F, E-10 fuel). Regal acetaldehyde emissions ranged from a low of 1.16 mg/mile (NM mode, 75 F, SG fuel) to a high of 97.54 mg/mile (O2 mode, -20 F, E-10 fuel). Focus acetaldehyde emissions ranged from a low of 0.28 mg/mile (O2 mode, 75 F, SG fuel) to a high of 18.08 mg/mile (NM mode, -20 F, E-10 fuel). Concord acetaldehyde emissions ranged from a low of 1.48 mg/mile (NM mode, 75 F, SG fuel) to a high of 19.61 mg/mile (NM mode, -20 F, E-10 fuel). Intrepid emissions ranged from a low of 0.36 mg/mile (NM mode, 75 °F, SG fuel) to a high of 21.59 mg/mile (NM mode, -20 °F, E-10 fuel). Disconnecting the oxygen sensor increased the acetaldehyde emissions from the Taurus, Regal, and Concord and generally from the Intrepid but generally decreased the emissions from the Focus with the base fuel. When tested with the E-10 fuel in the O2 disconnect mode, the acetaldehyde emissions from the Taurus and Regal were more than doubled and the emissions from the Focus and Concord were slightly decreased and Intrepid emissions were generally decreased. Testing with the E-10 fuel increased the acetaldehyde emissions from all vehicles, in both NM and O2 modes, from about 2 to almost 10 times depending upon the

vehicle and the test temperature.

Particulate Emissions

PM2.5 and PM 10 - UDDS Cycle. The particulate emissions (PM2.5 and PM10) from all vehicles (Tables 3-7b) generally increased (both modes) as the test temperature decreased. The PM2.5 particle emissions were about the same as the PM10 particle emissions (Figure 191), indicating that gasoline fueled vehicle particulate emissions are less than 2.5 um. Figure 192 is a regression plot of THC vs PM2.5 for both vehicles at all test conditions, showing some correlation (R^2 = .551) at these conditions. A regression analysis of the Taurus emissions showed some correlation at all test conditions (R^2 of 0.627). The Regal showed little THC vs PM2.5 correlation (R^2 = .144) as regression analysis was performed at different test modes and fuels. Regression analysis of THC vs PM2.5 for the Intrepid was very good at R^2 = .915, fair for the Focus at R^2 = .579 and Concord at R^2 = .725. The greatest PM2.5 emissions was produced by the Taurus when tested with E-10 fuel, at -20 °F, in the O2 mode and the least emissions were produced by the Focus when tested with the SG fuel, at 75 °F, in the NM mode (157.53 vs 2.00 mg/mile, respectively). Taurus PM2.5 emissions ranged from a low of 5.49 mg/mile (O2 mode, 75 °F, SG fuel) to a high of 157.53 mg/mile (O2 mode, -20 °F, E-10 fuel). Regal PM2.5 emissions ranged from a low of 3.20 mg/mile (O2 mode, 75 °F, base fuel) to a high of 84.10 mg/mile (base fuel, -20 °F, NM mode). Focus PM2.5 emissions ranged from a low of 2.00 mg/mile (NM mode, 75 °F, SG fuel) to a high of 117.25 (O2 mode, -20 ºF, base fuel, . Concord PM2.5 emissions ranged from a low of 2.27 mg/mile (O2 mode, 75 °F, SG fuel) to a high of 123.10 mg/mile (O2 mode, -20 °F, base fuel). Intrepid PM2.5 emissions ranged from a low of 2.50 mg/mile (NM mode, 75 °F, SG fuel to a high of 93.85 mg/mile (NM mode, -20 °F, base fuel). Disconnecting the oxygen sensor generally increased the PM2.5 emissions from all the vehicles with the base fuel. With the E-10 fuel, the Focus and Regal PM2.5 emissions were decreased, the Intrepid generally increased, the Concord generally decreased, but the Taurus showed no trend. The E-10, NM mode, reduced emissions from the Intrepid but showed no trend with the other vehicles. In the malfunction mode, the E-10 fuel reduced PM2.5 emissions from the Focus, generally reduced emissions from the Concord, Taurus, and Regal, but the Intrepid showed no trend. The PM10 emissions generally followed the PM2.5 trend.

PM2.5 and PM10 - IM240 Cycle. The particle emissions (Tables 8-12a) were generally greater at the lower test temperatures. The use of E-10 fuel generally showed a decrease in emissions. When operating in the malfunction mode emissions were generally increased.

Alcohols and Ether

In addition to the regulated emissions (HCs, CO, and NOx), aldehydes, and particulates, the two alcohols, methanol (MeOH) and ethanol (EtOH), and methyltertiarybutyl ether (MTBE) were determined from each vehicle test (Figures 17-22, 55-60, 93-98, 131-136, and 169-174). These compounds are not present in the base fuel but are combustion products. Ethanol was added to the base winter grade fuel to prepare the E-10 test fuel. The base winter grade fuel did not contain either methanol or MTBE. Ethanol was not generally present in the emissions until the vehicles were fueled with the E-10 fuel. When testing with E-10 fuel the ethanol emission were generally greater when the vehicles were tested in the NM mode as compared with O2 mode emissions. Alcohol and ether emissions generally increased as the test temperature decreased. Methanol emissions were present when the vehicles were tested with both modes and fuels, with the E-10 fuel and O2 mode generally producing the most emissions. The MTBE

emissions generally followed the methanol trend.

SUMMARY AND CONCLUSIONS

In reviewing the regulated emissions (HC, CO, and NOx), the toxic emissions (benzene, 1,3-butadiene, formaldehyde, and acetaldehyde), and the particulate emissions (PM2.5 and PM10) data it should be noted that these are emissions from only five vehicles. These test vehicles could or could not be representative of the on-road fleet. The malfunction conditions that were introduced are extreme conditions in which the vehicle's oxygen sensor valve was rendered completely inoperable. In actuality, the condition of this simulated malfunctions (oxygen sensor valve disconnected) for on-road vehicles could be anywhere in the range of being completely operable to inoperable. Limited resources restricted our testing to five vehicles and to duplicate runs (one at 75 °F) at 40, 20, 0 and -20 °F. Also, due to resource limitations we were able to take only single PM2.5 and PM10 particulate filter from each of the UDDS test cycles (all three phases combined) rather than individual PM2.5 and PM10 particle filters from each of the UDDS's three phases.

Hydrocarbons-UDDS cycle - Hydrocarbons generally increased as test temperature decreased and the most HCs were emitted when the O2 sensor was disconnected. The E-10 fuel generally reduced HC emissions.

Hydrocarbons-IM240 cycle - In general, lowering the test temperature and disconnecting the O2 sensor increased the HC emissions. The E-10 fuel generally reduced the HC emissions.

Carbon Monoxide-UDDS cycle - There was a general increase in CO emissions as the test temperature decreased and disabling the O2 sensor resulted in the most CO emissions. The E-10 fuel generally reduced CO emissions from the vehicles.

Carbon Monoxide-IM240 cycle - There was a general increase in CO emissions as the test temperature decreased and the most CO was emitted when the O2 sensor was disconnected. The E-10 fuel generally reduced CO emissions from the vehicles.

Oxides of Nitrogen-UDDS cycle - Disconnecting the oxygen sensor generally produced greater NOx emissions from the vehicles.

Oxides of Nitrogen-IM240 cycle - Most emissions were produced in the malfunction mode, at lower temperatures with the E-10 fuel.

Benzene - Benzene emissions generally increased as test temperature decreased, when the O2 sensor was disconnected, and when tested on the E-10 fuel.

1,3-Butadiene - The 1,3-butadiene emissions generally increased as the test temperature decreased and when operating in the malfunction mode. The E-10 fuel generally reduced the emission rates from the vehicles.

Aldehydes - Formaldehyde and acetaldehyde emissions generally increased as the test temperatures

decreased, when testing in the malfunction mode, and when testing with E-10 fuel.

PM2.5 and PM10 particulate-UDDS cycle - The PM2.5 and PM10 particulate emissions levels were comparable (indicating that all PM emissions are less than 2.5 um). Emissions from both vehicles followed the HC trend and increased as the test temperatures decreased and the E-10 fuel generally reduced particulate emissions. Disconnecting the O2 sensor on the vehicles generally increased emissions.

PM2.5 and PM10 particulate-IM240 cycle - Particulate emissions generally increased as test temperature decreased and when testing with E-10 fuel. In general, disconnecting the O2 sensor produced the most emissions.

Alcohols and Ethers-Most emissions were produced when the test temperature was decreased, when the vehicles were operated in the malfunction mode, and when tested with E-10 fuel.

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DISCLAIMER

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Figure 1. Taurus, THC, UDDS Cycle, NM mode

