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TECHNICAL REPORT

RUNNING LOSS EVAPORATIVE EMISSIONS DETERMINATION BY THE POINT SOURCE METHOD

Prepared for
California Air Resources Board
Sacramento, California
ARB Agreement No. A732-151

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ABSTRACT

The purpose of this work was to examine the potential of determining running loss emissions by examining the sources of evaporation of fuel from a vehicle during operation. This required the use of equipment based on constant volume sampling with multiple sources that could simultaneously monitor different locations. The hydrocarbon emissions were measured for their total content with two California certified vehicles. The operating temperature and fuel vapor pressure were control variables that were examined for their effect. Evaporative running losses were found at the charcoal canister and purge air vent. Differences in the losses were observed with the two vehicles. The fuel vapor pressure and driving cycle were major factors over the ranges examined, but temperature had statistical significance. A model used to predict vapor generation from the fuel was in general agreement with the running loss experimental data.

ACKNOWLEDGMENT

This report was submitted in fulfillment of ARB Agreement No. A732-151 by the IIT Research Institute under the sponsorship of the California Air Resources Board. Work was completed in February of 1989.

DISCLAIMER

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INTRODUCTION

Most hydrocarbons can react with the oxides of nitrogen (NO_x) in the presence of sunlight to form ozone and other oxidants in the atmosphere. Automobiles are a significant source of these reactive hydrocarbons which contribute to the smog occurring in the air in and around many major cities. Hydrocarbons are emitted from a vehicle as unburned or partially oxidized fuel in the exhaust from the engine and as vapors from the fuel tank and fuel system. The evaporative emissions have been well quantified for two conditions:

1. Simulation of fuel tank heating caused by daily ambient temperature rise.

2. Fuel system heating caused by transfer of heat from the engine and exhaust system heating after the engine has been fully warmed-up and then shut-down.

These two conditions are commonly referred to as the diurnal heat build and hot soak, respectively.

There is another condition during which evaporative losses can occur; specifically, while the vehicle is being driven. These emissions ("running losses") have only recently been measured (1,2)* and only a very fragmentary data base has been established.

The procedure that has been used to quantify running losses consisted of enclosing a chassis dynamometer in Sealed Housing for Evaporative Determination (SHED) (3) and measuring the increase in hydrocarbon level in the enclosure while the vehicle was being driven on the dynamometer. This approach provides an overall measurement of running losses but does not allow identification of the specific sources of the hydrocarbon losses. This information would be necessary in formulating effective emission controls and

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*Underlined numbers in parentheses refer to items in the list of references at the end of this report.

in assessing their adequacy. The sealed cell enclosure approach can also cause problems in control of fuel tank temperature rise because of inadequate air flow around the tank and the addition of heat from the engine to the enclosure.

An alternative approach to the sealed enclosure technique was developed by NIPER to identify the specific sources of running losses and to quantify the losses from each source. This system design is based on constant-volume-sampling (CVS) which enables computation of mass emissions directly from concentration measurements. This system was subsequently used by NIPER in this project sponsored by the California Air Resources Board to investigate running losses from automobiles.

OBJECTIVE

The objective of this work was to quantify running losses from vehicles operated at conditions that are representative of those in California. The influences of fuel volatility, ambient temperature, fuel tank temperature rise, and driving cycle on running losses were examined. The specific objectives were:

1. To quantify running loss emissions from California-certified vehicles.

2. To identify the specific sources in the vehicle and determine their relative significance.

3. To investigate and assess options for control of running loss emissions.

OUTLINE OF TEST MATRIX

A summary outline of the test matrix is included below:

VEHICLES

Two vehicles were used for testing representing a fuel-injected vehicle and a carbureted vehicle. These were a 1985 Buick Regal with a 3.8 liter V-6 with port fuel injection engine and a 1987 Chevrolet Caprice with a 5.0 liter V-8 carbureted engine.

FUELS

Two fuels with different volatilities were used for testing. The Reid Vapor Pressures (RVP) were 7 and 9 psi for the two gasolines.

TANK TEMPERATURE INCREASE

Fuel tank temperature was monitored and controlled to simulate the vehicle in-use operation. One profile was used for each vehicle.

AMBIENT TEMPERATURE

Two test temperatures of 80° and 95°F were used to represent moderate and hot climates.

REPLICATES

Duplicate tests were collected and averaged for each data point.

DATA COLLECTED

Regulated emissions (exhaust and evaporative) were measured as prescribed by the Federal Test Procedure.

For the determination of running losses, the test variables included vehicle, fuel, driving cycle, ambient temperature, and fuel temperature rise. The running losses were the only emissions measured in these tests. A test matrix for each vehicle was based on a fractional factorial design (eight tests of each vehicle). Two additional tests were conducted on the carbureted car to obtain a measure of test repeatability and of predictability. The fractional factorial design of experiments was used in order to obtain good estimates of the main effects of the independent variables without requiring an inordinately large number of tests.

METHODOLOGY

DISCUSSION OF RUNNING LOSS MEASUREMENT TECHNIQUE

Four sampling probes were designed into the sampling system.[1] They were designed on the principle of constant volume sampling with plant air (dried and regulated to 30 psi) as the input to carry the sample. The sample was then regulated to 20 psi and carried through individual eductors for each sample line. The sample was taken by a four-way control valve to a Beckman 402 hydrocarbon instrument with a regulated flow pump to the instrument. Further, sample capture into a Tedlar bag was accomplished with individual flow control pumps regulated to volumes based on the sampling times. The regulators selected had a capacity up to 800 cc/minute. This allowed for a sampling period of as little as 2 hours to fill the 100 liter Tedlar bags at the maximum sampling rate so sufficient sample for GC analysis can be collected in approximately 2 minutes. The regulators were flow tested to rates as low as 30 cc/minute and had linear response. This allowed for continuous sample durations as long as 48 hours.

A block diagram of the point source sampling/analysis system is presented in Figure 1. This figure illustrates the concept of using a constant volume sampling system as the control for the sample collection. Figure 2 is a detailed schematic of the sampling/analysis system and shows four coupled CVS systems with a hydrocarbon analyzer and collection bags. The system components that are listed in the box on Figure 2. Photographs of the system are presented in Figure 3.

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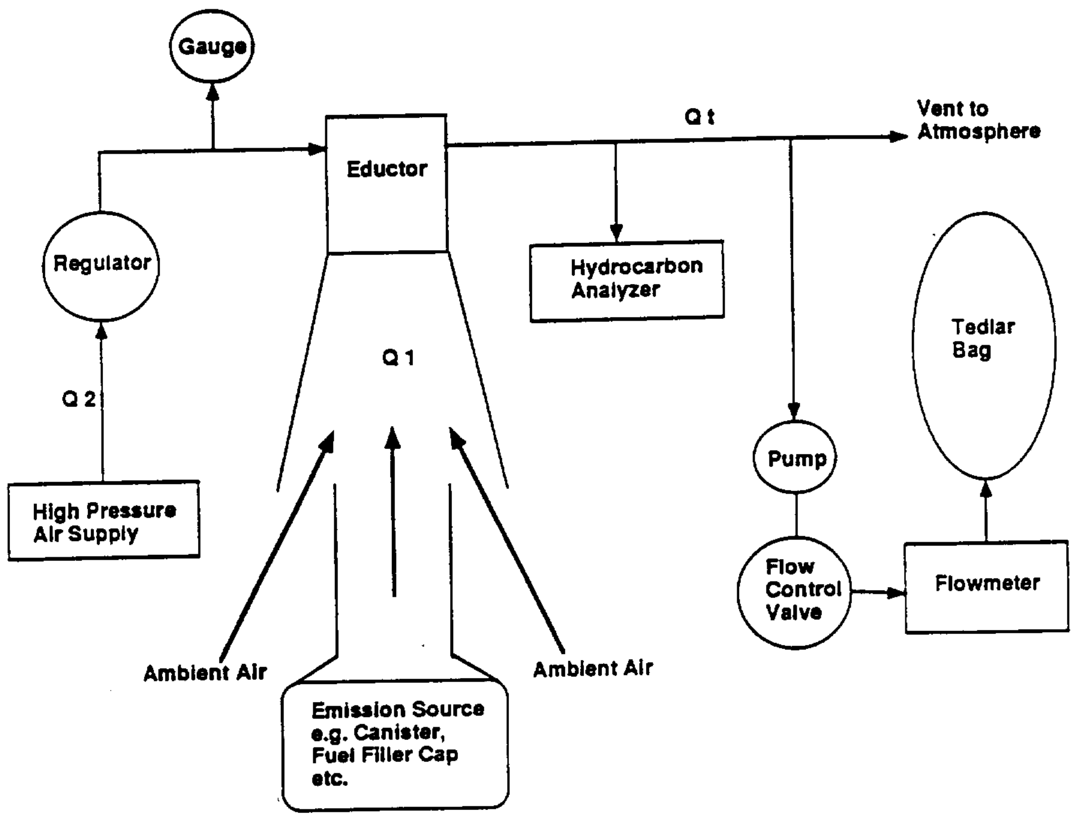
[1] The system that was used for this experimental work was developed on NIPER funds and a patent application filed prior to beginning this work for the California Air Resources Board.



