

# **CRC Report No. 649**

## **EVALUATION OF LOW TEMPERATURE OPERABILITY PERFORMANCE OF LIGHT-DUTY DIESEL VEHICLES FOR NORTH AMERICA**

**VEHICLE TEST REPORT  
CRC PROJECT NO. DP-2-04-1**

## **EVALUATION OF LOW TEMPERATURE OPERABILITY FOR LIGHT-DUTY DIESEL VEHICLES FOR NORTH AMERICA**

**DATA ANALYSIS REPORT  
CRC PROJECT NO. DP-2-04-2**

**November 2007**



**COORDINATING RESEARCH COUNCIL, INC.**  
3650 MANSELL ROAD·SUITE 140·ALPHARETTA, GA 30022

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## **Evaluation of Low Temperature Operability Performance of Light-Duty Diesel Vehicles for North America**

### **Vehicle Test Report**

**CRC Project Number DP-2-04-1**

Submitted by:

Automotive Test Section  
Imperial Oil Research  
Sarnia, Ontario

## **Evaluation of Low Temperature Operability for Light-Duty Diesel Vehicles for North America**

### **Data Analysis Report**

**CRC Project Number DP-2-04-2**

Prepared by:

Low Temperature Operability Panel Members of the  
CRC Diesel Performance Group

Prepared for:

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## PREFACE

This document combines final reports by Imperial Oil Research and Panel Members of the CRC Diesel Performance Group, in a single comprehensive report to document the experimental procedures, results, and analyses conducted in association with CRC Project No. DP-2-04.

The following Members of the Operability Panel of the CRC Diesel Performance Group participated in the development of this report: Andy, Buczynsky, John Chandler, Chung-Lai Wong, Dave Daniels, Harold Martin, Ken Mitchell, Manuch Nikanjam, Rob Davidson. Preparation of the Final Report was led by John Chandler.

**CRC Report No. DP-2-04-1**

**EVALUATION OF LOW TEMPERATURE  
OPERABILITY PERFORMANCE OF  
LIGHT-DUTY DIESEL VEHICLES  
FOR NORTH AMERICA**

**VEHICLE TEST REPORT**

**August 2006**



**COORDINATING RESEARCH COUNCIL, INC.  
3650 MANSELL ROAD·SUITE 140·ALPHARETTA, GA 30022**

# Evaluation of Low Temperature Operability Performance of Light-Duty Diesel Vehicles for North America

## Vehicle Test Report

CRC Project Number DP-2-04

Submitted by:

Automotive Test Section  
Imperial Oil Research  
Sarnia, Ontario

Jordan Coutu  
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Section Head

## **EXECUTIVE SUMMARY**

A test program was conceived and designed by the Low Temperature Operability Panel of the CRC Diesel Performance Group to evaluate the correlation between bench test results and actual North American light-duty diesel vehicle performance. The vehicle testing portion of the program was conducted under contract by the Automotive Test Section (ATS) of Imperial Oil Research.

ATS assisted in the procurement of the five test vehicles, four of which were donated for the testing by the vehicle manufacturers, and one by a CRC member company. Sensors were installed on the vehicles for data collections and the fuel tanks modified to aid efficient flushing of the fuel systems between tests.

Four base test fuels and two cold flow additives were sent to ATS. Ten test fuels were blended according to instructions provided by CRC. Of the ten fuels, nine were used by the end of the program.

The execution of the program went largely according to plan with a few minor adjustments. For example: proper testing of two vehicles was delayed for a couple of days until engine block heaters were installed. Also, the 30-second idle portion of the test protocol was lengthened to 2 minutes 30 seconds after a turbocharger failure was concluded to be caused by insufficient time for lubricant pressurization at cold temperature.

Even with time taken to repair the above mentioned turbocharger failure and a transmission failure with another vehicle, a total of 121 tests were completed over the 27 test day period. Close contact was maintained with a member of the CRC technical committee to facilitate the daily decisions on fuel choices and test temperatures for the following test day. The test results indicated influence of different fuel system designs on performance. The actual analysis of the correlations between bench tests and vehicle tests will be conducted separately by the Low Temperature Operability Panel.

Test vehicles have been returned to the donors. Their assistance was very helpful to the success of this program.

## **PROJECT OBJECTIVE**

The objective of the CRC program is to evaluate existing low temperature operability prediction test methods and to determine their applicability to North American light duty diesel vehicles with a wide variety of fuel systems, operating with a representative sampling of on road ultra low sulfur diesel (ULSD) fuels under real-world temperature conditions.

## **TEST PROGRAM SCOPE**

The Imperial Oil Research portion of this test program was to organize and prepare test vehicles, prepare test fuels with top-treating of appropriate cold-flow additives, conduct testing per a specified procedure, compile test data, and return test vehicles to owners in original conditions. Detail analysis of test data with respect to laboratory bench test correlation is not part of the scope.

## **TEST FACILITY**

The test program was conducted in the All Weather Chassis Dynamometer (AWCD) facility of Imperial Oil Research in Sarnia. The test temperature range of the AWCD is from 43°C to -40°C. The AWCD has a test cell housing the dynamometers and a pre-soak room that can hold up to five vehicles. The test cell and the pre-soak room can be controlled at different temperatures at the same time and are capable of overnight soaking and testing five vehicles per day. Test vehicles can be a mixture of Front Wheel Drive (FWD), Rear Wheel Drive (RWD), or Four Wheel Drive (4WD) vehicles. The computerized data acquisition system can record up to 250 channels of data at 10 times per second. The dynamometers have a Road-load Simulation Module that provides realistic loading on the test vehicle.

The photographs below show the test cell and the pre-soak room of the facility with the test vehicles on a typical test day.



**Test Cell**



**Pre-soak Room**

## **TEST VEHICLES**

Procurement of the test vehicles was a critical part in the program preparation. Five test vehicles were selected based on market representation, fuel system differences, and availability. Due to availability, the Ford F350 selected was over the weight limit considered light-duty. Vehicles used in testing were donated by individual companies.

<b>Test Vehicle</b>	<b>Model Year</b>	<b>Donated By</b>
Chevrolet Silverado with 6.6L Duramax engine	2004	General Motors
Ford F350 SD with 6.0L PowerStroke engine	2005	Ford Motor Company
Dodge Ram with 5.9L Cummins engine	2006	DaimlerChrysler
VW Passat with 2.0L TDI engine	2005	VW North America
Jeep Liberty Diesel with 2.8L I-4 engine	2005	BP Products NA Inc.

VINs of test vehicles can be found in Attachment 2.

## **TEST VEHICLE PREPARATION**

Sensors were installed on each test vehicle to measure and record temperatures, pressures, and engine speed. The vehicle speed, wind speed, and tractive force were measured by facility sensors. Following are the key parameters.

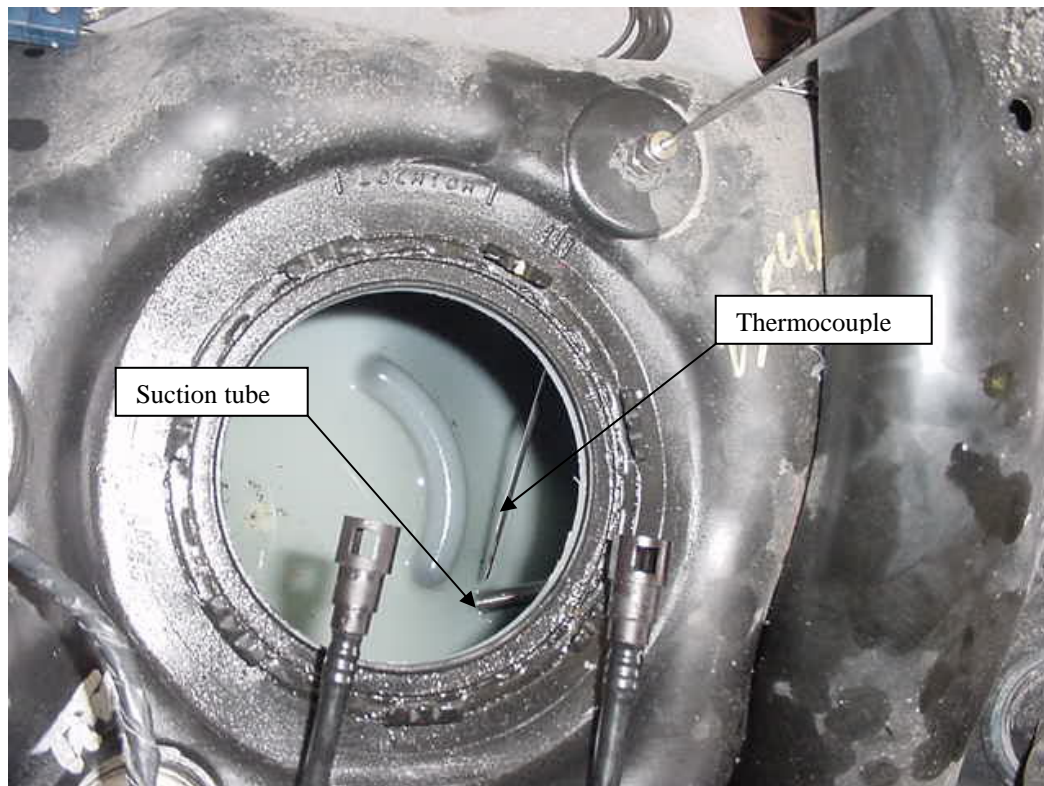
- Temperatures: ambient, fuel tank, fuel before and after filter, fuel return, engine oil, and coolant.
- Pressure: before and after fuel filter, before and after pre-filter (if equipped).
- Speed: engine speed (rpm), vehicle speed (kph), wind speed (kph).
- Force: tractive force (N).

The fuel systems of the vehicles are shown in schematic drawings indicating the locations of pressure and temperature sensors.

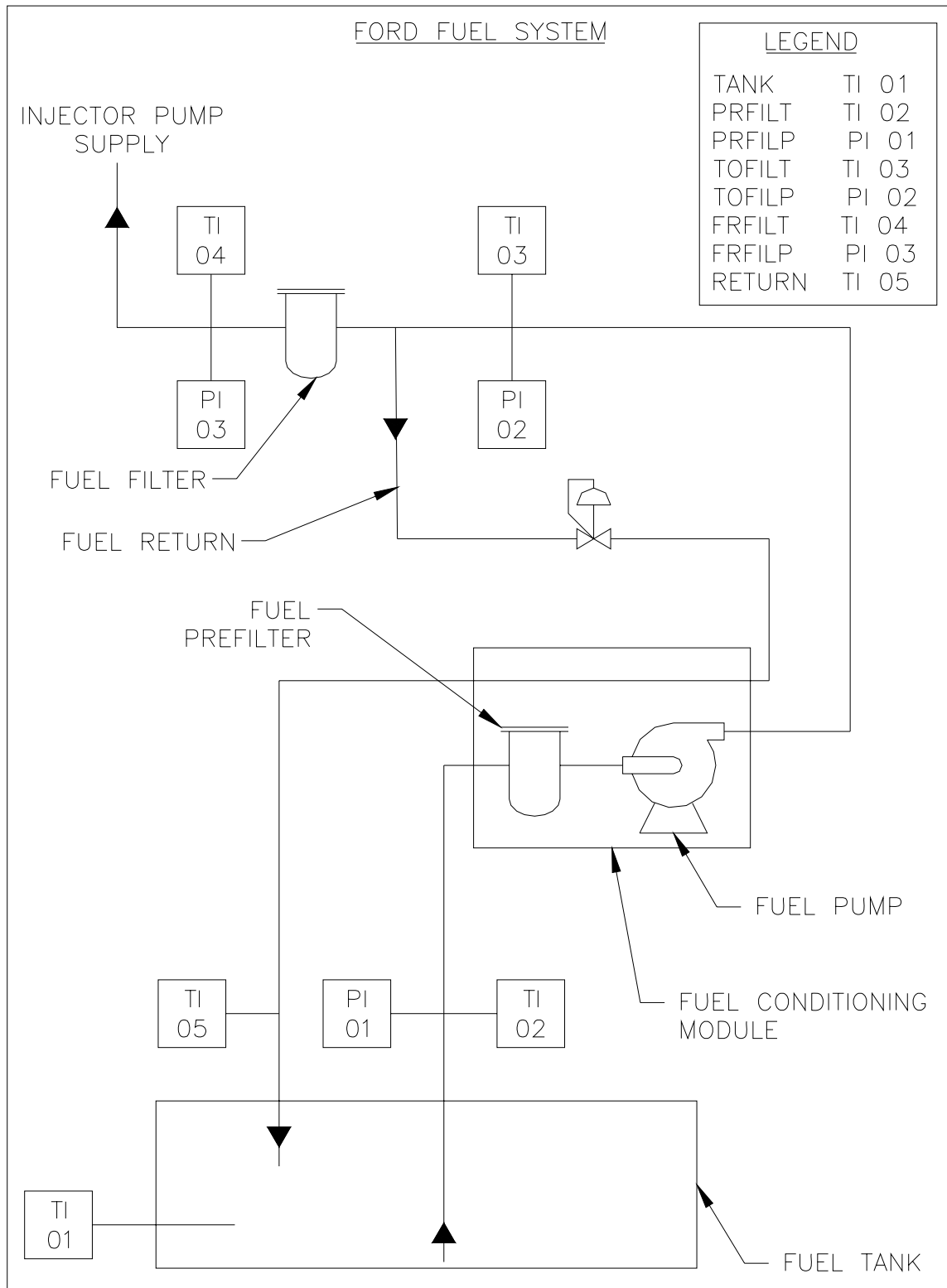
The engine oil in each vehicle was replaced with SAE 5W40 synthetic multi-grade oil. The engine oil was changed about every 5 tests.

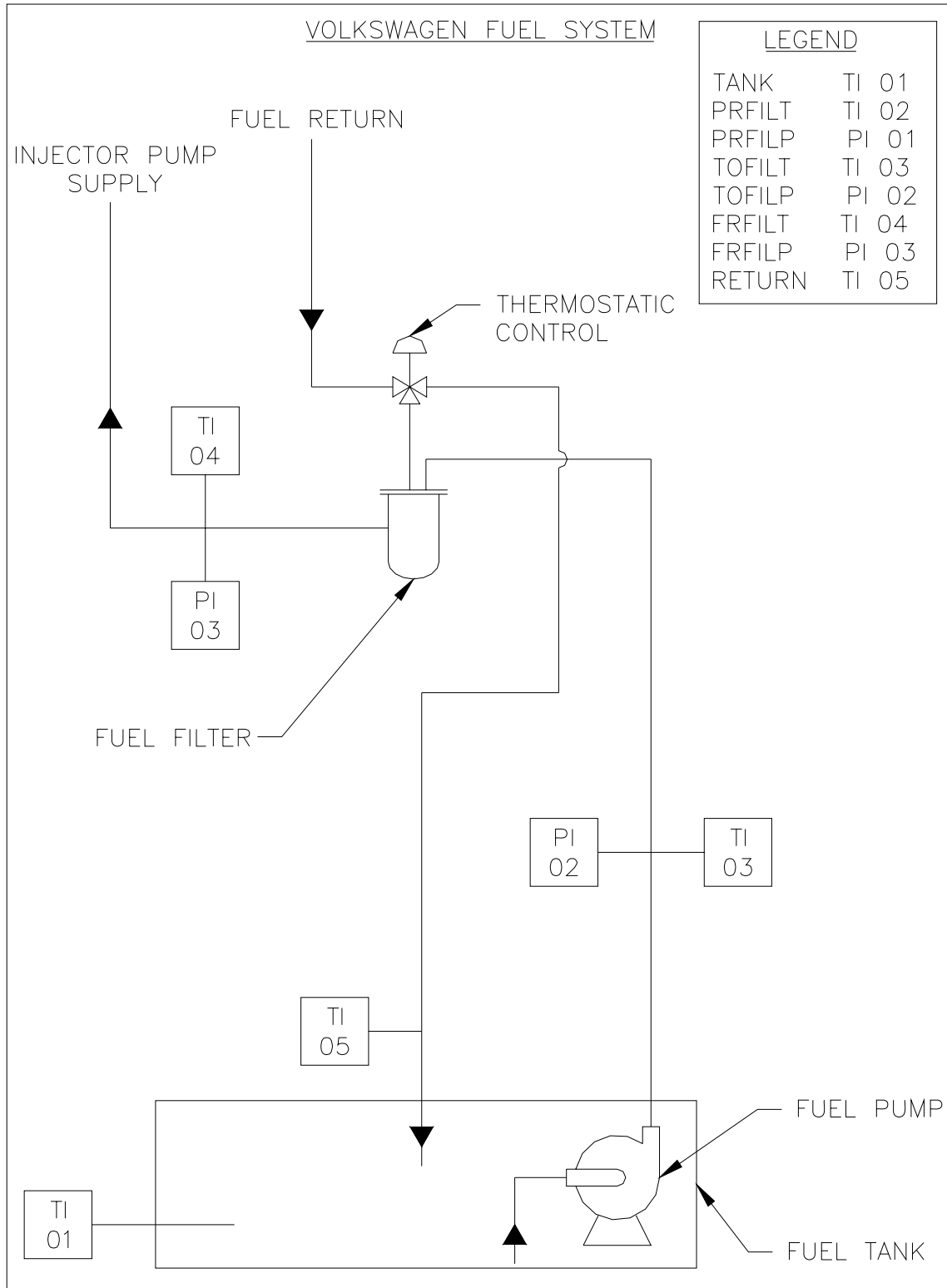
Engine block heater was standard equipment in some but not all of the test vehicles. Engine block heaters were installed on the rest of test vehicles that were not so equipped, including an after-market version on the VW Passat. Some installations were done after the program started.

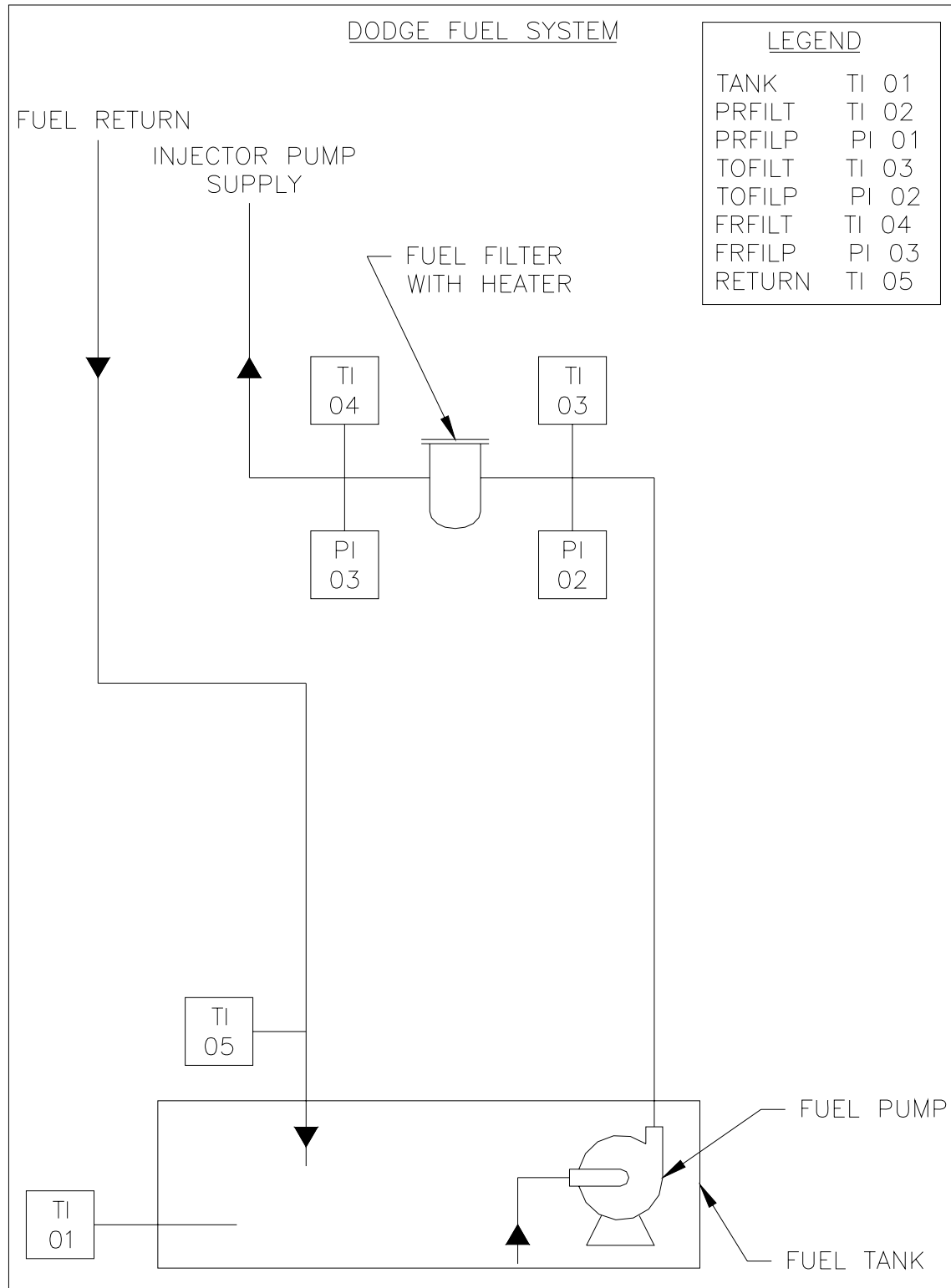
To facilitate efficient fuel changes between tests, the fuel tanks of the vehicles were modified with a suction tube installed at the lowest point within the tank. This allowed the use of a vacuum pump to withdraw the maximum amount of unused fuel from the previous test before introduction of the next fuel for flushing and final fill. Contaminations and fuel usage were both minimized.

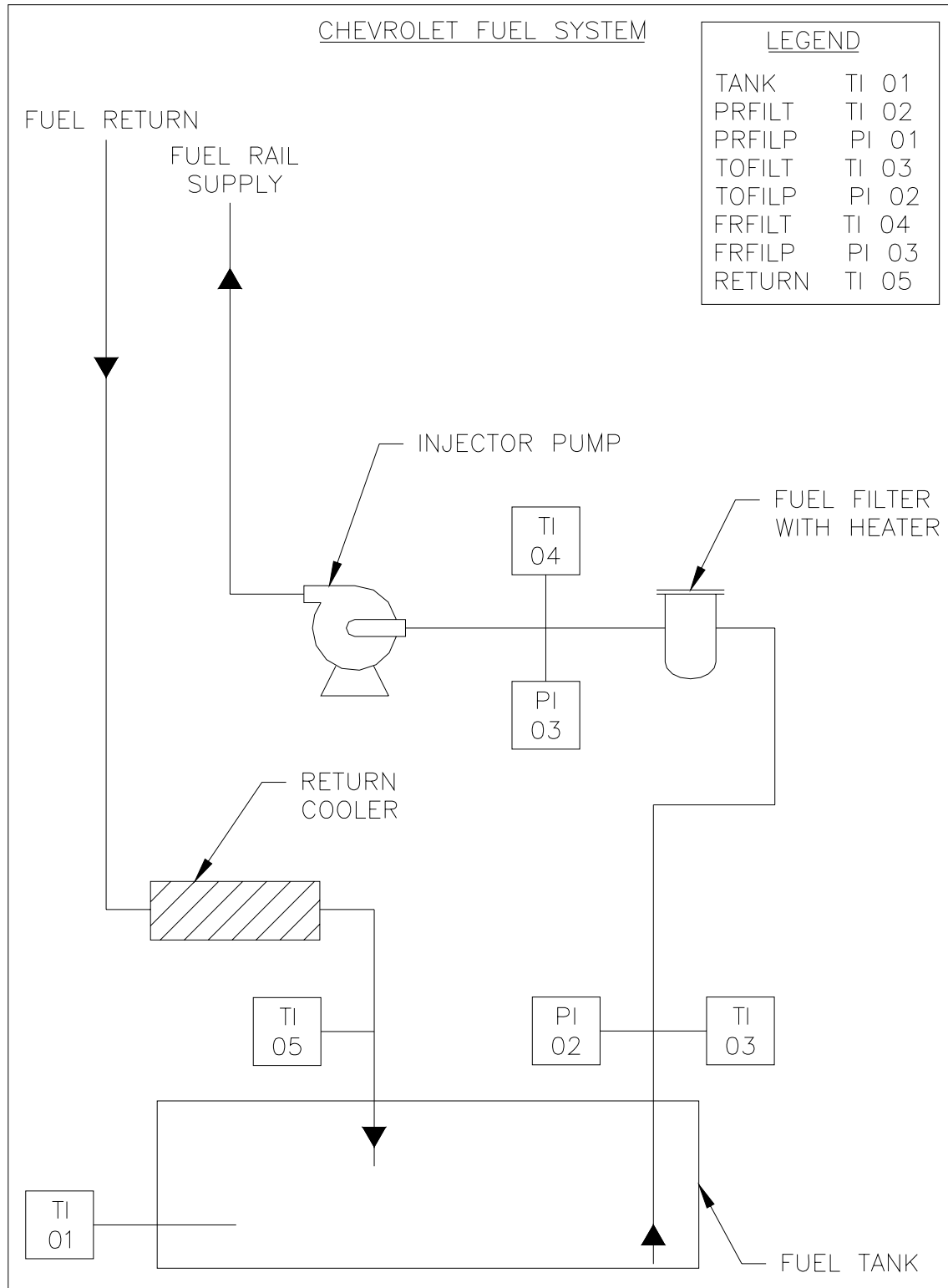


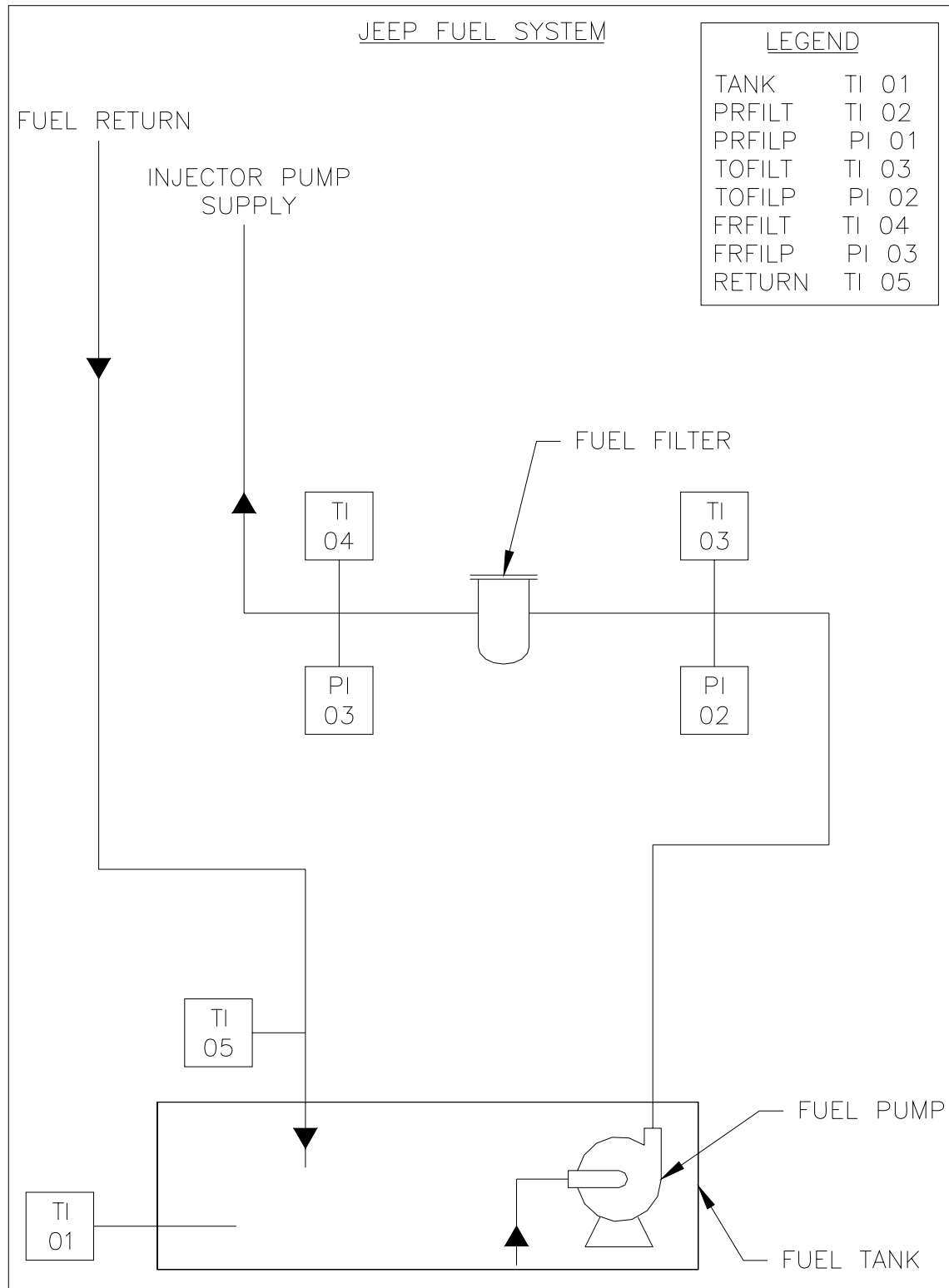
**Typical fuel tank modification for efficient fuel changes**











## TEST FUELS AND ADDITIVES

Four test fuels without cold flow additives were shipped to Sarnia (Fuels 1- 4). Using two cold flow additives at different treat rates, a total of ten test fuels were blended (Fuels A-K. Fuel H was dropped after the fuel matrix was finalized). Nine out of the ten test fuels were utilized in the program (Fuel K was not tested). The description of the test fuels is below. To aid the selections of initial test temperatures, some characteristics of the fuels were estimated. However, the firm measurements of these characteristics will be determined by multiple laboratories after the test program.

Test Fuel	Base Fuel	Additive	Treat Rate wppm	Cloud, °C
Fuel A	Fuel 3	R500	300	-9.5
Fuel B	Fuel 3	R524	500	-10.6
Fuel C	Fuel 1	R500	100	-22.5
Fuel D	Fuel 1	R524	500	-24.2
Fuel E	Fuel 1	R500	200	-22.8
Fuel F	Fuel 4	R500	1000	-9.2
Fuel G	Fuel 2	R500	500	-22.2
Fuel I	Fuel 3	R500	500	-9.9
Fuel J	Fuel 2	R524	2000	-22.2
Fuel K	Fuel 4	R524	2000	-9.7

## TEST PROCEDURE

The Low Temperature Operability Panel prepared a Test Protocol (Attachment 1) to evaluate low temperature vehicle operability. The actual test procedure followed that protocol with two modifications as indicated below.

1. The batteries of the test vehicles were not removed during overnight soaking to test temperature. Instead, a dedicated battery for each vehicle was fully charged at room temperature, then moved into the test cell and connected to the vehicle just prior to starting of the vehicle.
2. The protocol specified the following sequence: start the engine; idle the engine for 30 seconds; accelerate to 60 kph; hold for 3 minutes 35 seconds; accelerate to 110 kph; hold for 30 minutes. On the sixth day of testing when the test temperature reached -33 °C for the first time, a turbocharger failure was encountered in the Ford F350 vehicle. It was concluded that under very cold temperatures, the 30 seconds idle after engine start-up was not long enough to allow the engine oil to reach and lubricate certain parts of the engine. From that point on, the engine idle time after start-up was lengthened to 2 minutes 30 seconds from 30 seconds.

The daily logistics of testing are described below:

- Up to five test vehicles were prepared per day to be soaked overnight per the Test Protocol to the test temperatures. Fuel tank temperature for each vehicle and air temperature data were collected at a rate of 12 times per hour during the soak. The starting temperatures of the cool-down were determined according to the cloud points of the fuels.
- Fully charged, warm (above 20°C) batteries were used to start each vehicle following the OEM recommended starting procedure.
- Operability procedure per the Test Protocol was used following start-up. Data acquisition rate at one per second was used for the whole cycle. Evaluation of both startability and operability were done as per the Test Protocol.
- Based on test results, the next day's test parameters were determined. Very close contact was maintained with a CRC technical committee member to make the daily decisions.
- Prepared vehicles (fuel changes, oil changes if necessary) for the next day.
- Soaked vehicles overnight for the next day tests.

## TEST ORDER

A total of 121 tests were conducted. Each test is listed in the following table identified with a test file number. The test data files will be supplied separately.

Test Order	Test Date	Data & Info. File #	Vehicle	Fuel	Test Temp. °C
1	4/24/06	CR042406A	Jeep Liberty	A	-26
2	4/24/06	CR042406B	VW Passat	A	-26
3	4/24/06	CR042406C	Ford F350	A	-26
4	4/24/06	CR042406D	Chevrolet Silverado	A	-26
5	4/24/06	CR042406E	Dodge Ram	A	-26
6	4/25/06	CR042506A	Chevrolet Silverado	A	-24
7	4/25/06	CR042506B	VW Passat	A	-28
8	4/25/06	CR042506C	Dodge Ram	A	-28
9	4/25/06	CR042506D	Jeep Liberty	A	-28
10	4/26/06	CR042606A	Chevrolet Silverado	A	-18
11	4/26/06	CR042606C	VW Passat	B	-26
12	4/26/06	CR042606D	Jeep Liberty	B	-26
13	4/26/06	CR042606E	Dodge Ram	B	-26
14	4/26/06	CR042606F	Ford F350	A	-26
15	4/27/06	CR042706A	VW Passat	B	-28
16	4/27/06	CR042706B	Ford F350	B	-24
17	4/27/06	CR042706C	Dodge Ram	B	-24
18	4/27/06	CR042706D	Chevrolet Silverado	B	-24
19	5/1/06	CR050106A	Chevrolet Silverado	C	-29
20	5/1/06	CR050106B	Ford F350	C	-33

21	5/1/06	CR050106C	Dodge Ram	C	-33
22	5/1/06	CR050106D	Jeep Liberty	C	-33
23	5/1/06	CR050106E	VW Passat	C	-33
24	5/2/06	CR050206A	Chevrolet Silverado	C	-25
25	5/2/06	CR050206B	Dodge Ram	C	-35
26	5/2/06	CR050206D	Jeep Liberty	C	-35
27	5/2/06	CR050206E	VW Passat	C	-35
28	5/3/06	CR050306A	Chevrolet Silverado	C	-27
29	5/3/06	CR050306B	Dodge Ram	D	-37
30	5/3/06	CR050306C	VW Passat	C	-37
31	5/3/06	CR050306D	Jeep Liberty	C	-37
32	5/4/06	CR050406A	Chevrolet Silverado	D	-27
33	5/4/06	CR050406B	Dodge Ram	D	-35
34	5/4/06	CR050406C	VW Passat	D	-35
35	5/4/06	CR050406D	Jeep Liberty	D	-35
36	5/8/06	CR050806A	Chevrolet Silverado	D	-29
37	5/8/06	CR050806B	Dodge Ram	E	-37
38	5/8/06	CR050806C	Ford F350	D	-37
39	5/8/06	CR050806D	VW Passat	D	-37
40	5/8/06	CR050806E	Jeep Liberty	D	-37
41	5/9/06	CR050906A	Chevrolet Silverado	E	-29
42	5/9/06	CR050906B	Dodge Ram	E	-35
43	5/9/06	CR050906C	Ford F350	E	-35
44	5/9/06	CR050906D	VW Passat	E	-35
45	5/9/06	CR050906E	Jeep Liberty	E	-35
46	5/10/06	CR051006A	Chevrolet Silverado	E	-27
47	5/10/06	CR051006B	Ford F350	E	-37
48	5/10/06	CR051006C	VW Passat	E	-37
49	5/10/06	CR051006D	Jeep Liberty	E	-37
50	5/11/06	CR051106A	Chevrolet Silverado	E	-25
51	5/11/06	CR051106B	Ford F350	G	-32
52	5/11/06	CR051106C	Dodge Ram	G	-32
53	5/11/06	CR051106D	VW Passat	G	-32
54	5/11/06	CR051106E	Jeep Liberty	G	-32
55	5/15/06	CR051506A	Chevrolet Silverado	E	-23
56	5/15/06	CR051506B	Ford F350	C	-34
57	5/15/06	CR051506C	Dodge Ram	G	-34
58	5/15/06	CR051506D	VW Passat	G	-34
59	5/15/06	CR051506E	Jeep Liberty	G	-34
60	5/16/06	CR051606A	Chevrolet Silverado	G	-28
61	5/16/06	CR051606B	Jeep Liberty	G	-36
62	5/16/06	CR051606C	Dodge Ram	G	-36
63	5/16/06	CR051606D	Ford F350	C	-36
64	5/17/06	CR051706A	Chevrolet Silverado	G	-24
65	5/17/06	CR051706B	Jeep Liberty	J	-35

66	5/17/06	CR051706C	Dodge Ram	J	-35
67	5/17/06	CR051706D	Ford F350	J	-35
68	5/18/06	CR051806A	Chevrolet Silverado	G	-26
69	5/18/06	CR051806B	Jeep Liberty	J	-37
70	5/18/06	CR051806C	Ford F350	J	-37
71	5/18/06	CR051806D	Dodge Ram	G	-37
72	5/19/06	CR051906A	Chevrolet Silverado	I	-24
73	5/19/06	CR051906B	Jeep Liberty	I	-30
74	5/19/06	CR051906C	Dodge Ram	I	-30
75	5/19/06	CR051906F	Ford F350	I	-30
76	5/23/06	CR052306A	Chevrolet Silverado	I	-22
77	5/23/06	CR052306B	Jeep Liberty	I	-28
78	5/23/06	CR052306C	Dodge Ram	I	-29
79	5/23/06	CR052306D	Ford F350	I	-29
80	5/24/06	CR052406A	Chevrolet Silverado	I	-20
81	5/24/06	CR052406B	Dodge Ram	I	-27
82	5/24/06	CR052406C	Ford F350	I	-27
83	5/24/06	CR052406D	Jeep Liberty	B	-28
84	5/25/06	CR052506A	Chevrolet Silverado	I	-18
85	5/25/06	CR052506B	Dodge Ram	F	-17
86	5/25/06	CR052506C	Ford F350	F	-17
87	5/25/06	CR052506D	Jeep Liberty	F	-17
88	5/26/06	CR052606A	Chevrolet Silverado	I	-18
89	5/26/06	CR052606B	Dodge Ram	F	-20
90	5/26/06	CR052606C	Ford F350	F	-20
91	5/26/06	CR052606D	Jeep Liberty	F	-20
92	5/26/06	CR052606E	VW Passat	F	-20
93	5/29/06	CR052906A	Chevrolet Silverado	F	-14
94	5/29/06	CR052906B	Ford F350	A	-24
95	5/29/06	CR052906C	Jeep Liberty	F	-23
96	5/29/06	CR052906D	VW Passat	F	-23
97	5/29/06	CR052906E	Dodge Ram	F	-23
98	5/30/06	CR053006A	Chevrolet Silverado	F	-16
99	5/30/06	CR053006B	Jeep Liberty	F	-25
100	5/30/06	CR053006C	Ford F350	A	-22
101	5/30/06	CR053006D	VW Passat	F	-26
102	5/30/06	CR053006E	Dodge Ram	F	-25
103	5/31/06	CR053106A	Chevrolet Silverado	A	-20
104	5/31/06	CR053106B	Ford F350	G	-30
105	5/31/06	CR053106C	Dodge Ram	A	-30
106	5/31/06	CR053106D	VW Passat	B	-30
107	6/1/06	CR060106A	Dodge Ram	J	-33
108	6/1/06	CR060106B	VW Passat	I	-28
109	6/1/06	CR060106C	Chevrolet Silverado	J	-26
110	6/1/06	CR060106D	Ford F350	B	-26

111	6/1/06	CR060106E	Jeep Liberty	B	-28
112	6/2/06	CR060206A	Ford F350	A	-20
113	6/2/06	CR060206B	Chevrolet Silverado	J	-29
114	6/2/06	CR060206C	Dodge Ram	J	-31
115	6/2/06	CR060206D	VW Passat	I	-30
116	6/2/06	CR060206E	Jeep Liberty	I	-30
117	6/5/06	CR060506A	Chevrolet Silverado	B	-20
118	6/5/06	CR060506B	Dodge Ram	F	-27
119	6/5/06	CR060506C	Jeep Liberty	I	-29
120	6/5/06	CR060506D	VW Passat	B	-32
121	6/5/06	CR060506E	Ford F350	D	-35

## TEST RESULTS

Each of the 121 tests has a data file consisting of the raw data collected at both once per second and 10 times per second rates, legend for the parameters, graphic plots of key parameters, and driver rating and observations. Due to the memory size of the files, they will be provided in a separate electronic medium (CD). The CD also contains the overnight temperature soaking data for each test day. A summary of the tests results with comments is included in Attachment 2.

## OBSERVATIONS

1. The program ran smoothly in general. It took a minimal length of time to become familiar with the vehicle characteristics and drive cycle behaviour.
2. Within the first few days of testing, it was determined that most of the test vehicles would not start at the lower end of the expected test temperature range without employment of an engine block heater. This indicated the startability of the vehicles was significantly more dependent on the effectiveness of the engine block heater than the characteristics of the fuels. Four out of five vehicles had standard original equipment engine block heaters available. The VW Passat did not have a factory designed heater, but an aftermarket heater specially designed for VW diesel engines was available, and after consultation with VW, was used. The same block heater designated by the OEM was used in each vehicle throughout the test program. The use of engine block heaters provided consistency for test to test comparison even though the coolant temperature at engine start did vary depending on the length of time the block heater was plugged-in and air movement (wind) around the engine during overnight soak. In order to minimize variation, all block heaters were plugged in at the beginning of the overnight soak.
3. The Test Protocol initially called for 30 seconds of engine idle before the vehicle acceleration to 60 kph. A turbocharger failure was encountered on day 5 of the

program. It was concluded that the short idle time was not adequate to allow the engine oil to lubricate some critical parts of the engine under very cold conditions. Therefore, the test procedure was changed from day 7 on to idle the engine for 2 minutes 30 seconds before acceleration.