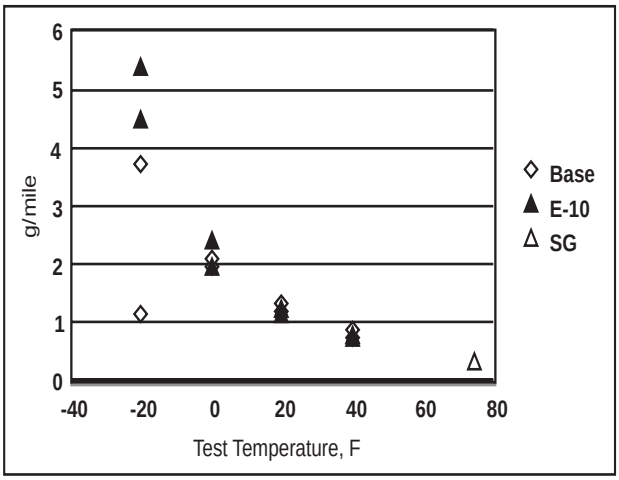

Figure 2. Taurus, THC, UDDS Cycle, O2 mode

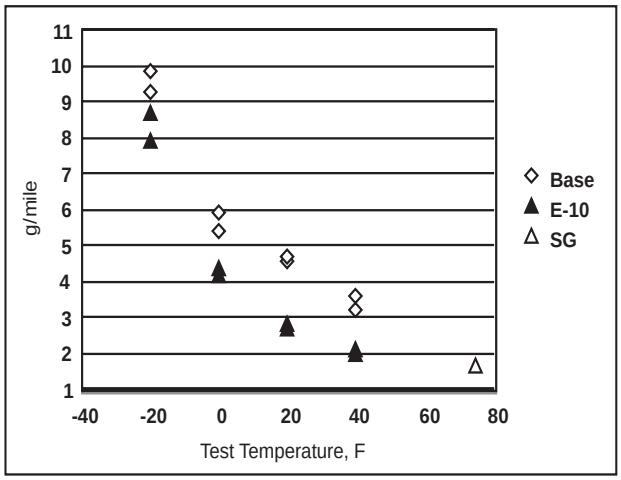

Figure 3. Taurus, CO, UDDS Cycle, NM mode

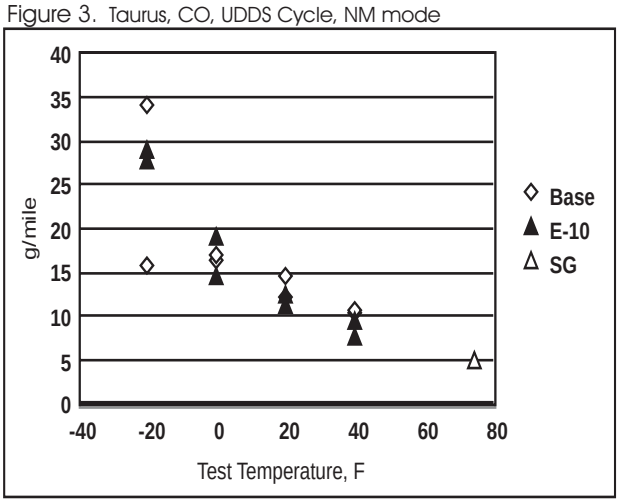

Figure 4. Taurus, CO, UDDS Cycle, O2 mode

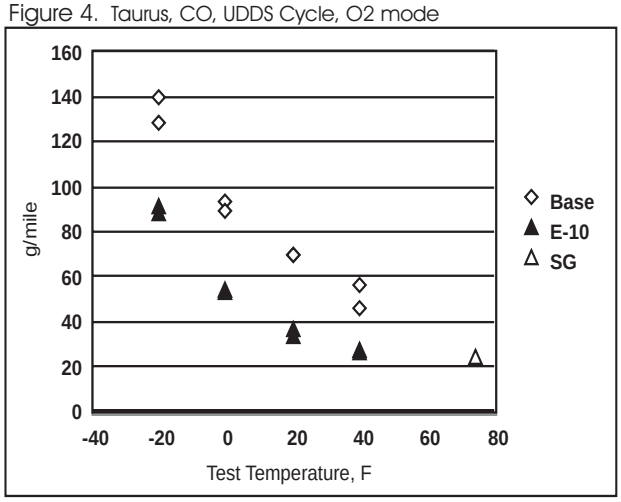

Figure 5. Taurus, NOx, UDDS Cycle, NM mode

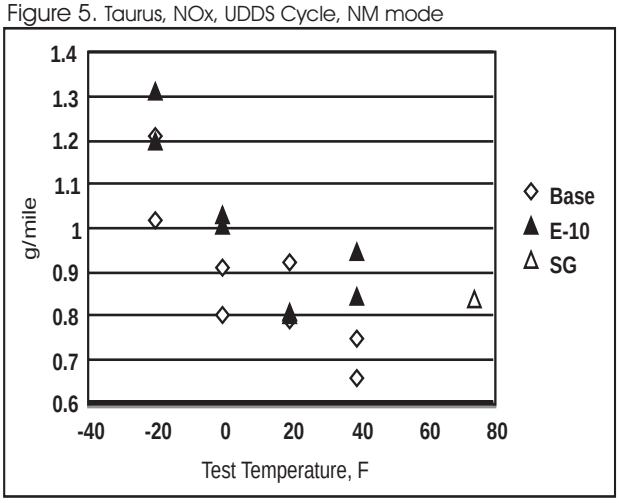

Figure 6. Taurus, NOx, UDDS Cycle, O2 mode

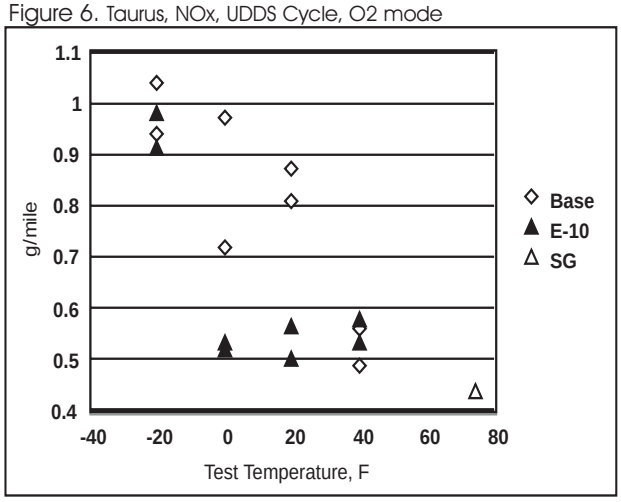

Figure 7. Taurus, Formaldehyde, UDDS Cycle, NM mode

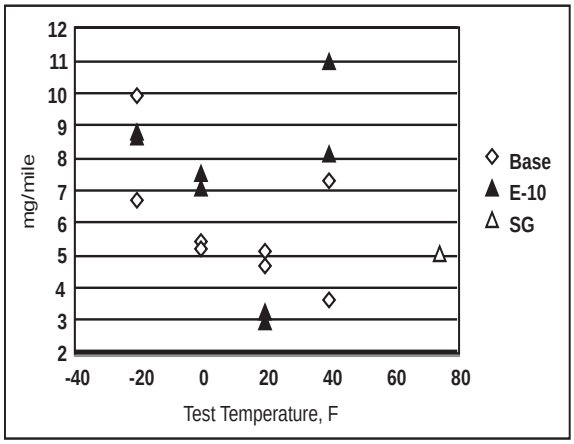

Figure 8. Taurus, Formaldehyde, UDDS Cycle, O2 mode

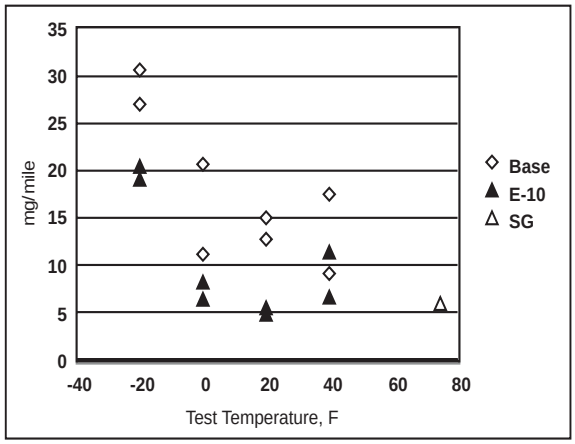

Figure 9. Taurus, Acetaldehyde, UDDS Cycle, NM mode

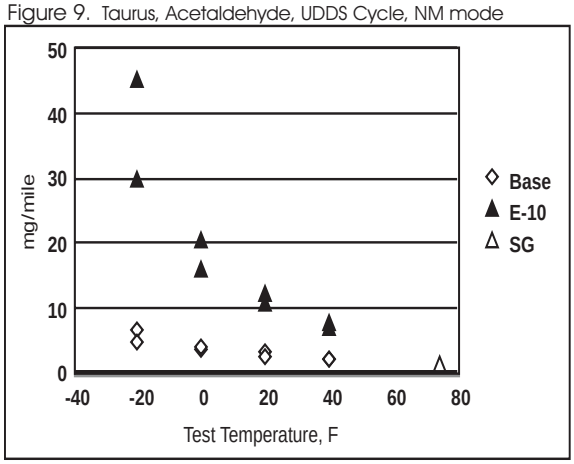

Figure 10. Taurus, Acetaldehyde, UDDS Cycle, O2 mode

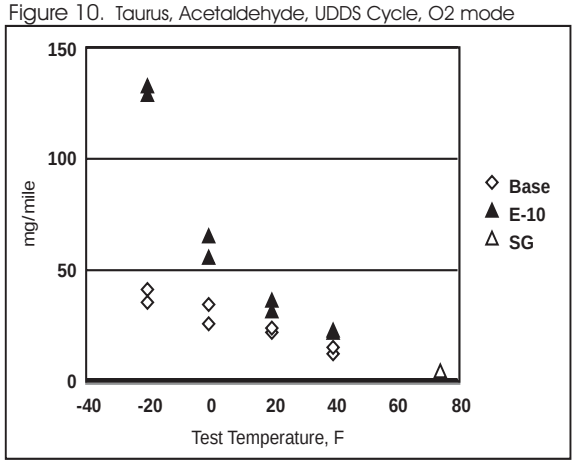

Figure 11. Taurus, Benzene, UDDS Cycle, NM mode

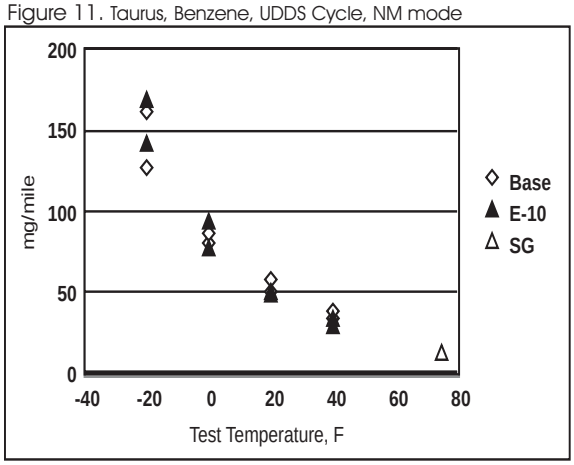

Figure 12. Taurus, Benzene, UDDS Cycle, O2 mode

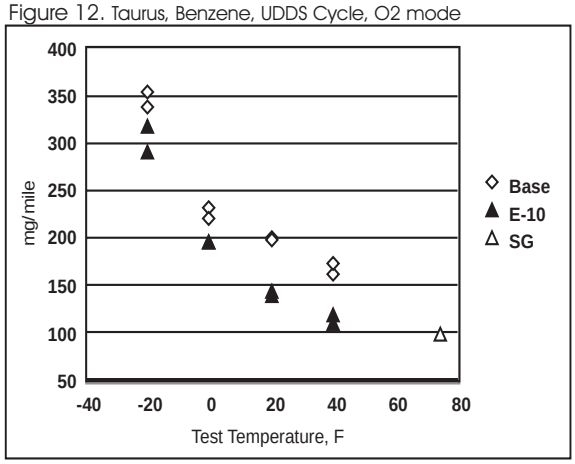

Figure 13. Taurus, 1,3-Butadiene, UDDS Cycle, NM mode

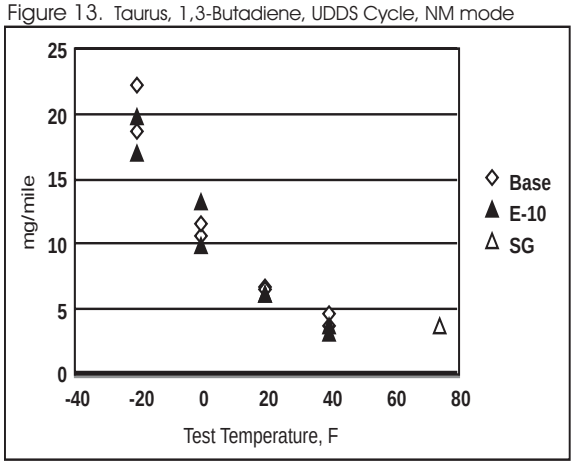

Figure 14. Taurus, 1,3-Butadiene, UDDS Cycle, O2 mode

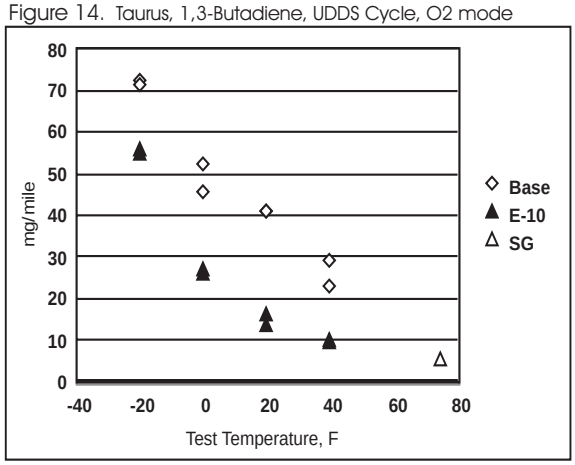

Figure 15. Taurus, Fuel Economy, UDDS Cycle, NM mode

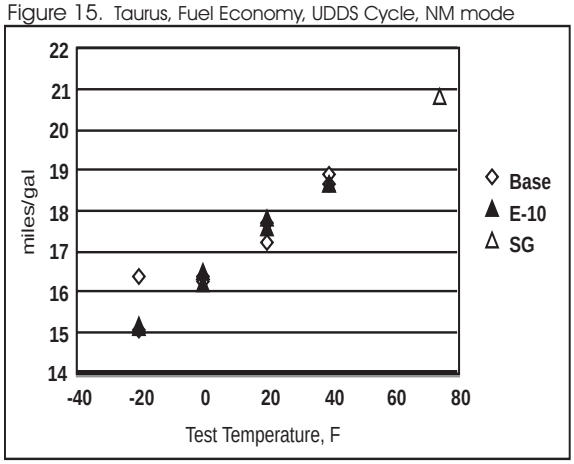

Figure 16. Taurus, Fuel Economy, UDDS Cycle, O2 mode

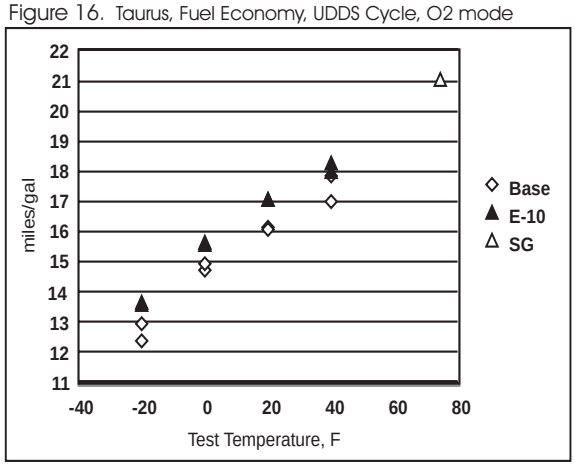

Figure 17. Taurus, MTBE, UDDS Cycle, NM mode

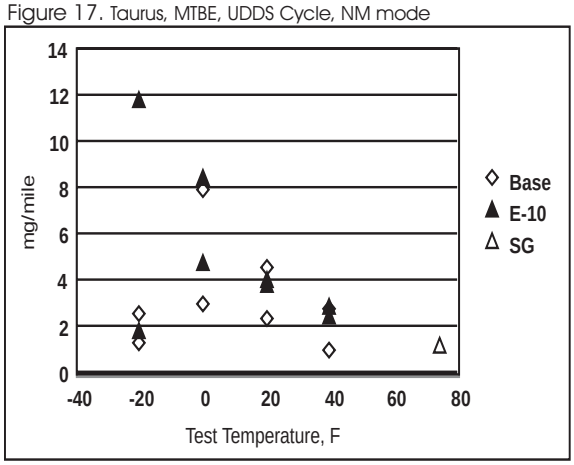

Figure 18. Taurus, MTBE, UDDS Cycle, O2 mode

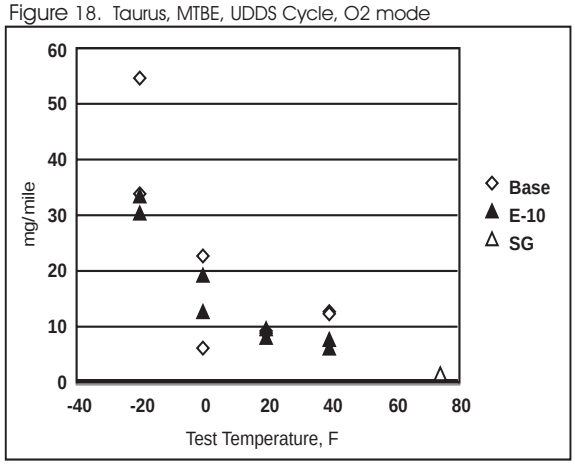

Figure 19. Taurus, EtOH, UDDS Cycle, NM mode

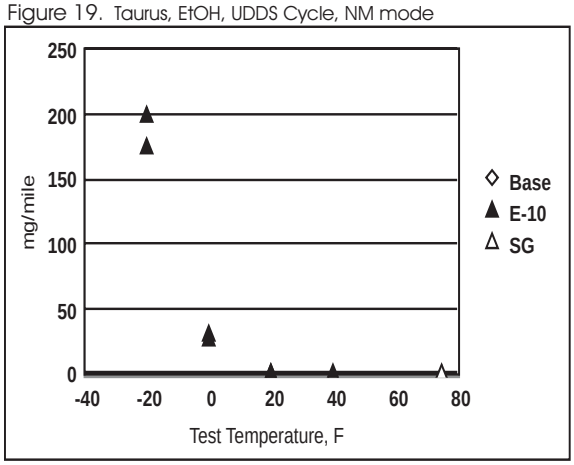

Figure 20. Taurus, EtOH, UDDS Cycle, O2 mode

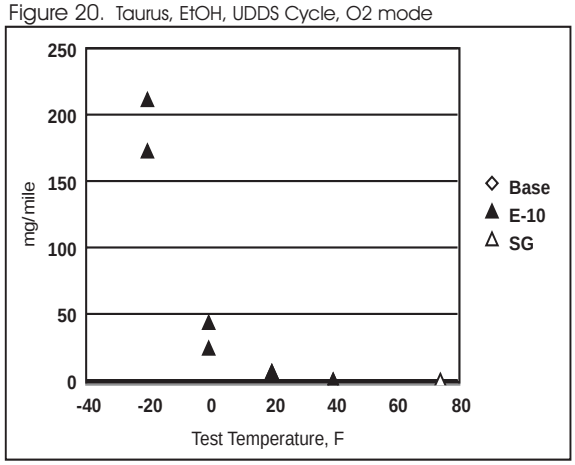

Figure 21. Taurus, MeOH, UDDS Cycle, NM mode

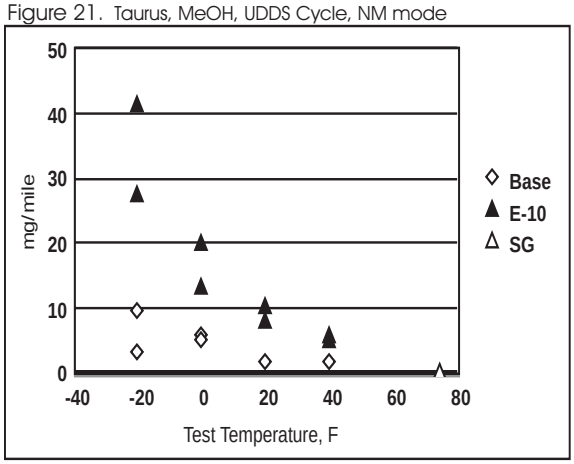

Figure 22. Taurus, MeOH, UDDS Cycle, O2 mode

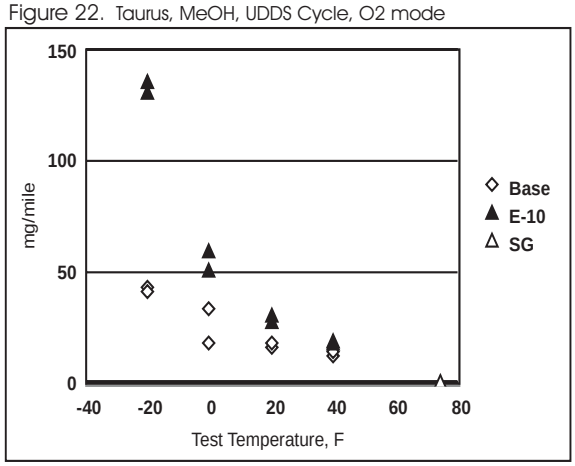

Figure 23. Taurus, PM2.5, UDDS Cycle, NM mode

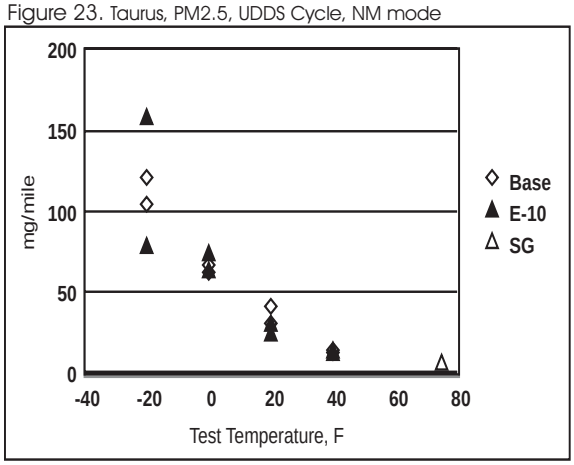

Figure 24. Taurus, PM2.5, UDDS Cycle, O2 mode

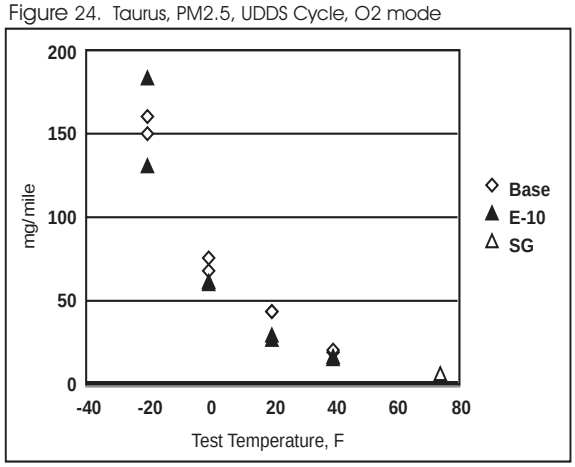

Figure 25. Taurus, PM10, UDDS Cycle, NM mode

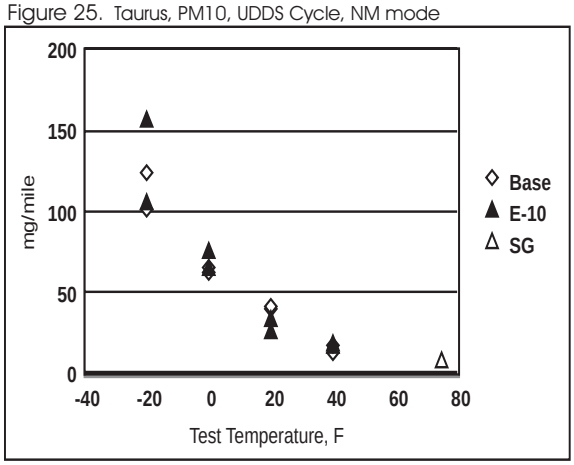

Figure 26. Taurus, PM10, UDDS Cycle, O2 mode

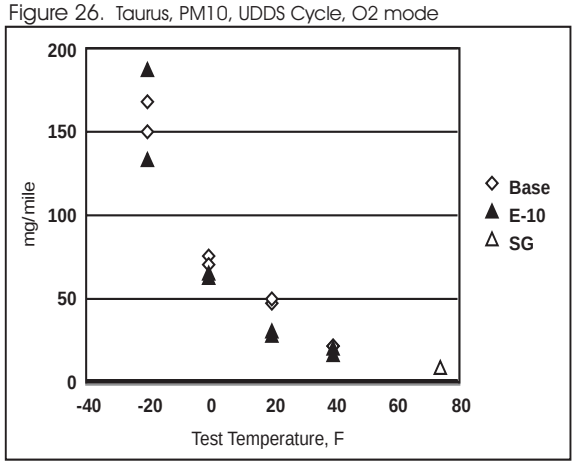

Figure 27. Taurus, THC, IM240 Cycle, NM mode

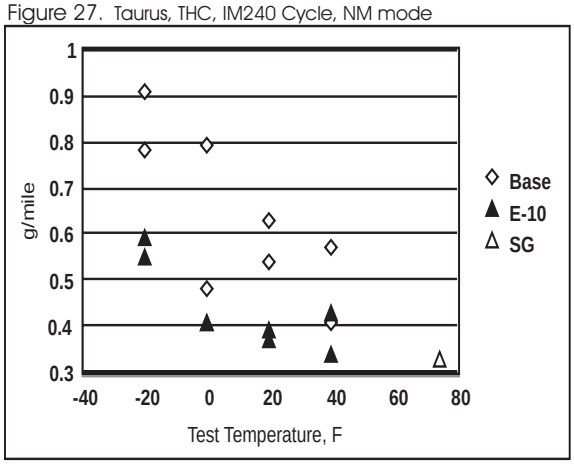

Figure 28. Taurus, THC, IM240 Cycle, O2 mode

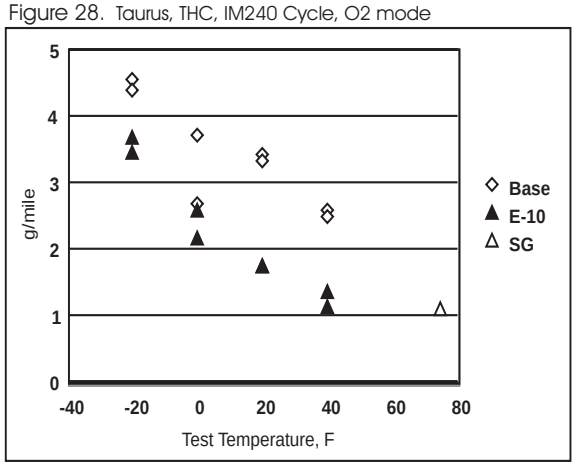

