# Investigation of Passenger Car Refueling Losses

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Scott Project #2608

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Scott Research Labs., Inc.
Project #2608

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## ABSTRACT

This paper reports the results of a pilot test program and field survey of hydrocarbon losses from passenger car refueling operations. The objectives of the test program were to identify and measure lost hydrocarbon weight at typical conditions. The survey objective was to determine the frequency of losses in the service station environment.

Overall refueling losses were segragated as to displaced vapor, liquid spill and nozzle drip losses. Each of these was measured in the laboratory and observed for frequency at service stations. The scope of this investigation is limited to the results of 285 laboratory tests and 754 survey observations.

Significant factors contributing to individual and overall refueling losses are examined and discussed.

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# 1. INTRODUCTION

## 1.1 CONTRACT BACKGROUND

The automobile has long been recognized as a major source of the hydrocarbons in the air over our cities. Emissions of hydrocarbons from automobiles arise primarily from incomplete burning of gasoline within the engine's combustion chamber, from the escape of combustion gases which blow by the piston rings and from evaporation of gasoline from the vehicle's fuel system. While accurate figures are not available, a typical automobile with no emission control devices will emit about 500 pounds of hydrocarbons a year. Approximately 60% of this weight is emitted in the exhaust gases, 25% as blowby and 15% as evaporative emissions. Emission control devices which are presently required on all new automobiles sold in the United States result in substantial reductions in exhaust gas and blowby hydrocarbons. Proposed future control of vehicle evaporation losses should result in meaningful reductions in hydrocarbon losses from this source.

One area of vehicle losses which has received little attention is that of passenger car refueling losses. These losses include:

1. Displaced fuel tank vapors
2. Entrained fuel droplets in the displaced vapors
3. Liquid spillage
4. Nozzle drippage

1.1 CONTRACT BACKGROUND - continued

On March 26, 1969, Scott Research Laboratories, Inc., was awarded a contract by the Coordinating Research Council, Inc., and the Department of Health, Education and Welfare to conduct a Study of Passenger Car Refueling Losses.

The general objective of this program was to investigate the magnitude and frequency of hydrocarbon losses due to refueling of typical passenger cars.

The specific objectives are listed below :

- Measure hydrocarbon losses from splash and subsurface filling, tank spillage and nozzle drip.
- Gather data relative to frequency of hydrocarbon losses above.
- Classify data according to fuel tank configuration and calculate probability of various losses for each configuration.

# 2. PROGRAM DESCRIPTION

The investigation was organized in two major tasks:

- Experimental Test Program
- Refueling Operations Survey

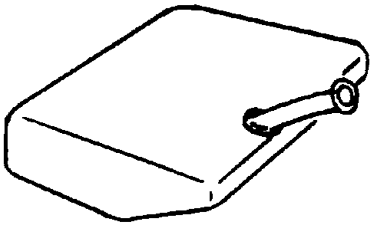
## 2.1 PLANNING AND DESIGN

In order to obtain a comprehensive assessment of passenger car refueling losses during a limited period, this program was designed to include the maximum number of variables in the fewest number of experiments.

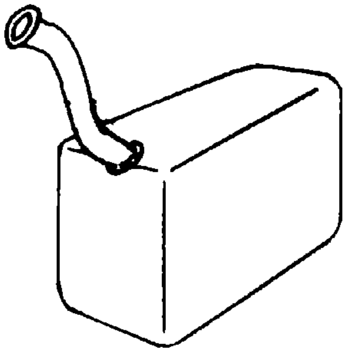
Information necessary to plan an effective test program and a pertinent survey was obtained by researching existing statistical papers, performing local measurements and interviewing equipment representatives.

From a previous investigation of an associated subject, six significantly different fuel tank configurations were identified and the relative distribution weight of each in the total population was estimated. These tanks are represented in Figure 2.1. Differentiation was originally based on external shape alone. Subsequent test results in this program have shown significant differences in the refueling loss liability between ostensibly identical tanks. Therefore, the design details of all tanks studied have been tabulated in Table 4.3 and test results are restricted to those subject tanks only. However, survey results are organized by the original six tank configurations.

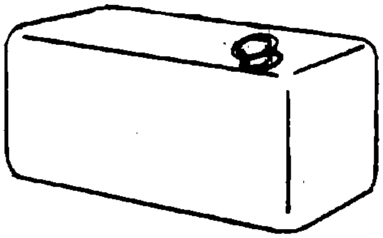
Gasoline temperature measurements were made in service station underground storage tanks in order to establish the temperature to which



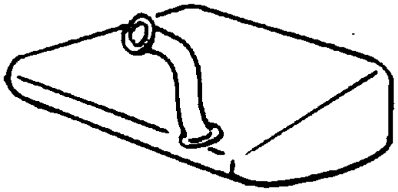
Type 1
Type 1A (with anti-spill device)



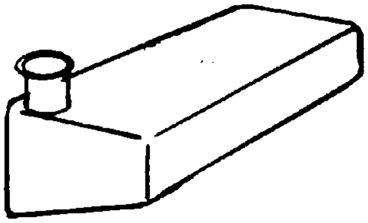
Type 2
Type 2P (pick up truck)



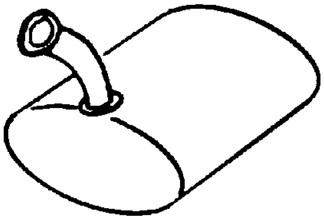
Type 3
Station Wagon



Type 4



Type 5



Type 6 (generalized)

Figure 2.1 Fuel Tank Configurations

## 2.1 PLANNING AND DESIGN - continued

laboratory gasoline would be conditioned before each test. The spread observed was between 57°F and 62°F. Therefore, 60°F was adopted as the conditioned fuel temperature throughout the subsequent test program.

Inquiries were made of local service station equipment distributors for descriptions of gasoline dispensing nozzles being employed in current refueling operations. Response to these inquires were unanimous that the automatic nozzle is almost universally installed in preference to the manual nozzle. Estimates of automatic nozzle usage and their sources are listed in Table 2.1. Therefore, testing with the manual nozzle was deleted from this investigation and the automatic nozzle was employed throughout.

## 2.2 EXPERIMENTAL TEST PROGRAM

The test program was conducted in three parts; each part addressed to a different portion of the total refueling loss:

- Displaced Vapor Loss
- Spilled Liquid Loss
- Nozzle Drip Loss

Laboratory test procedures and test data collection forms used to measure each loss are presented in Appendix 6.2.

### 2.2.1 Displaced Vapor Loss

Hydrocarbon vapor forced out of the tank as a result of and in nearly equal volume to the gallons of gasoline dispensed into the tank is

Table 2.1 Automatic Nozzle Usage Estimates

| Source | Distributor | Usage % |
|---|---|---|
| Charles E. Thomas | Tokheim | 98 |
| Shields Harper & Co. | Wayne | 98 |
| John Wood Co. | Bennett | 99.5 |

### 2.2.1 Displaced Vapor Loss - continued

classified here as the displaced vapor loss. Under certain conditions, this vapor may also carry, suspended in it, gasoline droplets which are classified here as the entrained droplet loss.

A special test apparatus, described in Section 3.3, was developed to collect these losses. Designed and built at Scott, the Mini-SHED is a reduced size SHED (an acronym for "sealed housing for evaporative determinations"). Vapor collected in the Mini-SHED was measured by the flame ionization detection method.

Displaced vapor losses were measured from the two most common fuel tank configurations. Three different unweathered RVP gasolines were dispensed into each tank at two filling rates. Both splash and subsurface fill methods were employed in an attempt to distinguish entrained droplets from displaced vapor. Tests were conducted at four ambient temperatures. Both tank liquid and vapor space temperatures were equilibrated to ambient before each test.

Eleven gallons of fuel were removed from a previously full tank before each test. After purge of background hydrocarbon vapor, the SHED was sealed with the tank inside. A measured ten gallon volume of gasoline was dispensed into the tank during each operation to obtain displaced measurements which may be compared directly.

### 2.2.2 Spilled Liquid Loss

Liquid gasoline spilled during and at the conclusion of a refueling operation as a result of "spit-back" and simple overfill is classified

2.2.2 Spilled Liquid Loss - continued

here as the spill loss. The full size SHED, described in Section 3.4, was employed, with the automobile inside, to collect this spill loss. The flame ionization detection method was used to measure spill losses.

Eight automobiles with different fuel tank configurations were subjected to refueling operations where gasoline is permitted to flow until the nozzle cuts off the flow automatically. The refueling operation is pursued for a total of three automatic nozzle cutoffs in each test. The resultant spill or spills, if any, were measured for each of the tank types. This procedure is described in the Appendix, Section 6.7, paragraph 10.7.

Each automobile was pushed into the SHED with a cold engine to minimize background evaporative losses. A further precaution was realized with a plastic bag over the carburetor inlet. After background hydrocarbons were purged, the SHED was sealed and refueling operations were performed. Any spills were permitted to evaporate in the SHED until the resultant hydrocarbon concentration reached equilibrium as observed on the Flame Ionization Detector.* Equilibrium was generally reached in 10 minutes but 30 minutes was allowed for each test. After the total gallons delivered

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* Only 75% of the measured liquid volume of nozzle drippage may be lost to the atmosphere. Preliminary calibration tests of the SHED apparatus determined that even when a previously spilled surface appeared dry, only about 75% of the liquid gasoline spill weight could be accounted for in a mass balance with the FID indication. A measured volume of propane gas was then injected into the SHED at the same conditions; 95% of the propane mass was recovered indicating that the FID response was valid.

Application of direct heat and air circulation to a gasoline spill in the SHED, drove the evaporated fraction to 90% of the original liquid volume.

### 2.2.2 Spilled Liquid Loss - continued

were recorded, a duplicate test was performed in which the same volume of gasoline was delivered to the automobile, but precautions were taken to prevent any spills. The resultant FID measurement reflects displaced vapor only and this value was subtracted from the previous total measurement of spill and unavoidable displaced vapor.

Review of early survey data permitted description of an "average" operator technique outlined here:

- Fully insert nozzle into the fill pipe at a convenient attitude. Latch trigger in second tooth and dispense gasoline until first automatic cut-off. Depress trigger to approximate second tooth position and dispense for two more automatic cut-offs.

This technique was employed throughout the spill loss procedure.

### 2.2.3 Nozzle Drip Loss

Liquid gasoline drippage measured from the nozzle immediately before and after insertion in the fill pipe is classified respectively as the pre-fill nozzle drip loss and the post-fill nozzle drip loss.

Individual funnels were fashioned for each tank configuration to collect nozzle drippage. The volume of the liquid collected was measured in a sensitive graduate. This apparatus is described in Section 3.5.

Each tank was filled and the operation was persued to three automatic nozzle cutoffs. The nozzle was immediately withdrawn and any drippage was collected. Post-fill nozzle losses were compared between the two extremes in withdrawal technique; careless (Normal) and careful (Rotated). After

### 2.2.3 Nozzle Drip Loss - continued

recording each of the above measurements, the nozzle was reinserted in the fill pipe and any resultant drippage was measured as Residual Nozzle contents (potential Pre-Fill Nozzle Drip Loss).

## 2.3 REFUELING OPERATIONS SURVEY

To supplement the quantitative data obtained in the laboratory, a survey was conducted to determine the frequency of occurrence of the various types of refueling losses. At the onset of the project, it was hoped that data obtained from both the laboratory testing and the survey could be combined in a mathematical model to predict refueling losses. However, only after evaluating the data gathered from both sources, has it become evident that there were certain variables relative to refueling losses which had not been fully understood or considered during the planning phase of the project. It was deemed impractical, at that time, to develop a mathematical model using the limited amount of data available.

The survey was conducted in two segments as described below in Sections 2.3.1 and 2.3.2. The following discussion will explain the survey procedures used. Suggestions for expanding and refining these survey techniques will be mentioned in Section 5.2.

### 2.3.1 Technician Survey

One segment of the survey consisted of sending a trained observer (technician) to various service stations in the San Bernardino, California, area. The observer divided his time between stations typical of community type service and freeway type service. Seven stations were surveyed over a four day period during this segment.

### 2.3.1 Technician Survey - continued

The surveyor approached the station manager in each instance using the guise of conducting a survey to determine "Average Number of Gallons Per Fill." A coded data sheet, shown on the following page, was used to preclude revealing the real intent of the survey (which would probably influence station attendants refueling technique).

Referring to Appendix 6.9, sufficient data were gathered for each vehicle to categorize it by fuel tank configuration and to determine the vehicle's refueling loss characteristics. The column marked "T.C." was used to enter tank configuration. Occurrence of spitback or overfill was entered in column "S," nozzle spillage before the nozzle insertion in the filler pipe in "B," and nozzle spillage after the nozzle is removed from the filler pipe in "A." In the spitback/overfill column an "X" was used to signify spitback (vigorous ejection of gasoline) occurring as the automatic nozzle cuts off while a ✓ was used to signify intentional or unintentional overfilling by the operator. Approximately 200 refueling observations were made during this segment. The observations provided data relevant to refueling losses for vehicles obtaining a full tank and vehicles refueled to less than full capacity.

### 2.3.2 Employee Survey

The second segment of the survey consisted of obtaining data relevant to the same refueling losses observed in the technician survey. A sample of the data sheet with definition of terms distributed to each

AVERAGE GALLONS OF GASOLINE
PER FILL

Freeway__________
Town__________

| Vehicle Description | | | | | Gallons | Fill? | | T.C. | S | B | A |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Make & Model | Sed. | Wag. | Tr. | | Yes | No | | | | |
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### 2.3.2 Employee Survey - continued

participant is presented on the following page. Employees of Scott Research Laboratories at the Pennsylvania, Detroit, and San Bernardino facilities, as well as employees of SAAS in Redlands, California, acted as observers over a 3-month period in this regard.

Data recorded by the participants covered the same parameters as did the technician with the following exceptions:

1) To obtain the largest sample base for determination of spitback/overfill characteristics, participants entered results only when obtaining a full tank of fuel.

2) No differentiation between spitback (at automatic nozzle cut off) and overfill (manual operation) was requested of the participants due to their diverse technical backgrounds.

Approximately 500 refueling observations were recorded during this segment.

## 2.4 DATA REDUCTION

Data forms as received from the field survey and laboratory study were subjected to preliminary treatment before being approved for computer processing.

### 2.4.1 Preliminary Treatment

Field survey forms were reviewed for completeness and data on vehicles other than passenger cars and light pick-up trucks were removed. The correct tank configuration number was attached to each observation.

## Refueling Questionnaire
## Project #2608

USE ONLY WHEN OBTAINING A FULL TANK

| | | | | | | | Section |
|---|---|---|---|---|---|---|---|
| Date | | | | | | | 1 |
| No. of Gals. | | | | | | | |
| Freeway Station | | | | | | | 2 |
| Town Station | | | | | | | |
| Car Make | | | | | | | 3 |
| Year | | | | | | | 4 |
| Sedan | | | | | | | 5 |
| Wagon | | | | | | | |
| Truck | | | | | | | |
| Operator Technique | | | | | | | |
| Spit-Back or Overfill | | | | | | | 6 |
| No Spit-Back or Overfill | | | | | | | |
| Nozzle Drip Prior to Filling | | | | | | | 7 |
| No Drip Prior to Filling | | | | | | | |
| Nozzle Drip After Filling | | | | | | | 8 |
| No Drip After Filling | | | | | | | |
| Do Not Fill in This Line | T.C. | | | | | | 9 |

INSTRUCTIONS

1. The purpose of this study is to document if and when fuel is spilled during service station filling operations.
2. Fill in Sections 1 (date and no. of gals.), 3 (car make) and 4 (year) completely each time you observe the refueling operation of your vehicle(s).
3. The questionnaire may be used for different vehicles providing Sections 1, 3, and 4 are filled out accordingly.
4. Sections 2, 5, 6, 7, and 8 require only one ✓ for each Section on any one date.
5. Do not fill in Section 9; it will be filled in by SCOTT personnel.

### 2.4.1 Preliminary Treatment - continued

Laboratory test data forms were reviewed for accuracy. Deviant measurements were suppressed and results observed under incorrect test conditions were removed.

### 2.4.2 Computer Processing

Symbols are assigned to all parameters employed in refueling loss computation.

Necessary equations to compute each loss in grams weight from observed hydrocarbon concentration were furnished to the data processing subcontractor.

# 3. TEST APPARATUS

Gasoline for all laboratory tests was dispensed by the Scott Model 403, Fuel Conditioning System. Displaced losses were measured in the Mini-SHED, spill losses in the full size SHED, and nozzle drippage in a graduate.

## 3.1 FUEL CONDITIONING SYSTEM

The Scott Model 403 Fuel Conditioning System, illustrated in Figure 3.1, is a self-contained unit equipped to store gasoline, establish and maintain it at a selected temperature, and dispense metered quantities to a vehicle. Storage capacity is 50 gallons. Heating and refrigeration are thermostatically controlled. Heater operation is automatically locked out at low gasoline level before the elements are exposed. A two-way vent valve minimizes vapor escape from the tank while providing automatic pressure relief during refill and dispensing operations.

## 3.2 FLAME IONIZATION DETECTOR

A flame ionization detector, abbreviated FID, was used to determine the concentration of displaced hydrocarbons and evaporated spill losses in the Mini-SHED and SHED, respectively. This apparatus consists of an electrometer to measure the ionization current, a burner assembly to contain the flame and controls to regulate hydrogen, air, and sample gas flow rates. The flame forms when hydrogen burns in air contains an almost negligible number of ions. Introduction of trace hydrocarbons into this flame, however, results in a complex ionization, producing a large number of ions. If the

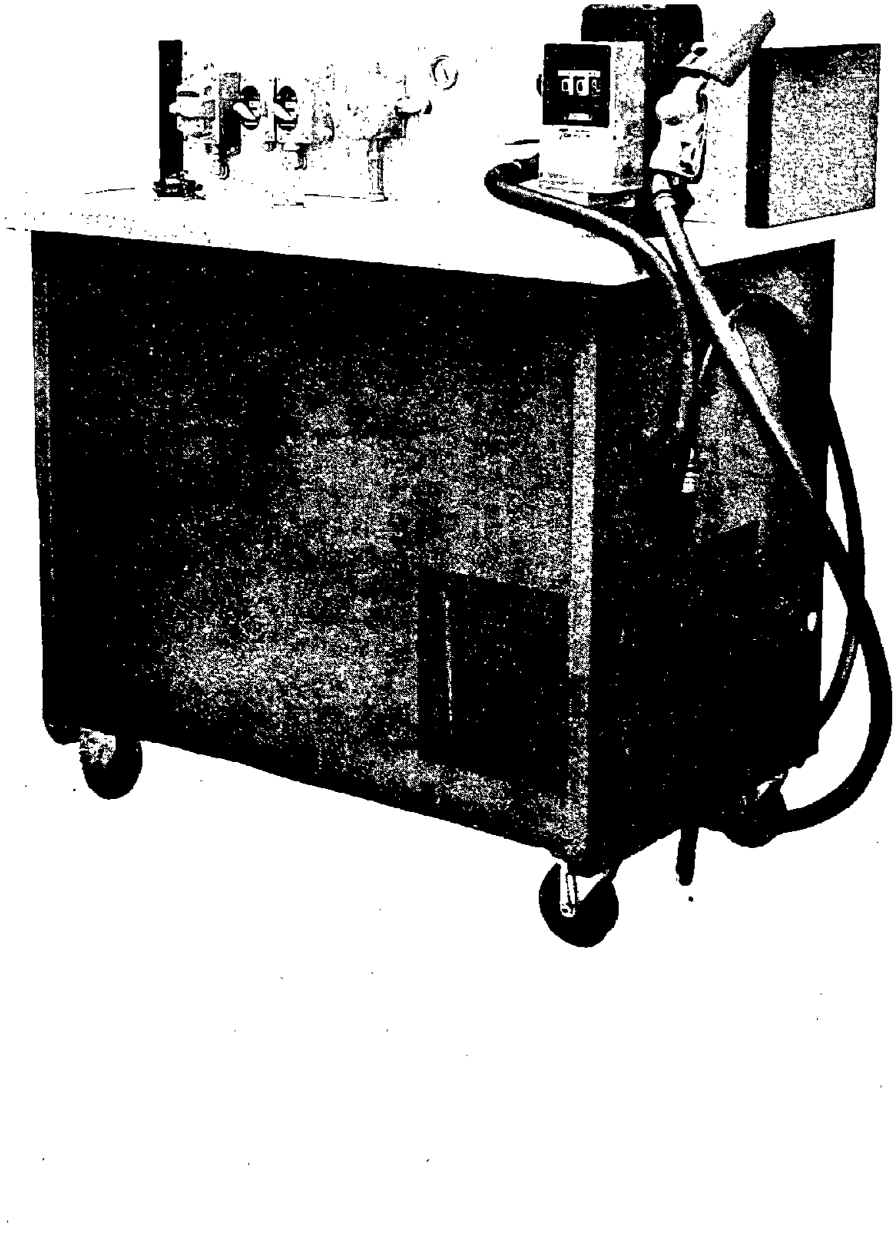


FIGURE 3.1 MODEL 403 FUEL CONDITIONING SYSTEM

### 3.2 FLAME IONIZATION DETECTOR - continued

hydrogen-air flow rates and sample injection rate are held constant, the measured ionization current is proportional to the hydrocarbon concentration of the sample.

