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Technical Support Report for Regulatory Action

Heavy Duty Truck Evaporative Emissions Regulations Development

A Progress Report

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Notice

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Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air and Waste Management
U.S. Environmental Protection Agency

Background

Heavy duty gasoline fueled vehicles are not currently covered by any evaporative hydrocarbon standard, except in California where they must meet the light duty standard of 2 grams/test. California certifies the system by design evaluation of the control system rather than requiring confirmatory testing of completed vehicles, so information on the performance of these systems is nonexistent.

The primary reason for the lack of a regulatory proposal to control evaporative emissions is the lack of a comprehensive test procedure. The adoption of an enclosure (SHED) procedure is expected to alleviate this constraint, but requires much development before it can be applied to heavy duty vehicles. Another important problem is the method of insuring compliance with evaporative standards. Testing requires a total vehicle while EPA currently certifies only engines for heavy duty vehicles and would have to begin dealing with total vehicle manufacturers in a complete vehicle compliance program. California has sidestepped this problem by not requiring a demonstration of compliance. Engineering judgment is substituted. If EPA were to merely adopt the California program the inability to insure compliance by certification testing of all possible vehicle configurations could further erode the estimates of potential emission reductions obtainable.

Purpose

This is a status report on the Heavy Duty Truck Evaporative Emissions Project. The specific goals of this project are as follows:

1. Develop a preliminary test procedure using the large enclosure (SHED) at MVEL.

2. Use the preliminary test procedure to get initial estimates of the magnitude of the evaporative losses from uncontrolled and controlled heavy duty trucks.

3. Apply these initial test results to a revised air quality impact assessment.

4. Estimate the performance potential of current control systems through an in-house technology assessment program.

5. Evaluate the alternative compliance assurance strategies.

6. Develop a complete regulations package including standards, and a finished test procedure.

The areas that will be covered in this report are:

1. Initial test procedures.

2. Initial test results.

3. Procedure development.

Summary and Conclusions

When tested in a manner similar to the proposed 1978 LDV SHED test for evaporative emissions, the uncontrolled heavy duty gasoline fueled trucks tested emitted an average of 44.63 grams/test HC which is equivalent to 4.04 grams/mile HC. Trucks with control systems for the current California standard show a significantly lower evaporative loss, 14.78 grams/test or 2.00 grams/mile, however they are still high when compared with the LDV exhaust and LDV-LDT evaporative emissions standards.

The one Diesel fueled truck tested indicates that evaporative losses from Diesel fueled trucks are low enough (1.65 grams/test, 0.9 grams/mile) that they are not a concern at this time.

The one hour diurnal loss test does not reasonably represent an actual diurnal cycle, therefore the measured losses may be less than those occurring from in-use vehicles. It appears that lengthening the diurnal loss test, to approximately 3 hours, may solve this problem. This will yield significantly higher losses than reported here, indicating that the HDV evaporative losses may be an even greater problem than anticipated.

Discussion

Initial Test Procedures

MVEL has an evaporative emissions enclosure (SHED) that will accommodate vehicles up to 10 feet wide, 11 feet high, and 33 feet long. It was decided to use this SHED for all heavy duty evaporative emissions testing. The SHED is similar to the one used for light duty vehicle testing. Hydrocarbon concentrations are measured with a Flame Ionization Detector (FID).

SAE Recommended Practice J171a was chosen as an initial test procedure, however, the following changes were made:

1. The vehicle background emissions were not separated from the total evaporative emissions. Background emissions are a source of hydrocarbons with an effect on air quality and should be considered part of the evaporative losses.

2. In place of a chassis dynamometer driving cycle between the diurnal and hot soak loss tests, the trucks were driven over an 8 mile road rôute. The route, shown in the appendix, was intended to provide a consistent means of bringing the vehicles up to operating temperatures for the hot soak test.

Aside from these changes, the test procedure is the same as SAE J171a. There is a diurnal test where the liquid fuel is heated from 60°F to 84°F in 60 minutes and a 60 minute hot soak test immediately following a driving cycle.