Figure 29. Taurus, CO, IM240 Cycle, NM mode

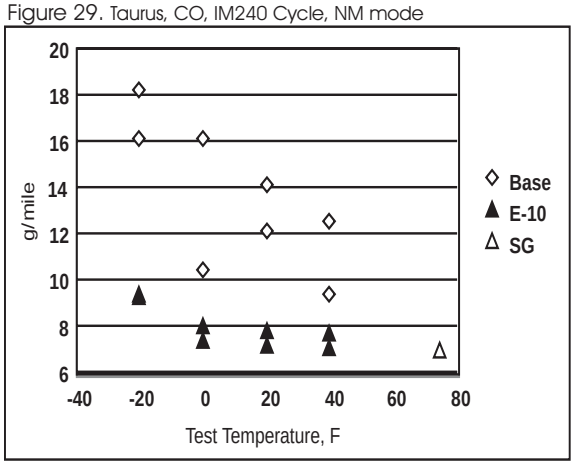

Figure 30. Taurus, CO, IM240 Cycle, O2 mode

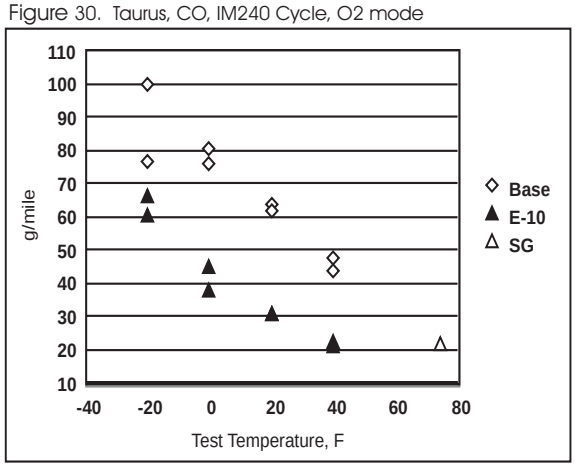

Figure 31. Taurus, NOx, IM240 Cycle, NM mode

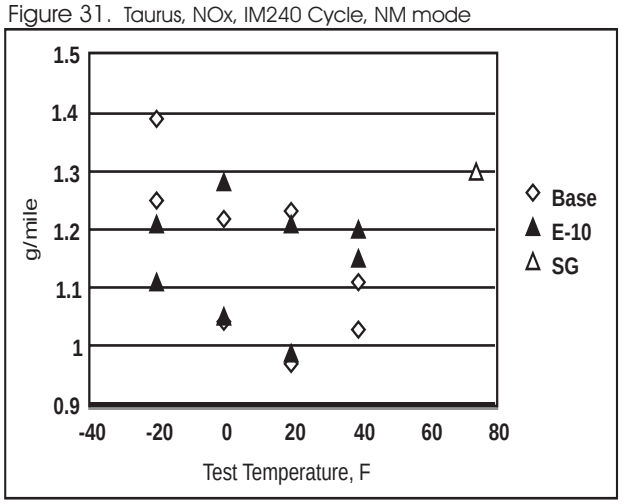

Figure 32. Taurus, NOx, IM240 Cycle, O2 mode

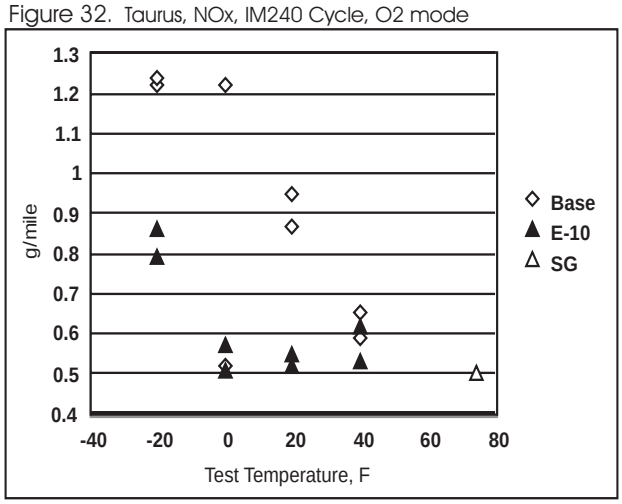

Figure 33. Taurus, Fuel Economy, IM240 Cycle, NM mode

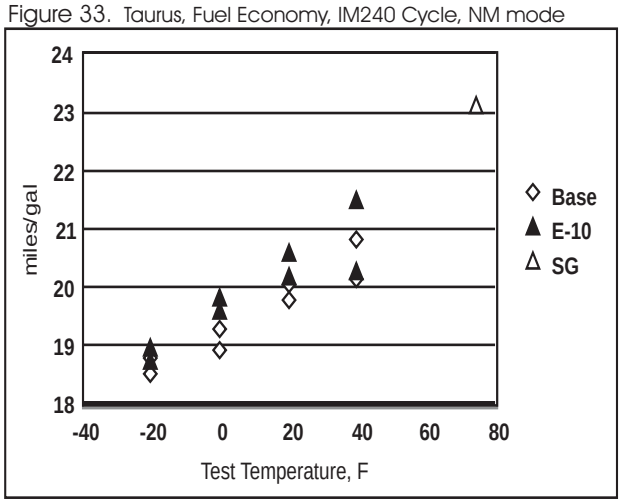

Figure 34. Taurus, Fuel Economy, IM240 Cycle, O2 mode

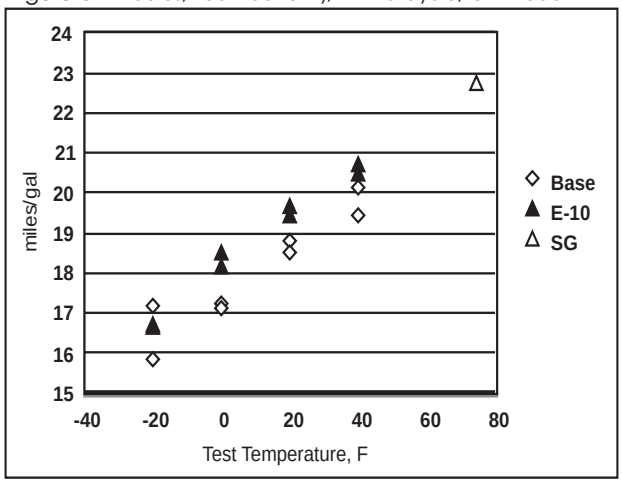

Figure 35. Taurus, PM2.5, IM240 Cycle, NM mode

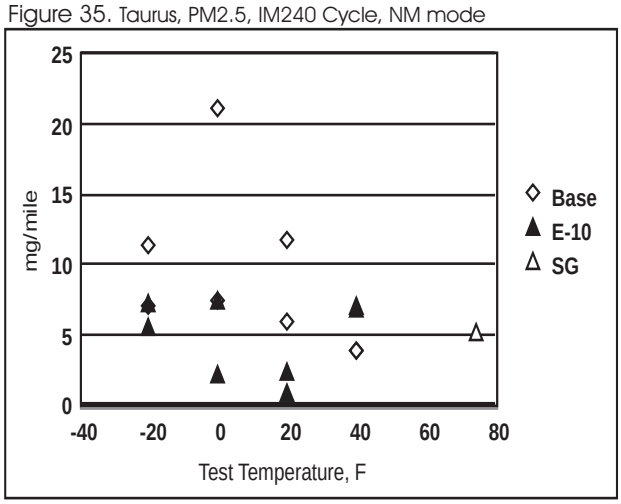

Figure 36. Taurus, PM2.5, IM240 Cycle, O2 mode

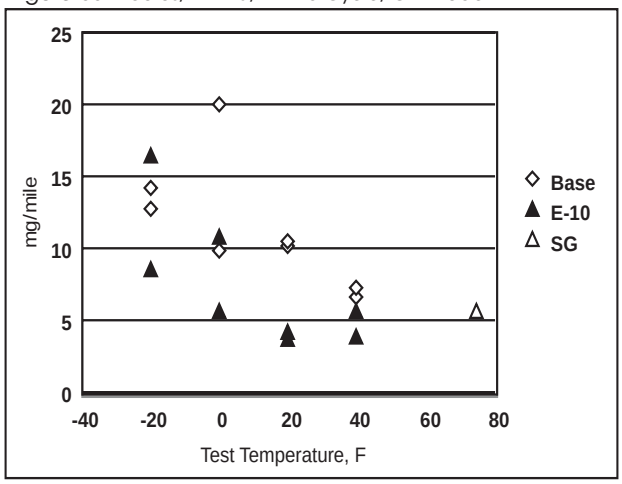

Figure 37. Taurus, PM10, IM240 Cycle, NM mode

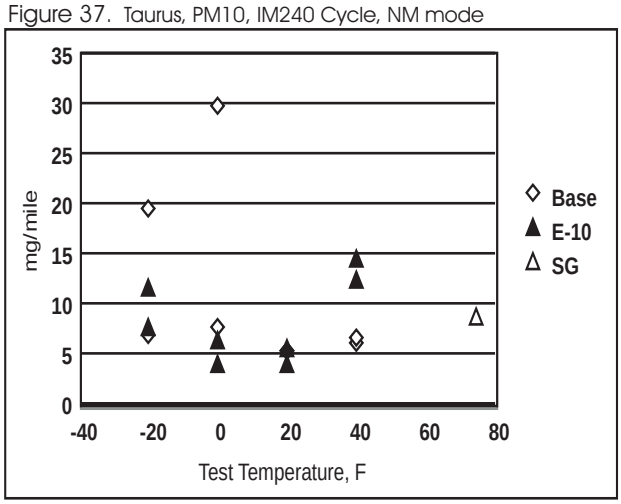

Figure 38. Taurus, PM10, IM240 Cycle, O2 mode

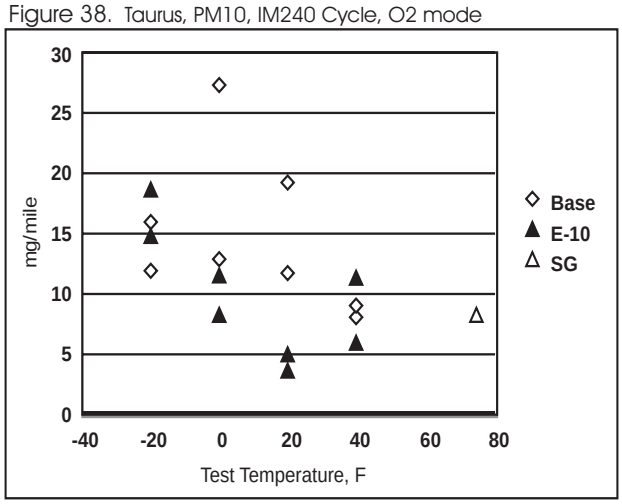

Figure 39. Concord, THC, UDDS Cycle, NM mode

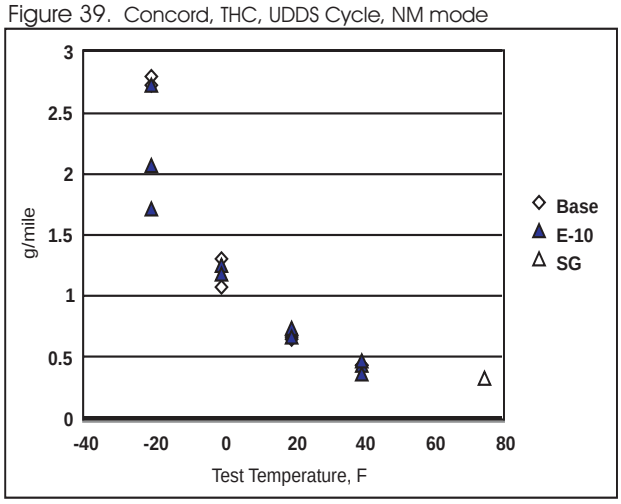

Figure 40. Concord, THC, UDDS Cycle, O2 mode

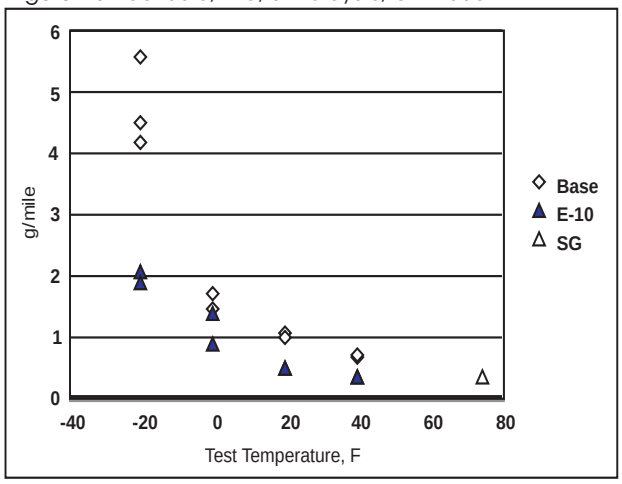

Figure 41. Concord, CO, UDDS Cycle, NM mode

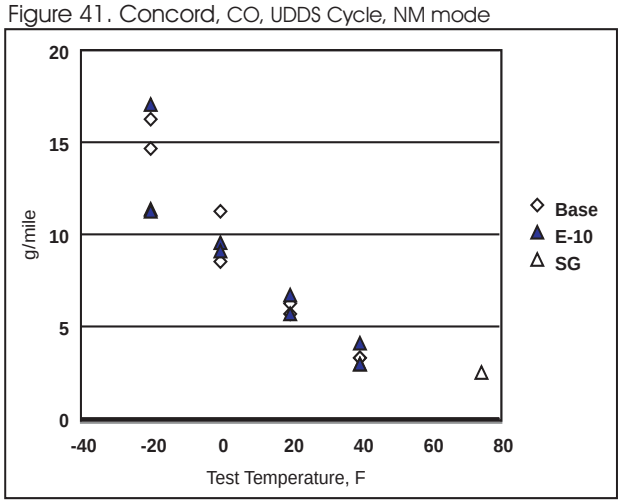

Figure 42. Concord, CO, UDDS Cycle, O2 mode

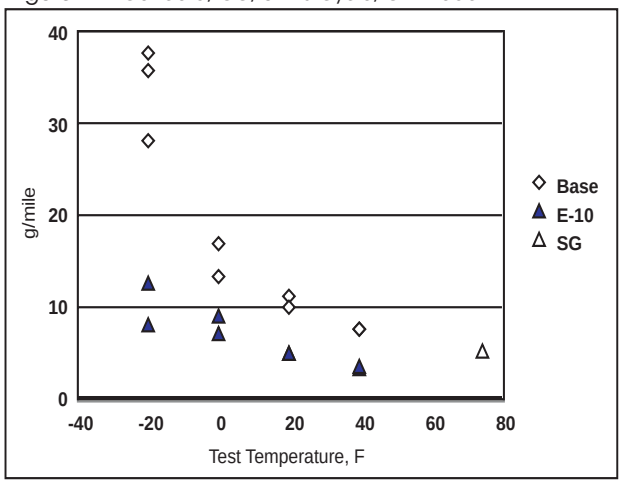

Figure 43. Concord, NOx, UDDS Cycle, NM mode

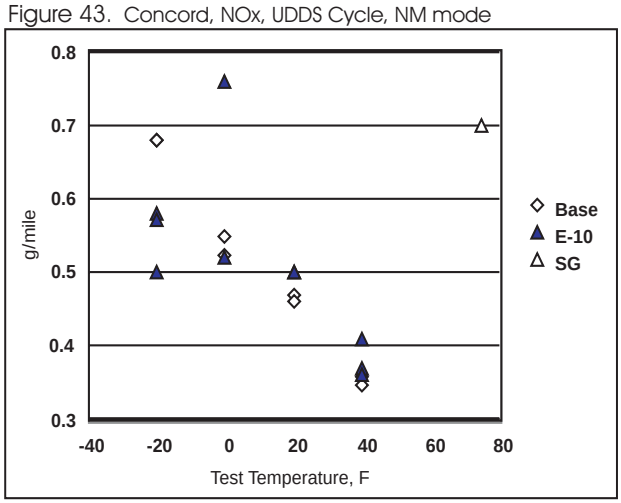

Figure 44. Concord, NOx, UDDS Cycle, O2 mode

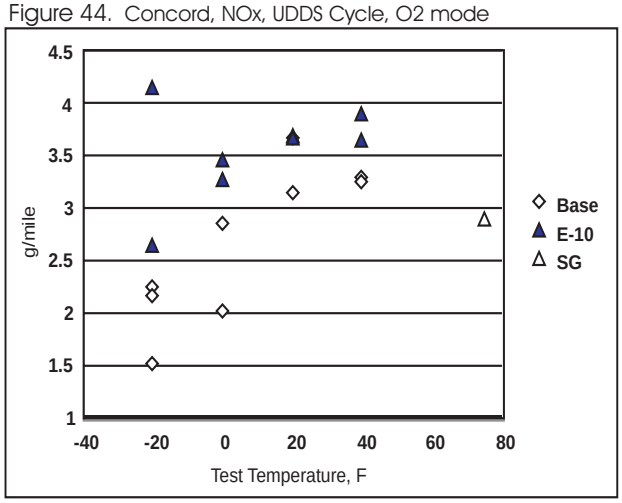

Figure 45. Concord, Formaldehyde, UDDS Cycle, NM mode

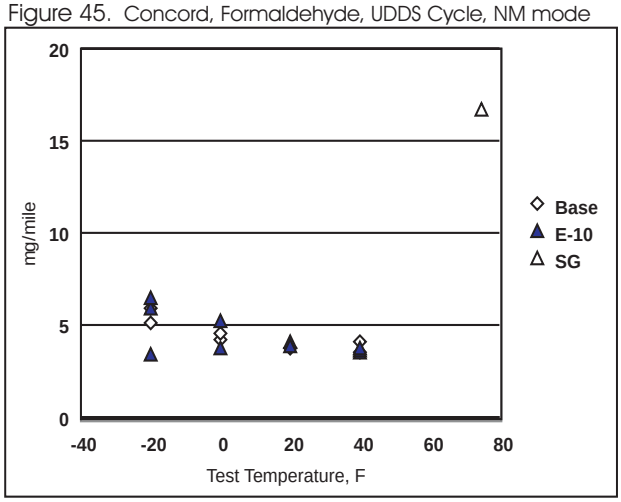

Figure 46. Concord, Formaldehyde, UDDS Cycle, O2 mode

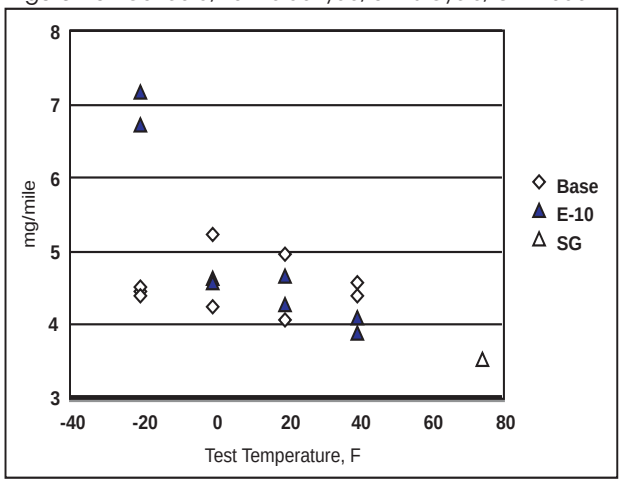

Figure 47. Concord, Acetaldehyde, UDDS Cycle, NM mode

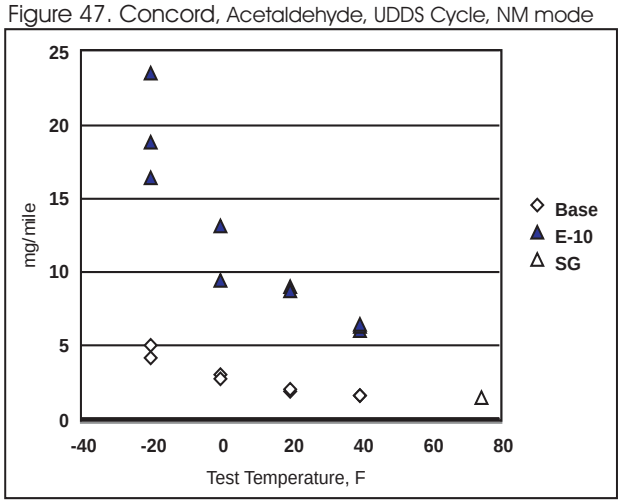

Figure 48. Concord, Acetaldehyde, UDDS Cycle, O2 mode

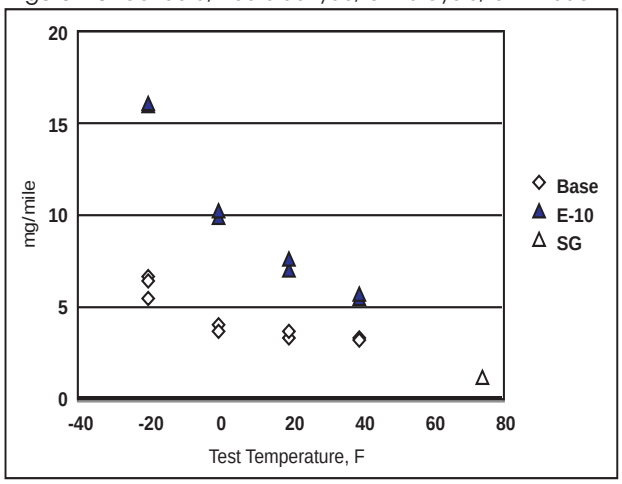

Figure 49. Concord, Benzene, UDDS Cycle, NM mode

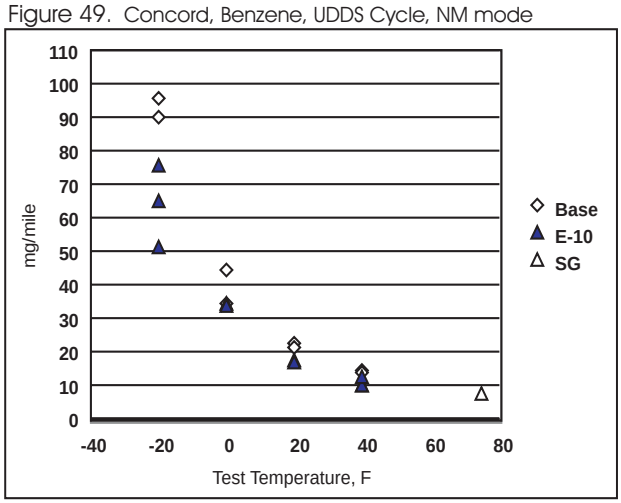

Figure 50. Concord, Benzene, UDDS Cycle, O2 mode

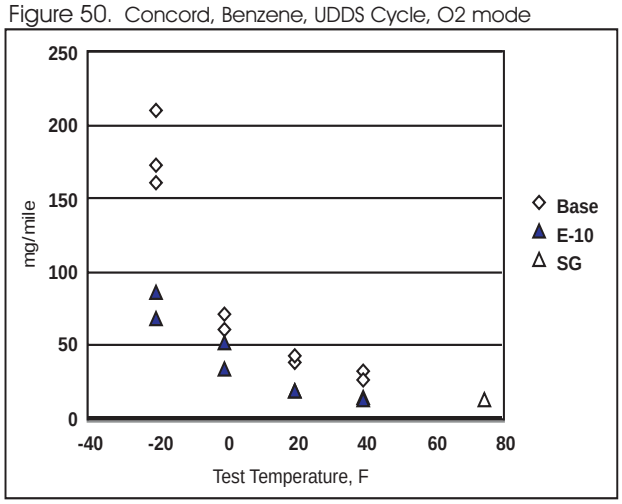

Figure 51. Concord, 1,3-Butadiene, UDDS Cycle, NM mode

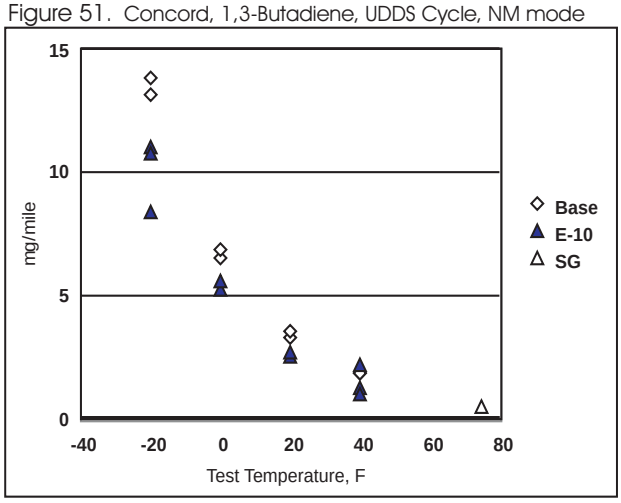

Figure 52. Concord, 1,3-Butadiene, UDDS Cycle, O2

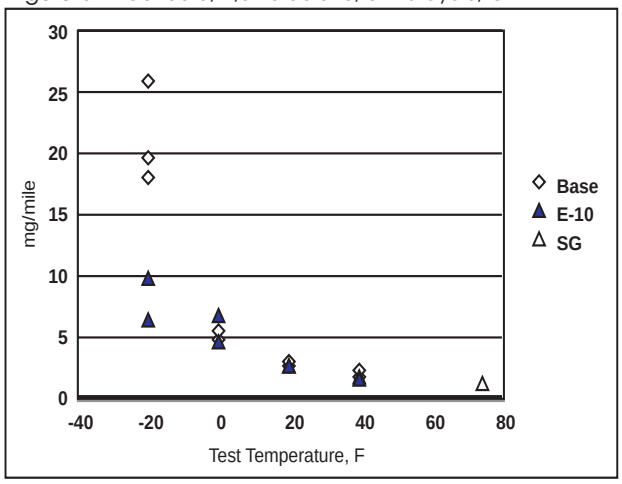

Figure 53. Concord, Fuel Economy, UDDS Cycle, NM mode

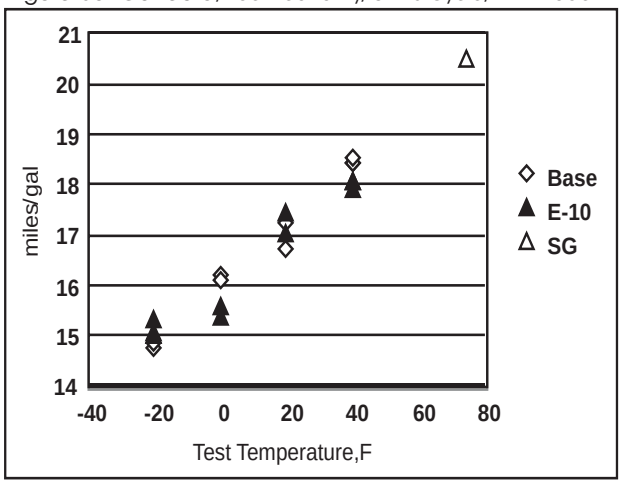

Figure 54. Concord, Fuel Economy, UDDS Cycle, O2 mode

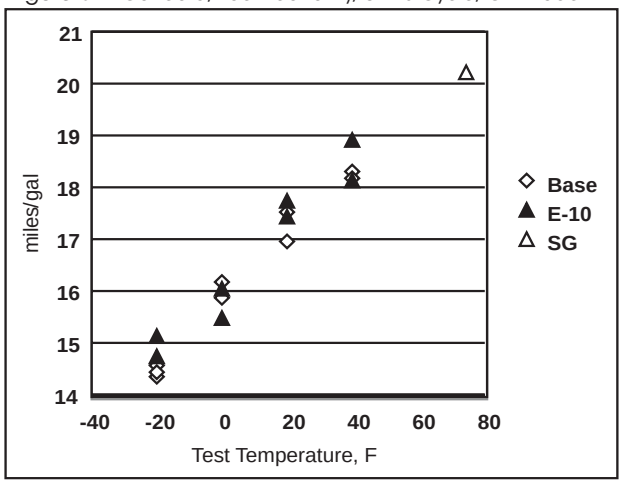

Figure 55. Concord, MTBE, UDDS Cycle, NM mode

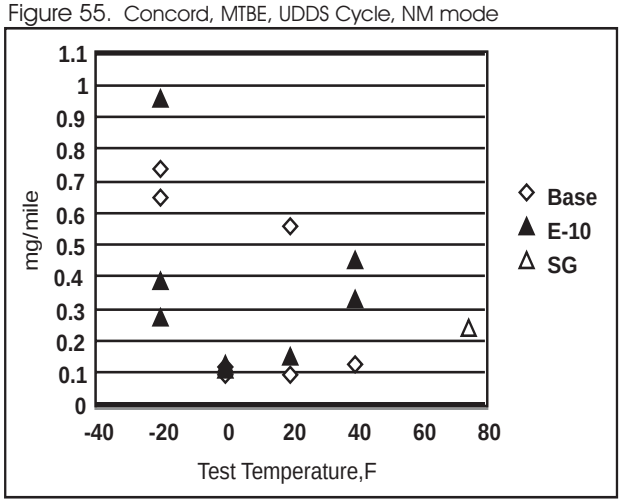