4. For the steady portions of the drive cycle, both 60 kph and 110 kph, the cruise-control function on the vehicle was used. This enhanced the steadiness of the vehicle speed. The trade-off was that when additional acceleration pedal movement was required, it would be applied by the vehicle rather than the driver.
5. The criterion for test pass/fail was whether the vehicle completed the 36-minute drive cycle without loss of vehicle speed and power. Since the pressure drop across the fuel filter was monitored, it was observed that some of the passing tests were running with significant filter blockage. Under these circumstances, if the vehicle encountered a higher load requirement such as coming upon a hill, the vehicle may lose speed and power. On a few occasions, at the end of the drive cycle where such blockages were observed, when an incline of 2% or 3% was simulated, the vehicle did lose speed and power.
6. All five test vehicles have different strategies in their fuel system design to meet low temperature operability requirements. Some systems were more consistent (predictable), whereas others can vary and be less predictable.
7. The space to install the engine speed (rpm) sensor on the VW Passat was very limited. As a result, the sensor shifted location during the testing on several occasions resulting in the lost of speed signal. However, in all cases with the VW Passat, the vehicle speed (in the running part of the drive cycle) was a good indicator of the engine operation.

## Attachments

**Exhibit A - CRC Project No. DP-2-04**

**TEST PROTOCOL for the EVALUATION of  
LOW TEMPERATURE OPERABILITY  
PREDICTION TESTS for LIGHT DUTY DIESEL  
VEHICLES for NORTH AMERICA**

**October 31, 2005**

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## **FOREWORD**

In recent years there has been an increasing interest in introducing the latest technology, light duty diesel (LDD) vehicles into North America. Of great concern is the cold weather performance of these vehicles and the concurrent introduction of ultra low sulfur diesel (ULSD) fuel. Some uncertainty exists as to the reliability of the commonly used low temperature operability prediction bench test methods relative to LDD vehicles in North America.

A number of organizations have developed in house procedures to assess operability, involving the running of vehicles in cold rooms and on cold climate chassis dynamometers.

This procedure is being developed by the CRC diesel performance working group and is intended to produce a data set for comparison of current low temperature operability bench tests against actual vehicle failures and to determine the reliability of the bench tests. In addition the data will allow the opportunity for development of a new test if the existing test methods fail to show adequate correlation.

## **SAFETY**

All exposed rotating parts of engines, gearboxes and drive shafts must be provided with suitable covers. All relevant safety regulations governing the operation of vehicles should be observed. The flammable and sometimes explosive nature of fuels should be borne in mind and appropriate warnings given.

## **COLD WEATHER PERFORMANCE TEST PROCEDURE FOR DIESEL VEHICLES**

### **1. PURPOSE, SCOPE AND OBJECTIVE**

Low temperature operability is an issue with middle distillate fuels because they contain straight and branched chain hydrocarbons (paraffin waxes). These waxes precipitate as crystals at ambient winter temperatures. When this happens, the wax may plug the fuel filter or fuel line, reduce pumpability or it may completely gel the fuel, making it impossible for the fuel system to deliver sufficient fuel to the engine. The end result can be stumbling, the inability to maintain speed and power, or in severe cases of wax formation, the vehicle may not start.

Previous work conducted by the CRC and by others has shown that both vehicle fuel system design and fuel properties are important in determining the susceptibility of a particular diesel vehicle operating on a particular fuel to filter plugging and other low-temperature operational problems. Some of these investigations have also shown substantial benefits in low-temperature operation when middle distillate flow improvers are included in the fuel.

The successful introduction of an extensive passenger fleet of light duty diesel (LDD) vehicles in North America will require consumer satisfaction. This satisfaction will be impeded if extensive winter operability problems plague the end user. The first step in precluding this problem is to have a practical bench test that adequately predicts the low temperature operability of diesel fuel relative to light duty diesels in North America. As yet, however, no laboratory test has been identified which adequately predicts the behavior of North American fuels both with and without flow improvers in a wide range of LDD fuel system designs.

The purpose of this project is to obtain data on the low-temperature performance of a wide variety of light duty diesel fuel systems, operating with a representative sampling of on road ultra low sulfur diesel (ULSD) fuels under real-world temperature conditions. It is intended that these data be used to evaluate existing laboratory tests for their effectiveness at predicting low-temperature performance of diesel fuels in light-duty equipment.

**Objective:**

Evaluate existing low temperature operability prediction test methods and determine their applicability to North American LDD vehicles using data developed from vehicle tests.

**2. Overview:**

- Test program to be run in an All Weather Chassis Dynamometer with a temperature range capability of -10°C to -40°C.
  - The Dynamometer facility must be capable of running a minimum of 4 vehicles per day (a minimum of 5 is preferred) and a minimum of two different temperatures daily.
  - The facility must have separately cooled Dynamometer cell and cold soak room.
  - The Dynamometer facility must also have the means of continuous computerized recording of vehicle performance while under test conditions.
  - The facility must be able to continuously monitor and record the overnight cool-down of each vehicle to be tested. A 5 second or less reporting interval is preferred.
  - The test facility must also have the capability of blending fuels and additives if the need arises.
- The test will use a minimum of four LDD vehicles with dissimilar fuel systems.
  - Vehicles will be selected from domestic manufacturers and import vehicles that are presently available or are proposed for introduction into the North American market in the near future, if they can be made available.
- ULSD Fuels will be collected and prepared for use. The Fuels will meet or exceed ASTM D975, Specification for Diesel Fuel Oils. Base fuel characteristics will be determined.
  - The fuels will be analyzed using current, commonly used low temperature operability test methods.
  - Two No. 2 ULSD base fuels and one No. 1 ULSD will be used. A third Base No. 2 ULSD will be obtained if available as a backup in case test cost is under run and test time is available. (The more different fuels tested the greater the confidence in the test conclusions.) Blends will be created using the No. 2 ULSD base fuels and No. 1 ULSD. Middle distillate flow improver additives will be used in conjunction

with the base fuel and blends. Example of one Base No. 2 ULSD and blends for testing:

- |   |                      |
|---|----------------------|
| • Base No. 2 ULSD A                         | Cloud ~ -10°C        |
| • Base No. 2 ULSD A + Additive              | CFPP ~ -22°C         |
| • Base No. 2 ULSD A + Additive              | LTFT ~ -22°C         |
| • Base No. 2 ULSD A + No. 1 ULSD            | Cloud ~ -22°C        |
| • Base No. 2 ULSD A + Additive              | CFPP ~ -25° to -30°C |
| • Base No. 2 ULSD A + Additive              | LTFT ~ -25° to -30°C |
| • Base No. 2 ULSD A + No. 1 ULSD + additive | CFPP ~ -35°C         |

Since Cold Flow Additives can impact Cloud Point, Pour Point, CFPP and LTFT results to greater or lesser degree, it can greatly complicate the test temperature choice. For this program the CFPP test result will be the initial test temperature target because it is the most commonly used test procedure for predicting low temperature vehicle performance throughout the world. As experience is gained with the vehicle/fuel combinations, it may be decided to target the fuel LTFT temperature if the CFPP temperatures are not protective enough.

If at the CFPP test temperature the vehicle passes, then vehicle/fuel combination would be run at lower and lower temperatures until a vehicle/fuel failure point is determined. If the test fails at the CFPP temperature, then the vehicle/fuel combination would be tested at higher and higher temperatures until a passing result is obtained. The lowest passing temperature for each vehicle/fuel combination will be compared to the Cloud Point, Pour Point, CFPP and LTFT result for each fuel tested.

- Complete analysis of each test fuel plus retain vehicle tank samples and drum quantities of each blend for future test development if needed.
- Middle distillate low temperature additive selection will be determined by the following process:
  - Each participating Additive Supplier may submit up to two commercial additives for each fuel. Note: The Base No. 2 ULSD and the No. 1 ULSD blends of that Base No. 2 ULSD are considered different fuels. Fuels for CFPP and LTFT additives are also considered different fuels.
  - The Additive Suppliers will be provided with fuels well in advance of the Vehicle testing to develop bench test cold flow response curves in order to select the appropriate additive(s) for submission.

- The Additive Suppliers will submit their additive recommendations for a blind selection process.
- The additives submitted will be coded on pieces of the same size paper and placed in a hat or some device to ensure no one can see the slip of paper being selected.
- A non-additive supplier member of the group will blindly select a slip for one of the additives submitted and that will be the additive used for that fuel. Note: The performance of each additive selected will be verified by the other labs in the group.
- This process will be carried out for each test fuel.
- The selected additives are expected to be supplied at no cost.
- If a selected additive does not perform as expected in laboratory testing prior to vehicle testing, then the group will decide on whether to try a higher treat rate or select a different additive in the same manner as before from the other additive submissions.

### 3. DEFINITIONS

*Startability:* The ability to start the vehicle using normal starting procedures.

*Operability:* Operability and vehicle driveability under fuel waxing conditions.

### 4. PREPARATION OF TEST VEHICLE

#### 4.1 *Measurements Required*

The following measurements are required on the test vehicle or engine:

##### 4.1.1 *Temperature*

Thermocouple No.	Point of Measurement
1	Cooling liquid (except where air cooled) in the upper hose and the thermostat
2	Oil in the sump for example at the end of the dipstick or, if practical, in the drain plug or gallery
3	Inlet air at the entry of the engine (under hood)
4	Air under the bonnet, in the longitudinal axis of the vehicle at the rear of the engine compartment (optional)
5	Fuel at the inlet of the main filter
6	Fuel at the outlet of the main filter

7	Fuel in the fuel tank (representing the bulk temperature)
8	Fuel in the recycle line close to the fuel tank
9	Fuel in the pre-filter (optional)
10	Ambient air

#### 4.1.2 Pressure

Instrument No.	Point of Measurement
1	Fuel at the inlet of the pre-filter (if fitted)
2	Fuel at main filter inlet
3	Fuel at main filter outlet
4	Fuel transfer pressure (rotary pumps) (optional)

4.1.3 *Ambient air temperature*  
Continuously monitored and recorded.

4.1.4 *Engine Speed*  
Continuously monitored and recorded.

4.1.5 *Vehicle Speed*  
Continuously monitored and recorded.

## 4.2 **Test Vehicle Preparation and Performance Checks**

The following operations will be carried out if possible but may be modified if necessary:

### 4.2.1 *Lubricants:*

- *Engine:* drain the engine oil before the test and refill with the quantity and the grade recommended by the vehicle manufacturer for the minimum test temperature.
- *Transmission and auxiliaries:* for the parts which will operate during the test, check that the appropriate grades are present and, if not, drain and refill with the quantity and the grade recommended by the constructor for the minimum test temperature.

### 4.2.2 *Filters:*

Fit new filters for: -Fuel. -Oil. -Air.

### 4.2.3 *Cooling system:*

Check the level and suitability of the antifreeze, for the minimum test temperature. Check the thermostat and the start point of the cooling fan. Check the tension of the drive belts.

### 4.2.4 *Battery:*

Use a fully charged battery. Preference is for connection to a battery outside the vehicle such that it can be easily removed as needed for recharging under more ideal conditions.

- Check the nominal capacity of the vehicle battery: charge completely, calculate the nominal capacity. If the calculated capacity is below the manufacturer's specification, use a new battery and recharge until the voltage does not vary by more than 2% during two hours consecutively.
- Where a new battery is used, stabilize its capacity by means of three consecutive cycles of discharge. Discharge until the voltage is equal to 10.5 V and recharge until the voltage does not vary by more than 2% over two consecutive hours.
- If necessary refer to the battery manufacturer.

**4.2.5**    *Electrical circuit:*

Check the conformity of the starter, of the alternator and the regulator.

**4.2.6**    *Pre-heater plugs:*

Check that all the pre-heater plugs are working effectively.

**4.2.7**    *Starting accessories:*

Check that type, specification and function are correct.

**4.2.8**    *Fuel system:*

- The fuel tank of the vehicle is to be used for cold operability testing.
  - Check for cleanliness and absence of leaks.

**4.2.9**    *Injection pump:*

Check and adjust if necessary:

- Initial timing
- Advance, if necessary.
- Hot idle speed.
- Maximum engine speed no load.
- Check "residual fuel" setting of the fuel pump (as defined in manufacturing service manual)

**4.2.10**   *Injectors:*

- Check opening pressure before tests and adjust if outside tolerance band.
- Fit new heat-shield washers.
- If necessary injectors should be pre-conditioned after refitting to the engine.

**4.2.11**   *Engine:*

Should have completed at least 1500 mi or have completed a running in procedure indicated by the manufacturer.

*For cold startability test or cold operability tests:*

- Check that the air circulation around the engine and around the fuel supply system is not restricted by any non-standard equipment.

**4.2.12 Tires:**

Inspect the tires to ensure suitability for test conditions. Check pressure.

**4.2.13 Road Test:**

For vehicles, a road test is recommended to check correct operation of the vehicle and produce data for setting the dynamometer (see Section 6).

## **5. TEST FUEL**

### **5.1 Characteristics:**

Cloud point, CFPP and LTFT will be artificially adjusted using ULS No. 1 and/or appropriate fuel additives in order to meet the fuel characteristics as described in section 2. Cetane number for all test fuels will be artificially adjusted to the same level using 2-Ethylhexyl Nitrate (2EHN). The following characteristics of test fuel will be measured.

- Fuel analysis to demonstrate compliance with ASTM D975 requirements and cold flow improving additive response curves will incorporate the following standardized test methods prior to acceptance for the test program. Test results will be confirmed by a minimum of four laboratories.
  - Cloud Point\*\* – D2500, or D5773 / D5772 / D5771
  - Pour Point\*\* – D97 or D5949
  - CFPP – D6371
  - LTFT – D4539
  - Distillation – D86 or D2887
  - Density – D1298 or D4052
  - Flash Point – D56 or D93
  - Viscosity @ 40°C - D445
  - Sulfur ppm wt. – D5453
  - Sediment and Water - D2709
  - Ramsbottom carbon residue on 10 %distillation residue, – D524
  - Ash % wt. – D482
  - Copper Strip Corrosion - D130
  - Cetane Number - D613
  - Conductivity – D2624
  - Lubricity at 60°C – D6079

Other tests may be made on the fuel if necessary.

The results of measurements will be noted in the column “Measures” on Table 3. Under “Observations”, include all information concerning the use of additives.

## **5.2      *Storage and Handling of Test Fuels***

- (a) The test fuel must be kept in closed containers to avoid contamination. Before use, warm up the fuel sufficiently to ensure that there is no wax out of solution and roll or shake the container to ensure homogeneity.
- (b) A vehicle test fuel may not be reused.
- (c) The quantity of fuel which must be in the vehicle it:
  - For operability tests, equal to 50% of the vehicle fuel tank capacity.

## **6.      TEST FACILITIES**

### **6.1      *Engine Tests for Low Temperature Operability***

The test facility must have a cold room equipped with a chassis dynamometer and must be capable of operating over the temperature range of ~ -10°C to -40°C. The test facility must have a cold room soak room with independent temperature capability with a temperature range of ~ -10°C to -40°C. The temperature of the cold room must be maintained within  $\pm 1^{\circ}\text{C}$  of the required.

### **6.2      *Vehicle Test on Chassis Dynamometer***

The chassis dynamometer must be capable of operating over the temperature range required for the tests. The temperature of the chassis dynamometer chamber must be maintained within  $\pm 1^{\circ}\text{C}$  of the required temperature.

When the vehicle is being driven on the chassis dynamometer, the air speed must be equal to vehicle speed or not be different by more than 7 mi/h.

Note: The vehicle speed indicator must be calibrated if it is used during the tests.

### **6.3      *Setting of Chassis Dynamometer Load for Cold Operability Tests***

To obtain the best correlation with road conditions, the load should be adjusted to simulate as closely as possible the vehicle load on a horizontal road over the speed range achieved during the test.

(a) Test vehicles:

The dynamometer load should be adjusted to simulate as accurately as possible the road load on the vehicle over the speed range of the test, paying particular attention to matching the road load at the test speed of 110 km/h. Note the time taken to accelerate from a steady speed of 60 km/h to 110 km/h.

Data for setting the dynamometer may be obtained from manufacturer's information or from road tests of vehicle performance, e.g. coast down measurements.

## **7. LOW TEMPERATURE OPERABILITY TEST METHOD**

### **7.1 *Test Preparation***

The following operations must be carried out before each test:

- (a) Warm up the vehicle to a temperature above 20°C or otherwise ensure elimination of any traces of wax.
- (b) Store and re-charge the battery, ideally at 20°C, according to paragraph 4.2.4. In any case this operation should not be carried out below 10°C to avoid serious loss of battery performance. Use an auxiliary battery during the recharge and for completion of the preparation.
- (c) Drain engine oil after five tests or at end of each working week. Engine oil appropriate for the test temperature will be used.
- (d) Drain the fuel tank. Flush the tank and lines as necessary with the fuel to be tested to ensure the previously tested fuel has been completely removed.
- (e) Fit a new filter.
- (f) Fill the fuel tank with test fuel, as described in 5.2(c). Ensure the temperature is at least 5°C above the fuel cloud point.
- (g) Disconnect the return line from the fuel tank, start the engine and recover the test fuel returned.

- (h) When 1-2 liters of fuel have been recovered, reconnect the return pipe to the fuel tank.
- (i) Drive at high load or at high engine speed to ensure correct operation and that all air has been purged from the system.
- (j) Check idle speed and stability.
- (k) Reconnect original recharged battery.

## **7.2 Cool down of the Test Cell**

- (a) Regulate wind speed as close as possible to 7 mi/h during the cool down.
- (b) Reduce the temperature of the test cell to 5°C above the cloud point of the fuel. Maintain the temperature at this level for not less than 2 hours. The temperature reduction must be linear.

Note: At the start of the controlled cool down the fuel tank temperature should be only about 8°C above that of the air. The pre-soak period at 5°C above fuel cloud point is intended to achieve this. Other means to achieve this objective could be accepted, such as pre-cooling of the fuel to the appropriate temperature before charging to the vehicle tank. If fuel is more than 8°C above the air temperature at the start of cool down this will have to be considered when interpreting the results.

- (c) Maintain the fuel tank test temperature for at least two hours.

## **7.3 Vehicle Start-up**

When the cool down procedure outlined in 7.2 has been carried out, proceed as follows:

- (a) Use the starting procedure recommended by the vehicle or engine constructor. Use all recommended starting aids (e.g. block heaters at very low temperatures, glow plugs, ether sprays, etc.) If a recommendation does not exist, the following procedure is suggested:
  - . Place the gear-lever in neutral. (In position “N” for vehicles equipped with automatic transmission.)
  - . Operate the starting aid(s).
  - . Declutch.
  - . Fully depress the acceleration pedal.

- (b) Start a timing device and turn the key to operate the starter motor in sequences of 30 seconds cranking, unless otherwise stated by the manufacturer. If possible record cranking speed as this may explain a poor result if too low.
- (c) In case of non-start, release the key, stop the stopwatch and wait 1 minute between each sequence. (If vehicle manufacturer advises longer than 30 seconds cranking the waiting period between successive attempts should be extended, e.g. 1 minute cranking, 2 minutes wait, etc.)
- (d) Repeat the above action (a) to (c) until a start has been achieved with a maximum of 3 attempts.
- (e) Keep the starter motor operating after the initial firings until the engine can auto-rotate. Release the accelerator pedal when the engine speed reaches a suitable level for that vehicle. For vehicles equipped with automatic fast idle, release the accelerator completely and note idle speed. For other vehicles, regulate the idle speed as appropriate for that vehicle. If the engine stalls during the first ten seconds of idling speed in auto-rotation, restart the engine, as from paragraph 7.3(a). If engine again stalls, terminate the cold start test. Report the result as "Stall at start" and commence a new test as from paragraph 7.1.

#### **7.4 Method of Evaluation**

The starting performance is evaluated by means of the parameters noted below as measured during the test.

- (a) *Time to start:*  
Defined as being the total time of action on the starter to obtain engine auto-rotation for at least ten seconds without starter.
- (b) *Time for engine speed rise:*  
Defined as being the total time of operation of the starter motor and of the time of auto-rotation of the engine just to the point of where the engine accelerates, to the speed defined in paragraph 7.3(e), followed by an operation time for at least ten seconds without stalling.
- (c) *Number of attempts to start.*
- (d) *Number of stalls.*
- (e) *Time of stalls after first auto-rotation.*
- (f) *Idle speed.*

#### **7.5 Reporting Start-Up Results**

Results should be reported in the form similar to that shown in the attached Table '4'.

## **8. OPERABILITY TEST METHOD**

Operability problems during a test, or road driving, are usually due to blockage of the main fuel filter or other parts of the fuel system. Blockage is generally caused by wax, although water maybe the cause in some cases on the road. As blockages develop, the pressure drop across the fuel filter increases. The first phenomenon observed is slight fluctuation in speed, 'surge' which may become more severe as the test continues. If the pressure drop continues to increase, significant pedal adjustment will be required to maintain the vehicle speed. Eventually the speed of the car will start to reduce, even with the pedal fully depressed, and the vehicle may finally stall.

The operability test method is carried out on a complete vehicle on a chassis dynamometer. The detailed procedure is written for chassis dynamometer testing.

### **8.1 *Test Sequence for Passenger Cars***

After following the preparation, cool down and engine starting procedures outlines in 7.1 – 7.3, the following test method should be used:

- (a) Switch on all electric accessories at their maximum power (head lights, lights, de-icing, vent, ...), and keep, or leave, the engine at fast idling for 30 seconds after cranking.
- (b) Start the timer for the beginning of the operability test, and accelerate through the gears so as to reach 60 km/h in the appropriate gear within approximately 35 seconds. For each vehicle determine a suitable engine speed for gear change. Thereafter always change at this engine speed in order to ensure consistency from test to test. For vehicles with automatic transmission, allow the transmission, to dictate the shifts, with gear selector in "D".  
If a stall occurs, restart the engine immediately and perform the acceleration again. Note the occurrence of the stall and record the length of time when engine was not operating.
- (c) Drive at 60 km/h in the appropriate gear.
- (d) At 3 min 35 s, accelerate at full load up to 110 km/h. within approximately 25 sec.
- (e) Drive at 110 km/h in the highest gear and maintain, if possible, for 30 min.
- (f) The total test time is 34 min. including the acceleration phase.
- (g) Data shall be recorded as described in Section 8.2.

## 8.2 *Method of Evaluation*

Depending upon the severity of wax plugging in the fuel system, the performance of a diesel vehicle will be affected in different ways. These are, in order of severity:

- 1) No observable effect upon performance.
- 2) Slight fluctuation of speed (surge), engine misfire, or the need for significant pedal adjustment to maintain speed.
- 3) Inability to maintain speed even with pedal fully depressed.
- 4) Stalling of engine.

The most severe of these occurrences is used to calculate an overall demerit rating for the tests, using the procedures below.

The evaluation procedures are defined in a way which enables the result to be represented in a continuous scale from 0 to 100.

- a. i) Occurrence of surge (i.e. a change in speed without change of pedal position) or misfire on the level at 110 km/h. Occurrences shall be recorded at the end of each minute during the 30 minute test period. Calculate a demerit rating as shown below:

Demerit a(i) = (No. of minutes during which incidents are recorded) x  $\frac{10}{30}$

The maximum demerits possible under this heading are 10.

- ii) The need for significant pedal adjustment to maintain test speed. Occurrences shall be recorded at the end of each minute during the 30 minutes test period. A demerit rating is calculated as follows:

	No. of	Weighting	
	Minutes	Factor	Rating
Slight(or no) pedal adjustment	W	0	-
Significant pedal adjustment	Y	3	3 x Y
Need to use full throttle	Z	6	6 x Z

The maximum rating is 180 (when Z = 30 minutes). The demerit is then calculated as:

Demerit a(ii) = Rating/18, so that a maximum demerit of 10 is achievable.

- iii) Calculate a total demerit for this section as:

A = demerit a(i) + demerit a(ii)

The maximum possible demerit is 20.

- b.** Severity of speed loss and vehicle failure will be assessed on a scale from 20 to 100. (Speed loss will be assessed during the 30 minute period of constant high speed driving, (110 km/h) defined in this procedure). The assessment will be defined as follows:

i) The vehicle operates through the 30 minute period but may suffer loss of speed at some time during the test.

$$\text{Demerit b(i)} = 20 + (M \times 40)/30$$

Where M = the total number of minutes during which the required speed cannot be maintained.

ii) The vehicle suffers a driving stall before the end of the 30 minute test.

$$\text{Demerit b(ii)} = 100 - (N \times 40)/30$$

Where N = the number of minutes operation before occurrence of the driving stall.

iii) The demerit for this section is B = demerit b(i) or demerit b(ii), whichever is applicable.

Note: M and N are to be calculated during the 30 minute driving period. Idle and acceleration times are excluded.

### **8.3 Reporting Results of Operability Procedure**

The result shall be reported as demerit A or demerit B, whichever is applicable. A table of performance throughout each vehicle test is required. The table should provide the information shown in Attachment 1 at a minimum.

**Table 1****CHARACTERIZATION OF TEST VEHICLE**

Make &amp; Model \_\_\_\_\_ Year \_\_\_\_\_

Registration No. \_\_\_\_\_ Chassis No. \_\_\_\_\_ Laboratory \_\_\_\_\_

Operator \_\_\_\_\_ Test No. \_\_\_\_\_ Date \_\_\_\_\_

<b>ENGINE</b>	<b>Specified</b>	<b>Measured</b>
Type of engine		
Number of engine		
Position of engine		
Cycle 2/4 Stroke		
Number of cylinders		
Capacity (cm <sup>3</sup> )		
Bore (mm)		
Stroke (mm)		
Type of injection Direct/Indirect		
Type of combustion chamber		
Compression ratio ( :1)		
Compression pressure (bar)		
Maximum power (kW)		
Valves gap Inlet (mm) Exhaust (mm)		
Heating plugs Make/Type		
Post-Heating Yes/No		
Other starting aids		
Heating of inlet air Yes/No		
Supercharging system Make/Type		
Cooling of supercharged air Yes/No		
High idle speed (rpm)		
Hot Idle speed (rpm)		
Maximum speed no load (rpm)		
Antipollution system EGR Others		
Grade of Oil Temperature/Grade Temperature/Grade		
Oil sump capacity + filter (L)		

## FUEL SYSTEM

Screen	Surface (mm2) Gage (mm)		
Prefilter	Make/Type Position		
Filter	Make/Type Position		
Reheater	Make/Type		
Fuel pump	Make/Type		
Injection pump	Make Type Initial timing(c.a.) Initial timing(mm) Extra advance(c.a.)		
Control system of extra advance			
Control system of extra delivery			
Inlet/transfer injection pump pressure			
Injectors	Make Type Calibration (bar)		
Fuel tank	Capacity (L) Position		

## COOLING SYSTEM

Level of protection	(°C)		
Drive system of cooling fan			
Thermostat opening temperature	(°C)		

## TRANSMISSION

Type gear box		
Manual/Automatic		
Number of gears		
Double ratio	Yes/No	
Front/rear wheel drive		
Speed at 1000 rpm in top gear	(km/h)	
Grade of oil in gear box	Temperature/Grade Temperature/Grade	
Capacity of gear box	(L)	
Axle oil grade	Temperature/Grade Temperature/Grade	
Capacity of axle(s)	(L)	
Tires	Type/Size Pressure (bar)	

## AUXILIARIES (List of the auxiliaries which consume power)


## PERFORMANCES

Maximum speed	(km/h)		
Weight	(kg)		

**Table 2****PREPARATION SHEET FOR TEST VEHICLE**

Make &amp; Model \_\_\_\_\_ Year \_\_\_\_\_

Registration No. \_\_\_\_\_ Chassis No. \_\_\_\_\_ Laboratory \_\_\_\_\_

Operator \_\_\_\_\_ Test No. \_\_\_\_\_ Date \_\_\_\_\_

(S = Startability)

(O = Operability)

S	O		
*	*	Thermocouples No. 1 Cooling system	
*	*	No. 2 Oil in sump	
*	*	No. 3 Inlet air	
*	*	No. 4 Air under hood (optional)	
*	*	No. 5 Fuel at filter entry	
*	*	No. 6 Fuel at injection pump entry	
*	*	No. 7 Fuel in fuel tank	
*	*	No. 8 Fuel outlet injection pump (optional)	
*	*	No. 9 Fuel in pre-filter (if it exists)	
*	*	No. 10 Ambient air	
*	*	Pressure Gauges No. 1 Fuel at pre-filter entry (if it exists)	
*	*	No. 2 Fuel at filter inlet	
*	*	No. 3 Fuel at filter outlet	
*	*	No. 4 Fuel transfer (optional)	
*	*	Calibration of speedometer (optional)	
*	*	Drainage Engine	
*	*	Gearbox	
*	*	Axles	
*	*	New filters Fuel	
*	*	Oil	
*	*	Air	
*	*	Antifreeze mixture Top level	
*	*	Protection	
*	*	Start point of cooling fan	
*	*	Drive belts	
*	*	Thermostat	
*		Battery Check of nominal capacity	
*		Charge	
*	*	Check of electrical circuit Starter	
*	*	Alternator	
*	*	Regulator	

S	O		
*	*	Preheating plugs	Check
*	*		Replacement (optional)
*	*		Operation
*	*		Connection
*		Starting accessories	Specification
*			Operation
*	*	Fuel supply circuit	Cleanliness
*	*		Leak
*	*	Injection pump	Initial timing
*	*		Extra advance
*	*		Hot idle speed
*	*		Maximum speed no load
*	*	Injectors	Calibration
*	*		Replacement heat-shield washer
*	*	Engine	Compressions
*	*		Valve gaps
*	*		Check of air circulation
*	*		Check of fuel system
	*	Tires	

**Table 3**  
**CHARACTERISTICS OF TEST FUEL**

Reference \_\_\_\_\_

Laboratory \_\_\_\_\_ Date \_\_\_\_\_

		<b>Method</b>	<b>Specified</b>	<b>Measured</b>
Density at 15°C	(kg/L)	ASTM D1298*		
Distillation	IBP (°C)	ASTM D86*		
	5 % (°C)			
	10% (°C)			
	20% (°C)			
	30% (°C)			
	40% (°C)			
	50% (°C)			
	60% (°C)			
	70% (°C)			
	80% (°C)			
	90% (°C)			
	95% (°C)			
	FBP (°C)			
Viscosity at 40°C	mm <sup>2</sup> /s	ASTM D445		
Sulfur	ppm	ASTM D5453*		
Cetane Number		ASTM D613		
Cloud Point	°C	ASTM D2500*		
CFPP	°C	ASTM D6371		
LTFT	°C	ASTM D4539		
Pour Point	°C	ASTM D97*		
Water and Sediment	% vol.	ASTM D2709		
Ash	% mass	ASTM D524		
Flash Point				

\* Other tests may be used.

**Table 4**

**Cold Startability Test Results**

Laboratory: \_\_\_\_\_ Date: \_\_\_\_\_ Test No.: \_\_\_\_\_

Make & Model of Engine/Vehicle: \_\_\_\_\_

Registration No.: \_\_\_\_\_ Chassis No.: \_\_\_\_\_ Engine No.: \_\_\_\_\_

Fuel: \_\_\_\_\_ Temperature: \_\_\_\_\_

Time to Start (seconds): \_\_\_\_\_

Time for Engine Speed to Rise (seconds): \_\_\_\_\_

Number of Attempts: \_\_\_\_\_

Number & Time of Stalls: \_\_\_\_\_

Idle Speed (rpm): \_\_\_\_\_

## Attachment 1

### Test Result Reporting

Requestor:				Transmission:				Antifreeze Type:					
Req. Activity:				Axle Ratio:				Evap Case:					
Truck TAG #: Truck A 608097 Detroit Diesel				Mileage:				Plenum:					
TestCell Temp: -21°C				Fuel Type:				R Seat Flr Duct:					
Presoak Temp: -21°C				EEC Calibration:				Heater Core:					
Filter 20 micron				Water Pump:				Blower Motor					
				Thermostat:				Blower Wheel:					
TIME	TIME	AIRTEMP	COOLANT	DYF_Force	DYF_Speed	DYM_Force	DYM_Speed	ENGSPD	FRFFILTER	FRFILTER	FUELTANK	OILPRESS	OILTEMP
HH:MM	HH:MM:SS	C	C	N	kph	N	kph	RPM	C	kPa	C	kPa	C
0:00:00	10:59:13	-21.0	7.5	6.3	0.0	7.0	0.1	-0.4	-18.2	-3.8	-21.0	-5.1	-16.3
0:00:05	10:59:18	-21.0	7.6	2.0	0.0	4.1	0.1	-1.3	-18.2	-3.8	-21.0	-5.1	-16.3
0:00:10	10:59:23	-21.0	7.6	8.5	0.0	7.0	0.1	-0.4	-18.3	-3.8	-21.0	-5.1	-16.3
0:00:15	10:59:28	-21.0	8.3	2.7	0.0	3.3	0.1	896.4	-16.8	-11.7	-21.0	445.7	-16.2
0:00:20	10:59:33	-21.0	6.9	-9.6	0.0	-1.1	0.0	899.1	-16.7	-11.8	-21.0	447.9	-16.4
0:00:25	10:59:38	-21.0	6.6	10.0	0.0	4.8	0.1	892.7	-17.1	-12.0	-21.0	452.1	-15.4
0:00:30	10:59:43	-20.9	6.7	-6.7	0.0	4.1	0.1	892.7	-17.4	-12.1	-21.0	452.1	-14.9
0:00:35	10:59:48	-20.9	6.9	2.7	0.0	4.1	0.1	892.7	-17.6	-12.2	-21.0	439.9	-14.5
0:00:40	10:59:53	-20.9	7.1	-1.6	0.0	4.1	0.1	894.6	-17.9	-12.2	-20.9	432.4	-13.9
0:00:45	10:59:58	-20.9	7.4	2.0	0.0	5.5	0.0	902.8	-18.1	-12.4	-20.8	427.9	-13.0
0:00:50	11:00:03	-20.9	7.7	0.5	0.0	5.5	0.1	903.7	-18.4	-12.5	-20.8	427.1	-12.2
0:00:55	11:00:08	-20.9	8.0	1.3	0.0	4.8	0.1	903.7	-18.6	-12.5	-20.8	432.2	-11.5
0:01:00	11:00:13	-20.9	8.3	1.3	0.0	5.5	0.1	905.5	-18.8	-12.7	-20.8	441.2	-10.6
0:01:05	11:00:18	-20.9	8.6	5.6	0.0	4.8	0.1	906.4	-19.0	-12.8	-20.8	441.8	-9.8
0:01:10	11:00:23	-20.9	9.0	4.9	0.0	5.5	0.1	904.6	-19.2	-13.0	-20.7	444.7	-9.0
0:01:15	11:00:28	-20.8	9.3	5.6	0.0	4.8	0.1	901.8	-19.3	-13.2	-20.6	447.3	-8.4
0:01:20	11:00:33	-20.9	9.6	12.9	0.0	17.3	0.1	899.1	-19.4	-13.4	-20.5	455.3	-7.7
0:01:25	11:00:38	-20.9	10.0	-0.2	0.0	8.5	0.1	905.5	-19.5	-13.6	-20.4	452.4	-7.1
0:01:30	11:00:43	-20.9	10.3	-0.2	0.0	8.5	0.1	905.5	-19.6	-13.9	-20.4	451.3	-6.3
0:01:35	11:00:48	-20.8	10.7	-0.9	0.0	4.1	0.1	905.5	-19.7	-14.1	-20.4	447.9	-5.5
0:01:40	11:00:53	-20.8	11.0	0.5	0.0	4.8	0.1	902.8	-19.8	-14.4	-20.3	459.6	-4.9
0:01:45	11:00:58	-20.8	11.3	7.1	0.0	7.0	0.1	903.7	-19.9	-14.7	-20.2	455.6	-4.2
0:01:50	11:01:03	-20.8	11.6	1.3	0.0	4.1	0.1	902.8	-19.9	-14.9	-20.2	452.4	-3.5
0:01:55	11:01:08	-20.8	12.0	1.3	0.0	4.1	0.1	902.8	-19.9	-15.4	-20.1	449.7	-2.7
0:02:00	11:01:13	-20.8	12.2	3.4	0.0	6.3	0.1	899.1	-20.0	-15.6	-20.1	477.2	-2.6

## Attachment 2 - CRC Test Index and Vehicle Information

Test No.	Test Date	File Name	Vehicle	Fuel	Test Temp	Passed / Failed	Tank T @ start	TOHTR T @ start	No.Cranks to Start	Comments
1	4/24/2006	CR042406A	JP	A	-26	Pass	-26.6	-5.8	1	
2	4/24/2006	CR042406B	VW	A	-26	Pass	-27.1	-25.6	3	No block heater. Engine rpm building up while cranking. Started at 28s in third 30s cranking period.
3	4/24/2006	CR042406C	FD	A	-26	Invalid	-25.1	-24.9	4	No engine block heater
4	4/24/2006	CR042406D	GM	A	-26	Fail	-26.8	-6.6	1	Lost speed and power during 60 kph phase
5	4/24/2006	CR042406E	DG	A	-26	Pass	-26.6	-4.6	1	Filter outlet pressure remained low until end of test
6	4/25/2006	CR042506A	GM	A	-24	Fail	-24.8	-19.7	1	
7	4/25/2006	CR042506B	VW	A	-28	Invalid	-28.6	-28.3	5	No start after 5 cranking tries.
8	4/25/2006	CR042506C	DG	A	-28	Pass	-27.9	5.5	1	Filter outlet pressure remained low until end of test. After test ended, put 1% grade on load. Maintained speed. Put 2% grade on load, vehicle lost speed and stalled.
9	4/25/2006	CR042506D	JP	A	-28	Fail	-27.7	-14.5	5	Vehicle would not accelerate at the normal rate. After test, tried acceleration at lower rate. Vehicle could get up to speed of 60 kph and 110 kph, but could not maintain speed at 110 kph.
10	4/26/2006	CR042606A	GM	A	-18	Pass	-18.1	-11.1	1	Filter outlet pressure dropped to -80 kPa until filter inlet pressure reached ~ -11 C, then recovered to -22 kPa at test end.
11	4/26/2006	CR042606C	VW	B	-26	Pass	-26.1	-6.3	1	Engine block heater installed.
12	4/26/2006	CR042606D	JP	B	-26	Pass	-26.4	-8.9	1	
13	4/26/2006	CR042606E	DG	B	-26	Fail	-26.6	10.4	1	
14	4/26/2006	CR042606F	FD	A	-26	Fail	-26.5	-16.4	1	Lost speed and power with 1 min. of reaching 110 kph phase
15	4/27/2006	CR042706A	VW	B	-28	Pass	-27.9	-18.0	4	Started at end of third cranking attempt. Heater warmed up block to -21 C only due to wind blow down
16	4/27/2006	CR042706B	FD	B	-24	Pass	-24.7	-7.4	1	
17	4/27/2006	CR042706C	DG	B	-24	Pass	-24.9	16.1	1	

## Attachment 2 - CRC Test Index and Vehicle Information

Test No.	Test Date	File Name	Vehicle	Fuel	Test Temp	Passed / Failed	Tank T @ start	TOHTR T @ start	No.Cranks to Start	Comments
18	4/27/2006	CR042706D	GM	B	-24	Fail	-24.8	-11.6	1	
19	5/1/2006	CR050106A	GM	C	-29	Fail	-28.5	-18.9	1	Could not accelerate, even at full 'throttle' beyond the 60 kph phase.
20	5/1/2006	CR050106B	FD	C	-33	Invalid	-32.5	-0.9	1	Turbocharger shaft broke shortly after test started
21	5/1/2006	CR050106C	DG	C	-33	Pass	-31.9	12.2	1	Filter out pressure remained low (~84 kPa) until end of test.
22	5/1/2006	CR050106D	JP	C	-33	Pass	-33.0	-9.9	2	
23	5/1/2006	CR050106E	VW	C	-33	Pass	-33.0	15.9	1	
24	5/2/2006	CR050206A	GM	C	-25	Pass	-24.9	-15.9	1	
25	5/2/2006	CR050206B	DG	C	-35	Fail	-34.4	0.5	1	Lost power at ~22 min. into 110 kph phase.
26	5/2/2006	CR050206D	JP	C	-35	Pass / Invalid	-34.8	-3.2	~9	Engine starting problem. Started once after 5 tries. Found air in fuel system. Removed air, engine started after 3 tries. Test not valid due to other parameters.
27	5/2/2006	CR050206E	VW	C	-35	Pass	-36.0	-0.5	2	
28	5/3/2006	CR050306A	GM	C	-27	Fail	-26.8	-25.9	2	Could not accelerate from 60 kph
29	5/3/2006	CR050306B	DG	D	-37	Fail	-36.4	3.3	1	Lost power ~ 14 min into 110 kph phase
30	5/3/2006	CR050306C	VW	C	-37	Pass	-36.7	-12.4	2	
31	5/3/2006	CR050306D	JP	C	-37	Pass	-36.5	-20.2	7	Initially very hard to start. A total of 7 tries. No engine rpm signal
32	5/4/2006	CR050406A	GM	D	-27	Pass	-26.7	-23.9	1	
33	5/4/2006	CR050406B	DG	D	-35	Pass	-34.5	8.7	1	
34	5/4/2006	CR050406C	VW	D	-35	Pass	-35.7	-3.4	2	
35	5/4/2006	CR050406D	JP	D	-35	Pass	-35.6	-17.7	7	Very hard to start. Total of 7 tries.
36	5/8/2006	CR050806A	GM	D	-29	Fail	-29.2	-23.5	1	Could not accelerate to 110 kph phase
37	5/8/2006	CR050806B	DG	E	-37	Fail	-36.9	3.2	1	Lost power/speed at ~20 min into 110 kph phase
38	5/8/2006	CR050806C	FD	D	-37	Fail	-37.2	-24.4	1	Lost speed and power at ~ 3 min. into 110 kph phase
39	5/8/2006	CR050806D	VW	D	-37	Pass	-37.5	-5.3	2	
40	5/8/2006	CR050806E	JP	D	-37	Pass	-37.1	-13.3	5	