Q 1 .... 4 CFM ambient air plus emission source
Q 2 .... 4 CFM dilution air
Q t .... 8 CFM total air flow
Eductor .... Air-Vac Vacuum Transducer Pump TD 190M
Regulator .... Pressure Regulator, 5 to 30 psig, controls air and sample flow
Gauge .... Pressure gauge, 0 to 50 psig
Flow Control Valve .... Needle Valve, maintains constant flow to Tedlar bag at 2 liters/minute
Flowmeter .... Rotameter, 0 to 5 liters/minute
Tedlar Bag .... Sample Container, 80 liters total volume, covered with illumination blocking material
Hydrocarbon Analyzer ..... Beckman Model 400 FID
Pump .... Teflon diaphragm pump
Temperatures .... Temperatures measured: ambient, canister, underhood, fuel tank

THE ON-LINE REAL TIME ANALYSIS IS QUALITATIVE TO IDENTIFY THE SOURCE OF EMISSIONS. THE ANALYSIS OF THE BAG SAMPLES IS FOR QUANTIFICATION OF THE HYDROCARBON EMISSIONS. THE FLOW RATES WERE SELECTED TO ADEQUATELY DILUTE THE SAMPLE WHILE RETAINING ACCEPTABLE ANALYTICAL SENSITIVITY. (1 G/MILE OVER THE LA-4 CYCLE EQUALS 2100 PPMC AT Q t OF 8 CFM)

FIGURE 1. - BLOCK DIAGRAM OF SAMPLING/ANALYSIS SYSTEM

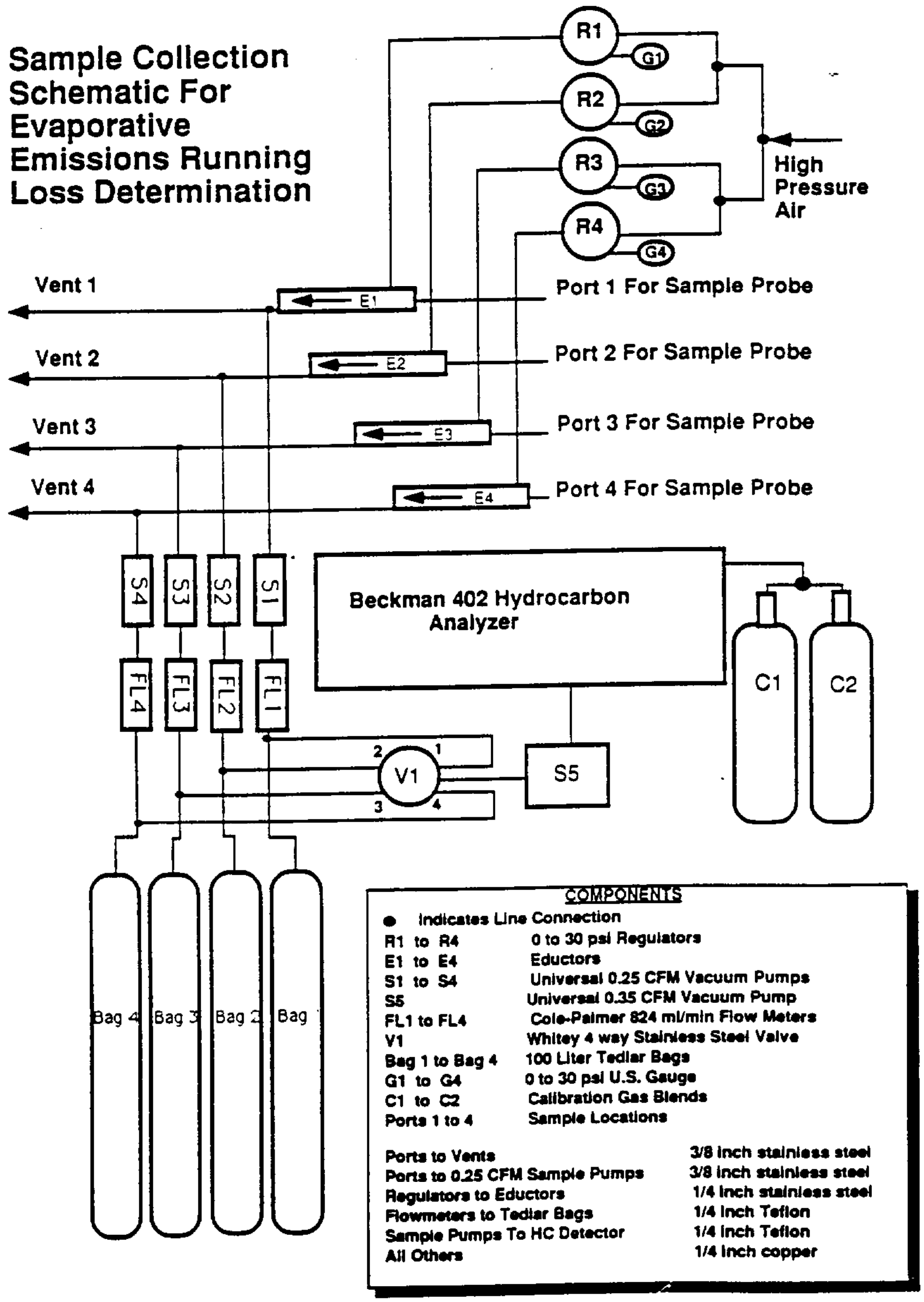


FIGURE 2. - DETAILED SCHEMATIC OF SAMPLING/ANALYSIS SYSTEM

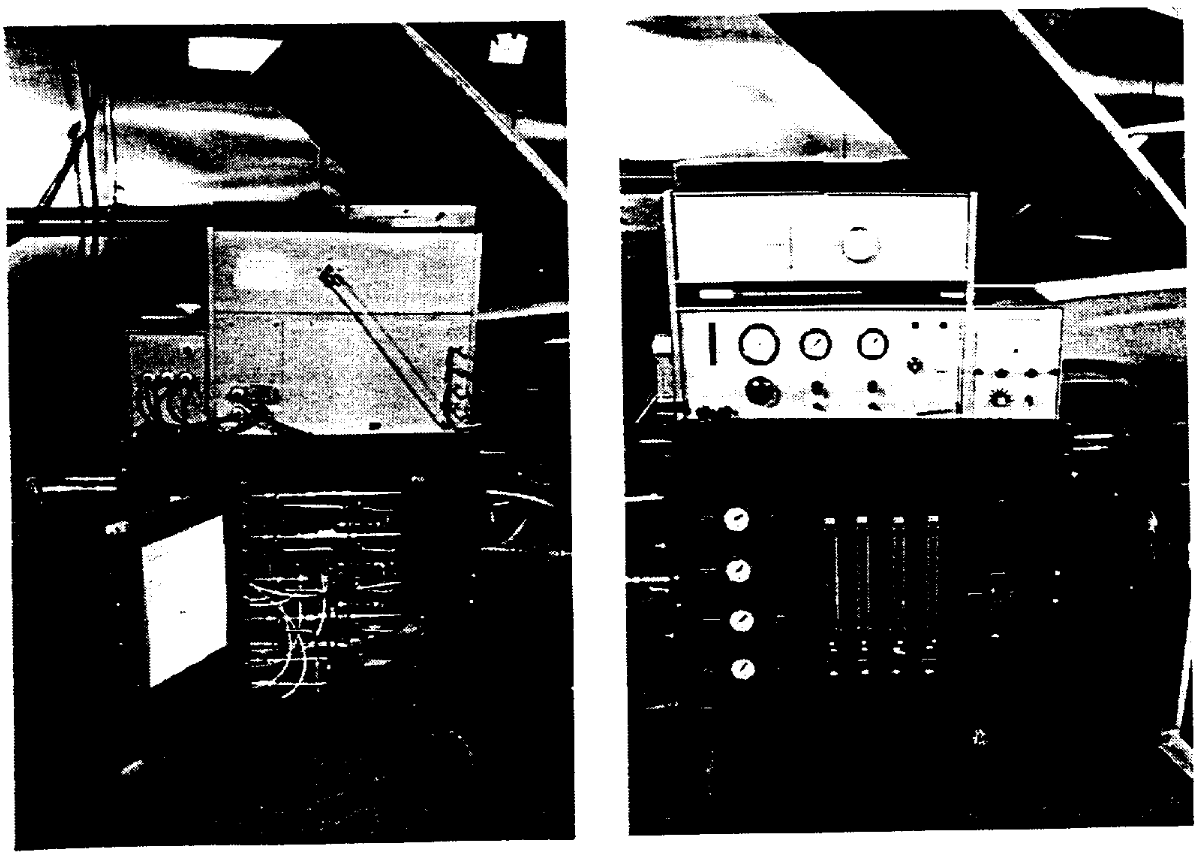


FIGURE 3. - PHOTOGRAPHS OF SAMPLING/ANALYSIS SYSTEM

Comparison of Point Source Device with Sealed Cell Approach

The point source equipment was compared with the sealed cell approach that is also used to measure running loss evaporative emissions. While experimental data were not collected that allow a direct comparison, the point source equipment has advantages in the following areas.