Figure 56. Concord, MTBE, UDDS Cycle, O2 mode

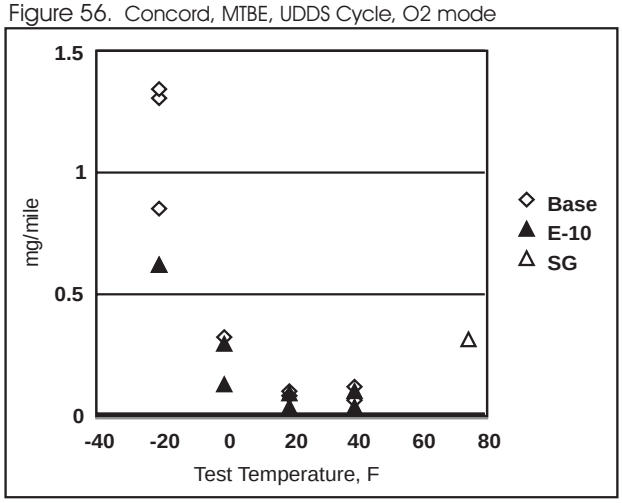

Figure 57. Concord, EtOH, UDDS Cycle, NM mode

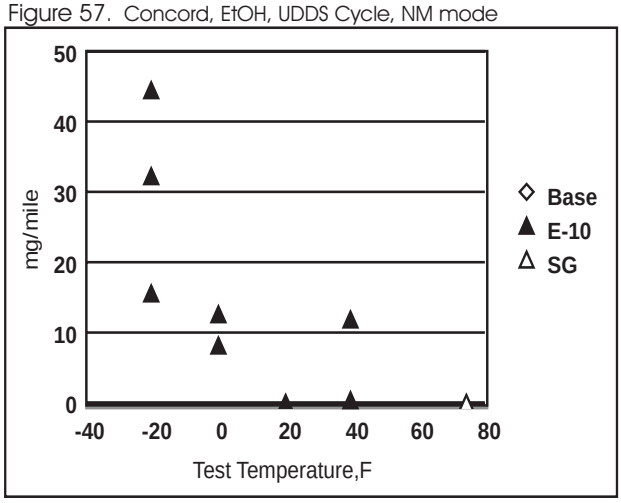

Figure 58. Concord, EtOH, UDDS Cycle, O2 mode

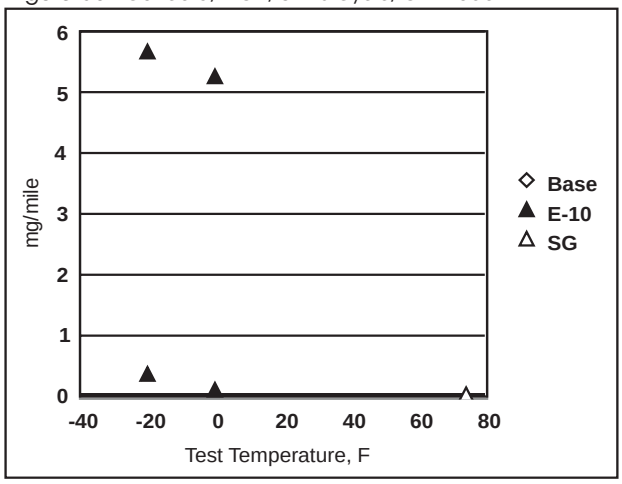

Figure 59. Concord, MeOH, UDDS Cycle, NM mode

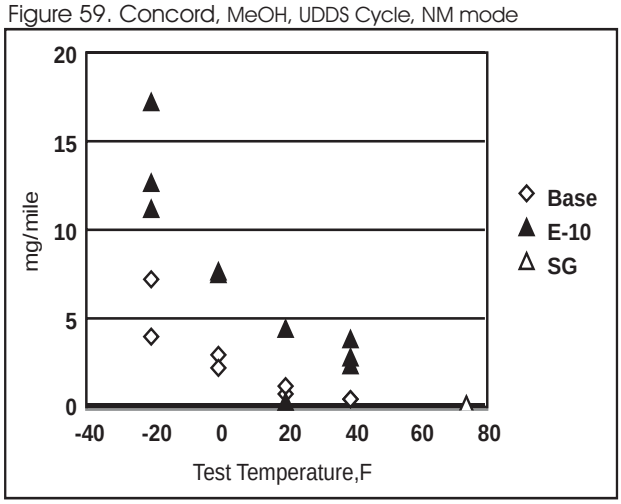

Figure 60. Concord, MeOH, UDDS Cycle, O2 mode

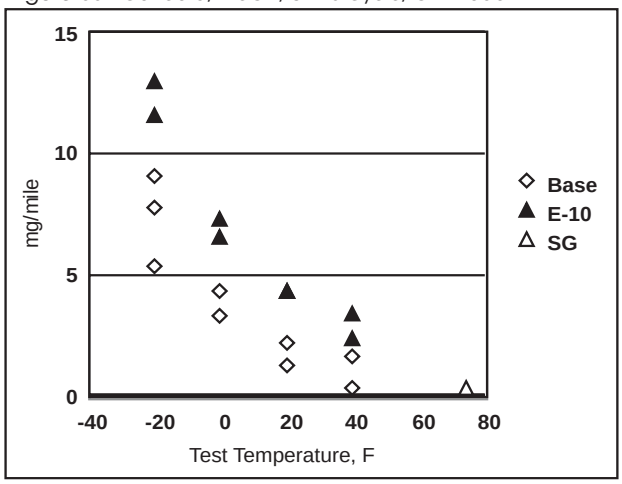

Figure 61. Concord, PM2.5, UDDS Cycle, NM mode

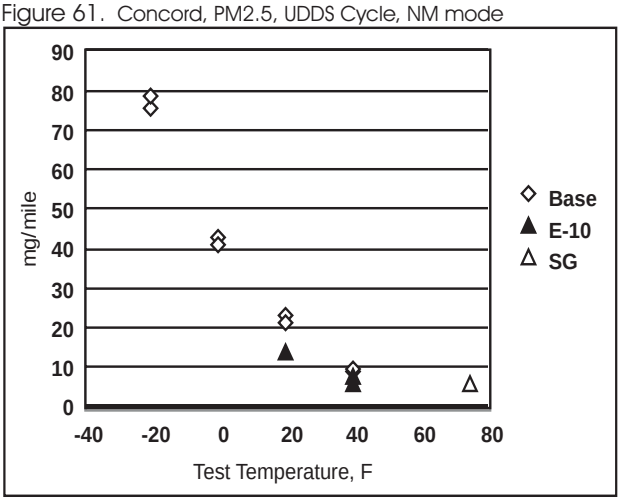

Figure 62. Concord, PM2.5, UDDS Cycle, O2 mode

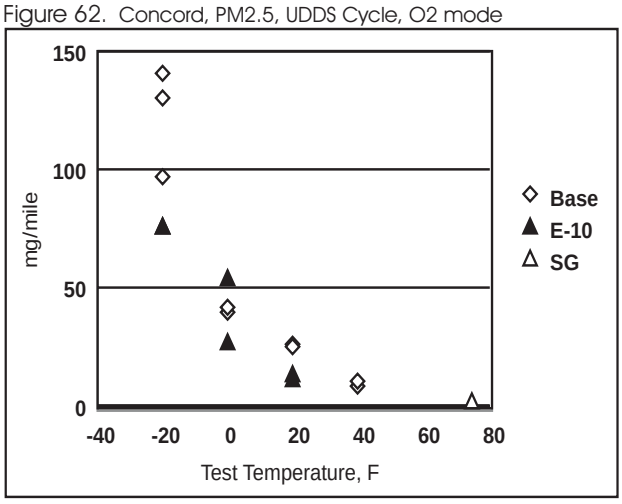

Figure 63. Concord, PM10, UDDS Cycle, NM mode

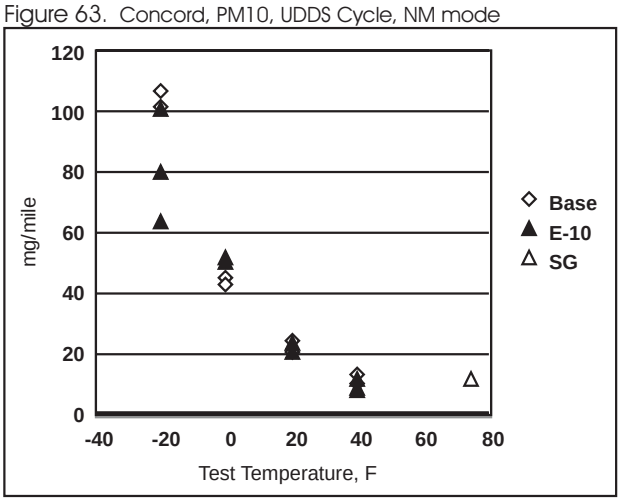

Figure 64. Concord, PM10, UDDS Cycle, O2 mode

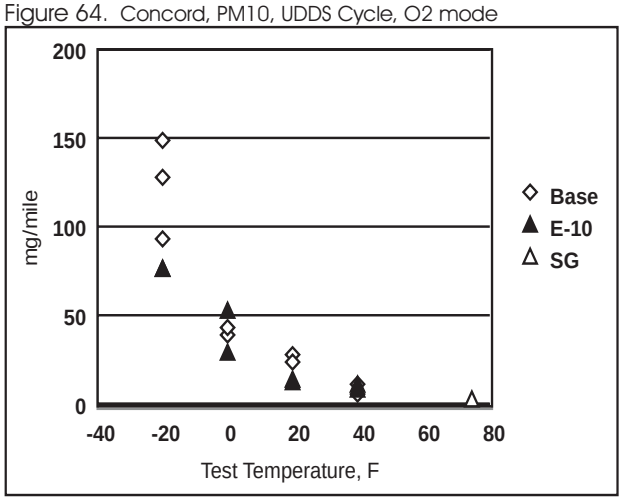

Figure 65. Concord, THC, IM240 Cycle, NM mode

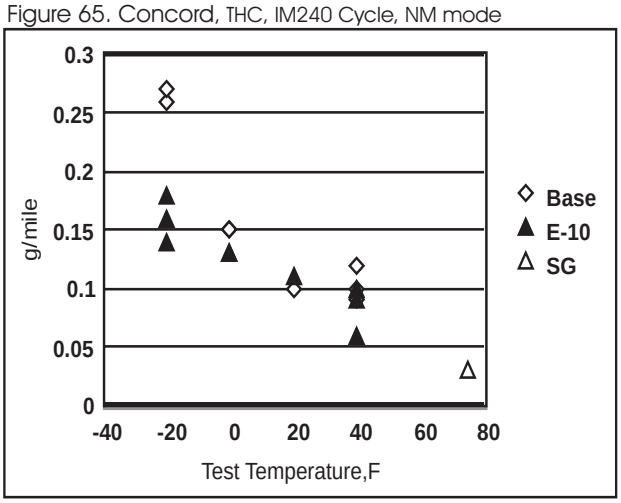

Figure 66. Concord, THC, IM240 Cycle, O2 mode

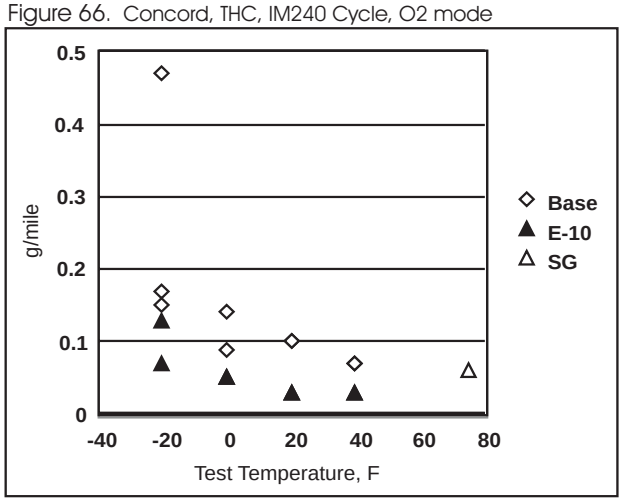

Figure 67. Concord, CO, IM240 Cycle, NM mode

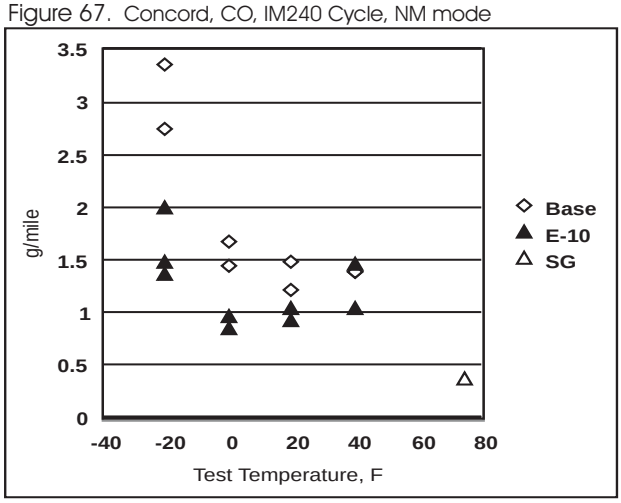

Figure 68. Concord, CO, IM240 Cycle, O2 mode

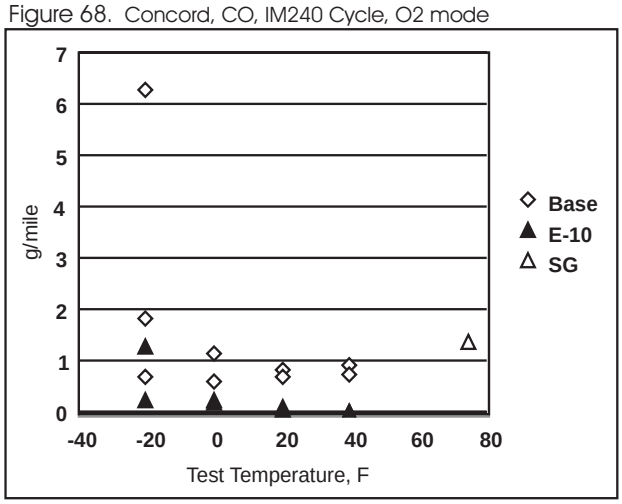

Figure 69. Concord, NOx, IM240 Cycle, NM mode

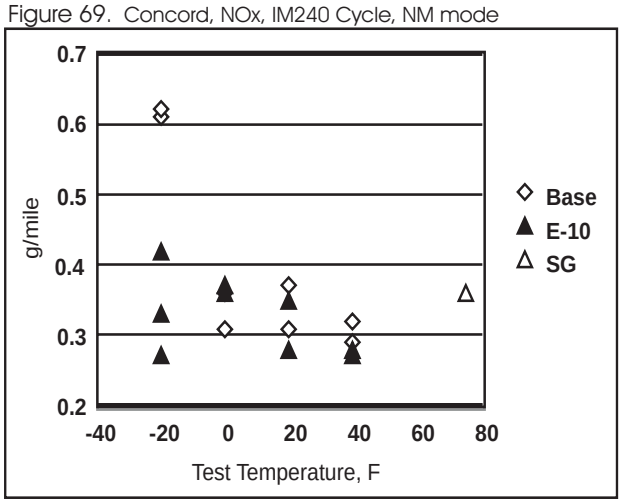

Figure 70. Concord, NOx, IM240 Cycle, O2 mode

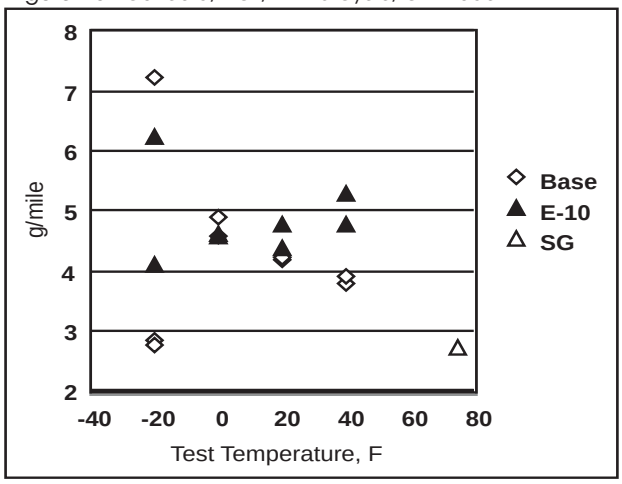

Figure 71. Concord, Fuel Economy, IM240 Cycle, NM mode

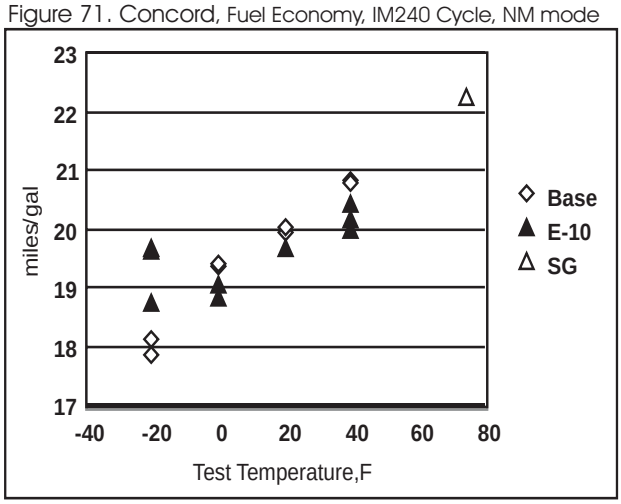

Figure 72. Concord, Fuel Economy, IM240 Cycle, O2 mode

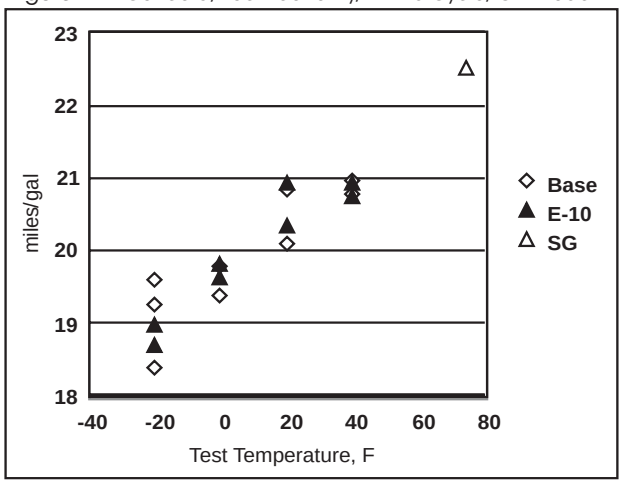

Figure 73. Concord, PM2.5, IM240 Cycle, NM mode

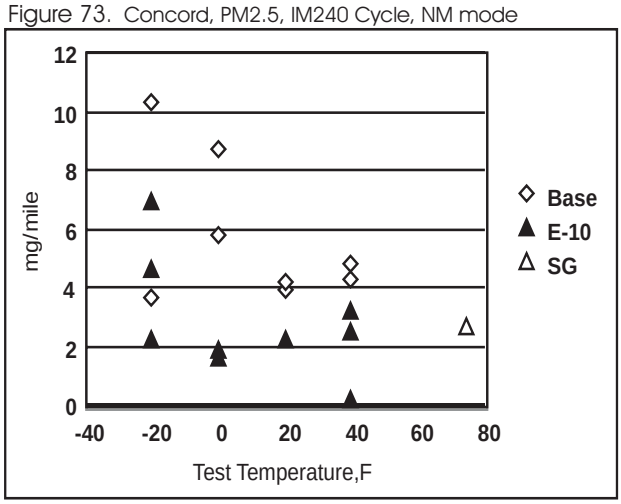

Figure 74. Concord, PM2.5, IM240 Cycle, O2 mode

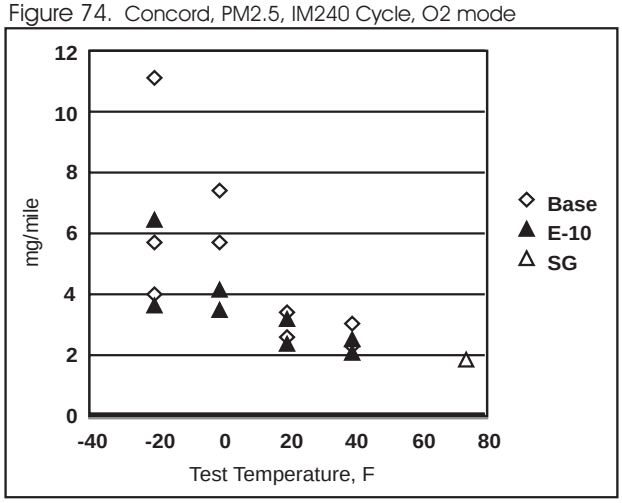

Figure 75. Concord, PM10, IM240 Cycle, NM mode

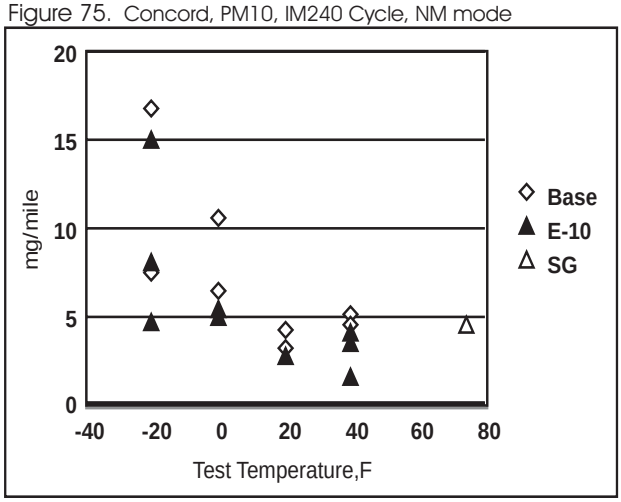

Figure 76. Concord, PM10, IM240 Cycle, O2 mode

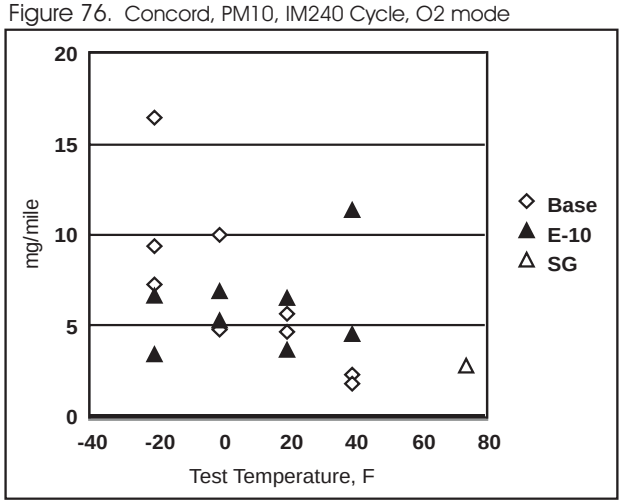

Figure 77. Focus, THC, UDDS Cycle, NM mode

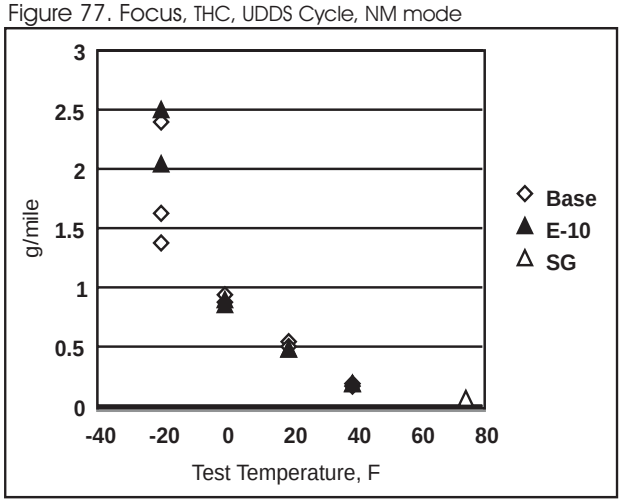

Figure 78. Focus, THC, UDDS Cycle, O2 mode

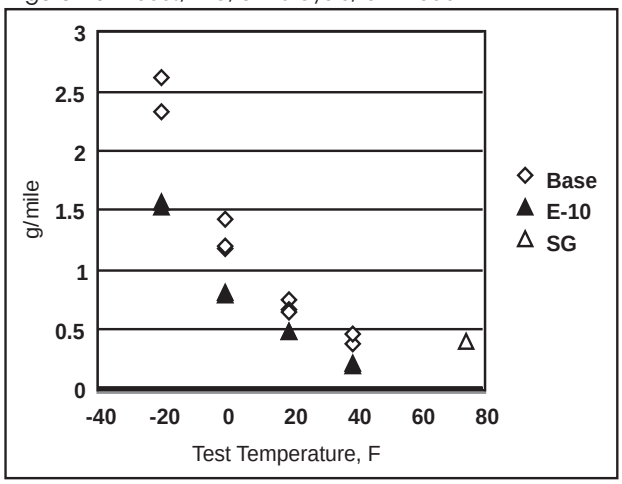

Figure 79. Focus, CO, UDDS Cycle, NM mode

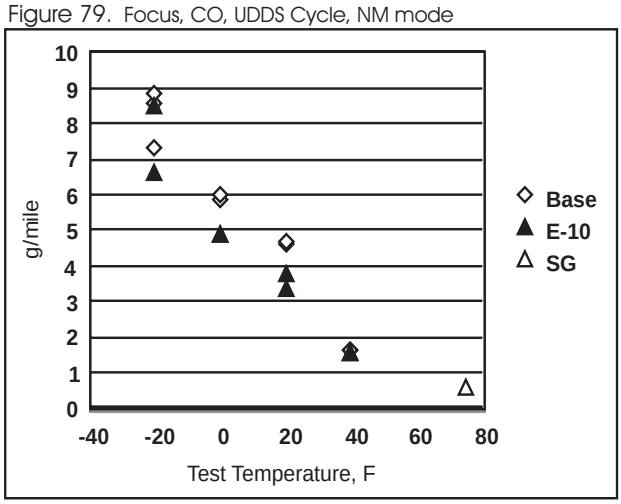

Figure 80. Focus, CO, UDDS Cycle, O2 mode

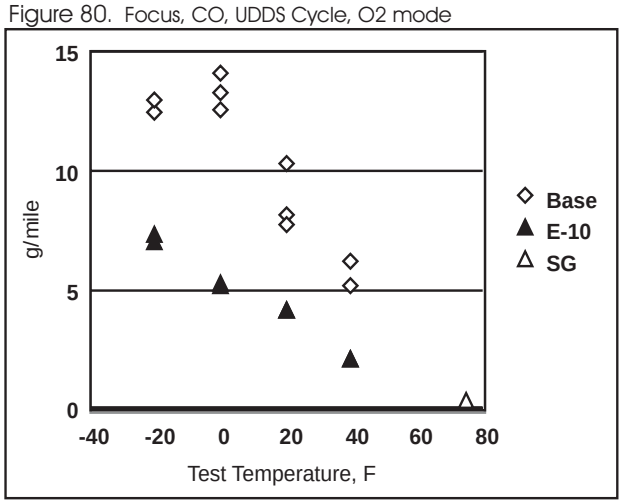

Figure 81. Focus, NOx, UDDS Cycle, NM mode

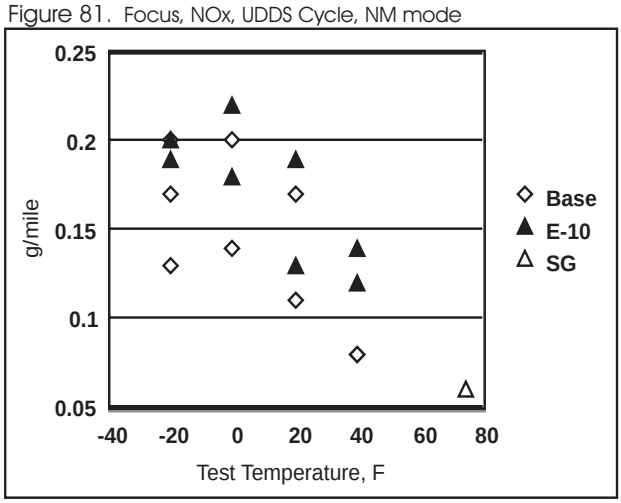

Figure 82. Focus, NOx, UDDS Cycle, O2 mode

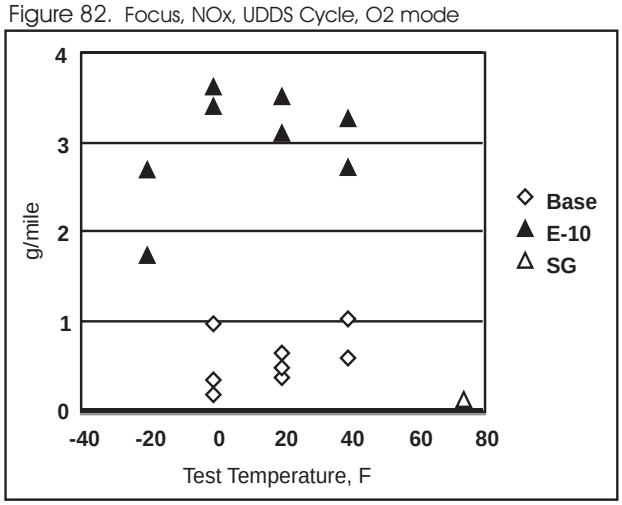

Figure 83. Focus, Formaldehyde, UDDS Cycle, NM mode

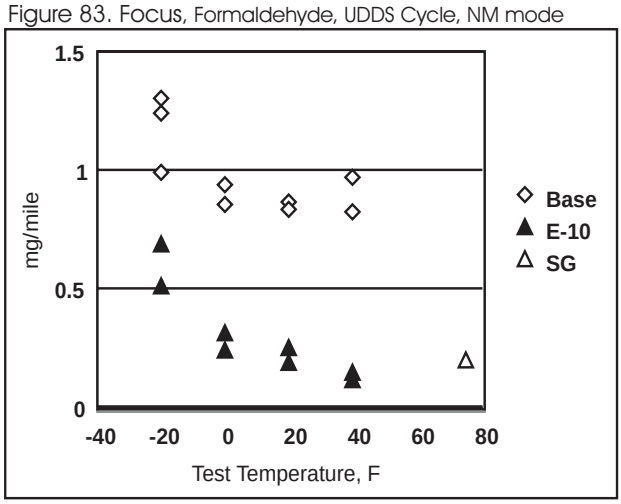