## Attachment 2 - CRC Test Index and Vehicle Information

Test No.	Test Date	File Name	Vehicle	Fuel	Test Temp	Passed / Failed	Tank T @ start	TOHTR T @ start	No.Cranks to Start	Comments
41	5/9/2006	CR050906A	GM	E	-29	Fail	-29.1	-27.4	1	Could not accelerate to 110 kph
42	5/9/2006	CR050906B	DG	E	-35	Pass	-35.4	5.9	1	
43	5/9/2006	CR050906C	FD	E	-35	Pass	-35.2	-22.2	1	
44	5/9/2006	CR050906D	VW	E	-35	Pass	-34.6	-21.4	2	
45	5/9/2006	CR050906E	JP	E	-35	Pass	-33.4	-7.8	1	
46	5/10/2006	CR051006A	GM	E	-27	Fail	-27.1	-17.9	1	Could not accelerate to 110 kph phase
47	5/10/2006	CR051006B	FD	E	-37	Pass	-36.1	-23.3	1	Fuel filter pressure continued to drop throughout the whole cycle. Filter in < 10 kPa
48	5/10/2006	CR051006C	VW	E	-37	Pass	-37.6	-0.7	3	
49	5/10/2006	CR051006D	JP	E	-37	Pass	-37.1	-14.4	3	
50	5/11/2006	CR051106A	GM	E	-25	Fail	-25.1	-14.7	1	
51	5/11/2006	CR051106B	FD	G	-32	Fail	-31.7	-18.3	3	Could not accelerate to the 110 kph phase
52	5/11/2006	CR051106C	DG	G	-32	Pass	-33.2	12.4	1	
53	5/11/2006	CR051106D	VW	G	-32	Pass	-33.0	10.9	1	
54	5/11/2006	CR051106E	JP	G	-32	Pass	-32.4	-9.4	2	
55	5/15/2006	CR051506A	GM	E	-23	Pass	-23.3	-17.8	1	
56	5/15/2006	CR051506B	FD	C	-34	Pass	-34.2	-25.1	1	
57	5/15/2006	CR051506C	DG	G	-34	Pass	-35.0	8.9	1	
58	5/15/2006	CR051506D	VW	G	-34	Pass	-35.2	-0.1	1	Return fuel regulator valve cycled causing short term unstable speed
59	5/15/2006	CR051506E	JP	G	-34	Pass	-34.4	-8.8	1	
60	5/16/2006	CR051606A	GM	G	-28	Fail	-28.0	-27.8	1	Could not accelerate to 60 kph phase
61	5/16/2006	CR051606B	JP	G	-36	Fail	-36.6	-15.7	7	7 cranking attempts. Engine fired several times but stalled immediately. Filter out pressure down to -93 kPa.
62	5/16/2006	CR051606C	DG	G	-36	Pass	-36.3	2.8	1	
63	5/16/2006	CR051606D	FD	C	-36	Fail	-36.1	-20.6	1	Lost speed and power 11 min. into 110 kph phase.
64	5/17/2006	CR051706A	GM	G	-24	Pass	-24.3	-20.1	1	
65	5/17/2006	CR051706B	JP	J	-35	Pass	-35.9	-15.2	2	
66	5/17/2006	CR051706C	DG	J	-35	Fail	-34.3	-3.0	1	Could not accelerate to 110 kph
67	5/17/2006	CR051706D	FD	J	-35	Pass	-34.2	-29.6	1	

## Attachment 2 - CRC Test Index and Vehicle Information

Test No.	Test Date	File Name	Vehicle	Fuel	Test Temp	Passed / Failed	Tank T @ start	TOHTR T @ start	No.Cranks to Start	Comments
68	5/18/2006	CR051806A	GM	G	-26	Pass	-26.2	-23.5	1	
69	5/18/2006	CR051806B	JP	J	-37	Fail	-37.4	-16.9	9	9 cranking attempts with repeat stalling. High vacuum in filter outlet pressure
70	5/18/2006	CR051806C	FD	J	-37	Fail	-36.9	-29.5	1	Could not accelerate to 60 kph phase
71	5/18/2006	CR051806D	DG	G	-37	Fail	-37.4	-7.8	1	Could not accelerate to 110 kph phase
72	5/19/2006	CR051906A	GM	I	-24	Fail	-24.1	-23.7	1	Engine started and idled for 2.5 min. Stalled when attempted to accelerate to 60 kph.
73	5/19/2006	CR051906B	JP	I	-30	Fail	-30.5	-9.1	1	Started and idled for 2.5 minutes. Stalled when accelerating to 60 kph.
74	5/19/2006	CR051906C	DG	I	-30	Fail	-30.7	9.8	1	Lost speed and power 23 min. into 110 kph phase
75	5/19/2006	CR051906F	FD	I	-30	Fail	-30.3	-1.1	3	Could not accelerate to 110 kph phase
76	5/23/2006	CR052306A	GM	I	-22	Fail	-22.2	-19.8	1	Could not accelerate to 60 kph
77	5/23/2006	CR052306B	JP	I	-28	Pass	-29.2	-6.3	1	
78	5/23/2006	CR052306C	DG	I	-29	Fail	-29.3	15.3	1	Lost speed and power 7 min. into 110 kph phase
79	5/23/2006	CR052306D	FD	I	-29	Fail	-29.3	-15.6	1	Lost speed and power during 60 kph phase
80	5/24/2006	CR052406A	GM	I	-20	Fail	-20.2	-9.2	1	Lost power during 60 kph phase
81	5/24/2006	CR052406B	DG	I	-27	Pass	-27.2	15.9	1	
82	5/24/2006	CR052406C	FD	I	-28	Fail	-28.1	-20.2	1	Could not accelerate to 110 kph phase
83	5/24/2006	CR052406D	JP	B	-28	Fail	-28.3	-5.3	1	Engine stalled during acceleration from 60 kph to 100 kph phase
84	5/25/2006	CR052506A	GM	I	-18	Fail	-18.2	-12.7	1	Could not reach 110 kph during acceleration from 60 kph
85	5/25/2006	CR052506B	DG	F	-17	Pass	-17.0	24.2	1	
86	5/25/2006	CR052506C	FD	F	-17	Pass	-16.8	-10.6	1	
87	5/25/2006	CR052506D	JP	F	-17	Pass	-17.1	-0.3	1	
88	5/26/2006	CR052606A	GM	I	-18	Pass	-18.3	-13.8	1	Repeat of the borderline failed test of previous day. Similar run up but completed drive cycle.
89	5/26/2006	CR052606B	DG	F	-20	Pass	-19.9	16.7	1	

## Attachment 2 - CRC Test Index and Vehicle Information

Test No.	Test Date	File Name	Vehicle	Fuel	Test Temp	Passed / Failed	Tank T @ start	TOHTR T @ start	No.Cranks to Start	Comments
90	5/26/2006	CR052606C	FD	F	-20	Fail	-20.0	-13.7	1	Lost speed and power ~ 4 min into 110 kph phase. After ~ 5 minutes of reduced speed at max fuel, vehicle resumed 110 kph speed for rest of cycle.
91	5/26/2006	CR052606D	JP	F	-20	Pass	-20.7	3.9	1	
92	5/26/2006	CR052606E	VW	F	-20	Pass	-20.6	-3.8	1	
93	5/29/2006	CR052906A	GM	F	-14	Pass	-14.7	-12.2	1	
94	5/29/2006	CR052906B	FD	A	-24	Fail	-23.8	-21.6	1	Could not accelerate to 110 kph phase
95	5/29/2006	CR052906C	JP	F	-23	Pass	-23.1	-0.8	1	
96	5/29/2006	CR052906D	VW	F	-23	Pass	-23.3	19.4	1	
97	5/29/2006	CR052906E	DG	F	-23	Pass	-23.3	6.6	1	
98	5/30/2006	CR053006A	GM	F	-16	Fail	-16.6	-12.2	1	Could not accelerate to 60 kph
99	5/30/2006	CR053006B	JP	F	-25	Fail	-24.9	-14.0	5	Stalled several times during idle. Stalled again during acceleration to 60 kph
100	5/30/2006	CR053006C	FD	A	-22	Fail	-22.4	-9.7	1	Lost speed and power ~ 8 min. into 110 kph phase
101	5/30/2006	CR053006D	VW	F	-26	Fail	-26.1	-14.7	1	Lost power and speed ~ 19 min. into 110 kph phase
102	5/30/2006	CR053006E	DG	F	-25	Pass	-25.2	14.0	1	
103	5/31/2006	CR053106A	GM	A	-20	Fail	-20.2	-19.6	1	Could not accelerate to 60 kph
104	5/31/2006	CR053106B	FD	G	-30	Pass	-30.1	-24.2	1	
105	5/31/2006	CR053106C	DG	A	-30	Fail	-30.1	4.1	1	Could not accelerate from 60 kph to 110 kph phase
106	5/31/2006	CR053106D	VW	B	-30	Pass	-29.6	-33.2	1	
107	6/1/2006	CR060106A	DG	J	-33	Fail	-32.7	-5.4	1	Could not accelerate from 60 kph to 110 kph phase.
108	6/1/2006	CR060106B	VW	I	-29	Pass	-29.2	6.0	1	
109	6/1/2006	CR060106C	GM	J	-26	Pass	-27.1	-18.2	1	
110	6/1/2006	CR060106D	FD	B	-26	Fail	-27.2	-19.7	1	Could not accelerate from 60 kph to 110 kph phase
111	6/1/2006	CR060106E	JP	B	-28	Fail	-27.9	-8.5	4	Engine repeatedly stalled at idle. High suction (negative pressure) at outlet of fuel filter

## Attachment 2 - CRC Test Index and Vehicle Information

Test No.	Test Date	File Name	Vehicle	Fuel	Test Temp	Passed / Failed	Tank T @ start	TOHTR T @ start	No.Cranks to Start	Comments
112	6/2/2006	CR060206A	FD	A	-20	Fail	-20.4	-20.0	1	Lost speed and power ~ 5 min. into 110 kph phase
113	6/2/2006	CR060206B	GM	J	-29	Fail	-29.3	-21.7	1	failed to accelerate to 60 kph
114	6/2/2006	CR060206C	DG	J	-31	Pass	-30.9	12.2	1	
115	6/2/2006	CR060206D	VW	I	-30	Pass	-30.8	4.0	1	
116	6/2/2006	CR060206E	JP	I	-30	Fail	-29.7	-10.9	1	Started and idled for 2.5 min. Stalled repeatedly when accelerating to 60 kph phase.
117	6/5/2006	CR060506A	GM	B	-20	Fail	-20.3	-17.0	1	Could not accelerate to 60 kph phase
118	6/5/2006	CR060506B	DG	F	-27	Pass	-27.5	6.8	1	
119	6/5/2006	CR060506C	JP	I	-29	Fail	-29.3	-12.5	4	Repeatedly stalled during idle.
120	6/5/2006	CR060506D	VW	B	-32	Pass	-31.8	-19.6	1	
121	6/5/2006	CR060506E	FD	D	-35	Pass	-35.0	-17.2	3	

**CRC Report No. DP-2-04-2**

**EVALUATION OF LOW  
TEMPERATURE OPERABILITY FOR  
LIGHT-DUTY DIESEL VEHICLES FOR  
NORTH AMERICA**

**DATA ANALYSIS REPORT**

**November 2007**



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**EVALUATION OF LOW TEMPERATURE  
OPERABILITY FOR LIGHT-DUTY DIESEL  
VEHICLES FOR NORTH AMERICA  
CRC Project No. DP-2-04-2**

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## **ABSTRACT**

A test program was conceived and designed by the Low Temperature Operability Panel of the CRC Diesel Performance Group to evaluate the correlation between laboratory bench test results and actual North American light-duty diesel vehicle low temperature operability performance. A set of 9 cold flow treated fuels were prepared covering the estimated operability range of -9°C to -37°C. Five commercially available late model light-duty diesel vehicles were selected for the test program. A specific vehicle test protocol was used and the operability limits determined for each fuel/vehicle combination. Commonly used laboratory tests (Cloud Point, CFPP, LTFT and SFPP) for estimating fuel low temperature operability limits were used by multiple laboratories to evaluate the test fuels for comparison with the actual vehicle performance.

## **I. SUMMARY**

Vehicle testing was conducted at Imperial Oil, All Weather Chassis Dynamometer, in Sarnia, Ontario, Canada, during the Spring and Summer of 2006 to establish the minimum operating temperatures for 9 cold flow additive-treated fuels in five late model, light-duty vehicles. The test temperature range covered was from -14°C to -37°C with fuels having Cloud Points of -9°C to -25°C. CRC Report DP-2-04-1 on the vehicle testing and a CD containing all the test data was issued in August 2006.

Samples of each fuel blend were collected and sent to labs for analysis of physical properties as well as low temperature laboratory testing. Samples from the vehicle tanks after each test were also collected in case confirmation of the fuel that was tested was required. The low temperature laboratory tests run included Cloud Point (ASTM D 2500 or alternate automated test methods), Cold Filter Plugging Point (ASTM D 6371 – CFPP), and Low Temperature Flow Test (ASTM D 4539 – LTFT). In addition one laboratory was asked to run the less widely used Simulated Filter Plugging Point (IP 419 - SFPP) test.

Vehicles were conditioned either on the dynamometer itself or in the adjoining independently cooled, cold soak room. Four or five vehicles were tested per day using single temperature/vehicle/fuel combinations. The original test protocol was to start the vehicle, idle for 30 seconds before accelerating to 60 kph, hold at that speed for 3 minutes 35 seconds, then accelerate to 110 kph and hold for 30 minutes. After a few tests, the initial idle period had to be extended to 2 minutes 30 seconds to protect the turbochargers.

An estimated minimum operating temperature (EMOT) was determined for each vehicle/fuel combination. The results showed large differences in performance among vehicles and fuels. Cloud Point, as expected, was the most conservative estimate of performance and protected all the vehicles, but considerable variation in operability was observed below the Cloud Points. Cold Flow additive treatment gave significant performance below Cloud Point. Average EMOT performance below Cloud Point was >7°C.

LTFT was the next best test for protecting all vehicles. Although the operability performance below LTFT was less than for Cloud Point, the operability giveaway was still significant.

One vehicle consistently underperformed the other vehicles for low temperature operability. Two vehicles gave very similar performance and two vehicles gave performance well below that predicted by any of the laboratory tests.

## **II. INTRODUCTION**

Low temperature operability has always been an issue with middle distillate fuels because they contain straight and branched chain hydrocarbons (paraffin waxes). These waxes precipitate as crystals depending on their concentrations and ambient temperatures in the geographic area. When this happens, the wax may plug the fuel filter, reduce pumpability or it may completely gel the fuel, making it impossible for the fuel system to deliver sufficient fuel to the engine. The end result can be stumbling or in severe cases of wax formation, the vehicle may not start.

The introduction of <15 ppm Sulfur diesel fuel in 2006 has raised concerns as to whether the low temperature performance of these new fuels will be adequately predicted and the vehicles protected by existing laboratory low temperature operability tests.

Previous work conducted by the CRC (CRC Report No. 463, June 1973 and CRC Report No. 528, September 1983) have shown that both vehicle fuel system design and fuel properties are important in determining the susceptibility of a particular diesel vehicle operating on a particular fuel to filter plugging and other low-temperature operational problems. Some of these investigations have also shown substantial benefits in low-temperature operation when middle distillate flow improvers are included in the fuel.

The successful introduction of an extensive passenger fleet of light-duty diesel (LDD) vehicles in North America will require consumer satisfaction. This satisfaction will be impeded if extensive winter operability problems plague the end user. The first step in precluding this problem is to have a practical bench test that adequately estimates the low temperature operability of diesel fuel relative to LDDs in North America.

The purpose of this project was to obtain data on the low-temperature performance of a wide variety of LDD fuel systems operating on a representative sampling of on road <15 ppm Sulfur diesel fuels under real-world temperature conditions. The data generated are being used to evaluate current laboratory test methods that characterize the low-temperature performance of diesel fuels in light-duty equipment and to determine if any or all of these test procedures still provide adequate protection. If the determination was that no existing laboratory test adequately protected these vehicles under test, then recommendations would be made to develop a new laboratory test.

### III. CONCLUSIONS

1. No laboratory test predicted low temperature performance in all vehicles for all fuels.
2. Of the individual tests, Cloud Point protected all the vehicles for all fuels, but the low temperature performance below Cloud Point was significant for every fuel/vehicle combination.
3. LTFT was the next best test for protecting all vehicles for all fuels. Although the operability performance below LTFT was less than for Cloud Point, the operability giveaway was still significant. LTFT, which was designed to correlate with a specific heavy-duty fuel deliver system, better predicted the most severe vehicle in this study because the vehicle's fuel delivery system was the most similar to the heavy-duty design.
4. CFPP protected four of the five vehicles under test. The overall fit to the CFPP data improve if the Cloud Point –CFPP difference is not greater than 10°C as recommended by the test method and the European experience.
5. The SFPP test results were only generated by one lab and analysis of the data suggested it performed similar to CFPP.
6. All of the tests showed significantly more give away in performance in the higher Cloud Point fuel blends than in the lower Cloud Point fuels.
7. Significant differences in low temperature performance were observed for the five LDD vehicles tested.
  - a. One vehicle was found to be much more severe than the other four. The severity is attributed to the placement of the filter on the suction side of the transfer pump, the low filter porosity, and the undersized filter heater.
  - b. The least severe of the test vehicles had the highest porosity filter as well as the use of a thermostatically controlled system to bypass hot return fuel to the filter to assist in preventing wax build-up.

### IV. RECOMMENDATIONS

No one test can predict low temperature performance in all vehicles for all fuels due to design differences and operating conditions, so it comes down to choosing the test that best fits the need and minimizes risk. LTFT and CFPP, which are the most commonly used for estimating additive performance in vehicles, should cover nearly all of the LDD vehicles in the marketplace.

Either of these tests could be used depending on the level of risk. LTFT is the more conservative test and protected all the vehicle/fuel combinations, but it takes many hours to run and the operability giveaway in this study was very large. CFPP did not protect one vehicle very well, but was very effective in protecting the other four with less performance giveaway.

In situations where it is known that more severe fuel delivery designs are in use or where the acceptable risk must be at a minimum, then Cloud Point or LTFT should be considered.

The CFPP test takes much less time to get a result than LTFT, so the chances are greater that fuel suppliers will be able to provide test results in a timely manner for the fuels they provide. Also, CFPP being the faster test is a test procedure offered by many more independent test labs and also provides the end user or fuel purchaser with more opportunities for checking fuels to make sure they are in compliance.

It is recommended that if CFPP is used, then a maximum Cloud Point minus CFPP differential of 10°C ( $\text{Cloud-CP} \leq 10^\circ\text{C}$ ) should also be used to limit overestimating low temperature performance.

SFPP may be a third test to consider, but more testing would be required and the limited results in this study do not indicate much improvement over CFPP.

## **V. TEST FUELS**

The Grade No. 2 and No. 1 <15 ppm sulfur diesel fuels were donated by BP Products NA and Chevron USA.

### **1. Selection Criteria**

It was agreed that the test fuels should address the following:

- All fuels and fuel blends would be <15 ppm sulfur commercial diesel fuels
- Grade No. 2 fuels and at least one Grade No. 1 fuel would be used to blend Cloud Point fuels to cover the -10°C to -35°C performance range.
- Cloud Point targets would be approximately -10°C and -22°C to allow for cold flow additive treatment to -22°C and -35°C, respectively. These targets were based on existing information that laboratory test predictions may be limited to about 10°C below Cloud Point.
- Fuel blends were to be pre-tested for additive response by Cloud Point, CFPP, LTFT, and Pour Point.
- In the selection process, CFPP and LTFT were to be the primary and secondary response criteria. In general, the expectation was that the additives should be capable of providing 10°C or more response below Cloud Point by CFPP and in some cases at higher treat rates to provide 6°C or more LTFT response below Cloud Point.
- By CFPP or LTFT laboratory testing some additive/fuel blends must suggest more than 10°C performance below Cloud Point.

Two Grade No. 2, <15 ppm sulfur diesel fuels and one Grade No. 1, <15 ppm sulfur diesel fuel were provided (Table 1); blends from the fuels were prepared and additive response curves were generated. Table 2 lists the results of the preliminary additive testing. The test results were generated by one lab, but it was agreed that multiple labs would be involved in the testing of the actual fuel/fuel blends used in vehicle testing.

After panel discussion the fuel additive combinations in Table 3 were selected for vehicle testing.

Tables 4 and 5 provide the physical fuel properties and the low temperature characteristics for the actual finished fuel blends used at the vehicle testing facility. Multiple test labs were involved in this process. Table 6 lists the average laboratory low temperature test performance showing the variability associated with each test.

## **VI. TEST VEHICLES**

This test program was restricted to five LDD vehicles consisting of three pick-up style trucks, one sport utility vehicle and a passenger car. Four of the vehicles were donated for the test program by vehicle manufacturers and the model choice was left up to them to decide which designs would be of greatest interest. One vehicle was donated for the test program by an oil company from their test fleet, and it is of a newer common rail design. All of the test vehicles were late models and very recently sold in N. America.

A list of the companies providing vehicles and a description of the vehicles is provided in Table 6. Figures 1 to 5 describe the fuel delivery design for each vehicle.

For more information on the vehicles and instrumentation set up refer to CRC Report DP-2-04-1.

## **VII. TEST PROCEDURES**

Refer to CRC Report Number DP-2-04-01 for additional details.

The technical committee of CRC prepared a Test Protocol for the evaluation of a low temperature operability prediction test. The test procedure of this program followed that protocol with two modifications as below:

1. The batteries of the test vehicles were not removed during overnight soaking to test temperature. Instead, a dedicated battery for each vehicle was fully charged at room temperature, then moved into the test cell and connected to the vehicle just prior to starting of the vehicle.
2. The protocol specified the following sequence: start the engine; idle the engine for 30 seconds; accelerate to 60 kph; hold for 3 minutes 35 seconds; accelerate to 110 kph; hold for 30 minutes. On the sixth day of testing when the test temperature reached -33 °C for the first time, a turbocharger failure was encountered in the Ford F350 vehicle. It was concluded that under very cold temperatures, the 30 seconds idle after engine start-up was not long enough to allow the engine oil to reach and lubricate certain parts of the engine. From that point on, the engine idle time after start-up was lengthened to 2 minutes 30 seconds from 30 seconds.

The daily logistics of testing is described below:

- Up to 5 test vehicles were prepared per day to be soaked overnight per the Test Protocol to the test temperatures. Fuel tank temperature for each vehicle and air temperature data were collected at a rate of 12 times per hour during the soak. The

starting temperatures of the cool-down were determined according to the cloud points of the fuels.

- Fully charged, warm (above 20°C) batteries were used to start each vehicle following the OEM recommended starting procedure.
- Operability procedure per the Test Protocol was used following start-up. Data acquisition rate at 1 per second was used for the whole cycle. Evaluation of both startability and operability were done as per the Test Protocol.
- Test results determined test parameters for the next day. Very close contact was maintained with a CRC technical committee member to make the daily decisions.
- Prepare vehicles (fuel changes, oil changes, if necessary) for the next day.
- Soaked vehicles overnight for the next day tests.

## **VIII. DISCUSSION OF RESULTS**

### Data Base

The raw data for this test program is available from CRC on a CD. The test parameters monitored during the overnight cool down are given in Table 7.

The test parameters for the actual dynamometer testing are described in Table 8.

The measurement parameters may vary slightly for specific vehicles. For example Vehicle 2 had two filters (one before and one after the transfer pump), so additional temperature and pressure transducers were used.

The data are reported at one and ten second intervals. Each test is stored as a workbook providing an easy way to plot the data. An attempt was made to use a demerit based system to evaluate each test and the results are provided in each workbook. However, the demerit system did not provide much insight because as mentioned earlier the tests were either clear passes (low demerits) or clear failures (no demerits because the vehicle did not complete the test) (Table 9).

The planned test protocol was to start the vehicle, idle for 30 seconds before accelerating to 60 kph, hold at that speed for 3 minutes 35 seconds, then accelerate to 110 kph and hold for 30 minutes. After a few tests and damage to the turbocharger in one of the vehicles, the initial idle period had to be extended to 2 minutes 30 seconds to allow oil to flow into the turbochargers and provide adequate lubrication. Figures 6 and 7 describe the start-up portion of a test and a typical completed test, respectively. The speed and the temperatures and pressures measured at various points along the fuel delivery and return system are normally plotted versus time, but any of the parameters in Table 8 could be included.

The example of overnight cool down temperature data shown in Figure 8 indicates the tank temperature lags behind the air temperature by approximately 2-3°C.

Table 9 summarizes all tests results with brief comments.

## Analysis Rationale

In order to establish a minimum operating temperature for each vehicle-fuel combination, the result of each test at each temperature was categorized as a Pass, Borderline Pass, Borderline Fail, or Fail. The criteria or description of each category used was described in CRC Report No. 528, “1981 CRC Diesel Fuel Low-Temperature Operability Field Test” (CRC Project No. CD-15-69) as follows:

Pass – The vehicle started and completed the trip with no more than minor driveability complaints (rating of 1).

Borderline Pass – The vehicle started and completed the trip with no more than minor driveability complaints, but excessive pressure drops occurred across one or more fuel filters during the trip (rating of 2).

Borderline Fail – The vehicle started and completed the trip, but could not reach or maintain 88 km/h during the test because of fuel waxing (as confirmed by pressure data) (rating of 3).

Fail – The vehicle would not start, or started but did not complete the trip, because excessive fuel waxing produced stalling or extremely slow speeds (rating 4).

To apply the criteria to the tests from this program one needs to establish what temperature will be used for each test. In field testing, the test temperature is generally accepted to be the minimum fuel tank temperature during the overnight cool down. However, in cold room/dynamometer testing where temperature is better controlled, the minimum temperature is generally the fuel tank temperature at the start of the test.

Using the start of test tank temperature and the 1 to 4 categories, we find that the vast majority of the tests fall into either 1 or 4 categories. Of the 121 tests, only 3 or 4 tests could be placed in the 2 category and possibly 1 test in the 3 category. The 2 and 3 category results will be further discussed in the specific vehicle and fuel analysis.

## Comparison of Fuel Performance in Each Vehicle

Figures 9-13 show the test results for the nine fuels in each of the five vehicles. Overall, the results show that the minimum operating temperatures were closely bracketed for those cases where a lowest pass and highest fail were determined. These data clearly show the advantage of the dynamometer approach for evaluating low temperature performance. The test program was not at the mercy or whim of ambient conditions, and precise temperature control was possible.

Graphical examples of passing and failing vehicle tests for each vehicle may be found in Appendix-Section C.

## Vehicle 1

The results in Figure 9 were generated with Vehicle 1 for the 9 test fuels. A total of 26 valid test runs were obtained for this vehicle. Except for Fuel F, minimum Passing and maximum Failing temperatures were determined. In Fuel F, 5 tests were run but all 5 gave passing results.

Thirteen runs in Vehicle 1 were clear Passes (Rating of 1). Three test runs could be considered as Borderline Pass (Rating of 2), and the remaining 10 test runs were clear Fails (Rating of 4). No Borderline Fail (Rating of 3) test runs were observed.

Vehicle 1 was equipped with a 10  $\mu$ m porosity filter located on the output or high pressure side of the transfer pump, which was located in the fuel tank. In the Borderline Pass cases, it was noticed that the filter pressure was quite high and as an experiment at the end of the test run in this vehicle the load was changed to simulate 1 and 2 degree inclines to see what impact it would have on the vehicle's performance. The 2 degree incline was found to be enough to cause the vehicle to lose power and speed, suggesting that the Borderline situation could result in vehicle failure under the right circumstances.

The Vehicle 1 failure mode in all cases was the result of filter blockage as indicated by the high filter pressure during acceleration to the 110 kph phase or in maintaining 110 kph.

### Vehicle 2

Figure 10 describes 21 test runs that were carried out with Vehicle 2. Lowest Pass and Highest Fail temperatures were determined for all fuels except with Fuel A where 4 failing results were obtained, and Fuel E where only 2 passing tests were run. In both cases, further testing was not carried out due to time constraints.

Eight of the 21 runs can be classified as a 1 (clear pass) and the other 13 were clear failures or a rating of 4.

The Vehicle 2 was equipped with a 5 micrometer filter located on the output or high pressure side of the transfer pump, which was located outside the tank.

The typical failure mode for the Vehicle 2 was failing to accelerate to the 110 kph mode or failing to maintain the 110 kph mode.

### Vehicle 3

Figure 11 describes 26 test runs that were carried out in the Vehicle 3. Lowest Pass and Highest Fail temperatures were determined for all fuels except Fuel B where only 2 failing tests were run. In Fuel I, a Borderline result may have been achieved since on repeated tests where the tank temperatures were almost identical, Passing and Failing results were obtained.

Eight of the 26 runs can be classified as a 1 (Clear Pass) and 16 were clear failures or had a rating of 4. The remaining two runs using Fuel I could be classified as a Borderline

Pass and a Borderline Fail because they were almost identical fuel tank temperatures at the start of test.

The Vehicle 3 was equipped with a 2 micrometer filter located on the suction or low pressure side of the transfer pump, which was outside the tank and also served as the injector pump.

The typical failure mode for the Vehicle 3 was to failing to accelerate to the 110 kph mode or failing to maintain the 110 kph mode.

#### D. Vehicle 4

Figure 12 describes the 23 pass/fail results for Vehicle 4. Lowest Pass and Highest Fail determinations were completed in five of the nine fuels. Fuels C, D and E passed all the way down to -37°C, and it was decided not to test any lower since results were already well below the predicted limits for these fuels. A passing result was not obtained for Fuel I due to scheduling issues.

Of the tests run, all were either clear passes or a 1 rating or clear failures or 4. Vehicle 4 was equipped with a 3 micrometer porosity filter located on the output or high pressure side of the transfer pump, which was located in the fuel tank.

#### E. Vehicle 5

Figure 13 describes the 18 pass/fail results for Vehicle 5. We were only able to generate a failing result in Fuel F using Vehicle 5. Vehicle 5 was by far the best to operate at low temperatures once a block heater was installed. In early testing without a block heater, Vehicle 5 would not operate below about -24°C regardless of the additive or the responsiveness of the fuel.

Of the tests run, all were either clear passes or 1 or clear failures or 4. Vehicle 4 was equipped with a 23 micrometer porosity filter located on the output or high pressure side of the transfer pump, which was located in the tank.

#### Minimum Operating Temperature Ranges For Each Vehicle-Fuel Combination

The data graphically represented in Figures 10 to 23 may be used to establish minimum operating temperature ranges for each vehicle-fuel combination. Table 10 lists these ranges. The minimum passing temperature (MPT) represents the lowest temperature at which a Pass, a Borderline Pass, or a Borderline Pass/Fail combination was obtained. The maximum fail temperature or MFT represents the highest temperature at which a Fail result was obtained. Missing values indicate that either a no passing or a no failing condition was achieved.

In previous CRC work, the difference between the Lowest Pass (rating 1) and the Highest Fail (rating 4) was calculated and the EMOT was arbitrarily decided to be 1/3 of the temperature difference above the Maximum Fail temperature or 2/3 below the

Lowest Passing result. In their situation, they had significantly larger differences between Lowest Pass and Highest Fail results because testing was done under ambient conditions. In our testing using the All Weather Chassis Dynamometer, there was much better and more consistent control of temperatures, so the Pass/Fail temperatures in general were much closer together. The result is if we apply the 1/3 – 2/3 approach or use the average of the difference between the Lowest Passing and Highest Failing temperatures, the EMOTs are not very different and don't significantly affect the outcome. For consistency with the previous work, the 1/3 – 2/3 approach was used for the EMOT.

### Comparison of Vehicle Performance by Fuel

#### Fuel A

Fuel A (Figure 18) was more severe in Vehicles 2 and 3 than in the other three Vehicles. The results in Vehicle 2 seemed a little out of line with performance in other fuels, but comparison with pressure profiles for passing tests with other fuels indicates a higher filter pressure in this group of tests leading to filter blockage. The laboratory test results shown in Figure 18 indicate that although Cloud and LTFT protect all the vehicles using Fuel A, both tests are quite conservative and the CFPP or the Cloud-CFPP $\leq 10^{\circ}\text{C}$  may be more applicable.

#### Fuel B

A lowest Pass result for Vehicle 3 and a highest Fail for Vehicle 5 was not obtained for Fuel B, but graphically the Cloud-CFPP $\leq 10^{\circ}\text{C}$  appears to fit the results better than the other tests. Fuel B (Figure 19) does show LTFT as less conservative than in Fuel A, but the performance give away is still significant except possibly in Vehicle 3. CFPP is too optimistic in three of the vehicles.

#### Fuel C

Fuel C (Figure 20) is interesting because all of the lab tests appear to be conservative relative to vehicle performance with the exception of Vehicle 3. Vehicle 3 performance with this fuel was predicted reasonably well by the CFPP/ Cloud-CFPP $\leq 10^{\circ}\text{C}$  value.

#### Fuel D

CFPP overestimated the operability limits with Fuel D (Figure 21) for Vehicles 1, 2, and 3. It is also possible that CFPP overestimated the performance in Vehicles 4 and 5 as well; but because no highest Failure results were determined for those Vehicles, it is impossible to prove. The Cloud-CFPP $\leq 10^{\circ}\text{C}$  gave the more conservative measure of operability but came close to predicting the performance in two of the five vehicles. LTFT came closer to the performance in Vehicle 1, but still gave away significant operability in the other vehicles.

### Fuel E

CFPP overestimated the operability limits with Fuel E (Figure 22) for Vehicles 1 and 3. It is also possible that CFPP may have correctly estimated the operability limits for Vehicles 2, 4, and 5; but because no highest Failure results were determined for those Vehicles, it is impossible to prove. The Cloud-CFPP $\leq 10^{\circ}\text{C}$  again gave the more conservative measure of operability but it did not predict the performance for any of the vehicles. LTFT came closer to the performance in Vehicle 3, but still gave away significant operability in the other vehicles.

### Fuel F

CFPP and Cloud-CFPP $\leq 10^{\circ}\text{C}$  underestimated the operability limits with Fuel F (Figure 23) for all vehicles except Vehicle 3. LTFT under estimated all the vehicles using Fuel F.

### Fuel G

CFPP and Cloud-CFPP $\leq 10^{\circ}\text{C}$  estimated the operability limit for Fuel G (Figure 24) in Vehicle 2 very well, but it overestimated the operability limits for Vehicle 3 and underestimated the performance in the other three vehicles. SFPP estimated the operability for Vehicle 3 quite well but underestimated performance in the other vehicles. LTFT underestimated performance in all the vehicles but came closest for Vehicle 3.

### Fuel I

CFPP did a reasonably good job of estimating performance in all but Vehicle 3 for Fuel I (Figure 25). Cloud-CFPP $\leq 10^{\circ}\text{C}$ , SFPP and LTFT all underestimated performance except for Vehicle 3. Cloud-CFPP $\leq 10^{\circ}\text{C}$  and SFPP overestimated the performance in Vehicle 3 by 2 to 3 $^{\circ}\text{C}$ . LTFT underestimated performance in all the vehicles.

### Fuel J

CFPP closely estimate the performance of Fuel J (Figure 26) in Vehicles 2 and 4 and overestimated the performance in Vehicles 1 and 3. Cloud-CFPP $\leq 10^{\circ}\text{C}$  and SFPP protected Vehicles 1, 2, and 4, but not Vehicle 3. LTFT underestimated performance but was more closely aligned with Vehicle 3.

## **IX. CORRELATION OF VEHICLE OPERABILITY WITH LABORATORY TEST PREDICTIONS**

Table 11 describes the EMOT for each vehicle with each fuel and the average EMOT for all vehicles in each fuel.

Figures 27 through 53 provide plots of EMOT versus the different laboratory tests for both the individual vehicles as well as for the average of all the vehicles. These graphs indicate that CFPP does a good job overall in estimating the operability in this group of vehicles, but that CFPP minus Cloud Point  $\leq 10^{\circ}\text{C}$  does a better job. The one exception being Vehicle 3 where LTFT fits the EMOT data better.

In Figures 54 through 58, the Vehicle tank temperatures are plotted for all the passing and failing tests versus the lab test results and indicate that the Cloud Point is most protective (fewest failures above the 1:1 line). LTFT is the next most conservative as expected. LTFT is closely followed by the SFPP test (more labs would have to be involved to confirm this.) CFPP – Cloud Point  $\leq 10^{\circ}\text{C}$  is the next most protective followed by CFPP.

## APPENDIX

### A. Tables

Table 1  
Fuel Blend Component Characteristics

	ASTM		Blend Components		
	Method		30430-128	30430-129	30430-130
AutoCloud, °C	D 5772		-10	-43.2	-9.4
CFPP, °C	D 6371		-12		-10
AutoPour, °C	D 5950		-18	-45	-21
SpGr	D 4052		0.825	0.8115	0.8248
S, wt%	D 5453		<0.001	<0.001	<0.001
KV@40°C, cSt	D 445		2.1	1.54	2.78
KV@20°C, cSt	D 445		3.12	2.17	4.36
Distillation, °C	D 86				
		IBP	175	169	190
		5	193	183	218
		10	200	187	229
		20	212	195	243
		30	223	202	254
		40	234	209	264
		50	244	217	273
		60	257	226	282
		70	272	235	292
		80	290	245	302
		90	315	258	316
		95	336	268	329
		FBP	351	283	338

Table 2  
Preliminary Response in Diesel Fuel Blends

ULSD No.2 30430-128 vol. %	ULSD No.1 30430-129 vol. %	ULSD No.2 30430-130 vol. %	Additive 1 wppm	Additive 2 wppm	Auto Cloud °C	Auto CFPP °C	Auto Pour °C	Lowest LTFT Pass °C
100	0	0	0	0	-10.2	-11	-18	-8
100	0	0	100	0	-9.7	-20	-24	
100	0	0	300	0	-9.5	-26	-30	
100	0	0	500	0	-9.9/-10.5	-29	-36/-33	-12
100	0	0	1000	0	-10.3	-28	-42	-12
100	0	0	0	100	-9.7	-20	-24	
100	0	0	0	300	-10.1	-25	-27	
100	0	0	0	500	-10.6/-10.9	-26	-27/-30	-18
100	0	0	0	1000	-11.2	-26	-33	-24
40	60	0	0	0	-22.5	-24	-33	-21
40	60	0	100	0	-22.5	-33	-36	
40	60	0	300	0	-23.1	-43	-39	
40	60	0	500	0	-23.7	-40	-42	-26
40	60	0	0	100	-23.1	-27	-36	
40	60	0	0	300	-24.3	-30	-36	
40	60	0	0	500	-24.2	-35	-39	-32
40	60	0	0	1000	-24.2	-36	-42	-34
0	0	100	0	0	-9.4/-9.0	-10	-18	-10
0	0	100	100	0	-9.4	-11	-24	
0	0	100	300	0	-9.3	-12	-30	
0	0	100	500	0	-9.3	-13	-33	
0	0	100	750	0	-9.1	-15	-39	
0	0	100	1000	0	-9.2/-9.1	-16	-42/-45d	-12
0	0	100	0	100	-8.7	-10	-21	
0	0	100	0	300	-9.0	-11	-24	
0	0	100	0	500	-9.2	-11	-27	
0	0	100	0	1000	-9.4	-11	-33	-14
0	0	100	0	2000	-9.7	-13	-42	-14
0	40	60	0	0	-20.6	-28	-30	-24
0	40	60	100	0	-20.3	-27	-33	
0	40	60	300	0	-21.6	-29	-36	
0	40	60	500	0	-21.1	-30	-39	-24
0	40	60	1000	0	-22.2	-31	-42	-26
0	40	60	0	100	-19.9	-27	-33	
0	40	60	0	300	-21.3	-28	-33	
0	40	60	0	500	-21.7	-29	-36	-24
0	40	60	0	1000	-21.4	-30	-39	-26
0	40	60	0	2000	-22.2	-34	-45	-28

Table 3  
Preliminary Response for Selected Test Fuel/Additive Combinations

	Blend Components			Additive	Treat Rate, wppm	Preliminary Cloud, °C	Preliminary CFPP, °C	Preliminary LTFT, °C
	30430-128 vol. %	30430-129 vol. %	30430-130 vol. %					
Fuel A	100			1	300	-9.5	-26	-12
Fuel B	100			2	500	-10.6	-26	-18
Fuel C	40	60		1	100	-22.5	-33	-22
Fuel D	40	60		2	500	-24.2	-35	-32
Fuel E	40	60		1	200	-22.8	-38	-24
Fuel F			100	1	1000	-9.2	-16	-12
Fuel G		60	40	1	500	-22.2	-30	-24
Fuel I	100			1	500	-9.9	-29	-12
Fuel J		60	40	2	2000	-22.2	-34	-28

Table 4  
Cold Flow Characteristics of Test Fuels

Fuel	Treat		Cloud Point, °C			CFPP, °C				LTFT, °C				SFPP, °C
	Additive	Rate, wppm	Lab 1	Lab4	Average	Lab 1	Lab 3	Lab4	Average	Lab 1	Lab 3	Lab4	Average	Lab 5
A	1	300	-9.5	-12	-10.8	-20	-27	-24	-23.7	-12	-12	≤-14	≤-12.7	-20
B	2	500	-10.6	-13	-11.8	-27	-27	-29	-27.7	-18	-18	≤-20	≤-18.7	-23
C	1	100	-22.5	-21	-21.8	-26	-32	-25	-27.7	-22	-21	≤-24	≤-22.3	-31
D	2	500	-24.2	-24	-24.1	-37	-44	-43	-41.3	-32	-31	-32	-31.7	-23
E	1	200	-22.8	-22	-22.4	-34	-41	-40	-38.3	-22	-22	≤-26	≤-23.3	-33
F	1	1000	-9.2	-12	-10.6	-14	-15	-17	-15.3	-14	-12	-12	-12.7	-13
G	1	500	-22.2	-23	-22.6	-28	-30	-35	-31.0	-24	-24	≤-26	≤-24.7	-27
I	1	500	-9.9	-12	-11.0	-22	-27	-34	-27.7	-14	-12	≤-14	≤-13.3	-20
J	2	2000	-22.2	-22	-22.1	-36	-36	-39	-37.0	-24	-24	-28	-25.3	-33

Table 5  
Physical Characteristics of Test Fuels

	Fuel A		Fuel B		Fuel C		Fuel D		Fuel E	
	Lab 1	Lab 2	Lab 1	Lab 2	Lab 1	Lab 2	Lab 1	Lab 2	Lab 1	Lab 2
Sp.Gr.	0.8248		0.8249		0.8169		0.8169		0.817	
API 60°F	40.1		40		41.7		41.7		41.7	
KV at 40°C, cSt	2.152	2.135	2.144	2.132	1.798	1.766	1.785	1.761	1.789	1.767
Ash, mass%	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sulfur, ppm	6.5	6.3	6.7	6.4	4.2	5.8	4	4.3	4.6	4.1
D 86, °F	IBP	338	337	343	335	332	320	330	327	326
	5	364	366	369	367	358	357	358	360	358
	10	383	382	385	385	369	368	370	368	369
	20	407	406	410	408	388	387	387	386	387
	30	428	427	430	428	405	403	404	404	404
	40	449	448	449	448	422	420	420	421	421
	50	469	468	469	467	440	438	438	437	437
	60	491	490	492	491	458	456	456	455	456
	70	517	516	518	518	479	477	477	476	477
	80	549	548	549	550	504	501	502	501	502
	90	592	592	592	594	545	542	542	541	542
	95	626	625	625	627	583	583	581	580	581
	FBP	657	653	651	651	619	618	620	619	618
	(90-20)	185	186	182	186	157	155	155	155	155
	(FBP-90)	65	61	59	57	74	76	78	78	76
D 130, Cu Corrosion			1A		1A		1A		1A	
D 2709, Water&Sed, vol%		0.01		0.01		0.01		0.01		0.01
D 93, Flash, °F		139		152		138		136		137
D 524, Rams.Bttm, wt%		0.06		0.05		0.07		0.07		0.06
n-paraffin, mass%	7	0.06		0.06		0.06		0.06		0.06
	8	0.23		0.24		0.22		0.23		0.22
	9	0.72		0.73		0.72		0.74		0.72
	10	1.11		1.13		1.91		1.96		1.93
	11	1.45		1.47		2.65		2.57		2.65
	12	1.58		1.58		2.35		2.37		2.35
	13	1.76		1.77		2.34		2.34		2.34
	14	1.65		1.65		2		1.99		1.99
	15	1.71		1.7		1.79		1.76		1.77
	16	1.64		1.62		1.27		1.24		1.26
	17	1.36		1.33		0.77		0.74		0.76
	18	1.1		1.04		0.55		0.52		0.54
	19	0.84		0.81		0.43		0.4		0.42
	20	0.64		0.61		0.29		0.27		0.28
	21	0.47		0.44		0.21		0.19		0.2
	22	0.34		0.32		0.15		0.14		0.15
	23	0.23		0.21		0.1		0.09		0.1
	24	0.14		0.13		0.06		0.05		0.06
	25	0.07		0.07		0.03		0.03		0.03
	26	0.03		0.03		0.02		0.01		0.02
	27	0.01		0.01		0.01				
	28									

Table 5  
Physical Characteristics of Test Fuels  
Cont'd

	Fuel F		Fuel G		Fuel I		Fuel J	
	Lab 1	Lab 2	Lab 1	Lab 2	Lab 1	Lab 2	Lab 1	Lab 2
Sp.Gr.	0.8246		0.8168		0.825		0.817	
API 60°F	40.1		41.7		40		41.7	
KV at 40°C, cSt	2.816	2.81	1.972	1.963	2.162	2.122	1.988	1.959
Ash, mass%	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sulfur, ppm	3.7	3.8	3.4	3	6.3	6.3	3.6	3.6
D 86, °F	IBP	365	323	334	342	334	339	337
	5	391	358	366	366	365	364	358
	10	423	375	379	383	382	376	376
	20	455	396	398	408	405	398	396
	30	480	416	417	429	428	417	417
	40	500	436	437	449	447	437	436
	50	517	455	457	469	466	457	456
	60	534	476	477	491	488	478	477
	70	551	499	499	517	514	500	499
	80	569	524	524	548	546	525	525
	90	594	559	558	593	590	560	559
	95	616	586	584	628	623	588	589
	FBP	633	609	610	657	651	610	610
	(90-20)	139	163	160	185	185	162	163
	(FBP-90)	39	50	52	64	61	50	51
D 130, Cu Corrosion		1A		1A		1A		1A
D 2709, Water&Sed, vol%		0.01		0.01		0.01		0.01
D 93, Flash, °F		172		146		142		140
D 524, Rams. Bttm, wt%		0.05		0.05		0.07		0.06
n-paraffin, mass%	7	0.02	0.05		0.06		0.05	
	8	0.14	0.2		0.24		0.2	
	9	0.38	0.59		0.73		0.6	
	10	0.63	1.75		1.13		1.77	
	11	0.93	2.44		1.46		2.46	
	12	1.27	2.3		1.58		2.3	
	13	1.58	2.31		1.75		2.32	
	14	1.89	2.1		1.64		2.09	
	15	2.33	2.04		1.69		2.05	
	16	2.6	1.61		1.57		1.6	
	17	2.41	1.19		1.33		1.17	
	18	1.93	0.86		1.05		0.88	
	19	1.35	0.58		0.82		0.57	
	20	0.88	0.38		0.62		0.37	
	21	0.45	0.19		0.45		0.19	
	22	0.21	0.09		0.32		0.09	
	23	0.09	0.04		0.21		0.04	
	24	0.04	0.02		0.13		0.02	
	25	0.02	0.01		0.07		0.01	
	26	0.01			0.03			
	27				0.01			
	28							

Table 6  
Test Vehicles

Test Vehicle	Donated By
Chevrolet Silverado with 6.6L Duramax engine	General Motors
Ford F350 SD with 6.0L PowerStroke engine	Ford Motor Company
Dodge Ram with 5.9L Cummins engine	DaimlerChrysler
VW Passat with 2.0L TDI engine	VW North America
Jeep Liberty Diesel with 2.8L I-4 engine	BP Products NA Inc.

