

FUEL WEATHERING

API PUBLICATION NO. 4493
HEALTH AND ENVIRONMENTAL SCIENCES DEPARTMENT
JULY 1989

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July 1989



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Abstract

A vehicle test program was conducted to determine the change in vapor pressure of gasoline in the fuel tank that occurs as the car is driven (and/or as a result of changes in diurnal temperatures). The test matrix was based upon five cars and three gasolines; the cars were driven over a public road route that included periodic daytime and overnight soaks, with daytime ambient temperatures averaging near 90°F.

Executive Summary

As gasoline in vehicle fuel tank systems is heated during normal vehicle operation (and/or as a result of diurnal temperature changes), many of the more volatile compounds in the fuel are lost, thus decreasing its volatility. This phenomenon, known as fuel weathering, is an important element in estimating vehicle evaporative emissions and therefore requires proper characterization.

To address this issue, the American Petroleum Institute (API) retained Southwest Research Institute (SWRI) to provide in-service data concerning RVP weathering of gasoline. Five cars were driven over public routes in ambient temperatures representative of warm/hot areas of the United States (daytime ambients averaging near 90°F). Three fuels with nominal Reid Vapor Pressures (RVP) of 11, 9, and 7 psi were tested. Each of the three gasolines were run four times in each of the five cars with consumption of a full tank of fuel during each run.

The results of the study showed that RVP loss was directly related to the volatility of the fresh fuel as follows:

Initial RVP (psi):	7.0 ---	9.5 ---	11.3 ----
RVP Loss from Weathering (psi):	0.4 - 0.6	0.9 - 1.1	1.5 - 2.3
Final RVP (psi):	6.4 - 6.6	7.9 - 8.1	8.7 - 9.5

Information on the flammability limits of hydrocarbon vapor concentrations in vehicle fuel tanks (not collected as part of this study) indicates that sub-9 RVP weathered fuel (as shown above) could fall within the explosive range if lower temperatures were encountered.

The study also collected data on fuel tank temperatures during vehicle operation. The results show that, on average, the temperature of the liquid fuel in the tank stabilizes at about 20°F above the ambient temperature during vehicle operation.

FUEL WEATHERING**Table of Contents**

ABSTRACT	Page ii
EXECUTIVE SUMMARY	iii
I. INTRODUCTION	1
II. PROCEDURE	1
A. Vehicles	1
B. Test Fuels	4
C. Mileage Accumulation	6
D. Test Matrix	6
III. RESULTS	6
APPENDIX A	
Summary of Test Data	1A

I. INTRODUCTION

At the request of the American Petroleum Institute, a vehicle test program was conducted at Southwest Research Institute to determine the change in the vapor pressure of the gasoline in the fuel tank that occurs as the car is driven. An important consideration for this test was that the ambient temperatures be representative of warm or hot areas of the United States where daytime ambients average near 90°F.

The test matrix was based upon five cars and three gasolines. These cars were driven over a public road route that included periodic daytime and overnight soaks. The Reid Vapor Pressure (RVP) of the gasoline in the tank was determined periodically.

Each of the three gasolines were run in each of the five cars four times. An essentially full tank of gasoline was consumed each time. The test parameters were:

- (1) Three test gasolines - Nominal RVP of 7, 9, and 11 psi
- (2) Five cars - 1985 and 1986 model, fuel injection and carburetor

The testing consisted of a total of 444 46-mile loops and 294 RVP analysis. The test data were compiled and comparisons made of the ambient temperature, fuel temperature, car, and initial and final gasoline RVP's. Testing was initiated on July 27th and completed on October 10, 1988.

II. PROCEDURE

The test procedure utilized for this program is presented as follows:

A. Vehicles

The test fleet consisted of five vehicles supplied by Southwest Research Institute. Selection criteria were based upon the model and condition of the vehicles. Popular models were chosen to represent fuel systems encompassing multiport and throttle body fuel injection and carburetion. The test vehicles and the assigned SWRI codes are shown in Table 1.