Figure 84. Focus, Formaldehyde, UDDS Cycle, O2 mode

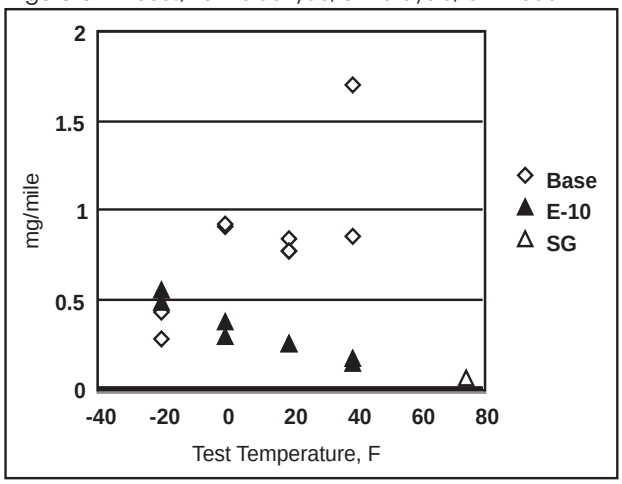

Figure 85. Focus, Acetaldehyde, UDDS Cycle, NM mode

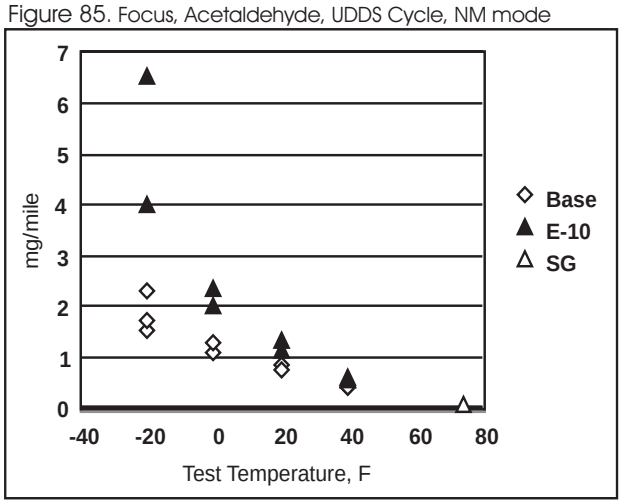

Figure 86. Focus, Acetaldehyde, UDDS Cycle, O2 mode

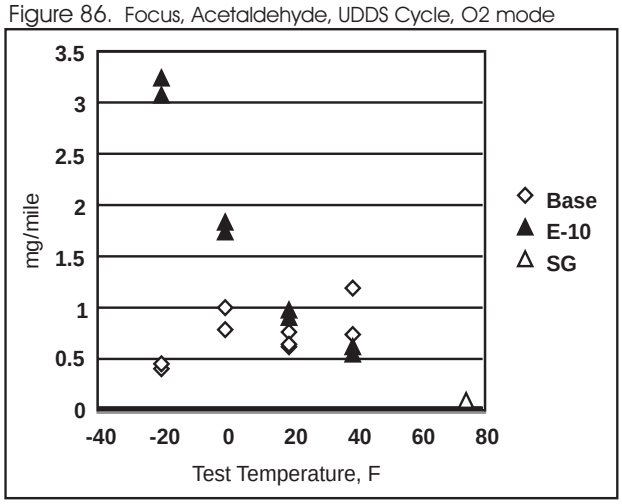

Figure 87. Focus, Benzene, UDDS Cycle, NM mode

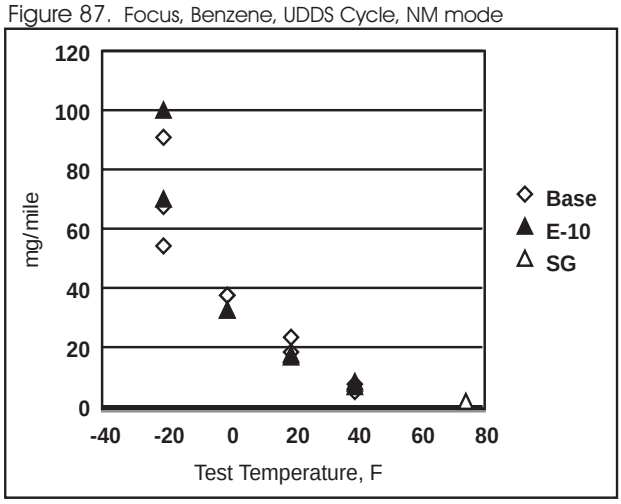

Figure 88. Focus, Benzene, UDDS Cycle, O2 mode

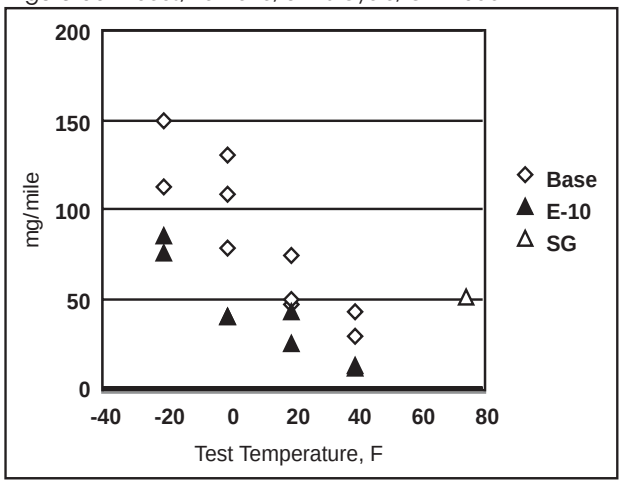

Figure 89. Focus, 1,3-Butadiene, UDDS Cycle, NM mode

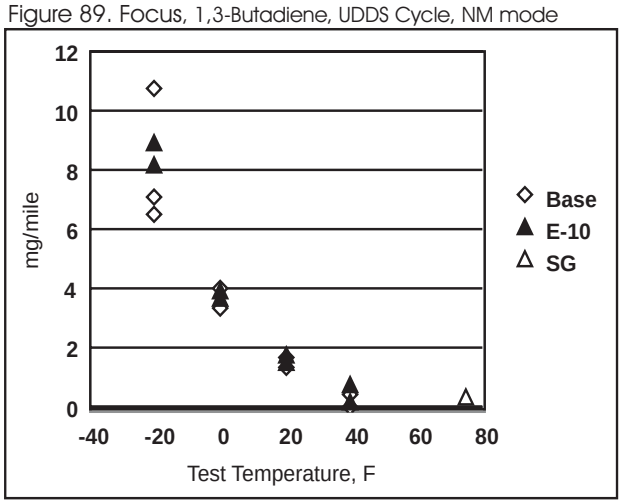

Figure 90. Focus, 1,3-Butadiene, UDDS Cycle, O2 mode

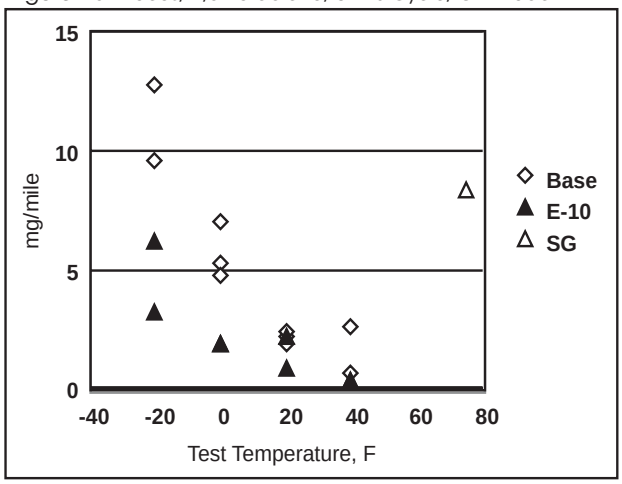

Figure 91. Focus, Fuel Economy, UDDS Cycle, NM mode

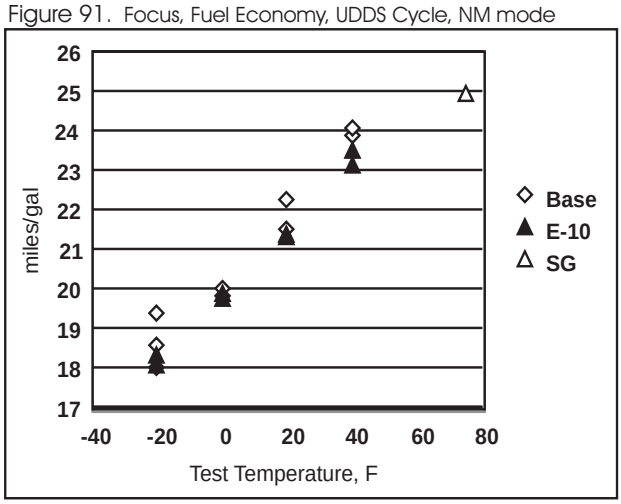

Figure 92. Focus, Fuel Ecenomy, UDDS Cycle, O2 mode

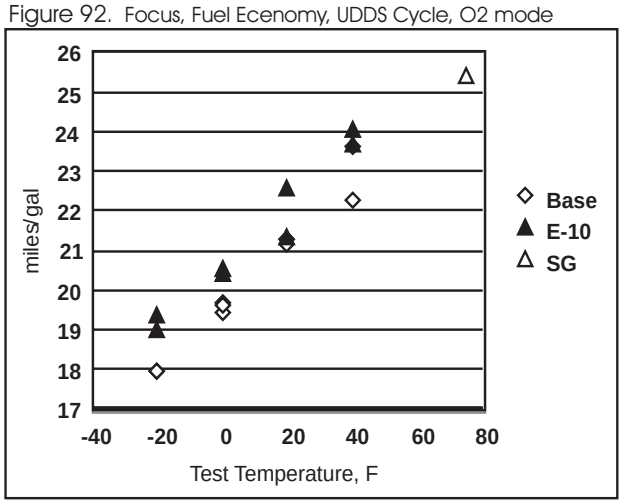

Figure 93. Focus, MTBE, UDDS Cycle, NM mode

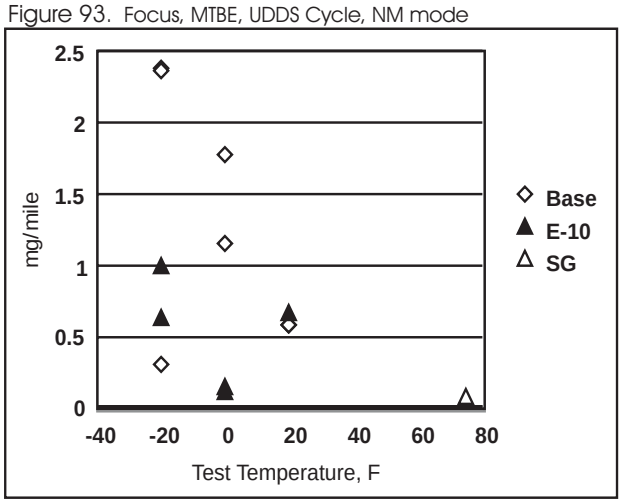

Figure 94. Focus, MTBE, UDDS Cycle, O2 mode

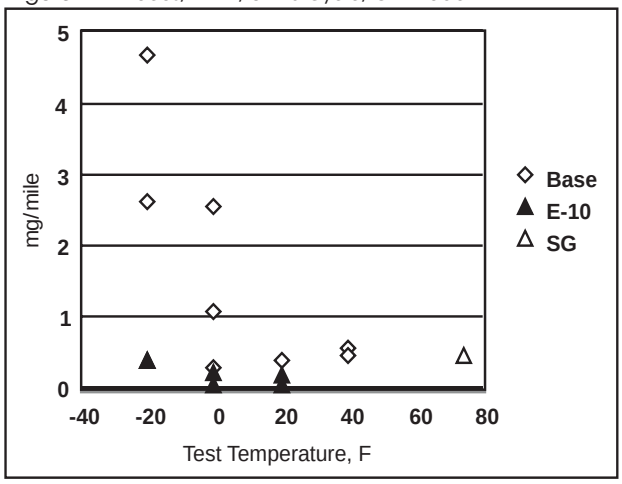

Figure 95. Focus, EtOH, UDDS Cycle, NM mode

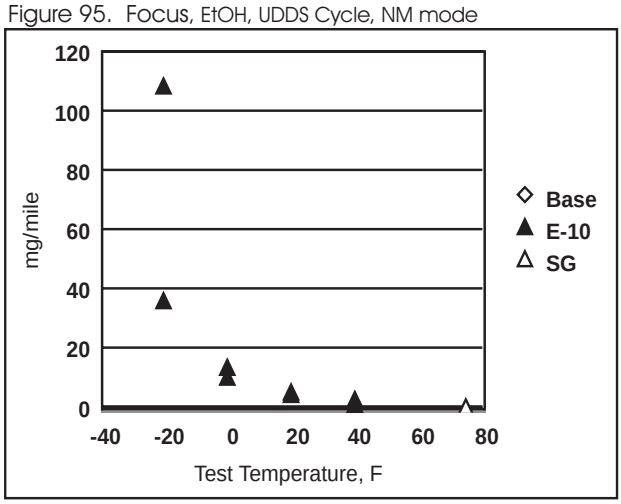

Figure 96. Focus, EtOH, UDDS Cycle, O2 mode

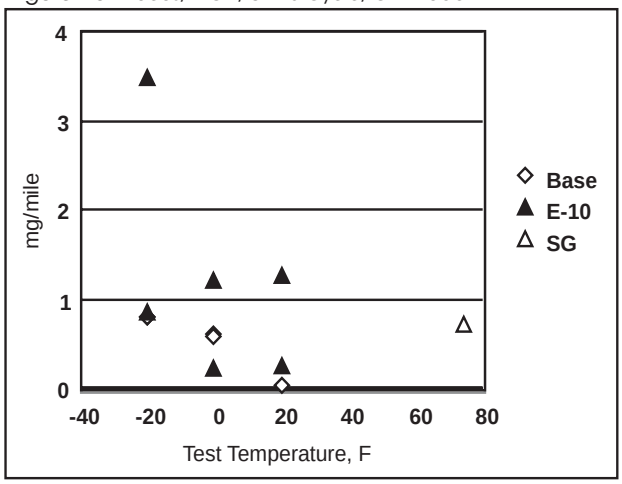

Figure 97. Focus, MeOH, UDDS Cycle, NM mode

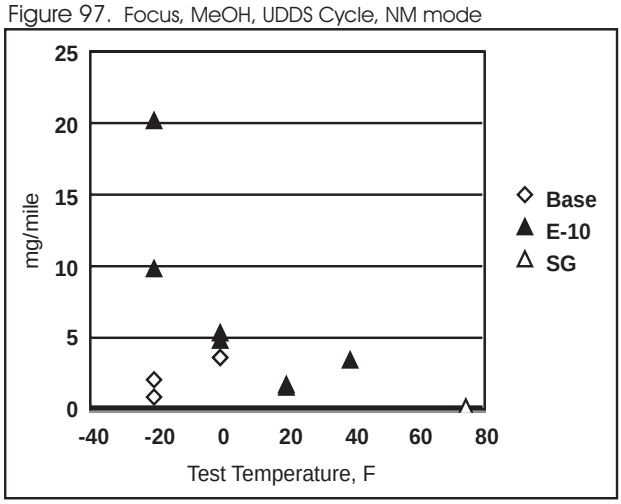

Figure 98. Focus, MeOH, UDDS Cycle, O2 mode

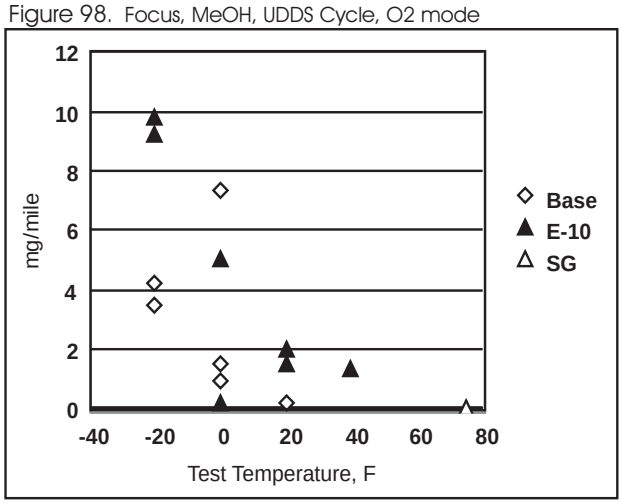

Figure 99. Focus, PM2.5, UDDS Cycle, NM mode

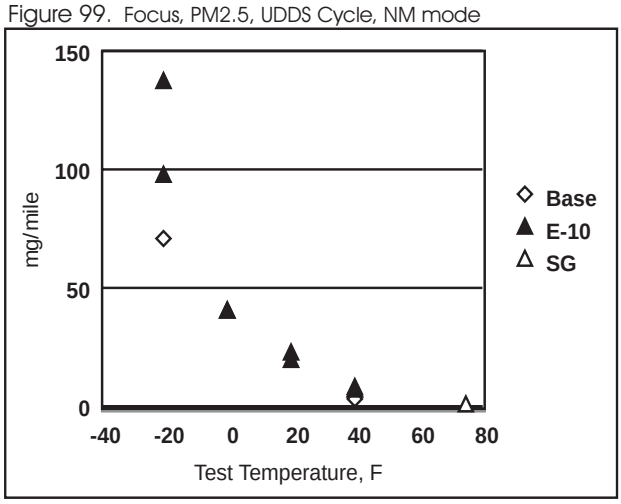

Figure 100. Focus, PM2.5, UDDS Cycle, O2 mode

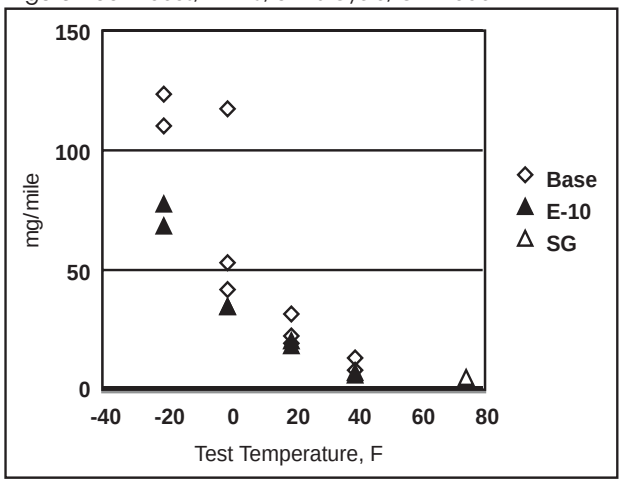

Figure 101. Focus, PM10, UDDS Cycle, NM mode

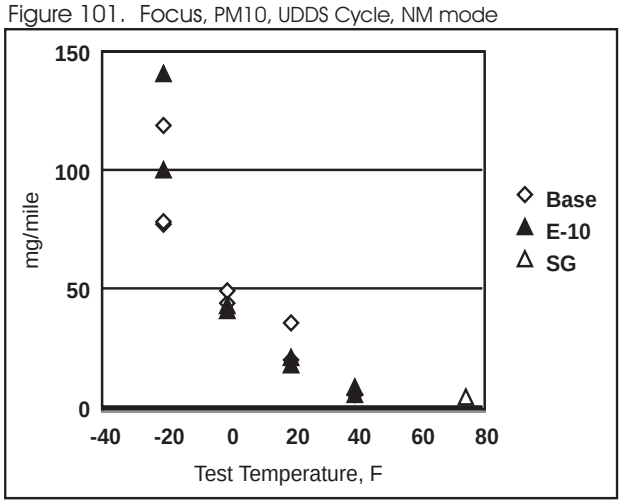

Figure 102. Focus, PM10, UDDS Cycle, O2 mode

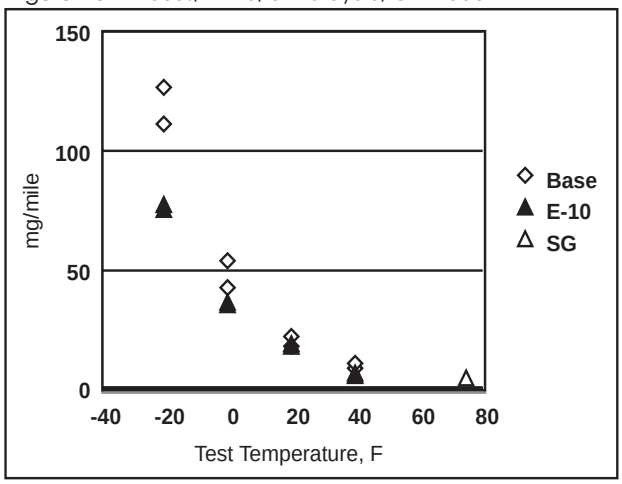

Figure 103. Focus, THC, IM240 Cycle, NM mode

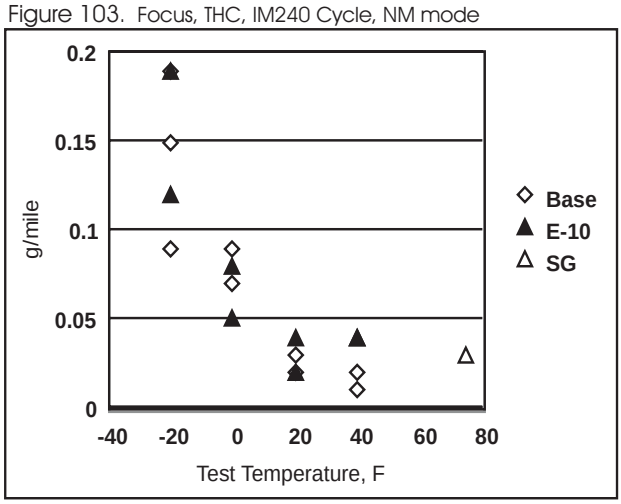

Figure 104. Focus, THC, IM240 Cycle, O2 mode

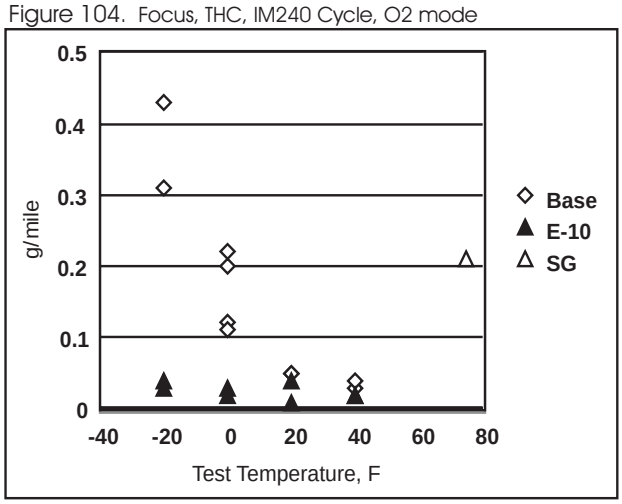

Figure 105. Focus, CO, IM240 Cycle, NM mode

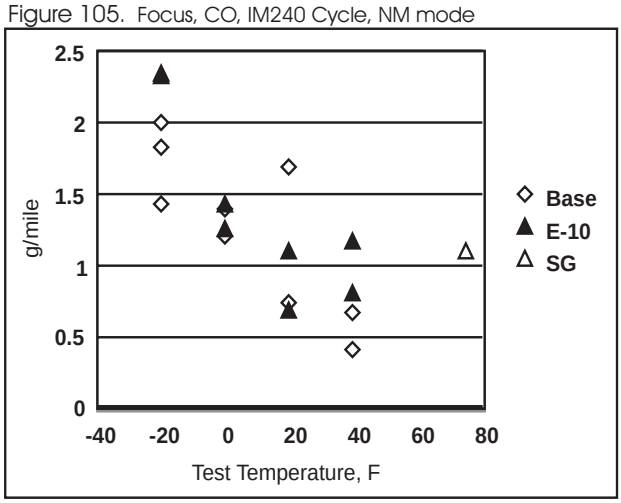

Figure 106. Focus, CO, IM240 Cycle, O2 mode

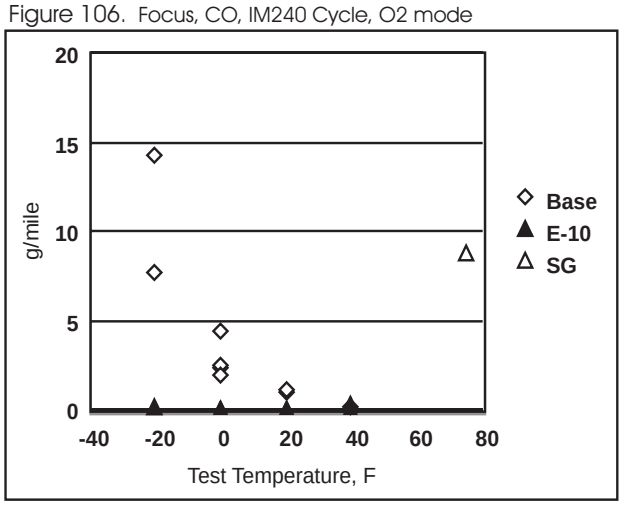

Figure 107. Focus, NOx, IM240 Cycle, NM mode

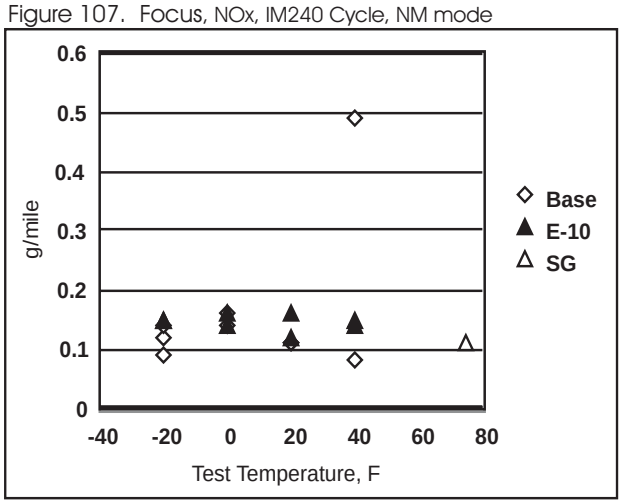

Figure 108. Focus, NOx, IM240 Cycle, O2 mode

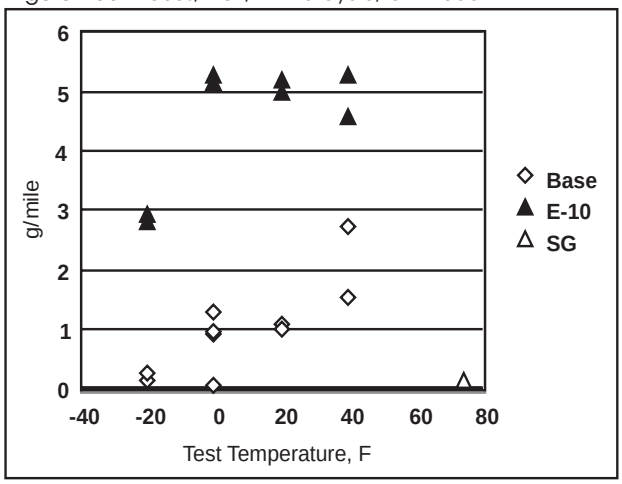

Figure 109. Focus, Fuel Economy, IM240 Cycle, NM mode

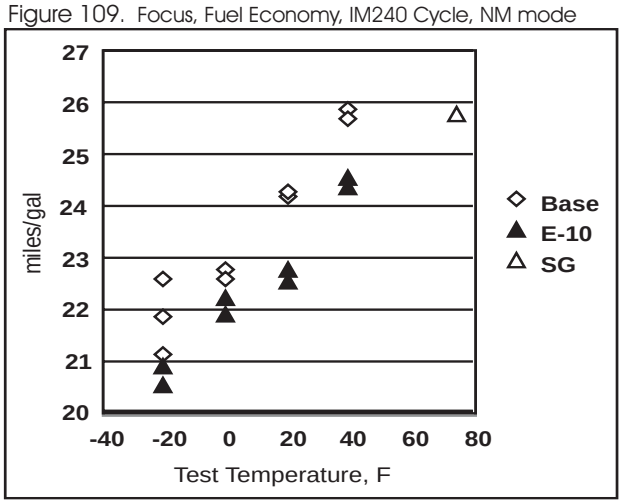

Figure 110. Focus, Fuel Economy, IM240 Cycle, O2 mode

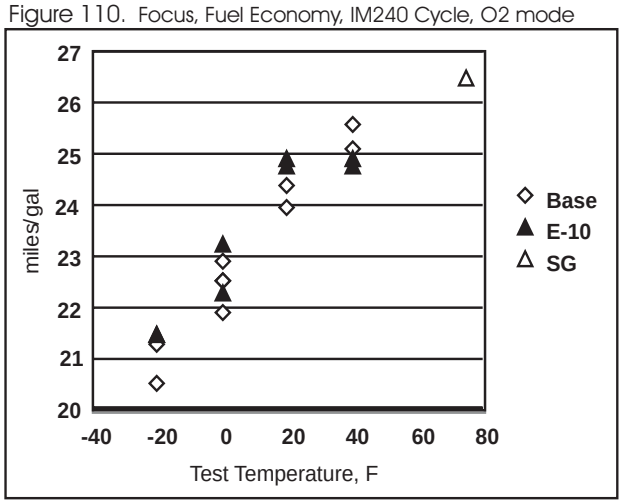

Figure 111. Focus, PM2.5, IM240 Cycle, NM mode