Determine Location of Running Loss Emissions - The unit is equipped with four probes. Three of these probes were attached to collector modules that were placed around sources of suspected fugitive emissions locations on the vehicle. The fourth probe was used to "sweep" the vehicle to determine if other sources existed (such as along a fuel line) and also to obtain background readings. The background reading can be essentially equivalent to the sealed cell approach since it provides the one reading for the cell. This background reading can be the total emissions from the vehicle if the three stationary probes are vented into the cell, or used to detect for other sources in the cell from the vehicle, or from operating equipment if the three stationary probes are vented outside of the cell.

Ease of Use - The unit can be set-up quickly and does not require that the test cell have an airtight seal. This can greatly reduce test time and the costs associated with these types of measurements.

Portability from Test Cell to Test Cell - The sealed cell approach requires a dedicated facility to measure the running loss emissions since the vehicle must be operated within the sealed cell. The point source equipment allows measurements to be performed in a reasonably air-tight cell. This difference permits the point source equipment to be moved between test cells and allows tests to be performed on different dynamometers that are not equipped with the sealed cell facility.

Perform Stand-Alone Emissions Collection - The point source equipment can also be configured to measure hydrocarbons (or other gaseous emissions) in a stand-alone mode either for general air sampling or for point source monitoring. This could allow the use of the point source equipment to monitor sources as diverse as air inlets in buildings through forced air registers to gasoline pump attendant locations to monitor air quality in a low air-flow operation. It could also perform simultaneous monitoring in this mode to determine how much of an emissions source is allowed to come into contact with air that is used to supply interior environment air. This could allow direct comparison of the sources of evaporative emissions from vehicles to locations where the products may be inhaled since the same equipment could be used for all measurements.

DISCUSSION OF FUEL TANK HEATING

The tests were conducted with vehicles at ambient temperatures of 80° and 95°F. Fuel tank temperature rises of 15° and 25°F above ambient to simulate operating conditions were achieved by controlling the voltage to an electric heat blanket that was attached to the bottom of the fuel tank. Approximately 65% of the temperature rise occurred in the first half of the test cycle. Selection of this temperature ramp was based on the results of on-road tests conducted by NIPER and by EPA for both carbureted and fuel-injected vehicles.

The initial tests indicated that the only sources of measurable running loss emissions from the two vehicles were the charcoal canister and fuel fill cap. Emissions from these two sources were collected in all tests. In addition, the dynamometer room air was sampled to obtain background air hydrocarbon levels and to detect any other source that may have been present.

Verification With Road Data

A determination of the fuel tank temperatures was measured by thermocouples installed in the fuel tank. This was performed since previous experience with vehicles operating through a running loss test indicated that fuel tank temperature was an important variable and was vehicle design sensitive. Tests with other vehicles have illustrated that prediction of the fuel tank temperature is not possible based on known design factors (4). The technique of obtaining road data is necessary to correlate the fuel tank heating rate during the chassis dynamometer operation. If the road fuel tank temperature is not known, then the emissions that are determined may not be representative of the vehicle in-use profile.

The determination and matching of road data was essential to obtain meaningful data as the information has been shown to be highly dependent on vehicle fuel tank temperature increase. The NIPER test cell has the capability to make this matching since it has independently controlled air from two different systems and the ability to direct air to different parts of the vehicle as required for temperature control. Supplemental heat is supplied as necessary through temperature controlled heating blankets that are attached to the vehicle fuel tank. Overheating of the vehicle fuel tank, a problem in some laboratories, is avoided in the NIPER laboratory.

The process consisted of a temperature soak at 70°F for 12 hours prior to the determination of the road data. The vehicle was fueled with the test fuel prior to the temperature soak as if the vehicle were to be tested through an FTP analysis. After the soak, the vehicle was operated on roads north of NIPER through a simulated road FTP driving cycle so that the temperatures could be determined. The vehicle was driven over a level road at an ambient temperature of approximately 70°F. The weather conditions were fair, sunshine, and calm wind. Readings of the temperatures in the vehicle fuel tank were made during the operation of the vehicle. This verification was performed once with each vehicle.

The purpose of this pretest FTP temperature determination of vehicle in-use profile was to establish the level of air movement required, the position of baffles and air movement within the test cell, and other controls necessary to obtain the road data. With this information, the vehicle fuel tank temperature was controlled so that the road conditions could be duplicated in the test cell. The process of establishing the fuel tank temperature in the test cell was repeated until the fuel tank temperature of the vehicle in the test cell was within 3°F of the road data.

DETAILED TEST PROCEDURES

Vehicle Description

Two in-use automobiles with California-emissions-certification were selected for the project. One vehicle was carbureted and the other had a port-fuel-injection system. Both vehicles were in good condition and had no obvious emissions control malfunctions. Vehicle data are given in Table 1 and schematics of evaporative emissions control systems are shown in Figure 4. Exhaust and evaporative emissions were measured for both vehicles using the Federal Test Procedure (FTP).

TABLE 1. - VEHICLE INFORMATION

Vehicle No.	505	712
Model Year	1985	1987
Make	Buick	Chevrolet
Model	Regal	Caprice
Odometer, miles	40,640	29,360
Displacement, L	3.8	5.0
Fuel System	Port Fuel Injection	Carbureted
Fuel tank volume	13.5	25.0
Canister volume, cc	1800	1800

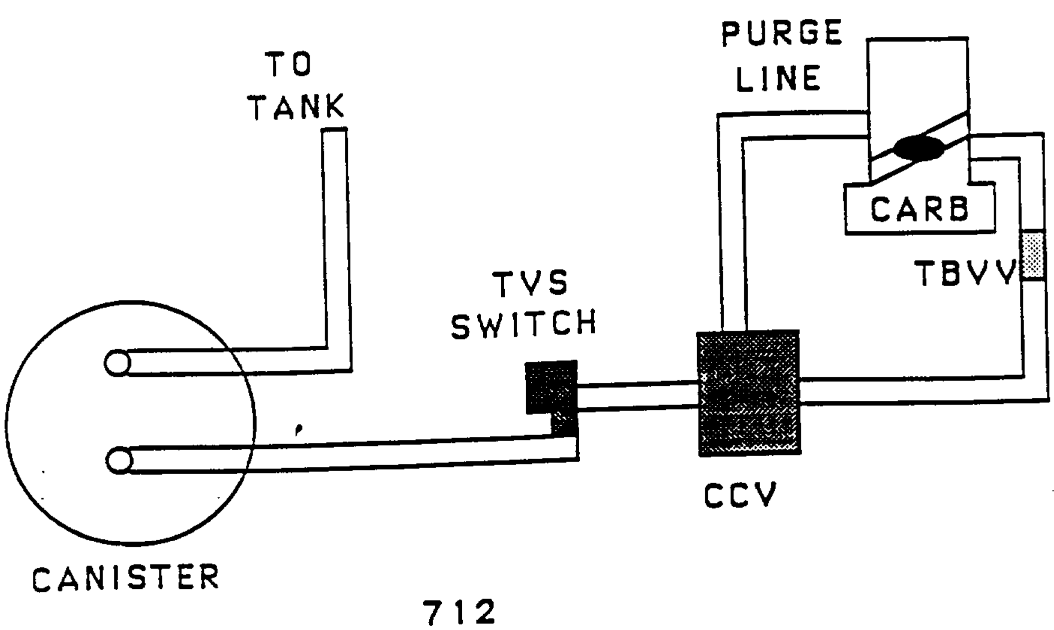


FIGURE 4. - SCHEMATICS OF EVAPORATIVE EMISSIONS CONTROL SYSTEM REPRESENTATIVE OF TEST VEHICLES

Vehicle Conditions

The condition of the two vehicles was important to consider since it could affect the result. The 1985 Buick was a company-owned vehicle that was maintained by NIPER staff personnel. The specified manufacturer's maintenance regimen was followed during the period when the vehicle was owned by NIPER. The vehicle was purchased as a used vehicle for a test program. As a result, the total maintenance history prior to NIPER's ownership is not certain. However, prior to purchase the vehicle was inspected for emissions computer code malfunctions - none were present - and operated on a chassis dynamometer for verification of emissions performance. The results of these initial tests and the new vehicle requirements for this vehicle are:

	CO g/mi	NO_x g/mi	HC g/mi
California New 1985 Vehicle Requirements (5)	7.0	0.40	0.41
Used 1985 Test Vehicle Performance	5.7	0.48	0.45

As a result of the checks, the vehicle was determined to be in good condition. No drivability problems were observed.