### 3.3 MINI-SHED

An abbreviated version of the full size SHED, the Mini-SHED is designed to collect lesser hydrocarbon losses while retaining a significant concentration for FID measurements. The net volume enclosed by the nylon reinforced vinyl skin is 150.5 cubic feet with two fuel tanks inside. Gasoline is dispensed from the conditioning systems into either tank through a sealed bulkhead fitting in the aluminum floor. Temperatures of the tank liquid, vapor space, and fill pipe, dispensed gasoline and the ambient are measured with thermocouples. The absence of any enclosure pressure differential is monitored by a slant tube water manometer.

All gasoline management can be accomplished outside the apparatus with the exception of inserting the nozzle in the fill pipe and capping the tank. The actual refueling operation is simulated by reaching through vinyl glove fittings in the wall of the Mini-SHED. Hydrocarbon concentration resulting from displaced vapor is measured by FID and recorded on chart paper.

A photograph of the complete test apparatus for determination of displaced losses is shown in Figures 3.2 and 3.3. The Mini-SHED and design details are illustrated in Figure 3.4.

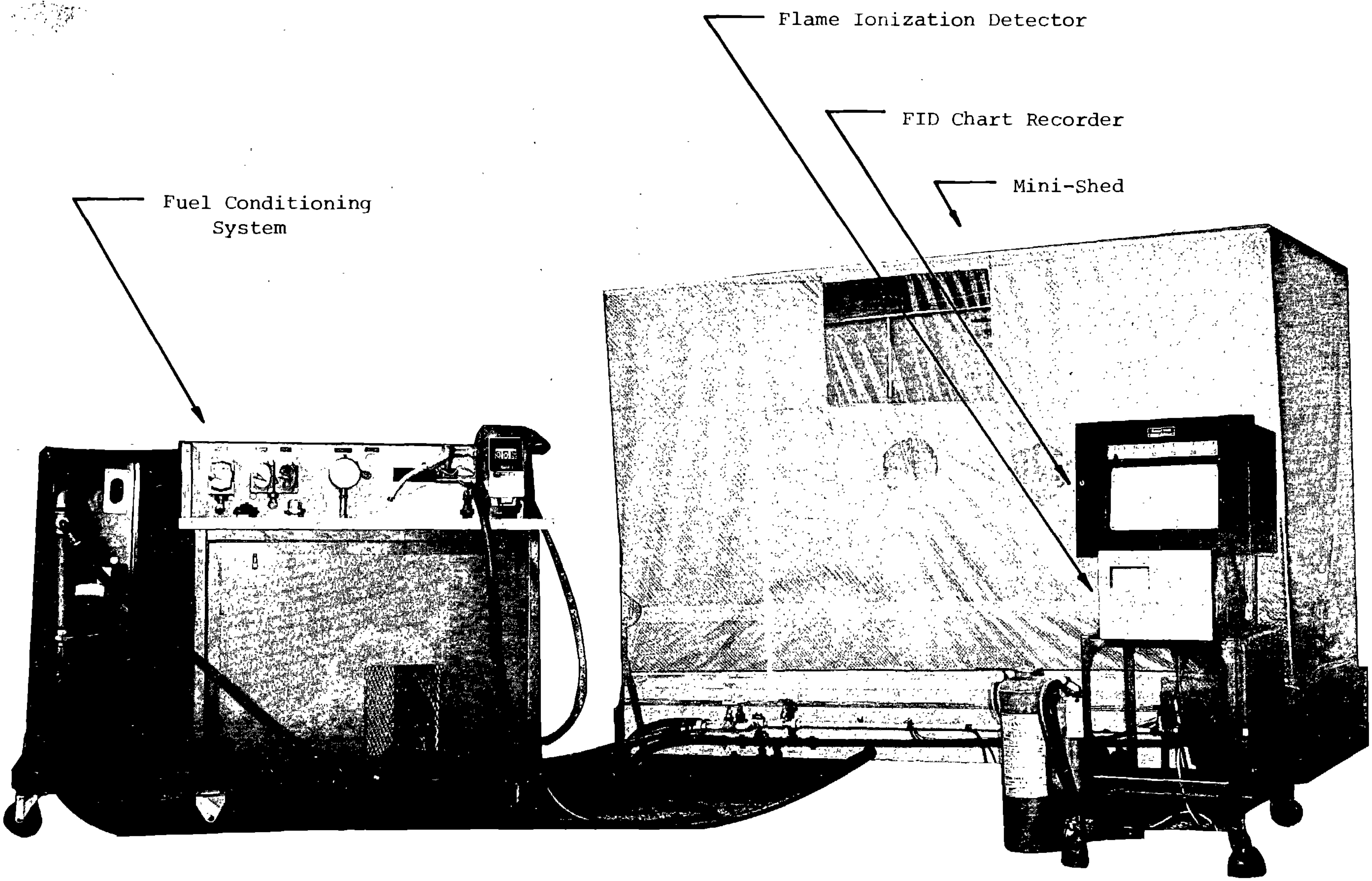
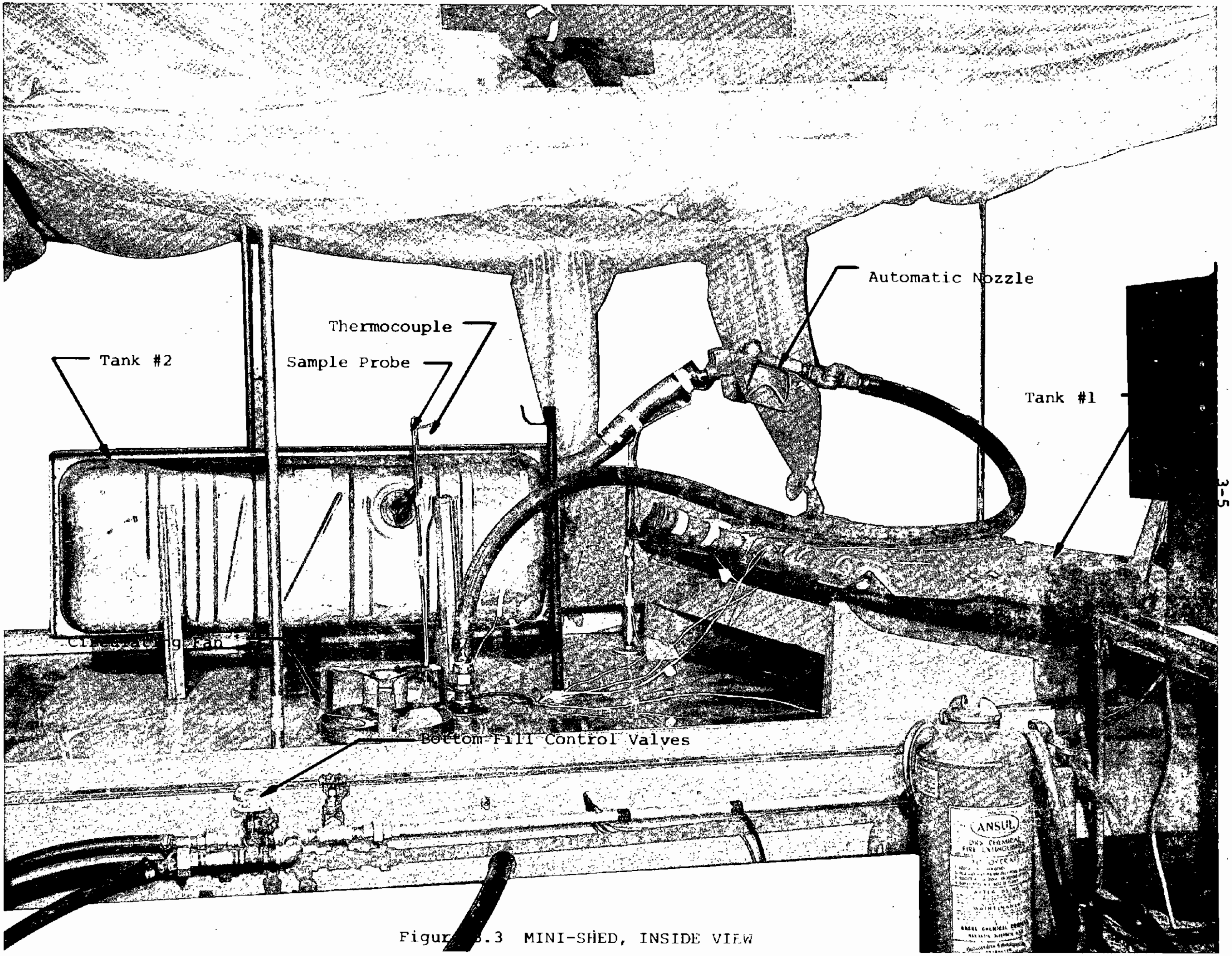


Figure 3.2 DISPLACED VAPOR MEASUREMENT APPARATUS



Figur[illegible].3 MINI-SHED, INSIDE VIEW

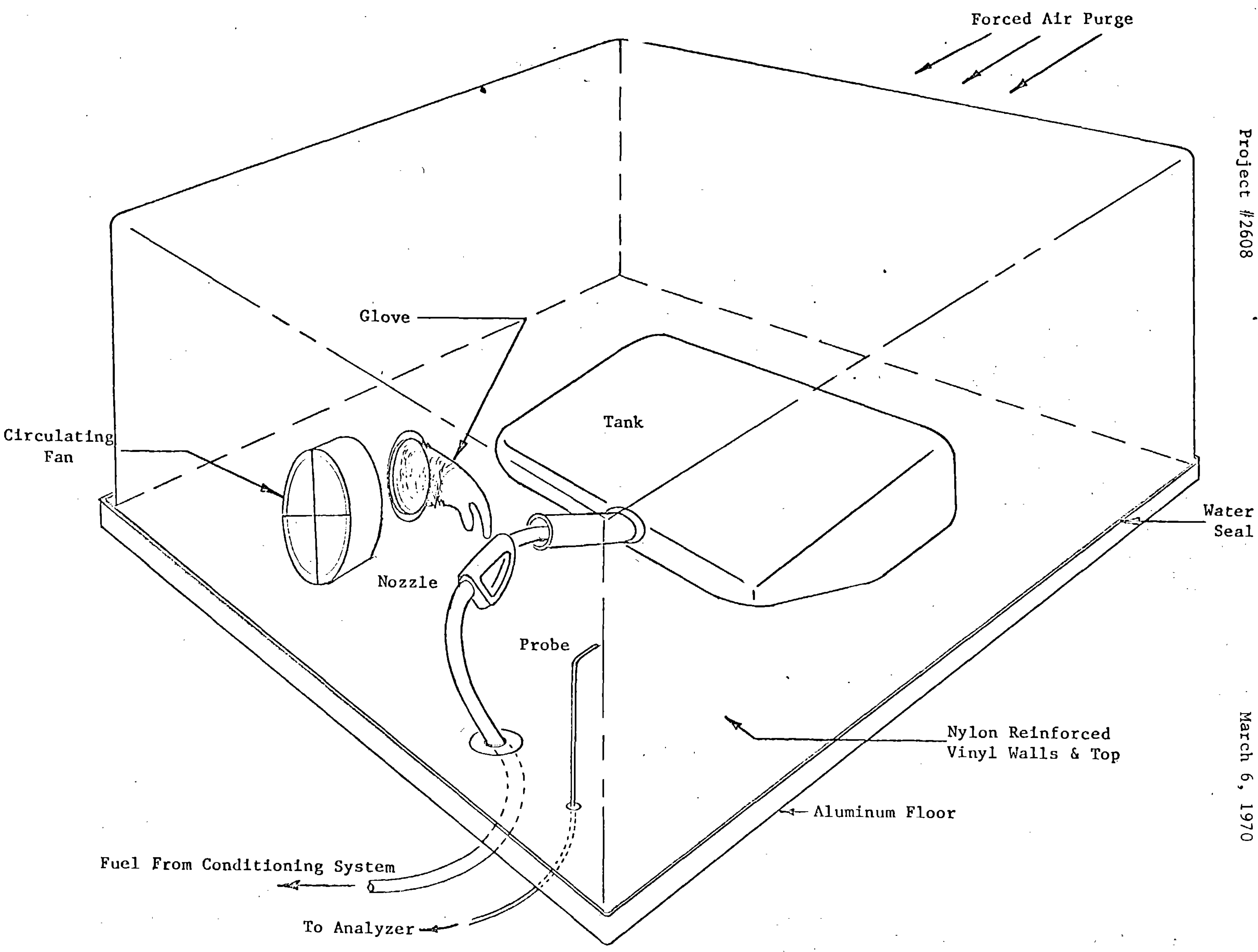


Figure 3.4 Mini-SHED Schematic

## 3.4 SHED

The full size SHED is designed to enclose complete automobiles for total evaporative type measurements. The gross volume with no car inside is 1960 cubic feet. Different automobiles reduce this to a net volume of about 1750 cubic feet. Wall and roof material is nylon reinforced vinyl; the floor is aluminum. Automobile entrance is gained through a large zippered end panel. Technicians may enter at the other end through a smaller zippered door which also serves as the purge fan entrance. Probes passing through a bulkhead pick up hydrocarbon concentration, enclosure pressure, and SHED ambient temperature. A gasoline hose also passing through this bulkhead joins the pump on the conditioning system outside the SHED to the dispensing nozzle inside.

Figure 3.5 shows a refueling operation inside the SHED. SHED design details are shown in Figure 3.6.

## 3.5 NOZZLE DRIP COLLECTORS

Special funnels were trimmed to the fill pipe area contour of each automobile such that gasoline drippage from a refueling nozzle could be collected. The volume of liquid collected was measured in a tapered graduated centrifuge tube accurate to .05 cc at 1 cc.

Several body styles incorporate a scupper design around the filler pipe neck to collect gasoline spills. In these cases the "built-in" funnel was initially cleaned and the graduate was placed under the funnel discharge to collect nozzle drippage.

A photograph of this test apparatus is presented in Figure 3.7.