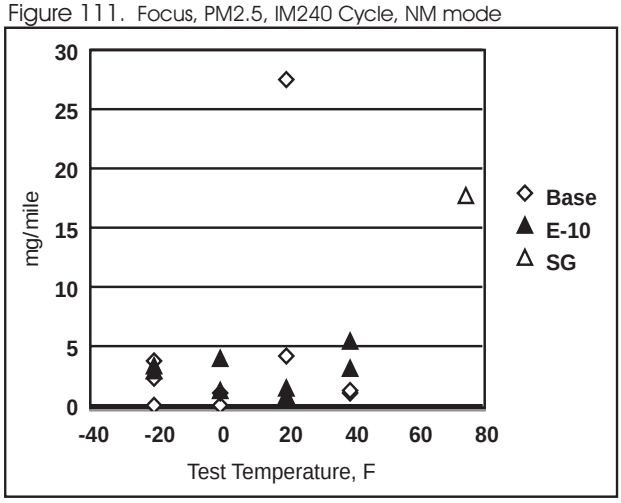

Figure 112. Focus, PM2.5, IM240 Cycle, O2 mode

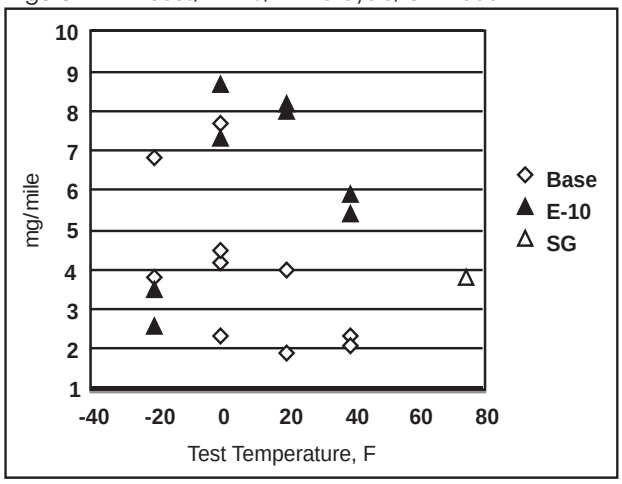

Figure 113. Focus, PM10, IM240 Cycle, NM mode

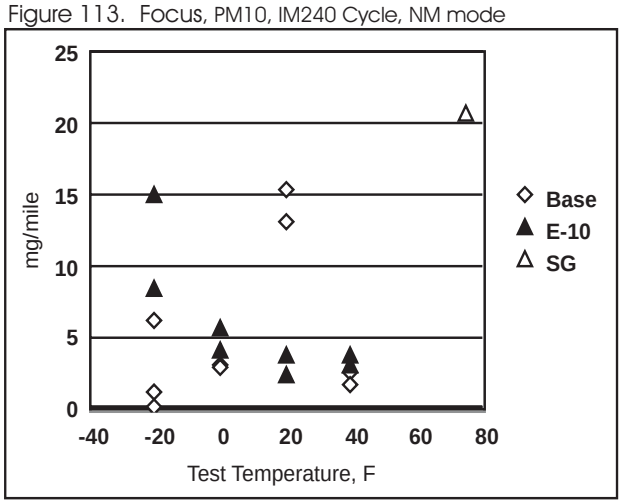

Figure 114. Focus, PM10, IM240 Cycle, O2 mode

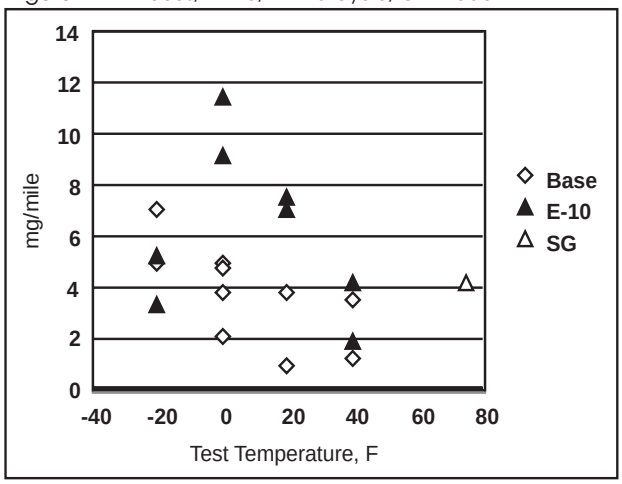

Figure 115. Regal, THC, UDDS Cycle, NM mode

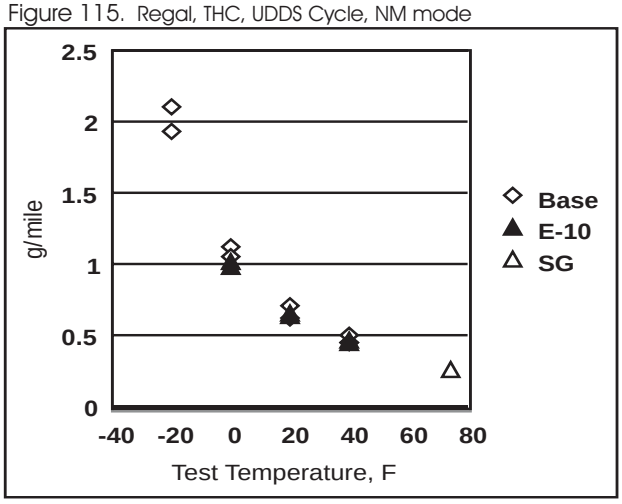

Figure 116. Regal, THC, UDDS Cycle, O2 mode

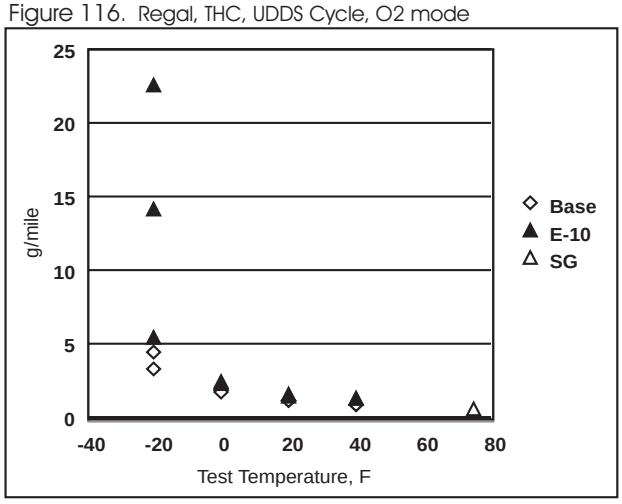

Figure 117. Regal, CO, UDDS Cycle, NM mode

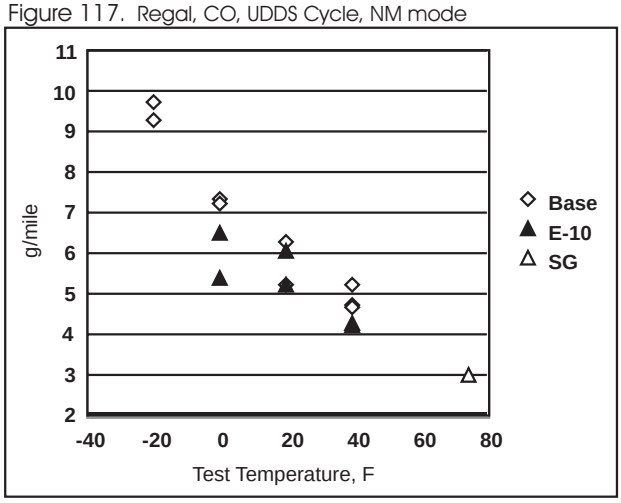

Figure 118. Regal, CO, UDDS Cycle, O2 mode

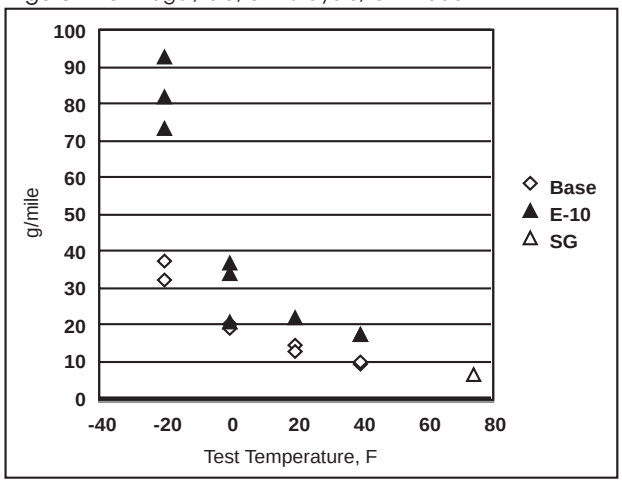

Figure 119. Regal, NOx, UDDS Cycle, NM mode

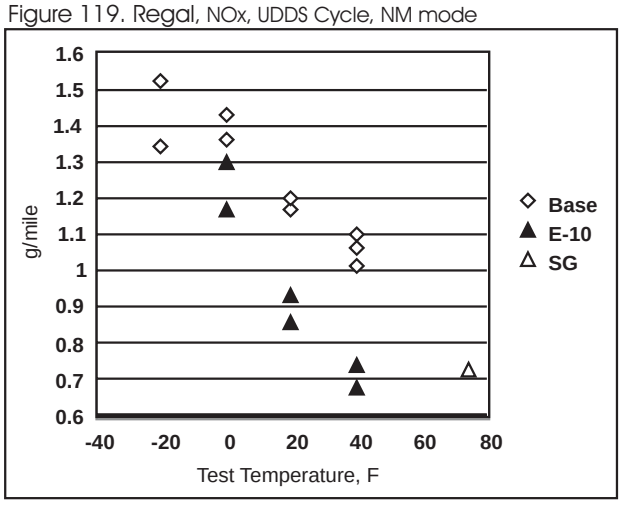

Figure 120. Regal, NOx, UDDS Cycle, O2 mode

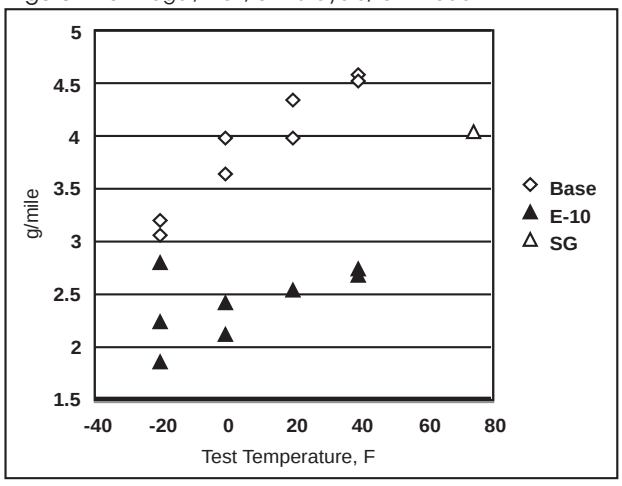

Figure 121. Regal, Formaldehyde, UDDS Cycle, NM mode

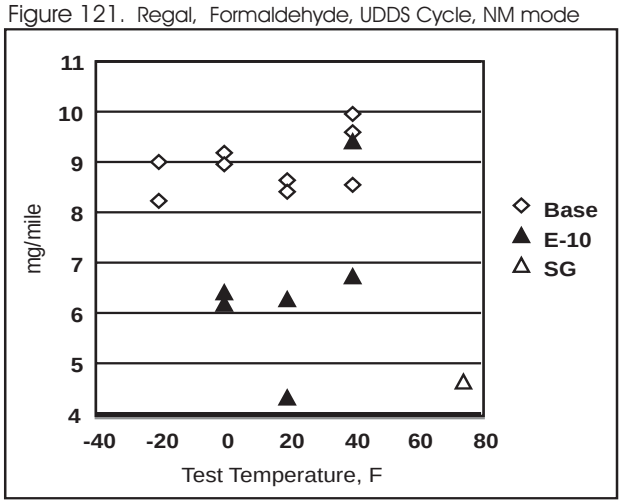

Figure 122. Regal, Formaldehyde, UDDS Cycle, O2 mode

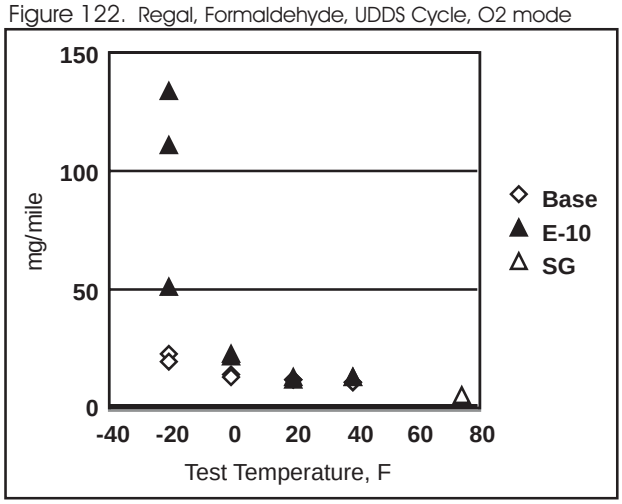

Figure 123. Regal, Acetaldehyde, UDDS Cycle, NM mode

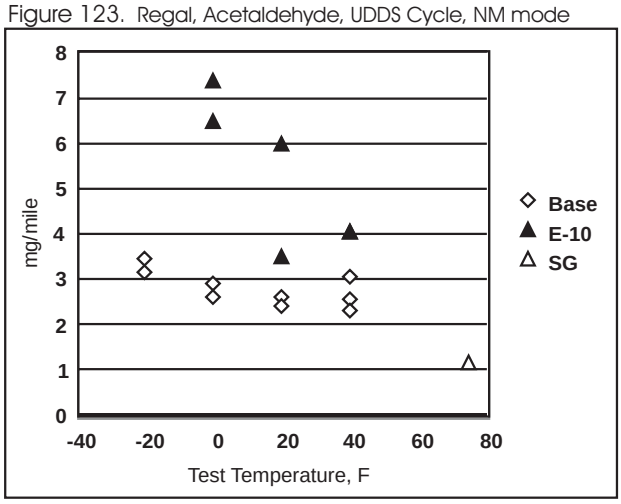

Figure 124. Regal, Acetaldehyde, UDDS Cycle, O2 mode

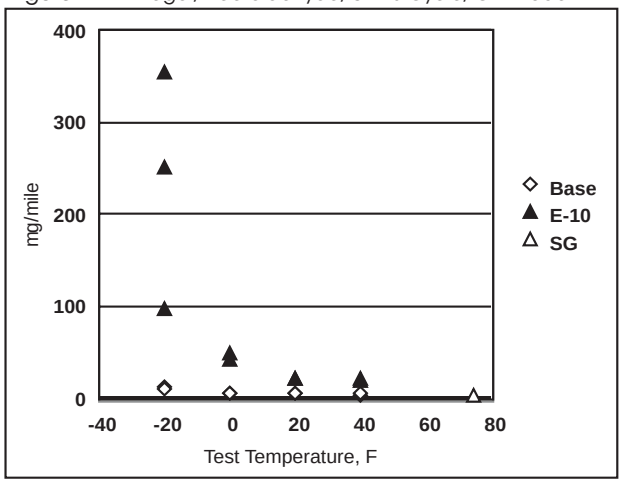

Figure 125. Regal, Benzene, UDDS Cycle, NM mode

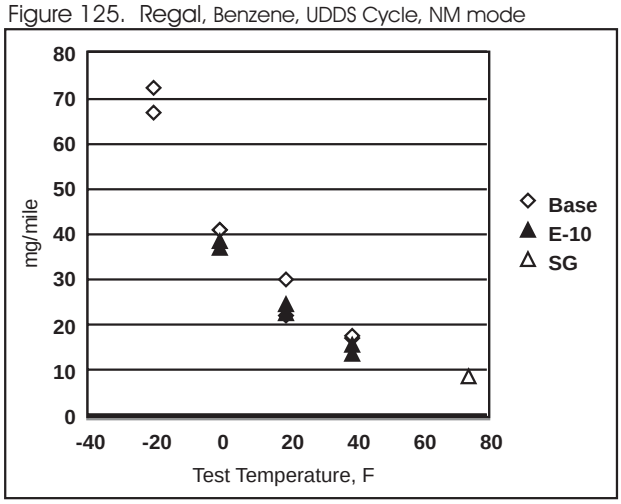

Figure 126. Regal, Benzene, UDDS Cycle, O2 mode

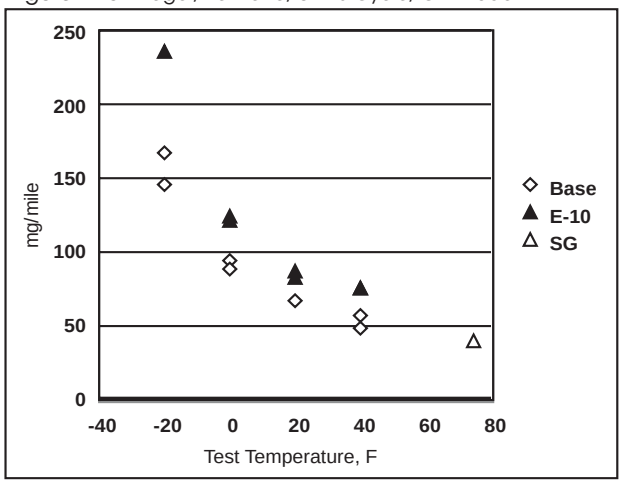

Figure 127. Regal, 1,3-Butadiene, UDDS Cycle, NM mode

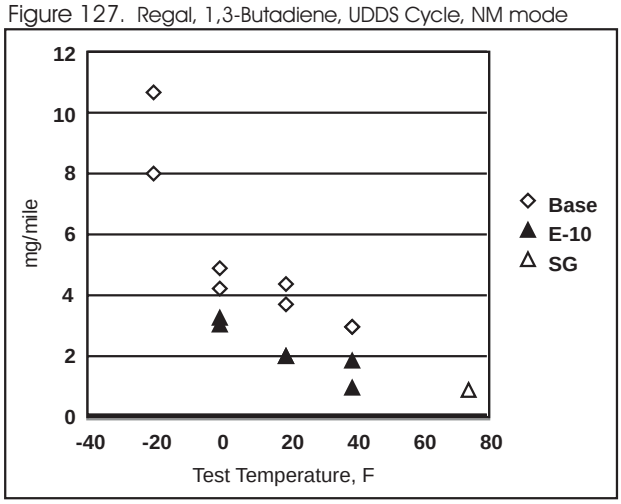

Figure 128. Regal, 1,3-Butadiene, UDDS Cycle, O2 mode

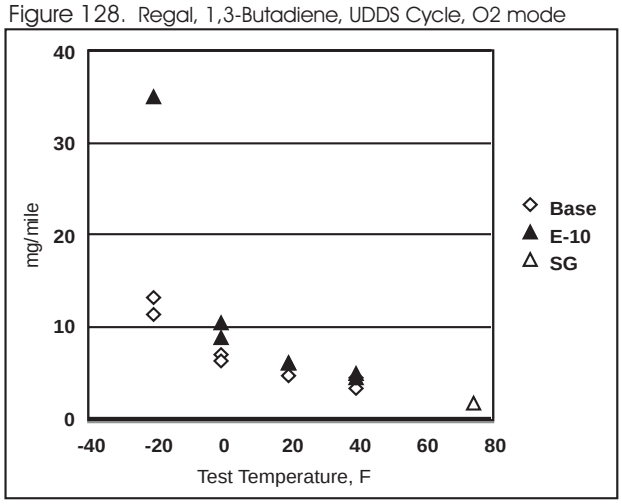

Figure 129. Regal, Fuel Economy, UDDS Cycle, NM mode

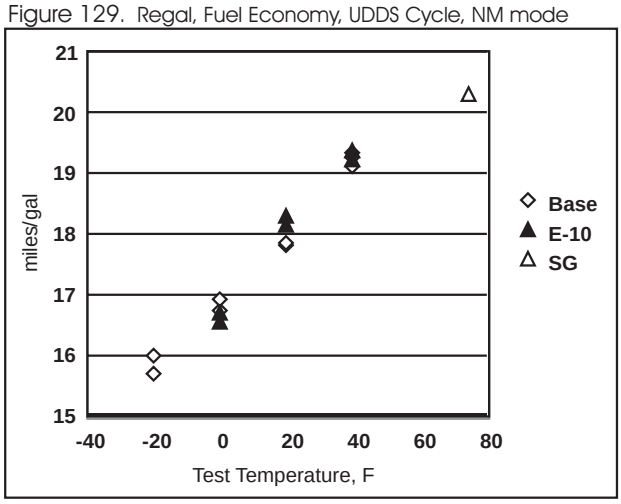

Figure 130. Regal, Fuel Economy, UDDS Cycle, O2 mode

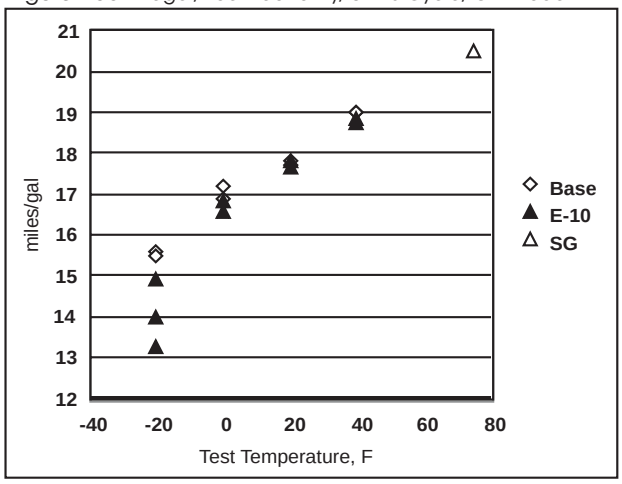

Figure 131. Regal, MTBE, UDDS Cycle, NM mode

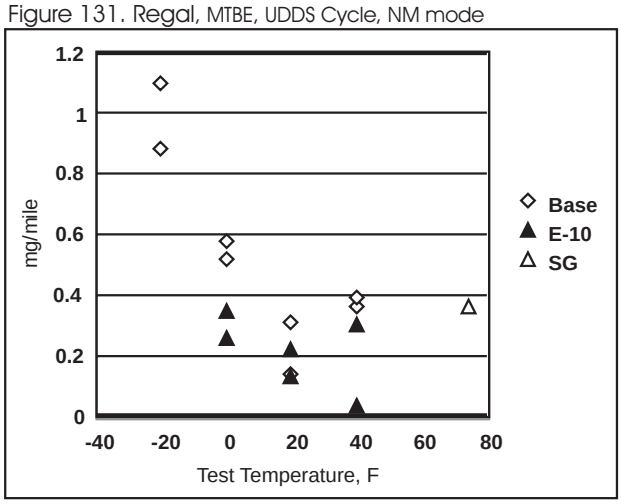

Figure 132. Regal, MTBE, UDDS Cycle, O2 mode

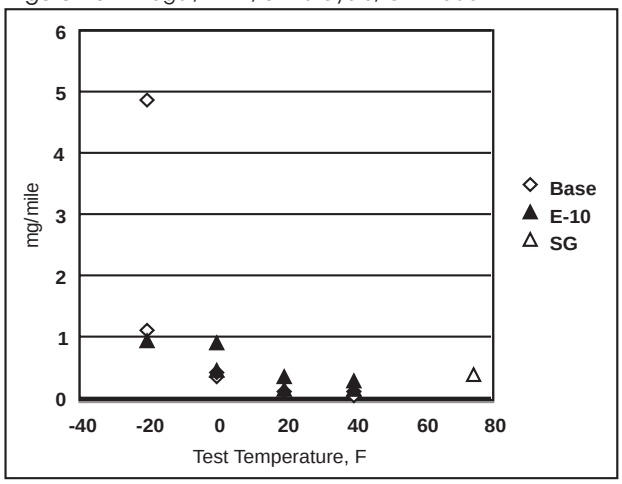

Figure 133. Regal, EtOH, UDDS Cycle, NM mode

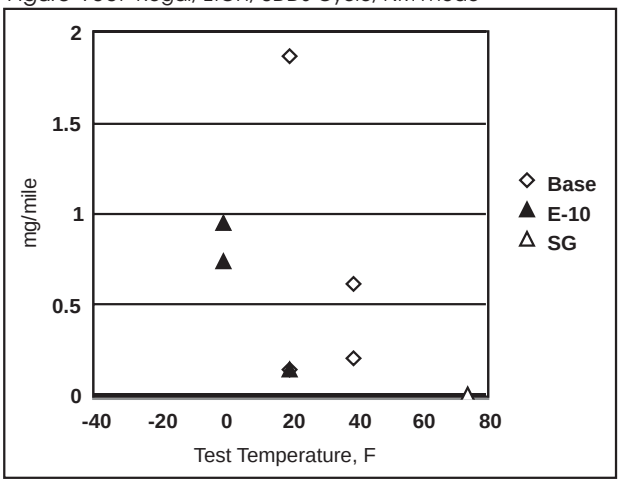

Figure 134. Regal, EtOH, UDDS Cycle, O2 mode

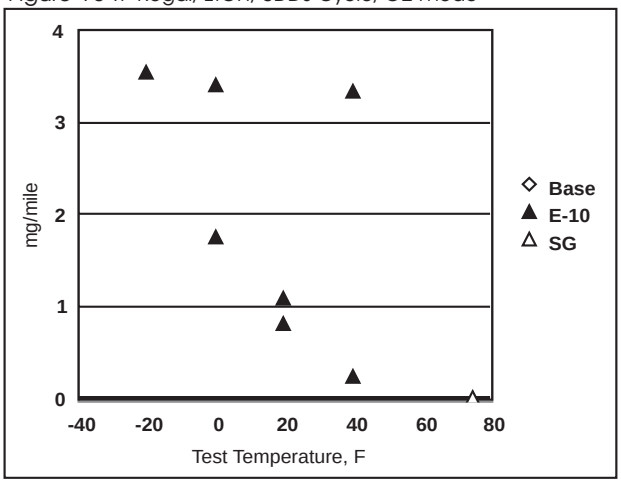

Figure 135. Regal, MeOH, UDDS Cycle, NM mode

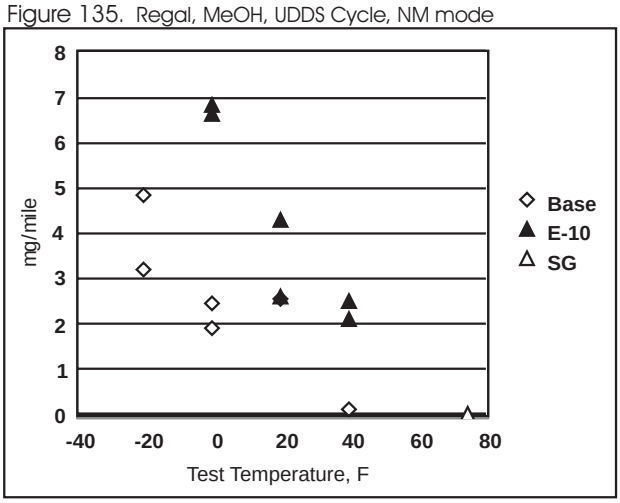

Figure 136. Regal, MeOH, UDDS Cycle, O2 mode

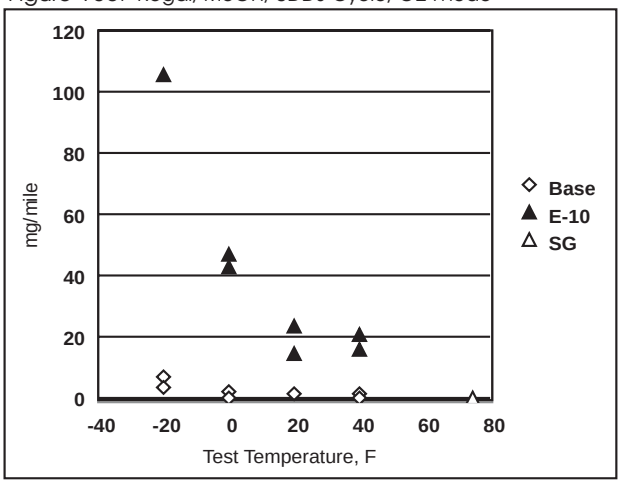

Figure 137. Regal, PM2.5 UDDS Cycle, NM mode

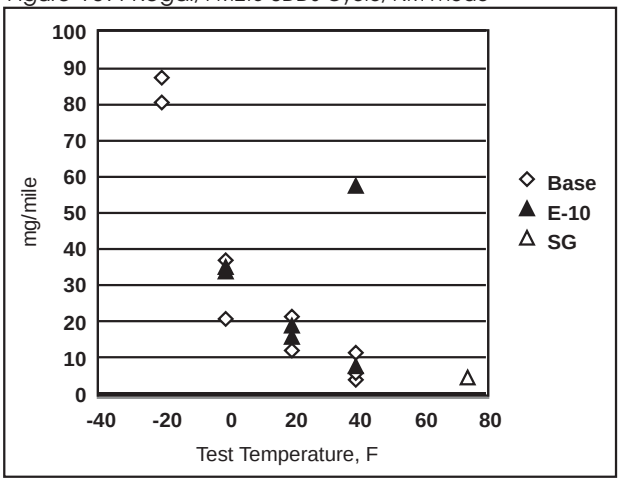

Figure 138. Regal, PM2.5, UDDS Cycle, O2 mode

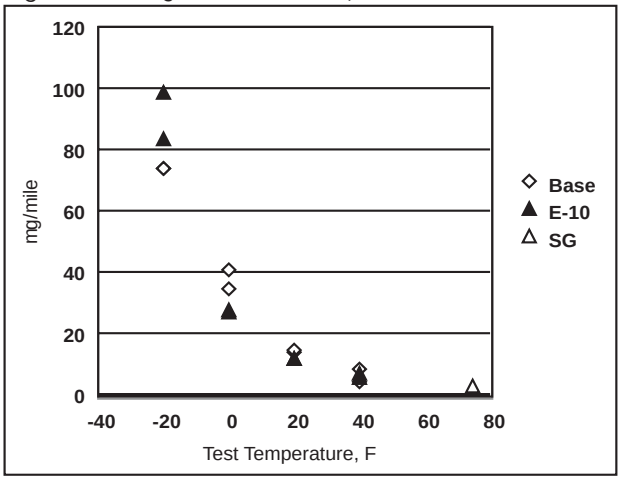

