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Technical Report

Evaluation of the Feasibility of Liquid Fillneck Seals

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NOTICE

Standards Development and Support Branch
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I. Introduction/Overview

The only significant uncontrolled source of hydrocarbon emissions from motor vehicles is the gasoline vapor which escapes during vehicle refueling. In an uncontrolled refueling, the vapors that are displaced during the refueling event pass through the fillneck and escape to the atmosphere. Systems designed to control these emissions are called refueling vapor control systems. When the controls are vehicle based, they are generally referred to as onboard vapor recovery systems. The essential ingredients of an onboard vapor recovery system are: 1) a fillneck seal to prevent vapors from escaping to the atmosphere via the fillneck, 2) a fuel tank vent and vapor line from the fuel tank to allow for displacement of refueling vapors, and 3) a method of removing hydrocarbons from the vapors displaced from the fuel tank and storing them for purging at a later time. Normally this is accomplished through the use of a carbon canister.

This report is primarily concerned with fillneck seal portion of the onboard vapor recovery system. Historically, the fillneck seals most often discussed as part of onboard systems are mechanical seals. In a mechanical seal system, a temporary physical barrier is created between the seal and the nozzle when the fuel nozzle is properly inserted into the fillneck (see Figure 1). This barrier (usually referred to as a seal) prevents the vapors from escaping out the fillneck when the fuel is dispensed.

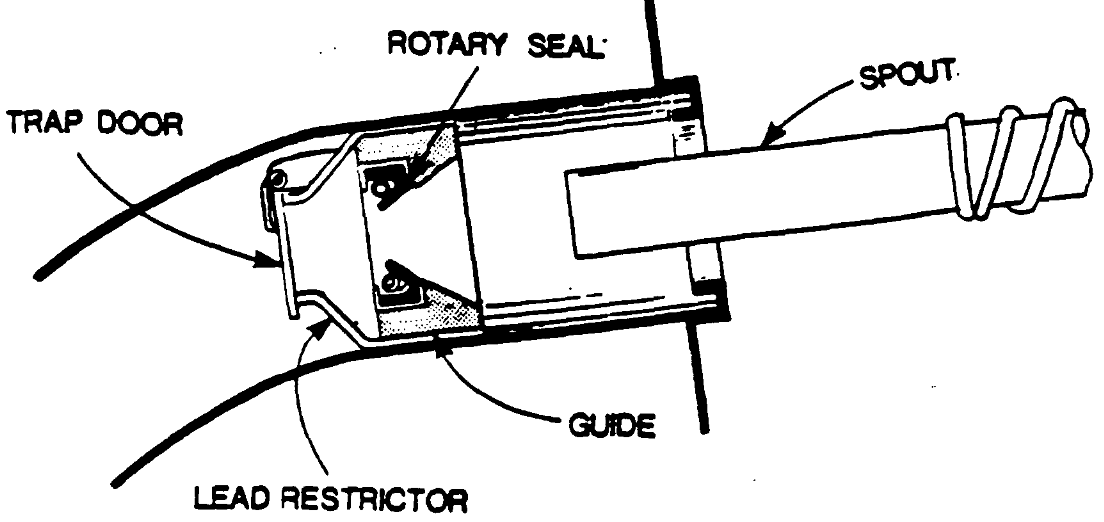
In an extensive development and testing program conducted in 1978, API demonstrated that mechanical seals can effectively prevent vapors from escaping through the fillneck over the useful life of a light-duty vehicle when used under normal conditions.[1] However, some concern has been expressed about the safety, durability, and integrity of the mechanical seal approach.

Concerns about the mechanical seal fall in three areas:

- Fillneck seals may require a pressure relief valve to deal with potential fuel tank overpressures which could occur as a result of failure of the fuel nozzle automatic shut-off mechanism or a blockage in the vapor line between the fuel tank and the carbon canister. Without a pressure relief valve, tank overpressures could result in a fuel spitback with potential fuel tank overpressures.