Table 7  
Overnight Cool Down Test Parameter Output

<u>Name</u>	<u>Description</u>	<u>Units</u>
Airtemp	(filtered) Air Temperature at the nozzle	Deg C
DodgeFuelTK2	Dodge Fuel Tank ( TCT-002 )	Deg C
FordFuelTK1	Ford Fuel Tank (TCT-001 )	Deg C
GMFuelTK3	GM Fuel Tank ( TCT-003 )	Deg C
JeepFuelTK5	Jeep Fuel Tank ( TCT-005 )	Deg C
Psk_Airtemp2	(filtered) Presoak Air Temperature #2	Deg C
VWFuelTK4	VW Fuel Tank ( TCT-004 )	Deg C

Table 8  
Dynamometer Test Parameter Output

<u>Name</u>	<u>Description</u>	<u>Units</u>
AIRINT	Air Into Engine	Deg C
Airtemp	(filtered) Air Temperature at the nozzle	deg C
DYM_Force	Moveable Dyno Force	N
DYM_Speed	Moveable Dyno Speed	kph
ENGOIL	Engine Oil Temperature	Deg C
ENGSPD	Engine R.P.M.	rpm
FRFILP	From Filter Pressure SN 127065	Kpa
FRFILT	Fuel From Filter Temp	Deg C
RETURN	Fuel Return At Tank	Deg C
TANKT	Fuel In Tank (3"From Bottom)	Deg C
TOFILP	To Filter Pressure SN 126824	Kpa
TOFILT	Fuel To Filter Temp	Deg C
TOHTR	To Heater ( Block )	Deg C
TOPRAD	Top Rad Hose	Deg C
UHT	Under Hood Temp	Deg C
Windspeed	Windspeed (filtered)	kph
AIRINT	Air Into Engine	Deg C
Airtemp	(filtered) Air Temperature at the nozzle	deg C
DYM_Force	Moveable Dyno Force	N
DYM_Speed	Moveable Dyno Speed	kph
ENGOIL	Engine Oil Temperature	Deg C
ENGSPD	Engine R.P.M.	rpm
FRFILP	From Filter Pressure SN 127065	Kpa
FRFILT	Fuel From Filter Temp	Deg C
RETURN	Fuel Return At Tank	Deg C
TANKT	Fuel In Tank (3"From Bottom)	Deg C
TOFILP	To Filter Pressure SN 126824	Kpa
TOFILT	Fuel To Filter Temp	Deg C
TOHTR	To Heater ( Block )	Deg C
TOPRAD	Top Rad Hose	Deg C
UHT	Under Hood Temp	Deg C
Windspeed	Windspeed (filtered)	kph

Table 9  
Summary of Dynamometer Test Results

Test No.	Test Date	File Name	Vehicle	Fuel	Test Temp	Passed / Failed	Tank T @ start	TOHTR T @ start	No.Cranks to Start	delta Pat end of test, kPa	Demerits calc. A	Demerits calc. B	Comments
1	4/24/2006	CR042406A	4	A	-26	Pass	-26.6	-5.8	1		0	20	No block heater. Engine rpm building up while cranking. Started at 28s in third 30s cranking period.
2	4/24/2006	CR042406B	5	A	-26	Pass	-27.1	-25.6	3	326	0	20	
3	4/24/2006	CR042406C	2	A	-26	Invalid	-25.1	-24.9	4				No engine block heater
4	4/24/2006	CR042406D	3	A	-26	Fail	-26.8	-6.6	1	95.0	N/A	N/A	Lost speed and power during 60 kph phase
5	4/24/2006	CR042406E	1	A	-26	Pass	-26.6	-4.6	1	8.9	0	20	Filter outlet pressure remained low until end of test
6	4/25/2006	CR042506A	3	A	-24	Fail	-24.8	-19.7	1	-4.4	N/A	N/A	
7	4/25/2006	CR042506B	5	A	-28	Invalid	-28.6	-28.3	5				No start after 5 cranking tries.
8	4/25/2006	CR042506C	1	A	-28	Pass	-27.9	5.5	1	9.1	0	20	Filter outlet pressure remained low until end of test. After test ended, put 1% grade on load. Maintained speed. Put 2% grade on load, vehicle lost speed and stalled.
9	4/25/2006	CR042506D	4	A	-28	Fail	-27.7	-14.5	5	3.4	N/A	N/A	Vehicle would not accelerate at the normal rate. After test, tried acceleration at lower rate. Vehicle could get up to speed of 60 kph and 110 kph, but could not maintain speed at 110 kph.
10	4/26/2006	CR042606A	3	A	-18	Pass	-18.1	-11.1	1	17.3	0	20	Filter outlet pressure dropped to -80 kPa until filter inlet pressure reached ~ -11 C, then recovered to -22 kPa at test end.
14	4/26/2006	CR042606F	2	A	-26	Fail	-26.5	-16.4	1	326.4	20.0	60.0	Lost speed and power with 1 min. of reaching 110 kph phase
11	4/26/2006	CR042606C	5	B	-26	Pass	-26.1	-6.3	1	17.4	0	20	Engine block heater installed.
12	4/26/2006	CR042606D	4	B	-26	Pass	-26.4	-8.9	1	8.1	0	20	
13	4/26/2006	CR042606E	1	B	-26	Fail	-26.6	10.4	1	161.8	16.7	53.3	
15	4/27/2006	CR042706A	5	B	-28	Pass	-27.9	-18.0	4	45.6	0	20	Started at end of third cranking attempt. Heater warmed up block to -21 C only due to wind blow down
16	4/27/2006	CR042706B	2	B	-24	Pass	-24.7	-7.4	1	1.9	0	20	
17	4/27/2006	CR042706C	1	B	-24	Pass	-24.9	16.1	1	10.5	0	20	
18	4/27/2006	CR042706D	3	B	-24	Fail	-24.8	-11.6	1	89.2	N/A	N/A	
19	5/1/2006	CR050106A	3	C	-29	Fail	-28.5	-18.9	1	89.1	N/A	N/A	Could not accelerate, even at full 'throttle' beyond the 60 kph phase.
20	5/1/2006	CR050106B	2	C	-33	Invalid	-32.5	-0.9	1				Turbocharger shaft broke shortly after test started
21	5/1/2006	CR050106C	1	C	-33	Pass	-31.9	12.2	1	15.7	0	20	Filter out pressure remained low (~84 kPa) until end of test.
22	5/1/2006	CR050106D	4	C	-33	Pass	-33.0	-9.9	2	9.3	0	20	
23	5/1/2006	CR050106E	5	C	-33	Pass	-33.0	15.9	1	17.6	0	20	
24	5/2/2006	CR050206A	3	C	-25	Pass	-24.9	-15.9	1	16.8	0	20	
25	5/2/2006	CR050206B	1	C	-35	Fail	-34.4	0.5	1	42.4	5.3	30.7	Lost power at ~22 min. into 110 kph phase.
26	5/2/2006	CR050206D	4	C	-35	Pass / Invalid	-34.8	-3.2	-9				Engine starting problem. Started once after 5 tries. Found air in fuel system. Removed air, engine started after 3 tries. Test not valid due to other parameters.
27	5/2/2006	CR050206E	5	C	-35	Pass	-36.0	-0.5	2	15.0	0	20	
28	5/3/2006	CR050306A	3	C	-27	Fail	-26.8	-25.9	2	86.4	N/A	N/A	Could not accelerate from 60 kph
29	5/3/2006	CR050306B	1	D	-37	Fail	-36.4	3.3	1	106	12	44	Lost power ~ 14 min into 110 kph phase
30	5/3/2006	CR050306C	5	C	-37	Pass	-36.7	-12.4	2	16.4	0	20	
31	5/3/2006	CR050306D	4	C	-37	Pass	-36.5	-20.2	7	12.0	0	20	Initially very hard to start. A total of 7 tries. No engine rpm signal
32	5/4/2006	CR050406A	3	D	-27	Pass	-26.7	-23.9	1	25.0	0	20	
33	5/4/2006	CR050406B	1	D	-35	Pass	-34.5	8.7	1	33.2	0	20	
34	5/4/2006	CR050406C	5	D	-35	Pass	-35.7	-3.4	2	15.8	0	20	
35	5/4/2006	CR050406D	4	D	-35	Pass	-35.6	-17.7	7	11.6	0	20	Very hard to start. Total of 7 tries.
36	5/8/2006	CR050806A	3	D	-29	Fail	-29.2	-23.5	1	85.6	NA	NA	Could not accelerate to 110 kph phase
37	5/8/2006	CR050806B	1	E	-37	Fail	-36.9	3.2	1	157	6.7	33.3	Lost power/speed at ~20 min into 110 kph phase
38	5/8/2006	CR050806C	2	D	-37	Fail	-37.2	-24.4	1	341.6	19.3	58.7	Lost speed and power at ~ 3 min. into 110 kph phase
39	5/8/2006	CR050806D	5	D	-37	Pass	-37.5	-5.3	2	28.7	0	20	
40	5/8/2006	CR050806E	4	D	-37	Pass	-37.1	-13.3	5	13.7	0	20	
41	5/9/2006	CR050906A	3	E	-29	Fail	-29.1	-27.4	1	32.5	NA	NA	Could not accelerate to 110 kph
42	5/9/2006	CR050906B	1	E	-35	Pass	-35.4	5.9	1	29.3	0	20	
43	5/9/2006	CR050906C	2	E	-35	Pass	-35.2	-22.2	1	359	0	20	
44	5/9/2006	CR050906D	5	E	-35	Pass	-34.6	-21.4	2	21.9	0	20	
45	5/9/2006	CR050906E	4	E	-35	Pass	-33.4	-7.8	1	11.9	0	20	
46	5/10/2006	CR051006A	3	E	-27	Fail	-27.1	-17.9	1	86.0	NA	NA	Could not accelerate to 110 kph phase

Table 9 Cont'd  
Summary of Dynamometer Test Results

Test No.	Test Date	File Name	Vehicle	Fuel	Test Temp	Passed / Failed	Tank T @ start	TOHTR T @ start	No.Cranks to Start	delta Pat end of test, kPa	Demerits calc. A	Demerits calc. B	Comments
47	5/10/2006	CR051006B	2	E	-37	Pass	-36.1	-23.3	1	352.2	0	20	Fuel filter pressure continued to drop throughout the whole cycle. Filter in < 10 kPa
48	5/10/2006	CR051006C	5	E	-37	Pass	-37.6	-0.7	3	13.4	0	20	
49	5/10/2006	CR051006D	4	E	-37	Pass	-37.1	-14.4	3	12.9	0	20	
50	5/11/2006	CR051106A	3	E	-25	Fail	-25.1	-14.7	1	27	NA	NA	
51	5/11/2006	CR051106B	2	G	-32	Fail	-31.7	-18.3	3	175.0	0	20	Could not accelerate to the 110 kph phase
52	5/11/2006	CR051106C	1	G	-32	Pass	-33.2	12.4	1	6.6	0	20	
53	5/11/2006	CR051106D	5	G	-32	Pass	-33.0	10.9	1	15.5	0	20	
54	5/11/2006	CR051106E	4	G	-32	Pass	-32.4	-9.4	2	11.1	0	20	
55	5/15/2006	CR051506A	3	E	-23	Pass	-23.3	-17.8	1	12.3	0	20	
56	5/15/2006	CR051506B	2	C	-34	Pass	-34.2	-25.1	1	337.4	0	20	
57	5/15/2006	CR051506C	1	G	-34	Pass	-35.0	8.9	1	9.1	0	20	
58	5/15/2006	CR051506D	5	G	-34	Pass	-35.2	-0.1	1	13.2	0	20	Return fuel regulator valve cycled causing short term unstable speed
59	5/15/2006	CR051506E	4	G	-34	Pass	-34.4	-8.8	1	12.2	0	20	
60	5/16/2006	CR051606A	3	G	-28	Fail	-28.0	-27.8	1	82.6	NA	NA	Could not accelerate to 60 kph phase
61	5/16/2006	CR051606B	4	G	-36	Fail	-36.6	-15.7	7	7.0	NA	NA	7 cranking attempts. Engine fired several times but stalled immediately. Filter out pressure down to -93 kPa.
62	5/16/2006	CR051606C	1	G	-36	Pass	-36.3	2.8	1	14.9	0	20	
63	5/16/2006	CR051606D	2	C	-36	Fail	-36.1	-20.6	1	339.5	NA	NA	Lost speed and power 11 min. into 110 kph phase.
64	5/17/2006	CR051706A	3	G	-24	Pass	-24.3	-20.1	1	16.4	0	20	
65	5/17/2006	CR051706B	4	J	-35	Pass	-35.9	-15.2	2	12.3	0	20	
66	5/17/2006	CR051706C	1	J	-35	Fail	-34.3	-3.0	1	139.5	NA	NA	Could not accelerate to 110 kph
67	5/17/2006	CR051706D	2	J	-35	Pass	-34.2	-29.6	1	372.7	0	20	
68	5/18/2006	CR051806A	3	G	-26	Pass	-26.2	-23.5	1	17.4	0	20	
69	5/18/2006	CR051806B	4	J	-37	Fail	-37.4	-16.9	9	46.7	NA	NA	9 cranking attempts with repeat stalling. High vacuum in filter outlet pressure
70	5/18/2006	CR051806C	2	J	-37	Fail	-36.9	-29.5	1	369.2	NA	NA	Could not accelerate to 60 kph phase
71	5/18/2006	CR051806D	1	G	-37	Fail	-37.4	-7.8	1	154.7	NA	NA	Could not accelerate to 110 kph phase
72	5/19/2006	CR051906A	3	I	-24	Fail	-24.1	-23.7	1	76.8	NA	NA	Engine started and idled for 2.5 min. Stalled when attempted to accelerate to 60 kph.
73	5/19/2006	CR051906B	4	I	-30	Fail	-30.5	-9.1	1	81.2	NA	NA	Started and idled for 2.5 minutes. Stalled when accelerating to 60 kph.
74	5/19/2006	CR051906C	1	I	-30	Fail	-30.7	9.8	1	9.3	4.7	29.3	Lost speed and power 23 min. into 110 kph phase
75	5/19/2006	CR051906F	2	I	-30	Fail	-30.3	-1.1	3	-12.8	NA	NA	Could not accelerate to 110 kph phase
76	5/23/2006	CR052306A	3	I	-22	Fail	-22.2	-19.8	1		NA	NA	Could not accelerate to 60 kph
77	5/23/2006	CR052306B	4	I	-28	Pass	-29.2	-6.3	1	9.8	0	20	
78	5/23/2006	CR052306C	1	I	-29	Fail	-29.3	15.3	1	149.1	12.7	45.3	Lost speed and power 7 min. into 110 kph phase
79	5/23/2006	CR052306D	2	I	-29	Fail	-29.3	-15.6	1	20.9	NA	NA	Lost speed and power during 60 kph phase
80	5/24/2006	CR052406A	3	I	-20	Fail	-20.2	-9.2	1				Lost power during 60 kph phase
81	5/24/2006	CR052406B	1	I	-27	Pass	-27.2	15.9	1				
82	5/24/2006	CR052406C	2	I	-28	Fail	-28.1	-20.2	1				Could not accelerate to 110 kph phase
83	5/24/2006	CR052406D	4	B	-28	Fail	-28.3	-5.3	1				Engine stalled during acceleration from 60 kph to 100 kph phase
84	5/25/2006	CR052506A	3	I	-18	Fail	-18.2	-12.7	1				Could not reach 110 kph during acceleration from 60 kph
85	5/25/2006	CR052506B	1	F	-17	Pass	-17.0	24.2	1				
86	5/25/2006	CR052506C	2	F	-17	Pass	-16.8	-10.6	1				
87	5/25/2006	CR052506D	4	F	-17	Pass	-17.1	-0.3	1				
88	5/26/2006	CR052606A	3	I	-18	Pass	-18.3	-13.8	1				Repeat of the borderline failed test of previous day. Similar run up but completed drive cycle.
89	5/26/2006	CR052606B	1	F	-20	Pass	-19.9	16.7	1				
90	5/26/2006	CR052606C	2	F	-20	Fail	-20.0	-13.7	1				Lost speed and power ~ 4 min into 110 kph phase. After ~ 5 minutes of reduced speed at max fuel, vehicle resumed 110 kph speed for rest of cycle.

Table 9 Cont'd  
Summary of Dynamometer Test Results

Test No.	Test Date	File Name	Vehicle	Fuel	Test Temp	Passed / Failed	Tank T @ start	TOHTR T @ start	No.Cranks to Start	delta Pat end of test, kPa	Demerits calc. A	Demerits calc. B	Comments
91	5/26/2006	CR052606D	4	F	-20	Pass	-20.7	3.9	1				
92	5/26/2006	CR052606E	5	F	-20	Pass	-20.6	-3.8	1				
93	5/29/2006	CR052906A	3	F	-14	Pass	-14.7	-12.2	1				
94	5/29/2006	CR052906B	2	A	-24	Fail	-23.8	-21.6	1				Could not accelerate to 110 kph phase
95	5/29/2006	CR052906C	4	F	-23	Pass	-23.1	-0.8	1				
96	5/29/2006	CR052906D	5	F	-23	Pass	-23.3	19.4	1				
97	5/29/2006	CR052906E	1	F	-23	Pass	-23.3	6.6	1				
98	5/30/2006	CR053006A	3	F	-16	Fail	-16.6	-12.2	1				Could not accelerate to 60 kph Stalled several times during idle. Stalled again during acceleration to 60 kph
99	5/30/2006	CR053006B	4	F	-25	Fail	-24.9	-14.0	5				Lost speed and power ~ 8 min. into 110 kph phase
100	5/30/2006	CR053006C	2	A	-22	Fail	-22.4	-9.7	1				Lost power and speed ~ 19 min. into 110 kph phase
101	5/30/2006	CR053006D	5	F	-26	Fail	-26.1	-14.7	1				
102	5/30/2006	CR053006E	1	F	-25	Pass	-25.2	14.0	1				
103	5/31/2006	CR053106A	3	A	-20	Fail	-20.2	-19.6	1				Could not accelerate to 60 kph
104	5/31/2006	CR053106B	2	G	-30	Pass	-30.1	-24.2	1				
105	5/31/2006	CR053106C	1	A	-30	Fail	-30.1	4.1	1				Could not accelerate from 60 kph to 110 kph phase
106	5/31/2006	CR053106D	5	B	-30	Pass	-29.6	-33.2	1				
107	6/1/2006	CR060106A	1	J	-33	Fail	-32.7	-5.4	1				Could not accelerate from 60 kph to 110 kph phase.
108	6/1/2006	CR060106B	5	I	-29	Pass	-29.2	6.0	1				
109	6/1/2006	CR060106C	3	J	-26	Pass	-27.1	-18.2	1				
110	6/1/2006	CR060106D	2	B	-26	Fail	-27.2	-19.7	1				Could not accelerate from 60 kph to 110 kph phase
111	6/1/2006	CR060106E	4	B	-28	Fail	-27.9	-8.5	4				Engine repeatedly stalled at idle. High suction (negative pressure) at outlet of fuel filter Lost speed and power ~ 5 min. into 110 kph phase
112	6/2/2006	CR060206A	2	A	-20	Fail	-20.4	-20.0	1				failed to accelerate to 60 kph
113	6/2/2006	CR060206B	3	J	-29	Fail	-29.3	-21.7	1				
114	6/2/2006	CR060206C	1	J	-31	Pass	-30.9	12.2	1				
115	6/2/2006	CR060206D	5	I	-30	Pass	-30.8	4.0	1				
116	6/2/2006	CR060206E	4	I	-30	Fail	-29.7	-10.9	1				Started and idled for 2.5 min. Stalled repeatedly when accelerating to 60 kph phase.
117	6/5/2006	CR060506A	3	B	-20	Fail	-20.3	-17.0	1				Could not accelerate to 60 kph phase
118	6/5/2006	CR060506B	1	F	-27	Pass	-27.5	6.8	1				
119	6/5/2006	CR060506C	4	I	-29	Fail	-29.3	-12.5	4				Repeatedly stalled during idle.
120	6/5/2006	CR060506D	5	B	-32	Pass	-31.8	-19.6	1				
121	6/5/2006	CR060506E	2	D	-35	Pass	-35.0	-17.2	3				

Table 10  
Estimated Minimum/Maximum Operating Temperatures

MPT = Minimum Pass Temperature																		
MFT = Maximum Fail Temperature																		
	Fuel	A	B	C	D	E	F	G	I	J								
		MPT	MFT	MPT	MFT	MPT	MFT	MPT	MFT	MPT	MFT	MPT	MFT	MPT	MFT	MPT	MFT	MPT
Vehicle 1		-27.9	-30.1	-24.9	-26.6	-31.9	-34.4	-34.5	-36.4	-35.4	-36.9	-27.5	-36.3	-37.4	-27.2	-29.3	-30.9	-32.7
Vehicle 2			-20.4	-24.7	-27.2	-34.2	-36.1	-35.0	-37.2	-36.1		-16.8	-20.0	-30.1	-31.7	-28.1	-34.2	-36.9
Vehicle 3		-18.1	-20.2		-20.3	-24.9	-26.8	-26.7	-29.2	-23.3	-25.1	-14.7	-16.6	-26.2	-28.0	-18.3	-20.2	-27.1
Vehicle 4		-26.6	-27.7	-26.4	-27.9	-36.5		-37.1		-37.1		-23.1	-24.9	-34.4	-36.6	-29.2	-29.3	-35.9
Vehicle 5		-27.1		-31.8		-36.7		-37.5		-37.6		-23.3	-26.1	-35.2		-30.8		

Table 11  
EMOT

Estimated Minimum Operating Temperature (°C) for Each Vehicle Fuel Combination										
	Fuel	A	B	C	D	E	F	G	I	J
<u>Vehicle</u>										
Vehicle 1		-29.0	-25.8	-33.2	-35.5	-36.2	<-27.5	-36.9	-28.3	-31.8
Vehicle 2			-26.0	-35.2	-36.1	<-36.1	-18.4	-30.9	>-28.1	-35.6
Vehicle 3		-19.2	>-20.3	-25.9	-28.0	-24.2	-15.7	-27.1	-19.3	-28.2
Vehicle 4		-27.2	-27.2	<-36.5	<-37.1	<-37.1	-24.0	-35.5	-29.3	-36.7
Vehicle 5		<-27.1	<-31.8	<-36.7	<-37.5	<-37.6	-24.7	<-35.2	<-30.8	
Average All Vehicles		-25.6	-27.7	-33.5	-34.8	-34.2	-22.1	-33.1	-26.9	-33.1