Table 1. Test Vehicles and SwRI Codes

<u>Vehicle</u>	<u>SwRI Code</u>	<u>Miles @ Test Start</u>
1985 Chevrolet Camaro 2.8l, V-6, MPFI Engine Family No. F1G2.8V8XGZ9	API 1	30,694
1986 Oldsmobile Delta 88 3.8l, V-6, MPFI Engine Family No. G4G3.8V8XEB4	API 2	23,260
1986 Pontiac Grand Am 3.0l, V-6, MPFI Engine Family No. G4G3.8V8XEB4	API 3	30,830
1985 Ford Escort 1.6l, 4-cyl., Carburetor Engine Family No. FFM1.6V2GDK8	API 4	41,310
1985 Plymouth Reliant-K 2.2l, 4-cyl., Fuel injected Engine Family No. ECR2.2V2HAC4	API 5	53,827

All of the vehicles were equipped with automatic transmissions and air conditioners.

1. Initial Preparation

Routine Service - The vehicles were inspected to verify that the engine, transmission, and emission control systems were the same as had been installed at the factory. The integrity of the evaporative control system was confirmed by pressurizing the system with nitrogen and observing that the pressure remained constant. Further engine and emission control system checks were conducted with computer-driven diagnostic equipment. Engine oil, oil filter, air filter, and canister filter were replaced.

Fuel Tank Calibrations - The fuel tanks were calibrated to determine the total volume and the vehicle gage reading vs. the actual volume of fuel in the tank. The total volume of the tank was determined by removing the fuel tank, emptying it completely, placing it on a scale, and then refilling it with gasoline. The weight of gasoline, including that in the vent tube and filler neck, was converted to volume using the standard API tables. The tank volume vs. fuel gage readings were obtained by use of a conventional dispensing pump and the observed fuel gage reading as the tank on the vehicle was filled. These data are presented in Tables 2 and 3.

Table 2. Measured Fuel Tank Volume

<u>Car</u>	<u>Tank Volume, Gal.</u>
API 1, Camaro	15.0*
API 2, Oldsmobile Delta 88	21.2
API 3, Pontiac Grand Am	14.5
API 4, Ford Escort	14.7
API 5, Plymouth Reliant-K	14.9

*Estimated from fueling data (Table 3)

Table 3. Fuel Volume vs. Vehicle Gage Reading

<u>Fuel Gage Reading</u>	<u>Fuel in Tank, Gallons</u>				
	<u>Car No.</u>				
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Empty	2	2	2	2-3.5	0
1/8	4	3.5	-	6	-
1/4	5.7	5	4	8	4
3/8	6.7	7	5.5	-	5.5
1/2	8.2	9	7	-	6.7
5/8	10.2	11.7	9.2	-	8.2
3/4	11.5	-	11.2	9.5	10
7/8	13	14.2	12.2	10.5	12
Full	14.2	17	13.5	13.5	13
Above Full	15	19.2	15	15	15

Fuel Return Flow - Vehicles with fuel injected engines typically pump more fuel from the fuel tank to the engine than the engine consumes. This excess fuel is returned to the vehicle fuel tank and represents an additional influence on fuel tank temperature. Knowledge of the volumetric flow rate of the fuel returned to the tank for the four fuel injected cars was considered to be important; therefore, the flow rates were determined. These data are shown in Table. 4.

Table 4. Fuel Return Flow Rates at Idle

<u>Car</u>	<u>Flow Rate, Gal./Min.</u>
API 1, Camaro	0.44
API 2, Oldsmobile Delta 88	0.59
API 3, Pontiac Grand Am	0.49
API 4, Ford Escort	NO RETURN
API 5, Plymouth Reliant-K	0.40

Instrumentation - Vehicle instrumentation consisted of thermocouples located in the fuel tank near the bottom of the tank and at the front of the grill. A calibrated digital thermocouple temperature indicator with a selector switch was located in the passenger compartment. The thermocouple at the front of the grill was designed to obtain ambient temperature readings. However, these readings were affected by heat convection from the radiator and engine. Therefore, a monitoring station located near the vehicle parking area was used to measure the ambient air temperature. All of the ambient temperature data used in the data analysis in this report are from the temperature monitoring station. The ambient conditions observed over the test period are reported in the individual data sheets in the Appendix.