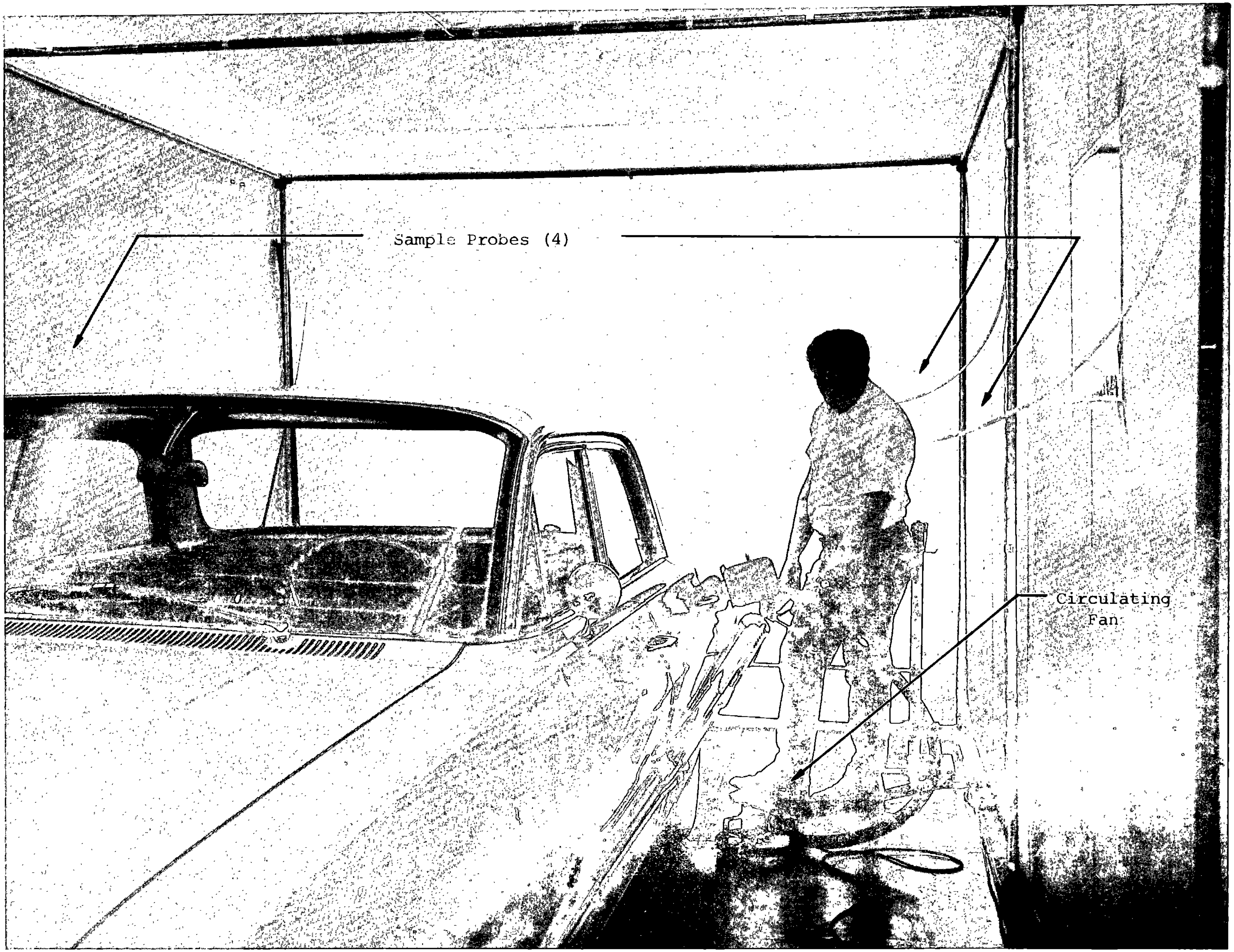


Figure 3.5 SPILL MEASUREMENT APPARATUS

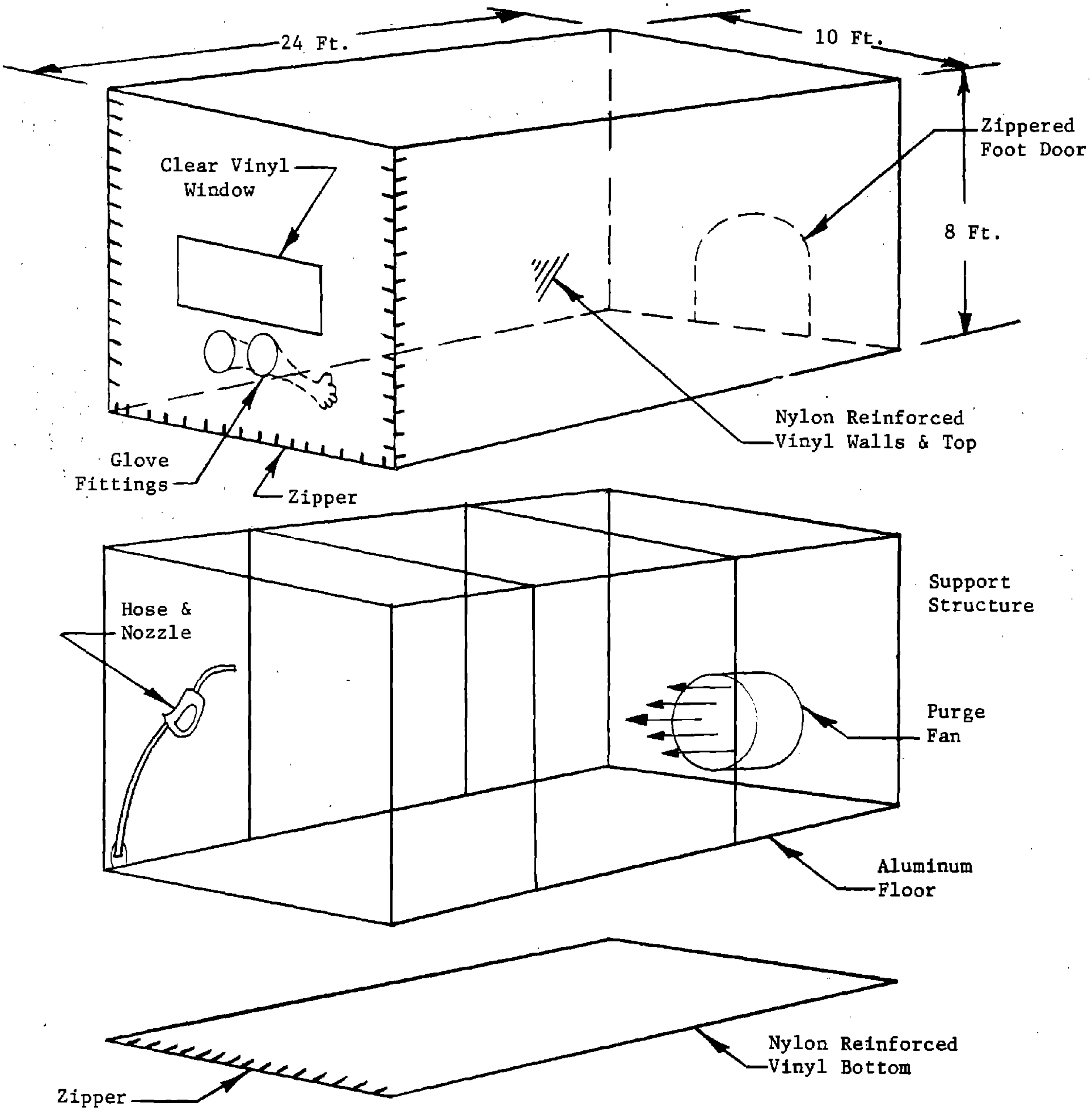


Figure 3.6 SHED - Schematic

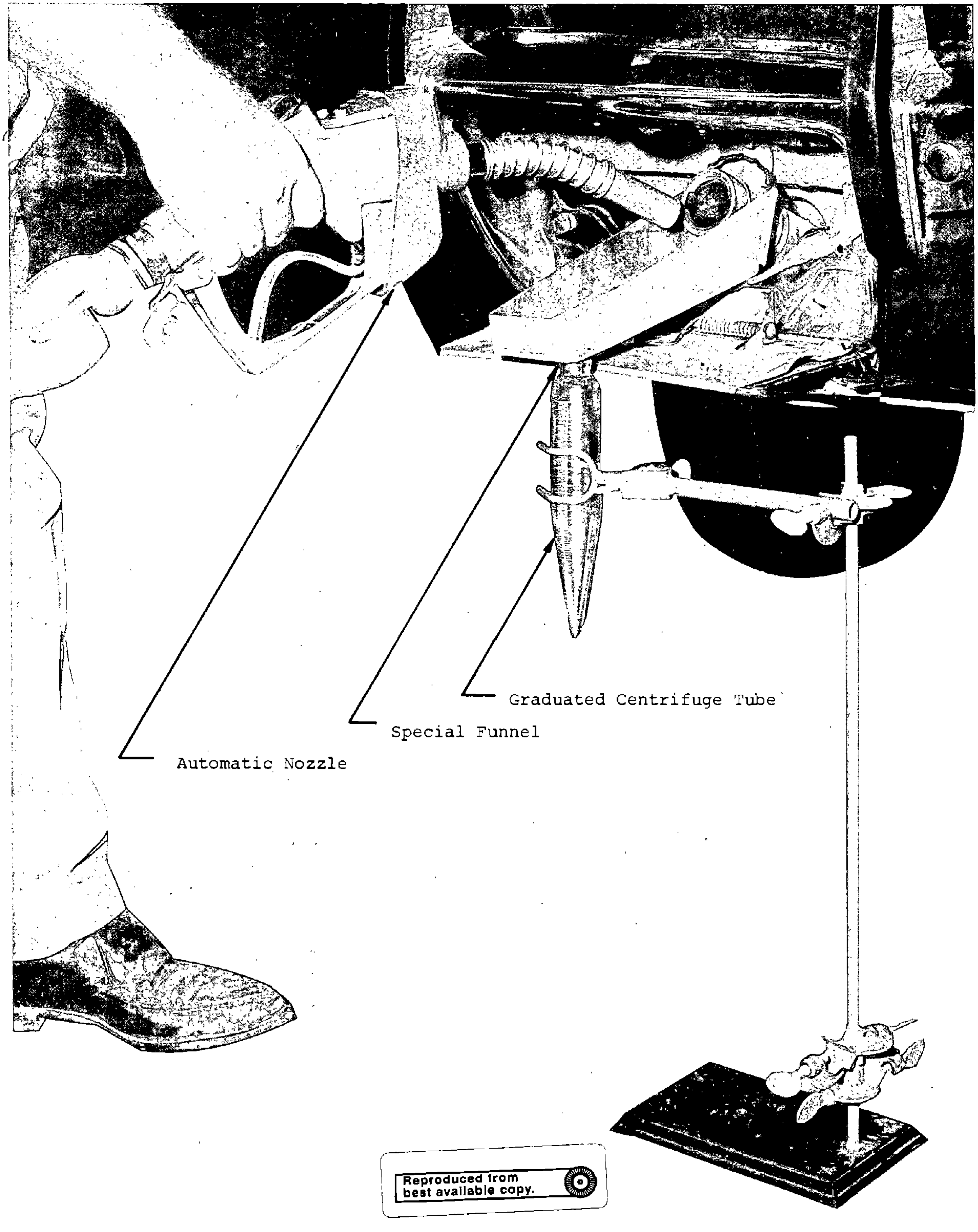


Figure 3.7 NOZZLE DRIP MEASUREMENT APPARATUS

# 4. RESULTS AND DISCUSSION

Results are presented and discussed in this section for the refueling loss magnitude measured in the test program and for refueling loss frequency observed in the field survey.

## 4.1 REFUELING LOSS MAGNITUDE

Weight measurements in grams are presented in this section for the following individual refueling losses:

- Displaced vapor
- Entrained droplets
- Spilled liquid
- Nozzle drippage

The relative effects of significant parameters on the magnitude of each loss are discussed.

A complete description of gasoline samples subjected to test is given in Appendix 6.1.

### 4.1.1 Displaced Vapor Weight, Tabular Results

The gram weight computed from FID measurements of hydrocarbon vapor displaced during 10 gallon refueling operations are grouped and averaged by column (test) number in Table 4.1. Results for one hundred and twenty tests are reported. The formula for converting FID measurements to grams is given in Appendix 6.3.

The tank types, "1" and "2," refer to fuel tank geometry. The fill methods, "N" and "B," refer to nozzle or bottom filling procedures, 4.1.1 Displaced Vapor Weight, Tabular Results - continued

respectively. Descriptions of column headings, and units of measure, for the results shown in the following tables are:

COL # = Column (test) number

DISPL = Displaced loss in grams (computed)

TANK = Tank type (1 or 2)

FILL = Fill method (N: Nozzle fill; B: Bottom fill)

RATE = Fill rate in gal/min

TAMB = Ambient and initial tank temperature in Fahrenheit

RVP = Reid vapor pressure in psig

TFUEL = Dispensed fuel temperature in Fahrenheit

TVAP = Vapor space temperature in Fahrenheit

TVP = True vapor pressure of initial gasoline in tank in psia (from RVP and TAMB)

H/C = Hydrogen/Carbon ratio

The ambient temperature listed in the tables are not exact, but are grouped as follows:

$$T \leq 52 \longrightarrow T = 45$$

$$52 < T \leq 67 \longrightarrow T = 60$$

$$67 < T \leq 82 \longrightarrow T = 75$$

$$82 < T \longrightarrow T = 90$$

Plotted ambient temperatures are as observed.

Foremost in the preparations for each test was the initial equilibration of both vapor space and residual gasoline temperatures in the tank to the ambient temperature established for that test.

Table 4.1 Displaced Vapor Test Results

| COL= | DISPL | TANK | FILL* | RATE | TAMB | RVP | TFUEL | TVAP | TVP | H/C |
|---|---|---|---|---|---|---|---|---|---|---|
| 1-1 | 24.5 | 2 | N | 5.0 | 60 | 7.2 | 57.0 | 57.0 | 3.5 | 2.40 |
|  | 24.5 |  |  |  |  |  |  |  |  |  |
| 2-1 | 24.8 | 2 | N | 12.8 | 60 | 7.2 | 58.0 | 58.0 | 3.5 | 2.40 |
|  | 24.8 |  |  |  |  |  |  |  |  |  |
| 3-1 | 23.1 | 2 | B | 12.8 | 60 | 7.2 | 58.0 | 58.0 | 3.5 | 2.40 |
|  | 23.1 |  |  |  |  |  |  |  |  |  |
| 4-1 | 29.5 | 1 | N | 5.0 | 60 | 7.2 | 62.0 | 59.0 | 3.5 | 2.40 |
| 4-2 | 27.4 | 1 | N | 5.0 | 60 | 7.2 | 59.0 | 61.0 | 3.5 | 2.40 |
|  | 28.5 |  |  |  |  |  |  |  |  |  |
| 5-1 | 27.9 | 1 | N | 12.6 | 60 | 7.2 | 59.0 | 60.0 | 3.5 | 2.40 |
|  | 27.9 |  |  |  |  |  |  |  |  |  |
| 6-1 | 25.1 | 1 | B | 12.6 | 60 | 7.2 | 58.0 | 59.0 | 3.5 | 2.40 |
|  | 25.1 |  |  |  |  |  |  |  |  |  |
| 7-1 | 25.4 | 2 | N | 4.8 | 75 | 7.2 | 74.0 | 72.0 | 4.7 | 2.40 |
|  | 25.4 |  |  |  |  |  |  |  |  |  |
| 8-1 | 25.0 | 2 | N | 13.2 | 75 | 7.2 | 72.0 | 70.0 | 4.7 | 2.40 |
|  | 25.0 |  |  |  |  |  |  |  |  |  |
| 9-1 | 31.3 | 2 | B | 13.2 | 75 | 7.2 | 73.0 | 73.0 | 4.7 | 2.40 |
|  | 31.3 |  |  |  |  |  |  |  |  |  |
| 10-1 | 29.9 | 1 | N | 4.8 | 75 | 7.2 | 72.0 | 71.0 | 4.7 | 2.40 |
|  | 29.9 |  |  |  |  |  |  |  |  |  |
| 11-1 | 30.4 | 1 | N | 12.6 | 75 | 7.2 | 73.0 | 70.0 | 4.7 | 2.40 |
|  | 30.4 |  |  |  |  |  |  |  |  |  |
| 12-1 | 26.7 | 1 | B | 12.6 | 75 | 7.2 | 73.5 | 73.0 | 4.7 | 2.40 |
|  | 26.7 |  |  |  |  |  |  |  |  |  |
| 13-1 | 21.6 | 2 | N | 4.8 | 90 | 7.2 | 92.0 | 85.0 | 6.3 | 2.40 |
|  | 21.6 |  |  |  |  |  |  |  |  |  |
| 14-1 | 15.7 | 2 | N | 12.6 | 90 | 7.2 | 92.0 | 83.0 | 6.3 | 2.40 |
| 14-2 | 24.7 | 2 | N | 12.6 | 90 | 7.2 | 89.0 | 84.0 | 6.3 | 2.40 |
|  | 20.2 |  |  |  |  |  |  |  |  |  |

* N = Nozzle Fill; B = Bottom Fill

Table 4.1 Displaced Vapor Test Results
(cont.)

| COL= | DISPL | TANK | FILL* | RATE | TAMB | RVP | TFUEL | TVAP | TVP | H/C |
|---|---|---|---|---|---|---|---|---|---|---|
| 15-1 | 42.0 | 2 | B | 12.6 | 90 | 7.2 | 87.0 | 88.0 | 6.3 | 2.40 |
|  | 42.0 |  |  |  |  |  |  |  |  |  |
| 16-1 | 36.4 | 1 | N | 4.8 | 90 | 7.2 | 92.0 | 89.0 | 6.3 | 2.40 |
|  | 36.4 |  |  |  |  |  |  |  |  |  |
| 17-1 | 37.5 | 1 | N | 12.6 | 90 | 7.2 | 94.0 | 88.0 | 6.3 | 2.40 |
| 17-2 | 30.5 | 1 | N | 12.6 | 90 | 7.2 | 87.0 | 88.0 | 6.3 | 2.40 |
| 17-3 | 28.1 | 1 | N | 12.6 | 90 | 7.2 | 90.0 | 87.0 | 6.3 | 2.40 |
|  | 32.0 |  |  |  |  |  |  |  |  |  |
| 18-1 | 45.4 | 1 | B | 12.6 | 90 | 7.2 | 94.0 | 91.0 | 6.3 | 2.40 |
|  | 45.4 |  |  |  |  |  |  |  |  |  |
| 19-1 | 33.7 | 1 | N | 4.8 | 60 | 9.2 | 58.0 | 58.0 | 4.7 | 2.31 |
| 19-2 | 33.3 | 2 | N | 4.8 | 60 | 9.2 | 62.0 | 62.0 | 4.7 | 2.31 |
|  | 33.5 |  |  |  |  |  |  |  |  |  |
| 20-1 | 34.6 | 2 | N | 12.4 | 60 | 9.2 | 62.0 | 60.0 | 4.7 | 2.31 |
| 20-2 | 31.2 | 2 | N | 12.6 | 60 | 9.2 | 60.0 | 60.0 | 4.7 | 2.31 |
| 20-3 | 27.6 | 2 | N | 12.6 | 60 | 9.2 | 62.0 | 60.5 | 4.7 | 2.31 |
|  | 31.1 |  |  |  |  |  |  |  |  |  |
| 21-1 | 40.4 | 2 | B | 12.4 | 60 | 9.2 | 62.0 | 61.0 | 4.7 | 2.31 |
| 21-2 | 30.8 | 2 | B | 12.6 | 60 | 9.2 | 58.0 | 57.0 | 4.7 | 2.31 |
| 21-3 | 30.3 | 2 | B | 12.6 | 60 | 9.2 | 58.0 | 59.0 | 4.7 | 2.31 |
|  | 33.8 |  |  |  |  |  |  |  |  |  |
| 22-1 | 35.7 | 1 | N | 4.8 | 60 | 9.2 | 62.0 | 54.0 | 4.7 | 2.31 |
| 22-2 | 29.4 | 1 | N | 4.8 | 60 | 9.2 | 58.0 | 59.0 | 4.7 | 2.31 |
|  | 32.6 |  |  |  |  |  |  |  |  |  |
| 23-2 | 32.4 | 1 | N | 12.6 | 60 | 9.2 | 58.5 | 61.0 | 4.7 | 2.31 |
| 23-3 | 32.4 | 1 | N | 12.6 | 60 | 9.2 | 59.0 | 59.0 | 4.7 | 2.31 |
| 23-4 | 27.1 | 1 | N | 12.6 | 60 | 9.2 | 60.0 | 60.0 | 4.7 | 2.31 |
|  | 30.7 |  |  |  |  |  |  |  |  |  |
| 24-1 | 37.0 | 1 | B | 11.8 | 60 | 9.2 | 60.0 | 60.0 | 4.7 | 2.31 |
| 24-2 | 31.1 | 1 | B | 12.6 | 60 | 9.2 | 59.0 | 59.0 | 4.7 | 2.31 |
|  | 34.1 |  |  |  |  |  |  |  |  |  |
| 25-1 | 37.2 | 2 | N | 4.8 | 75 | 9.2 | 70.0 | 71.0 | 6.2 | 2.31 |
| 25-2 | 33.0 | 2 | N | 4.9 | 75 | 9.2 | 76.0 | 76.0 | 6.2 | 2.31 |
|  | 35.1 |  |  |  |  |  |  |  |  |  |

* N = Nozzle Fill; B = Bottom Fill

Table 4.1 Displaced Vapor Test Results
(cont.)

| COL= | DISPL | TANK | FILL* | RATE | TAMB | RVP | TFUEL | TVAP | TVP | H/C |
|---|---|---|---|---|---|---|---|---|---|---|
| 26-2 | 25.5 | 2 | N | 12.5 | 75 | 9.2 | 76.5 | 71.0 | 6.2 | 2.31 |
| 26-3 | 26.9 | 2 | N | 12.8 | 75 | 9.2 | 76.0 | 72.0 | 6.2 | 2.31 |
| 26-4 | 34.1 | 2 | N | 12.6 | 75 | 9.2 | 76.0 | 72.0 | 6.2 | 2.31 |
|  | 28.8 |  |  |  |  |  |  |  |  |  |
| 27-1 | 41.3 | 2 | B | 12.6 | 75 | 9.2 | 72.0 | 72.0 | 6.2 | 2.31 |
| 27-2 | 40.8 | 2 | B | 12.5 | 75 | 9.2 | 75.0 | 73.0 | 6.2 | 2.31 |
|  | 41.0 |  |  |  |  |  |  |  |  |  |
| 28-1 | 35.2 | 1 | N | 4.8 | 75 | 9.2 | 74.0 | 70.0 | 6.2 | 2.31 |
| 28-2 | 32.9 | 1 | N | 5.0 | 75 | 9.2 | 77.0 | 73.0 | 6.2 | 2.31 |
|  | 34.0 |  |  |  |  |  |  |  |  |  |
| 29-1 | 36.8 | 1 | N | 12.6 | 75 | 9.2 | 73.0 | 70.0 | 6.2 | 2.31 |
| 29-2 | 31.4 | 1 | N | 12.6 | 75 | 9.2 | 74.0 | 72.0 | 6.2 | 2.31 |
| 29-3 | 32.9 | 1 | N | 12.6 | 75 | 9.2 | 74.0 | 73.0 | 6.2 | 2.31 |
|  | 33.7 |  |  |  |  |  |  |  |  |  |
| 30-2 | 41.6 | 1 | B | 12.6 | 75 | 9.2 | 73.0 | 72.0 | 6.2 | 2.31 |
| 30-3 | 41.9 | 1 | B | 12.6 | 75 | 9.2 | 74.0 | 74.0 | 6.2 | 2.31 |
|  | 41.7 |  |  |  |  |  |  |  |  |  |
| 31-1 | 28.4 | 2 | N | 4.8 | 90 | 9.2 | 85.0 | 82.0 | 8.2 | 2.31 |
| 31-2 | 36.5 | 2 | N | 4.8 | 90 | 9.2 | 88.0 | 88.0 | 8.2 | 2.31 |
|  | 32.4 |  |  |  |  |  |  |  |  |  |
| 32-1 | 23.0 | 2 | N | 12.0 | 90 | 9.2 | 86.0 | 82.0 | 8.2 | 2.31 |
| 32-2 | 19.4 | 2 | N | 12.6 | 90 | 9.2 | 88.0 | 82.0 | 8.2 | 2.31 |
| 32-3 | 32.0 | 2 | N | 12.6 | 90 | 9.2 | 90.0 | 82.0 | 6.2 | 2.31 |
|  | 24.8 |  |  |  |  |  |  |  |  |  |
| 33-1 | 54.5 | 2 | B | 12.0 | 90 | 9.2 | 89.0 | 91.0 | 8.2 | 2.31 |
| 33-2 | 53.0 | 2 | B | 12.6 | 90 | 9.2 | 90.5 | 92.0 | 8.2 | 2.31 |
|  | 53.8 |  |  |  |  |  |  |  |  |  |
| 34-1 | 38.3 | 1 | N | 4.8 | 90 | 9.2 | 93.0 | 83.0 | 8.2 | 2.31 |
| 34-2 | 34.5 | 1 | N | 4.8 | 90 | 9.2 | 93.0 | 90.0 | 8.2 | 2.31 |
|  | 36.4 |  |  |  |  |  |  |  |  |  |
| 35-1 | 31.1 | 1 | N | 12.0 | 90 | 9.2 | 87.5 | 84.0 | 8.2 | 2.31 |
| 35-2 | 32.8 | 1 | N | 12.6 | 90 | 9.2 | 89.0 | 89.0 | 8.2 | 2.31 |
| 35-3 | 33.9 | 1 | N | 12.6 | 90 | 9.2 | 91.0 | 87.0 | 6.2 | 2.31 |
|  | 32.6 |  |  |  |  |  |  |  |  |  |

* N = Nozzle Fill; B = Bottom Fill

Table 4.1 Displaced Vapor Test Results
(cont.)

| COL= | DISPL | TANK | FILL* | RATE | TAMB | RVP | TFUEL | TVAP | TVP | H/C |
|---|---|---|---|---|---|---|---|---|---|---|
| 36-1 | 53.6 | 1 | B | 12.0 | 90 | 9.2 | 89.0 | 89.0 | 8.2 | 2.31 |
| 36-2 | 52.1 | 1 | B | 12.6 | 90 | 9.2 | 89.0 | 92.0 | 8.2 | 2.31 |
|  | 52.9 |  |  |  |  |  |  |  |  |  |
| 79-1 | 29.2 | 2 | N | 5.0 | 45 | 9.8 | 47.5 | 47.0 | 3.8 | 2.40 |
| 79-2 | 28.8 | 2 | N | 4.9 | 45 | 9.8 | 48.0 | 48.0 | 3.8 | 2.40 |
|  | 29.0 |  |  |  |  |  |  |  |  |  |
| 80-1 | 32.4 | 2 | N | 12.6 | 45 | 9.8 | 44.0 | 44.0 | 3.8 | 2.40 |
| 80-2 | 31.8 | 2 | N | 12.6 | 45 | 9.8 | 45.0 | 44.0 | 3.8 | 2.40 |
|  | 32.1 |  |  |  |  |  |  |  |  |  |
| 81-1 | 24.8 | 2 | B | 12.6 | 45 | 9.8 | 45.5 | 44.0 | 3.8 | 2.40 |
| 81-2 | 27.9 | 2 | B | 12.6 | 45 | 9.8 | 45.0 | 44.0 | 3.8 | 2.40 |
|  | 26.4 |  |  |  |  |  |  |  |  |  |
| 82-1 | 30.2 | 1 | N | 4.8 | 45 | 9.8 | 46.0 | 44.0 | 3.8 | 2.40 |
| 82-2 | 26.5 | 1 | N | 5.0 | 45 | 9.8 | 46.0 | 46.0 | 3.8 | 2.40 |
| 82-3 | 30.1 | 1 | N | 4.8 | 45 | 9.8 | 47.0 | 44.0 | 3.8 | 2.40 |
|  | 28.9 |  |  |  |  |  |  |  |  |  |
| 83-1 | 26.9 | 1 | N | 12.6 | 45 | 9.8 | 47.0 | 45.0 | 3.8 | 2.40 |
| 83-2 | 26.1 | 1 | N | 12.6 | 45 | 9.8 | 47.0 | 44.0 | 3.8 | 2.40 |
|  | 26.5 |  |  |  |  |  |  |  |  |  |
| 84-1 | 26.2 | 1 | B | 12.6 | 45 | 9.8 | 47.0 | 44.0 | 3.8 | 2.40 |
| 84-2 | 27.0 | 1 | B | 12.6 | 45 | 9.8 | 47.0 | 44.0 | 3.8 | 2.40 |
|  | 26.6 |  |  |  |  |  |  |  |  |  |
| 85-1 | 36.2 | 2 | N | 4.8 | 60 | 9.8 | 62.0 | 62.0 | 5.1 | 2.40 |
| 85-2 | 36.4 | 2 | N | 4.8 | 60 | 9.8 | 59.0 | 58.0 | 5.1 | 2.40 |
|  | 36.3 |  |  |  |  |  |  |  |  |  |
| 86-1 | 32.7 | 2 | N | 12.6 | 60 | 9.8 | 62.0 | 61.0 | 5.1 | 2.40 |
| 86-2 | 34.6 | 2 | N | 12.6 | 60 | 9.8 | 58.0 | 58.0 | 5.1 | 2.40 |
|  | 33.7 |  |  |  |  |  |  |  |  |  |
| 87-1 | 32.2 | 2 | B | 12.6 | 60 | 9.8 | 58.0 | 59.0 | 5.1 | 2.40 |
| 87-2 | 34.1 | 2 | B | 12.6 | 60 | 9.8 | 58.0 | 59.0 | 5.1 | 2.40 |
|  | 33.1 |  |  |  |  |  |  |  |  |  |
| 88-1 | 30.4 | 1 | N | 5.0 | 60 | 9.8 | 59.0 | 58.0 | 5.1 | 2.40 |
| 88-2 | 33.3 | 1 | N | 4.8 | 60 | 9.8 | 58.0 | 59.0 | 5.1 | 2.40 |
|  | 31.9 |  |  |  |  |  |  |  |  |  |