B. Figures

Figure 1  
Vehicle 1 Fuel Delivery System

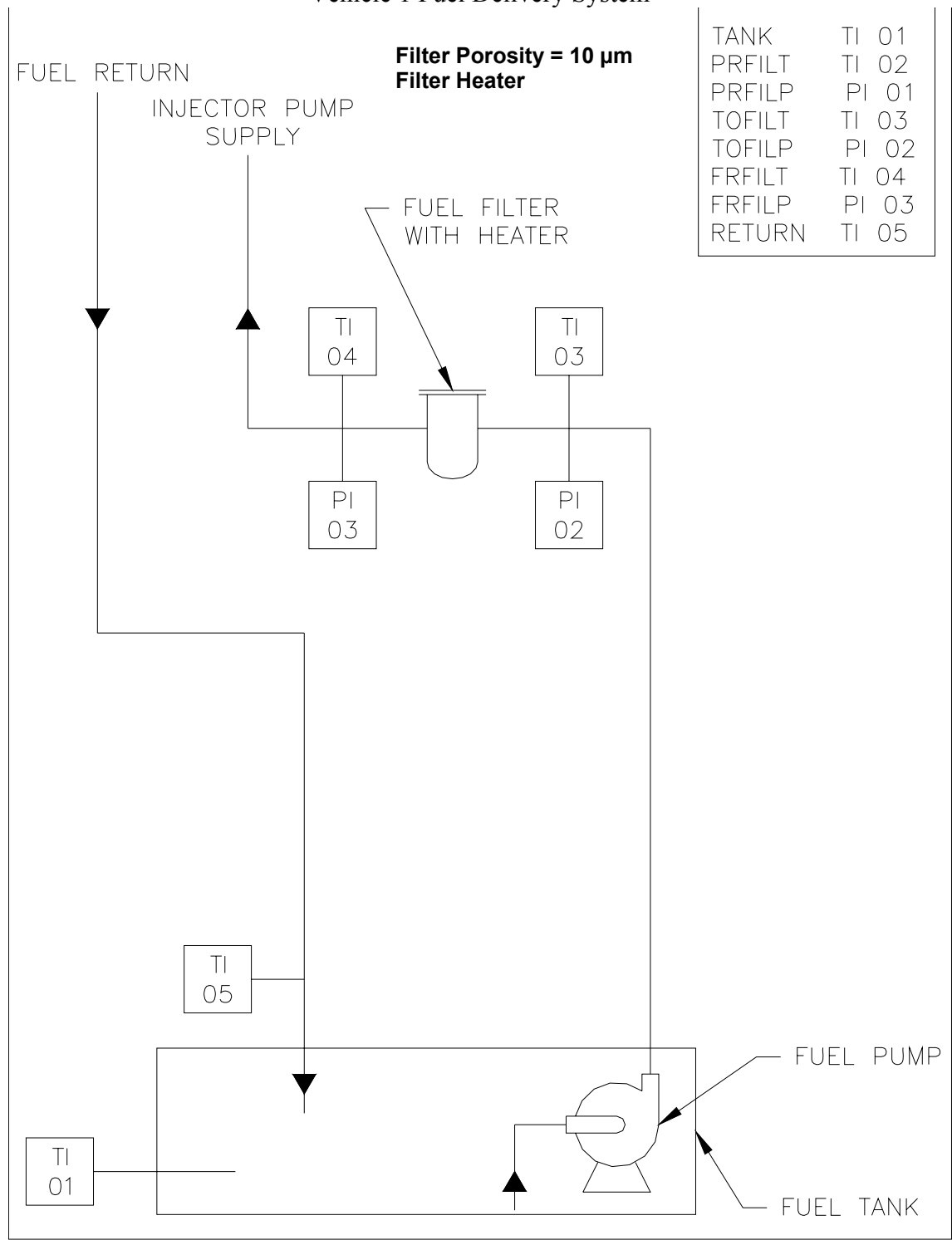


Figure 2  
Vehicle 2 Fuel Delivery System

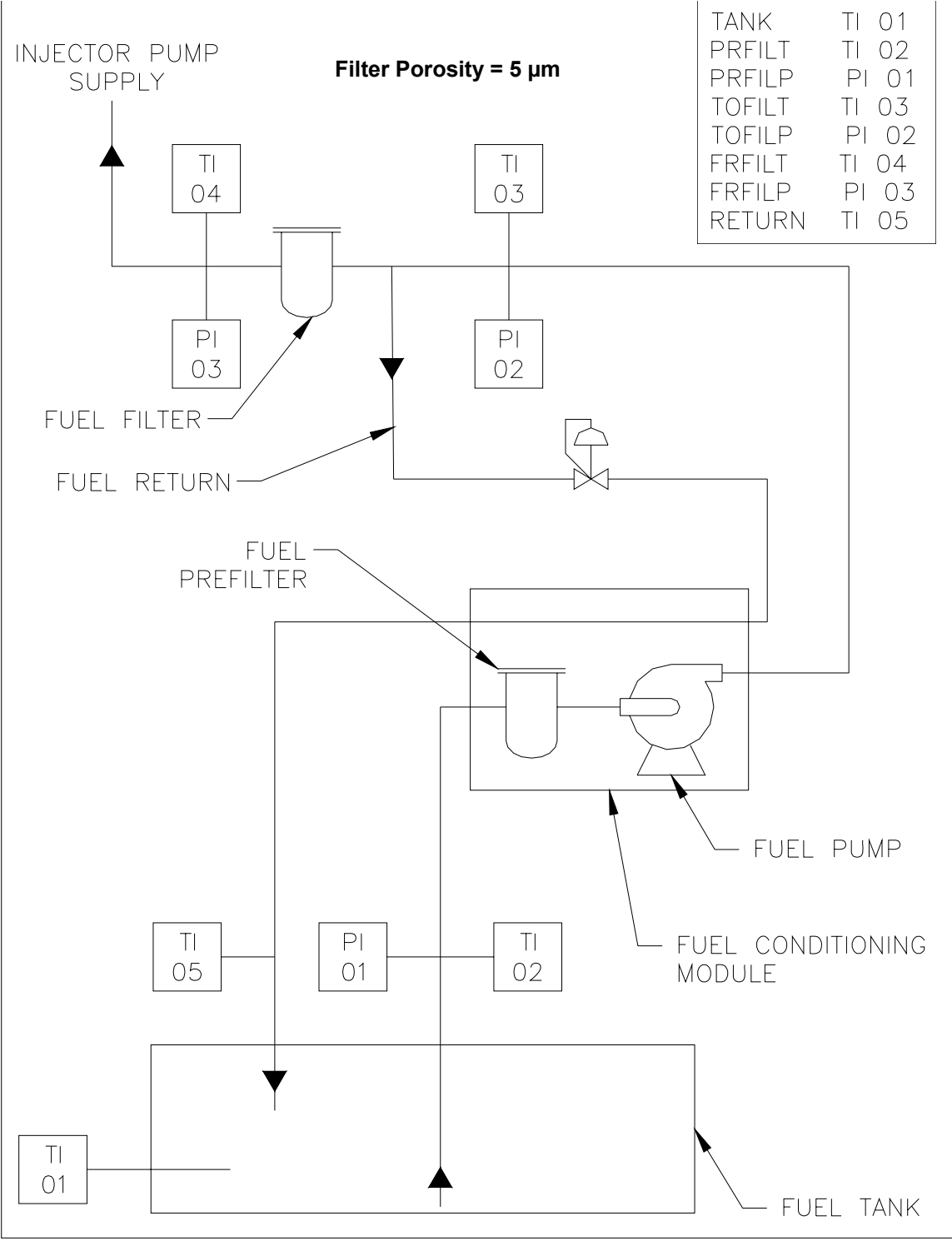


Figure 3  
Vehicle 3 Fuel Delivery System

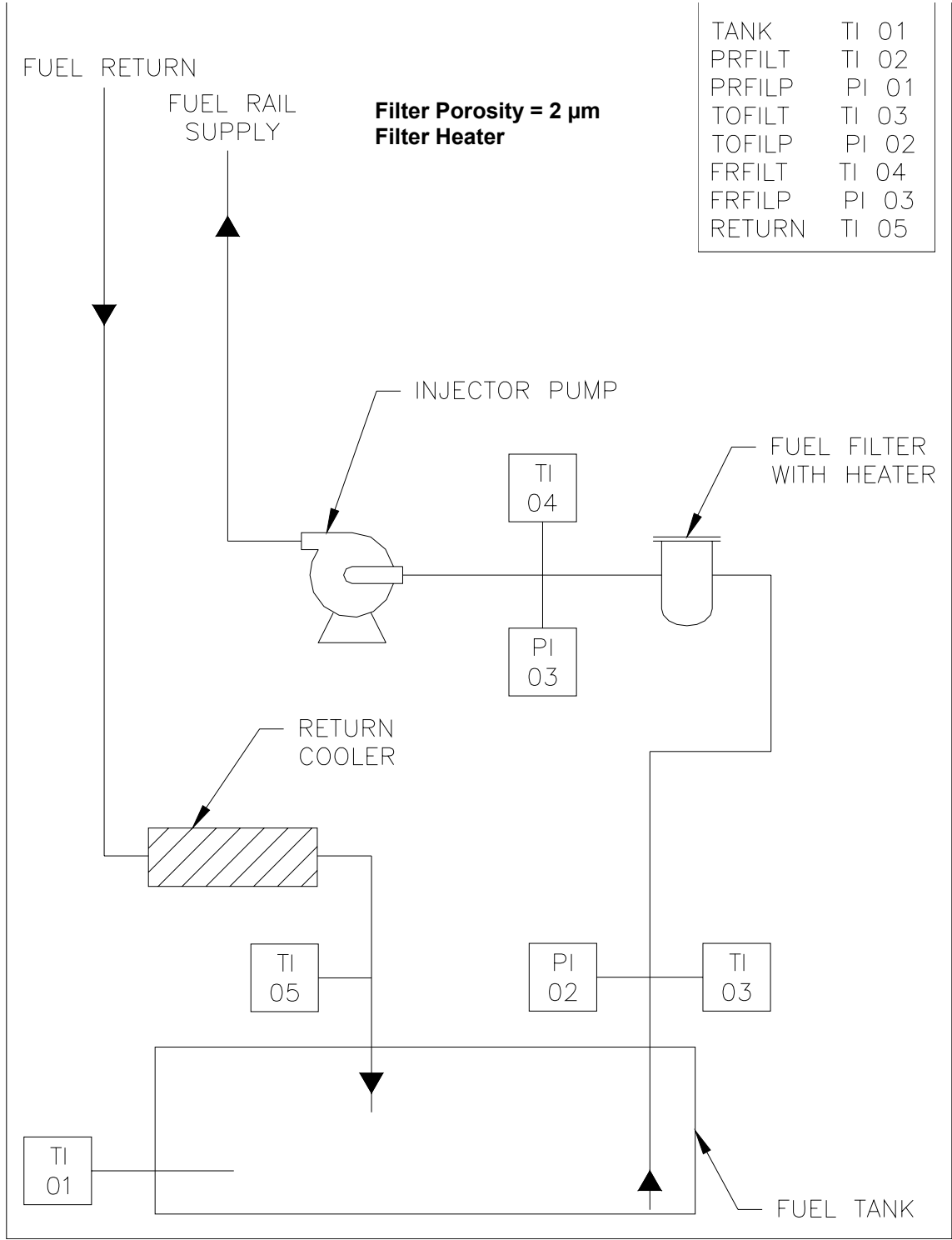


Figure 4  
Vehicle 4 Fuel Delivery System

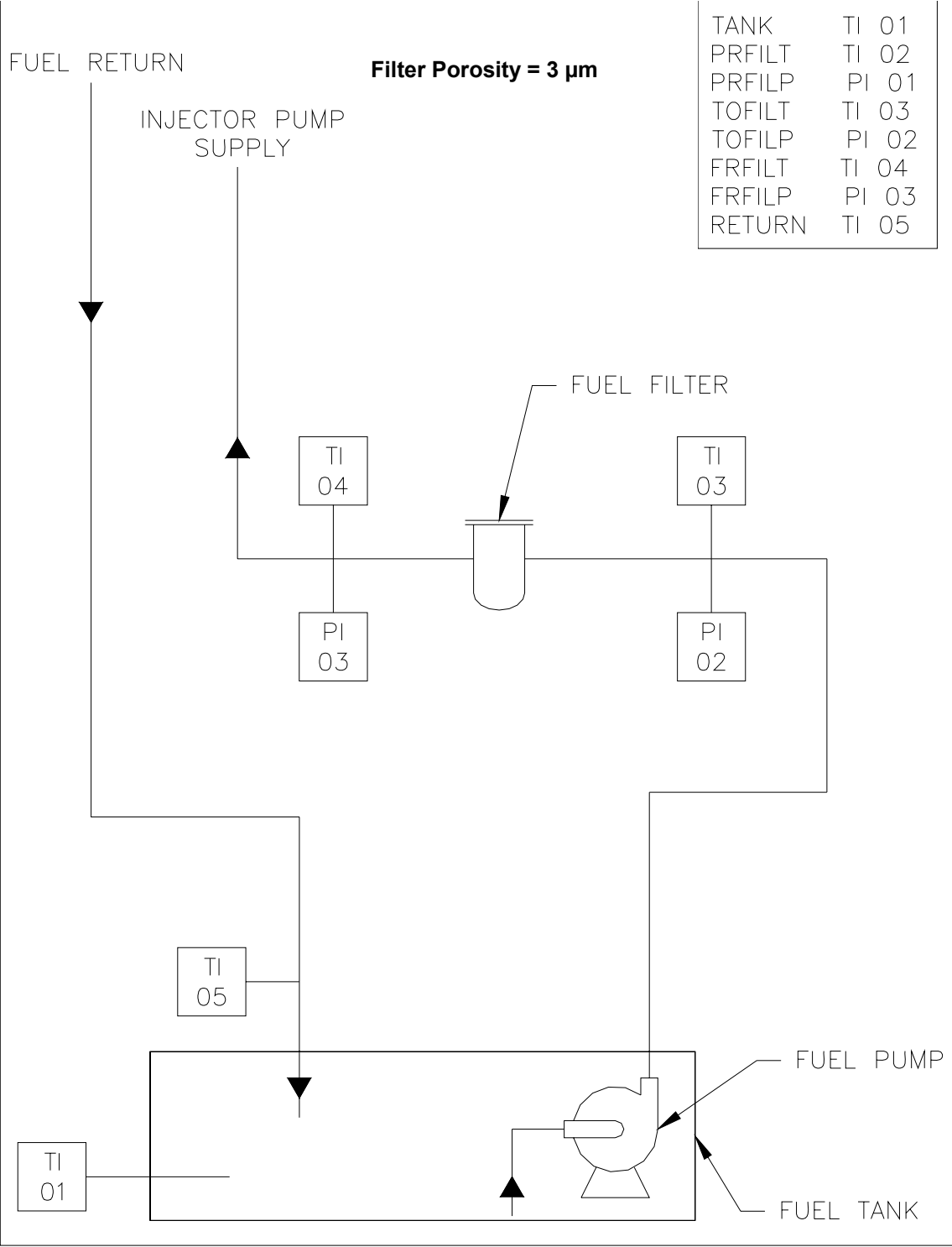


Figure 5  
Vehicle 5 Fuel Delivery System

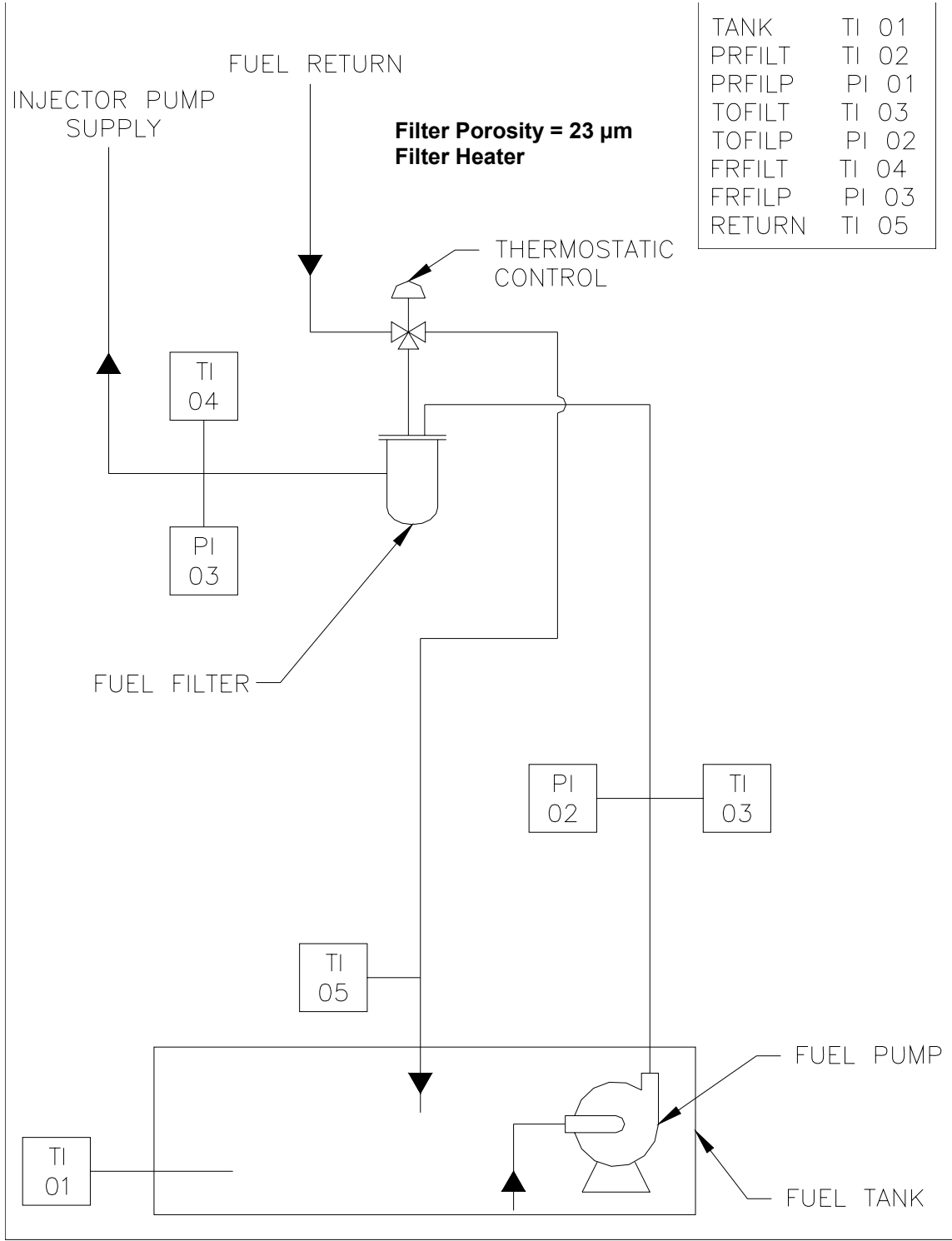


Figure 6  
Example Plot of Start-Up Data

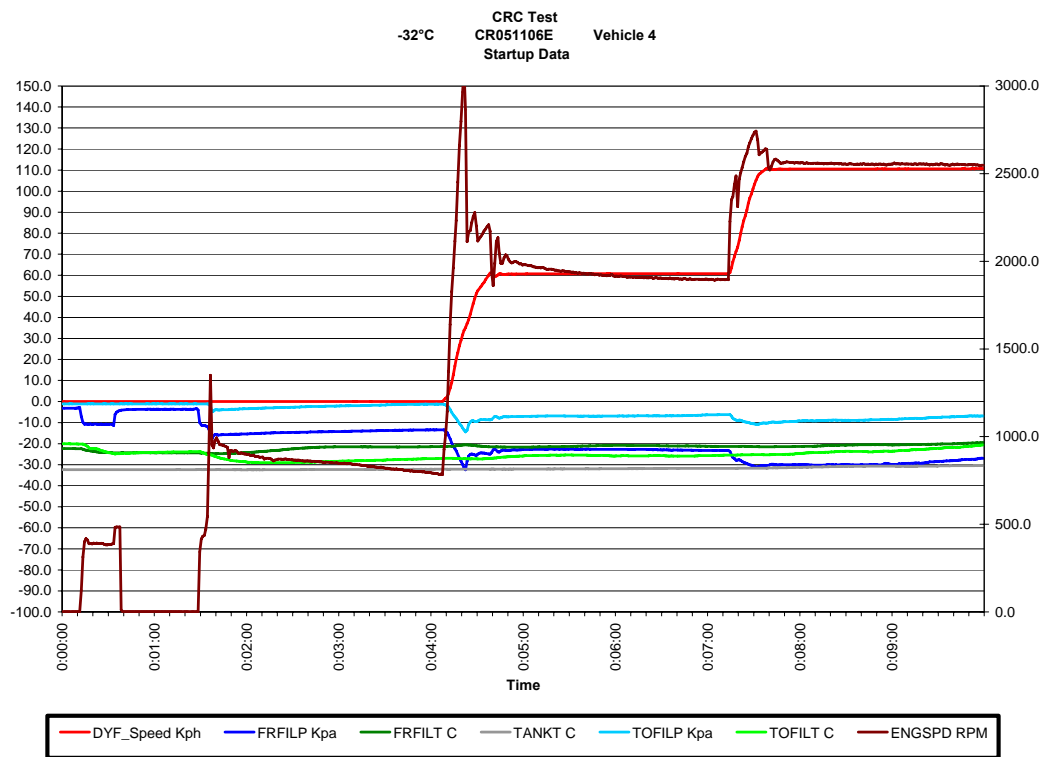


Figure 7  
Example Plot of Completed Test

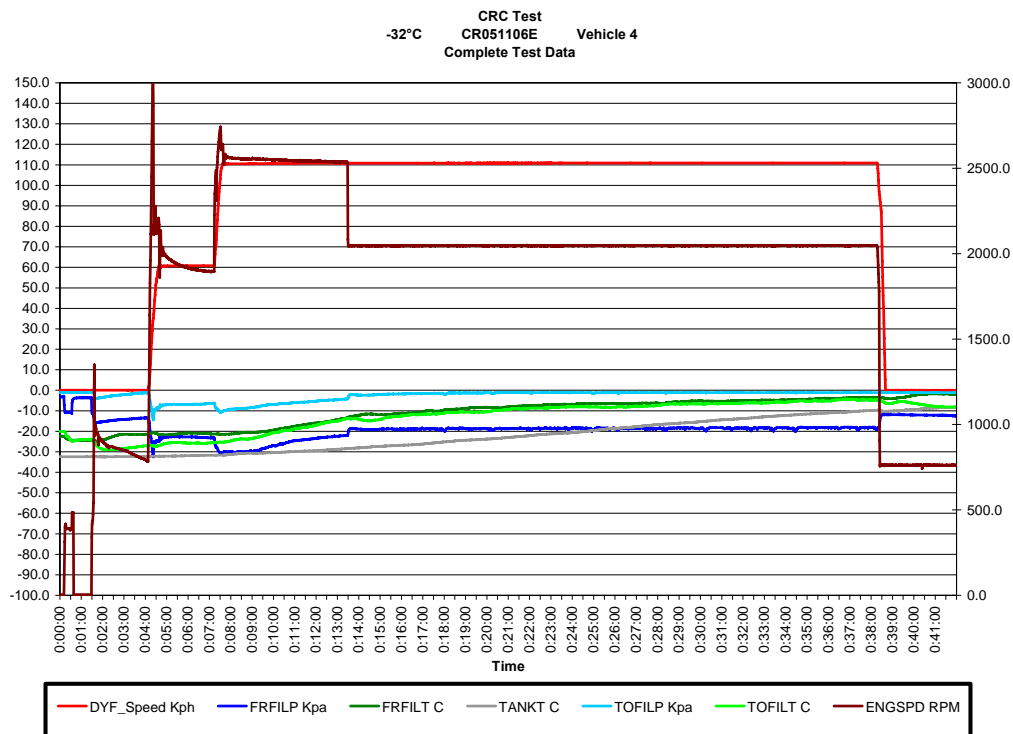


Figure 8  
Example Plot of Cool Down Data for the Cold Soak Room and Dynamometer

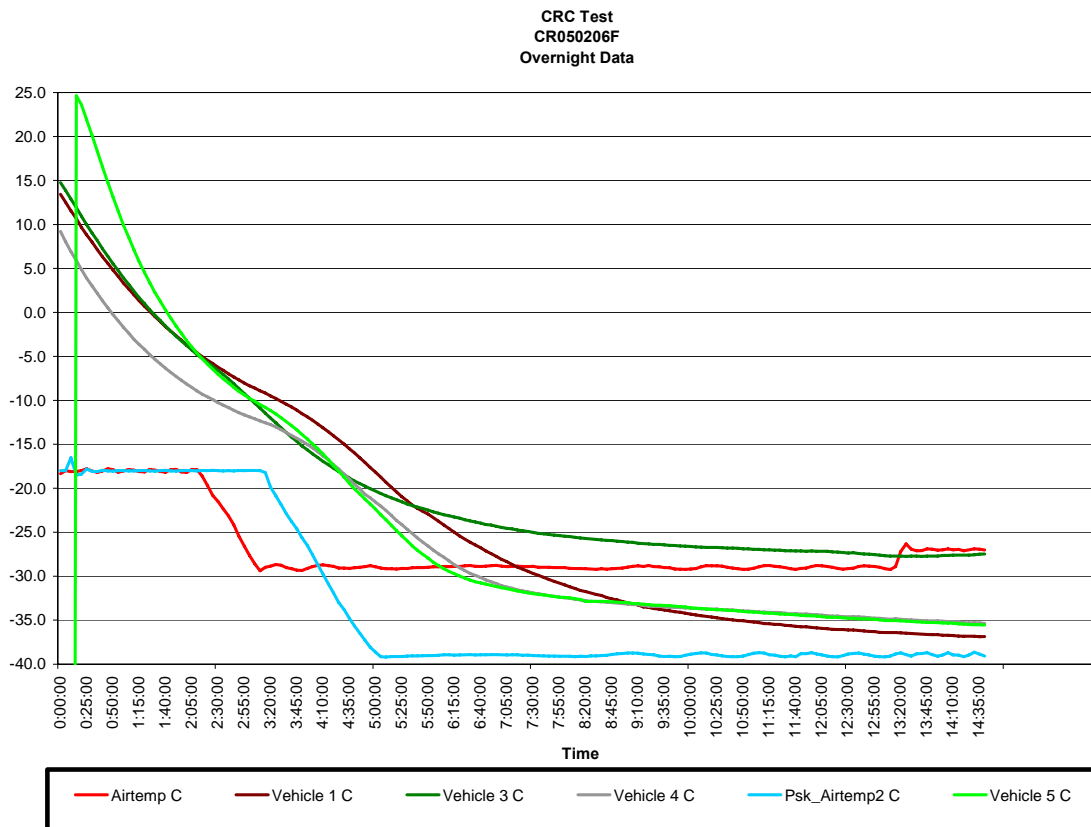


Figure 9  
Vehicle 1 Performance in Test Fuels

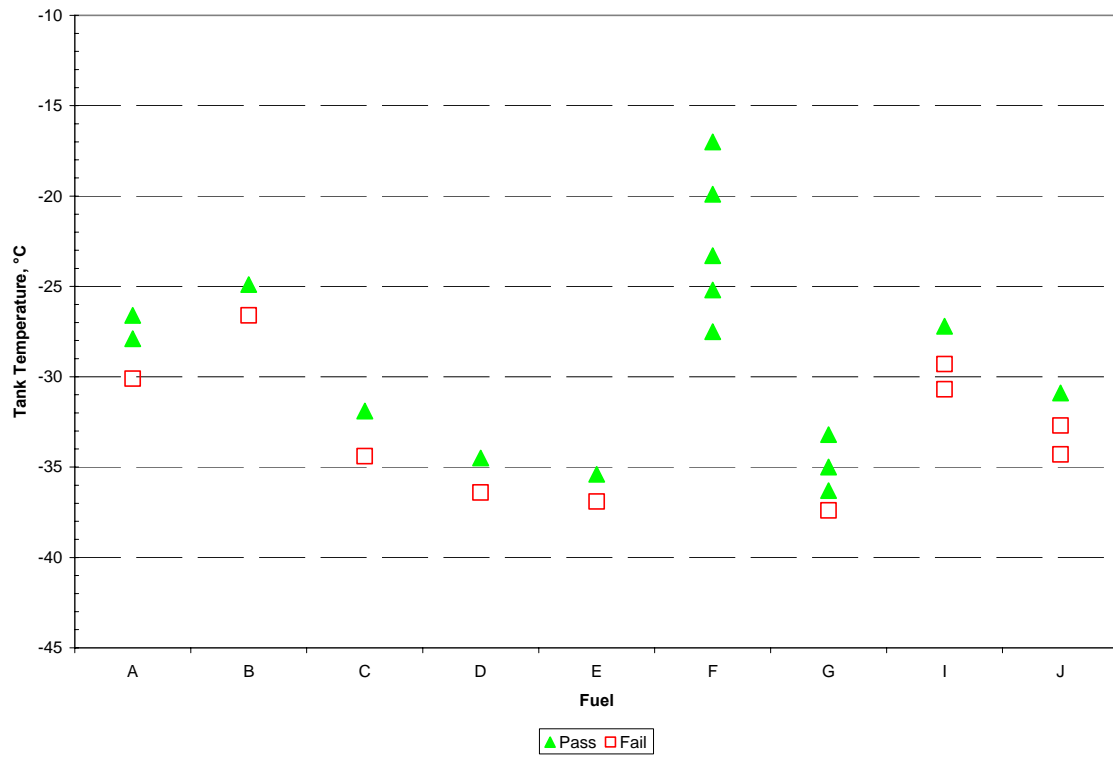


Figure 10  
Vehicle 2 Performance in Test Fuels

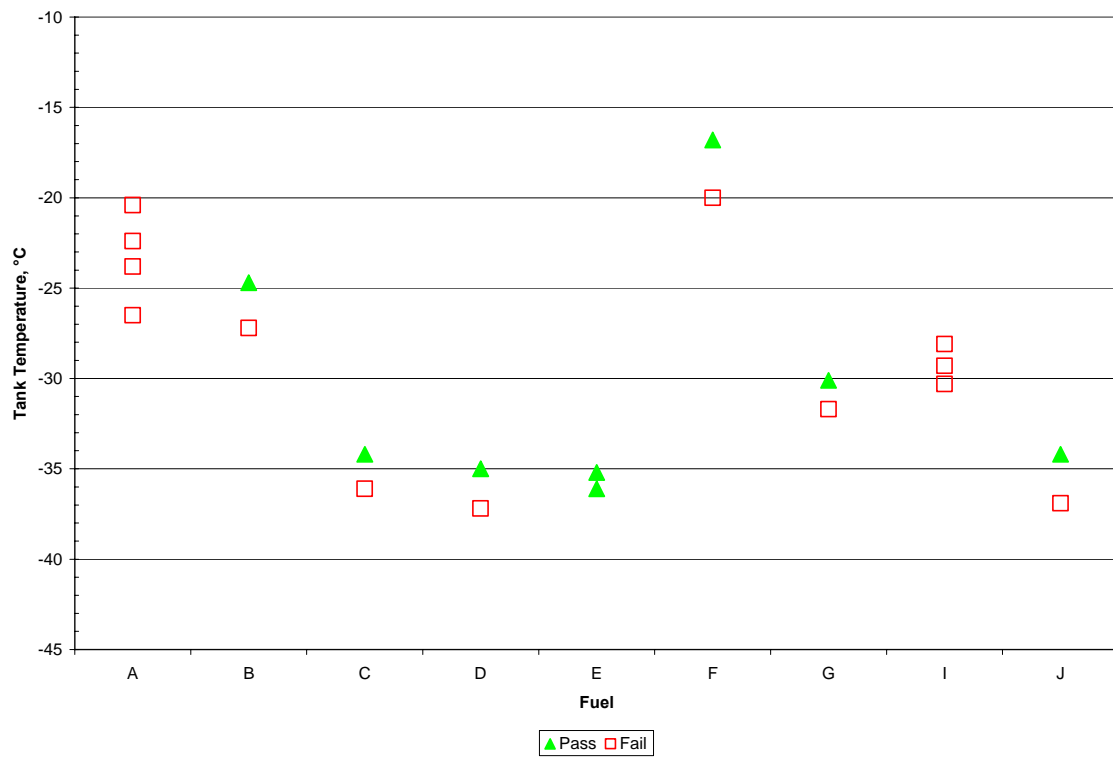


Figure 11  
Vehicle 3 Performance in Test Fuels

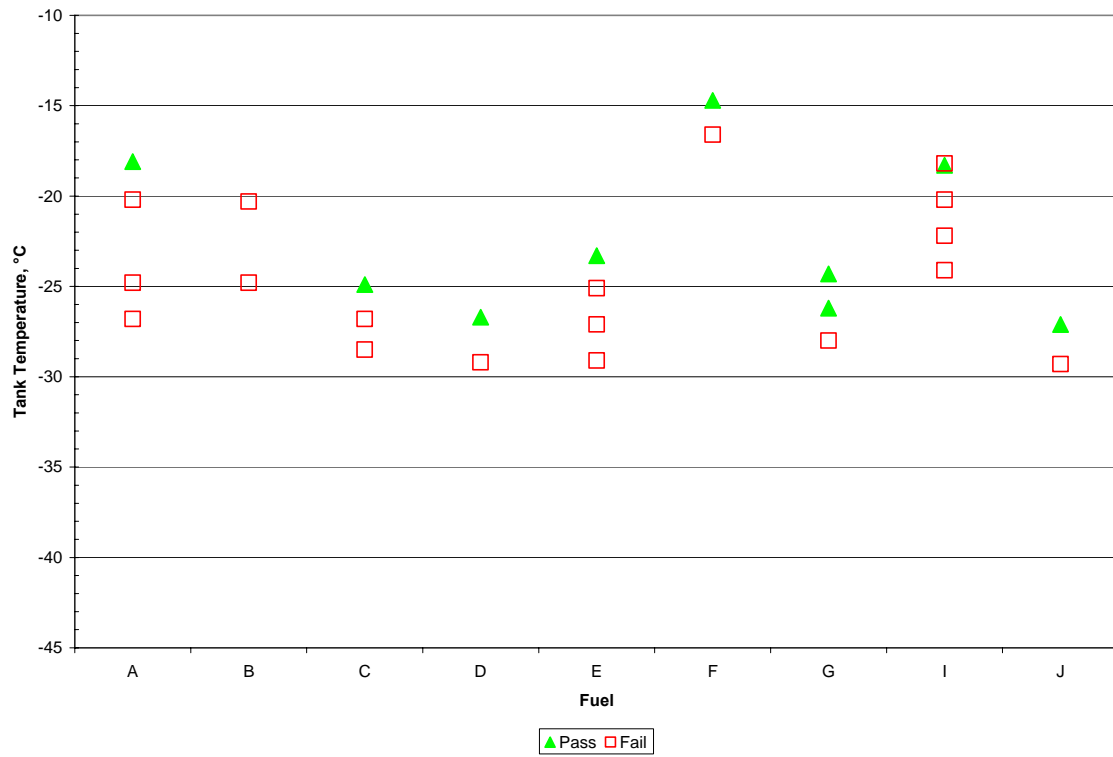


Figure 12  
Vehicle 4 Performance in Test Fuels

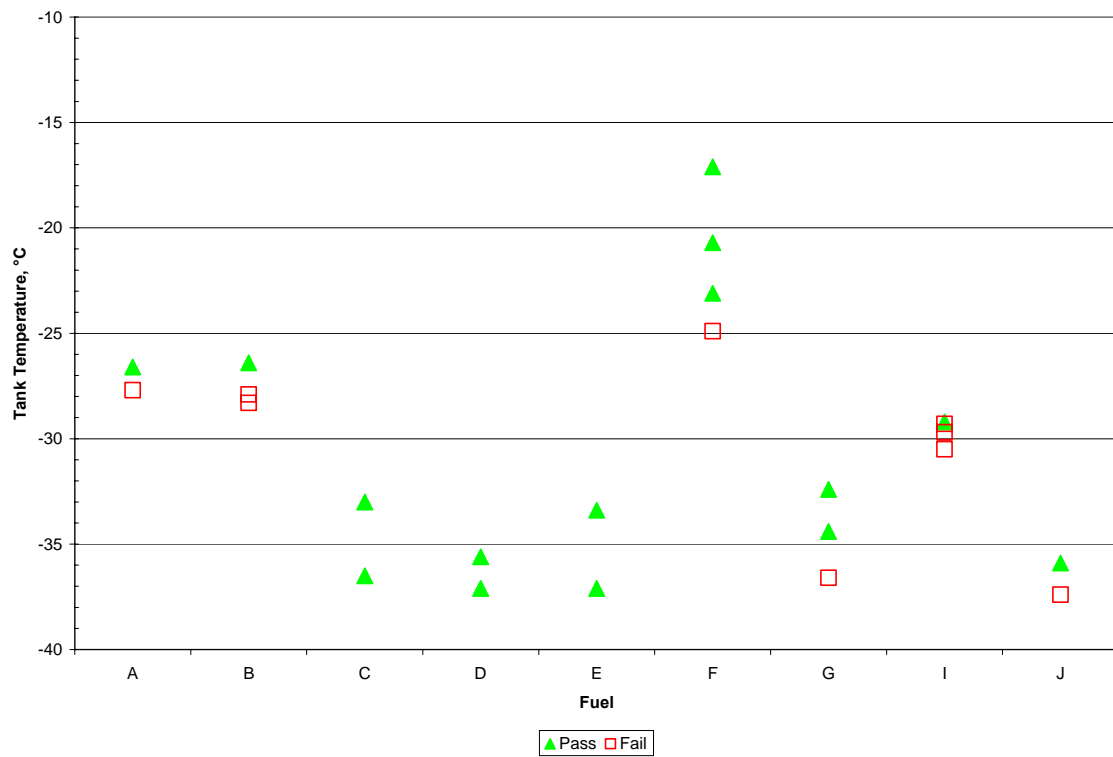


Figure 13  
Vehicle 5 Performance in Test Fuels

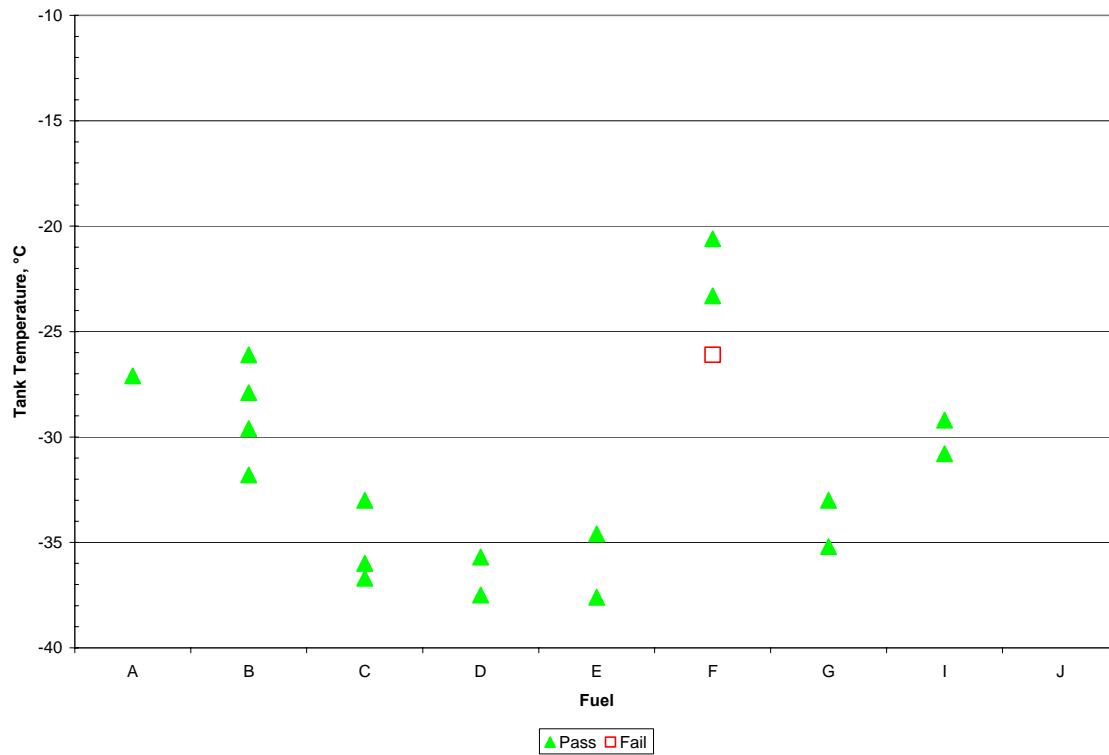


Figure 14  