Figure 1

FILL PIPE MODIFICATIONS
ROTARY SEAL



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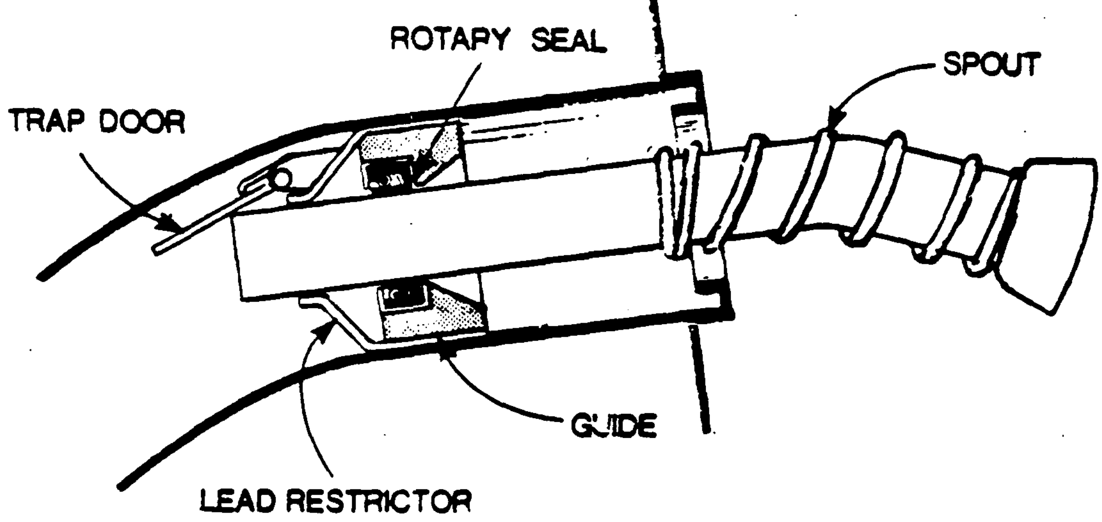


- Under some adverse in-use conditions, a mechanical seal may require maintenance or replacement to retain a high in-use efficiency. This depends in large part on the material used to make the seal and the degree to which the mechanical seal mounting within the fillneck protects it from unusual wear or abuse.

- If not properly designed, the mechanical seal may be susceptible to tampering by the consumer.

Instead of using a mechanical seal in the fillneck, one alternative is the use of a liquid seal. The idea of using a liquid seal in the fillneck was introduced early in the development of onboard vapor recovery systems. A report published in 1973 by the American Petroleum Institute identified and briefly evaluated several different liquid seal concepts.[2] A liquid seal system uses a fillneck design which routes the incoming fuel in such a way that the fuel itself prevents the vapors from escaping via the fillneck.

The use of a liquid seal design would help to eliminate the potential problems associated with a mechanical seal. Since a new seal is formed at each refueling, in use durability and maintenance are not in question. Also, since the liquid seal fillneck is no different in appearance than current fillnecks and the fuel itself forms the seal, liquid seals are essentially tamper-proof. The problem of overpressure during refueling would be eliminated, because fuel would back up in the fillneck as soon as any pressure built up. The fuel nozzle would then either shut off automatically or could be shut off manually, since the nozzle operator could see the overfill condition. In addition, liquid seal systems may be somewhat less costly than mechanical seals since a pressure relief device may not be required.

The purpose of this report is to evaluate the liquid seal approach to fillneck vapor containment as a practical alternative to the more widely recognized mechanical seal. After evaluating several different liquid seal approaches, the performance of one of the liquid seal designs is then evaluated in a simple prototype onboard control system.

The first portion of the report covers evaluation of the liquid seal concepts. It starts with a conceptual analysis of the liquid seal and provides an overview of the experimental and analytical methodology used in the testing. Then it examines each of three basic liquid seal designs individually: the "in-tube" liquid trap, the "J-tube," and the submerged fill. The testing done on each design is outlined and the strengths and weaknesses of each are noted. Next, a problem common to each design, air entrainment and bubble proliferation in the fillneck, is discussed and various methods of controlling these problems are evaluated. The first portion of the report closes with conclusions about the adaptability of these liquid seal designs to current fuel tank fillneck configurations.

The second portion of the report discusses the performance of a crude, first generation liquid seal fillneck (J-tube) on a simple prototype onboard system. It begins with a description of the key components needed for an onboard control system and then describes the components used in EPA's system and how these met the performance criteria needed for the liquid seal. The test procedure used to evaluate the performance of this system in a series of bench tests is described and this is followed by a discussion of the test results including system efficiency and sources of emissions.

The report then closes with some conclusions about the performance of liquid seals and compares them to results achieved for mechanical seals.

II. Evaluation of Liquid Seal Concepts

A. Preliminary Analysis and Experimental Design

1. Introduction

The term "liquid seal" in the context of an onboard vapor recovery system refers to any system of fuel tank and fillneck in which a column of liquid separates in-tank vapor from atmospheric air. One key parameter in evaluating the feasibility and performance of liquid seals is the fill height required to maintain a liquid seal during a refueling event. If the fill height available is less than that needed, the fuel rising in the neck will cause a premature shut-off of the nozzle. One of the major goals in these evaluations was to determine the minimum fill heights necessary to completely refill the tank using liquid seals in the fillneck. This section develops some models which help to predict the manner in which these liquid seals would perform and what fill height might be necessary to make use of a liquid seal as an alternative to a mechanical seal. First, the static situation is discussed and a mathematical model relating fillneck height to tank backpressure in the static situation is presented. Then the dynamic effects that are part of a typical refueling event and that complicate the mathematical model are introduced. Third, an experimental design for testing the various fillneck configurations is outlined. Fourth, the general test procedure for testing the liquid seal concepts is developed.