Sampling Lines - Hansen quick-couples were inserted into the fuel lines of each vehicle to facilitate sampling, pump-out, and flushing of the entire fuel system. Lines were kept as short as practical and routing was such that temperature environments were disturbed as little as possible.

B. Test Fuels

1. Blend Requirements

Three gasoline blends, nominal RVP's of 7, 9, and 11 psi, were purchased from Phillips Petroleum Company. The criteria of these fuels were that they meet ASTM D-439 specifications and that the RVP value be ± 0.3 psi of the target value. The distillation data (ASTM Method D86) on the fuels received at Southwest Research Institute are reported in Table 5. Eight drums of each blend, 24 total, were acquired.

Table 5. Distillation of the Three Test Fuels

% (Volume)	Degrees F		
	Nominal RVP, psi		
	7.0	9.5	11.3
IBP	94	83	75
5	122	104	96
10	136	118	109
30	174	159	152
50	214	204	200
70	257	248	247
90	323	314	314
95	365	350	348
EP	426	426	430

2. Fuel Storage

Opened drums being used to fuel the cars and two reserve drums were stored in a cold-box where the temperature was maintained at 40°F. All fueling was performed with cold fuel that was dispensed directly to the vehicles from the drums by means of a manual pump.

3. Sampling Procedure

Fuel samples were obtained from the vehicle fuel tank immediately after fill-up, each morning prior to beginning mileage accumulation, and just prior to introducing the next test fuel blend. In most instances the sample obtained immediately after fill-up was used as the starting sample for the RVP loss determinations. The basic sampling procedure involved pumping the test gasoline from the fuel tank through an ice-cooled coil into a chilled 1-quart can. The pump, coil, and can were purged with fuel prior to obtaining the sample of record. All sample cans were coded with a number that was logged to identify the car, date, miles, and fuel code. These samples were then provided to the analytical laboratory daily for RVP analysis. These vapor pressures were determined by the Southwest Research Institute automated vapor pressure instrument. This instrument is in the final stages of approval by the ASTM.

C. Mileage Accumulation

1. Test Route

A 46-mile test route (loop) was developed to provide predominant periods of sustained highway speeds while allowing convenient stopping points consistent with parking area and fuel sampling requirements. The loop began and ended in the paved parking area at the Automotive Fleet Laboratory located on the SwRI campus. Approximately 4 miles of the loop consisted of 25 to 45 mph speed limits while the remainder was at 55 mph. The time allotted for the loop was 1-hour which resulted in an average speed of 46 mph.

2. Run-Soak Schedule

Driving shifts began in the morning once the ambient air temperature reached 75°F. The 1-hour, 46-mile loop was followed by a 3-hour soak, a second 46-mile loop and 3-hour soak, and finally a third 46-mile loop. The car was then allowed to soak overnight in preparation for the next day's run. The driving loops continued until the vehicle tanks were judged to no longer contain an adequate supply of gasoline (at the empty mark) to safely complete another loop.

3. On-board Temperature Measurements

The vehicle drivers were required to log the fuel tank temperature, vehicle air temperature, time, and fuel gage level at the beginning, turnaround (mid-loop), and end of the loop. A typical driver's log is presented in the Appendix to illustrate these entries.

D. Test Matrix

The fuel/vehicle assignments were originally set up to run each fuel in each car four times on a randomized matrix basis to assist in blocking out ambient temperature effects. In general, these goals were accomplished even though some fuel/vehicle assignments were changed. These changes were due to a delay in the start of one car (Car No. 5), and a thermocouple problem in another car. All cars did achieve at least four valid cycles on each fuel.

III. RESULTS

Results of this study are summarized in Tables 6, 7, and 8. The individual data on the RVP values from which these tables were prepared are presented in the Appendix of this report.

As shown in Table 6, RVP loss was found to be directly related to the RVP of the fresh fuel. Results from four of the cars are similar; however, the Pontiac Grand Am (Car No. 3) demonstrated higher RVP loss than all the other vehicles with all three fuels.