Temperature Profile -18.3°C Vehicle 3 Pass

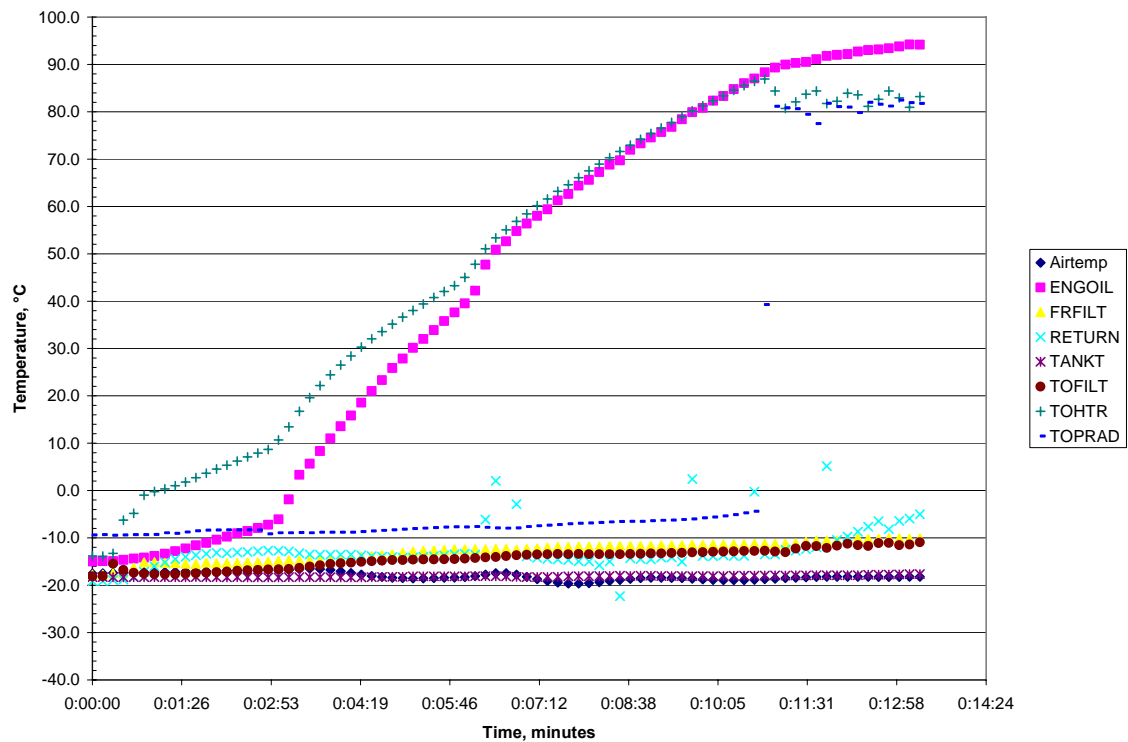


Figure 15  
 Temperature Profile for -18.2°C Vehicle 3 Fail

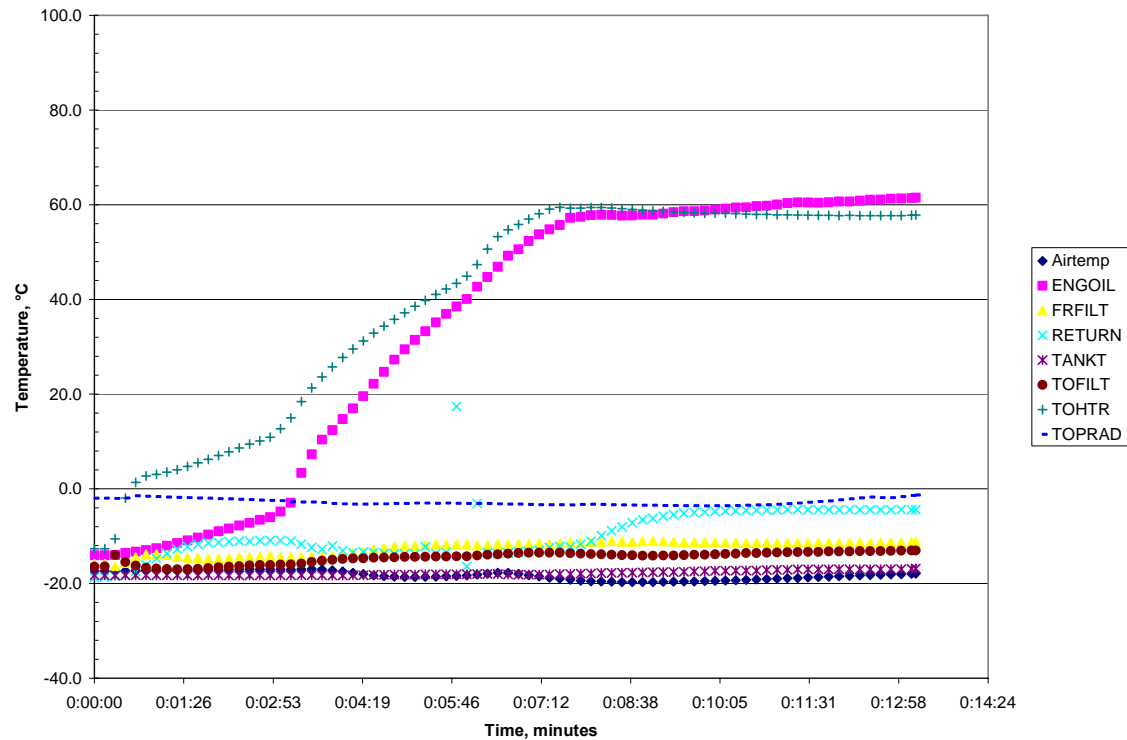


Figure 16  
 Pressure Profile for -18.3°C Vehicle 3 Pass

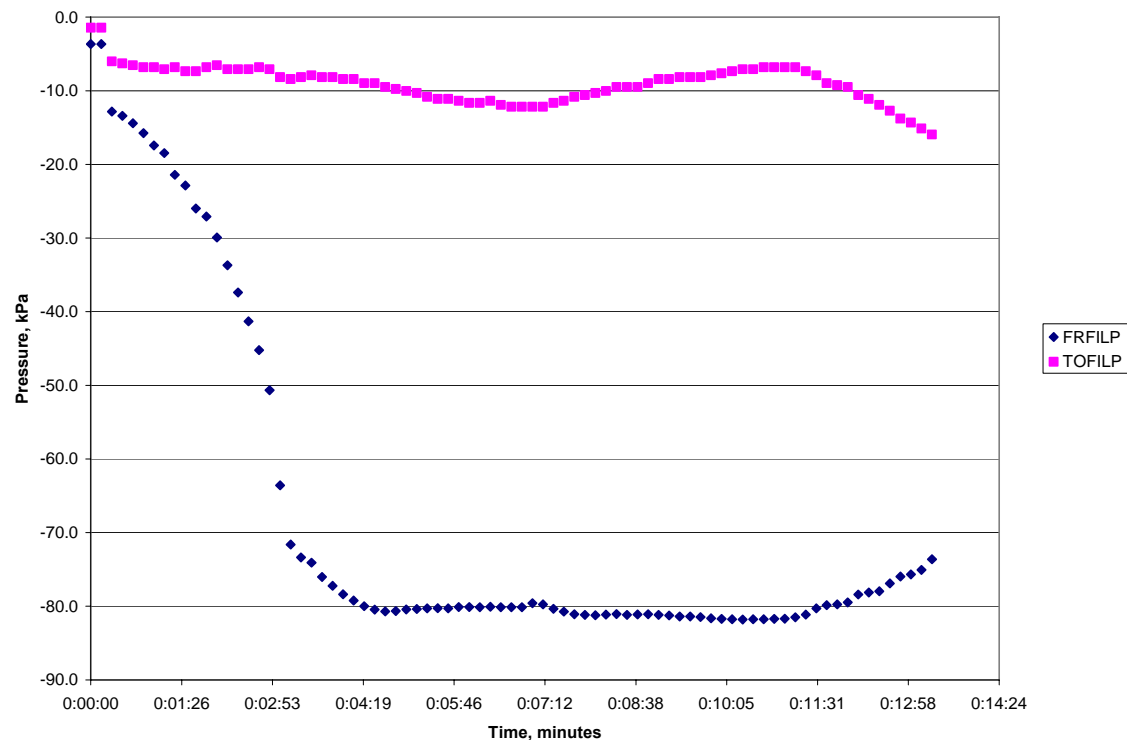


Figure 17  
Pressure Profile for -18.2°C Vehicle 3 Fail

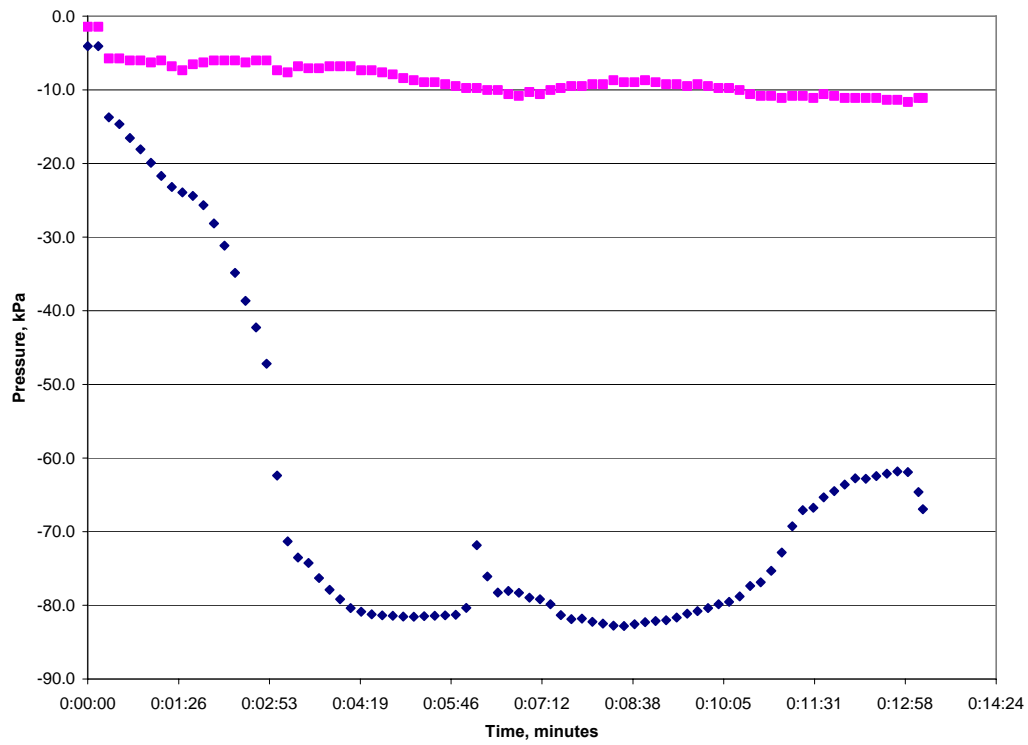


Figure 18  
Vehicle Performance with Fuel A

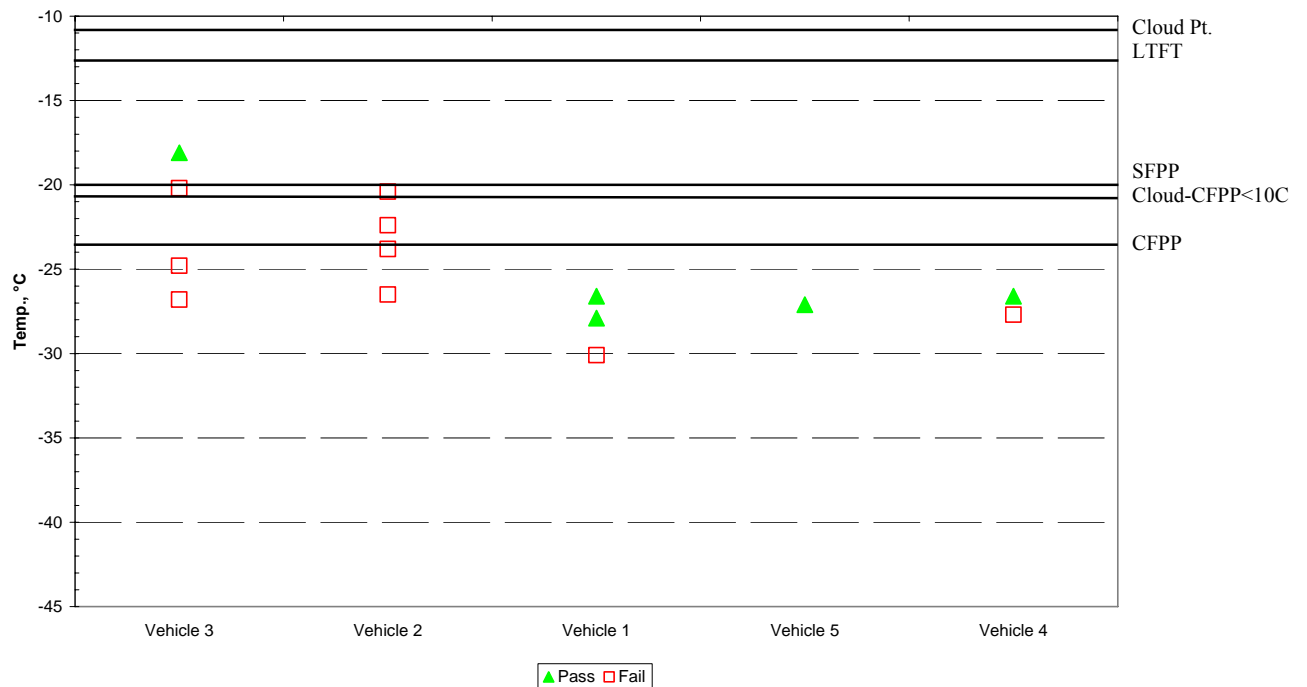


Figure 19

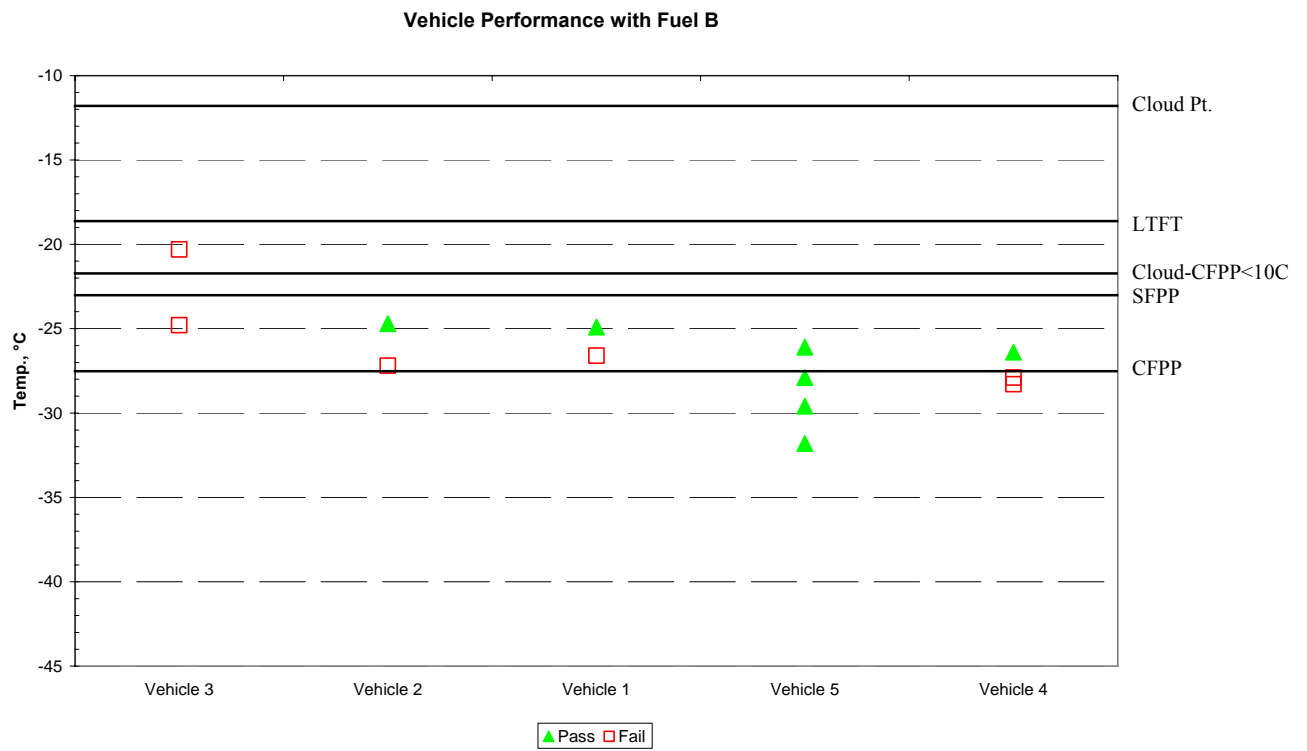


Figure 20

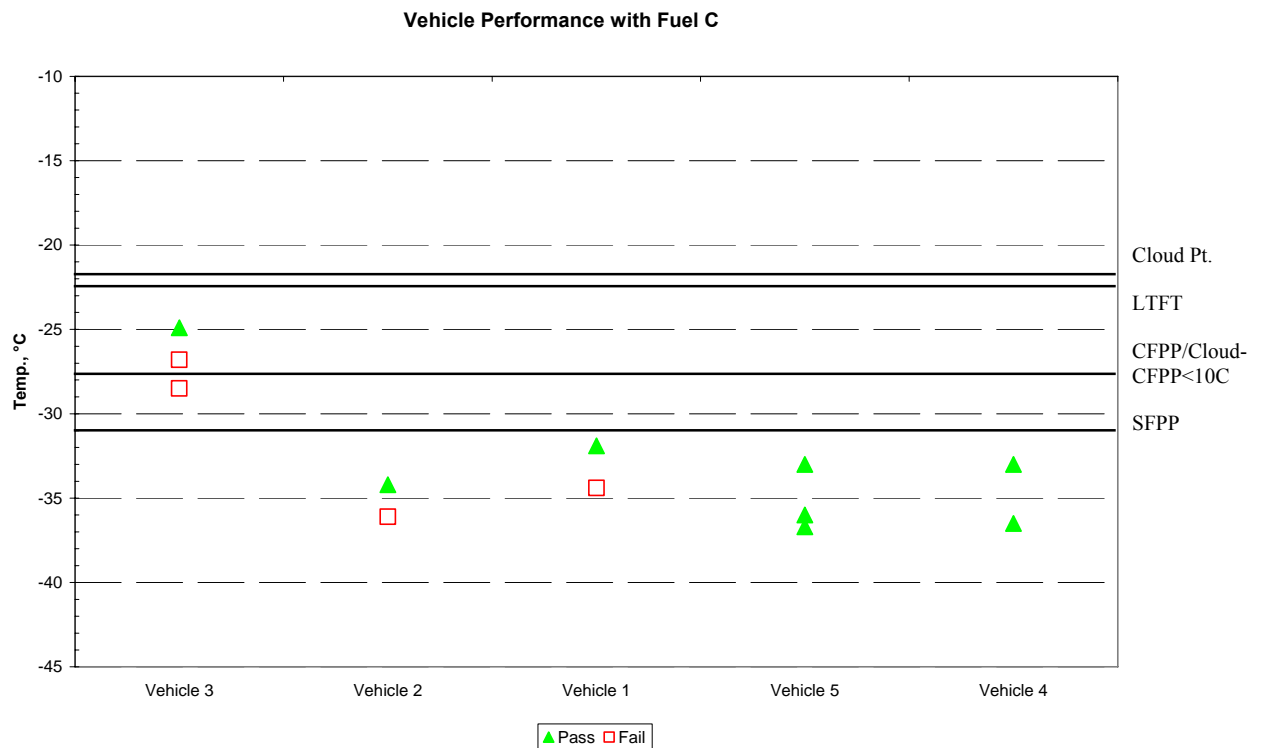


Figure 21

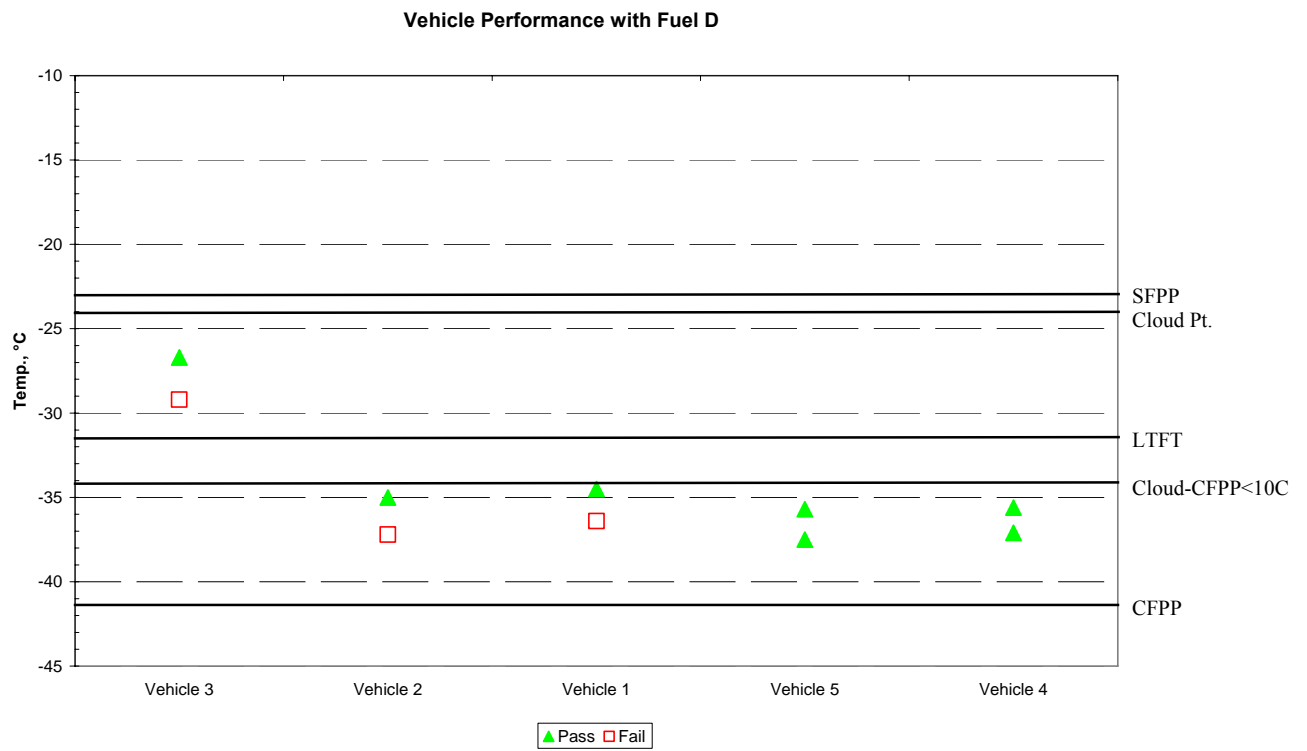


Figure 22

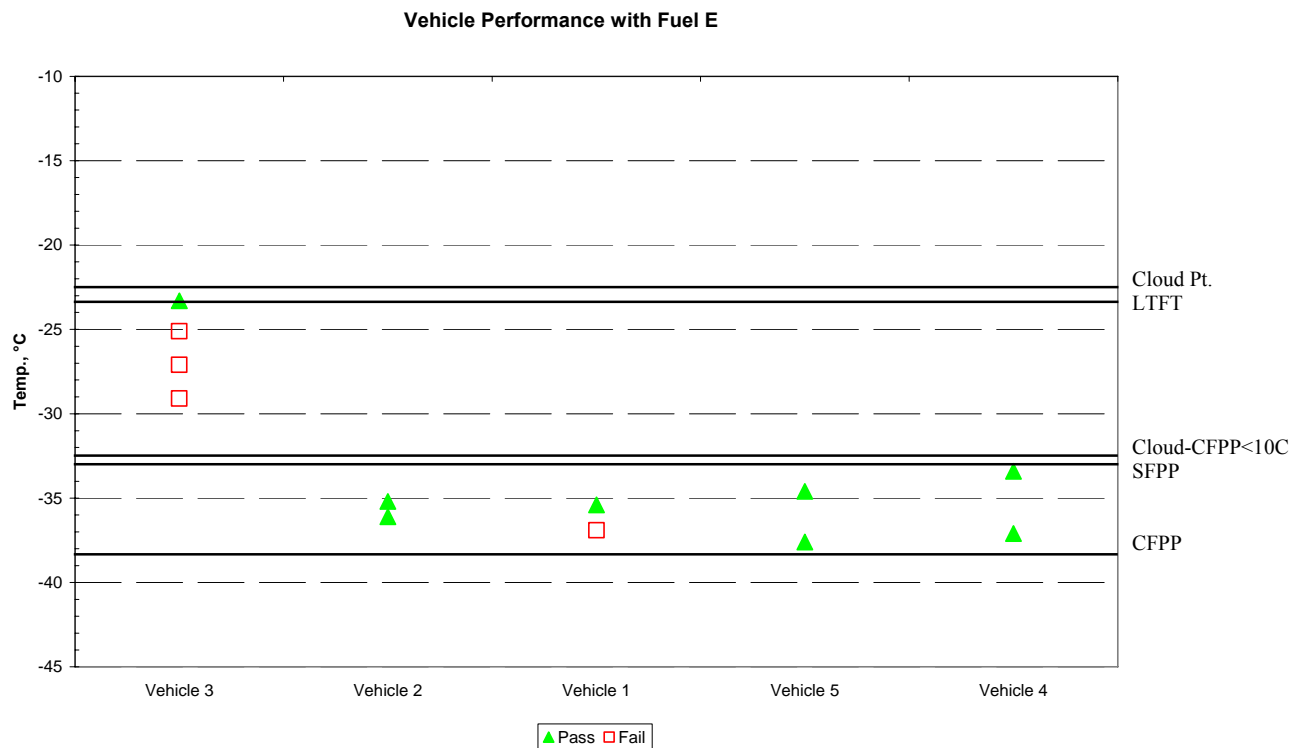


Figure 23

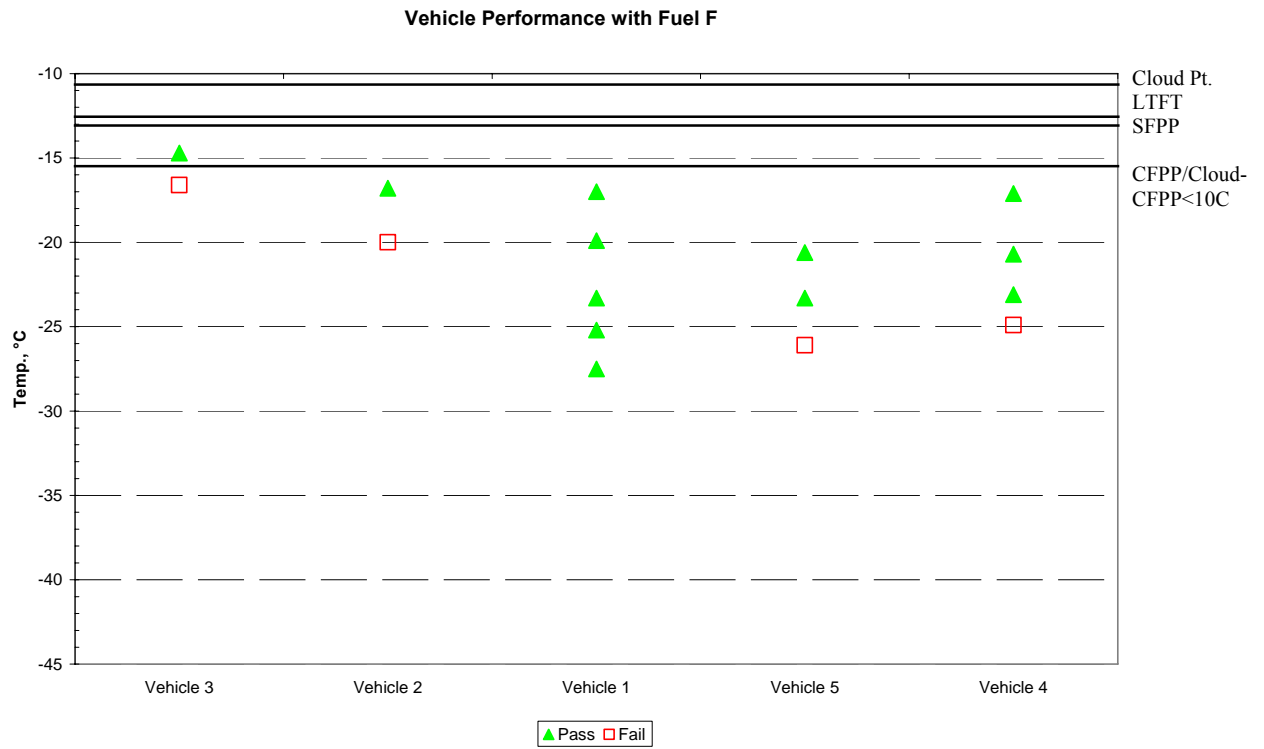


Figure 24

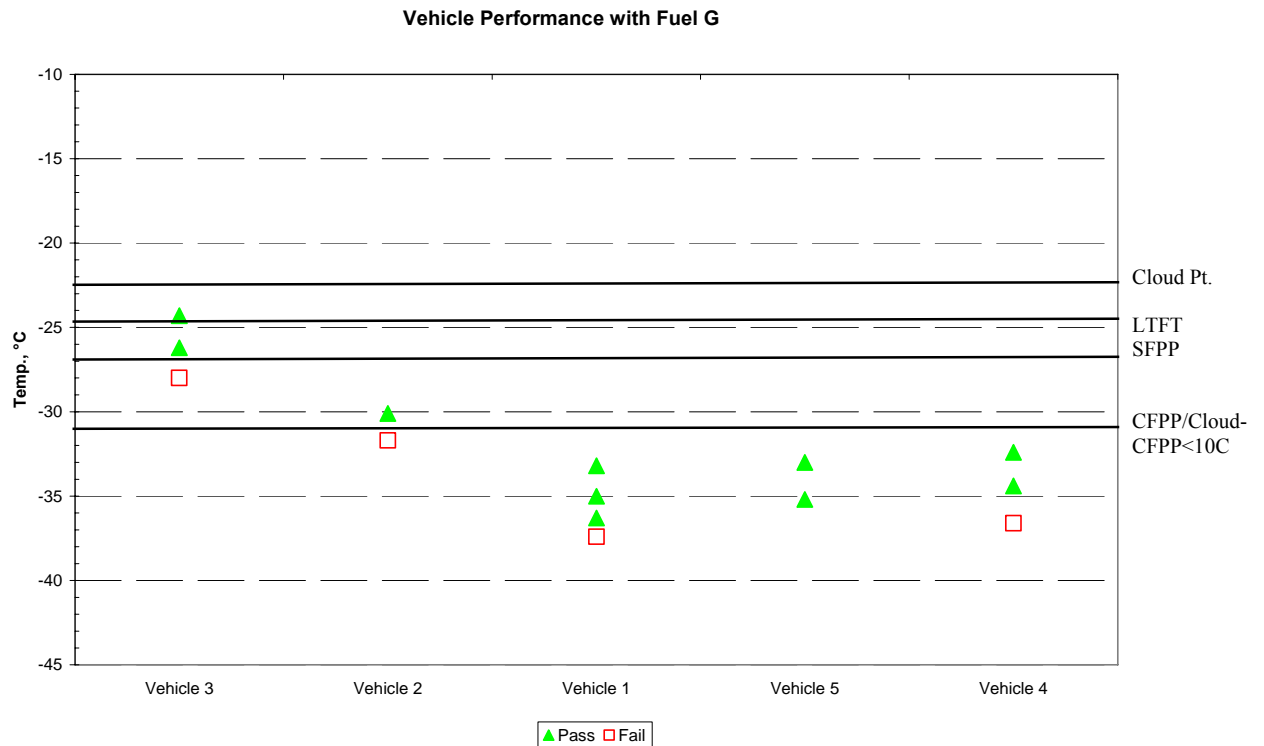


Figure 25

Vehicle Performance with Fuel I

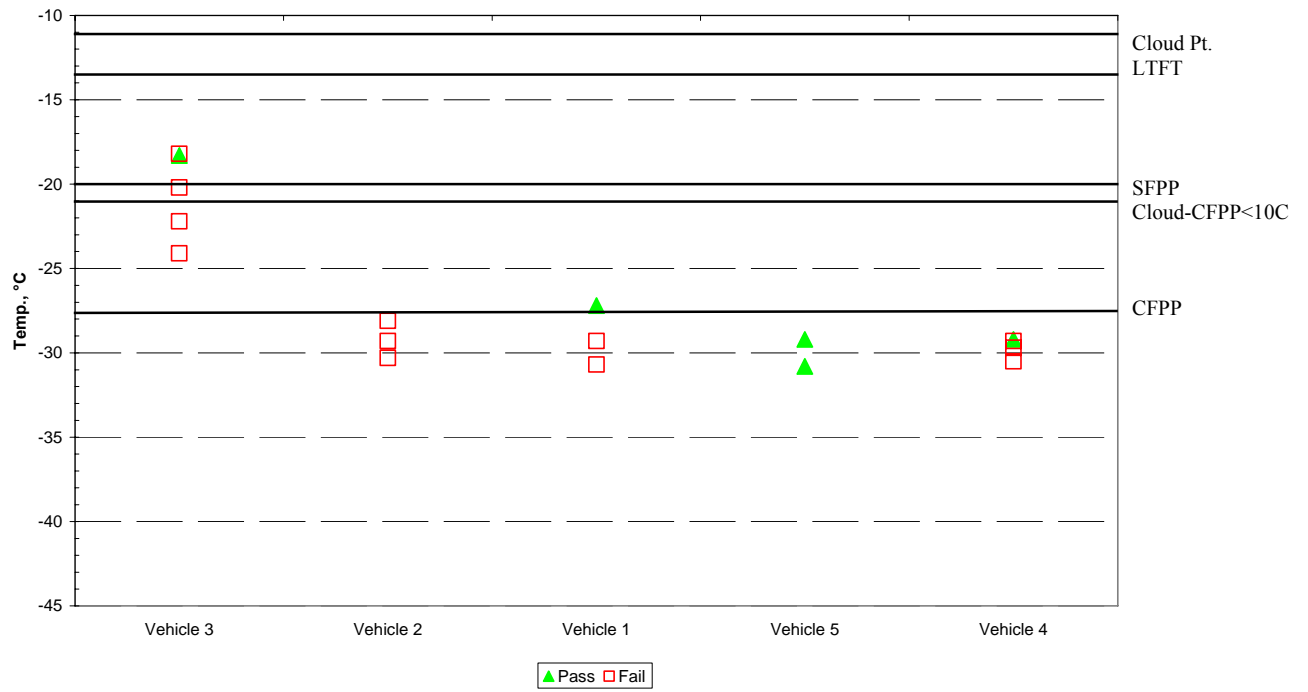


Figure 26

Vehicle Performance with Fuel J

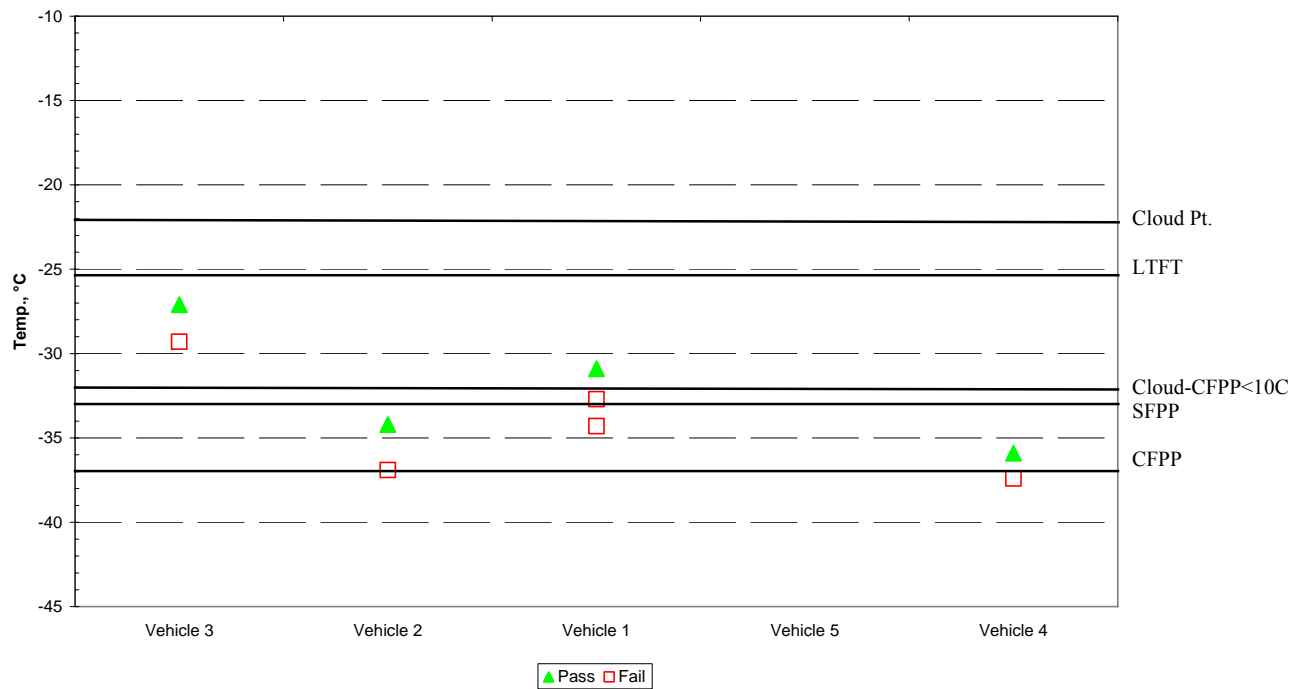


Figure 27  
Vehicle 1  
EMOT vs. Cloud Point

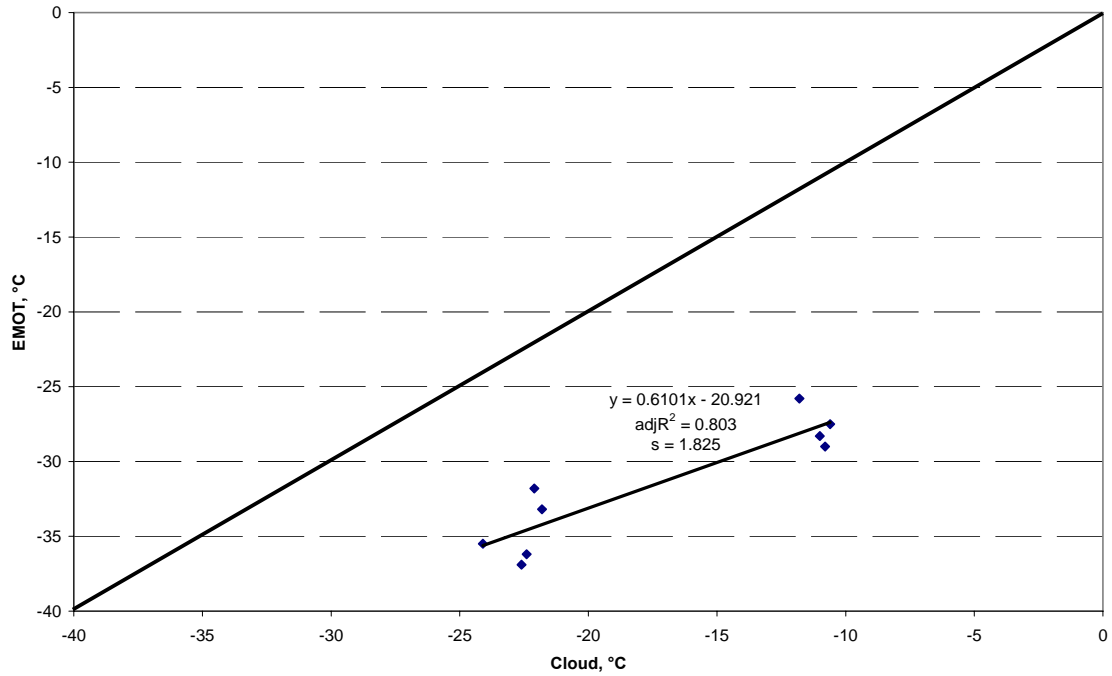


Figure 28  
Vehicle 1  
EMOT vs. CFPP

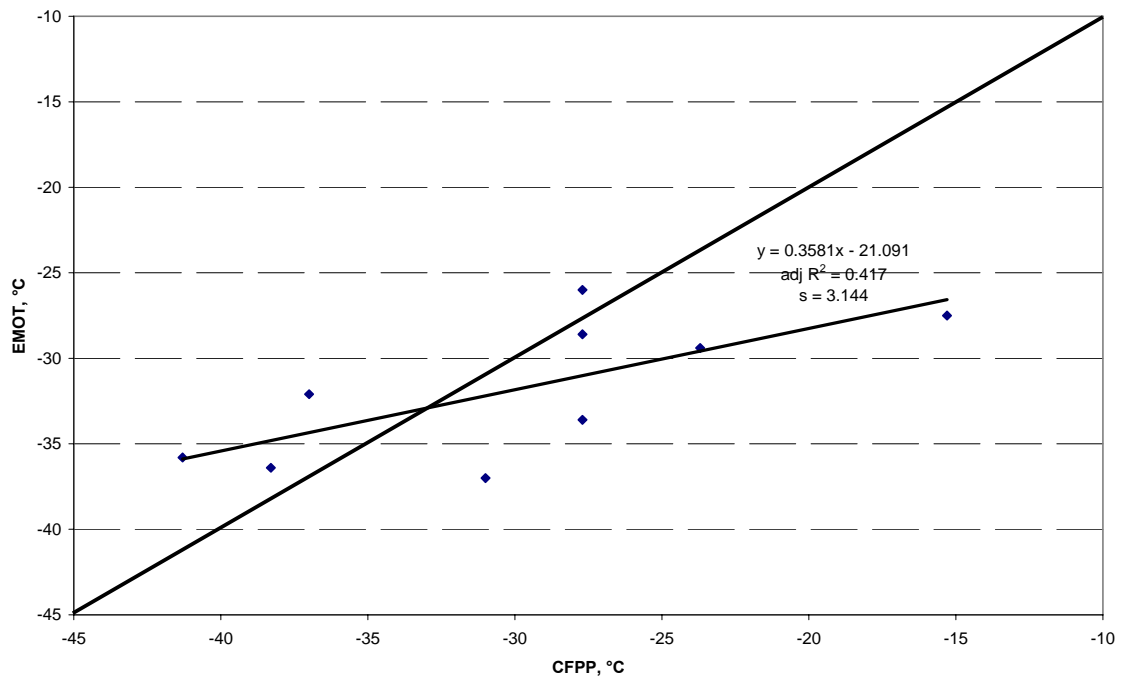


Figure 29  
Vehicle 1  
EMOT vs. Cloud-CFPP = 10°C max.