Initial Test Results

Nine gasoline fueled trucks, with Gross Vehicle Weight Ratings in excess of 6,000 lbs., without evaporative emission control systems were tested by the above procedure. The results vary from 21.43 to 75.8 grams/test and are detailed in Table 1. The equivalent grams/mile HC was determined from the assumption that heavy duty vehicles experience 1 diurnal cycle and 9 hot soak cycles (trips) per day, and travel 36.2 miles. This duty cycle is based on studies of in-use vehicles in New York City. (EPA Contract Number: 68-01-0414)

This data shows several points worthy of discussion:

First - The trucks with two 50 gallon tanks had approximately twice the diurnal losses of the truck with one 50 gallon tank. Since the tanks were approximately the same shape this was expected, however, for the trucks with single fuel tanks, the losses are not directly proportional to the volume of the tank. The losses from the 36 gallon tank averaged 21.33 grams, while the losses from the 75 gallon tank averaged 27.01 grams. Therefore, there must be other factors, besides tank volume, contributing to the diurnal losses.

Second - There seems to be no pattern to the hot soak losses. These losses are affected most by carburetor design and underhood temperatures (which are a function of engine compartment packaging). It is unlikely that a pattern would show up in such a varied sample of trucks.

Third - The hot soak loss is the dominant term in the determination of the equivalent grams/mile HC. Comparing the Chevrolet pick-up truck and van the total losses for the pick-up are less than 10% greater than those of the van. However, the equivalent grams/mile HC for the pick-up is 50% higher than the van's. This is due to the higher hot soak losses of the pick-up and the large number of trips (hot soaks) used in calculating the equivalent HC.

Four gasoline fueled trucks with evaporative emissions control systems designed for use in California were also tested. The results of

Table 1

EVAPORATIVE EMISSIONS FROM UNCONTROLLED GASOLINE FUELED TRUCKS

Truck (GVW)	Fuel Capacity	Engine (CID)	Loss (g) Diurnal	Hot Soak	Total	Equiv. HC Gms/mi.
Ford N-600	50 Gal.	361	25.86	13.41	39.27	
(EPA-162)		V-8	21.90	16.21	38.11	3.48
(22,000)			19.69	8.41	28.10	
			22.18	7.93	30.11	
		Avg. =	22.41	11.49	33.90	
Ford	25 Gal.	391	17.63	4.02	21.65	
L-800		V-8	17.41	3.67	21.08	
(31,000)			16.48	4.91	21.39	1.47
			18.13	2.18	20.31	
			17.52	5.19	22.71	
		Avg. =	17.43	3.99	21.43	
Ford	75 Gal.	534	28.42	12.76	41.18	
LT-900		V-8	24.62	14.72	39.34	
(46,000)			26.86			4.16
			28.12			
		Avg. =	27.01	13.74	40.75	
Ford Van	22 Gal.	300	18.19	9.15	27.34	
E-150		I-6	19.68	11.53	31.21	3.09
(6,300)		Avg. =	18.94	10.34	29.28	
Chevy Pickup	20 Gal.	292	18.13	10.44	28.57	
C-20		I-6	18.44	10.03	28.47	3.05
(8,200)		Avg. =	18.29	10.24	28.52	
Chevy Van	36 Gal.		22.36	4.79	27.15	
(7,900)			20.29	5.56	25.85	1.88
		Avg. =	21.33	5.18	26.50	
GMC - 6500	100 Gal.	427	52.44	24.02	76.46	
6,500	(2 X 50)	V-8	52.74	23.87	76.61	7.28
(27,500)			51.87	22.46	74.32	
		Avg. =	52.35	23.45	75.80	
GMC - 6500	100 Gal.	366	48.83	22.50	71.50	
Sierra	(2 X 50)	V-8	49.99			
(23,000)			52.06	15.75	67.81	
			53.10	17.99	71.09	6.09
			53.18	17.01	70.19	
			52.56	20.44	73.00	
		Avg. =	51.62	18.74	70.36	
GMC - 6000	100 Gal.	350	57.88	17.77	75.65	
(24,000)	(2 X 50)	V-8		16.67		5.88
		Avg. =	57.88	17.22	75.10	