* N = Nozzle Fill; B = Bottom Fill

Table 4.1 Displaced Vapor Test Results
(cont.)

| COL= | DISPL | TANK | FILL* | RATE | TAMB | RVP | TFUEL | TVAP | TVP | H/C |
|---|---|---|---|---|---|---|---|---|---|---|
| 89-3 | 31.6 | 1 | N | 12.6 | 60 | 9.8 | 58.0 | 60.0 | 5.1 | 2.40 |
| 89-4 | 28.5 | 1 | N | 12.6 | 60 | 9.8 | 58.5 | 58.0 | 5.1 | 2.40 |
| | 30.0 | | | | | | | | | |
| 90-1 | 32.6 | 1 | B | 12.6 | 60 | 9.8 | 58.0 | 59.0 | 5.1 | 2.40 |
| 90-2 | 31.8 | 1 | B | 12.6 | 60 | 9.8 | 58.0 | 59.0 | 5.1 | 2.40 |
| | 32.2 | | | | | | | | | |
| 91-1 | 40.6 | 2 | N | 4.8 | 75 | 9.8 | 75.0 | 72.0 | 6.7 | 2.40 |
| 91-2 | 35.5 | 2 | N | 4.7 | 75 | 9.8 | 73.5 | 71.0 | 6.7 | 2.40 |
| | 38.1 | | | | | | | | | |
| 92-1 | 41.4 | 2 | N | 12.6 | 75 | 9.8 | 73.5 | 71.0 | 6.7 | 2.40 |
| 92-3 | 36.0 | 2 | N | 12.6 | 75 | 9.8 | 73.5 | 68.0 | 6.7 | 2.40 |
| 92-4 | 34.7 | 2 | N | 12.6 | 75 | 9.8 | 73.0 | 70.0 | 6.7 | 2.40 |
| 92-5 | 32.5 | 2 | N | 12.6 | 75 | 9.8 | 73.0 | 70.0 | 6.7 | 2.40 |
| | 36.2 | | | | | | | | | |
| 93-1 | 43.8 | 2 | B | 12.6 | 75 | 9.8 | 73.0 | 73.0 | 6.7 | 2.40 |
| 93-2 | 43.8 | 2 | B | 12.6 | 75 | 9.8 | 73.0 | 72.0 | 6.7 | 2.40 |
| | 43.8 | | | | | | | | | |
| 94-1 | 45.4 | 1 | N | 4.7 | 75 | 9.8 | 74.0 | 71.0 | 6.7 | 2.40 |
| 94-2 | 43.7 | 1 | N | 4.8 | 75 | 9.8 | 72.0 | 72.0 | 6.7 | 2.40 |
| | 44.6 | | | | | | | | | |
| 95-1 | 44.5 | 1 | N | 12.6 | 75 | 9.8 | 74.0 | 73.0 | 6.7 | 2.40 |
| 95-2 | 41.2 | 1 | N | 12.6 | 75 | 9.8 | 74.0 | 73.0 | 6.7 | 2.40 |
| 95-3 | 37.2 | 1 | N | 9.7 | 75 | 9.8 | 74.0 | 72.0 | 6.7 | 2.40 |
| 95-4 | 35.0 | 1 | N | 12.6 | 75 | 9.8 | 74.0 | 72.0 | 6.7 | 2.40 |
| 95-5 | 38.3 | 1 | N | 12.6 | 75 | 9.8 | 74.0 | 74.0 | 6.7 | 2.40 |
| 95-6 | 38.5 | 1 | N | 12.6 | 75 | 9.8 | 73.0 | 74.0 | 6.7 | 2.40 |
| | 39.1 | | | | | | | | | |
| 96-1 | 48.2 | 1 | B | 12.6 | 75 | 9.8 | 74.0 | 72.0 | 6.7 | 2.40 |
| 96-2 | 46.4 | 1 | B | 12.6 | 75 | 9.8 | 73.0 | 74.0 | 6.7 | 2.40 |
| | 47.3 | | | | | | | | | |

NOTE: Whereas temperature of all gasoline dispensed in Tests #1 through #96 was conditioned to 60°F, temperature of gasoline dispensed in the following tests, #101 through #20 J-5, was conditioned to equal ambient.

* N = Nozzle Fill; B = Bottom Fill

Table 4.1 Displaced Vapor Test Results
(cont.)

| COL= | DISPL | TANK | FILL** | RATE | TAMB | RVP | TFUEL | TVAP | TVP | H/C |
|---|---|---|---|---|---|---|---|---|---|---|
| 101-1 | 42.9 | 2 | N | 12.8 | 76 | 9.2 | 74.0 | 76.0 | 6.2 | 2.31 |
| 101-2 | 38.0 | 2 | N | 12.7 | 74 | 9.2 | 74.0 | 75.5 | 6.2 | 2.31 |
|  | 40.5 |  |  |  |  |  |  |  |  |  |
| 102-1 | 36.6 | 2 | B | 12.6 | 74 | 9.2 | 76.0 | 74.0 | 6.2 | 2.31 |
| 102-2 | 35.8 | 2 | B | 12.6 | 76 | 9.2 | 75.0 | 76.0 | 6.2 | 2.31 |
|  | 36.2 |  |  |  |  |  |  |  |  |  |
| 103-1 | 32.4 | 1 | N | 12.6 | 74 | 9.2 | 76.0 | 74.0 | 6.2 | 2.31 |
|  | 32.4 |  |  |  |  |  |  |  |  |  |
| 104-1 | 33.3 | 1 | B | 12.6 | 73 | 9.2 | 74.0 | 73.0 | 6.2 | 2.31 |
|  | 33.3 |  |  |  |  |  |  |  |  |  |
| 105-1 | 58.6 | 2 | N | 12.6 | 89 | 9.2 | 87.0 | 89.0 | 8.2 | 2.31 |
|  | 58.6 |  |  |  |  |  |  |  |  |  |
| 106-1 | 23.4 | 2 | B | 12.6 | 89.5 | 9.2 | 89.0 | 89.5 | 8.2 | 2.31 |
| 106-2 | 35.4 | 2 | B | 12.6 | 91 | 9.2 | 91.0 | 91.0 | 8.2 | 2.31 |
|  | 29.4 |  |  |  |  |  |  |  |  |  |
| 107-1 | 51.3 | 1 | N | 12.6 | 90 | 9.2 | 90.0 | 90.5 | 8.2 | 2.31 |
|  | 51.3 |  |  |  |  |  |  |  |  |  |
| 108-1 | 46.4 | 1 | B | 12.6 | 90 | 9.2 | 90.0 | 90.0 | 8.2 | 2.31 |
|  | 46.4 |  |  |  |  |  |  |  |  |  |
| 20J-5 | 55.3 | 2 | N | 12.6 | 64 | 9.2 | 74.0 | 70.0* | 4.7 | 2.31 |
|  | 55.3 |  |  |  |  |  |  |  |  |  |

* Temperature of dispensed gasoline = 85.5°F and vapors displaced = 79°F in Test #20J-5.

** N = Nozzle Fill; B = Bottom Fill

4.1.1 Displaced Vapor Weight, Tabular Results - continued

The relative effects on displaced vapor losses are discussed in subsequent sections for the following parameters:

- Ambient temperature
- Fill method
- Tank configuration
- Reid vapor pressure
- Fill rate
- Dispensed fuel temperature

The graphical results shown in the following pages fall into three major types:

- Displaced Loss (grams) versus Temperature (Fahrenheit, Ambient)
- Displaced Loss (grams) versus Reid Vapor Pressure (psig)
- Displaced Loss (grams) versus Fill Rate (Gallons/Minute)

Within each type, one or more sets of graphs were prepared for diverse parameters. Continuous functions are plotted on each graph, as well as actual data points. These functions were obtained by means of a first or second order polynomial regression. These curves are intended only to illustrate the general characteristics of the functions underlying the data presented. They do not, in any way, afford opportunity to interpolate. Cursory inspection will show that the grouping of data collected prohibits accurate curve fitting. Consequently, the attendant statistics to the regressions were neither obtained from the computer, nor included in the data presented.

#### 4.1.1.1 Ambient Temperature

Refueling operations were conducted under four ambient temperatures:

- 45°F
- 60°F
- 75°F
- 90°F

Vapor space and residual gasoline temperatures in the tank were equilibrated to the ambient temperature before starting the fill.

Displaced losses computed from measurements taken after dispensing 10 gallons of gasoline, by means of an automatic nozzle at these four ambient temperatures, are plotted in Figure 4.1. Losses are shown for 9.8 RVP gasoline dispensed into tank configuration #2 and for 9.2 RVP gasoline dispensed into tank #1. The same fill rate of about 12.6 GPM was held in each test shown. The displaced loss weight did not increase with succeedingly warmer ambient tests.

Failure of the displaced loss weight to increase with ambient temperature rise indicates that ambient temperature alone does not affect the magnitude of displaced losses between 45°F and 75°F.

#### 4.1.1.2 Fill Method

Gasoline was introduced to each fuel tank by two methods:

- Nozzle fill
- Bottom fill

The first method simulates a normal service station operation in which gasoline dispensed through a nozzle splashes upon the liquid surface inside

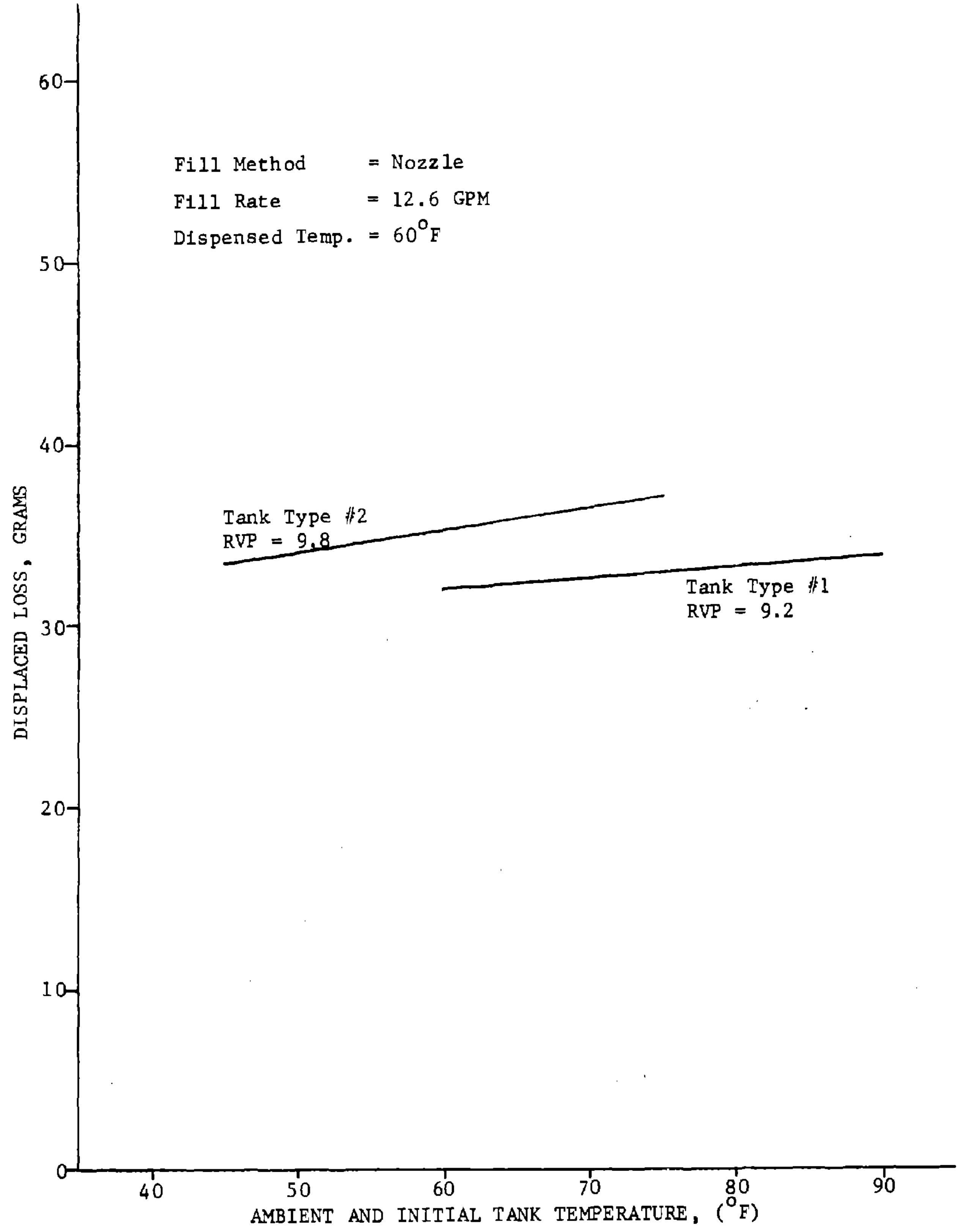


Figure 4.1 Effect of Ambient Temperature on Displaced Hydrocarbon Loss From 10 Gallon Refueling Operations

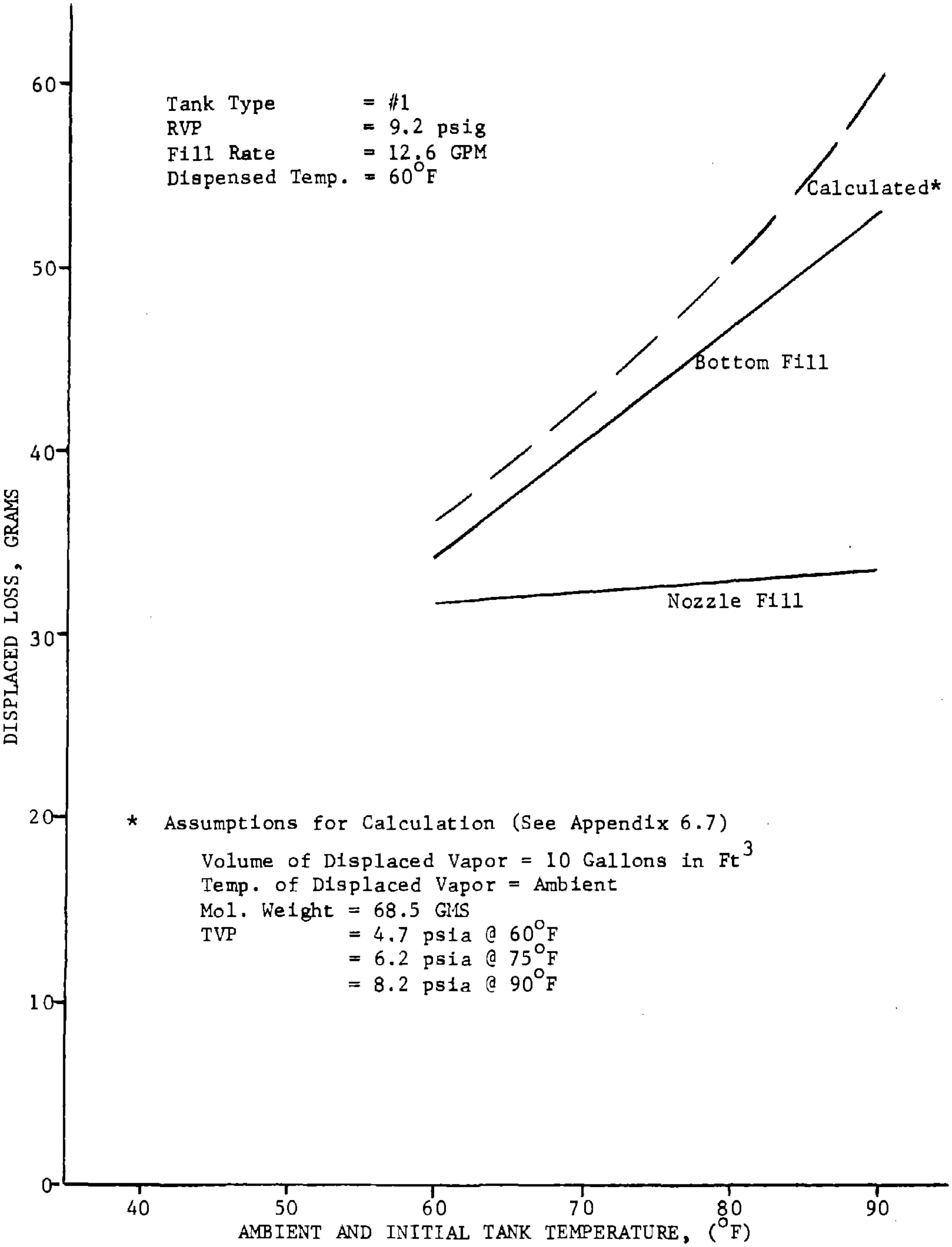
4.1.1.2 Fill Method - continued

the tank. The second method represents a proposed alternative of dispensing gasoline through a fitting in the bottom of the tank with minimum disturbance to the liquid surface.

Displaced losses computed from bottom and nozzle fill measurements at the same set of test conditions are compared in Figure 4.2. Also shown, is the calculated weight of a 10 gallon equivalent volume of vapor in equilibrium with each ambient temperature. The formula used to calculate this weight of equilibrated vapor is given in Appendix 6.4. Bottom fill losses rise with warmer ambients and closely agree with losses calculated for vapor equilibrated to that ambient temperature. It can be noted that nozzle fill losses are nearly independent of ambient temperature. This characteristic was generally found at other test conditions.

Bottom and nozzle fill displaced losses are nearly equal at 60°F ambient only. These two curves converge at 60°F because that is the only ambient where the respective temperatures of vapor displaced from both methods are equal. The influence of 60°F dispensed gasoline on the temperature of displaced vapor, and consequently on the magnitude of the displaced loss, is discussed in Section 4.1.1.6.

Displaced losses computed from bottom fill measurements at all conditions tested are presented in Figures 4.3.1 and 4.3.2. The calculated loss for vapor temperature equilibrated to the ambient is shown for each RVP. The agreement between measured and calculated losses indicates that the temperature of vapor displaced during a bottom fill is nearly equal to ambient.