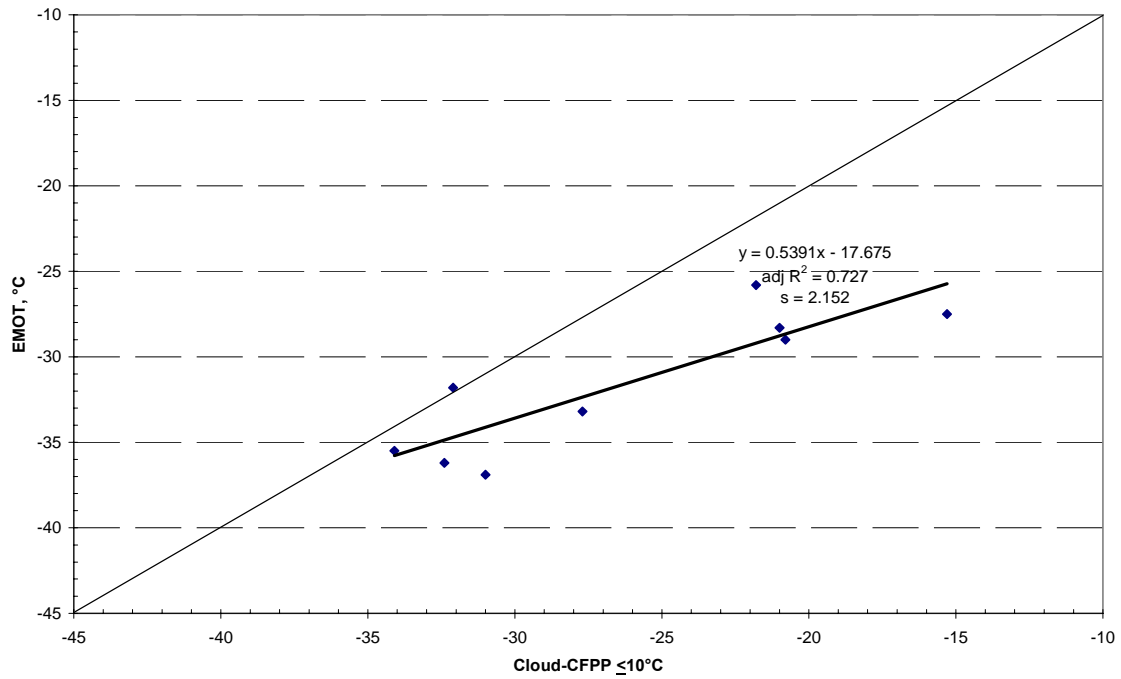


Figure 30  
Vehicle 1  
EMOT vs. LTFT

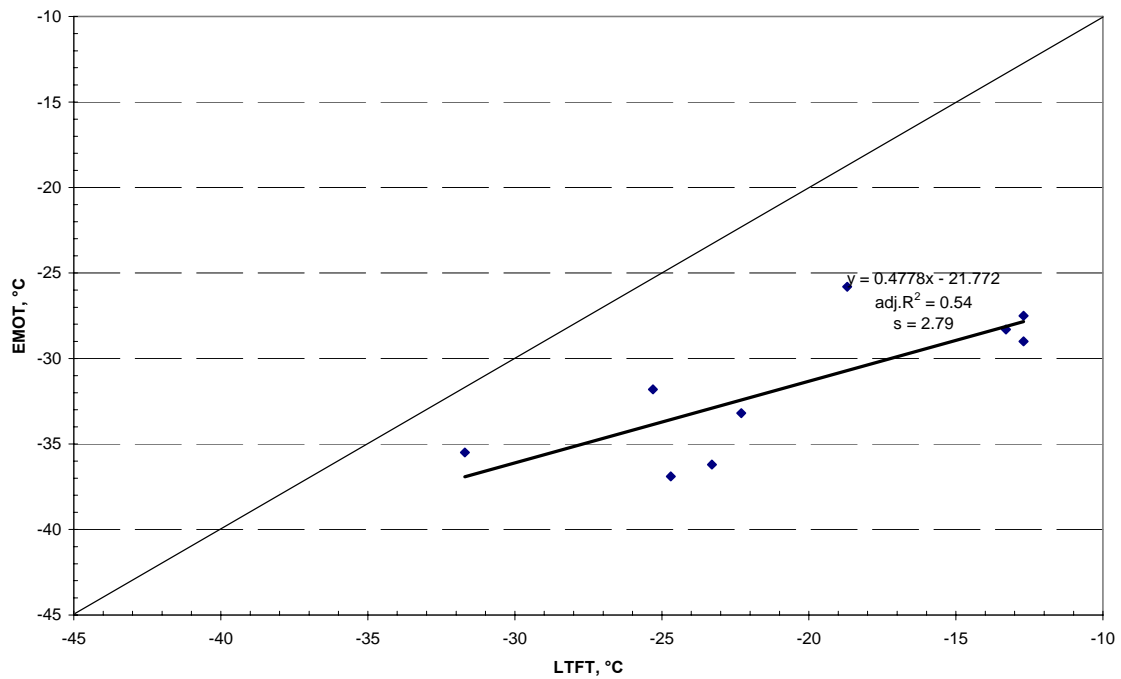


Figure 31  
Vehicle 2  
EMOT vs. Cloud Point

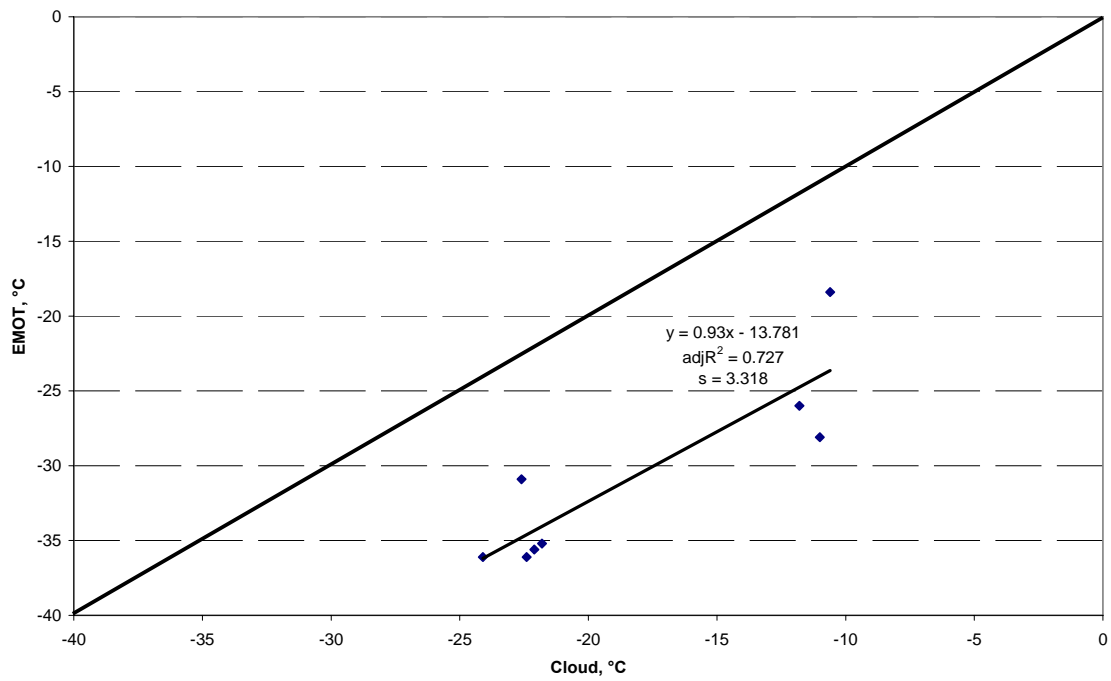


Figure 32  
Vehicle 2  
EMOT vs. CFPP

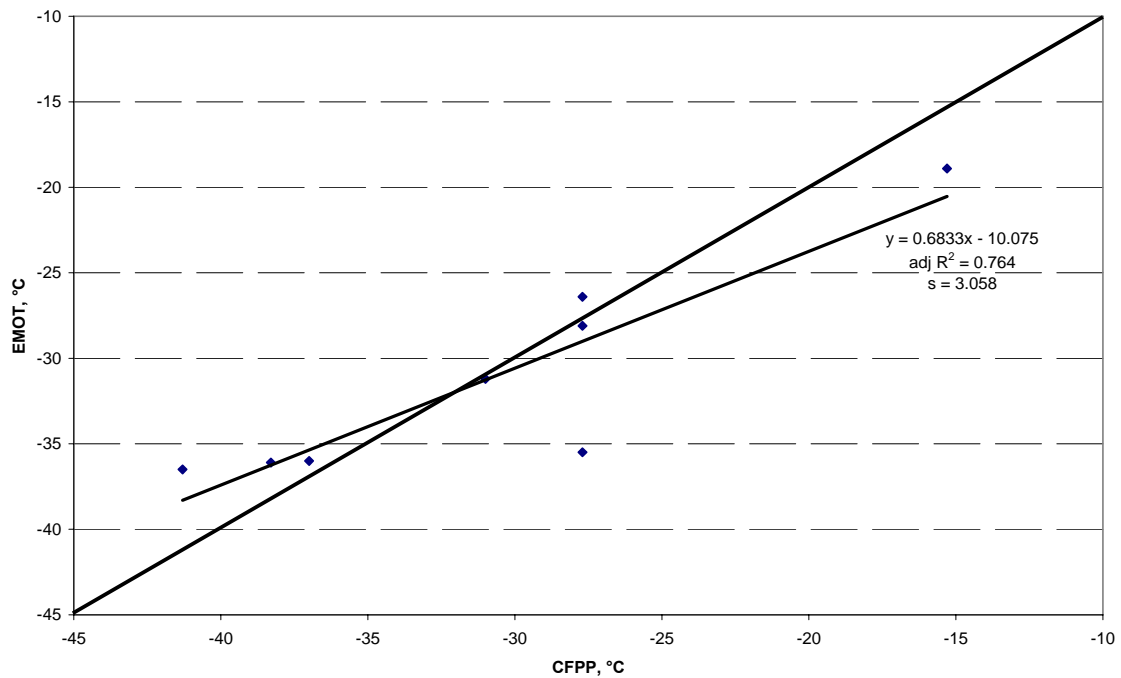


Figure 33  
Vehicle 2  
EMOT vs. Cloud-CFPP  $\leq 10^{\circ}\text{C}$

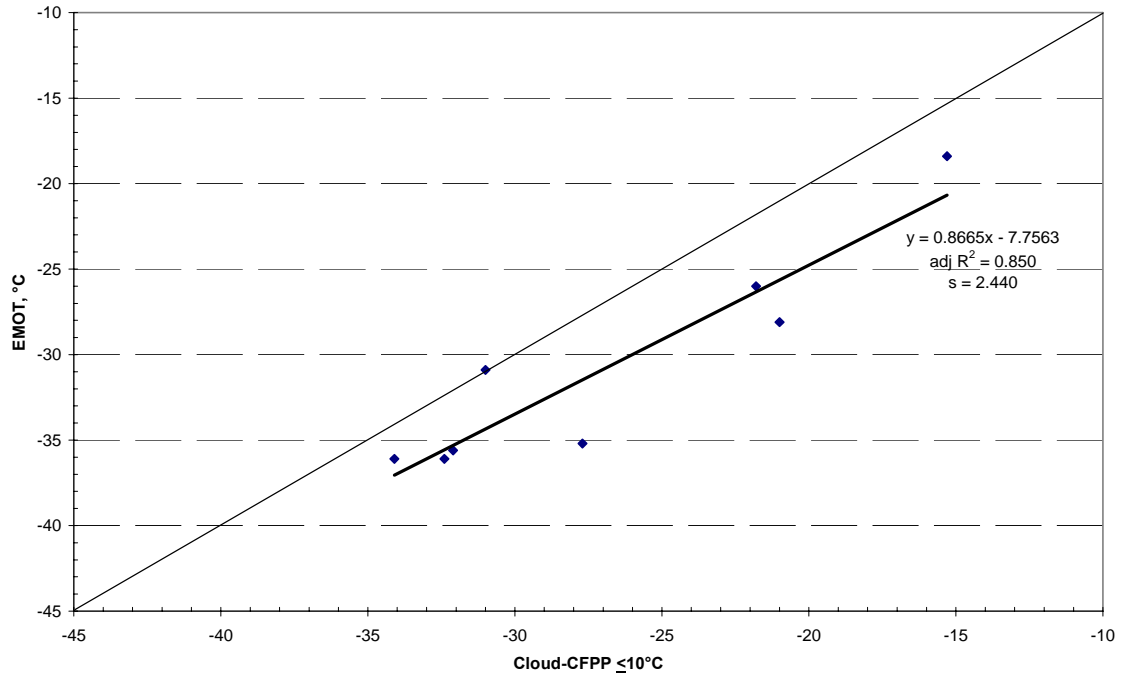


Figure 34  
Vehicle 2  
EMOT vs. LTFT

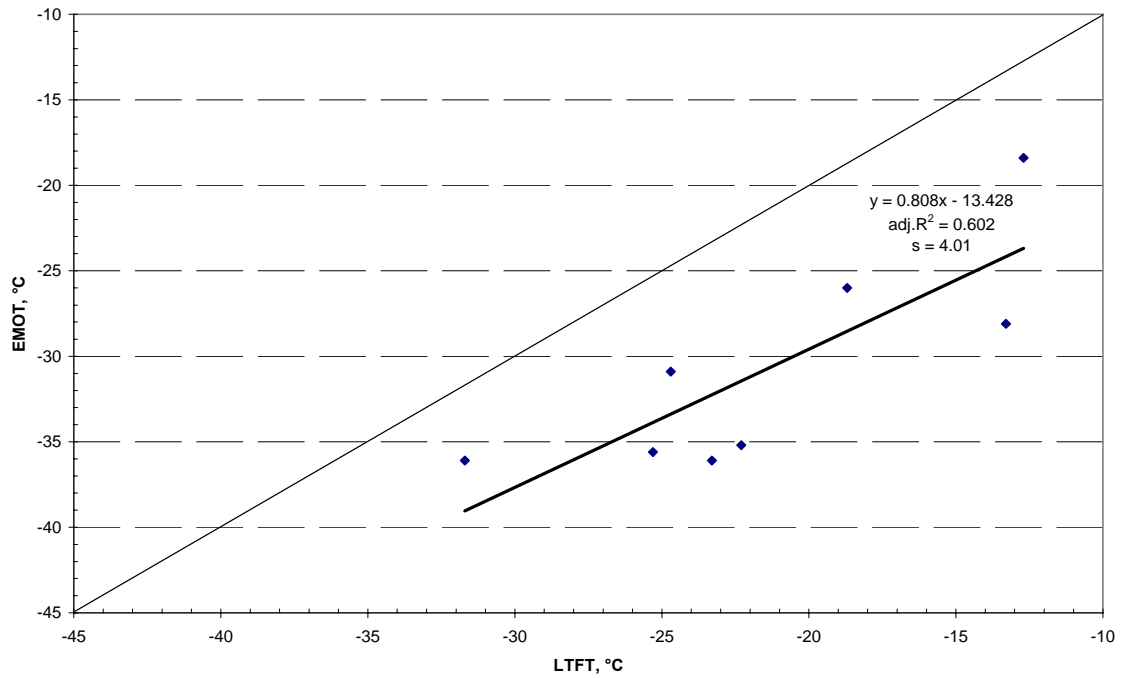


Figure 35  
Vehicle 3  
EMOT vs. Cloud Point

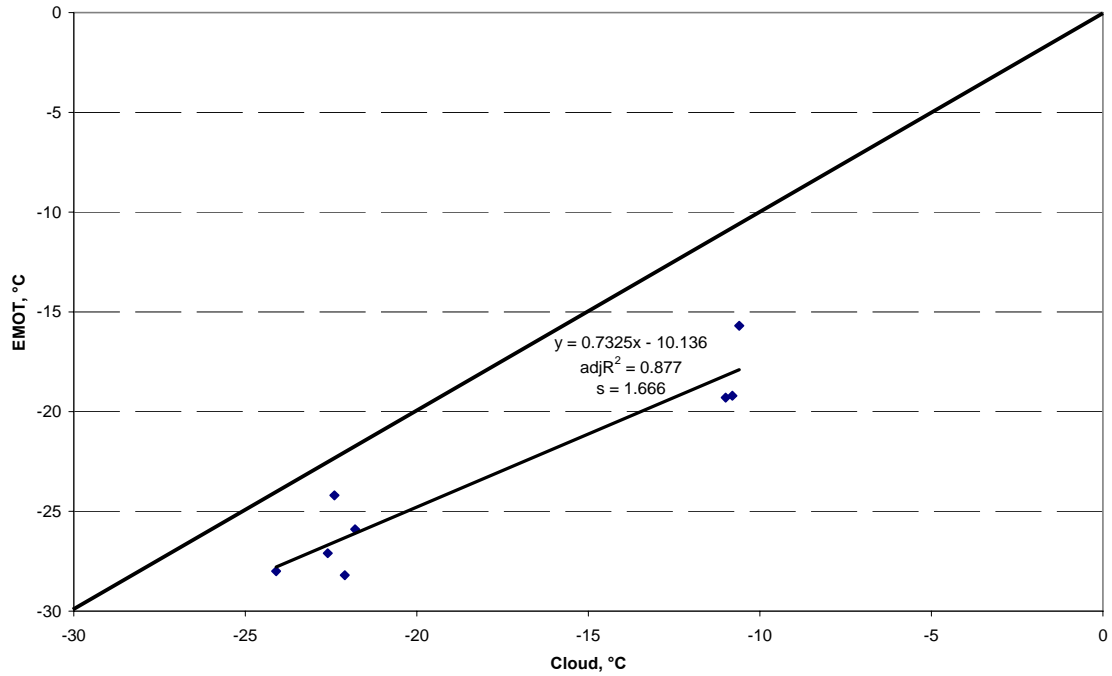


Figure 36  
Vehicle 3  
EMOT vs. CFPP

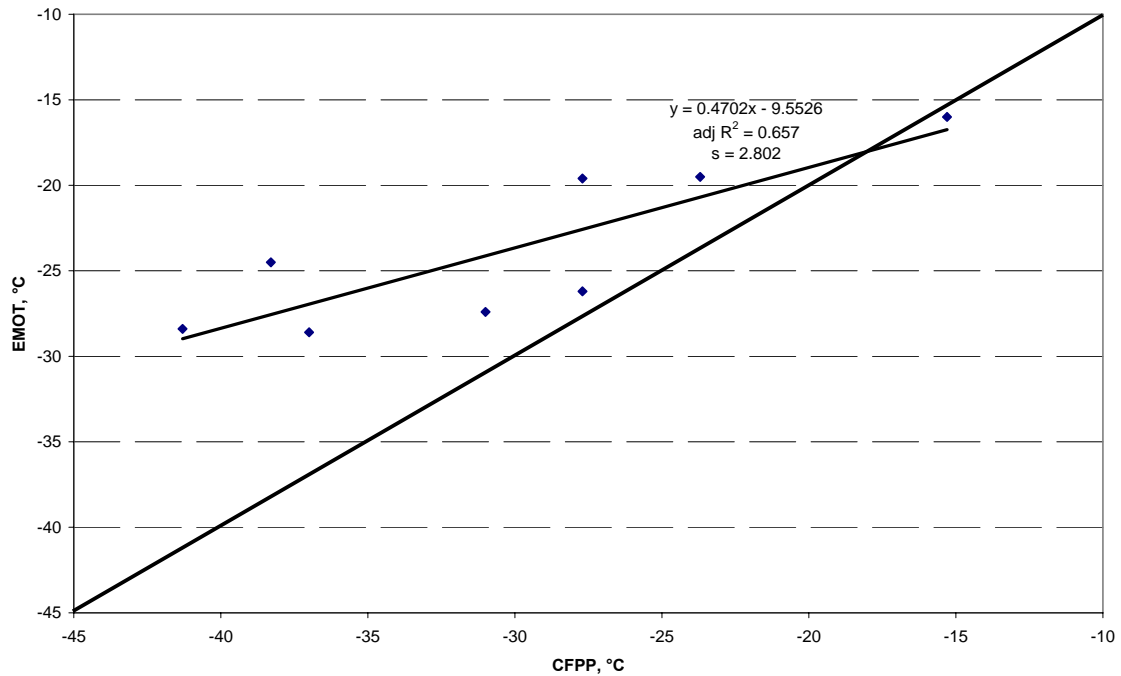


Figure 37  
Vehicle 3  
EMOT vs. Cloud-CFPP  $\leq 10^{\circ}\text{C}$

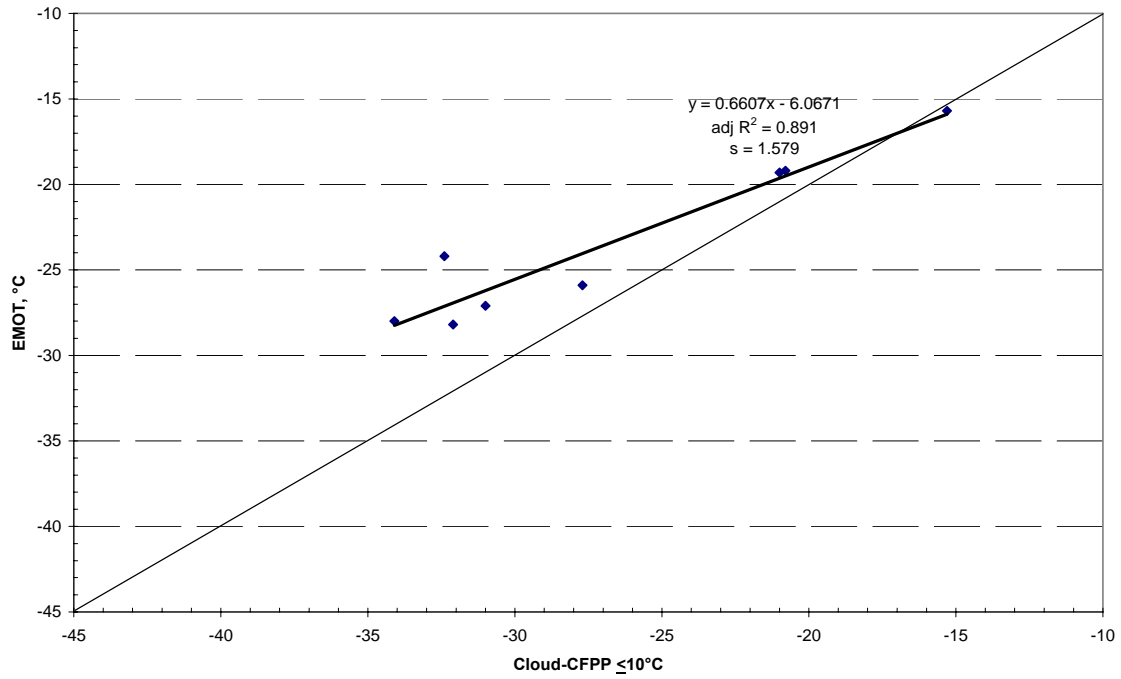


Figure 38  
Vehicle 3  
EMOT vs. LTFT

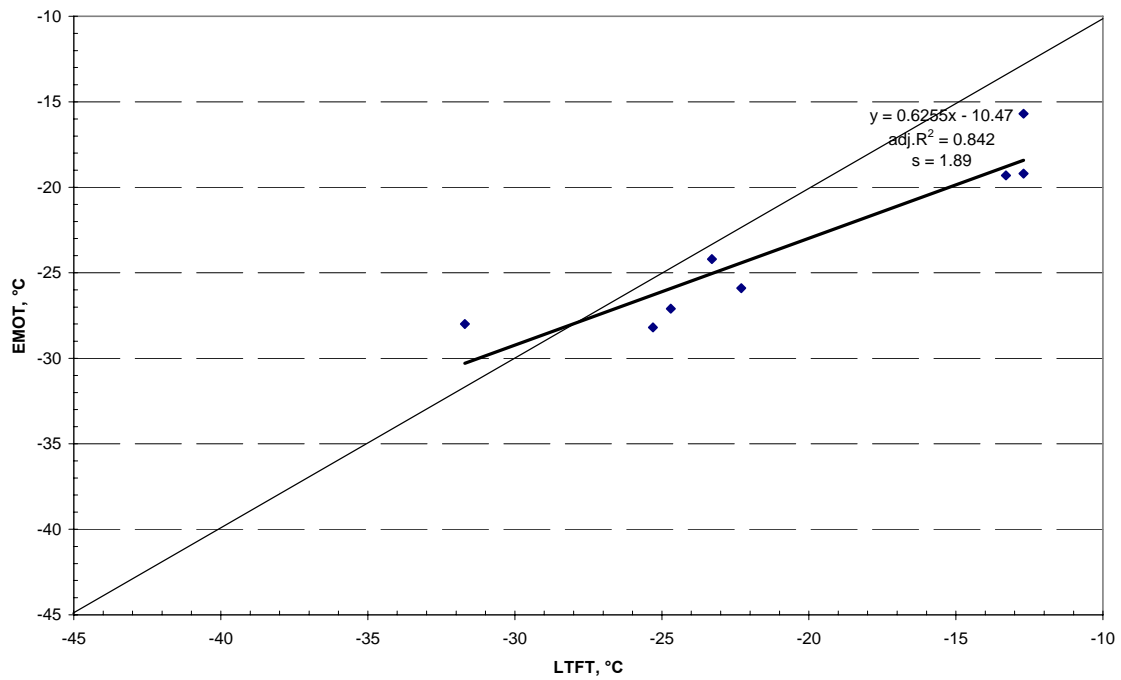


Figure 39  
Vehicle 4  
EMOT vs. Cloud Point

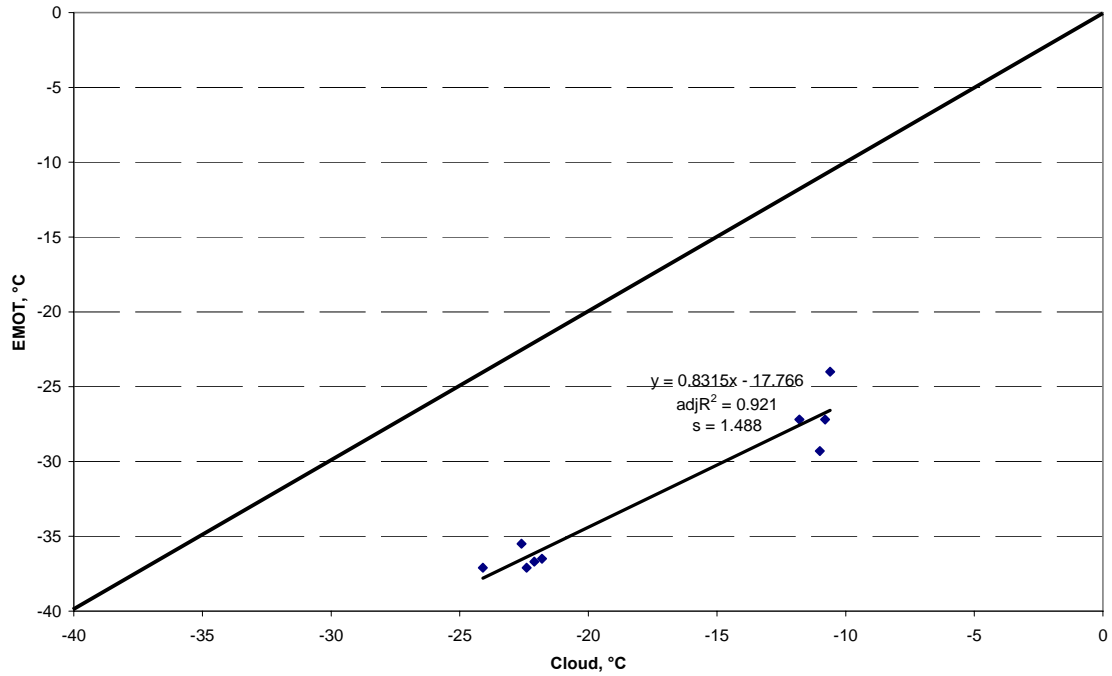


Figure 40  
Vehicle 4  
EMOT vs. CFPP

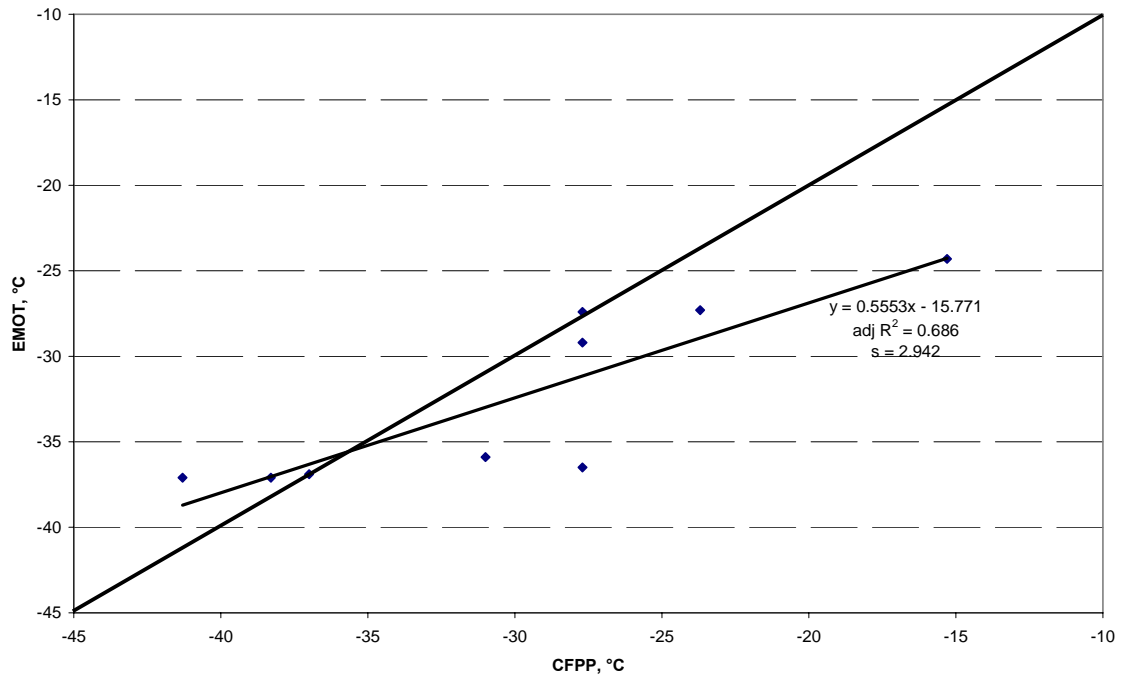


Figure 41  
Vehicle 4  
EMOT vs. Cloud-CFPP  $\leq 10^{\circ}\text{C}$

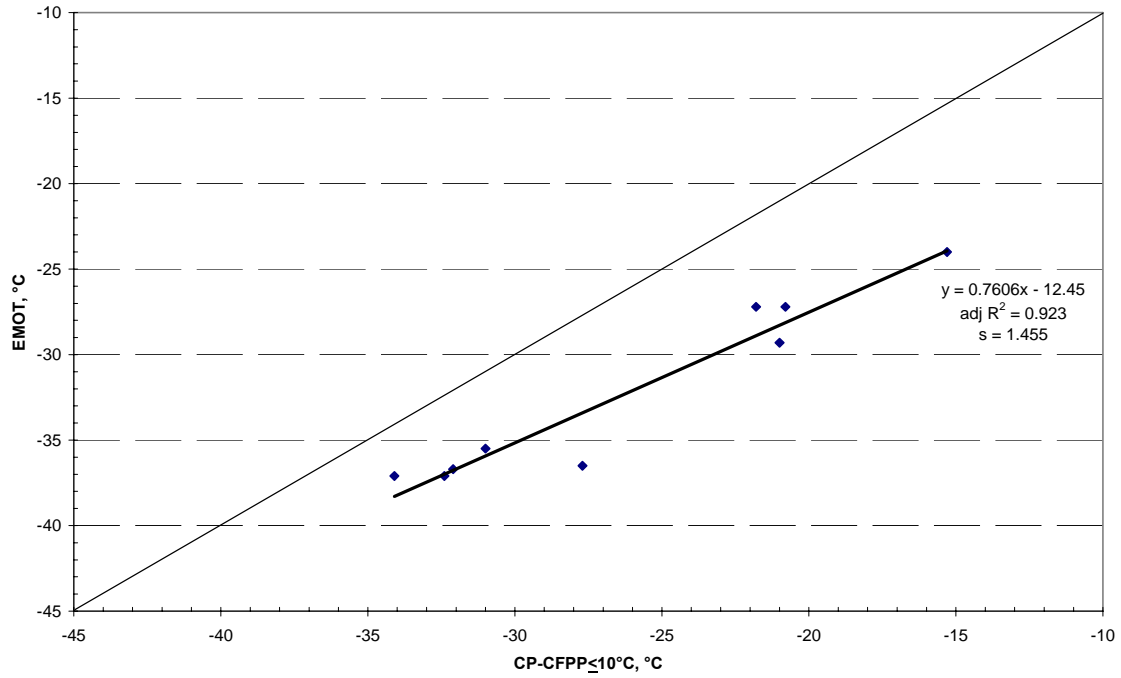


Figure 42  
Vehicle 4  
EMOT vs. LTFT

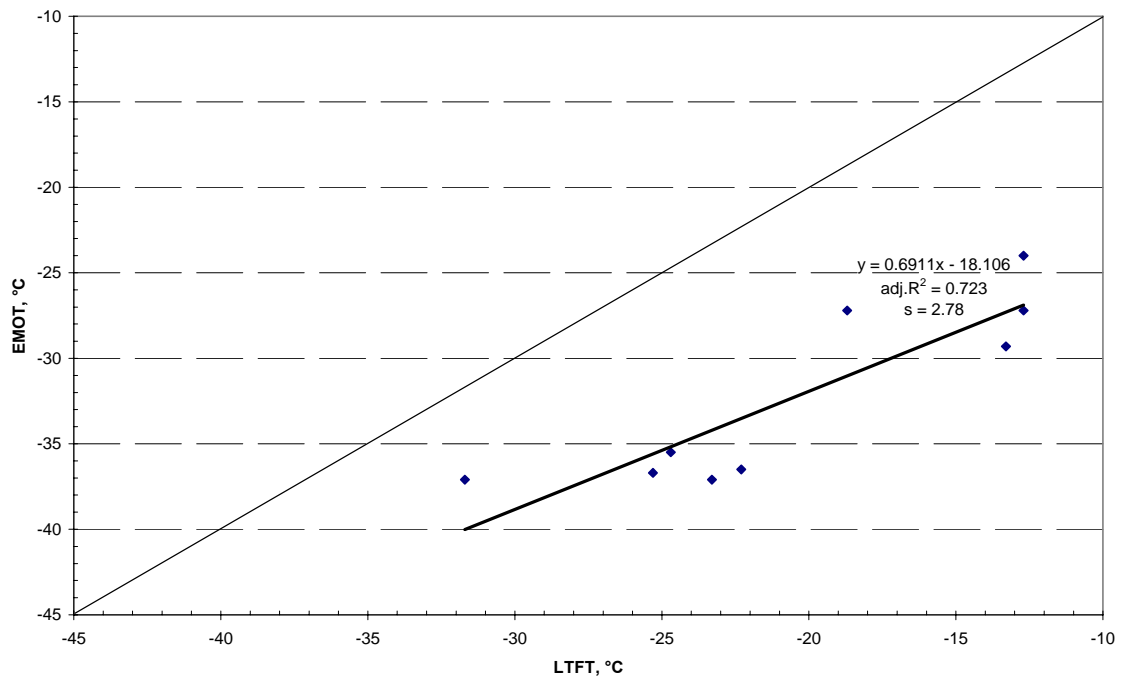


Figure 43  
Vehicle 5  
EMOT vs. Cloud Point

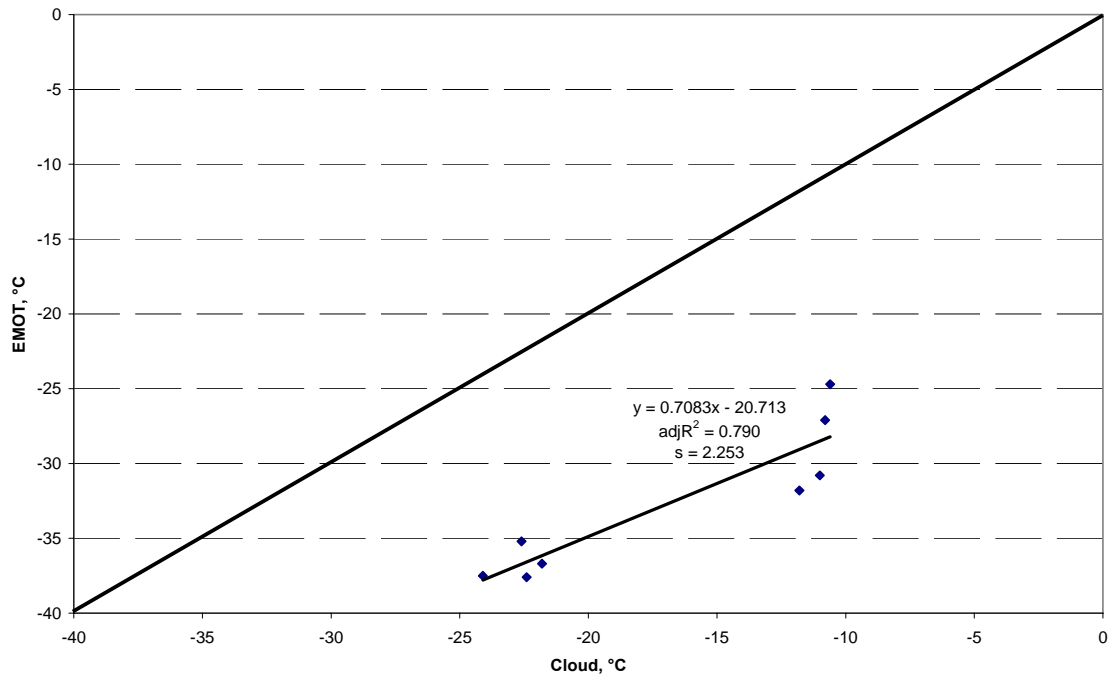


Figure 44  
Vehicle 5  
EMOT vs. CFPP

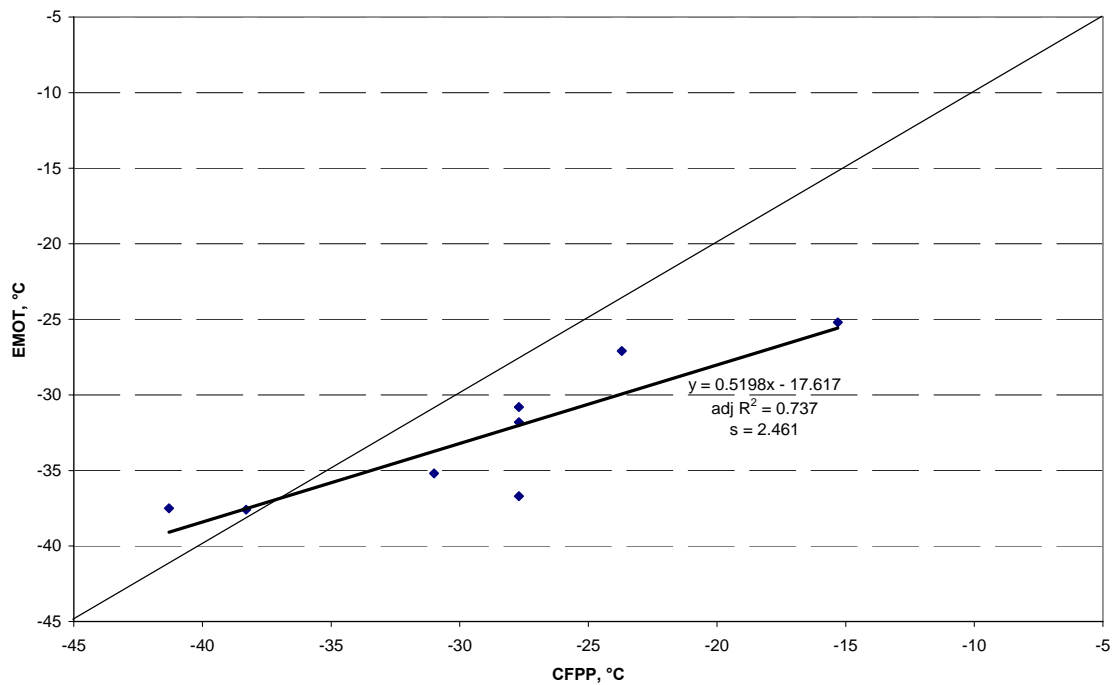


Figure 45  
Vehicle 5  
EMOT vs. Cloud-CFPP  $\leq 10^{\circ}\text{C}$

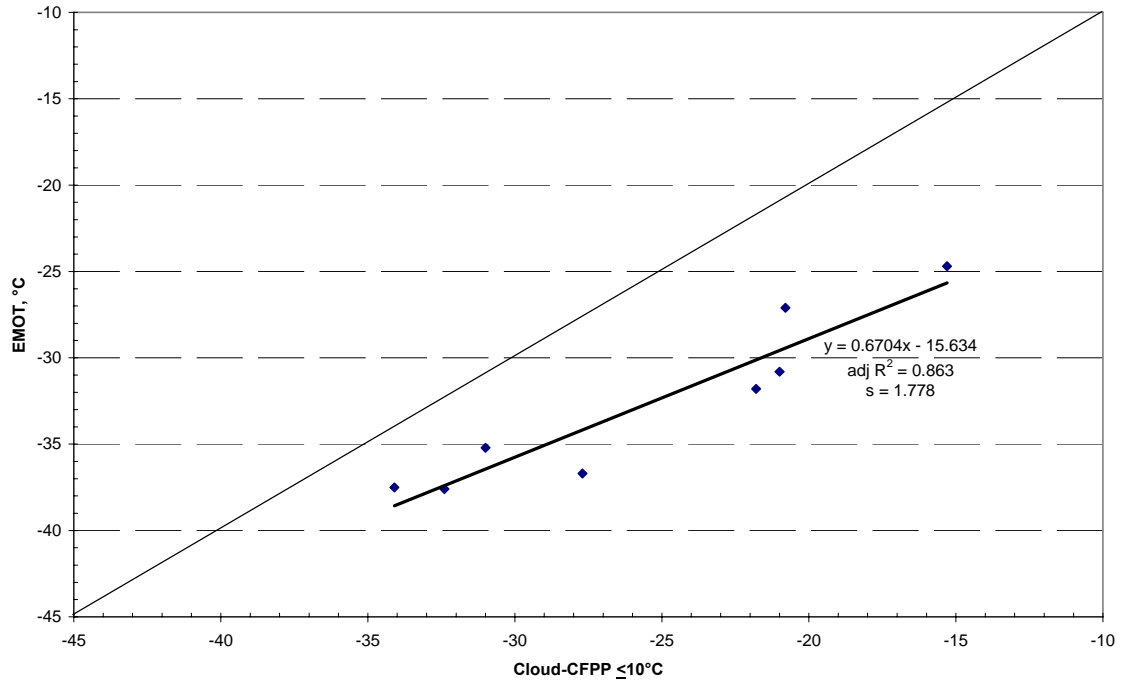


Figure 46  
Vehicle 5  
EMOT vs. LTFT

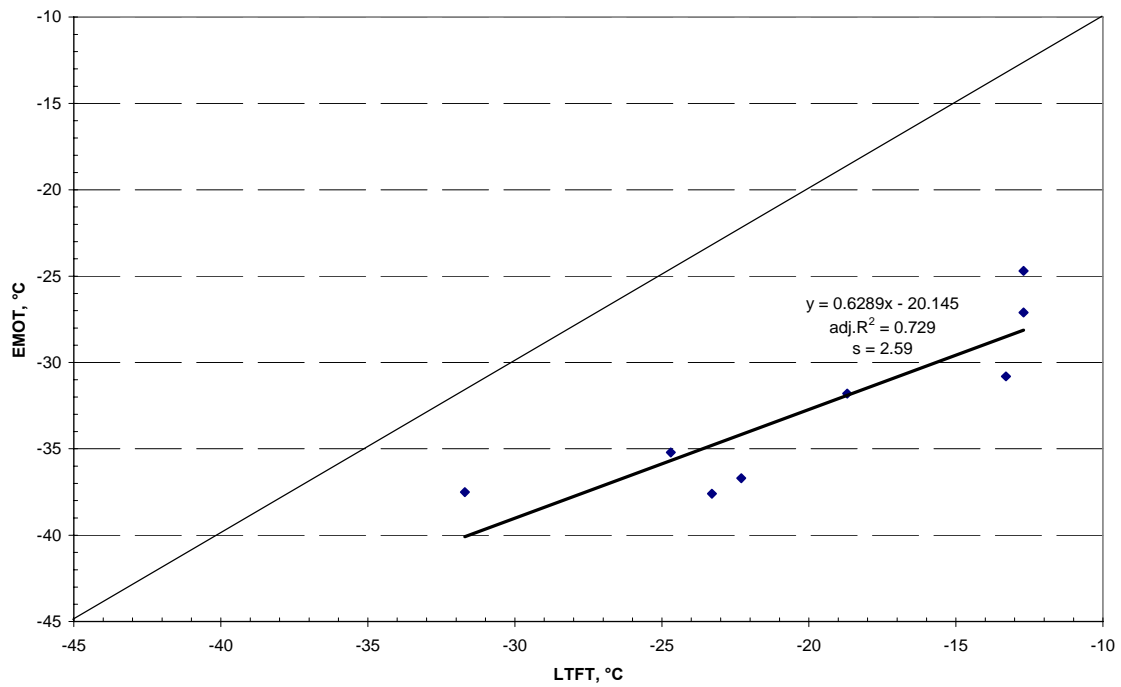


Figure 47  
All Vehicles  
EMOT vs. Cloud Point

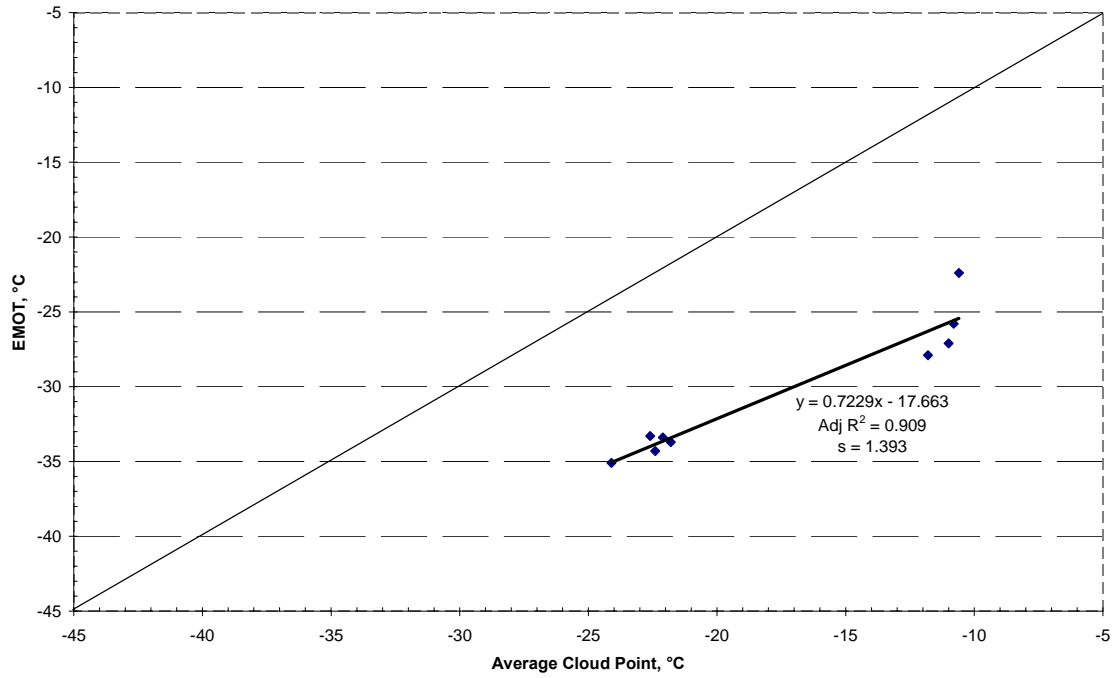


Figure 48  
All Vehicles  
EMOT vs. CFPP

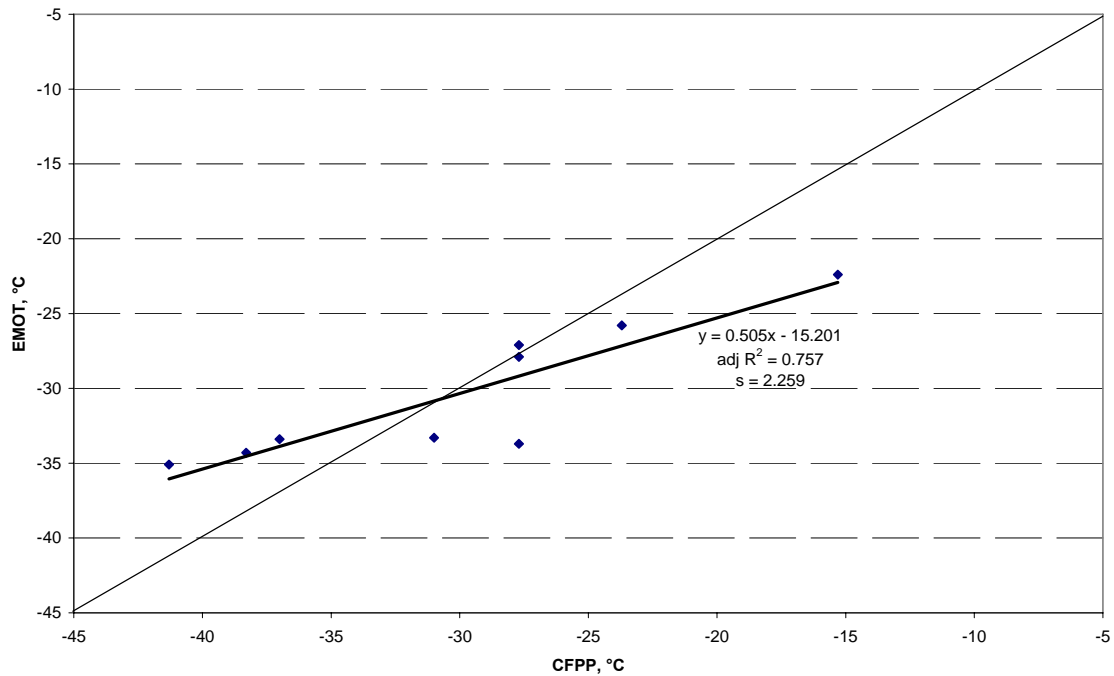


Figure 49  
All Vehicles  
EMOT vs. Cloud-CFPP  $\leq 10^{\circ}\text{C}$

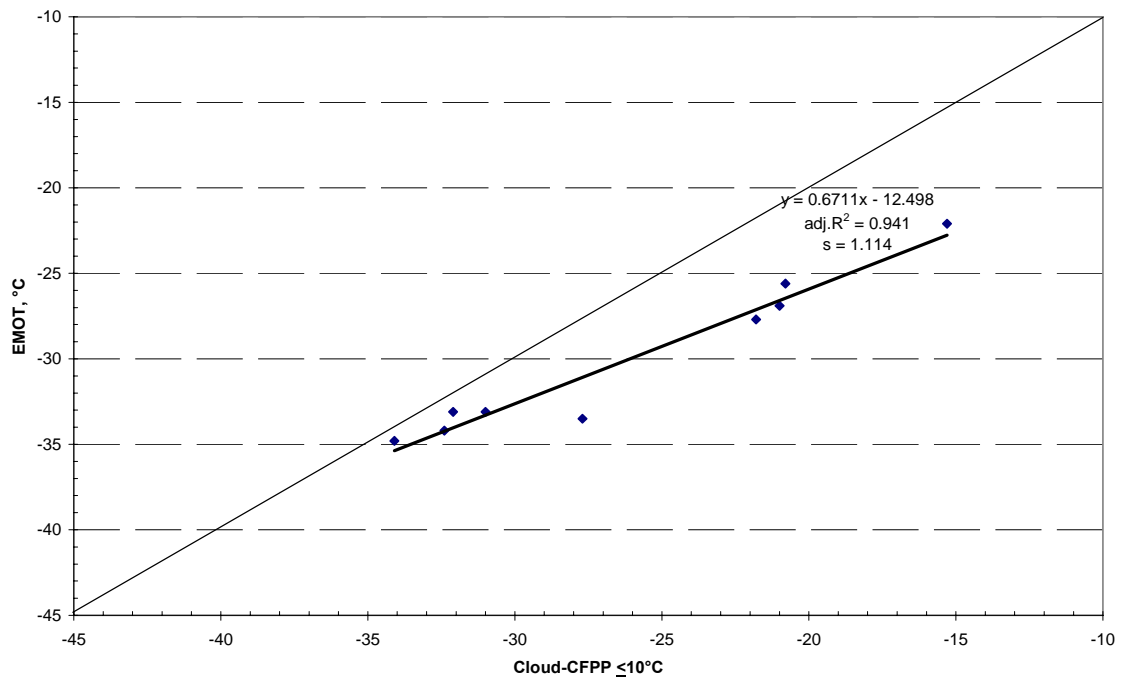


Figure 50  
All Vehicles  
EMOT vs. LTFT

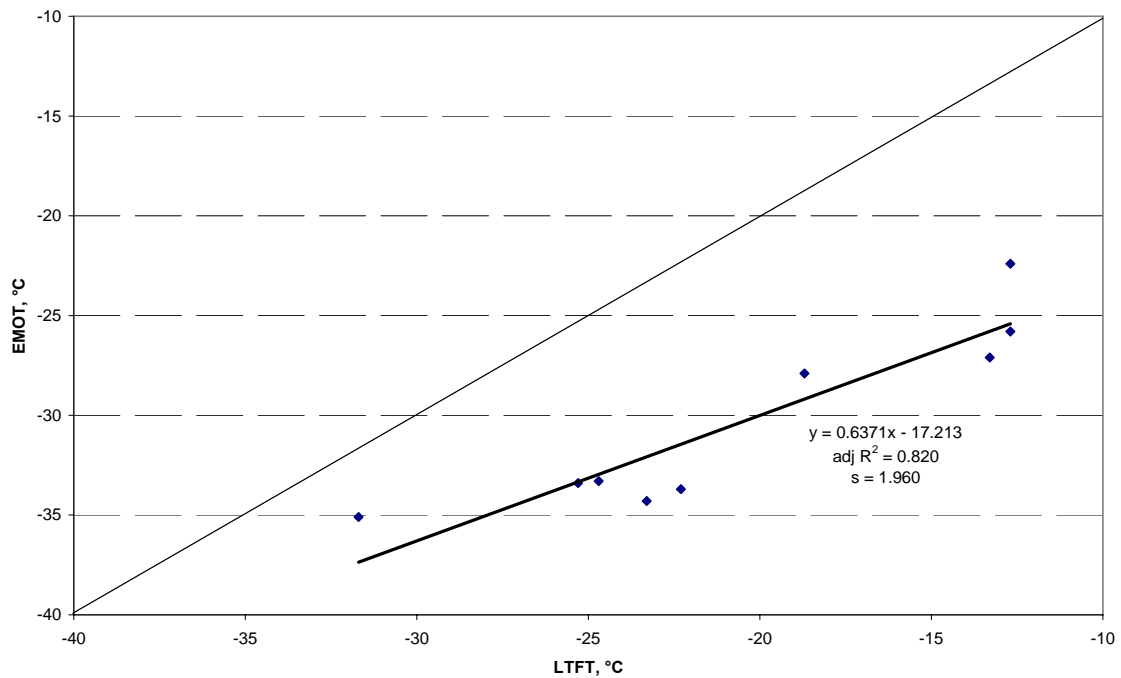


Figure 51  
All Vehicles except Vehicle 3  
EMOT vs. CFPP

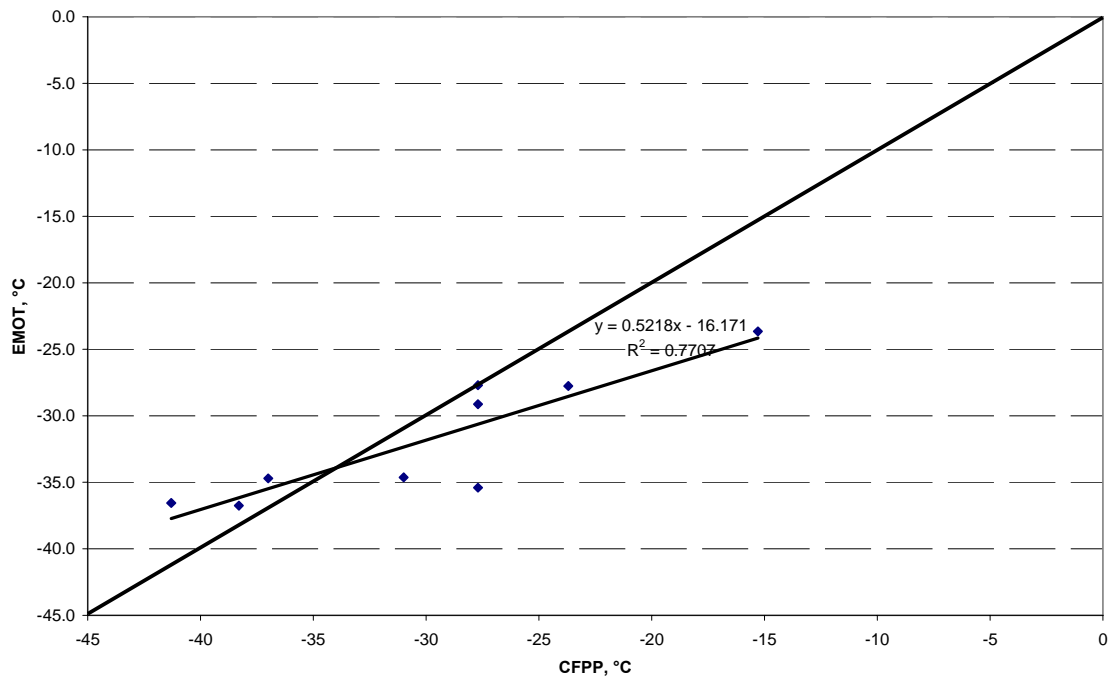


Figure 52  
All Vehicles except Vehicle 3  
EMOT vs. Cloud-CFPP  $\leq 10^\circ\text{C}$