Group Average = 4.04

Table 2

EVAPORATIVE EMISSIONS FROM CONTROLLED GASOLINE FUELED TRUCKS

Truck (GVW)	Fuel Capacity	Engine (C.I.D.)	Loss (g) Diurnal	Hot Soak	Total	Equiv. HC Gms/mi.
Ford	50 Gal.	361	12.49	5.78	18.27	
LN-700		V-8	12.64	4.00	16.64	1.51
(25,500)			13.63	4.08	17.71	
		Avg. =	12.92	4.62	17.54	
Ford	41.5 Gal.	390	3.87	11.93	15.80	
F-250	(22.5 +	V-8	3.64	13.51	17.15	3.27
(6,900)	19)	Avg. =	3.76	12.72	16.48	
Ford	50 Gal.	534	4.08	6.63	10.71	
L-900		V-8	4.48	3.97	8.45	1.31
(56,000)			5.28	3.72	9.00	
		Avg. =	4.61	4.77	9.38	
I.H.C.	126 Gal.	537	2.78	5.04	7.82	
Fleetstar	(2 X 63)	V-8		5.94		
2010A			14.09	6.07	20.16	
(34,500)			13.47	9.05	22.52	1.91
			9.37	9.25	18.62	
			5.26	4.68	9.95	
		Avg. =	8.99	6.67	15.7	

Group
Average = 2.00

these tests varied from 9.38 to 17.54 grams/test and are shown in Table 2. For the three Ford trucks, the test results are quite consistent. However, the diurnal losses from the I.H.C. Fleetstar varied widely and no explanation has yet been found.

In order to make a rough comparison between the controlled and uncontrolled trucks, the mean of the total loss and the mean of the equivalent HC are shown in Table 3.

Table 3

Comparison of Uncontrolled and Controlled Trucks

	Mean Values	
	Total Loss (Gms/Test)	Equivalent HC (Gms/Mi)
9 Uncontrolled Trucks	44.63	4.04
4 Controlled Trucks	14.78	2.00

There is a significant reduction in hydrocarbons with the evaporative control systems. However, the magnitude of the losses from the controlled trucks is still quite high.

These initial tests indicate that an improvement of approximately 2 grams/mile HC is possible with the control systems designed for the current California regulations. However, these tests also indicate that even with the current control systems heavy duty evaporative emissions will continue to have a significant impact on total HC emissions. At 14.78 grams/test or 2 grams/mile individual gasoline-fueled controlled vehicles have much higher losses than emissions which will be allowed from future light duty vehicles (See Table 4).

Table 4

Future Light Duty Vehicle Emission Standards

	Total SHED Evaporative Loss (gm/test)	Equivalent HC (gms/mi)
LDV (1978 Statutory exhaust standard)	-	0.41
LDV (1979 Proposed evaporative standard)	2.0	0.2

One Diesel-fueled truck has been tested as shown in Table 5. If this truck is representative of all Diesel trucks, Diesel evaporative emissions regulation is not critical at this time.

Table 5

Evaporative Emissions From A Diesel Fueled Truck

Truck (GVW)	Fuel Capacity	Engine	Diurnal	Loss(g) Hot Soak	Total	Equivalent gms/mi
GMC ASTRO-95 (120,000 GCW)	100 Gal. (2 x 50)	8V71N	1.44	.21	1.65	.09

Test Procedure Development

Before testing began, it was assumed that hot soak losses from uncontrolled heavy duty vehicles would be approximately equal to those from uncontrolled light duty vehicles. Hot soak losses are primarily carburetor losses and essentially the same carburetors are used on light and heavy duty vehicles. The Los Angeles FY 71 test program showed that uncontrolled light duty vehicles had a mean hot soak loss of 14.86 grams/test. The nine uncontrolled trucks in Table 1 had a mean hot soak loss of 12.71 grams/test. Therefore, the assumption is accurate.

It was also assumed that diurnal losses from uncontrolled heavy duty vehicles would be several times greater than those from uncontrolled light duty vehicles. This was based on the fact that heavy duty vehicles have larger fuel tanks than light duty vehicles, and many heavy duty vehicles have multiple fuel tanks. The Los Angeles FY 71 test program revealed a mean diurnal loss of 25.73 grams/test for uncontrolled light duty vehicles. The three trucks in Table 1 with single fuel tanks of 25 gallon capacity or less had a mean diurnal loss of 18.22 grams/test and a mean fuel tank capacity of 22.33 gallons. The three trucks equipped with two 50 gallon tanks had a mean diurnal loss of 53.95 grams/test or 26.98 grams/tank/test. There is some increase due to tank size but, the assumption that the diurnal losses are directly proportional to fuel tank volume is incorrect. There must be some other variables that also contribute to the diurnal loss.