The 1987 Chevrolet was an employee-owned vehicle that was purchased new from a local dealer. The employee reported that the vehicle received dealer maintenance required to maintain the vehicle warranty. In addition, the employee reported that routine maintenance of lubrication and oil filter changes were performed every 3 months. The last tune-up prior to this test was performed approximately 5 months before data was collected. Some vehicle drivability problems were observed, but these were corrected by carburetor adjustments by a certified ASE mechanic prior to conducting these tests.

Fuels Inspection

Two fuels were used in both the FTP tests and the running loss tests. One fuel was an emissions certification fuel (Indolene) with Reid Vapor Pressure (RVP) of 9.0 psi. The other fuel was formulated by blending a low vapor pressure gasoline blending stock with the Indolene to produce a finished fuel with 7.0 psi RVP. Fuel inspection analyses are given in Table 2. The vapor pressures were measured by the ASTM procedure ASTM D-323 (5).

TABLE 2. - FUEL INSPECTION ANALYSIS

FUEL:	8912	8913
RVP, psi	9.0	7.0
Gravity, API	58.9	56.6
Spec. Grav.	0.743	0.752
Vol. %, FIA		
Saturates	67.7	65.4
Olefins	1.1	1.4
Aromatics	31.2	33.2
Distillation Temp @ % off		
IBP	102	105
6	111	121
10	135	148
20	167	180
30	193	202
40	209	217
50	220	227
60	229	236
70	240	247
80	258	268
90	308	314
95	358	355
EP	423	418
% Recovered	98.6	98.8
RON	96.4	96.1
MON	85.3	85.3
R + M/2	90.8	90.7

Test Cycles

For the work of the effort described by this report, a point source technique of measuring running losses was used.

The system used in these running loss tests has four independent sampling systems. Initial tests indicated that the only sources of measurable running loss emissions from the two vehicles were the charcoal canister and fuel fill cap. These two sources were subsequently sampled in all tests. In addition, the dynamometer room air was sampled in order to subtract background levels and to detect any other source.

The use of the NIPER developed system provides the overall response of the vehicle that is obtained from the sealed cell approach. It also provides information on specific sources simultaneously with the overall vehicle response. As a result, the information obtained with this technique provides additional information beyond the sealed cell approach.

The vehicles were operated through two different test cycles. These cycles were based on the FTP and a low-speed cycle (6). The FTP is defined by the Code of Federal Regulations and is shown schematically in Figure 5. The actual driving cycle consisted of the first two phases of the FTP (LA-4 cycle) followed by another LA-4 without interuption or shut-down. The low-speed cycle was defined by the EPA as a very slow cycle that may indicate movement through congested city surface streets. The speed versus time trace is shown in Figure 6. To provide information which may be meaningful, the low-speed cycle was modified for this project and consisted of the low-speed cycle followed by an LA-4 cycle and then another low-speed cycle. This may provide an illustration of an approach to a freeway from a cold-start, operation over the highway cycle, and then movement over congested streets to a parking location.

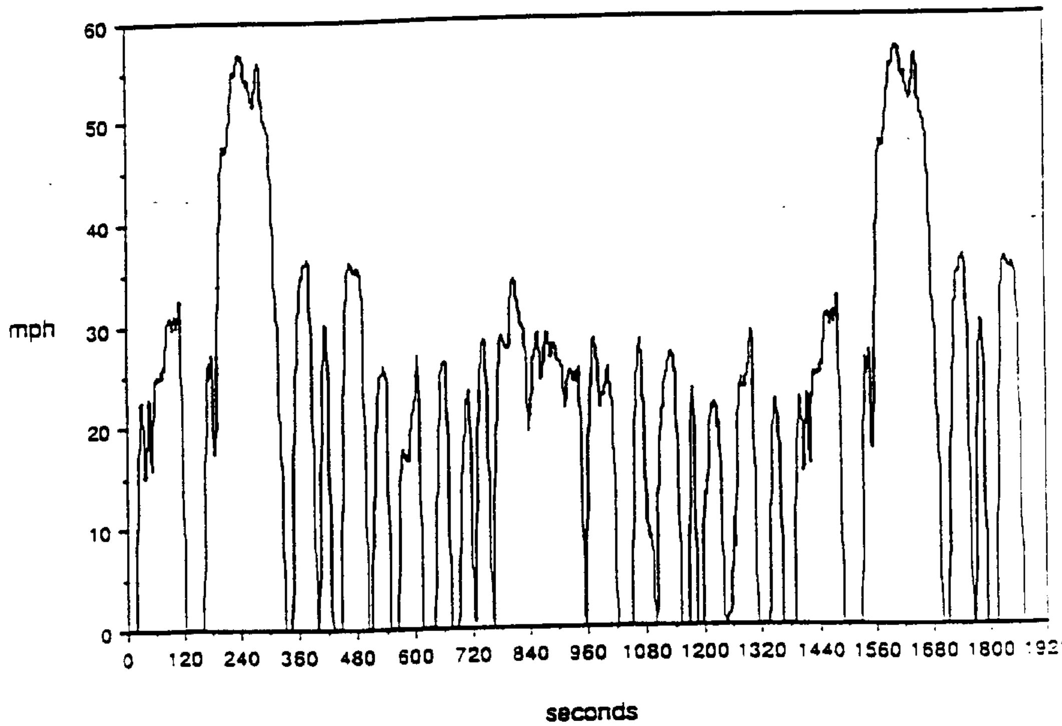


FIGURE 5. - EPA FTP DRIVING SCHEDULE

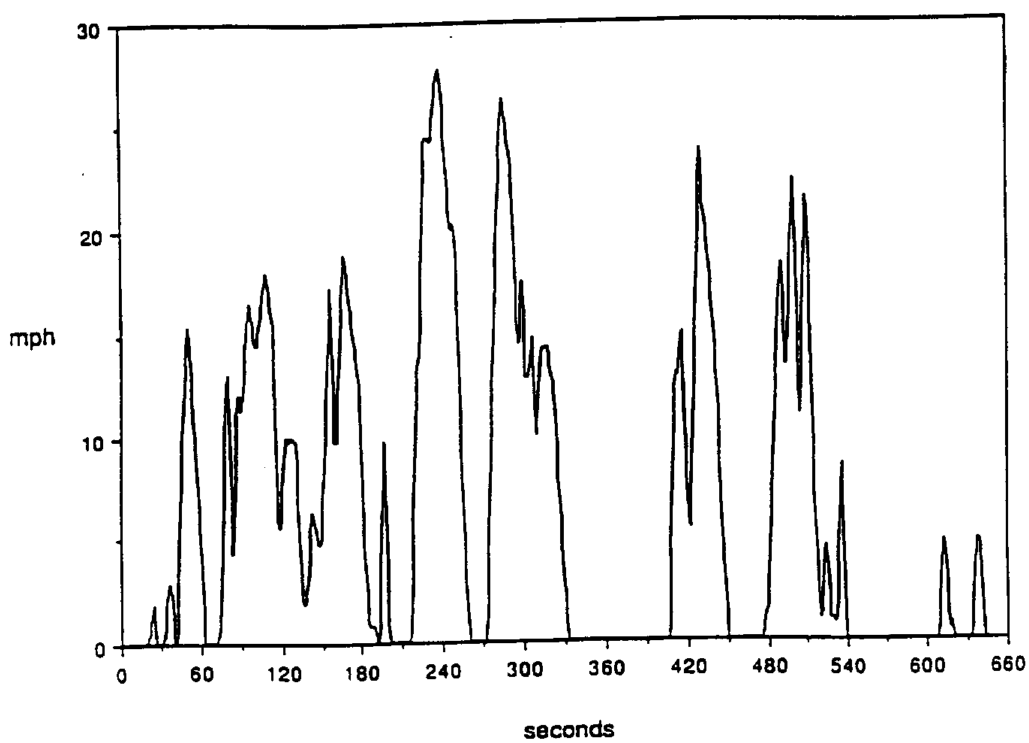


FIGURE 6. - LOW-SPEED CYCLE DRIVING SCHEDULE

Preconditioning Sequence

The vehicles were prepared for each running loss test as follows:

1. Replace the fuel in the fuel tank with test fuel to a 40% fill level. The fuel temperature was between 55° and 60°F when added to the fuel tank.