Tank Type = #1
RVP = 9.2 psig
Fill Rate = 12.6 GPM
Dispensed Temp. = 60°F

* Assumptions for Calculation (See Appendix 6.7)

Volume of Displaced Vapor = 10 Gallons in $Ft^3$
Temp. of Displaced Vapor = Ambient
Mol. Weight = 68.5 GMS
TVP = 4.7 psia @ 60°F
= 6.2 psia @ 75°F
= 8.2 psia @ 90°F

Figure 4.2 Effect of Fill Method on Displaced Hydrocarbon Loss From 10 Gallon Refueling Operations

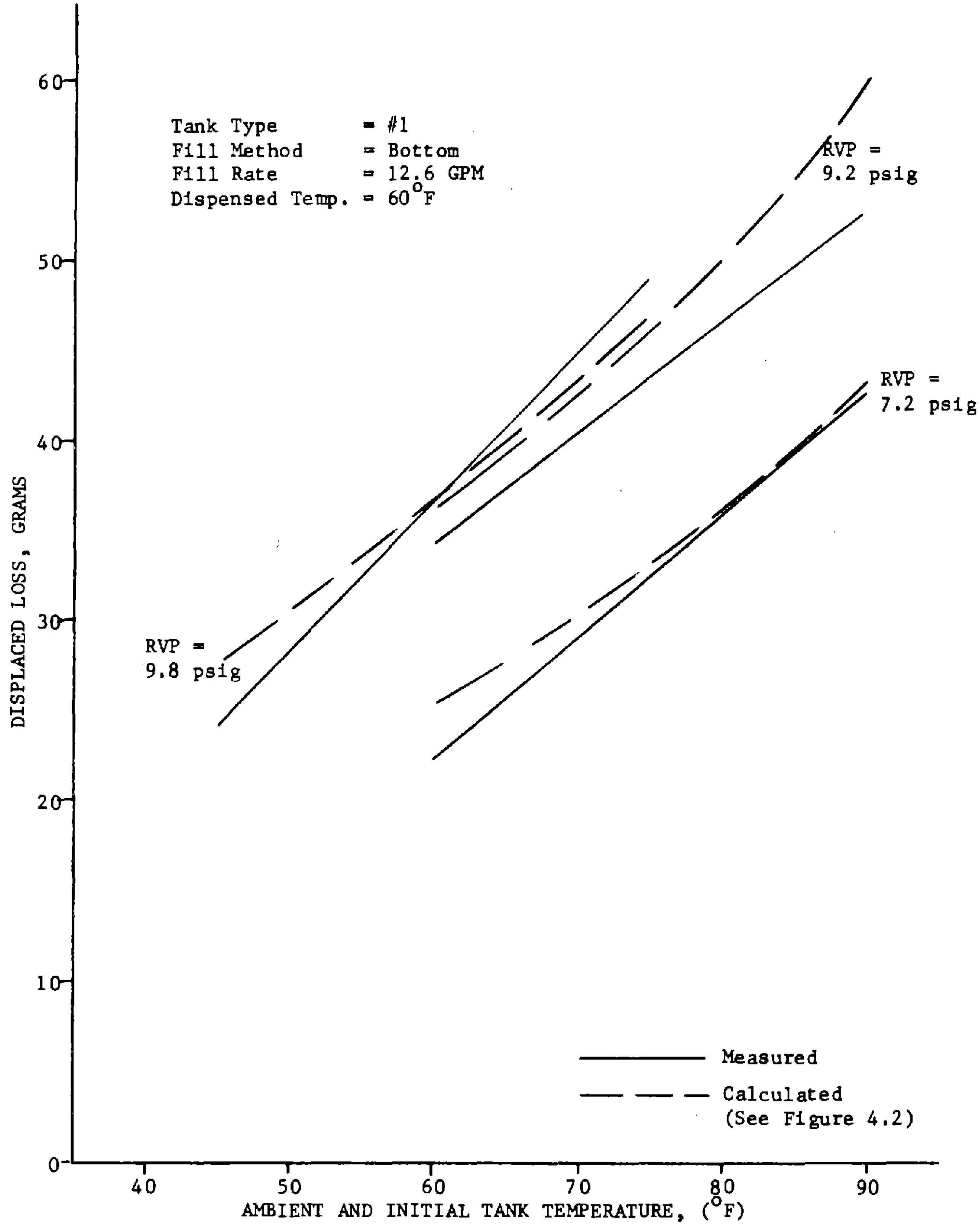


Figure 4.3.1 Bottom Fill Displaced Hydrocarbon Loss From 10 Gallon Refueling Operations

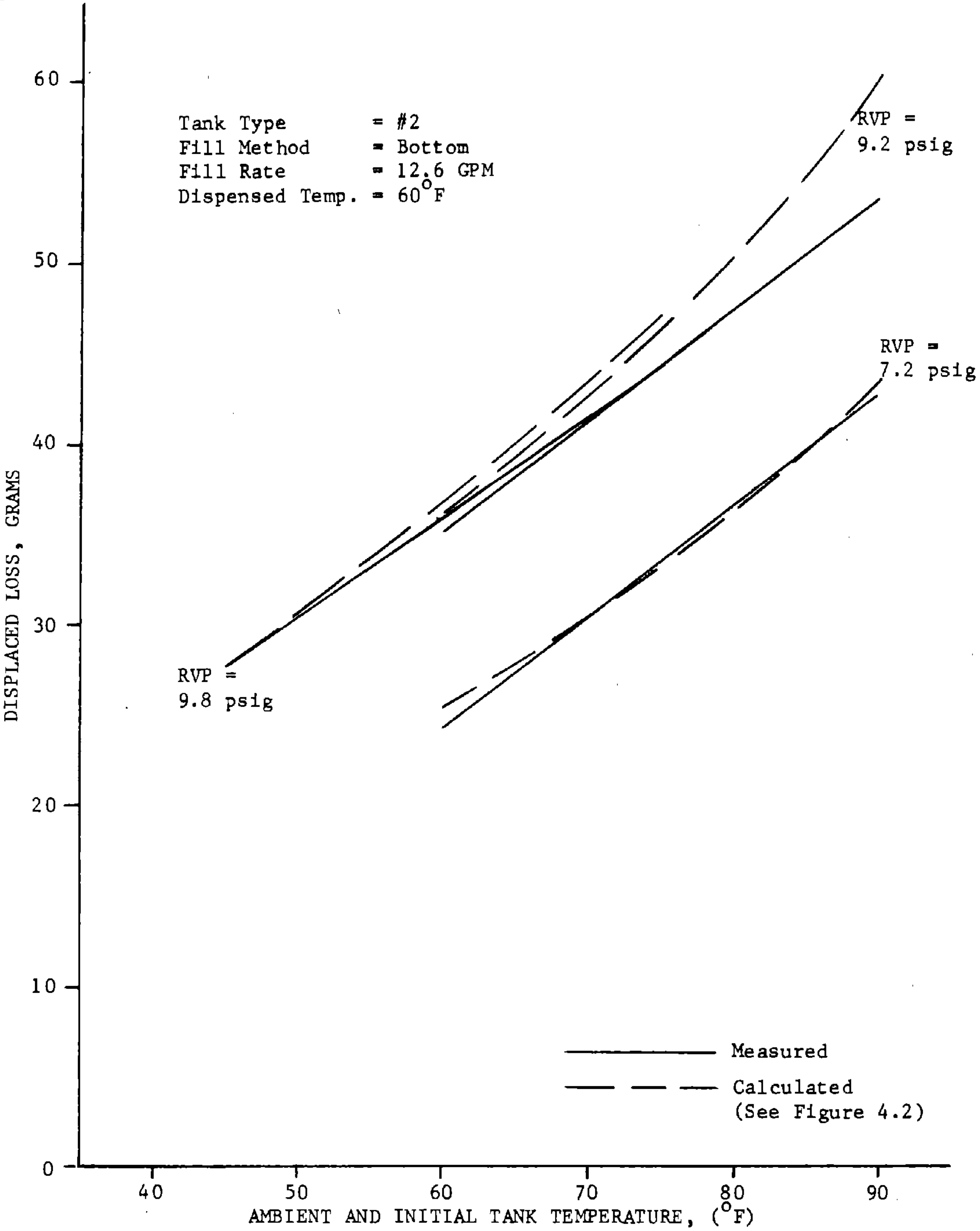


Figure 4.3.2 Bottom Fill Displaced Hydrocarbon Loss From 10 Gallon Refueling Operations

### 4.1.1.3 Tank Configuration

Gasoline was dispensed into two tanks with distinctly different fill pipe designs and different enclosed liquid surfaces.

Configuration #1 exhibits a nearly horizontal fill pipe attitude and broad surface while #2 exhibits a nearly vertical pipe and narrow liquid surface. Displaced losses computed from type #1 and #2 measurements are compared in Figures 4.4.1 and 4.4.2.

Inspection of these figures discloses that displaced vapor losses from both tank configurations are nearly identical at the following conditions:

- Same RVP fuel dispensed into both tanks
- Dispensed fuel temperature (60°F) equals ambient and initial tank temperature

Individual tank losses diverge with ambient temperatures other than equal to the dispensed temperature.

The narrow tank with the steep fill pipe (Tank #2) is seen to generate a lesser displaced loss from 7.2 psig and 9.2 psig RVP fuels at higher ambient temperatures. Although losses from nozzle fills are not directly affected by ambient temperature alone, the Tank #2 - 7.2 and 9.2 RVP test series displayed vapor loss reduction with warmer ambients while the Tank #1 - 7.2, 9.2, and 9.8 RVP series showed loss increase. This divergence could be explained by different heat transfer characteristics between dispensed gasoline and displaced vapor in the two filler pipes. This mechanism will be discussed in Section 4.1.1.6.

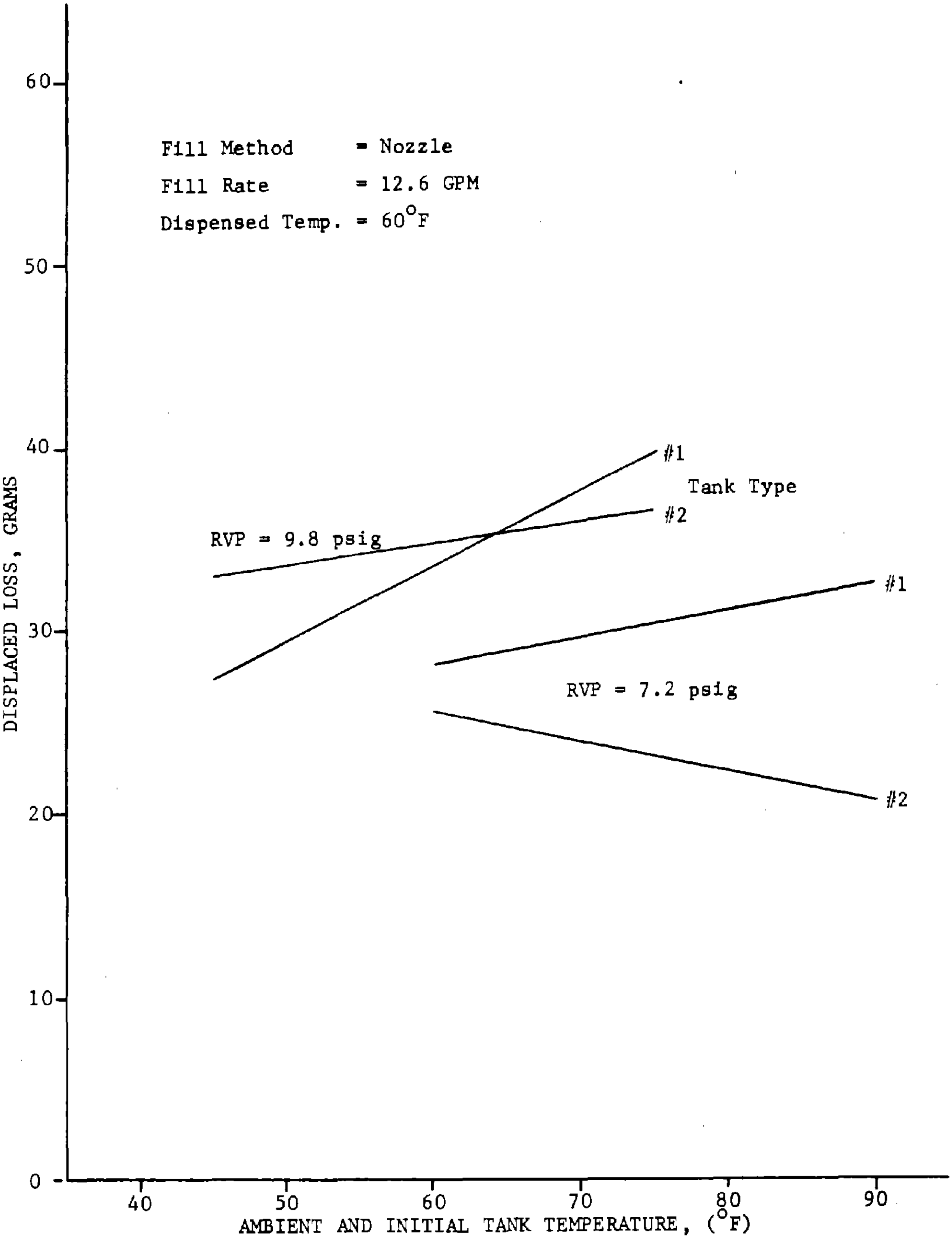


Figure 4.4.1 Effect of Tank Configuration on Displaced Hydrocarbon Loss From 10 Gallon Refueling Operations

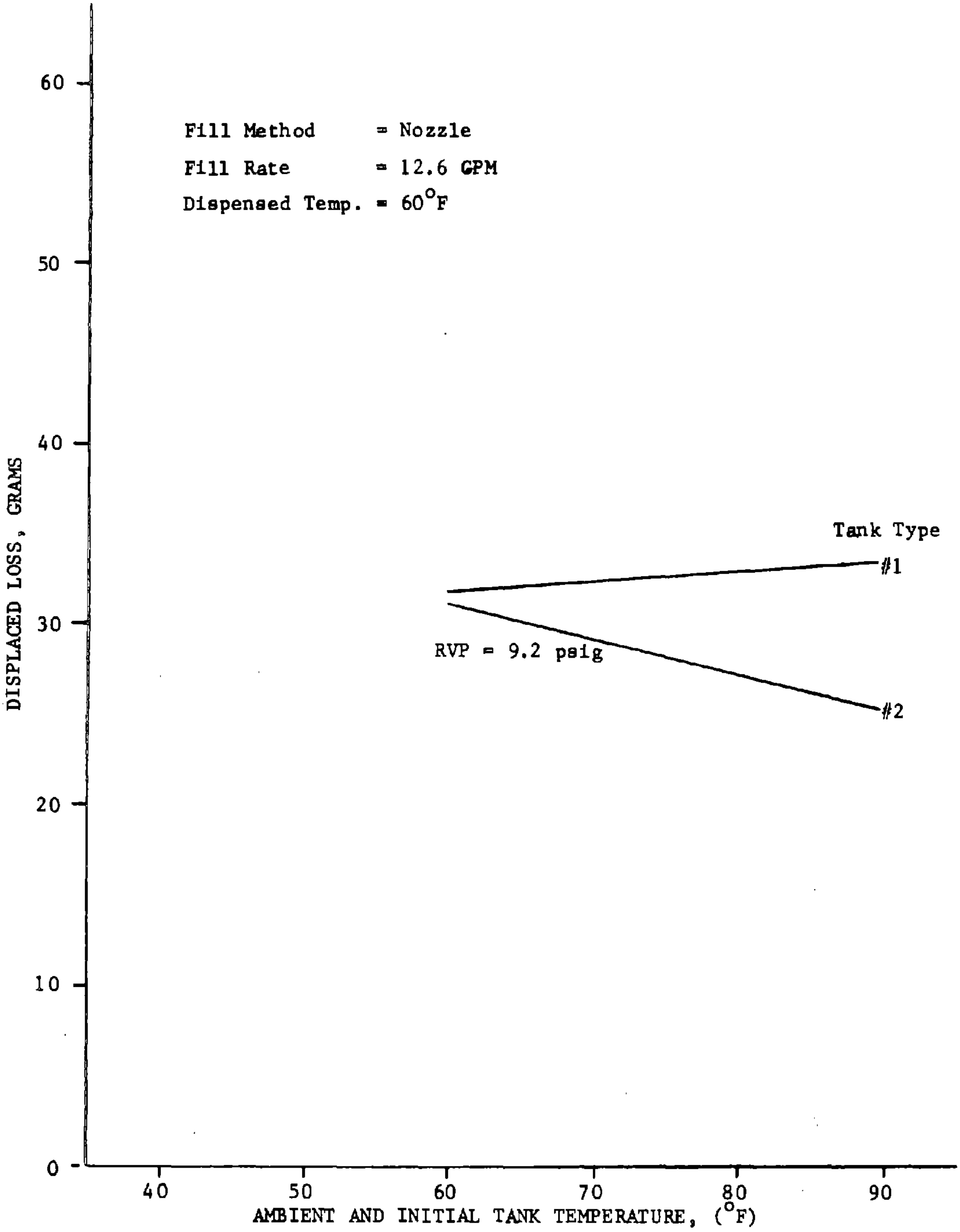


Figure 4.4.2 Effect of Tank Configuration on Displaced Hydrocarbon Loss From 10 Gallon Refueling Operations

### 4.1.1.4 Reid Vapor Pressure

Three different Reid vapor pressure blends of gasoline were dispensed into each tank.

The average RVP identified for each blend is listed below:

7.2 psig

9.2 psig

9.8 psig

Displaced losses computed from measurements taken while dispensing these three RVP fuels are plotted in Figure 4.5. Results are shown for each ambient temperature and for each tank tested.

Displaced vapor losses in Figure 4.5 are observed to rise with higher Reid vapor pressure gasolines. Increased losses are to be expected because the true vapor pressure TVP rises with RVP increase at any of these ambient temperatures. True vapor pressure, in pounds per square inch absolute, was determined from the measured RVP and the ambient and initial tank temperature established for each test. These data were applied to a nomogram* from which the TVP was read-off.

Little spread is observed between the Tank #2 test results because expected ambient temperature effects were suppressed by the same 60°F dispensed gasoline temperature used throughout. Better control of fuel temperatures and more precise RVP determination would have closed-up the spread in Tank #1 test results.

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* API Bulletin 2518, dated June, 1962. Evaporation Loss From Fixed-Roof Tanks, Figure 3, page 10, "Vapor Pressures of Gasolines - 5 lb to 14 lb RVP."

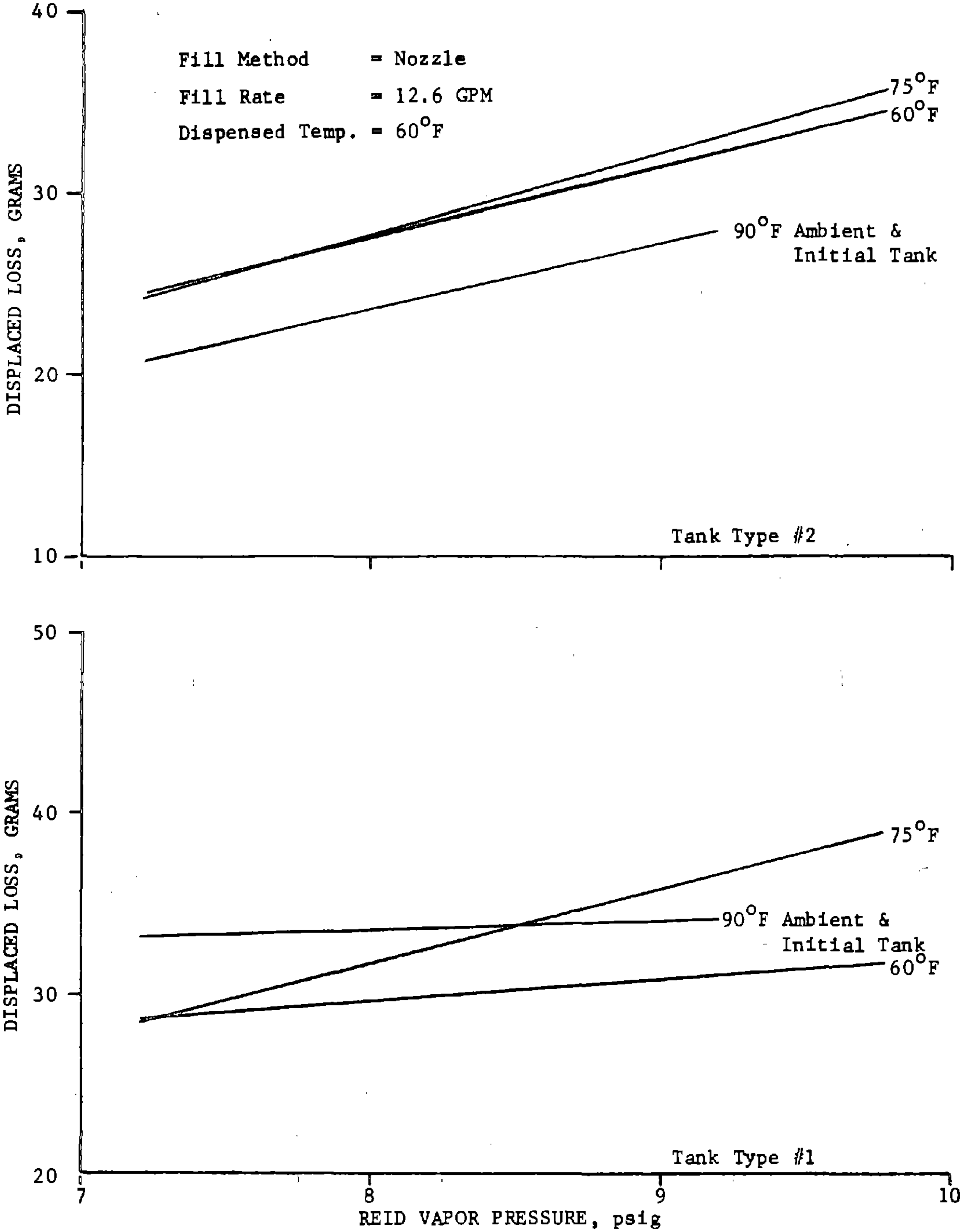

Figure 4.5 Effect of Reid Vapor Pressure on Displaced Hydrocarbon Loss From 10 Gallon Refueling Operations

### 4.1.1.5 Fill Rate

Gasoline was dispensed into each tank with the nozzle latched alternately in the first and then the third notch. In these positions the approximate flow rates are respectively, 4.9 and 12.6 GPM.

Displaced losses are extrapolated between 4.9 and 12.6 GPM in Figure 4.6. Results are shown for each tank configuration and for each ambient and initial tank temperature tested.

The anticipated spread between losses due to different RVP fuels is evident at each ambient temperature. Most significant in this figure is the flat characteristic of all plots indicating that displaced loss magnitude is not affected by fill rate.

### 4.1.1.6 Dispensed Fuel Temperature

Gasoline dispensed during the planned test program was conditioned to 60°F throughout. After completion of the regular program, additional tests were performed during which the dispensed gasoline was conditioned to 75°F and 90°F.