In an SAE paper entitled "Factors Influencing Vehicle Evaporative Emissions", paper number 670126, D.T. Wade of Esso (Exxon) Research and Engineering Co. presents the mechanisms controlling diurnal losses and a mathematical relationship for predicting the losses. Wade contends that, when there is equilibrium between the liquid and vapor in the tank, the diurnal losses are a function of the properties of the fuel, the atmospheric pressure, the pressure inside the tank, the initial and final fuel and vapor temperatures, and the vapor space in the tank. The test procedure keeps all of the factors constant except the vapor space, which is a function of the tank design. Therefore, the diurnal loss should be directly proportional to the vapor space. The test results show that this was not so. As the vapor space increased, the measured losses also increased but not in the same proportion as the vapor space. Wade cautions that heating rates faster than the rate of equilibration, will produce measured losses that are smaller than the simulation predicts. Further investigation revealed that the one hour diurnal test cycle is not an equilibrium process. Figure 1 shows the fuel and vapor temperatures (measured at the centroids) and losses plotted against time for an uncontrolled 50 gallon tank. The fuel and vapor temperatures are not equal at the start of the test and the fuel temperature rise is faster than the vapor temperature rise. Increasing the length of the diurnal cycle (in effect, slowing the heating rate) to 3 hours does not significantly alter the relationship shown in Figure 1. However, it does cause a significant increase in the measured losses, to 31.63 grams for the tank tested.

Apparently, when the diurnal loss test is not an equilibrium process predicting the results is currently not possible. Added to the variables already known are the proportions of the tank (which will affect the initial vapor temperature, the rate of increase of the vapor temperature, and the temperature gradients in the fuel and vapor), the length of the test (which possibly affects the temperature gradients in the fuel and vapor, and the HC concentration of the expelled vapor), and the heating method (which affects the temperature relationships).

It is necessary to know whether the diurnal temperature cycling of in-use vehicles is an equilibrium process. If it is, then the current one hour diurnal test cycle will never yield losses as great as those from vehicles in the real world, and the test will need to be improved. The only available data on this comes from the CRC/CAPE-5-68 program run by Scott Research Laboratories and is shown in Figure 2. Twenty-nine vehicles were parked outside from 8 A.M. until 12 noon and the temperatures were recorded. Since the test was started at eight and ended at noon the ambient temperature rise, 12.9°F, was only about half of the 24°F rise on which the SAE J171a procedure is based. Figure 2 shows that in-use diurnal cycles are not equilibrium processes. If the results of Figure 2 are extended to a 24°F ambient temperature rise then a fuel temperature rise of 12.84°F and a vapor temperature rise of 20.09°F would be expected. The one-hour diurnal test (SAE J171a) shown in Figure 1 shows a 24°F fuel temperature rise and a 10°F vapor temperature rise. Therefore, the SAEJ171a procedure does not reproduce actual conditions.

Figure 2 also indicates that the ambient air temperature is the forcing function for the diurnal cycle. The fuel and vapor temperature cycles follow the ambient air temperature cycle, but there is a time lag caused by the "thermal inertia" of the fuel or vapor. An attempt was made to duplicate the real world conditions by letting the circulating air in the SHED heat the fuel and the vapor. For this test it was

Figure 1 - 1 Hour Diurnal Loss Test (SAE J171a)