2. Condition the vehicle (and fuel) by driving it through one LA-4 cycle at a 75°F ambient temperature.

3. Soak the vehicle at the appropriate running loss test temperature (80° or 95°F) for a period of 12 to 24 hours.

FACILITIES AND TEST EQUIPMENT

DYNAMOMETER TEST CELL

The NIPER fuels/engines research chassis dynamometer test cell and related equipment used for this program was designed to test vehicles and fuels as a total system over a wide range of ambient conditions using the FTP employed by the EPA for certification of new vehicles.

Considerable care was exercised in the design of the NIPER test facility with regard to controlling the influence of contaminating hydrocarbons in the test facility. The NIPER test facility completely isolated the CVS dilution air from the vehicle test area. In addition, the dilution air was filtered, dried, cooled, humidified, and reheated prior to usage by the CVS system. This technique allowed repeatable measurements to be made independent of the ambient test conditions. It increased the quality of the data and allows direct comparison of the test results. An illustration of a typical test cycle using this facility is shown in Figure 7.

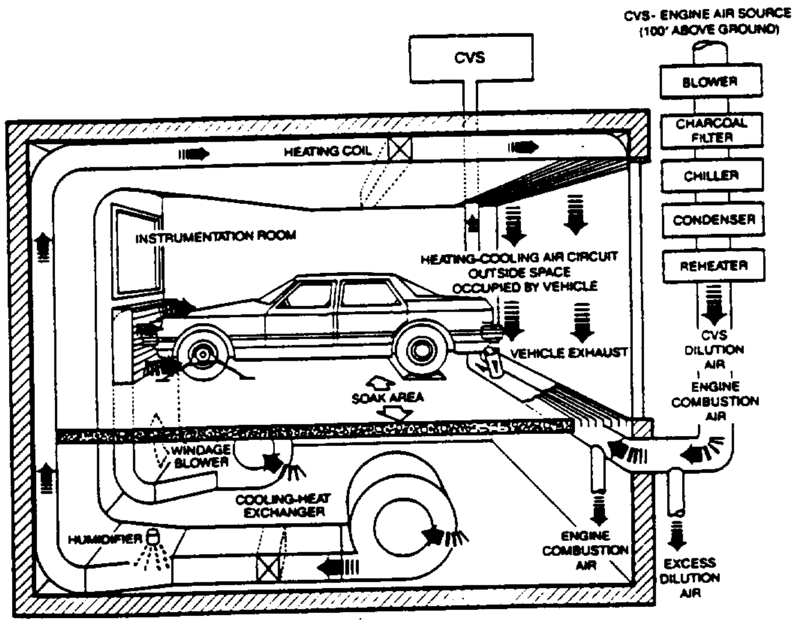


FIGURE 7. - CONTROLLED AMBIENT CHASSIS DYNAMOMETER TEST FACILITY

The dynamometer test cell has the following specifications:

Test vehicles	under driver control
Controlled Test cell temperature range	20° to 110°F
Wind tunnel	synchronized to vehicle speed to 60 mph
Vehicle simulation weight	1750 to 9625 lb in 25-lb increments
Maximum power, speed	50 hp, 22 to 60 mph
Roll diameter	8.65 inches
Maximum speed	90 mph
Maximum axle weight	4,000 pounds
Maximum vehicle track	77.75 inches

The dynamometer was controlled in real-time by a Hewlett-Packard 21MX computer which was dedicated to chassis dynamometer data acquisition. As part of the test equipment, the test cell was equipped with a complete bank of analytical instruments for routine emissions measurements including:

Emission	Technique for Measurement
CO	nondispersive infrared
CO_2	nondispersive infrared
NO	chemiluminescence
NO_2	chemiluminescence
C	flame ionization detector
O_2	polarographic detection
Fuel economy	volumetric and carbon balance

Exhaust sampling was accomplished using a commercial CVS critical flow sampling system. The system provides for the EPA-specified three-bag FTP and highway test procedure by sending a portion of the raw sample flow into a dilution tunnel. In the tunnel, the exhaust was diluted with control air and was well mixed prior to gas sampling. Measurements at critical locations precisely determined the gas quantity and the component temperatures.

In addition, on-line data acquisition was provided with the mass of each emission determined at the rate of five samples per second and accumulated for diagnostic purposes.

The NIPER exhaust emissions test facility consisted of a set of controls that allows for the collection of accurate and repeatable data. The CVS system source of air came from a specially designed air intake stack that was approximately 50 feet above the ground. This provided a source of clean air that did not contain excessive hydrocarbons or present a high background for the tests and measurements. The air was propelled by a blower through a charcoal filter, then chilled, and the water was removed with a condenser to a controlled dew point of approximately 0°F. The air was reheated to the test temperature with controls on excess dilution air and engine combustion air flow. The vehicle exhaust was mixed with this cleaned air, and the air-exhaust mixture was then taken to instrumentation for analysis.

Inside the test cell, the air was provided in an envelope around the vehicle engine with a large blower. This air was humidified to specified levels and then heated or cooled as necessary for the test conditions. The important point is that the heating-cooling air circuit was outside the space occupied by the vehicle engine and does not perturb the test results.

Additional air was provided by a windage blower that directed air to the front of the vehicle through an expandable duct system which was placed close to the vehicle radiator. This windage blower was controlled by the vehicle speed, based on the speed of the wheels on the dynamometer rolls. Comparison tests of on-the-road underhood temperatures and underhood dynamometer temperatures have provided a good match to the engine compartment temperatures.

The test cell also contained a large thermal mass that moderates the heat radiated by the engine and vehicle during operation. This system has demonstrated the capability to maintain 20° to 110° ± 3°F test cell temperatures during all tested driving cycles.

FUELS STORAGE AND BLENDING

NIPER used a fuels storage and blending facility that has state-of-the-art fuels preparation equipment. This 5000-square-foot building was constructed to allow fuels to be stored at temperatures that will maintain fuel quality. Temperatures of 45°, 50°, 55°, and 60°F are maintained in separate rooms in the building. The building also has a blending facility where fuels can be prepared using the available feedstocks that are stored in the building. The use of this facility provided assurance the fuels remained in consistent condition throughout the test.

QUALITY CONTROL DYNAMOMETER TEST CELL

Calibration procedures for all FTP tasks were followed as described in the Code of Federal Regulations, 40 CFR 86 a & b and EPA FTP test procedures. The procedures are described in ASTM D-323 (RVP) and ASTM D4052 (relative density). Fuel calibration procedures were performed as described in detail in the Annual Book of ASTM Standards.