Displaced losses computed from measurements taken while dispensing 60°, 75°, and 90°F conditioned gasoline are compared in Figure 4.7. While ambient and initial tank temperature has little apparent effect, it can be seen that higher dispensed temperatures produced predictably higher displaced losses. The displaced loss plots intersect with the calculated plot for equilibrated displaced vapor and ambient temperatures only when the dispensed temperatures equal ambient.

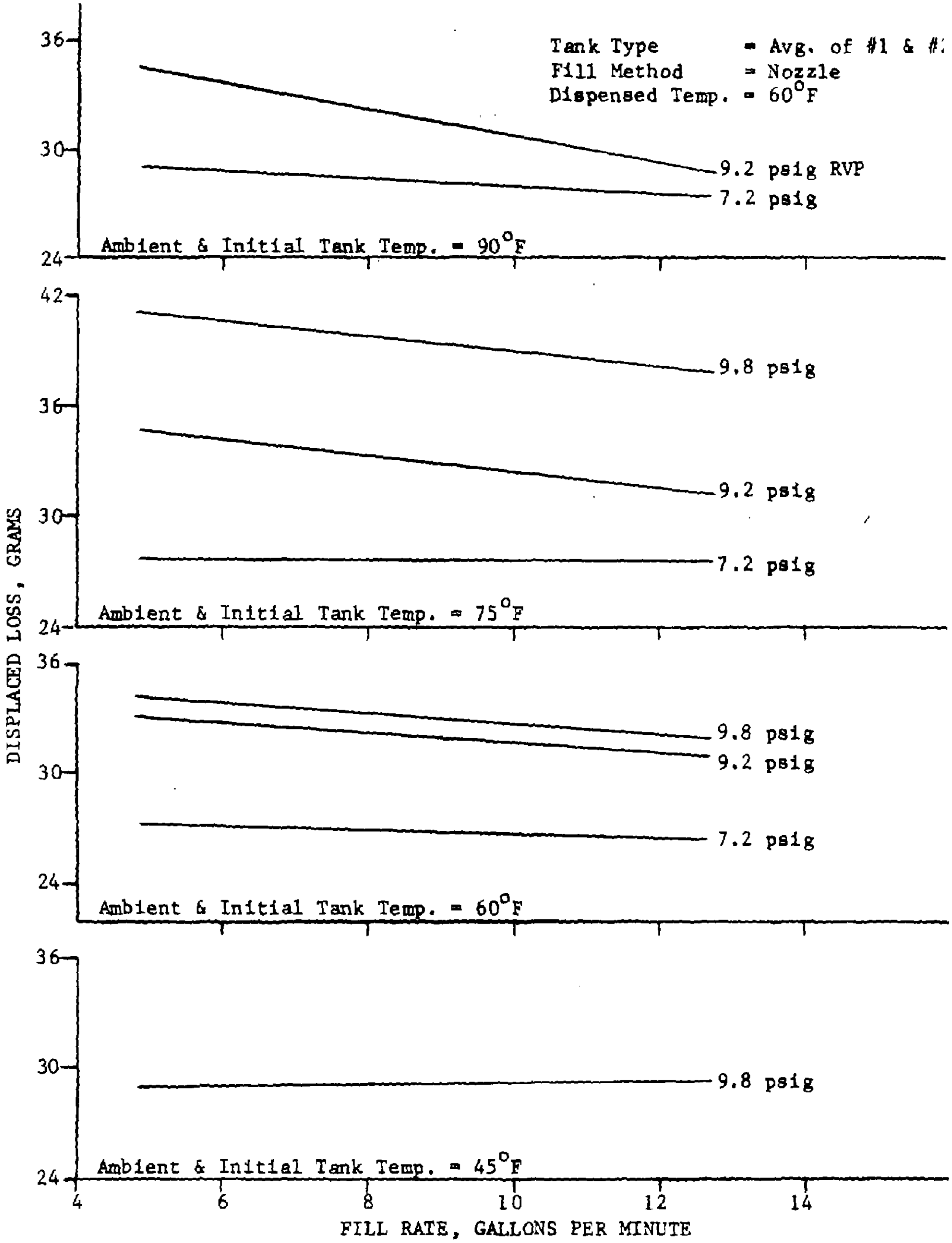

Figure 4.6 Effect of Fill Rate on Displaced Hydrocarbon Losses From 10 Gallon Refueling Operations

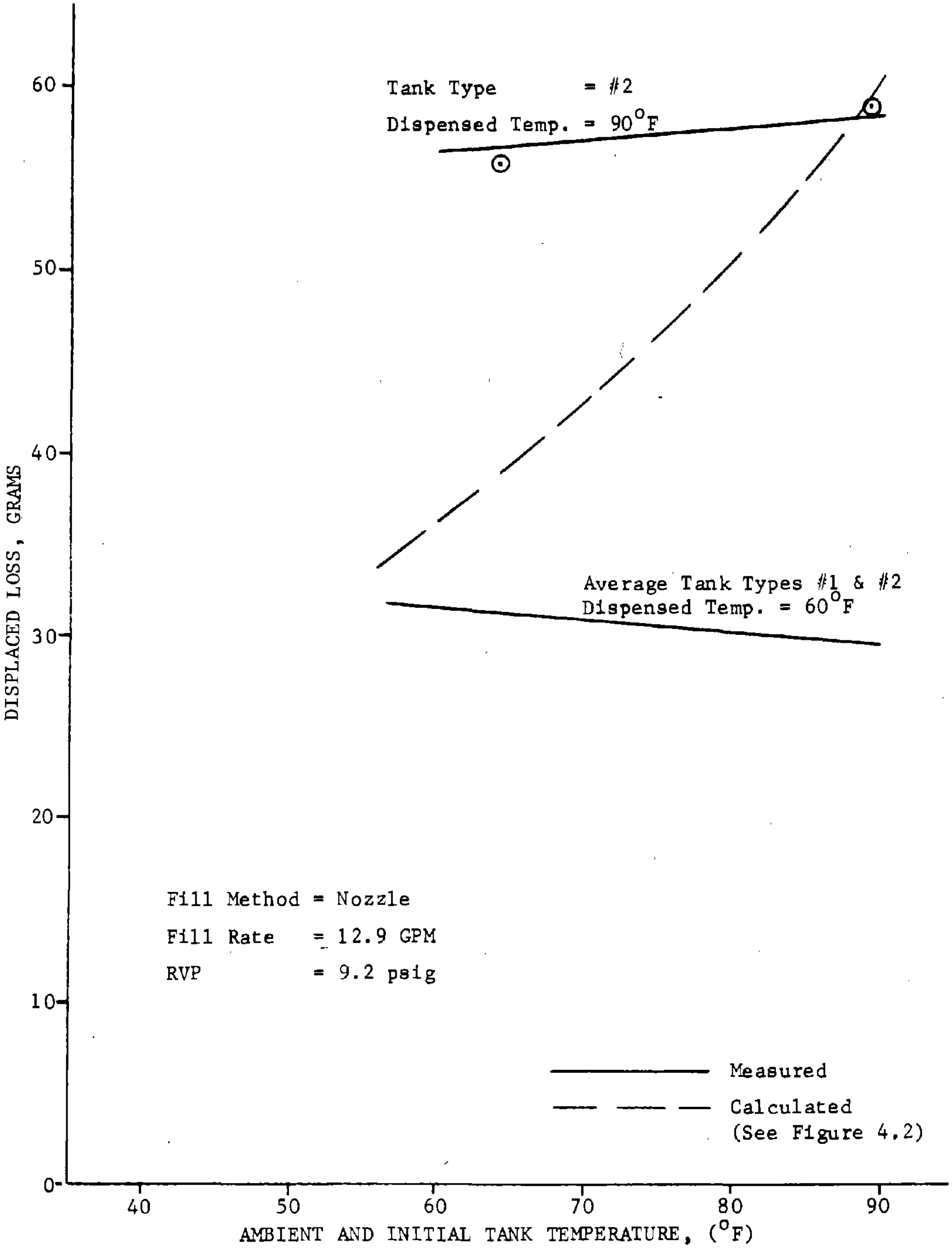

Figure 4.7 Displaced Hydrocarbon Loss From 10 Gallon Refueling Operations at Different Dispensed Gasoline Temperatures

4.1.1.6 Dispensed Fuel Temperature - continued

Two conclusions about displaced vapor loss weight can be drawn from Figure 4.7:

- Loss is relatively independent of ambient temperature
- Loss increases predictably with dispensed temperature

The mechanism by which dispensed temperature determines displaced losses was desired. Thermocouples were placed in the nozzle spout and in the filler pipe mouth in order to measure the respective temperatures of gasoline dispensed and vapor displaced. Refueling operations were performed and the observed responses of both vapor weight and vapor temperature to dispensed temperature are shown in Figure 4.8.

The lower curve follows the increase of displaced vapor temperature with dispensed temperature rise.

The upper plot represents the increase in displaced loss magnitude with dispensed temperature rise from Figure 4.7.

It can now be observed from these data that both the temperature and mass of a 10 gallon volume of displaced vapor respond in a like manner to dispensed gasoline temperature rise. Vapor loss magnitude increase should be expected because of the greater true vapor pressure of a given RVP gasoline at higher temperatures. Figure 4.8 shows that the dispensed gasoline temperature governs displaced vapor temperature and consequently the magnitude of displaced losses.

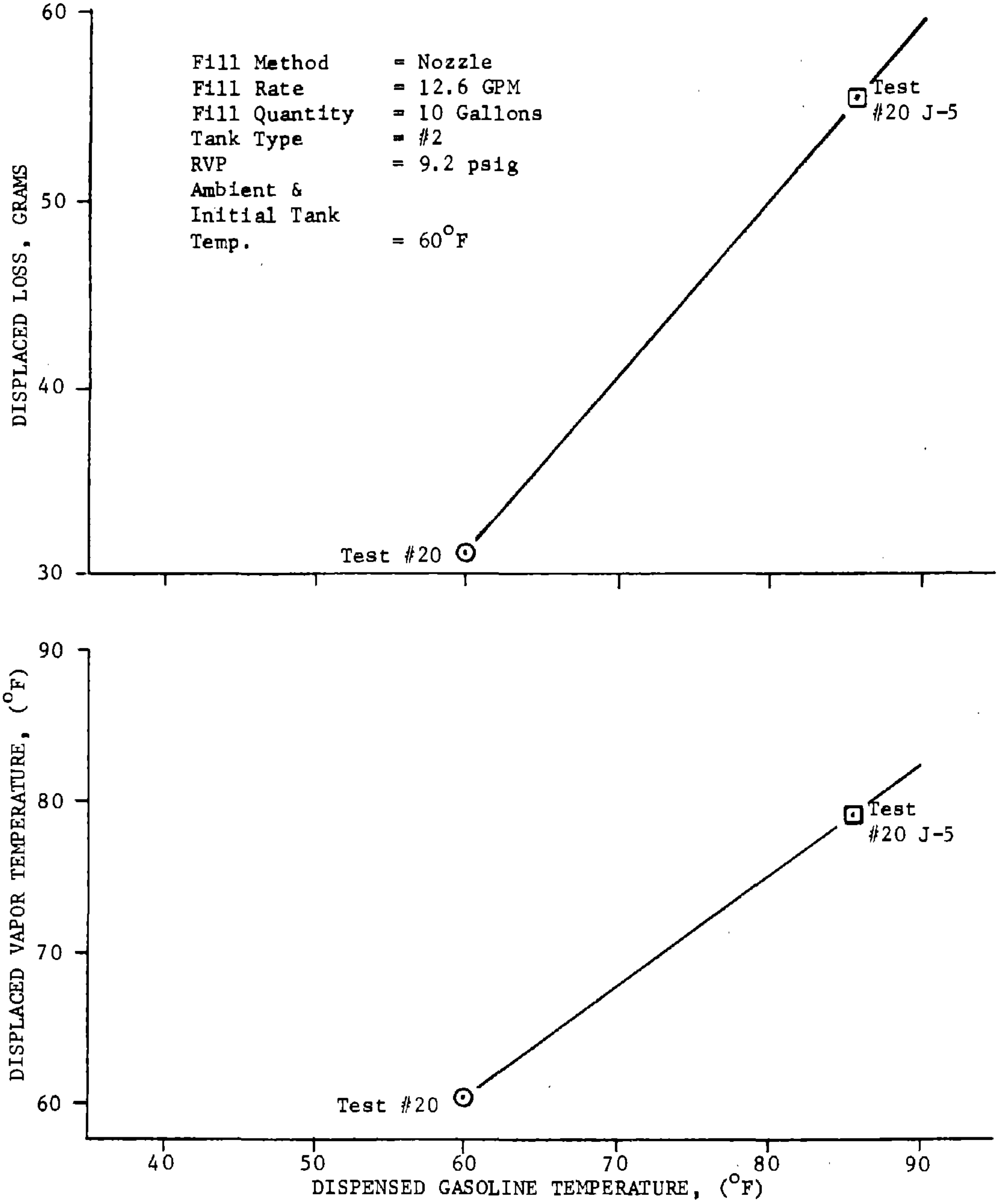

Figure 4.8 Effect of Dispensed Gasoline Temperature on Temperature and Mass of Vapor Displaced

4.1.1.6 Dispensed Fuel Temperature - continued

The following two conclusions can be made:

- Dispensed gasoline temperature is the major factor determining the temperature of vapor displaced.
- Consequently, displaced vapor is a function of dispensed gasoline temperature.

### 4.1.2 Entrained Droplet Loss

The weight of entrained droplets was to have been determined from the difference between nozzle and bottom fill losses. Introducing fuel from below the tank liquid surface with minimum disturbance should have produced no entrainment and consequently lesser bottom fill losses than nozzle fill losses. This differential could not be obtained in the planned program because bottom losses, as previously discussed in Section 4.1.1.2, were always greater at ambient temperatures higher than dispensed gasoline temperatures.

Additional refueling operations were performed during which the dispensed gasoline was conditioned to equal the 60°, 75°, and 90°F ambient temperatures.

Total displaced losses computed from nozzle and bottom fill measurements at equal dispensed and ambient temperatures are compared in Figure 4.9 for tank type #2. The difference between these losses is plotted at the bottom of the figure. This difference may be the entrained droplets associated with the turbulent dispensed liquid from a refueling operation using the nozzle. However, these data are supported by only one test at each set of conditions. Therefore, no firm conclusions can be drawn until replicate tests are run.

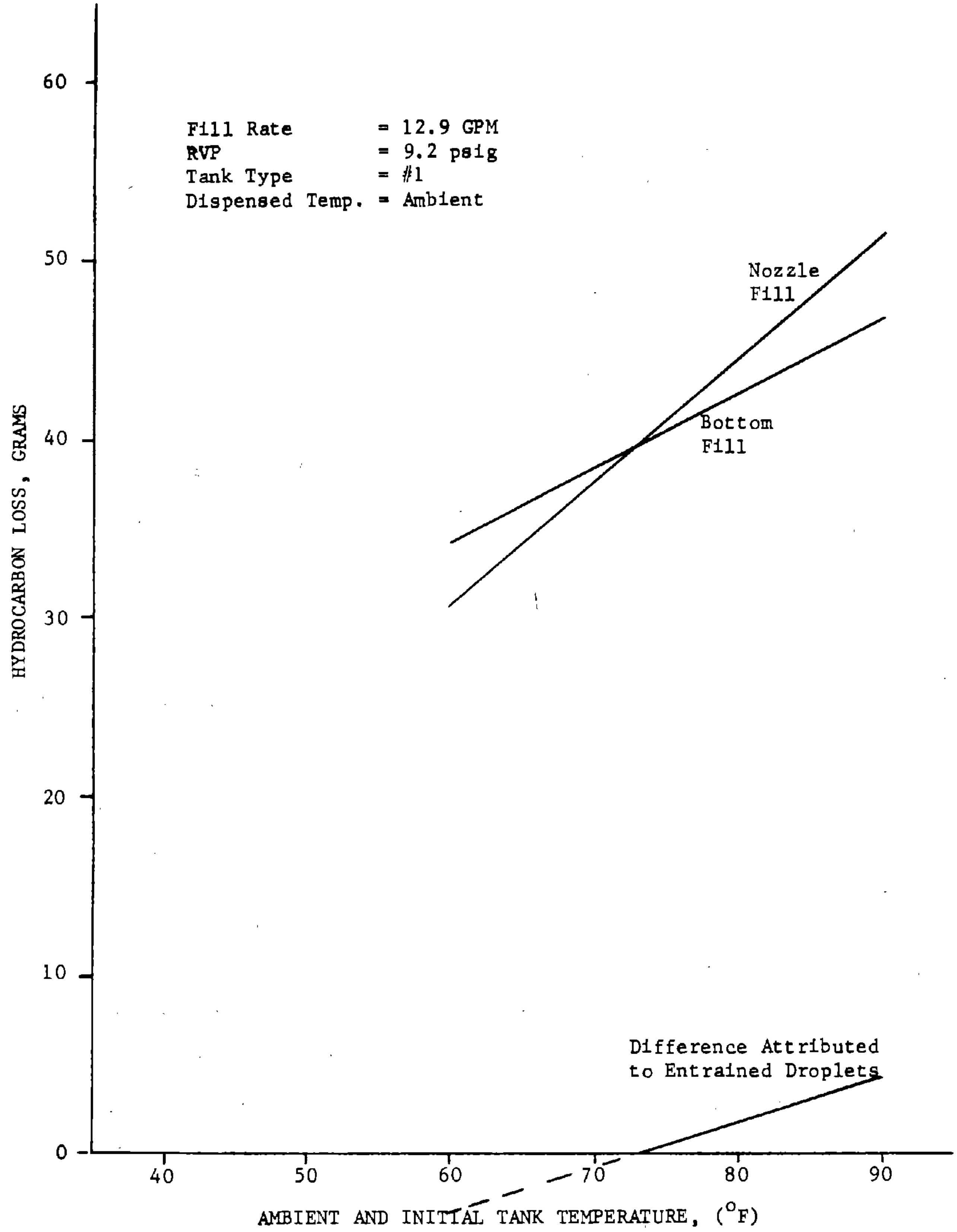

Figure 4.9 Loss Attributed to Entrained Hydrocarbon Droplets Displaced by 10 Gallon Refueling Operations

### 4.1.3 Spilled Liquid Loss

In these experiments complete passenger cars were placed inside the SHED and "average technique"* refueling operations were performed.

The experimental strategy was to collect data from tests in which both displaced losses and spillage occurred and, under the same conditions, to collect data on tests in which only displaced losses occurred; subsequently to eliminate displaced losses from those tests where both losses occurred, to obtain spillage alone. This strategy enables one to account for the hydrocarbon contribution of spilled gasoline.

The weight, in grams, of composite losses was computed from the formula given in Appendix 6.3.

Seventy tests were run in an attempt to gather data on the two eventualities (spill and vapor, vapor only) for eight vehicles. In each test the gallonage of fuel dispensed was recorded. From this data a factor was developed for the vapor weight displaced per gallon dispensed. This factor was computed as an average over all tests without spillage for a given tank type:

$$F = \left(\frac{1}{n}\right) \sum^{n} \left(\frac{\text{Wt.}}{\text{Gal.}}\right)$$

Where, n = Number of tests without spillage, in the tank type

and, F = Average displaced vapor weight per gallon dispensed.

This factor was then applied to the gallonage dispensed in each test in which spillage occurred, and subtracted from the composite loss to give spillage alone.

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* Described in Section 2.2.2.

4.1.3 Spilled Liquid Loss - continued

Spill test results are presented in Table 4.2, for each of eight vehicles. It will be noted that spillage was not achieved for some types. The averaged spillage is shown as the last entry in each type. Table headings are as follows:

TANK = Coded Tank Type
SPILL = Spillage in grams (computed: Total-Displ)
DISPL = Displaced vapor loss in grams (computed: Factor "F" x gal.)
TOTAL = Composite spill and displaced vapor loss in grams (computed)
TSHED = Ambient temperature inside SHED in $^{o}R$
COL # = Column (test) number

These test results are summarized in Table 4.3. The minimum, maximum, and average spill weight observed for each tank tested are tabulated against the individual filler pipe designs.

Liquid spill test results presented in Table 4.2 and summarized in Table 4.3 reflect FID measurements taken in the SHED 30 minutes after the spill had been precipitated. As mentioned in the note in Section 2.2.2, page 2-6 of this report, only about 75% of a spilled liquid volume actually evaporated into the SHED and was accounted for on the FID. These test results should be treated accordingly.