Also included in Table 6 are the average ambient temperatures during the driving loops. The temperature data were included in Table 6 to illustrate that vehicles/fuels combinations experienced reasonably consistent ambient temperatures.

Fuel temperatures in the vehicle tank were expected to increase as the vehicles were being driven. These temperature increases result in large part from convection-conduction into the tank and the fuel return in case of the fuel injected cars. The magnitude of the observed increase of the fuel temperature above the ambient temperature at the end of the loop is shown in Table 7. These temperature data represent the averages from all of the first daily driving loop for each car. The first loop was the only one that began from an overnight soak and was not influenced by heat from a previous run.

Table 8 compares the rise in liquid fuel temperature with the difference between fuel temperature and air temperature for each daily driving loop and vehicle. At the end of the first loop the rise in liquid fuel temperature (from start to end of loop) was slightly greater than the rise in fuel temperature above ambient in the case of cars 1, 2, 3, and 5. This occurred because the fuel temperature was less than the ambient at the start of the loop. The lower fuel temperature was due to the fact that the fuel did not warm as fast as the ambient after the overnight soak. From this standpoint it should be noted that the fuel temperature rise above ambient is a more reliable indicator of tank temperature than is the increase in liquid fuel temperature. It is clear that the liquid fuel in the tank had stabilized at about 20°F over the ambient temperature by the end of the third loop. The evidence for this statement is that the Δ , Fuel and Air Temp. between the middle and end of the 3rd loop showed only a 1°F increase, from 19°F to 20°F.

Table 8 also shows that the rate of increase in the liquid fuel temperature dropped 4-5 degrees F. for each additional daily loop.

Table 6. Fuel Weathering, RVP and Average Ambient Air Temperature

CAR NO.	RVP			Average Ambient Temperature, °F During Driving Loops		
	Nominal Fuel RVP, psi			Nominal Fuel RVP, psi		
	7.0	9.5	11.3	7.0	9.5	11.3
1	0.4	0.9	1.8	91	91	91
2	0.5	1.0	1.7	90	89	90
3	0.6	1.1	2.7	93	92	90
4	0.5	1.2	1.8	91	89	90
5	0.4	0.9	1.5	87	89	89
AVERAGE	0.5	1.0	1.9	90	90	90
*90% C.I. ±	0.1	0.1	0.4			
Range	0.4-0.6	0.9-1.1	1.5-2.3			

*Based upon student's t-distribution

Table 7. Fuel Temperature Rise Above Ambient (End of First Loop of Day)

<u>Car No.</u>	<u>Δ, Fuel-Air, °F</u>	<u>Air Temp. °F</u>
API 1	16	85
API 2	14	83
API 3	19	85
API 4	20	82
API 5	18	81
AVERAGE	17	83

Table 8. Summary of Fuel Temperatures During Each Loop

Loop No.	Car No.	No. Tests	*Fuel Temp. Rise During Each Loop, °F	Δ , Fuel Temp. and Air Temp. During Each Loop, °F		
				Start	Middle	End
1	API 1	36	18	-2	7	16
	API 2	43	15	-1	7	14
	API 3	27	20	-1	12	19
	API 4	29	20	0	12	20
	API 5	31	19	-1	11	18
Avg. of First Loop			18	-1	10	17
2	API 1	25	10	7	11	17
	API 2	41	12	9	15	21
	API 3	26	15	9	17	24
	API 4	28	18	9	22	27
	API 5	26	16	10	22	26
Avg. of Second Loop			14	9	17	23
3	API 1	23	5	13	16	18
	API 2	30	5	12	15	17
	API 3	26	8	12	21	20
	API 4	27	15	10	24	25
	API 5	26	13	9	21	22
Avg. of Third Loop			9	11	19	20

*Increase in fuel temperature (liquid in tank) from start of loop to end of loop

NOTE: The average daily ambient temperature during all of the driving loops was 90°F with a minimum of 87° and a maximum of 93°F.