The QC check objectives and frequency are illustrated in the following table:

PARAMETER	QC CHECK PROCEDURE	FREQUENCY
Dew point Hygrometer zero & span	EG&G procedure	daily
Barometer zero & span	W. H. Curtain procedure	daily
Driver's aid performance	zero, span, handling & response	daily
Dilution air background level	<10 ppmC <10 ppm CO	daily
Sufficient cylinder pressure (analyzer span & zero gas)	NO_x gas cyl press >250 psi other gas cyl press >100 psi	daily
Torque cell zero & span	zero ± 0.2 span ± 0.5	daily
HC bag hang-up check	HC bag zero air <1 ppmC	daily
Analyzer flows & pressures	set to normal values	daily
Leak check sample bags & lines	evacuate each bag plug and evacuate sample lines	daily
Inspect exhaust boots	check for cracks & leaks	daily
Fuel vapor pressure RVP Herzog procedure	ASTM procedure	after blending
Fuel relative density Mettler procedure	ASTM procedure before use	after blending
Fuel octane level	ASTM procedure before use	after blending
Fuel oxygenate level	NIPER procedures before use	after blending
CVS propane recovery NBS referenced gases	CFR/EPA procedures	weekly
Dyno coastdown check	CFR/EPA procedures	weekly
NO_x gas analyzer check (converter efficiency)	CFR/EPA procedures NBS referenced gases	weekly
Leak check CVS sample system	plug and evacuate sample lines	monthly

The calibration objectives and frequency are:

PARAMETER	CALIBRATION METHOD	FREQUENCY	REFERENCE
GC calibration	NIPER procedures	daily	NIPER manuals
GC calibration gas (verification traceable to within ± 1% or NBS gas standards)	NIPER procedures	monthly	NIPER manuals
CO, CO_2, HC, NO_x (gas analyzer calibration)	CFR/EPA procedures NBS referenced gas	monthly	40 CFR 86.116,121-124 Beckman manuals
Gas analyzer calibration gas (verification traceable to within ± 1% of NBS gas standards)	CFR/EPA procedures	monthly	40 CFR 86.114
CFV (cal. coeff. k value)	CFR/EPA procedures	monthly	40 CFR 86.116,119
Dynamometer system	CFR/EPA procedures	monthly	40 CFR 86.116,118
CVS system	CFR/EPA procedures	yearly	40 CFR 86.116-126

NIPER ANALYTICAL EQUIPMENT LIST

GAS ANALYZERS		OPERATING RANGE		CALIBRATION GASES*
Beckman 865 gas analyzer	Low CO	1	0-1000 ppm	900 ppm
		2	0-500	450
		3	0-100	90
Beckman 865 gas analyzer	High CO	1	0-5.0%	4.50 %
		2	0-1.0	0.90
		3	0-0.5	0.45
Beckman 864 gas analyzer	CO_2	1	0-10.0%	9.00 %
		2	0.5.0	4.50
		3	0.3.0	2.70
Beckman 402 gas analyzer	HC	25	0-2500 ppmC	2250 ppmC
		10	0-1000	900
		1	0-100	90
Beckman 400 gas analyzer	HC	100	0-1000 ppmC	900 ppmC
		25	0-250	225
		10	0-100	90
Beckman 951H gas analyzer	NO/NO_x	100	0-1000 ppm	900 ppm
		25	0-250	900
		10	0-100	90

*Each analyzer is calibrated on the normally used operating ranges noted above with calibration and span gases traceable within ± 1% NBS gas standards (10).

QUALITY CONTROL RUNNING LOSS EMISSIONS MEASUREMENT DEVICE

After the Point Source Evaporative Measurement Equipment was fabricated, initial measurements were made to determine the effectiveness of its performance. The components were selected based on their accuracy and reliability. Each component was examined for the degree of experimental error and found to have a minimum amount. The fabricated assembly was also examined to determine the accuracy and repeatability of its performance. The result was that essentially all of the hydrocarbon vapors that were measured were measured by the fabricated equipment based on a total vapor distribution analysis. After the initial measurements on vehicles, some of the values that were obtained during the test were questioned by NIPER staff personnel. To resolve the questions, another calibration was made of the system. The equipment repeated its earlier calibration of 99 ± 3% recovery of the hydrocarbon emissions.

Based on the calibrations and the repeatability of the measurements, the fabricated equipment was determined to be sufficiently accurate to determine the amount of running loss emissions by location from the vehicle. While the unit was used in this work for running loss emissions, it could also measure evaporative emissions during SHED tests to determine location of emissions.

RESULTS AND CONCLUSIONS

RESULTS

Before the running loss tests were conducted, the exhaust and evaporative emissions of both vehicles were determined over the FTP. The results of those tests are given in Table 3. The exhaust emission levels indicate some deteriation of the exhaust emission control system for the 1985 Buick (Car 505) and, to a lesser extent, for the 1987 Chevrolet (Car 712). The evaporative emission levels were well within the standard for both vehicles.

TABLE 3. - FTP TEST RESULTS

FUEL:	7.0 RVP	9.0 RVP	7.0 RVP	9.0 RVP
Exhaust Emissions	Buick		Chevrolet	
HC, gpm	0.53	0.55	0.34	0.29
CO, gpm	9.6	10.0	2.1	2.0
NO_x, gpm	1.02	0.70	0.81	0.89
MPG	19.6	20.0	17.5	18.3
Evaporative Emissions				
Diurnal, g	0.29	0.69	0.24	0.19
Hot soak, g	0.07	0.11	0.43	0.33
Total, g	0.36	0.70	0.67	0.52

The experimental design and subsequent results are summarized in Tables 4 and 5. The detailed test results are given in Tables 9 and 10. The running losses from the 1985 Buick were very low in all tests. The maximum was less than 1 gram of hydrocarbons per hour. Background air levels did not show any significant changes over the duration of each test, indicating that there were no major evaporative emissions sources that were not sampled. The only detectable running losses were from the charcoal canister.

The running loss emissions from the 1987 Chevrolet were about an order of magnitude greater than those from the fuel-injected vehicle. In many cases, the running losses were greater than the exhaust hydrocarbon emission rates over the FTP. The variability of the repeated tests with this vehicle is probably due to differences in the canister loading at the start of the test and to small differences in fuel tank temperature. Examination of data from other experiments indicates that some vehicles have fuel tank temperature sensitive emissions where very large changes in emissions can occur in temperature variations as small as 2°F. Diurnal emissions and running losses are significantly influenced by these variables.

The main source of running loss emission was the charcoal canister. In preliminary testing the area around the carburetor and the intake to the air cleaner were sampled to determine if these were sources of running losses. Neither was found to be a source of any measurable hydrocarbon emissions. This was not unexpected as the carburetor float bowl is vented to the charcoal canister. Also, since the engine was running during the entire running loss test, air was always flowing into the intake system, thereby preventing the escape of fuel vapor.

The most likely cause of the differences in running losses for the two vehicles is differences in canister purging. Purge rate and engine operating modes at which purging occurs are functions of their effects on drivability. With the sophisticated fuel-air management controls of an electronic fuel-injection system, it should be possible to maintain canister purging over a large portion of a driving schedule without sacrifice to drivability.

TABLE 4. - RESULTS OF RUNNING LOSSES EXPERIMENTS
1985 BUICK REGAL, CAR NO. 505

RVP (psi)	Initial Fuel Temperature °F	Fuel Temperature Rise °F	Cycle	Distance	HC g/mi	HC g/hr
9.0	95	25	LA-4	14.90	0.007	0.13
9.0	95	26	MLSC	9.75	0.056	0.76
9.0	80	26	LA-4	14.90	0.007	0.13
9.0	80	20	MLSC	9.75	0.003	0.04
7.0	95	15	LA-4	14.90	0.004	0.08
7.0	94	17	MLSC	9.75	0.007	0.09
7.0	80	28	LA-4	14.90	0.002	0.03
7.0	80	24	MLSC	9.75	0.002	0.03

TABLE 5. - RESULTS OF RUNNING LOSS EXPERIMENTS
1987 CHEVROLET CAPRICE, CAR NO. 712

RVP (psi)	Initial Fuel Temperature °F	Fuel Temperature Rise °F	Cycle	Distance	HC g/mi	HC g/hr
9.0	80	22	LA-4	14.90	0.31	6.1
9.0	80	24	MLSC	9.75	0.44	5.6
7.0	80	15	LA-4	14.90	0.10	1.9
7.0	80	14	MLSC	9.75	0.09	1.2
7.0	95	27	LA-4	14.90	0.29	5.7
7.0	95	26	MLSC	9.75	0.92	12.1
9.0	97	15	LA-4	14.90	0.10	1.9
9.0	96	15	MLSC	9.75	0.47	6.2
9.0	95	16	LA-4	14.90	0.51	10.0
9.0	81	16	LA-4	14.90	0.08	1.5

STATISTICAL DISCUSSION

A simple statistical analysis of the results was performed to evaluate the relative significance of the independent variables (RVP, initial ambient temperature, fuel tank temperature rise, and driving cycle). The results of this multiple regression analysis are shown in Tables 6 and 7. These show that the effect of RVP on running losses was not statistically significant for either car. Also, driving cycle had little effect on the time rate of running losses. Examination of the emissions as grams per mile indicates that cycle does have a moderately significant effect. Initial fuel temperature and fuel tank temperature rise had comparable statistical significance for the 1987 Chevrolet.