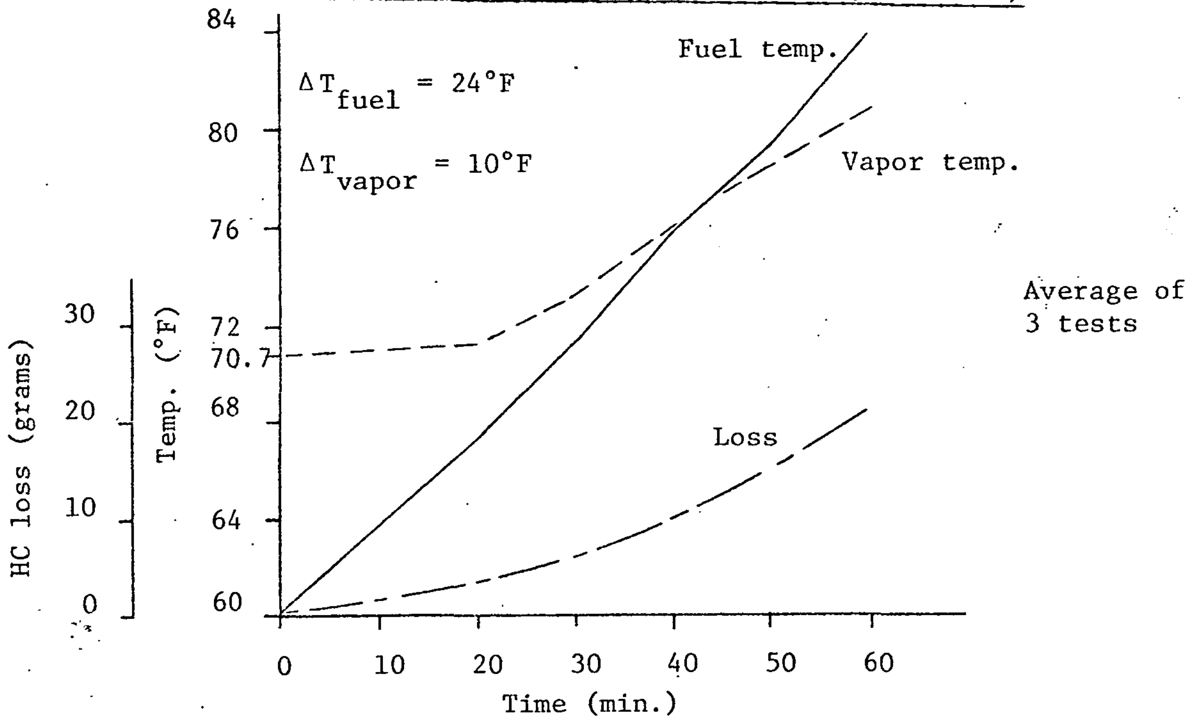
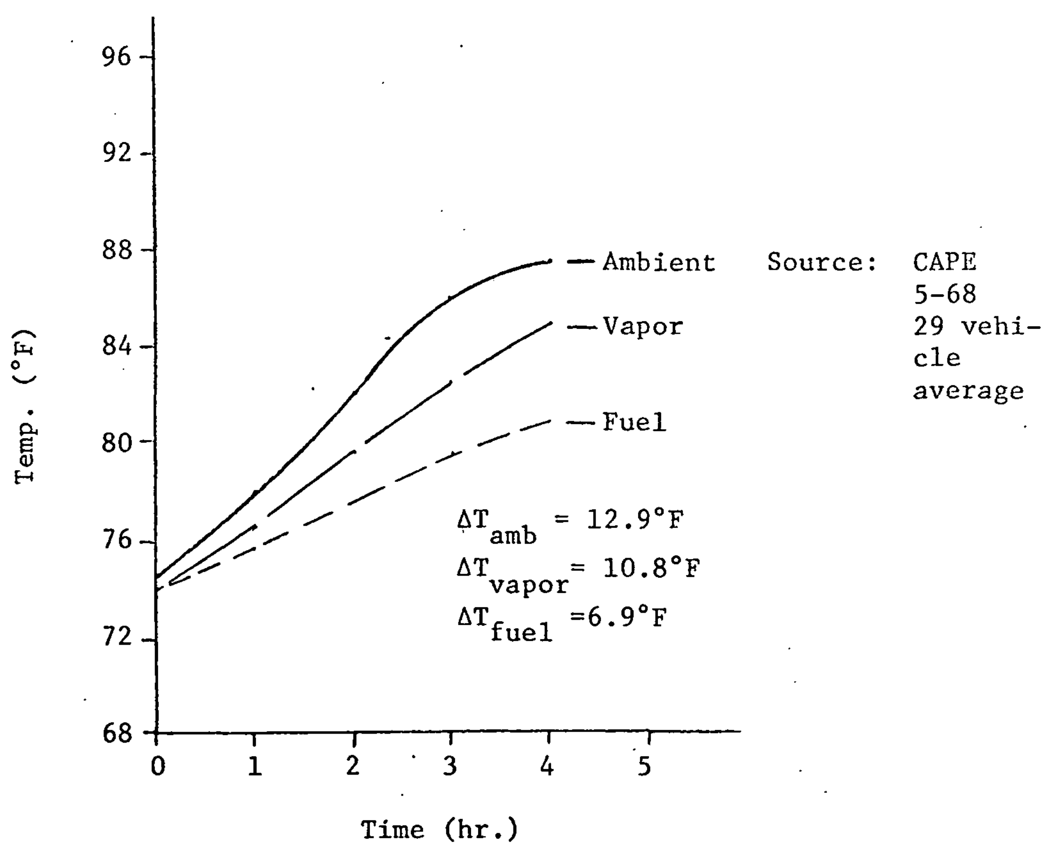