2. Static Situation

Any liquid trap system can be modeled by the simple 'U' tube system shown in Figure 2. In the static situation, the vertical fill height, h_f, required to support any induced tank backpressure, P_B, can be found using the basic equation of fluid statics. In this case:

$$P_B = P_o + pgh_f, \text{ where}$$

P_B = tank backpressure, gauge
P_o = reference gauge pressure at reference height, h = 0
p = density of fluid in tank
g = acceleration of gravity at test altitude
h_f = required fill height above reference height

For example, to support a backpressure of 5 inches H_2O under static conditions, a gasoline column (specific gravity = 0.72) would have to rise approximately 7 inches above the reference height. So vertical fill height would have to be at least 7 inches. During testing, a water manometer was used to gauge pressure so that pressure could be read directly in inches of H_2O. If fuels were dispensed very slowly, this model could be used to analyze the system. It is not, however, and the next section looks at the dynamic effects of a refueling.

3. Dynamic Effects

A number of factors complicate this model for a typical refueling event. These include:

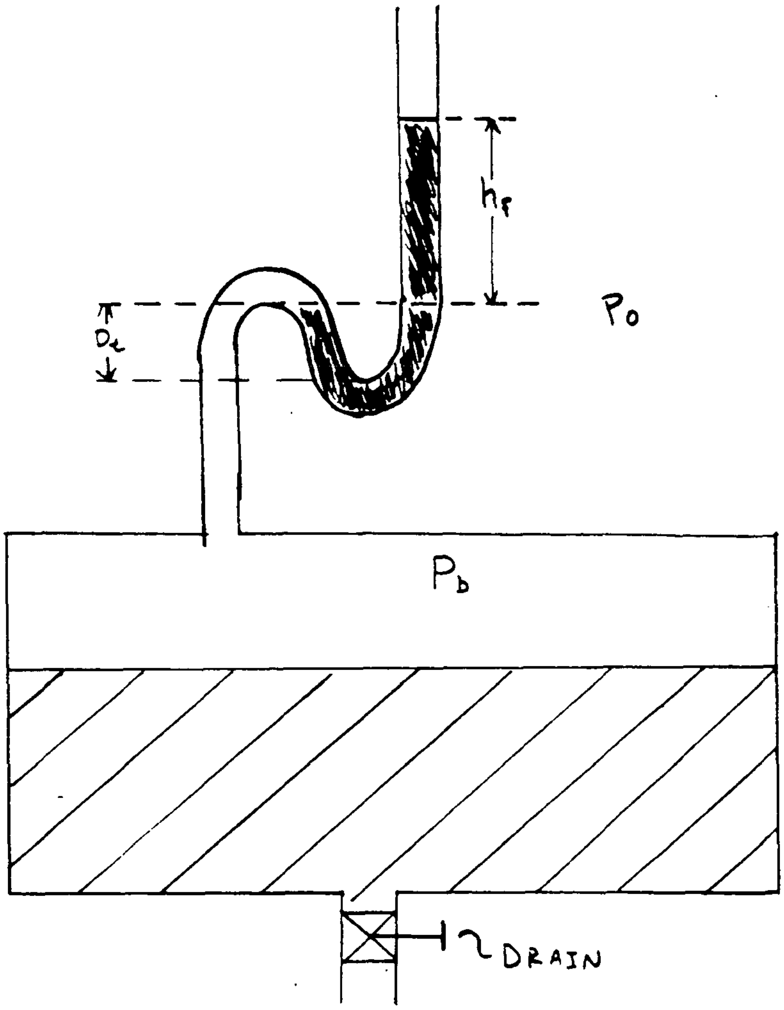
- Dynamics: At a typical gasoline pump fuel is dispensed at a rate of 7-10 gallons/minute (gal/min); thus the system is not static.

- Injection effect: The kinetic energy of the gasoline as it flows out of the dispensing nozzle tends to aid the flow of gasoline into the tank and to reduce the required fill height.

- Turbulence and air entrainment: The interaction between liquid and air in the fillneck is quite turbulent. This interaction tends to greatly increase the required fill height.