A simple model was used to predict vapor generation rates for each test. The prediction equation is

$$\Delta m/\Delta t = [MVP_m / R(B-P)_m] \; [\Delta\{(B-P)/T\}]/\Delta t$$

Where:

Δm = mass of hydrocarbon vapor generated
Δt = time difference
M = molecular weight of hydrocarbon
V = volume of vapor space
P_m = mean vapor pressure over temperature range
R = universal gas constant
B = total pressure in fuel tank (essentially barometric pressure)
P = vapor pressure of hydrocarbons
$(B-P)_m$ = mean tank to hydrocarbon pressure difference

The predicted vapor generation rates are given in Table 8. The actual results are plotted against the predicted vapor generated in Figures 8 and 9. The trends are directional as expected, although the least square fits are not good. This is not surprising as the losses from the canister should occur only when, simultaneously, vapor is being generated and the canister is saturated and the purge system is not activated. The most direct way in which running losses can be eliminated or minimized is through a canister purge system which is active for a large portion of the driving period. This would also ensure that the canister is not saturated upon engine shut-down, thereby controlling diurnal and hot soak losses.

TABLE 6. - REGRESSION ANALYSIS
1985 BUICK REGAL, CAR NO. 505

Multiple Regression Y 1 :HC-G/H 4 X variables

Count:	R:	R-squared:	Adj. R-squared:	RMS Residual:
8	.78	.609	.088	.234

Analysis of Variance Table

Source	DF:	Sum Squares:	Mean Square:	F-test:
REGRESSION	4	.257	.064	1.168
RESIDUAL	3	.165	.055	p = .4679
TOTAL	7	.421		

No Residual Statistics Computed

Note: 8 cases deleted with missing values.

Multiple Regression Y 1 :HC-G/H 4 X variables

Beta Coefficient Table

Variable:	Coefficient:	Std. Err.:	Std. Coeff.:	t-Value:	Probability:
INTERCEPT	-.344				
HI RVP	.055	.234	.12	.235	.8295
HI TO	.36	.234	.784	1.536	.2221
HI dT	.305	.331	.576	.92	.4253
LSSC5	.138	.166	.3	.83	.4675

Multiple Regression Y 1 :HC-G/H 4 X variables

Confidence Intervals and Partial F Table

Variable:	95% Lower:	95% Upper:	90% Lower:	90% Upper:	Partial F:
INTERCEPT					
HI RVP	-.691	.801	-.496	.606	.055
HI TO	-.386	1.106	-.191	.911	2.36
HI dT	-.75	1.36	-.475	1.085	.847
LSSC5	-.39	.665	-.252	.527	.689

TABLE 7. - REGRESSION ANALYSIS
1987 CHEVROLET CAPRICE, CAR NO. 712

Multiple Regression Y 1 :HC-G/H 4 X variables

Count:	R:	R-squared:	Adj. R-squared:	RMS Residual:
10	.775	.601	.281	3.152

Analysis of Variance Table

Source	DF:	Sum Squares:	Mean Square:	F-test:
REGRESSION	4	74.754	18.689	1.881
RESIDUAL	5	49.687	9.937	p = .252
TOTAL	9	124.441		

No Residual Statistics Computed

Note: 6 cases deleted with missing values.

Multiple Regression Y 1 :HC-G/H 4 X variables

Beta Coefficient Table

Variable:	Coefficient:	Std. Err.:	Std. Coeff.:	t-Value:	Probability:
INTERCEPT	.874				
HI RVP	.769	2.085	.107	.369	.7275
HI TO	3.94	1.994	.558	1.976	.1051
HI dT	3.531	2.085	.49	1.694	.1511
LSSC5	1.281	2.085	.178	.614	.5658

Multiple Regression Y 1 :HC-G/H 4 X variables

Confidence Intervals and Partial F Table

Variable:	95% Lower:	95% Upper:	90% Lower:	90% Upper:	Partial F:
INTERCEPT					
HI RVP	-4.592	6.129	-3.433	4.971	.136
HI TO	-1.186	9.066	-.078	7.958	3.905
HI dT	-1.829	8.892	-.671	7.733	2.868
LSSC5	-4.079	6.642	-2.921	5.483	.378

TABLE 8. - PREDICTED VAPOR GENERATION RATES, G/HR

Fuel RVP	Initial Temp, °F	Temperature Rise, °F	Vapor Generation, g/hr Car 505	Vapor Generation, g/hr Car 712
7	80	15	8	14
7	80	25	16	30
7	95	15	14	26
7	95	25	33	62
9	80	15	16	29
9	80	25	33	59
9	95	15	32	59
9	95	25	64	119