Table 4.2 Spilled Gasoline Test Results from "Average Technique" Refueling Operations

| | Measured (Grams)* | | | TSHED | |
|---|---|---|---|---|---|
| TANK | SPILL | DISPL | TOTAL | °R | COL |
| 1 | 62.8 | 15.6 | 78.4 | 518 | 37-01 |
| | 41.0 | 17.9 | 58.9 | 528 | 37-02 |
| | 27.7 | 15.3 | 43.1 | 529 | 37-03 |
| | 72.9 | 15.9 | 88.9 | 537 | 37-04 |
| | 96.9 | 17.2 | 114.2 | 538 | 37-05 |
| | 29.3 | 15.9 | 45.3 | 540 | 37-06 |
| | 32.7 | 15.6 | 48.3 | 537 | 37-07 |
| 1 | 51.9 AVERAGE | | | | |
| 1A | No Spills Observed | | | | |
| 2 | 14.6 | 20.8 | 35.5 | 519 | 38-01 |
| | 11.0 | 21.6 | 32.6 | 520 | 38-02 |
| | 28.8 | 20.0 | 48.9 | 523 | 38-03 |
| | 19.6 | 20.4 | 40.0 | 532 | 38-04 |
| | 14.3 | 22.4 | 36.8 | 537 | 38-05 |
| | 7.6 | 20.8 | 28.4 | 538 | 38-06 |
| | 14.3 | 20.4 | 34.7 | 538 | 38-07 |
| 2 | 15.7 AVERAGE | | | | |
| 2P | 8.0 | 18.3 | 26.4 | 549 | 40-01 |
| | 11.2 | 17.9 | 29.1 | 550 | 40-02 |
| | 4.3 | 20.0 | 24.3 | 550 | 40-03 |
| | 7.1 | 22.0 | 29.1 | 550 | 40-04 |
| | 30.7 | 20.0 | 50.7 | 546 | 40-05 |
| | 1.2 | 20.0 | 21.2 | 534 | 40-07 |
| | 1.1 | 20.8 | 22.0 | 540 | 40-08 |
| 2P | 9.1 AVERAGE | | | | |
| 3 | No Spills Observed | | | | |
| 4 | 4.2 | 15.6 | 19.9 | 537 | 42-08 |
| | 15.7 | 17.3 | 33.0 | 537 | 42-09 |
| | 3.5 | 17.6 | 21.1 | 535 | 42-10 |
| 4 | 7.8 AVERAGE | | | | |
| 5 | No Spills Observed | | | | |
| 6 | No Spills Observed | | | | |

* FID measurement of the evaporated fraction of a spilled liquid volume; estimated to be 75% in 30 minutes. See Section 2.2.2

Table 4.3 Spilled Liquid Losses for "Average Operator Technique"*

| Tank Type | Measured (Grams)** Min. | Max. | Avg. | Fill Pipe Device | Angle From Horizontal | Length, inches | Dia. |
|---|---|---|---|---|---|---|---|
| 1 | 27.7 | 96.9 | 51.9 | No | 20° | 13 | 2 1/8 |
| 1A | 0 | 0 | 0 | Yes | 15° | 8 | 2 1/8 |
| 2 | 7.6 | 28.8 | 15.7 | No | 45° | 16 | 2 1/4 |
| 2P | 1.1 | 30.7 | 9.1 | No | 40° | 10 | 2 1/4 |
| 3 | 0 | 0 | 0 | No | 85° | 1 | 2 1/4 |
| 4 | 3.5 | 15.7 | 7.8 | No | 45° | 8 | 2 1/4 |
| 5 | 0 | 0 | 0 | No | 90° | 4 | 2 1/2 |
| 6 | 0 | 0 | 0 | Yes | 60° | 30 | 2 |

* "Average Operator Technique" defined as:

> Maximum nozzle insertion at a convenient attitude in the fill pipe with the trigger latched in the second tooth; dispense until three automatic cut-offs.

** FID measurement of the evaporated fraction of a spilled liquid volume; estimated to be 75% in 30 minutes. See Section 2.2.2.

### 4.1.3.1 Fill Pipe Configuration

Comparison of spill losses from fuel tanks with no anti-spill devices finds measurable effects related to:

- Fill pipe angle with horizontal
- Fill pipe length
- Fill pipe diameter

Measured spill losses increase as the fill pipe angle approaches the horizontal. Greatest losses among three tanks with fill pipes at about 45° were measured from the longest pipe; the least losses were observed from the shortest. Largest spill losses were measured from the smallest diameter fill pipe; the least losses were observed from the largest diameter pipe.

Spill magnitude may be a function of fill rate into a given fuel tank configuration. Fill rate, as it affects spillage, was excluded from the scope of this investigation.

### 4.1.3.2 Anti-Spill Devices

Devices installed in the filler pipes of two vehicles tested were effective in preventing spill losses during refueling operations. Automatic cutoff of nozzle flow was obtained before any gasoline was lost in every instance tested.

After observing no spills at about 9 GPM (second notch of nozzle latch), the maximum flow rate of about 13 GPM was imposed on these devices. Again no spills were observed. Relative effectiveness of different anti-spill devices and vent tubes were not investigated in this program.

### 4.1.4 Nozzle Drip Losses

In these experiments passenger cars were refueled and nozzle drippings collected as the refueling nozzle was withdrawn from the filler pipe (Post-Fill Nozzle Drip Loss). After a short interval, residual fuel in the nozzle was drained and collected (Residual Nozzle Contents). These residual liquid contents are equal to the maximum potential pre-fill nozzle drip loss.

The weights, in grams, of Residual and Post-Fill losses were computed from the formula:

Wt. = Specific Gravity x Volume Observed

Wt. = 0.744 x cc

Average losses were computed by assigning equal weight to the maximum and minimum losses experienced in a group of tests.

Ninety-five tests were run, gathering data on eight vehicle types and two nozzle withdrawal methods; normal and rotated. In the following tables results are presented for each type and method. Each tank type is presented on a separate page, and an average loss is computed for each handling method within a tank type. Table headings are as follows:

TANK = Coded tank type
METHOD = Normal, Rotated
LOSSES = Collected losses in grams (computed)
   Post-Fill (Lost at Withdrawal)
   Residual (Potential Pre-fill Nozzle Loss)
COL = Column (test) number

Table 4.4 Nozzle Drip Test Results

| Tank | Method | Measured (Grams) |  | Col |
|---|---|---|---|---|
|  |  | Post-Fill | Residual |  |
| 1 | Normal | 53.5 | 0.0 | 43-0 |
|  |  | 68.4 | 0.0 | 43-0 |
|  | AVG. | 61.0 | 0.0 |  |
|  | Rotated | 3.6 | - | 44-0 |
|  |  | 0.3 | - | 44-0 |
|  | AVG. | 2.0 |  |  |
|  | Rotated | - | 52.8 | 45-0 |
|  |  | - | 44.5 | 45-0 |
|  | AVG. | - | 48.7 |  |
| 1A | Normal | 66.2 | 0.0 | 43-1 |
|  |  | 71.4 | 0.0 | 43-2 |
|  | AVG. | 68.8 | 0.0 |  |
|  | Rotated | 0.0 | - | 44-1 |
|  |  | 0.0 | - | 44-2 |
|  | AVG. | 0.0 |  |  |
|  | Rotated | - | 63.2 | 45-1 |
|  |  | - | 63.8 | 45-1 |
|  | AVG. |  | 63.5 |  |
| 2 | Normal | 52.8 | 0.0 | 49-0 |
|  |  | 53.5 | 0.0 | 49-0 |
|  | AVG. | 53.2 | 0.0 |  |
|  | Rotated | 2.3 | - | 50-0 |
|  |  | 0.5 | - | 50-0 |
|  | AVG. | 1.4 |  |  |
|  | Rotated | - | 37.2 | 51-0 |
|  |  | - | 42.4 | 51-0 |
|  | AVG. |  | 39.8 |  |
| 2P | Normal | 57.2 | 0.0 | 61-0 |
|  |  | 51.3 | 0.0 | 61-0 |
|  | AVG. | 54.3 | 0.0 |  |
|  | Rotated | 1.5 | - | 62-0 |
|  |  | 4.4 | - | 62-0 |
|  | AVG. | 3.0 |  |  |
|  | Rotated | - | 49.0 | 63-0 |
|  |  | - | 38.7 | 63-0 |
|  | AVG. |  | 43.9 |  |

Table 4.4 Nozzle Drip Test Results - cont.

| Tank | Method | Measured (Grams) Post-Fill | Measured (Grams) Residual | Col |
|---|---|---|---|---|
| 3 | Normal | 26.0 | 0.0 | 56-0 |
| | | 32.7 | 0.0 | 56-0 |
| | AVG. | 29.4 | 0.0 | |
| | Rotated | 2.1 | - | 57-0 |
| | | 3.6 | - | 57-0 |
| | AVG. | 2.9 | | |
| | Rotated | - | 18.5 | 58-0 |
| | | - | 37.9 | 58-0 |
| | AVG. | | 28.2 | |
| 4 | Normal | 20.0 | 0.0 | 73-0 |
| | | 39.4 | 0.0 | 73-0 |
| | AVG. | 29.7 | 0.0 | |
| | Rotated | 0.7 | - | 74-0 |
| | | 1.7 | - | 74-0 |
| | AVG. | 1.2 | | |
| | Rotated | - | 14.8 | 75-0 |
| | | - | 8.8 | 75-0 |
| | AVG. | | 11.8 | |
| 5 | Normal | 46.0 | 0.0 | 67-0 |
| | | 43.1 | 0.0 | 67-0 |
| | AVG. | 44.6 | 0.0 | |
| | Rotated | 2.1 | - | 68-0 |
| | | 0.3 | - | 68-0 |
| | AVG. | 1.2 | | |
| | Rotated | - | 22.9 | 69-0 |
| | | - | 37.9 | 69-0 |
| | AVG. | | 30.4 | |
| 6 | Normal | 40.1 | 0.0 | 67-1 |
| | | 43.1 | 0.0 | 67-2 |
| | AVG. | 41.6 | 0.0 | |
| | Rotated | 0.1 | - | 68-1 |
| | | 0.1 | - | 68-2 |
| | AVG. | 0.1 | | |
| | Rotated | - | 20.8 | 69-1 |
| | | - | 23.7 | 69-2 |
| | AVG. | | 22.3 | |

### 4.1.4 Nozzle Drip Losses - continued

Equivalent weight in grams of the average Post-Fill Nozzle Drip Loss for each technique and tank type is listed in Table 4.5. Pertinent filler pipe design details are listed for each tank tested.

Equivalent weight in grams of the average residual contents for each technique and tank type is listed in Table 4.6.

Table 4.5 Post-Fill Nozzle Drip Losses

| Tank | Average Grams | | Fill Pipe | |
|---|---|---|---|---|
| Type | Normal | Rotated | Attitude | Dia. |
| 1 | 61.0 | 2.0 | 20° | 2 1/8 |
| 1A | 68.8 | 0.0 | 15° | 2 1/8 |
| 2 | 53.2 | 1.4 | 45° | 2 1/4 |
| 2P | 54.3 | 3.0 | 40° | 2 1/4 |
| 3 | 29.4 | 2.9 | 85° | 2 1/4 |
| 4 | 29.7 | 1.2 | 45° | 2 1/4 |
| 5 | 44.6 | 1.2 | 90° | 2 1/2 |
| 6 | 41.6 | 0.1 | 60° | 2 |

### Table 4.6 Residual Nozzle Contents

| Tank Type | Average Grams | |
|---|---|---|
| | Normal | Rotated |
| 1 | 0.0 | 48.7 |
| 1A | 0.0 | 63.5 |
| 2 | 0.0 | 39.8 |
| 2P | 0.0 | 43.9 |
| 3 | 0.0 | 28.2 |
| 4 | 0.0 | 11.8 |
| 5 | 0.0 | 30.4 |
| 6 | 0.0 | 22.3 |

### 4.1.4.1 Operator Technique

Intuitively, it was expected that careful operator technique (rotated withdrawal) would significantly reduce or prevent nozzle drip losses. This expectation was borne out in these test results.

These data also show that careful technique is most beneficial in reduction of nozzle loss from fill pipes of large diameter and low angle with the horizontal.

### 4.1.4.2 Fill Pipe Attitude

Comparison of post-fill nozzle drip losses finds measurable effects related to the fill pipe angle with the horizontal.

The greatest post-fill nozzle losses after a careless (normal) withdrawal were observed from the lowest angle fill pipes. Conversely, lower post-fill losses could be derived and the greatest residual liquid volume could be retained in the nozzle by careful (rotated) withdrawal technique at these same low fill pipe angles.

### 4.1.4.3 Residual Nozzle Liquid

Residual gasoline contained by the nozzle after careless (normal) and careful (rotated) withdrawals is listed in Table 4.6 by the tank type from which it was obtained. Residual contents were nil after careless withdrawals by definition. Contents after careful withdrawals varied with fill pipe geometry. Between these two extremes lies the potential for pre-fill nozzle drip losses during subsequent refueling operations.

## 4.2 REFUELING LOSS FREQUENCY

### 4.2.1 Preliminary Results

The data obtained in the technician survey was evaluated to determine the following:

- The average amount of fuel acquired during a refueling stop
- The percentage of vehicles that obtain a full tank of fuel
- The effect of obtaining a full tank of fuel or whether or not a post-fill nozzle loss occurs
- The expected distribution of fuel tank configurations among the population

It is not purported that the technician survey is a true representative sample of refueling operations throughout the country. The results, however, can be applied (with restrictions) for the purpose of illustrating basic concepts and defining future survey techniques of greater sophistication.

The results of the <u>technician survey</u> (200 data points) indicate the following:

- $F_{ff}$, the frequency of obtaining a full tank at freeway service stations is 74.3%.
- $F_{fc}$, the frequency of obtaining a full tank at community service stations is 61.5%.
- $F_f$, the overall frequency of obtaining a full tank is 68.5% (137 of 200 observations).
- $G_f$, the average number of gallons obtained at freeway service stations is 11.4.

### 4.2.1 Preliminary Results - continued

- o $G_c$, the average number of gallons obtained at community service stations is 10.6.
- o G, the overall average quantity of fuel obtained is 11.0 gallons.
- o The frequency of occurrence for post-fill nozzle losses is independent of whether or not the vehicle's tank is filled. This statement is based on calculated spill frequencies of 50.3% for tanks filled and 49.2% for tanks not filled to capacity.

The forementioned values are applicable to the overall refueling loss scheme. The integrity of these values is limited by the sample size, geographical area surveyed and possibly climatic or weather influences.

### 4.2.2 Overall Survey Results

All refueling observations (where a full tank of fuel was obtained) were grouped into two categories, freeway service station operations and community service station operations. The frequency of the three types of spill losses was determined for each of the six fuel tank configurations in the two underlined groups.

The three types of spill losses are:

1. Spitback/overfill
2. Pre-fill nozzle loss
3. Post-fill nozzle loss

Results obtained by combining the observations from the employee survey (554 data points) and the technician survey (136 "fill-ups" only) yielded the following:

4.2.2 Overall Survey Results - continued

- o Total observations - 690
- o Overall frequency of overfill/spitback - 26.1%
- o Overall frequency of pre-fill nozzle losses - 8.6%
- o Overall frequency of post-fill nozzle losses - 34.2%

Table 4.7 shows how the forementioned values were broken down by type of service station and fuel tank configuration. Table 4.8 presents the results categorized by fuel tank configuration only.

From Table 4.7 it can be seen that there exists differences between the frequencies of certain spill losses for freeway and community service stations (of the same tank type). These differences show no consistent trend which would indicate either type of station as being more prone to refueling losses than the other. The total (average) frequencies for the three types of losses agree quite well between the two types of service stations possibly indicating that the sample size associated with each sub-group was smaller than desired.

Table 4.8 shows the distribution of spill loss frequencies after combining the results from both the freeway stations and the community stations. This figure best illustrates the refueling loss picture. Therefore, the ensuing discussion will be based on values taken from Table 4.8.

Spitback/Overfill: This phenomenon is believed to be a function primarily of fuel system design and nozzle performance, operator technique not being a significant factor. It is possible, however, that less than optimum insertion of the nozzle into the filler tank could affect a spitback in an otherwise spill-free system.

## Table 4.7 Refueling Loss Frequencies For All Observations Where a Full Tank of Fuel Was Obtained

| Tank Type | Overfill/Spitback | Nozzle Losses Pre-Fill | Nozzle Losses Post-Fill | Sample Size |
|---|---|---|---|---|
| Community Service Stations | | | | |
| 1 | 0.249 | 0.118 | 0.408 | 245 |
| 2 | 0.269 | 0.075 | 0.373 | 67 |
| 3 | 0.250 | 0.105 | 0.276 | 76 |
| 4 | 0.265 | 0.000 | 0.306 | 49 |
| 5 | 0.161 | 0.000 | 0.194 | 31 |
| 6 | 0.316 | 0.105 | 0.368 | 19 |
| TOTAL | 0.250 | 0.090 | 0.357 | 487 |
| Freeway Service Stations | | | | |
| 1 | 0.296 | 0.065 | 0.259 | 108 |
| 2 | 0.345 | 0.069 | 0.483 | 29 |
| 3 | 0.321 | 0.071 | 0.393 | 28 |
| 4 | 0.294 | 0.000 | 0.235 | 17 |
| 5 | 0.000 | 0.181 | 0.273 | 11 |
| 6 | 0.200 | 0.200 | 0.200 | 10 |
| TOTAL | 0.261 | 0.074 | 0.305 | 203 |

### Table 4.8 Refueling Loss Frequencies For All Observations Where a Full Tank of Fuel Was Obtained

| Tank Type | Overfill/Spitback | Nozzle Losses Pre-Fill | Nozzle Losses Post-Fill | Sample Size |
|---|---|---|---|---|
| All Observations | | | | |
| 1 | 0.264 | 0.102 | 0.362 | 353 |
| 2 | 0.292 | 0.073 | 0.407 | 96 |
| 3 | 0.269 | 0.096 | 0.308 | 104 |
| 4 | 0.273 | 0.000 | 0.288 | 66 |
| 5 | 0.119 | 0.048 | 0.214 | 42 |
| 6 | 0.276 | 0.138 | 0.310 | 29 |
| TOTAL | 0.261 | 0.086 | 0.342 | 690 |

4.2.2 Overall Survey Results - continued

Referring to Table 4.8, the frequency of spitback/overfill appears to be consistent among the different fuel tank categories with the exception of configuration #5. This category is composed primarily of certain foreign cars with the filler neck opening located under the front deck lid.

Although the frequencies of spitback/overfill all appear to be in the .26 to .29 range (except configuration #5), laboratory tests indicate that losses from configuration #1 vary considerably. This category includes a large segment of the automotive population which has a generally flat fuel tank, located beneath the trunk, and a low filler neck opening, usually behind the license plate. One vehicle with this type fuel tank was observed to spitback consistently during laboratory tests while another vehicle of the same apparent configuration could not be made to spitback at all. It is assumed that similar results (variations in performance) would have been encountered with other fuel tank configurations if more vehicles could have been evaluated.

The concept of classifying the vehicles by the external shape of their fuel tank and filler neck will have to be investigated more completely in the future. It is presumed that the existence of internal preventative devices in the filler neck and other subtle design factors in this area are the primary influence in preventing losses of this type, rather than external shape.

4.2.2 Overall Survey Results - continued

Pre-Fill Nozzle Losses: Losses of this type were observed infrequently as indicated by the average frequency of occurrence (.086). Values for different fuel tank configurations ranged from .000 (type #4) to .138 (type #6).

Pre-fill nozzle losses are thought to be primarily attributed to operator technique. Vehicles with body panels adjacent to the filler neck opening sometimes create accessibility problems which would result in a higher probability of pre-fill nozzle losses occurring.

Post-Fill Nozzle Losses: Post-fill nozzle losses are related to both operator technique and filler neck location. With the exception of tank type number 5, the frequency of post-fill nozzle losses ranges from .288 (type number 4) to .407 (type number 2). Type number 5 indicated a loss frequency of only .214. Due to the underhood filler opening associated with many vehicles of this type, it is presumed that station attendants use more caution upon withdrawing the nozzle from these vehicles as fuel would essentially be spilled inside the trunk area.

With most vehicles evaluated in the laboratory, withdrawal of the nozzle from the filler pipe could be effected with no spillage if precautions (rotating the nozzle) were taken. The magnitude of the values in this category appears to be primarily related to less than optimum operator technique.

# 5. CONCLUSIONS

## 5.1 SIGNIFICANT FACTORS CONTRIBUTING TO REFUELING LOSS

This investigation determined that some of the parameters studied significantly affect the magnitude and frequency of refueling losses while others do not.

Those factors which were found to have no significant effect by themselves are:

- o Tank Shape (exclusive of fill pipe)
- o Fill rate
- o Ambient temperature

The following factors did affect refueling losses and their relative effects are discussed in Section 4.

- o Dispensed quantity
- o Reid vapor pressure
- o Dispensed gasoline temperature
- o Operator technique
- o Fill pipe design

# 6. APPENDIX

## APPENDIX 6.1 TEST GASOLINE ANALYSIS

Throughout the test program, samples of all gasolines used were taken for subsequent analysis. Ethyl Corporation performed the following RVP, ASTM distillation, and hydrocarbon analyses, on liquid samples taken from subject fuel tanks during the test procedure. Scott Research Laboratories performed the gas chromatographic analyses on vapor samples taken from filler pipes while gasoline was being dispensed.