Figure 2 - Actual Vehicle Fuel System Temperatures



desirable that the fuel and vapor temperatures be approximately equal at the start of the test. The test was performed on a 50 gallon uncontrolled tank which was placed outside overnight to cool it below 60°F. It was brought into the SHED and filled to 40% of rated capacity with 60°F gasoline. The SHED was sealed, and left for 7 hours (Figure 3). The temperature profiles do not resemble Figure 2. The main reason for this is the constant 80°F ambient temperature. Since the vapor has a lower "thermal inertia" than the fuel it is heated more rapidly. However, the temperature changes are quite similar to the real world conditions, 15.8°F vs. an expected 12.84°F for the fuel and 17.8°F vs. an expected 20.09°F for the vapor. The losses for this test were 30.28 grams. The same tank tested by the 1 hour procedure (SAE J171a) had losses that averaged 20.85 grams, with fuel and vapor temperature changes of 24°F and 10°F respectively.

It was not possible to lower the ambient temperature in the SHED so that the vapor temperature would rise at the same rate as the fuel temperature. So, for a subsequent test, the rate of increase of the fuel temperature was increased by heating the fuel with a heat blanket. The fuel and vapor temperatures were both 60°F at the start of the test, and the fuel was heated to 84°F in one hour (Figure 4). A comparison of the three types of tests is given in Table 7.

Table 7

Comparison of Diurnal Test Cycles

Test Type	Fuel Temp (°F) Initial	Final	Δ	Vapor Temp (°F) Initial	Final	Δ	Losses (gr HC)
SAE J171a (Fig. 1)	60	84	24	70.7	80.7	10	20.85
SAE J171a (Fig. 4) $T_{(fuel)_i} = T_{(vapor)_i}$	60	83.7	23.7	60	79.9	19.9	23.29
7 Hour Soak (Fig. 3)	61	76.8	15.8	60	77.8	17.8	30.28

The variables in this series of tests were the initial and final fuel and vapor temperatures and the test length. The two one hour tests had essentially the same initial and final fuel temperatures, so the only difference in the tests are the vapor temperatures. However, the final vapor temperatures are almost equal so that the only difference is the initial vapor temperature and, therefore, the vapor temperature change. Doubling the vapor temperature change, by lowering the initial vapor temperature, increased the losses approximately 12%, from 20.85 grams to 23.29 grams. The 7 hour soak test had fuel and vapor temperature changes that were less than the one hour test shown in Figure 4, yet the