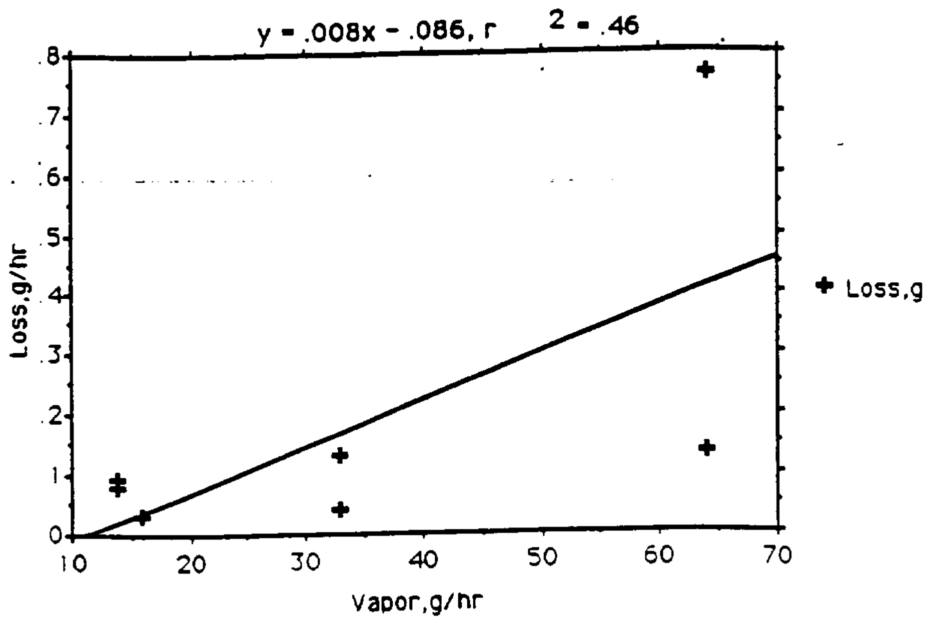


FIGURE 8. - RUNNING LOSSES VS. PREDICTED VAPOR GENERATION RATES
1985 BUICK REGAL, CAR NO. 505

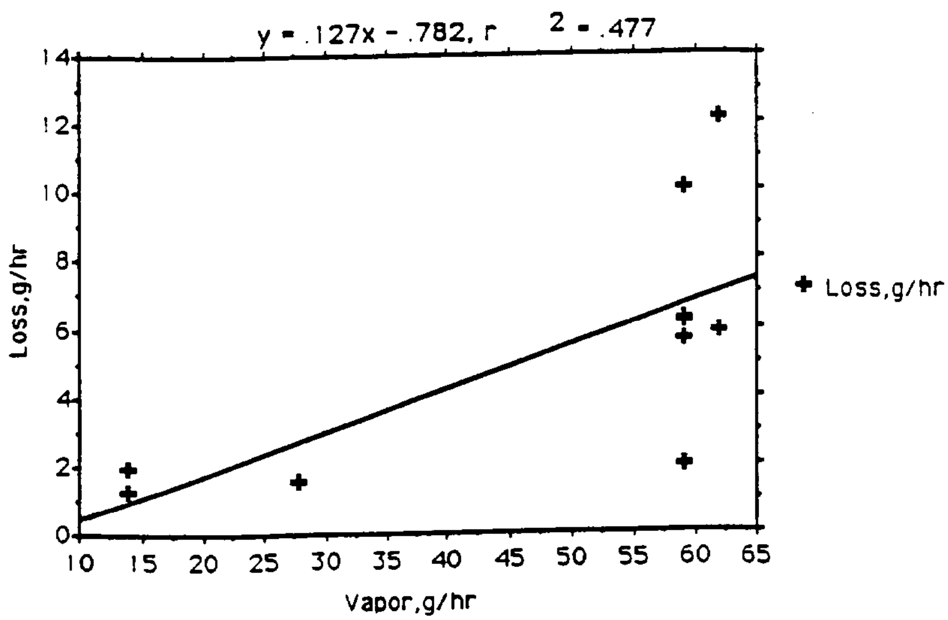


FIGURE 9. - RUNNING LOSSES VS. PREDICTED VAPOR GENERATION RATES
1987 CHEVROLET CAPRICE, CAR NO. 712

TABLE 9. - 1985 BUICK RUNNING LOSS TESTS

CAR 505	FUEL				FUEL	HC (G)	HC (G)	BKGD
TEST NO.	RVP	CYCLE	PHASE	TIME	TEMP	CANISTER	FUEL CAP	PPMC
1	9	LA4	0	0	95			
			1	1372	112	0.04	0.00	7.5
			2	2744	120	0.06	0.00	8.9
2	9	SC	0	0	95			
			1	647	102	0.15	0.00	8.7
			2	2019	116	0.28	0.00	7.3
			3	2666	121	0.12	0.00	8.4
3	9	LA4	0	0	80			
			1	1372	93	0.08	0.00	11.3
			2	2744	106	0.02	0.00	9.9
4	9	SC	0	0	80			
			1	647	84	0.02	0.00	10.0
			2	2019	96	0.01	0.00	9.0
			3	2666	100	0.01	0.00	7.0
5	7	LA4	0	0	95			
			1	1372	105	0.05	0.00	8.8
			2	2744	110	0.01	0.00	6.9
6	7	SC	0	0	94			
			1	647	97	0.04	0.00	6.4
			2	2019	107	0.02	0.00	8.7
			3	2666	111	0.01	0.00	9.6
7	7	LA4	0	0	80			
			1	1372	98	0.02	0.00	7.7
			2	2744	108	0.01	0.00	7.7
8	7	SC	0	0	80			
			1	647	88	0.01	0.00	9.4
			2	2019	103	0.01	0.00	7.3
			3	2666	104	0.00	0.00	7.7

TABLE 10. - 1987 CHEVROLET RUNNING LOSS TESTS

CAR 712								
	FUEL				FUEL	HC (G)	HC (G)	BKGD
TEST NO.	RVP	CYCLE	PHASE	TIME	TEMP	CANISTER	FUEL CAP	PPMC
1	9	LA4	0	0	80			
			1	1372	94	4.35	0.00	14.5
			2	2744	102	0.25	0.01	12.5
2	9	SC	0	0	80			
			1	647	86	3.04	0.03	24.8
			2	2019	101	0.32	0.10	13.4
			3	2666	104	0.72	0.05	16.4
3	7	LA4	0	0	80			
			1	1372	88	1.31	0.05	14.2
			2	2744	95	0.03	0.06	10.9
4	7	SC	0	0	80			
			1	647	83	0.72	0.01	26.4
			2	2019	91	0.07	0.03	19.2
			3	2666	94	0.01	0.02	15.5
5	7	LA4	0	0	95			
			1	1372	105	3.25	0.02	34.5
			2	2744	122	1.10	0.04	22.4
6	7	SC	0	0	95			
			1	647	99	6.03	0.08	29.8
			2	2019	117	0.87	0.24	25.2
			3	2666	121	1.62	0.13	27.2
7	9	LA4	0	0	97			
			1	1372	102	0.44	0.35	13.6
			2	2744	112	0.16	0.49	11.6
8	9	SC	0	0	96			
			1	647	97	2.76	0.11	9.1
			2	2019	110	0.34	0.34	14.7
			3	2666	111	0.88	0.16	22.2
9	9	LA4	0	0	95			
			1	1372	105	7.12	0.22	31.8
			2	2744	111	0.00	0.25	22.8
10	9	LA4	0	0	81			
			1	1372	90	0.89	0.10	13.5
			2	2744	97	0.00	0.18	10.3

CONCLUSIONS

Running losses were determined for two vehicles operating over various conditions for a total of 18 tests. The independent variables were fuel vapor pressure, ambient temperature, fuel temperature rise, and driving cycle. A sampling/analysis system based on constant-volume-sampling was designed and built for measurement of running losses from specific sources in/on the vehicles. The results were:

1. The major source of running losses was the charcoal canister. Under some conditions hydrocarbon vapor escaped from the purge air vent.

2. There were marked differences in the amount of running losses between the two vehicles. Emission rates from a carbureted 1987 vehicle were about 10 times greater than those from a fuel-injected 1985 vehicle. The difference is probably due to different canister purge strategies.

3. Analysis of the results indicates that fuel vapor pressure did not have a statistically significant effect on running losses. The Reid Vapor Pressure of the two gasolines used in this study was 7.0 and 9.0 psi.

4. The effects of ambient temperature and fuel temperature rise had the greatest statistical significance. The initial fuel temperature was equal to the ambient temperature.

5. Driving cycle had little, if any, effect on the time rate of running losses. On the basis of grams per mile, running losses were somewhat greater for a low-speed driving cycle.

6. A simple model was used to predict vapor generation from the fuel tank. The results of the running loss experiments generally showed the same trends as the vapor generation predictions.

7. The sampling system collected essentially all of the running losses as evidenced by little or no change in the hydrocarbon levels in the dynamometer test cell.

8. The running loss emissions in some vehicles is strongly dependent on fuel tank temperature where a large variation in emissions can occur with small fuel tank temperature changes.

NECESSITY FOR ADDITIONAL INVESTIGATIONS

The Point Source Running Loss Emissions Measurement Equipment used for this work has shown to be accurate and has the potential to provide information that can be of value to state, federal, and industrial groups. A fleet of representative vehicles should be examined with this technique to determine the actions necessary to properly control running loss emissions. NIPER is willing to use its (company funded and patent applied) process to obtain these results.

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GLOSSARY

Included in this list of glossary words are terms as they are used in this report. The purpose of this list of definitions is to establish a common reference of terms that may not be familiar to all readers.

Aromatics - cyclic chained hydrocarbons or derivatives.

Background Air Levels - contamination level of local ambient air.

Charcoal Canister - container filled with charcoal to collect hydrocarbon vapors.

Charcoal Canister Purging - elimination of hydrocarbon vapors collected in charcoal canister.

Constant Volume Sampling (CVS) - method for sampling gaseous emissions. Typically denotes mixing emissions with ambient air to a constant flow and sampling the total flow.

Dilution Air - ambient air used as makeup for constant volume sampling.

Distillation - a process of driving gas from liquids or solids by heating and condensing to liquid products.

Diurnal Heat Build - refers to temperature heating profile of fuel tank used in performing evaporative emissions testing for vehicles.

Drivability - a measure of vehicle operation referring to performance of vehicle.

Dynamometer - a device used to absorb and dissipate power.

Evaporative Emissions - hydrocarbon vapors expelled from a test unit due to evaporation.

Factorial Design - experimental design that includes equal investigation of each element to be investigated.

Federal Test Procedure (FTP) - test procedure specified by the U.S. EPA for certifying vehicles for emissions control.

Florescence Indicator Absorbance (FIA) - ASTM procedure for determining hydrocarbon classifications profiles.

Fuel Volatility - a measure of the ability of fuel to change from a liquid or solid state to a gaseous state.

Hot Soak - refers to a portion of vehicle testing in which the engine is turned off for a period of time.

Hydrocarbons Emissions - in this context refers to unburned or partially oxidized fuel hydrocarbon emissions from a vehicle.

Indolene - trade name describing a reference fuel used for certifying light-duty gasoline vehicles.

LA-4 - refers to a driving cycle used for certifying light-duty gasoline vehicles.

Low-Speed Cycle (LSC) - refers to a driving cycle used for measuring emissions from light-duty gasoline vehicles.

Olefins - a hydrocarbon classification referring to an unsaturated straight chained structure (CnH2n).

Oxides of Nitrogen - compounds consisting of nitrogen and oxygen; may be an emission product of engine operations.

Ozone - an allotrophic triatomic form of oxygen.

Point Source Evaporative Measurement Equipment - refers to a method for measuring vehicular evaporative emissions at various sources.

Reid Vapor Pressure (RVP) - an ASTM procedure for determining the propensity of a liquid to change to a gaseous state.

Running Loss Evaporative Emissions - refers to vehicular emissions due to fuel evaporation as the vehicle is in operation.

Saturates - refers to hydrocarbon structure which contain no multiple bonds.

Sealed Housing for Evaporative Determination (SHED) - refers to an enclosure specified for enclosing a vehicle and containing all evaporative hydrocarbon emissions for measurement.

Tedlar Bag - trade name specifying material used to construct containers to collect vehicular exhaust.

Temperature Soak - refers to temperature profile of vehicle during engine-off operation.

Thermocouple - device that provides electrical output proportional to temperature.

Three Bag FTP - refers to the test procedure specified by EPA for light-duty vehicle certification in which three distinct sample bags are collected.

Vehicle In-Use Profile - the use on duty cycle a vehicle receives.

Windage Blower - refers to windage supplied to the vehicle frontage during testing operations.