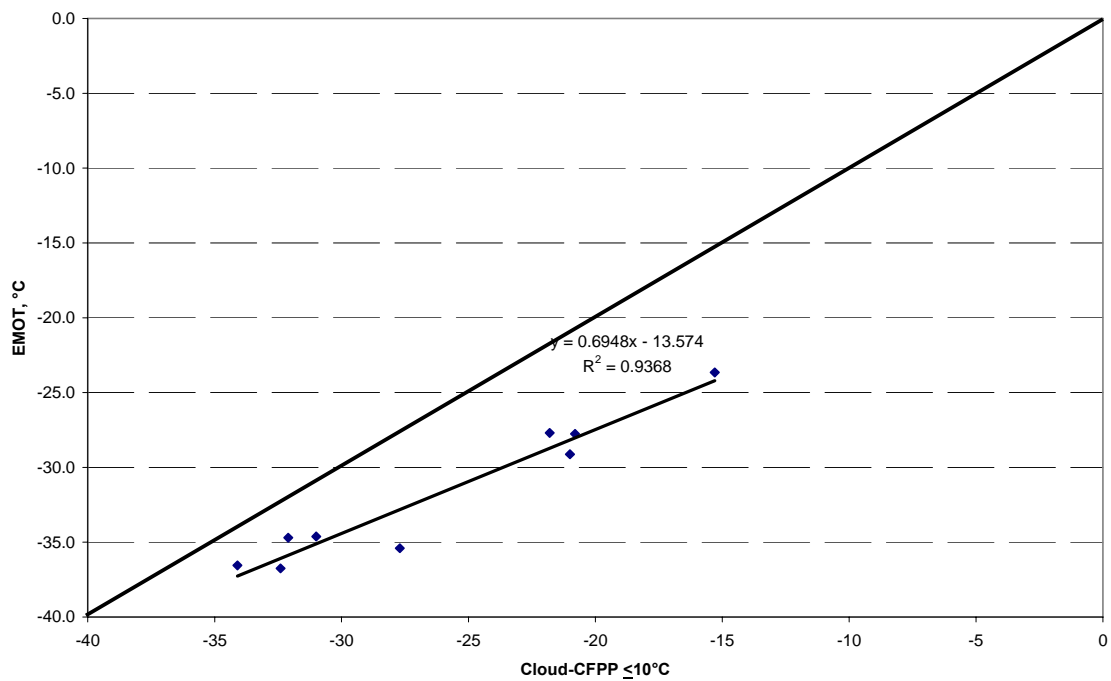


Figure 53  
All Vehicles except Vehicle 3  
EMOT vs. LTFT

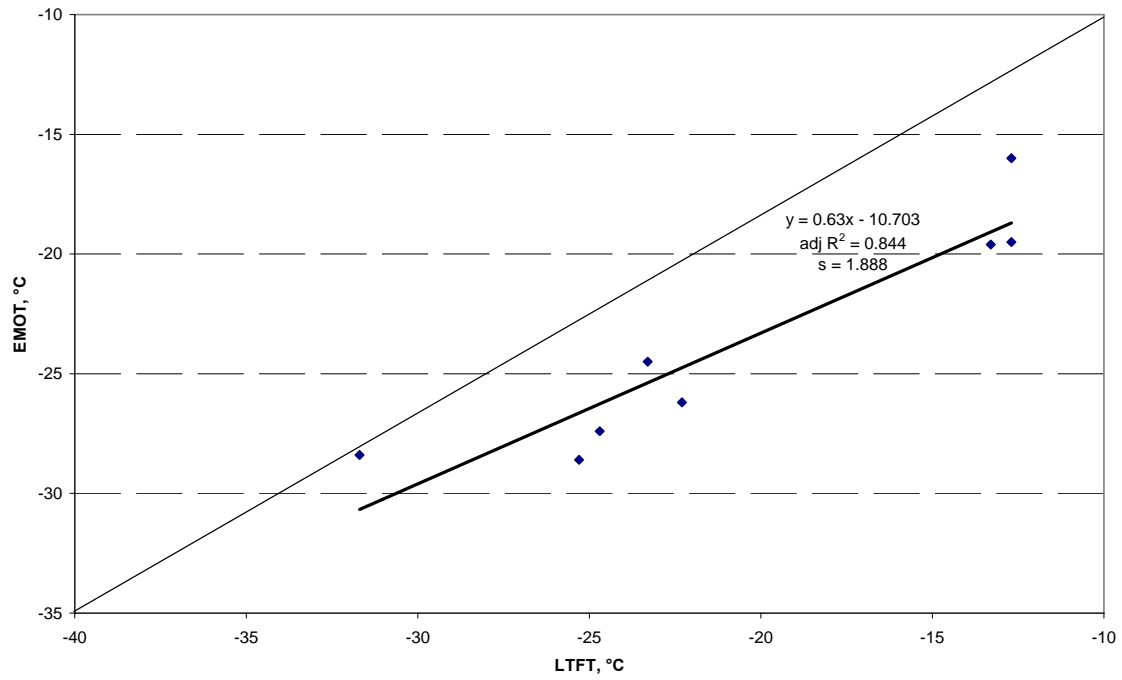


Figure 54  
Operability Test Results vs. Cloud Point

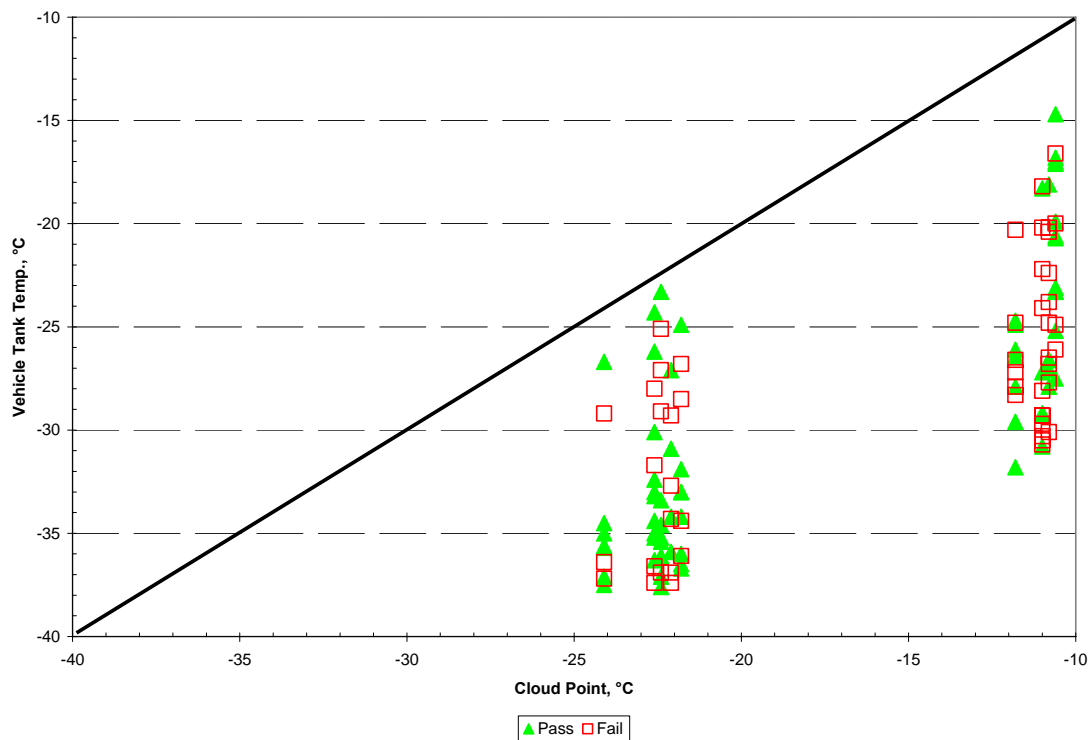


Figure 55  
Operability Test Results vs. CFPP

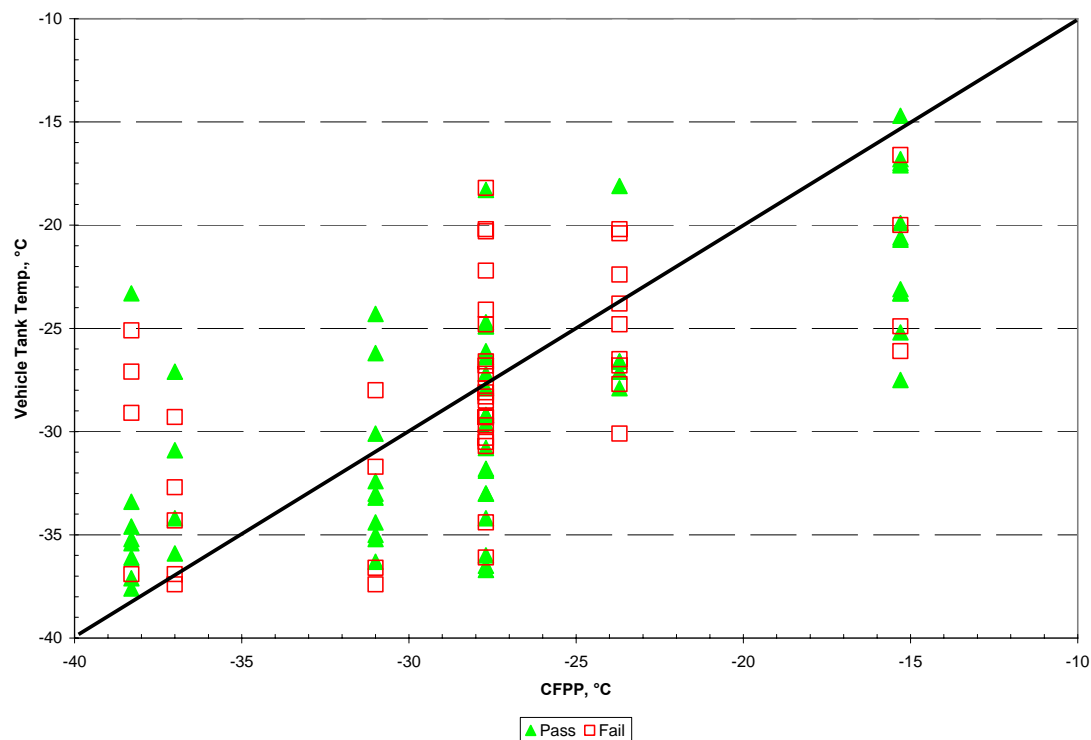


Figure 56  
Operability Test Results vs. Cloud-CFPP<sub>≤10°C</sub>

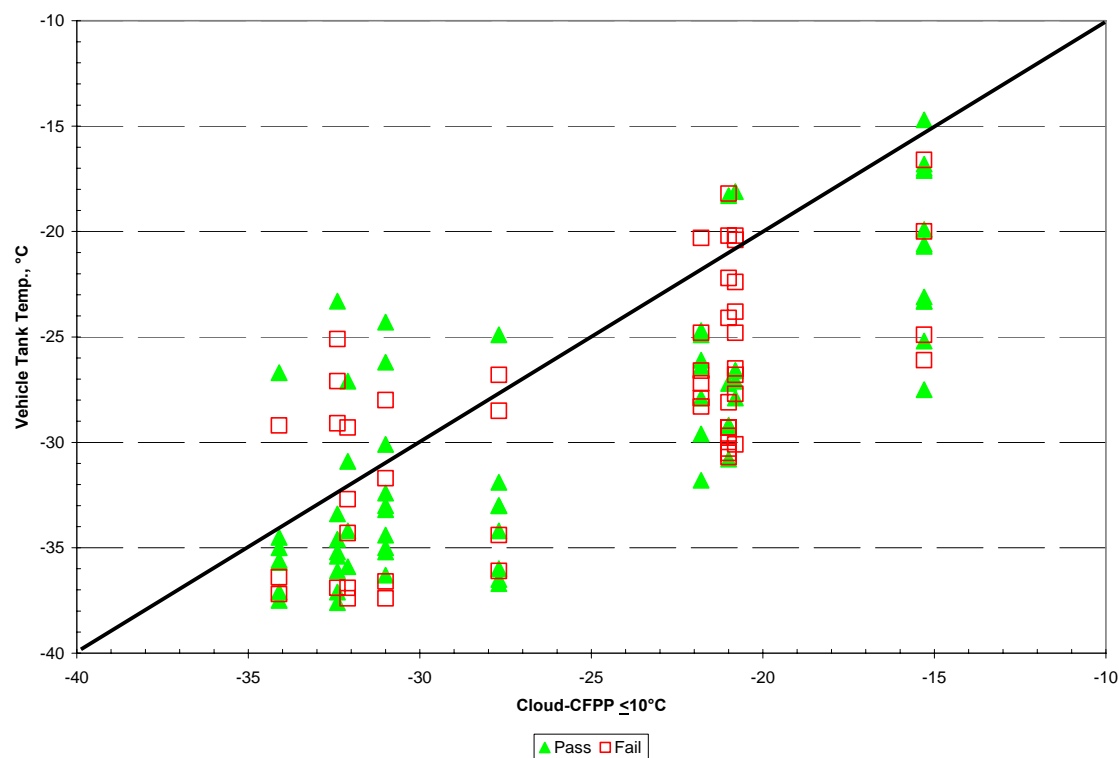


Figure 57  
Operability Test Results vs. LTFT

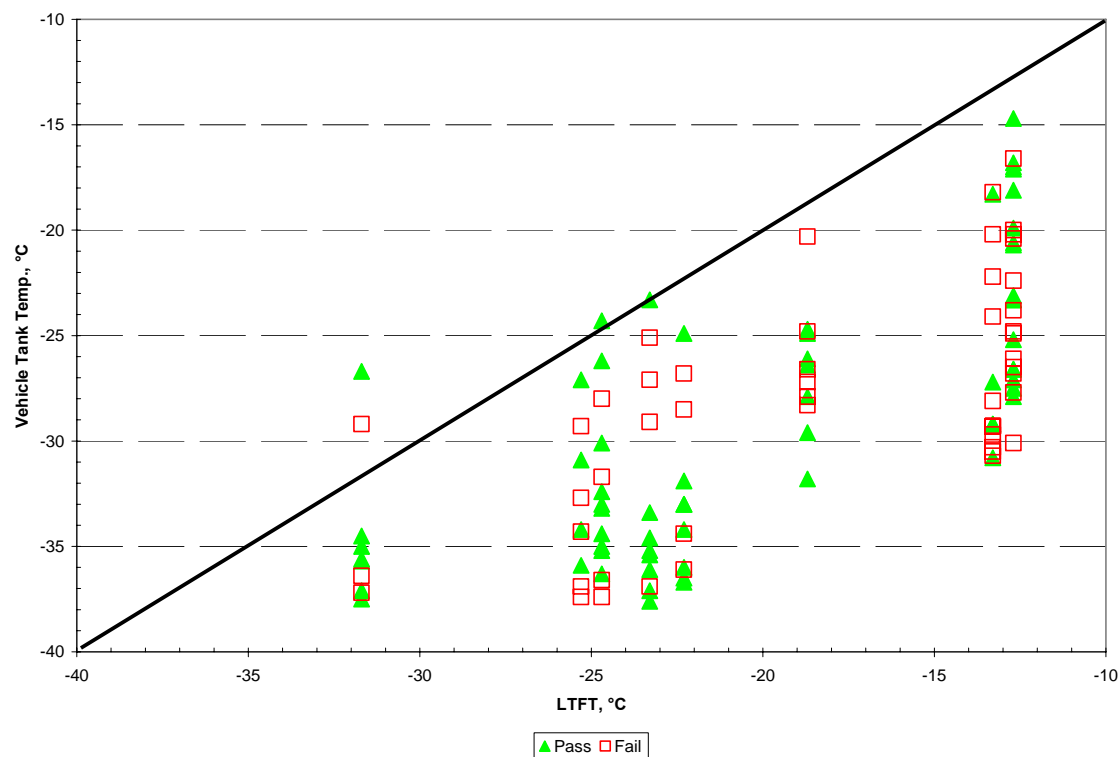
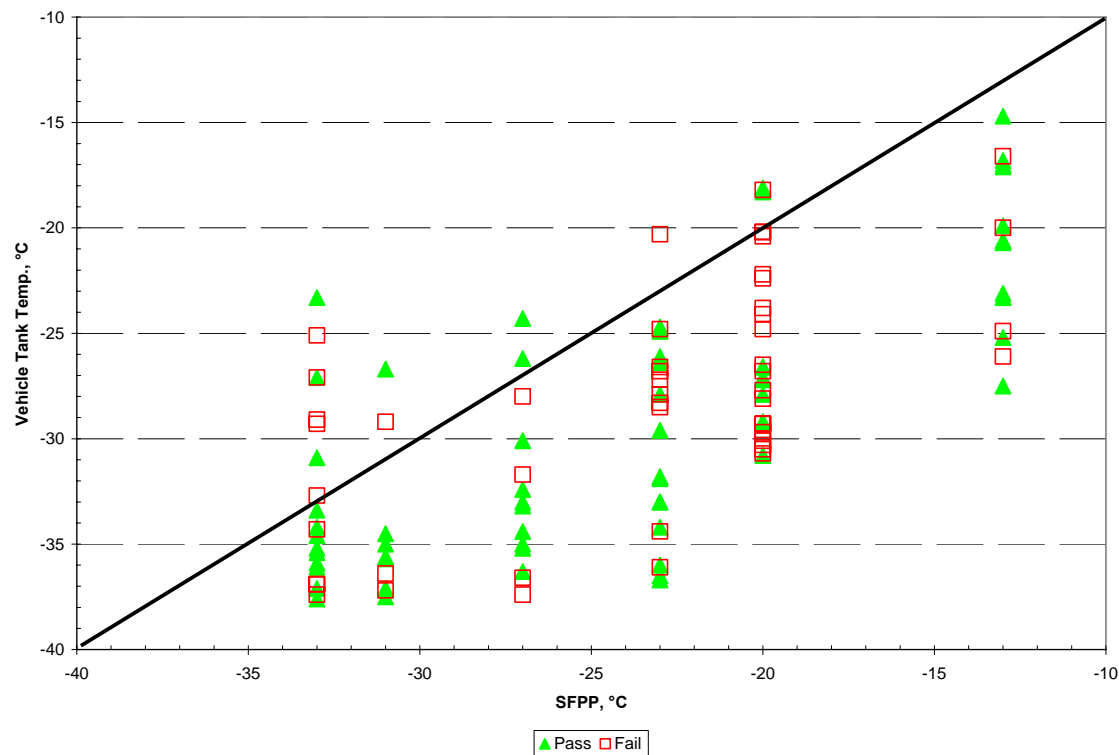
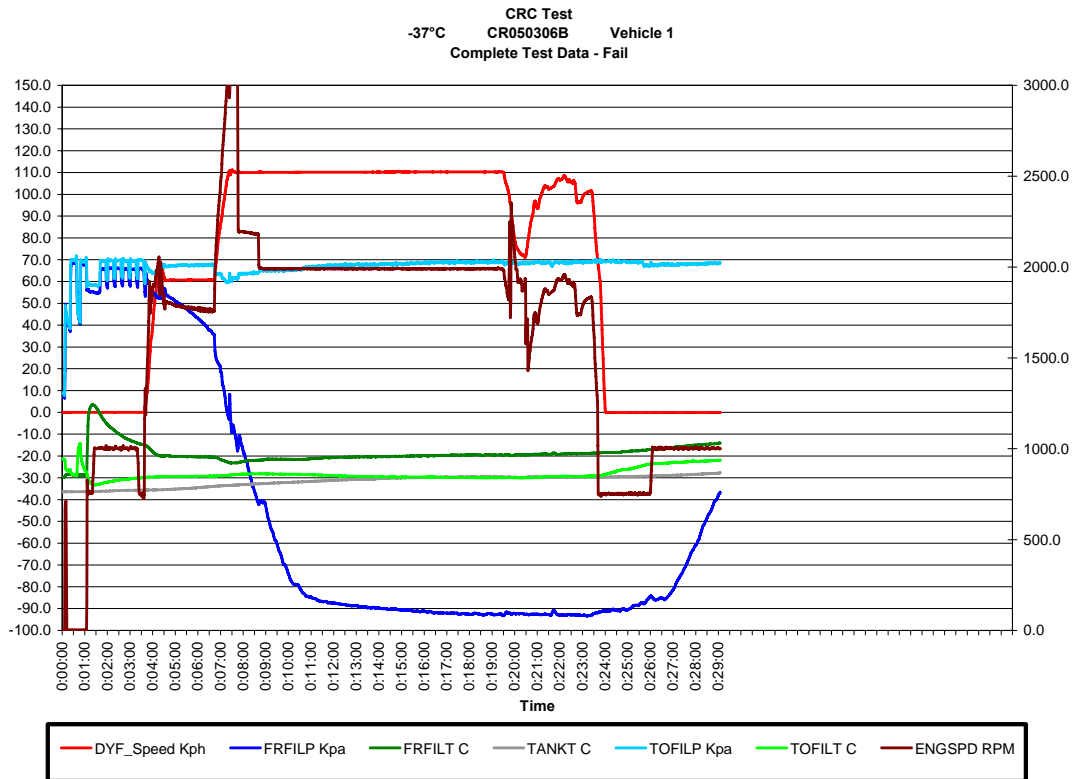
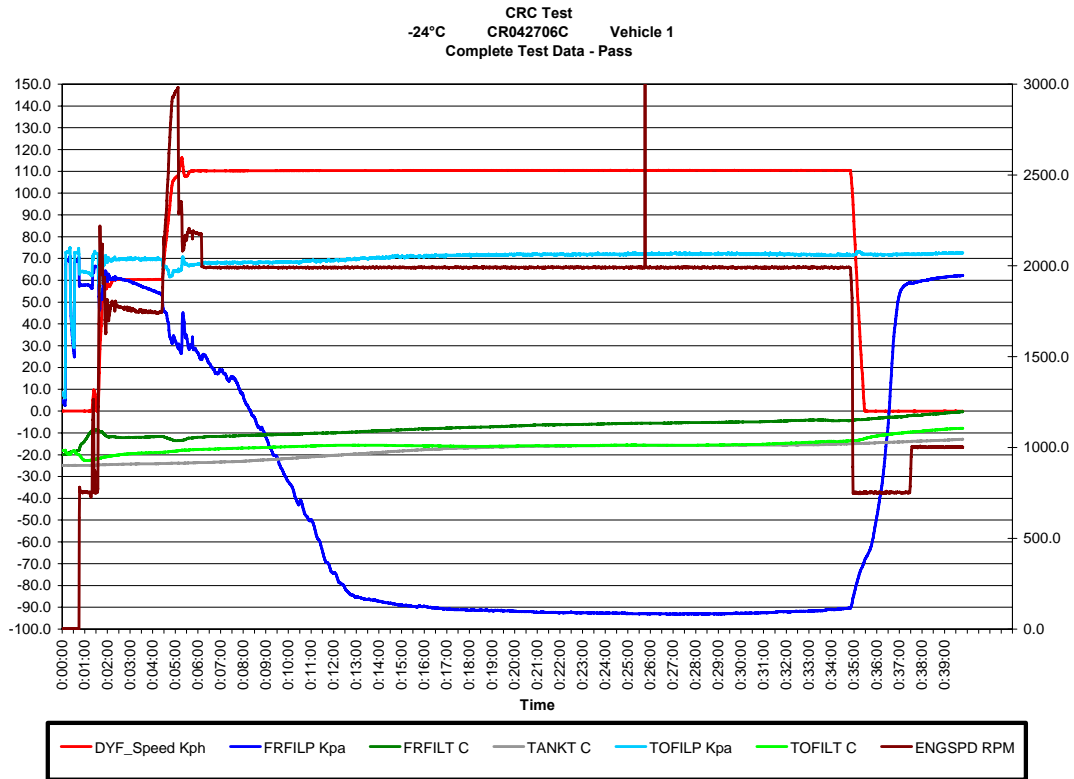
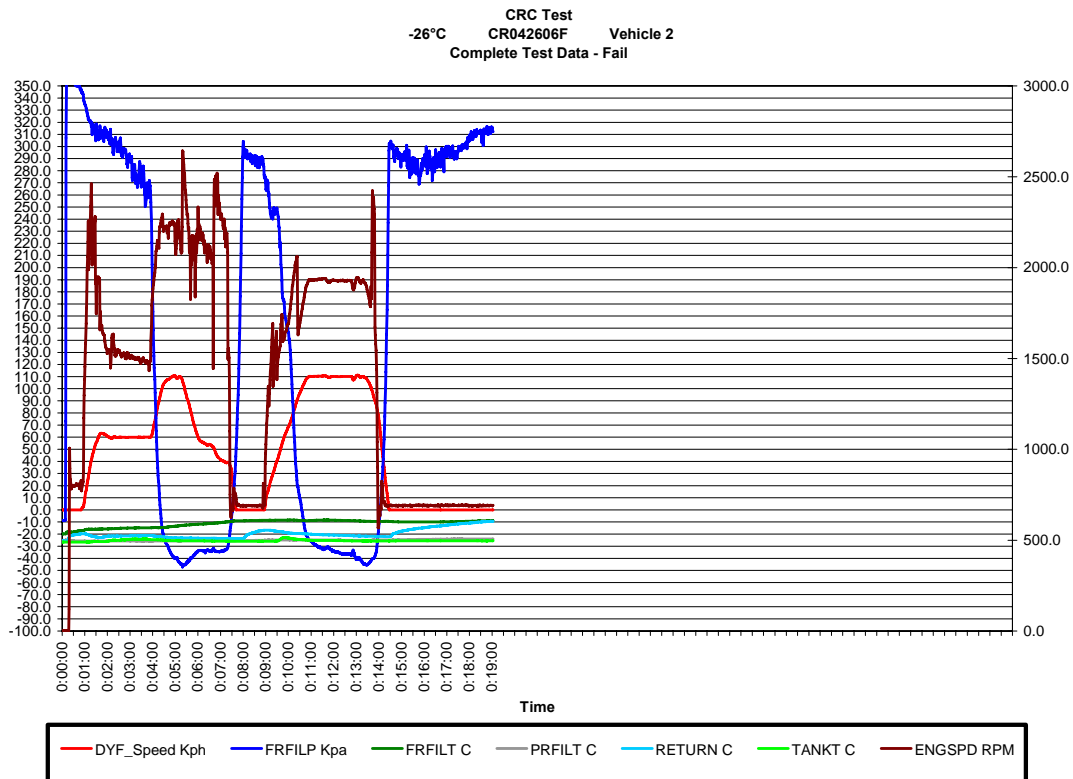
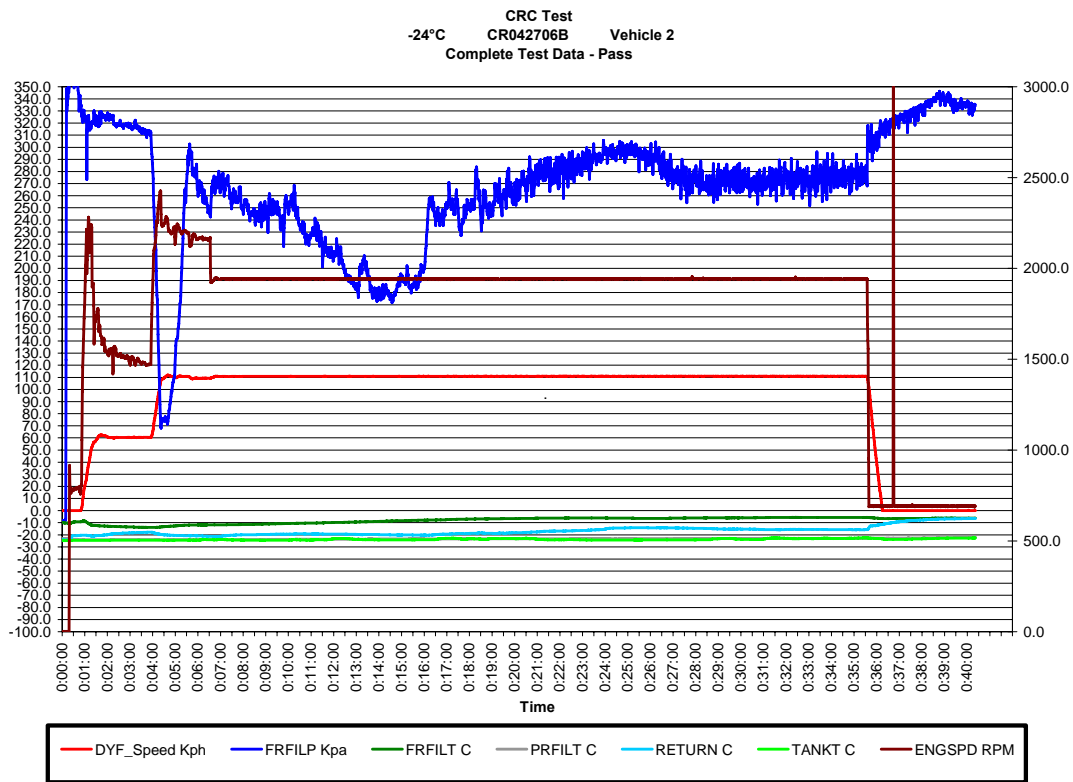


Figure 58  
Operability Test Results vs. SFPP

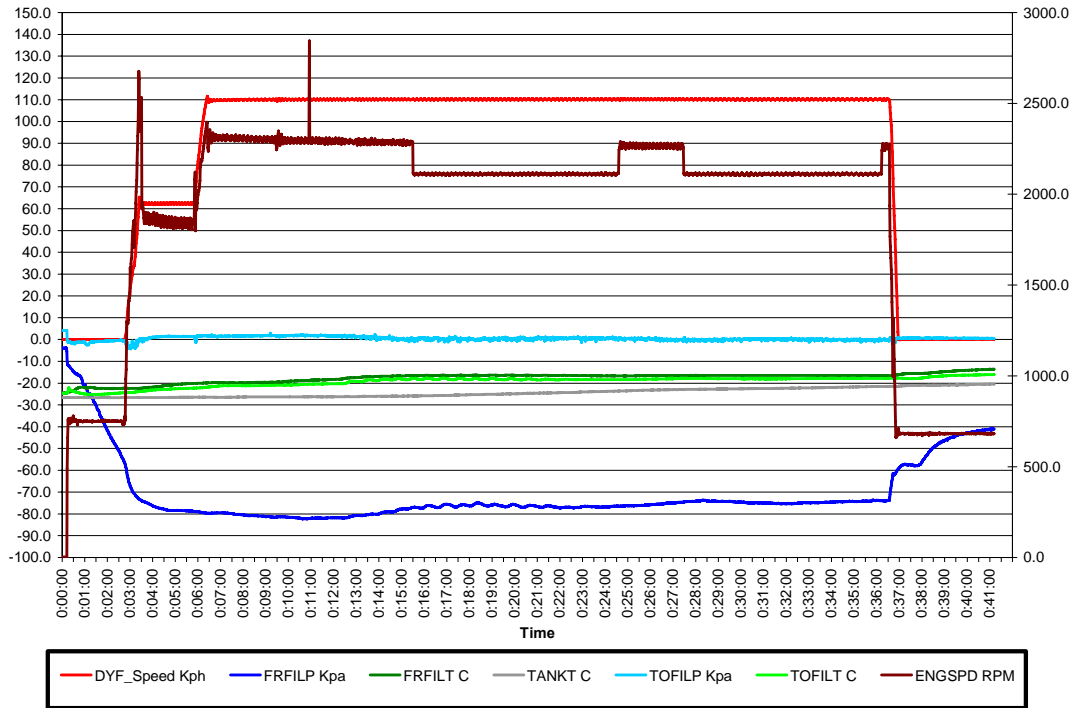


## C. Examples of Vehicle Passes and Failures

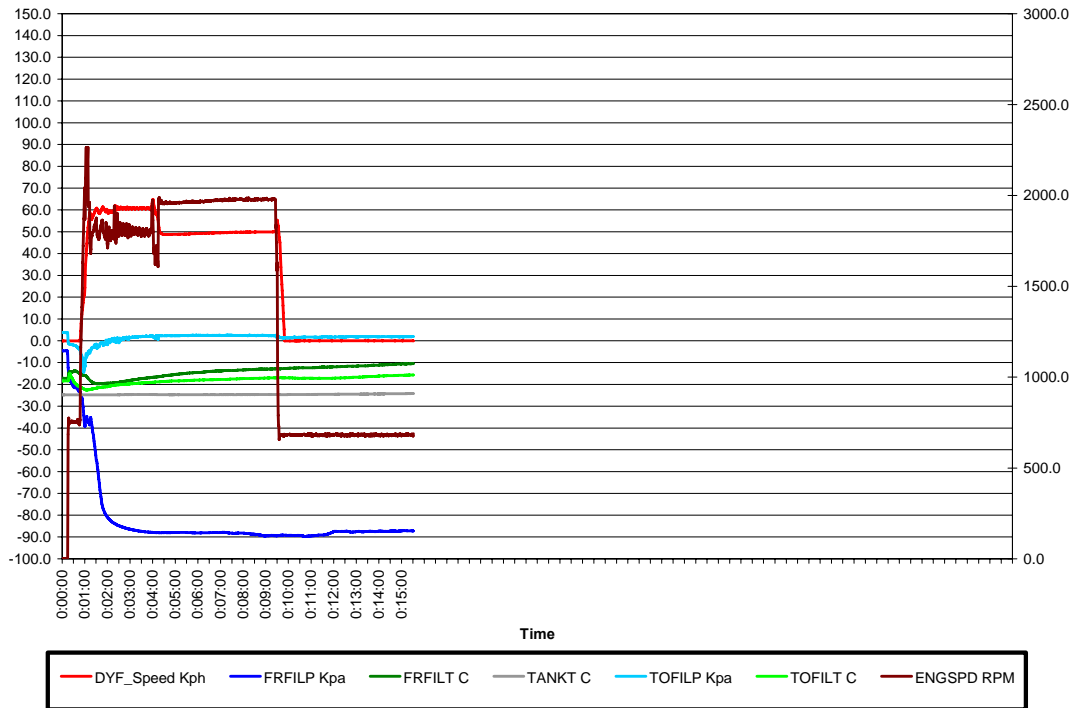


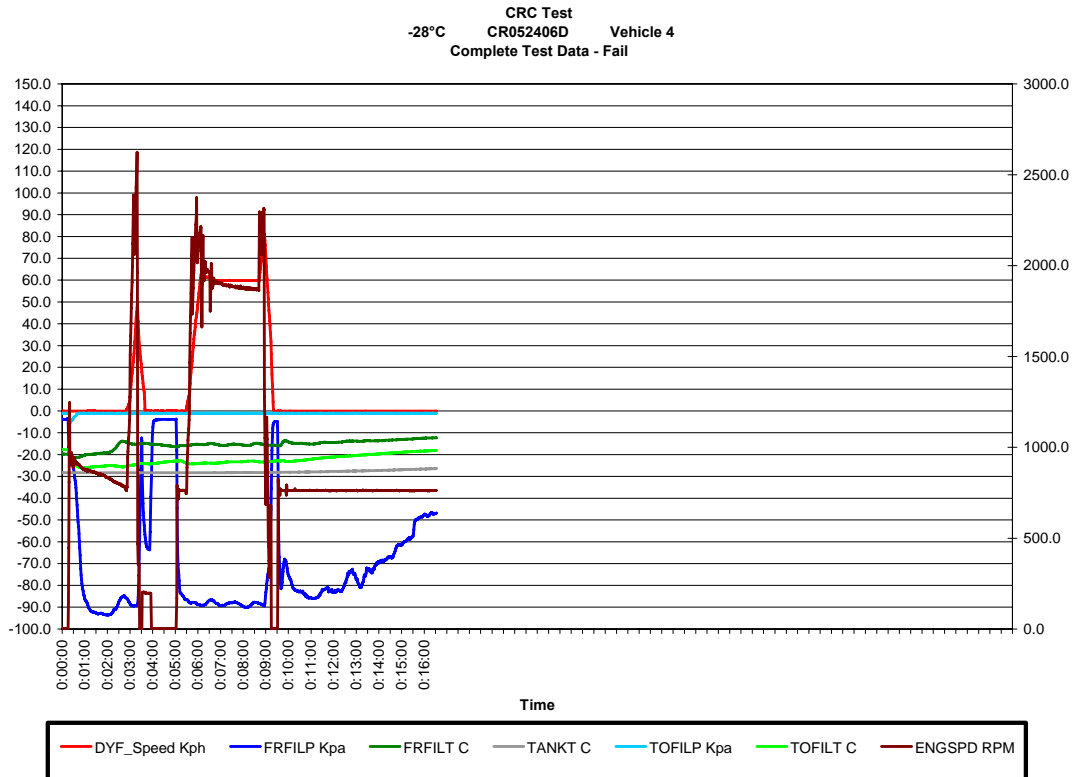
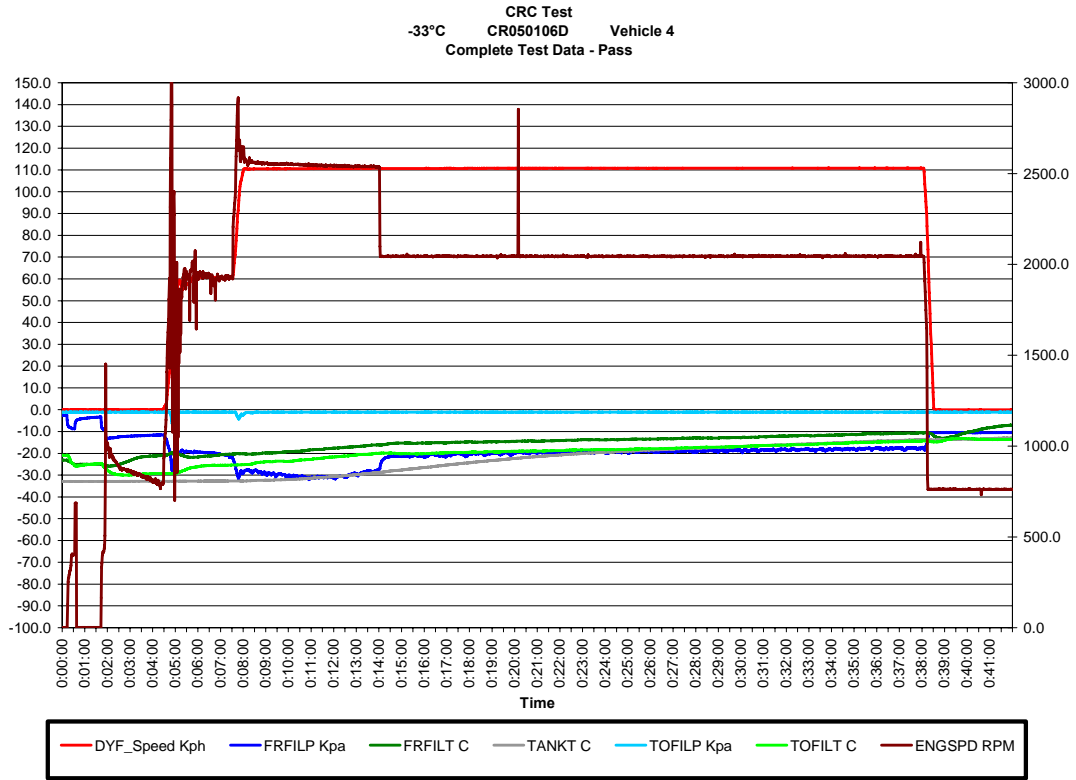


CRC Test  
-27°C CR050406A Vehicle 3  
Complete Test Data - Pass

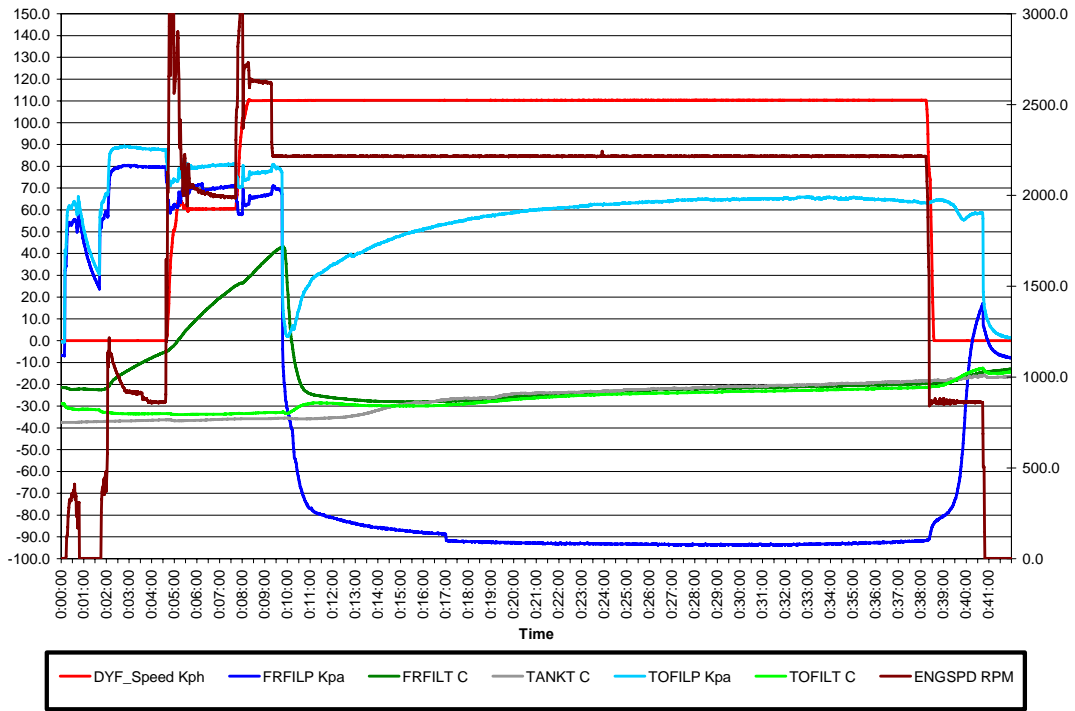


CRC Test  
-24°C CR042706D Vehicle 3  
Complete Test Data - Fail





CRC Test  
-37°C CR050806D Vehicle 5  
Complete Test Data - Pass



CRC Test  
-26°C CR053006D Vehicle 5  
Complete Test Data - Fail