Figure 3 - 7 Hour Soak Diurnal Cycle

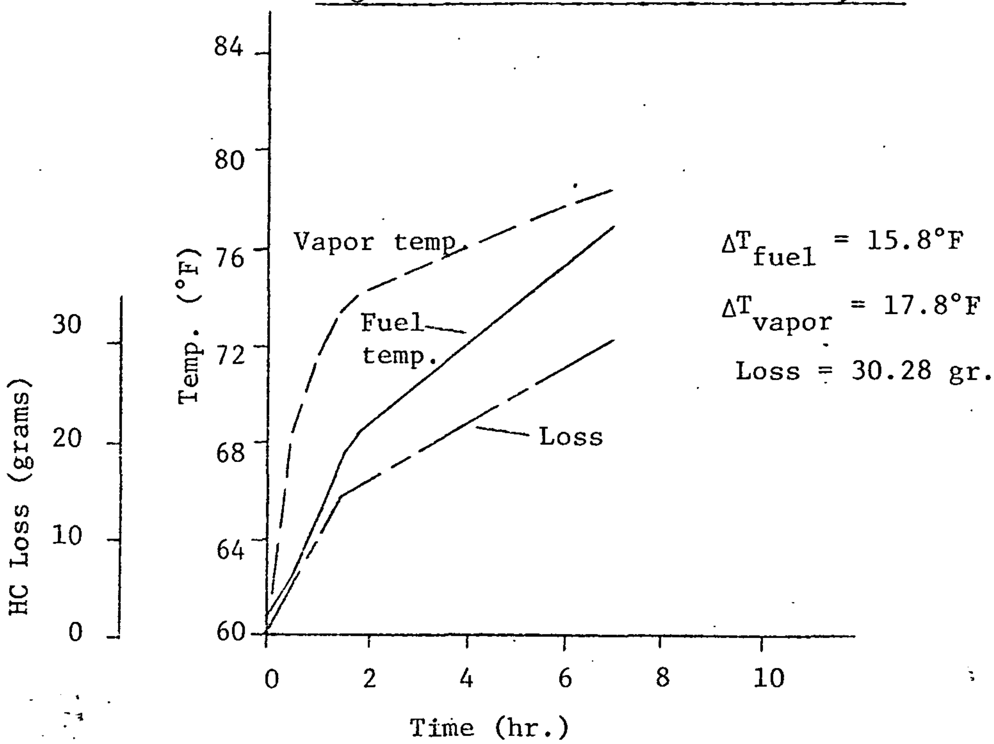
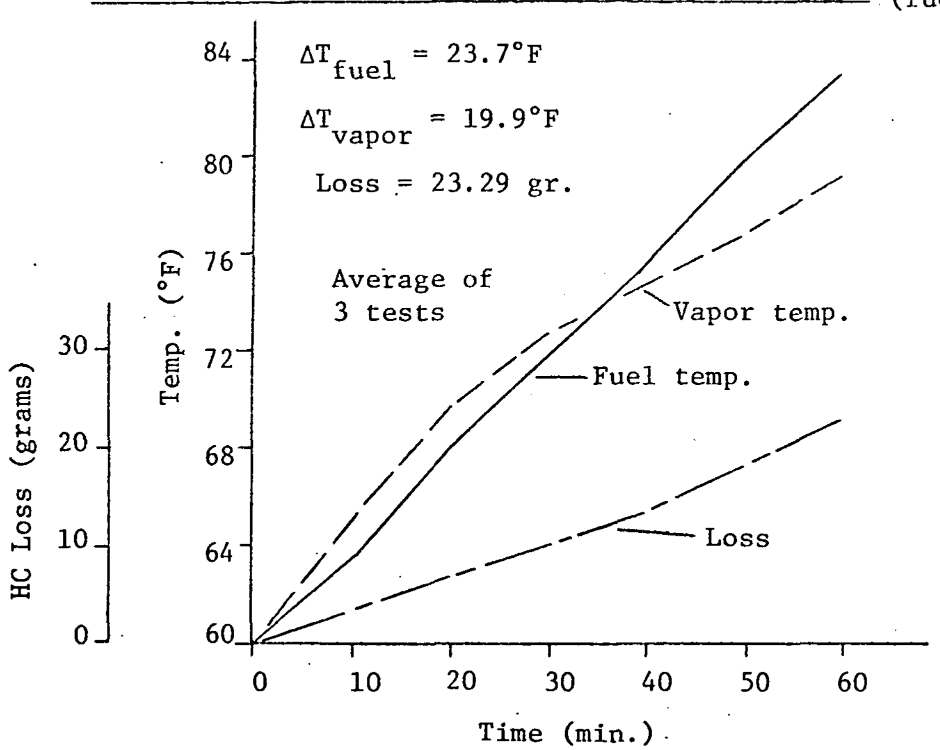


Figure 4 - 1 Hour Diurnal Test (SAE J171a) with $T_{(fuel)_i} = T_{(vapor)_i}$



losses were 30% higher, 30.28 grams vs 23.29 grams. Therefore, the length of the test is an important variable which cannot be overlooked. This was not mentioned in Wades simulation which only applies to equilibrium processes where the test length is always the same. Since actual diurnal cycles and any laboratory simulations are not equilibrium processes the length of the test is a variable that must be taken into account.

Of all the lab tests run, the 7 hour soak (Figure 3) is the best simulation of the actual diurnal cycle (Figure 2) when the major variables are compared (Table 8).

Table 8

	7 Hour Soak	Actual Diurnal Cycle*
Fuel Temperature		
Increase	15.8°F	12.89°F
Vapor Temperature		
Increase	17.8°F	20.09°F
Time	7 hr	>4 hr