Figure 139. Regal, PM10, UDDS Cycle, NM mode

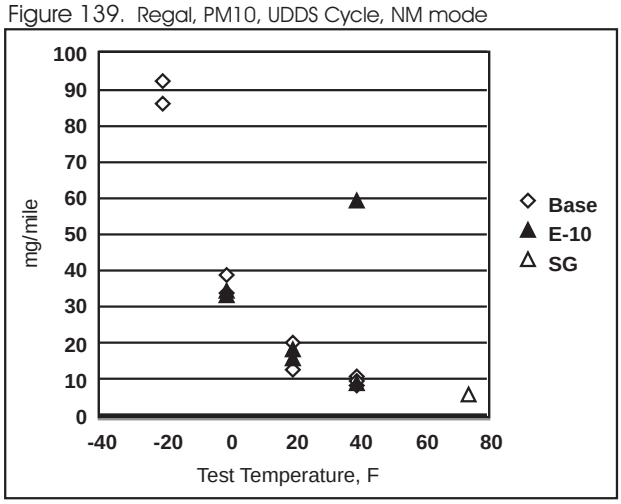

Figure 140. Regal, PM10, UDDS Cycle, O2 mode

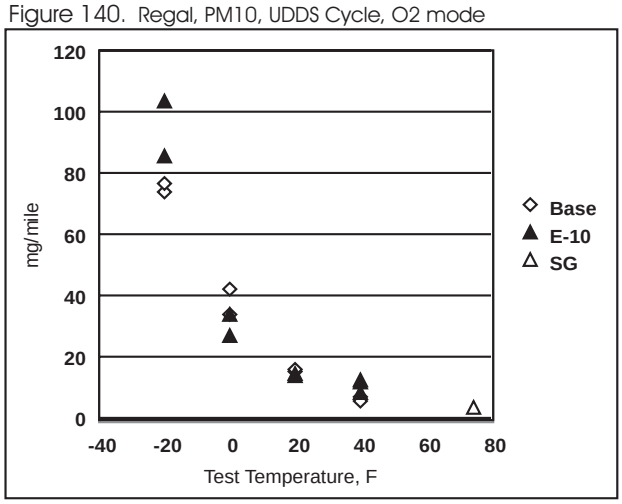

Figure 141. Regal, THC, IM240 Cycle, NM mode

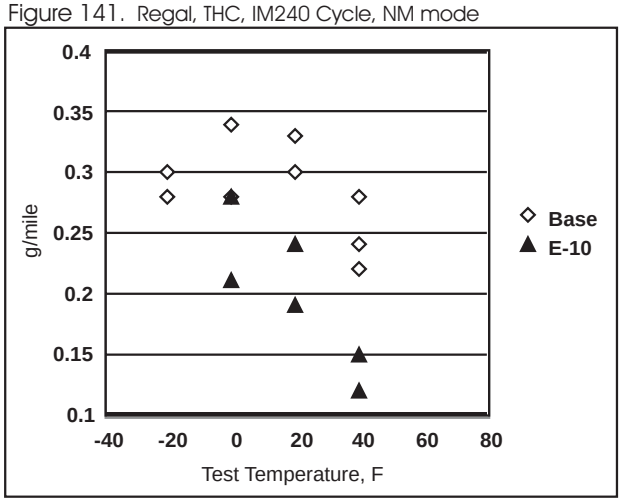

Figure 142. Regal, THC, IM240 Cycle, O2 mode

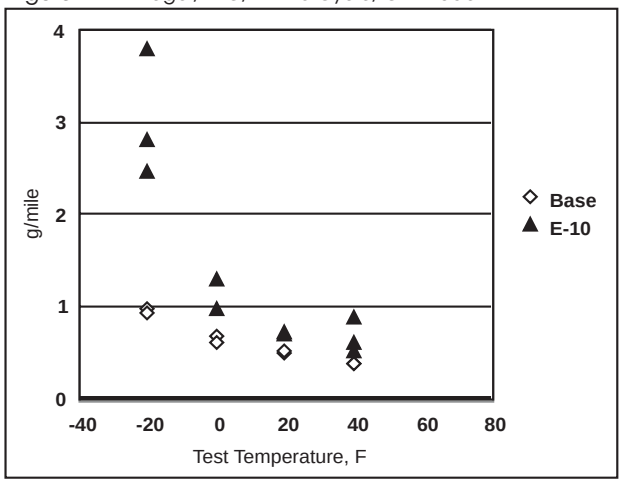

Figure 143. Regal, CO, IM240 Cycle, NM mode

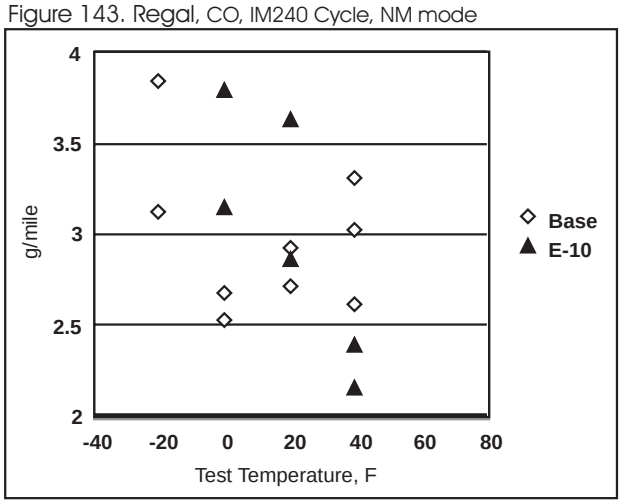

Figure 144. Regal, CO, IM240 Cycle, O2 mode

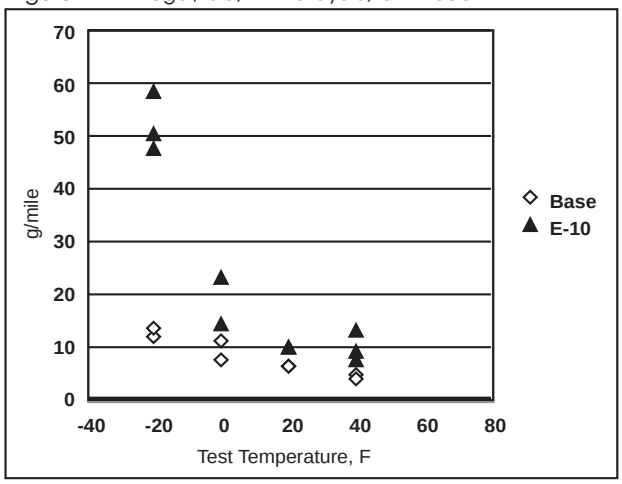

Figure 145. Regal, NOx, IM240 Cycle, NM mode

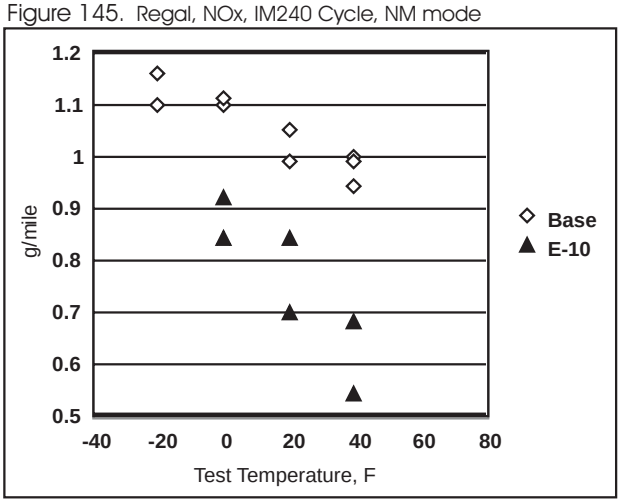

Figure 146. Regal, NOx, IM240 Cycle, O2 mode

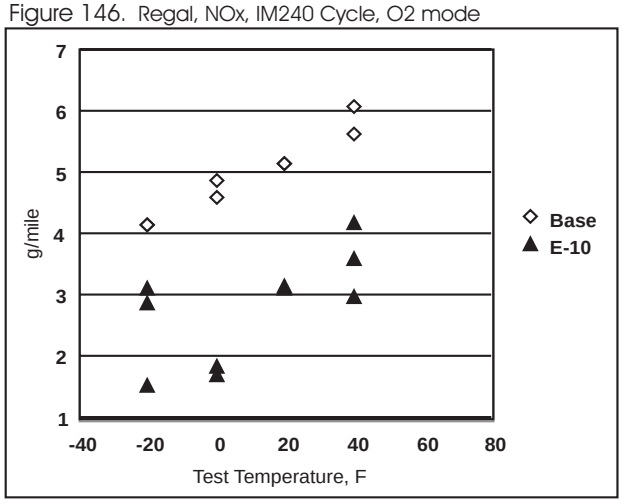

Figure 147. Regal, Fuel Economy, IM240 Cycle, NM mode

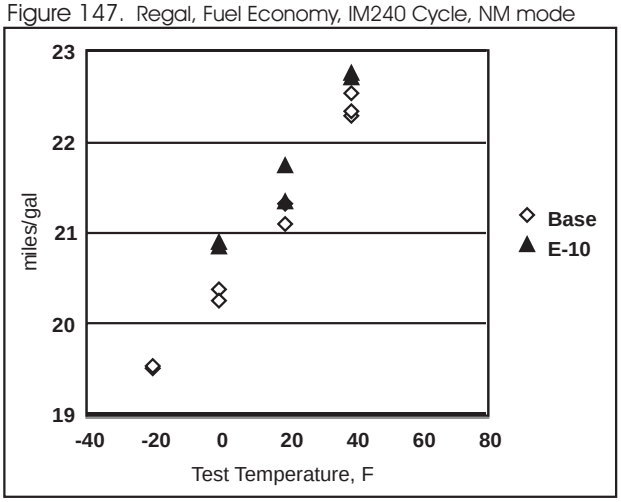

Figure 148. Regal, Fuel Economy, IM240 Cycle, O2 mode

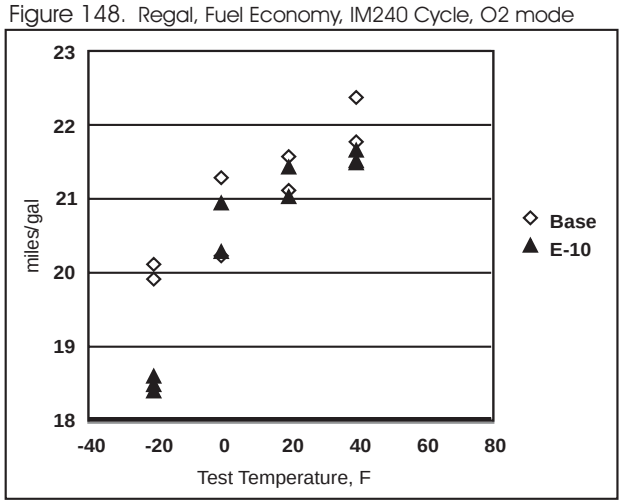

Figure 149. Regal, PM2.5, IM240 Cycle, NM mode

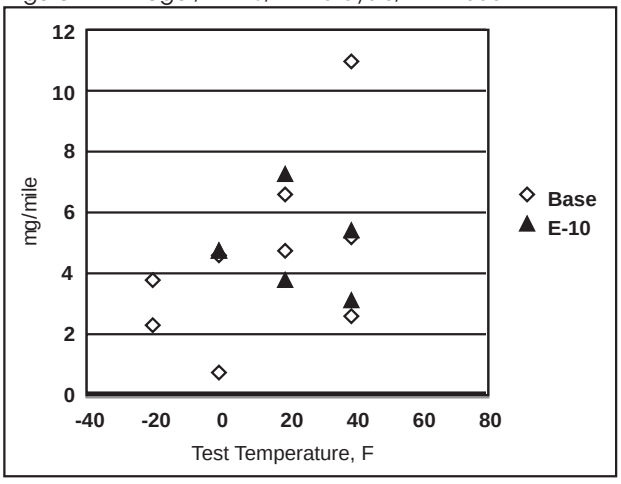

Figure 150. Regal, PM2.5, IM240 Cycle, O2 mode

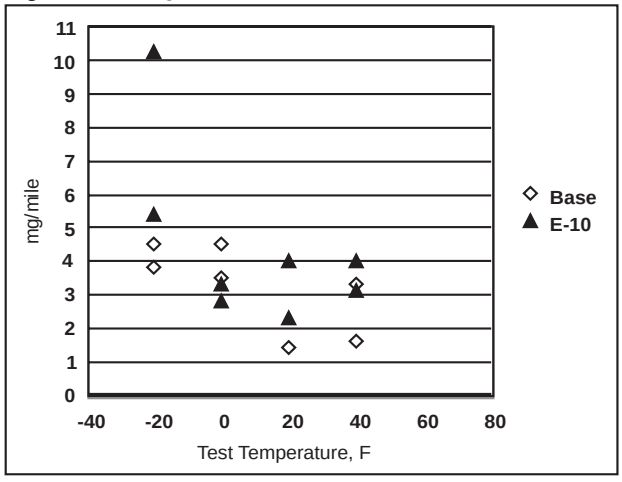

Figure 151 Regal, PM10, IM240 Cycle, NM mode

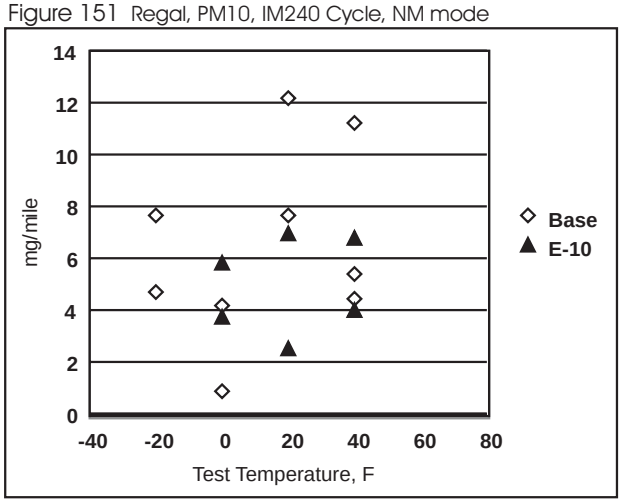

Figure 152. Regal, PM10, IM240 Cycle, O2 mode

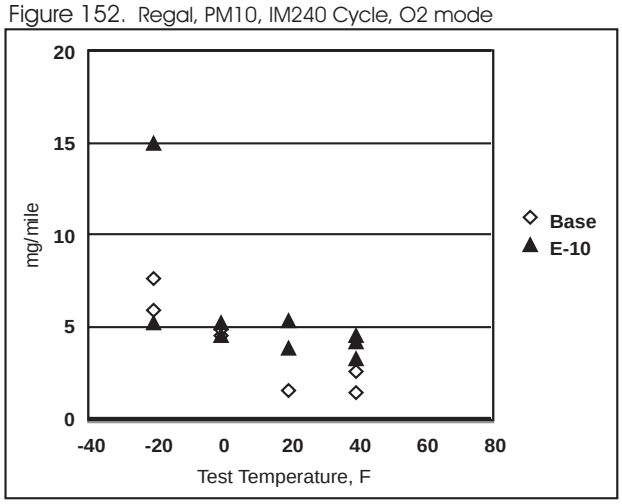

Figure 153. Intrepid, THC, UDDS Cycle, NM mode

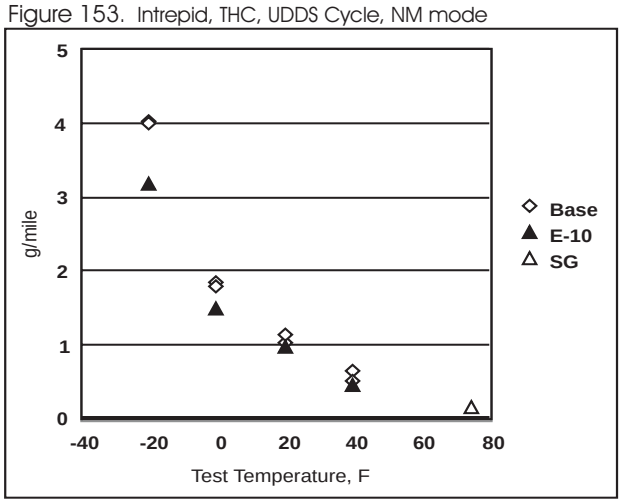

Figure 154. Intrepid, THC, UDDS Cycle, O2 mode

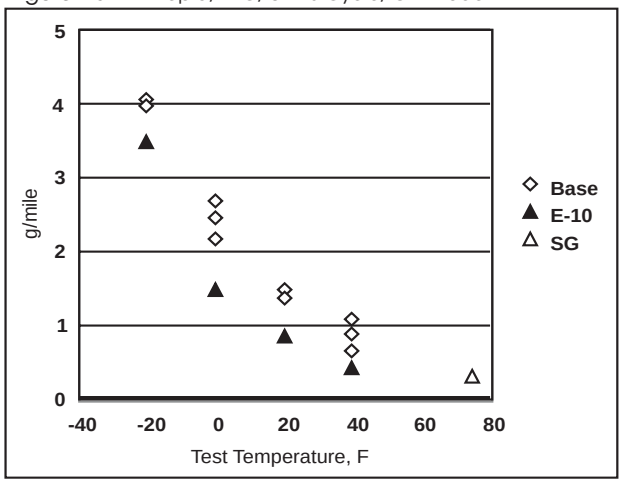

Figure 155. Intrepid, CO, UDDS Cycle, NM mode

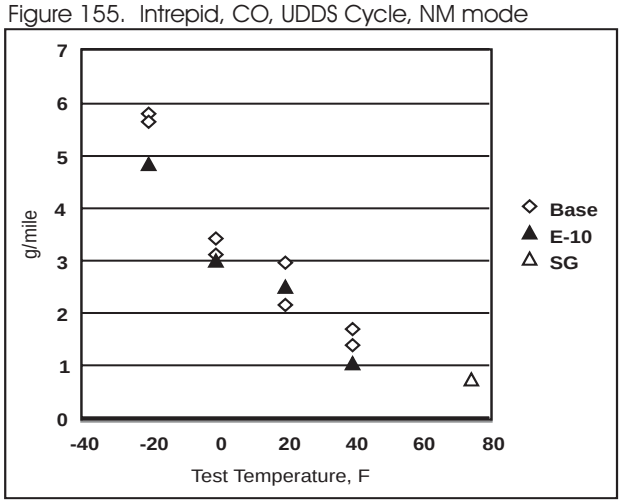

Figure 156. Intrepid, CO, UDDS Cycle, O2 mode

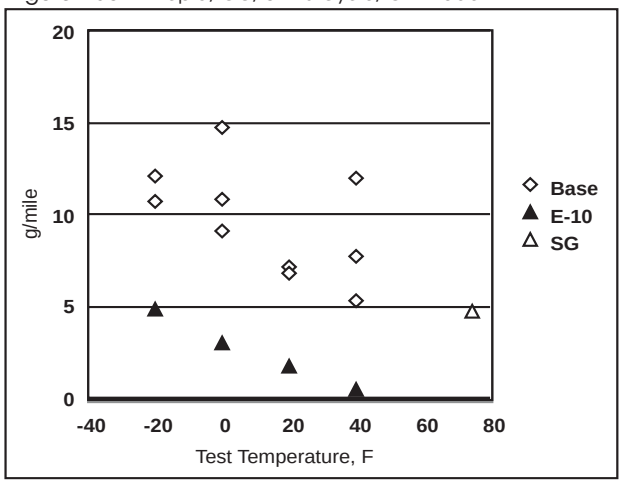

Figure 157. Intrepid, NOx, UDDS Cycle, NM mode

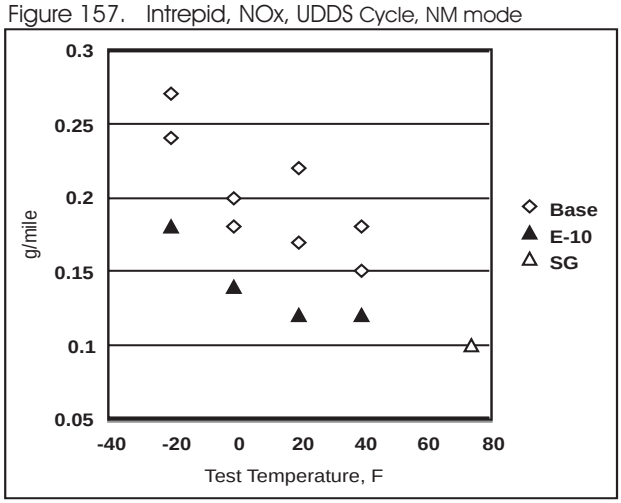

Figure 158. Intrepid, NOx, UDDS Cycle, O2 mode

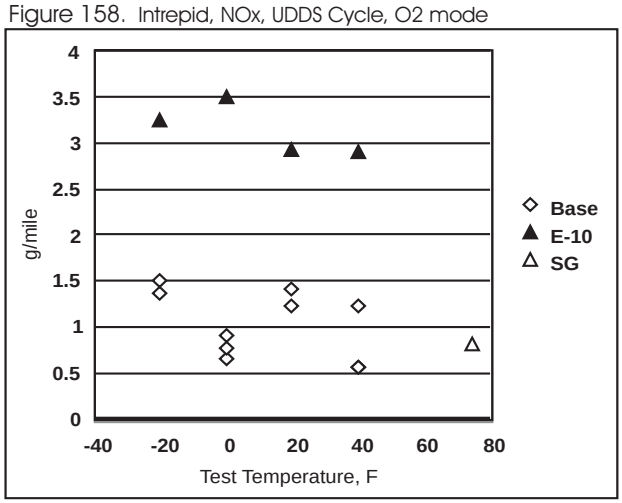

Figure 159. Intrepid, Formaldehyde, UDDS Cycle, NM mode

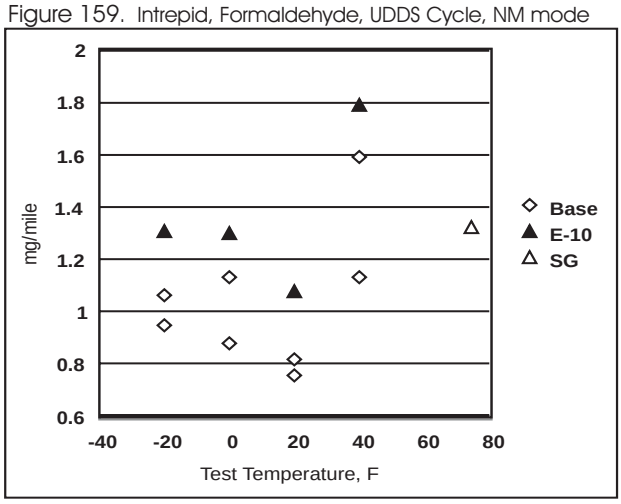

Figure 160. Intrepid, Formaldehyde, UDDS Cycle, O2 mode

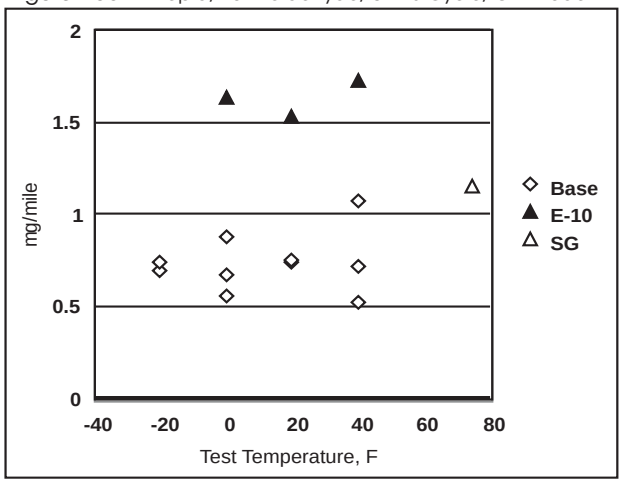

Figure 161. Intrepid, Acetaldehyde, UDDS Cycle, NM mode

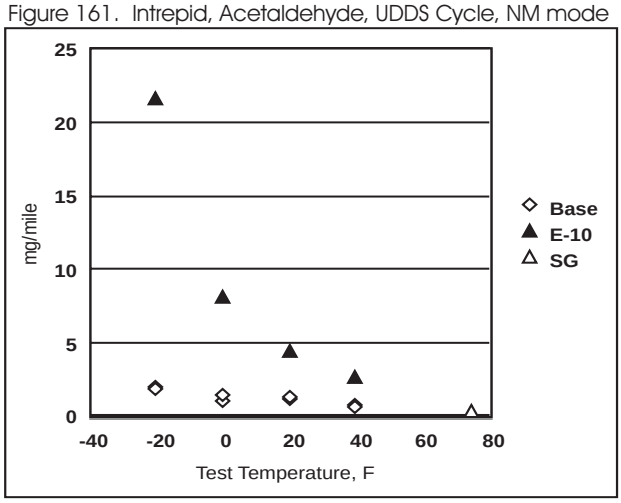

Figure 162. Intrepid, Acetaldehyde, UDDS Cycle, O2 mode

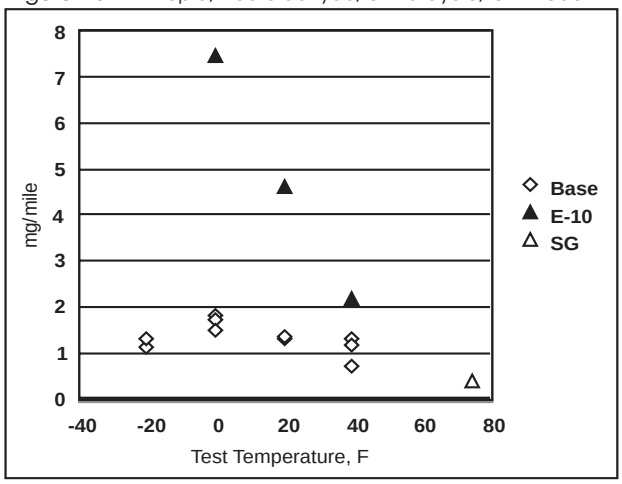

Figure 163. Intrepid, Benzene, UDDS Cycle, NM mode

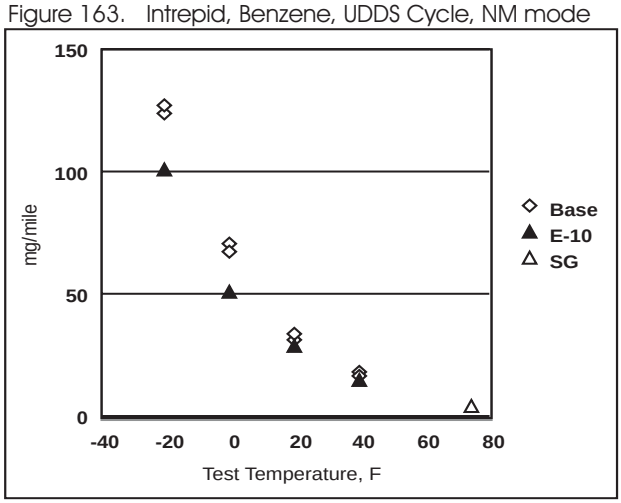

Figure 164. Intrepid, Benzene, UDDS Cycle, O2 mode

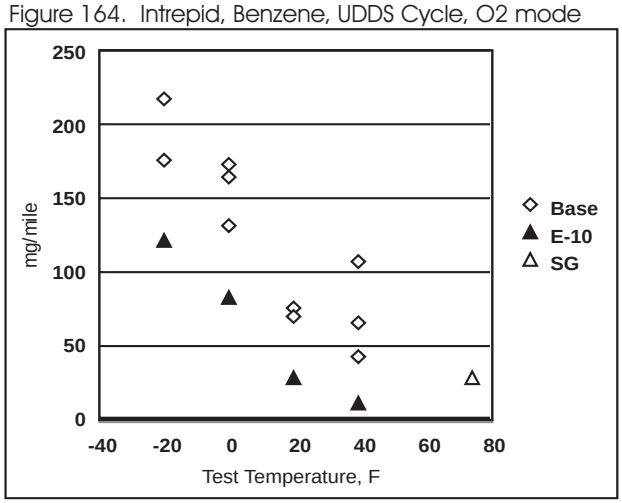

Figure 165. Intrepid, 1,3-Butadiene, UDDS Cycle, NM mode

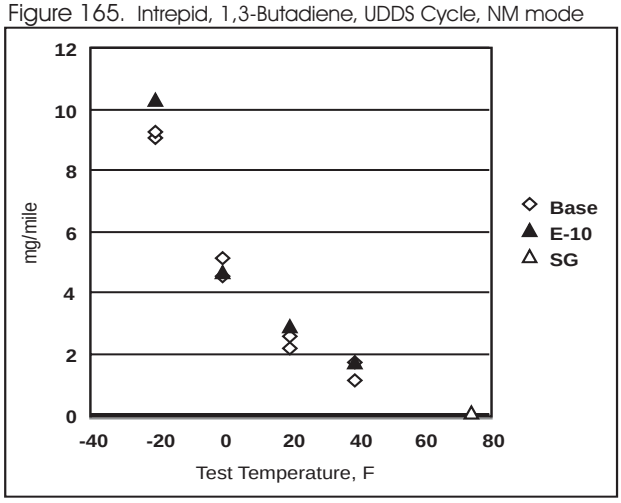