APPENDIX 6.1 TEST GASOLINE ANALYSIS - continued

| Loss | Displaced | | | | | | | | | Spill & Nozzle Drip | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Test No. | 1-18 | | | | 19-36 & 101-108 | | | | 79-96 | 37-78 | |
| Sample | A | B | C | E | D | F | G | H | I | J | K |
| RVP | 7.0 | 7.2 | 7.0 | 7.6 | 9.8 | 8.9 | 9.3 | 8.8 | 9.8 | 8.1 | 9.0 |
| RVP Average | 7.2 | | | | 9.2 | | | | 9.8 | 8.6 | |
| Hydrocarbon Analysis | | | | | | | | | | | |
| % Aromatics | 36.3 | | | | 31.9 | | | | 32.4 | 28.0 | 28.5 |
| % Olefins | 11.0 | | | | 7.6 | | | | 8.4 | 5.4 | 5.5 |
| % Saturates | 52.7 | | | | 60.5 | | | | 59.2 | 66.0 | 66.0 |
| ASTM Distillation | | | | | | | | | | | |
| Initial Boiling Point, °F | 101 | | | | 90 | | | | 91 | 95 | 92 |
| 5% Evaporated, °F | 123 | | | | 101 | | | | 108 | | |
| 10% Evaporated, °F | 134 | | | | 114 | | | | 127 | 136 | 133 |
| 15% Evaporated, °F | 142 | | | | 123 | | | | 142 | | |
| 20% Evaporated, °F | 150 | | | | 131 | | | | 158 | | |
| 30% Evaporated, °F | 167 | | | | 150 | | | | 187 | | |
| 50% Evaporated, °F | 214 | | | | 201 | | | | 234 | 221 | 223 |
| 90% Evaporated, °F | 353 | | | | 358 | | | | 343 | 313 | 319 |
| Final Boiling Point, °F | 424 | | | | 423 | | | | 411 | 398 | 399 |
| Slope | 1.9 | | | | 2.2 | | | | 3.4 | | |
| Recovery, % | 98.0 | | | | 98.0 | | | | 97.5 | 98.0 | 98.0 |
| Loss, % | 0.9 | | | | 0.9 | | | | 1.4 | 1.0 | 1.0 |
| GC Analysis | | | | | | | | | | | |
| $C_x$ | $C_{4.46}$ | | | | $C_{4.79}$ | | | | $C_{4.42}$ | | |
| $H_y$ | $H_{10.71}$ | | | | $H_{11.04}$ | | | | $H_{10.61}$ | | |
| H/C Ratio | 2.40 | | | | 2.31 | | | | 2.40 | 2.31 | |
| Mol. Wt. | 64.3 | | | | 68.5 | | | | 63.7 | | |

APPENDIX 6.2 TEST PROCEDURES

## REFUELING LOSSES
## TEST PROCEDURE

Date: 7-10-69

Revision: 11-21-69

### I. Vapor Loss Test Conditions 1-36 and 79-96

1.0 Set up test apparatus as shown in Figure 1.

1.1 Place Mini-SHED Assembly in controlled temperature room.

1.2 Place one drum of the specified Reid Vapor Pressure fuel and one clean empty drum in a position conducive to rapid conditioning to the controlled ambient temperature.

1.3 Position the Scott Model 403 Fuel Conditioning System for convenience to the Mini-SHED and fuel drums. Primary attention must be directed against recirculation of explosive gases in the controlled temperature room and unnecessary hydrocarbon additions to the SHED background. Secure static ground cable from the cart to any tanks or drums with which it is exchanging gasoline. Observe NO SMOKING rule.

1.4 Fill the conditioning cart from another drum of the same Reid Vapor Pressure specified in 1.2 above.

1.5 Condition fuel in 1.4 above to 60°F. Record conditioned fuel temperature.

2.0 Establish Conditions for Respective Test.

2.1 Raise Mini-SHED skirt. Control the ambient air and fuel drums to the ambient temperature specified in the test matrix.

2.2 Transfer fuel from the full drum (in 1.2 above) into the auto gas tank specified. Then return 11.0 gallons to the same fuel drum. The fuel remaining in the auto tank shall be called tare fuel.

APPENDIX 6.2 TEST PROCEDURES - continued

2.3 Obtain a tare fuel sample by the displaced water technique for subsequent exact RVP measurement. Take sample only when so directed in matrix.

2.4 Verify that the specified tare fuel temperature is established.

3.0 Background Concentration

3.1 Plug auto tank vent, cap the fill neck and cork the filler nozzle.

3.2 Operate the temperature recorder and flame ionization detector recorder throughout procedures 3.3 to 4.5.

3.3 Calibrate FID.

3.4 Observe for a stable ambient hydrocarbon concentration Record the ambient and tare fuel temperatures, and ambient pressure.

3.5 Secure the Mini-SHED skirt in the water seal.

3.6 Observe for a stable background hydrocarbon concentration and record on test sheet. Also record bag differential pressure and Mini-SHED interior temperature.

4.0 Refueling Loss Concentration

4.1 Unplug tank vent, uncap fill neck and uncork filler nozzle.

4.2 Observe for a stable open tank hydrocarbon concentration.

4.3 Dispense 10 gallons of 60°F conditioned fuel through the fill nozzle into the auto tank at the specified fill rate. The automatic nozzle passes about 6 GPM when latched in the first tooth; 15 GPM in the third tooth. Observe for no fuel "Spit-back" out of fill neck.

4.4 Upon completion of the 10 gallon fill operation, perform the following procedure without hesitation:

4.4.1 Remove the nozzle from the filler neck, taking care to avoid any fuel spillage.

4.4.2 Plug auto tank vent, cap the fill neck and cork the filler nozzle.

APPENDIX 6.2 TEST PROCEDURES - continued

4.5 Observe for a stable refueling loss hydrocarbon concentration and record on test sheet. Also record bag differential pressure and Mini-SHED interior temperature.

5.0 Purge

5.1 Raise the Mini-SHED skirt and permit the controlled ambient air to purge the SHED interior of all displaced hydrocarbon vapors.

5.2 Sump pump all fuel from the auto gas tank into the empty fuel drum (in 1.2 above) for temporary storage and reconditioning to the controlled ambient temperature.

6.0 Second Fill Rate

6.1 Repeat procedures 2.0 through 5.2 above for the second fill rate.

7.0 Subsurface Fill

7.1 Repeat procedures 2.0 through 5.2 with following exceptions:

7.1.1 In procedure 4.1, unplug the tank vent and uncap fill neck ONLY. Do not uncork filler nozzle.

7.1.2 In 4.3, dispense 10 gallons of 60°F conditioned fuel through the pipe fitting in the bottom of the auto tank at the same fill rate as recorded in 6.1 above.

7.1.3 Delete 4.4.1.

7.1.4 In 4.4.2, plug auto tank vent and cap the fill neck ONLY. The filler nozzle was not uncorked in 7.1.1 above.

8.0 Test Matrix

8.1 Adjust test conditions as described in the test matrix for vapor losses and repeat the above procedures 2.0 through 7.1.4, where applicable, for the remaining 36 test conditions.

APPENDIX 6.2 TEST PROCEDURES - continued

8.2 In 5.2 above, continue to sump pump fuel into the temporary storage drum until it is full. Then sump pump into the other empty drum originally used to fill the conditioning cart.

8.3 In 2.2 above, continue to transfer fuel from the originally full drum into the auto gas tank until it is exhausted. Then transfer from the, now full, temporary storage drum used to recondition fuel to the controlled ambient temperature in 5.2 above.

8.4 When all the fuel has been dispensed from the conditioning cart in 4.3 above, refill the cart from the "now full" drum from which the cart was originally filled. Do not dispense again until the fuel has been reconditioned to $60^{\circ}$F.

## II. Spill Loss Test Conditions 37-42

9.0 Set up test apparatus as shown in Figure 2.

9.1 Assemble SHED in protected area capable of garaging automobiles.

9.2 Fill the conditioning cart with fuel of the specified Reid vapor pressure.

9.3 Condition fuel in 9.2 above to $60^{\circ}$F. Obtain one fuel sample by the displaced water technique from each barrel of gasoline used in the spill tests.

9.4 Identify and locate an automobile with the fuel tank shape and location specified in the test matrix. Remove air cleaner and seal carburetor in plastic bag. Measure and record length, width, and height of automobile.

9.5 Open SHED entrance and push automobile into SHED taking care not to damage entrance zipper. Close windows, doors, and trunk lid of automobile.

9.6 Calibrate FID before each test.

## APPENDIX 6.2 TEST PROCEDURES - continued

### 10.0 Perform Liquid Spill Test

10.1 Fill the automobile fuel tank with gasoline and then remove five gallons. Replace the tank cap and wipe up any gasoline spillage.

10.2 With the SHED entrance open, operate the purge fan until the ambient hydrocarbon concentration is negligible.

10.3 Connect static cable from the nozzle to the automobile. Observe the NO SMOKING RULE. Turn off purge fan and secure the SHED entrance and foot door zippers. Record barometric pressure.

10.4 Operate the FID recorder throughout procedures 10.5 to 10.9.

10.5 Observe for a stable background hydrocarbon concentration. Record the background concentration, SHED temperature, and bag differential pressure.

10.6 Uncap the fuel tank fill neck, uncork filler nozzle and insert nozzle in fill neck. Avoid pre-fill nozzle spillage.

10.7 Squeeze trigger, latch in second tooth and dispense fuel in a conventional manner until the automatic nozzle trips off for the first time. Again, squeeze the trigger but now without latching and continue to dispense for a total of three automatic trip-offs. Make no attempt to prevent a spill during the above procedure.

10.8 Without hesitation, remove nozzle while avoiding post-fill nozzle drip. Cork the nozzle and cap the fill neck.

10.9 Observe for a stable hydrocarbon concentration on the FID recorder. Record hydrocarbon concentration resulting from the total spill, bag differential pressure, and SHED interior temperature on the test sheet. Turn off sample pump until a stable reading can be obtained. Complete evaporation of the total spill must be observed.

10.10 Record total gallons of gasoline dispensed in 10.7 above.

APPENDIX 6.2 TEST PROCEDURES - continued

11.0 Measure Vapor Displaced During Spill Test

11.1 Fill the automobile fuel tank with gasoline and then remove six gallons. Replace the tank cap and wipe up any gasoline spillage.

11.2 Repeat procedures 10.2 through 10.10 except that in 10.7, dispense only as many gallons of gasoline as recorded in 10.10 above and make every attempt to prevent a spill during this fill procedure. Void and repeat this measurement if a spill does occur.

11.3 Open SHED entrance and foot door, and operate purge fan. Pull automobile out taking care not to damage zipper, gasoline hoses or thermocouple leads.

11.4 Clean up any oil or fuel spillage. Inspect for and repair any damage to SHED enclosure.

11.5 With the SHED entrance and foot door open, operate the purge fan until the background hydrocarbon concentration is negligible.

12.0 Repeat Spill Tests on Other Automobiles

12.1 Identify and locate additional automobiles with the other fuel tank shapes and locations specified in the test matrix.

12.2 Repeat procedures 9.4 to 11.5 above for each automobile.

## III. Post Nozzle Loss Test Conditions 43-78

13.0 Set up test apparatus as shown in Figure 3.

13.1 Identify and locate an automobile with the fuel tank shape and location specified in the test matrix.

13.2 Fill the conditioning cart and condition the fuel to 60°F. Obtain specific gravity of each barrel of fuel used.

14.0 Normal Attitude Losses

14.1 Remove two gallons of gasoline from the previously full automobile tank.

APPENDIX 6.2 TEST PROCEDURES - continued

14.2 With the automatic nozzle trigger latched in the first tooth, dispense fuel back into the tank until three automatic trip-offs have been performed.

14.3 Immediately after the third trip-off, place the funnel and graduate under the tank fill neck and withdraw the nozzle. Do NOT rotate nozzle from normal attitude during withdrawal, but capture all the liquid which escapes from the nozzle.

14.4 Record collected liquid volume on test sheet.

15.0 Rotated Nozzle Losses

15.1 Repeat procedures 14.1 through 14.4 with the following exception:

15.1.1 During withdrawal in 14.3 above, ROTATE the nozzle making every attempt NOT to lose liquid from the spout. Capture any liquid that does manage to escape, and record volume on test sheet.

15.2 Immediately proceed to 16.0 below.

16.0 Residual Nozzle Losses

16.1 Immediately after collecting inverted losses in 15.1.1 above, point nozzle down into another graduate and collect the liquid remaining in the spout.

16.1.1 Record residual liquid volume on test sheet.

16.2 Remove one gallon of fuel from automobile tank, dispense fuel back into tank until third trip-off and withdraw while rotating nozzle in an attempt NOT to lose liquid. Hang nozzle in vertical position.

16.2.1 After five minutes in the vertical position, point nozzle down into a graduate, and collect and record the liquid remaining in the spout.

16.3 Repeat 16.2 above.

16.3.1 Repeat 16.2.1 above, after ten minutes instead of five.

APPENDIX 6.2 TEST PROCEDURES - continued

16.4 Repeat 16.2 above.

16.4.1 Repeat 16.2.1 above, after fifteen minutes instead of five.

17.0 Identify and locate automobiles with the remaining fuel tank shape and locations specified in the test matrix.

17.1 Repeat procedures 14.0 through 16.4.1 for each of the additional auto types.

REFUELING LOSSES TEST SHEET NO.__________ TECHNICIAN____________________ DATE____________

I. VAPOR LOSSES

| | | | TEST CONDITIONS 1-36 | | | | |
|---|---|---|---|---|---|---|---|
| PARA. | OBSERVATIONS | UNITS | | | | | |
| 1.2 | RVP, Nominal | psig | | | | | |
| 1.3 | Secure Static Cable | Yes/No | | | | | |
| 1.3 | Observe - NO SMOKING - Rule | Yes/No | | | | | |
| 1.5 | TEMP., Conditioned Fuel | $^oF$ | | | | | |
| 2.2 | SHAPE, Auto Tank | FLAT/RECT. | | | | | |
| 2.3 | Qty., Tare Fuel Sample | qt. | | | | | |
| 3.3 | Calibrate FID | Yes/No | | | | | |
| 3.4 | CONC., HC Ambient | Deflect Scale | | | | | |
| 3.4 | TEMP., Ambient | $^oF$ | | | | | |
| 3.4 | TEMP., Tare Fuel | $^oF$ | | | | | |
| 3.4 | PRESS., Ambient | in. Hg | | | | | |
| 3.6 | CONC., HC Background | Deflect Scale | | | | | |
| 3.6 | PRESS., Bag Diff. | in. $H_2O$ | | | | | |
| 3.6 | TEMP., SHED Background | $^oF$ | | | | | |
| 4.2 | CONC., HC Open Tank | Deflect Scale | | | | | |
| 4.3 | METHOD, Fill | NOZZLE/BOTTOM | | | | | |
| 4.3 | RATE, Fill | mm | | | | | |
| 4.3 | Qty., Fill | gal. | | | | | |
| 4.3 | OBSERVE, "Spit-Back" | Yes/None | | | | | |
| 4.5 | CONC., HC Refueling | Deflect Scale | | | | | |
| 4.5 | PRESS., Bag Diff. | in. $H_2O$ | | | | | |
| 4.5 | TEMP., SHED | $^oF$ | | | | | |

| CALCULATIONS | | | | | | |
|---|---|---|---|---|---|---|
| RVP, Analysis | psig | | | | | |
| TVP | psia | | | | | |
| TEMP., SHED | $^oR$ | | | | | |
| PRESS., SHED | in. Hg | | | | | |
| VOLUME, SHED Net | $Ft^3$ | | | | | |
| RATE, Fill | gpm | | | | | |
| Conc., Refueling<br>Conc., Background<br>Conc., Loss | $ppm_c$<br>$- ppm_c$<br>$ppm_c$ | — | — | — | — | — |
| Wt., Refueling Loss | gms | | | | | |
| Wt., Displaced Loss | gms | | | | | |
| Wt., Entrained Loss | gms | | | | | |
| CALIBRATION | | | | | | |
| ANALYSIS, Calib. Gas | $ppm_3$ | | | | | |
| ANALYSIS, Carbon | $ppm_c$ | | | | | |
| METER Reading Scale | Deflect Scale | | | | | |

REFUELING LOSSES TEST SHEET NO.________ TECHNICIAN__________________ DATE__________________

II. SPILL LOSSES

| PARA. | OBSERVATIONS | UNITS | TEST CONDITIONS 37-42 | | | | |
|---|---|---|---|---|---|---|---|
| 9.2 | RVP, Nominal | psig | | | | | |
| 9.3 | TEMP., Cond. Fuel | °F | | | | | |
| 9.3 | QTY., Fuel Sample | qt. | | | | | |
| 9.4 | Shape/Location Tank | | | | | | |
| 9.6 | Calibrate FID | Yes/No | | | | | |
| 10.1.1 | CONC., Purge | ppm | | | | | |
| 10.1.1 | TEMP., SHED | °F | | | | | |
| 10.1.2 | Secure Static Cable | Yes/No | | | | | |
| 10.1.2 | Observe - NO SMOKING - Rule | Yes/No | | | | | |
| 10.1.2 | PRESS., Barometric | in. Hg | | | | | |
| 10.1.4 | CONC., Background | Deflect Scale | | | | | |
| 10.1.4 | TEMP., SHED | °F | | | | | |
| | SPILL SEQUENCE | NUMBER | | | | | |
| 10.1.8 | CONC., Spill | Deflect Scale | | | | | |
| 10.1.8 | TEMP., SHED | °F | | | | | |
| 10.1.8 | PRESS., Bag Diff. | in. $H_2O$ | | | | | |
| 10.1.8 | Complete Evaporation Observe | Yes/No | | | | | |

| CALCULATIONS | | | | | | |
|---|---|---|---|---|---|---|
| RVP, Analysis | psig | | | | | |
| TVP | psia | | | | | |
| TEMP., SHED | °R | | | | | |
| PRESS., SHED | in. Hg | | | | | |
| VOLUME, SHED net | $Ft^3$ | | | | | |
| Conc., Spill<br>Conc., Previous<br>Conc., Loss | $ppm_c$<br>$- ppm_c$<br>$ppm_c$ | — | — | — | — | — |
| Wt., Spill Loss | gms | | | | | |

| CALIBRATION | | | | | | |
|---|---|---|---|---|---|---|
| ANALYSIS, Calib. Gas | $ppm_?$ | | | | | |
| ANALYSIS, Carbon | $ppm_c$ | | | | | |
| METER Reading Scale | Deflect. X------ | | | | | |

REFUELING LOSSES TEST SHEET NO.__________ TECHNICIAN_______________ DATE_______________

III. POST NOZZLE LOSSES

| | | | TEST CONDITIONS 43-78 | | | | | |
|---|---|---|---|---|---|---|---|---|
| PARA. | OBSERVATIONS | UNITS | | | | | | |
| 13.1 | Shape/Location Tank | | | | | | | |
| 13.2 | Temp., Cond. Fuel | $^{o}F$ | | | | | | |
| 13.2 | Specific Gravity Fuel | | | | | | | |
| 14.3 | Method of Withdrawal | N: Normal<br>R: Rotated | | | | | | |
| 14.4 | Volume, Withdrawal Loss | cc | | | | | | |
| 16.1.1 | Volume, Residual Loss | cc | | | | | | |
| 16.2.1 | Delay Before Collection | Minutes. | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CALCULATIONS | | | | | | | |
| Wt., Withdrawal Loss | gms | | | | | | |
| Wt., Residual | gms | | | | | | |

## APPENDIX 6.3 VAPOR WEIGHT COMPUTATION

Concentration measurements of displaced gasoline vapor and evaporated spills were converted to grams with the following formula:

$$\text{DISPL} = \frac{20.8(12 + H/C)\ C\ V\ P\ 10^{-6}}{T}$$

Where: DISPL = hydrocarbon weight, grams

$20.8 \times 10^{-6}$ = Units correction factor

H/C = Hydrogen carbon ratio

C = Net concentration as carbon, ppm

V = Net enclosure volume, $ft^3$

P = Enclosure pressure, in. Hg.

T = Enclosure temperature, °R

C = Net concentration as carbon, ppm

$$C = \frac{J - B}{W} \times Q$$

Where: J = FID, Refueling loss

B = FID, Background

W = FID, Calibration

Q = ppm, Calibration Gas

APPENDIX 6.3 VAPOR WEIGHT COMPUTATION - continued

Example - Test No. 23-2:

$Q = 29100$ ppm

$W = 95.9$ deflections

$J = 43.7$ deflections

$B = 29.5 \times \frac{30}{3000} = .295$ deflections.

$C = \frac{43.7 - .295}{95.9}\ 29100 = 13160$ ppm

$H/C = 2.31$

$V = 150.5\ ft^3$

$P = 28.56 - 0 = 28.56$ in. Hg.

$T = 60^{\circ}F = 520^{\circ}R$

$$DISPL = \frac{20.8\ (12 + 2.31)\ 13160 \times 150.5 \times 28.56 \times 10^{-6}}{520}$$

DISPL = 32.4 grams

## APPENDIX 6.4 EQUILIBRATED VAPOR CALCULATION

Gram weight calculations for hydrocarbon vapor displaced at the same temperature as ambient were made with the following formula:

$$W = \frac{46.2 \times MW \times MF \times V}{T}$$

Where: MW = Mole Weight of hydrocarbon

46.2 = Units correction factor

V = Volume of vapor, gallons

T = Temperature of ambient and initial tank, $^{\circ}K$

MF = Mole fraction of vapor

$$MF = \frac{TVP}{BAR}$$

Where: TVP = True vapor pressure at T $^{\circ}F$, psia

BAR = Barometric pressure, psia

Example - Test No. 23

MW = 68.5 gm/mole

V = 10 gallons

T = $60^{\circ}F = 288.5^{\circ}K$

TVP = 4.7 psia

BAR = 14.1 psia

$$MF = \frac{4.7}{14.1} = .334$$

$$W = \frac{46.2 \times 68.5 \times .334 \times 10}{288.5}$$

$$= 36.6 \text{ grams}$$