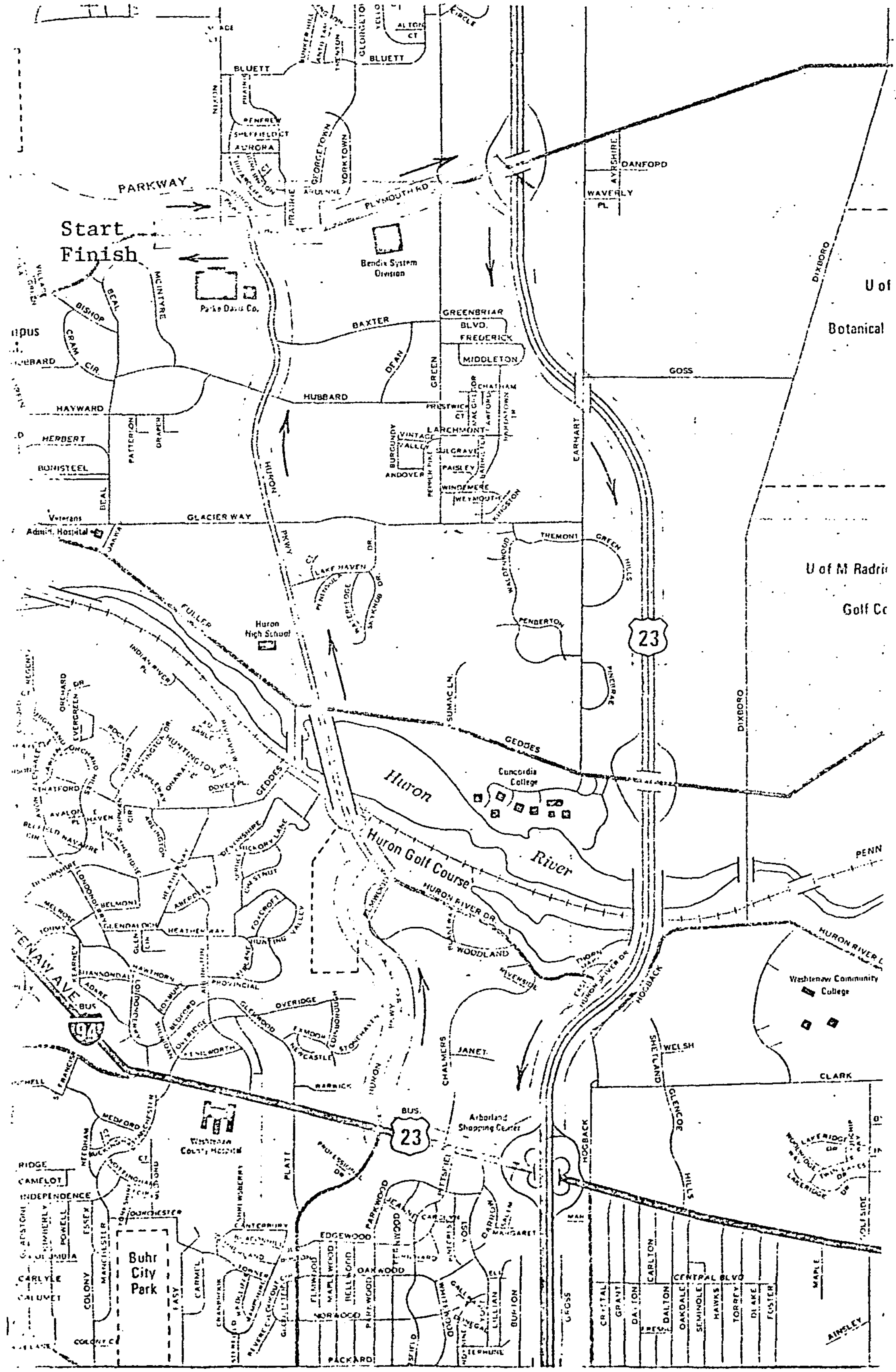
*Extrapolating Figure 2 to a 24°F ambient temperature rise.

Getting a better simulation of the actual diurnal cycle requires controlling the temperature of the air in the SHED which is not possible at this time. However, a 7 hour test is burdensome for a certification procedure, and controlling the SHED air temperature is complex and expensive. What is needed is a shorter test that yields representative losses.

It was mentioned earlier that lengthening the diurnal test, while using the same 24°F fuel temperature rise, increased the measured losses without any other change in the process. Therefore, it is possible to lengthen the SAE J171a test until the losses equal the losses from an actual diurnal cycle. It was not possible to measure the losses from an actual diurnal cycle, however, for the truck tested, the 7 hour soak yields losses similar to the real world cycle. The losses from the 7 hour soak were 30.28 grams, the 3 hour version of the SAE J171a gave losses of 31.63 grams. A considerable amount of time can be saved, without changing the losses, by using a longer version of the SAE J171a test instead of a 7 hour soak. Further testing will be needed to determine the proper length for the diurnal test.

APPENDIX (Ann Arbor, Michigan)

Evaporative Emissions Test Road Route



Abstract

Initial evaporative emissions testing of heavy duty vehicles by the SHED technique is described and test results reported. A potential weakness in the diurnal loss measurement method is discussed and further testing recommended.

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