Figure 166. Intrepid, 1,3-Butadiene, UDDS Cycle, O2 mode

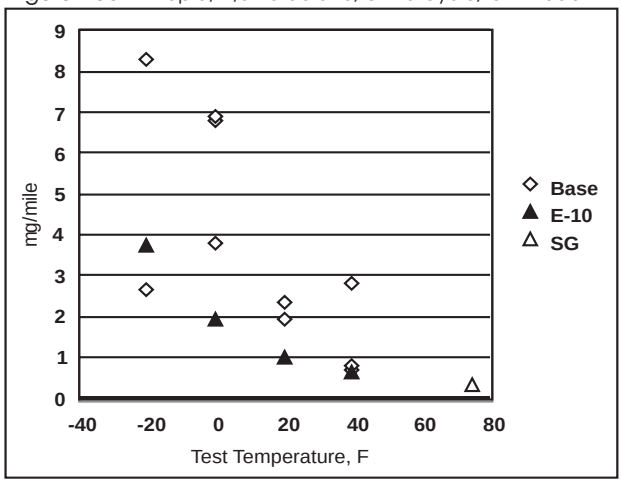

Figure 167. Intrepid, Fuel Economy, UDDS Cycle, NM mode

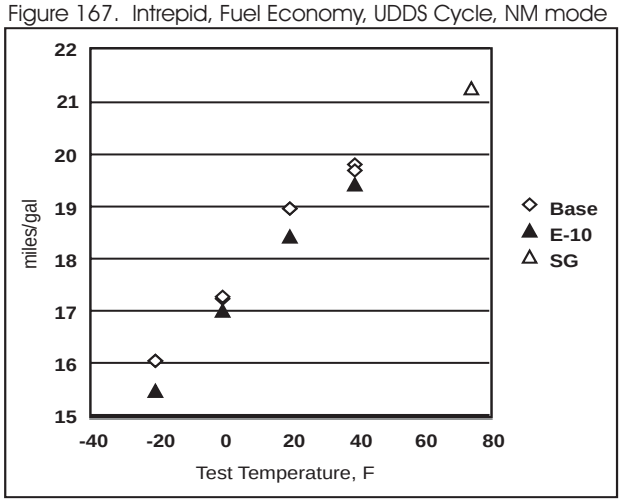

Figure 168. Intrepid, Fuel Economy, UDDS Cycle, O2 mode

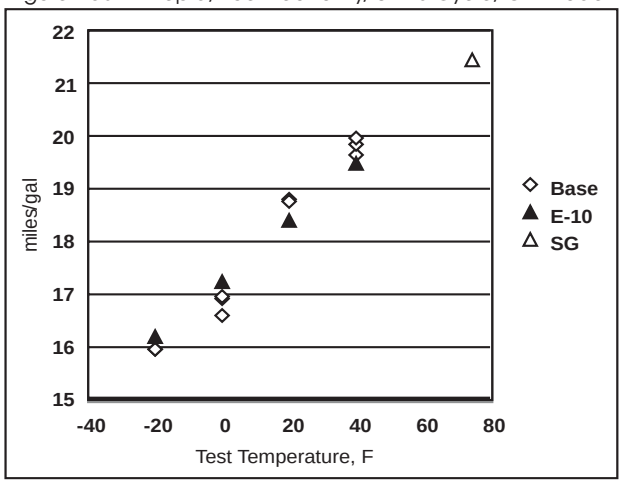

Figure 169. Intrepid, MTBE, UDDS Cycle, NM mode

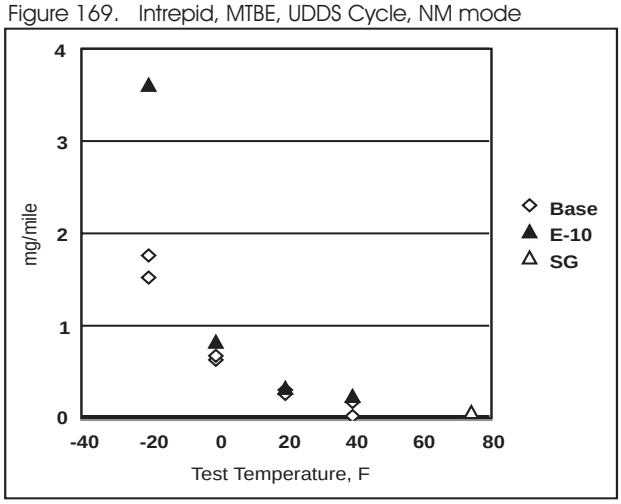

Figure 170. Intrepid, MTBE, UDDS Cycle, O2 mode

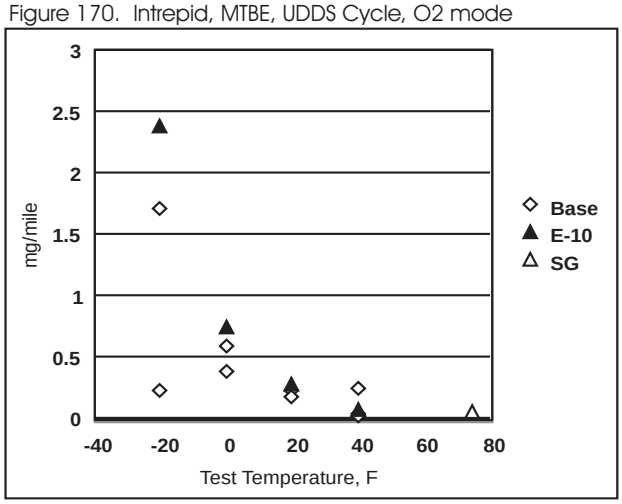

Figure 171. Intrepid, EtOH, UDDS Cycle, NM mode

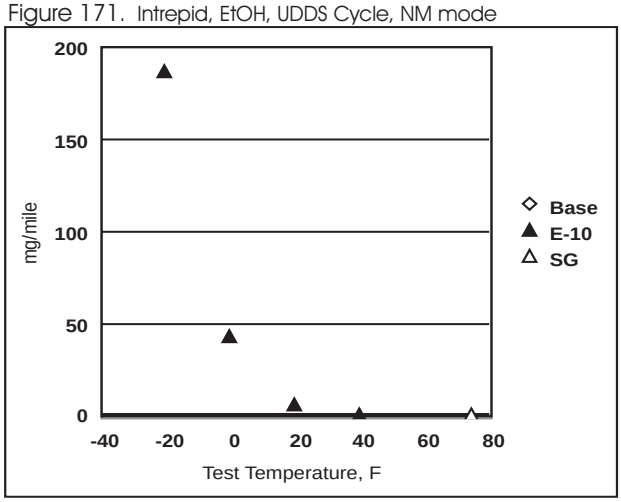

Figure 172. Intrepid, EtOH, UDDS Cycle, O2 mode

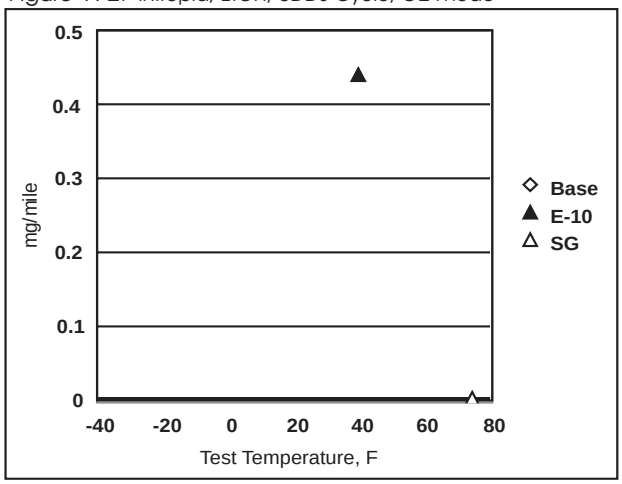

Figure 173. Intrepid, MeOH, UDDS Cycle, NM mode

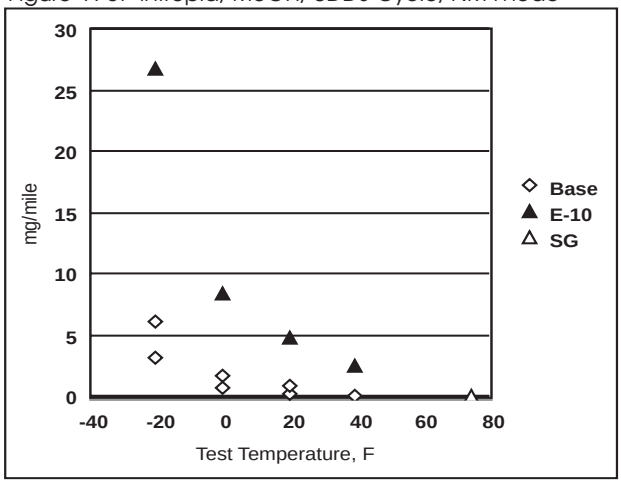

Figure 174. Intrepid, MeOH, UDDS Cycle, O2 mode

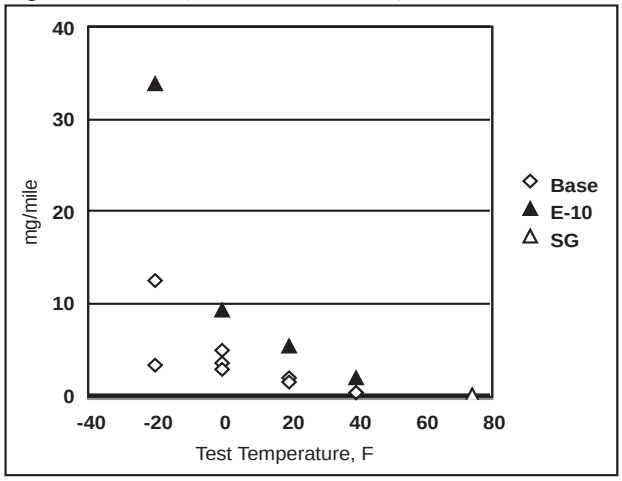

Figure 175. Intrepid, PM2.5, UDDS Cycle, NM mode

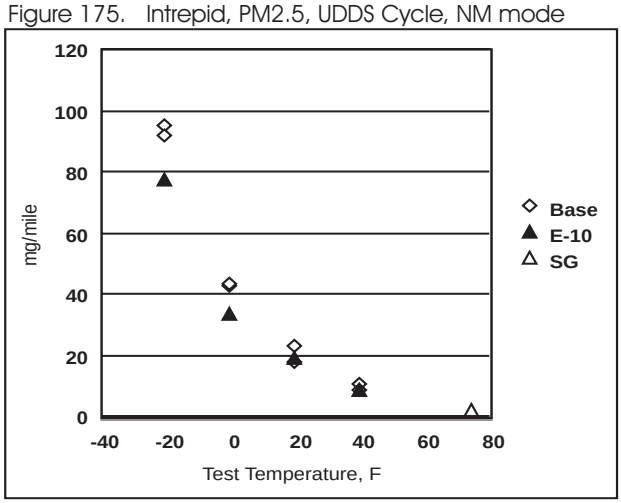

Figure 176. Intrepid, PM2.5, UDDS Cycle, O2 mode

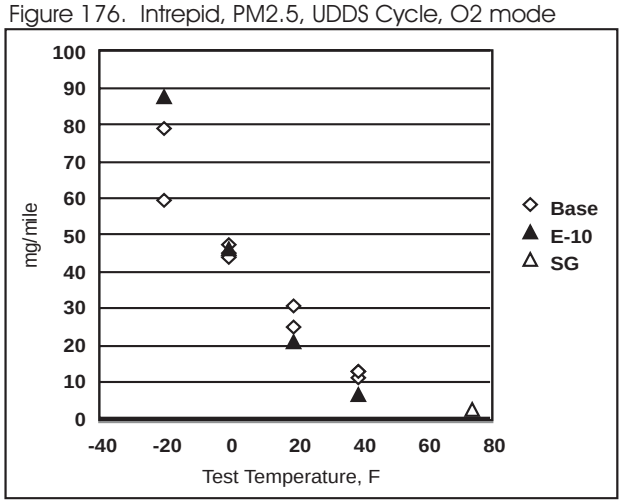

Figure 177. Intrepid, PM10, UDDS Cycle, NM mode

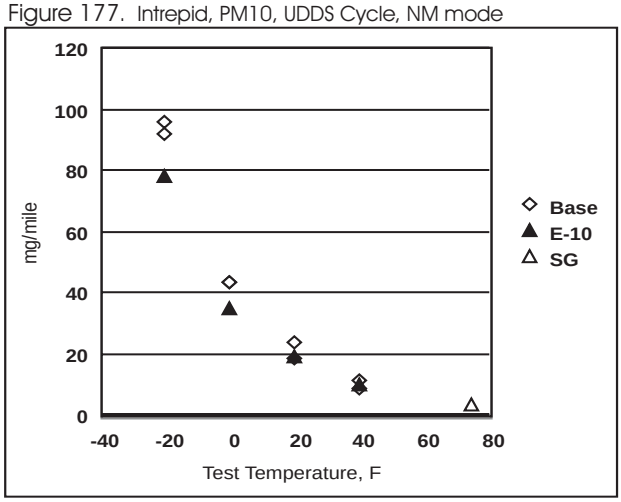

Figure 178. Intrepid, PM10, UDDS Cycle, O2 mode

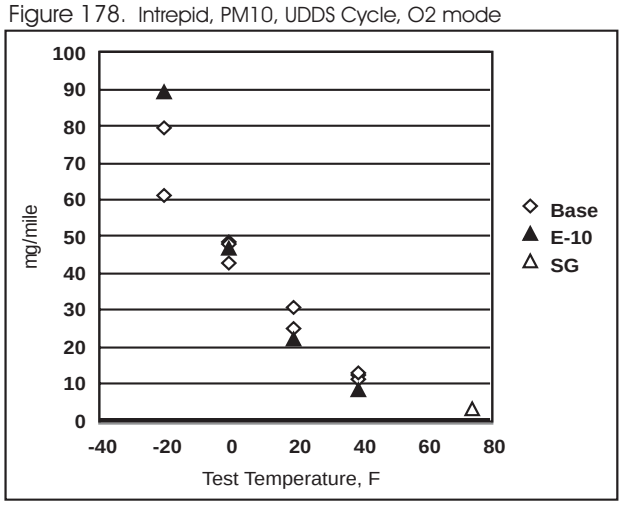

Figure 179. Intrepid, THC, IM240 Cycle, NM mode

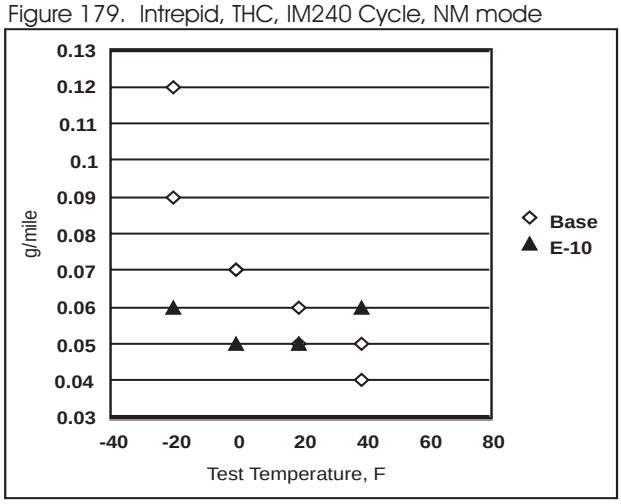

Figure 180. Intrepid, THC, IM240 Cycle, O2 mode

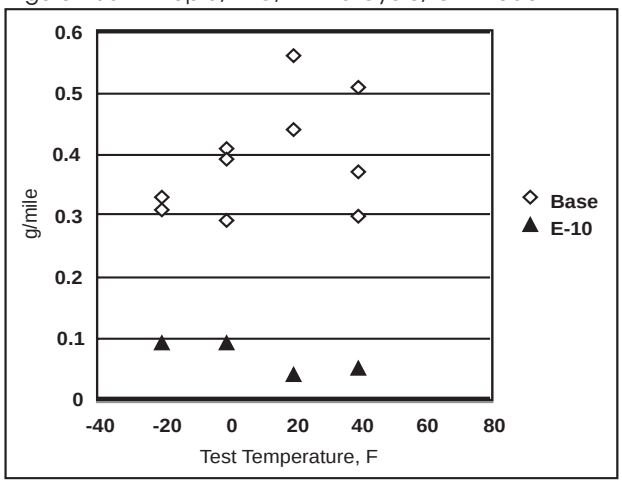

Figure 181. Intrepid, CO, IM240 Cycle, NM mode

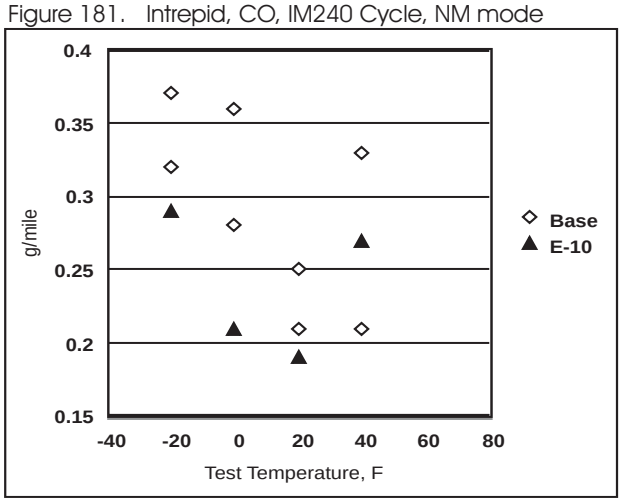

Figure 182. Intrepid, CO, IM240 Cycle, O2 mode

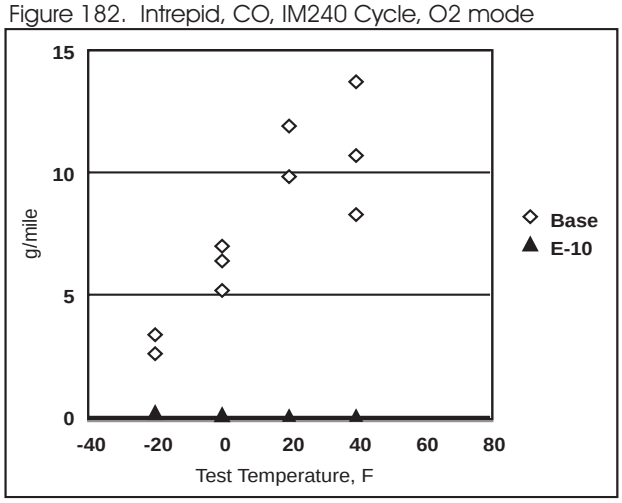

Figure 183. Intrepid, NOx, IM240 Cycle, NM mode

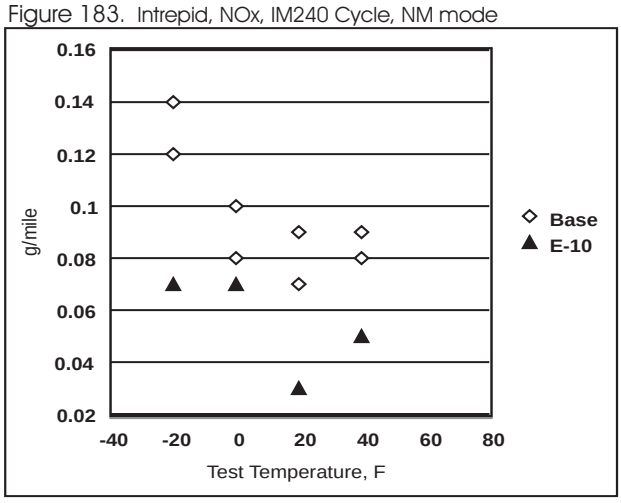

Figure 184. Intrepid, NOx, IM240 Cycle, O2 mode

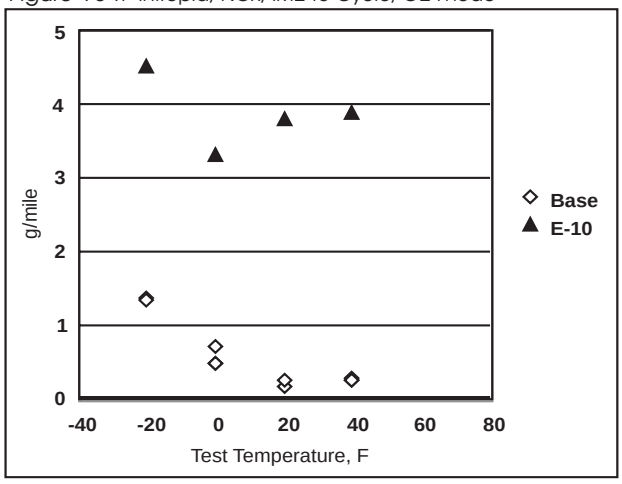

Figure 185. Intrepid, Fuel Economy, IM240 Cycle, NM mode

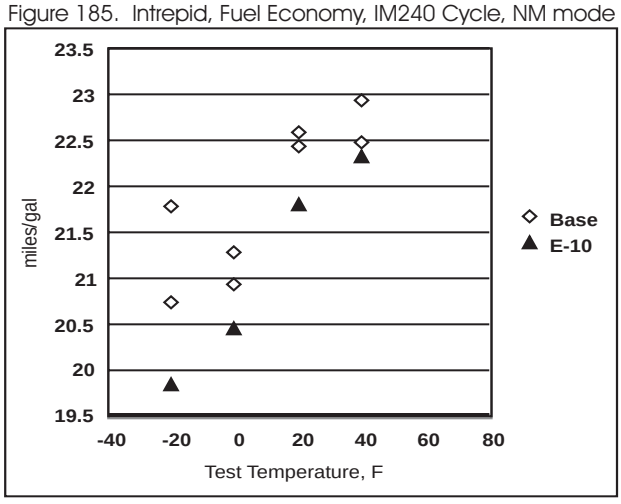

Figure 186. Intrepid, Fuel Economy, IM240 Cycle, O2 mode

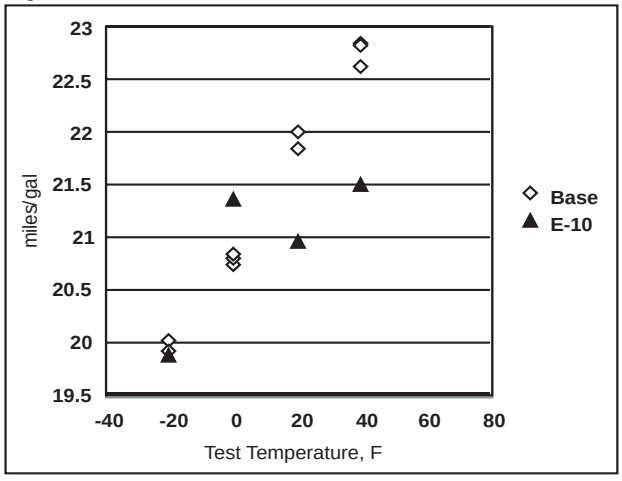

Figure 187. Intrepid, PM2.5, IM240 Cycle, NM mode

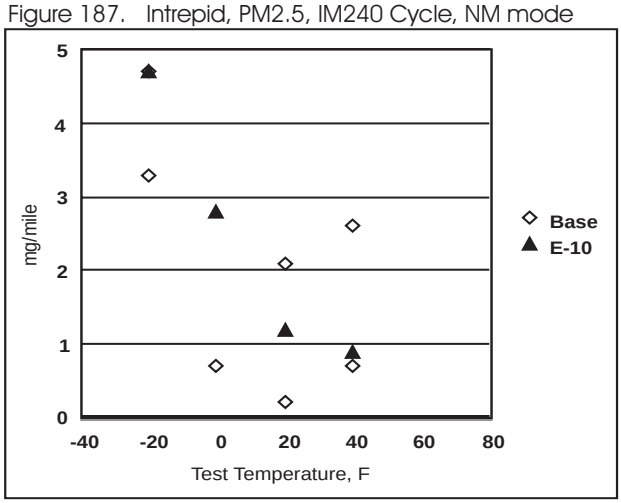

Figure 188. Intrepid, PM2.5, IM240 Cycle, O2 mode

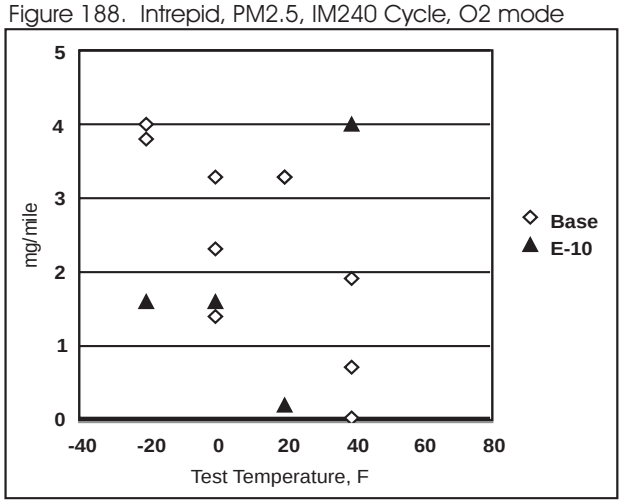

Figure 189. Intrepid, Pm10, IM240 Cycle, NM mode

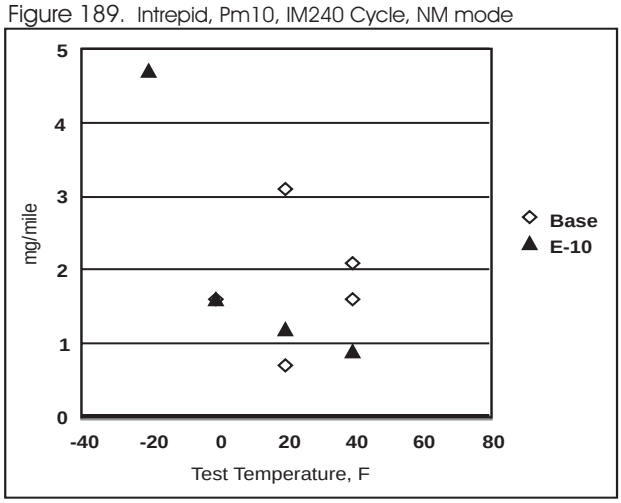

Figure 190. Intrepid, PM10, IM240 Cycle, O2 mode

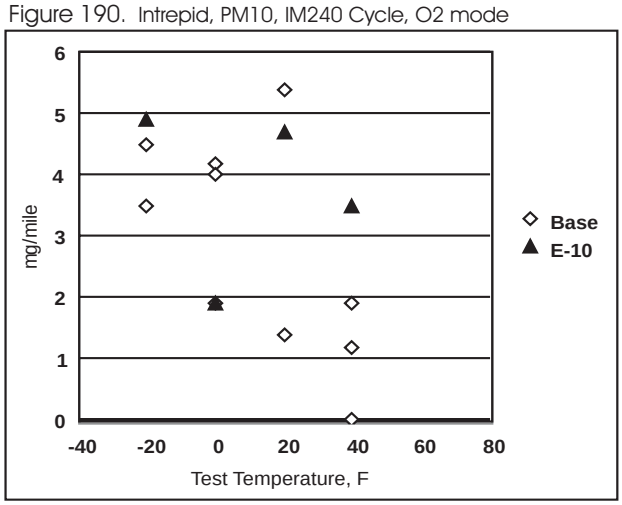

Figure 191. PM2.5 vs Pm10, All vehicles at all test conditions

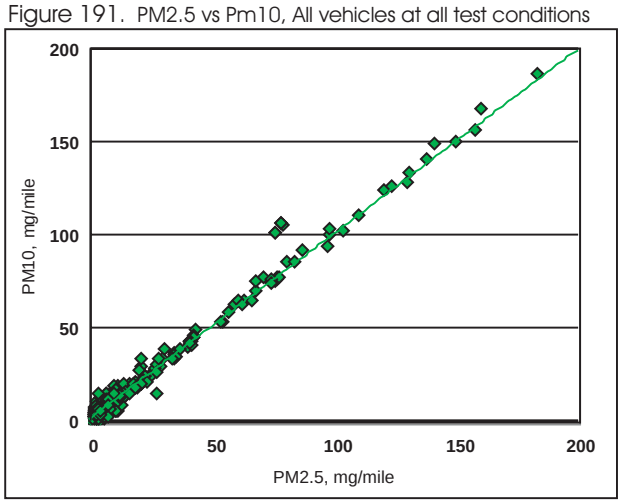

Figure 192. THC vs PM2.5, All vehicles at all test conditions