Figure 2 - 'U' Tube

P_b = tank backpressure, guage
P_o = o = reference guage pressure
h_f = required fillneck height



Observations during informal testing of the 'U' tube set up of Figure 2, support the intuitive hypothesis that required fill height is directly related to tank backpressure for any given fuel flow rate and fillneck configuration. In the static situation, P_B and h_f are related by a constant conversion factor, the liquid density. In the dynamic situation, the relationship is much more complex, with fluid density, viscosity, surface tension, and other factors all interacting in a highly turbulent flow. In this dynamic, turbulent situation, it was expected that P_B and h_f would vary directly and that an increase in tank backpressure would increase the fill height necessary to support that pressure. A mathematical analysis of such a turbulent, dynamic flow was outside the scope of this investigation, so a mathematical model was not developed. Instead, the relationship between tank backpressure and fillneck height was determined experimentally for the three liquid seals evaluated.

4. Experimental Design

The ultimate goal of the tests conducted by EPA was to compare the performance of a number of liquid seal fillneck configurations under uniform test conditions and procedures. Because the optimal experimental design was not intuitively obvious when testing began, a series of developmental tests were performed with water as the test fluid. These tests were done to evaluate a number of experimental designs without the safety concerns and expense involved with gasoline testing.

These preliminary tests were performed using standard tap water, and fillneck systems were constructed using metal, tygon, and plexiglass. These systems were then attached to a standard automotive fuel tank having a nominal capacity of about 18 gallons. All gasoline tests were performed with indolene clear as the test fluid, and since plexiglass is incompatible with gasoline, systems were built of metal and tygon. The temperature during this testing was the prevailing ambient temperature (nominally 80°F).

The developmental water tests were carried out in a 'U' tube system such as the one described above and diagrammed in Figure 2. Data was taken relating fill height to tank backpressure for different fillneck configurations during these developmental water tests. The numerical results of these tests proved to be of little use in predicting the results of the gasoline testing, however, because of the great differences in the properties of water and gasoline (see Table 1). However, the tests were very helpful in isolating the parameters that would prove critical in determining required

Table 1

Properties of Water and Gasoline at 20°C

Property	Water	Gasoline (n-Octane)
Density (lb/gal)	8.30	5.83
Viscosity (Centipoise)	1.0	0.54
Surface Tension (Dynes/cm)	72.8	21.8

Source: CRC - Chemistry and Physics Handbook and Perry's Chemical Engineering Handbook, 5th Ed.

fillneck height. The qualitative results of this preliminary testing which are important to the experimental design are outlined below:

- The system performed as predicted by the 'U' tube model - required fill height varied directly with tank backpressure.
- Increasing fuel inflow rate increased required fill height. Bubbling caused by the mixing of fluid entering the fillneck with air in the fillneck was observed to increase as dispensing rate increased.
- Changes in fillneck diameter (or volume per unit length) affected required fill heights. Generally, required fill heights increased with decreasing fillneck diameters.
- The orientation of the dispensing nozzle in the fillneck affected fill height. If the nozzle was oriented appropriately, the liquid tended to adhere to the fillneck wall. If this was done, air entrainment and bubbling were reduced leading to a decrease in required fill height.

The results of these tests confirmed that these factors would have to be controlled to ensure consistent test results.

Based on observations during the water testing, the U-tube system appeared to create a very adequate seal. To further evaluate the feasibility of this approach, a "u" was built into a 2-inch plexiglass pipe and tested using water. As will be discussed below, the testing showed that the smaller cross sectional area for flow within the trap required too high a fill height to be practical. However, this experiment revealed useful information on flow and turbulence characteristics.

Based on the experience gained from this preliminary testing and supplemented by information contained in the SAE Recommended Practice regarding refueling emissions, standard test conditions were chosen to test the liquid seal fuel tank systems using gasoline under conditions likely to occur during a typical refueling event.[3] These conditions were used in the tests which evaluated the fill height requirements and other performance aspects of the liquid seals system.

The backpressure was set at five inches H_2O. It is expected that carbon canisters and their accompanying tubing and valves can be designed to accommodate normal refueling rates with tank backpressures of 5 inches H_2O or less. This is supported by experimental evidence presented in an API report dated October, 1978.[1] The report quotes backpressures as low as 2 inches H_2O, at a refueling rate of eight gal/min. All three of the fillneck seal approaches evaluated by EPA were tested at 5 inches H_2O backpressure and most were tested at some lesser backpressures.

Fuel dispensing rate was also standardized. Typical fuel dispensing rates average from 7 to 10 gal/min, but the fuel cart available for use in this testing had a maximum fuel dispensing rate of 7.5 gal/min. Therefore, this was the designated fuel flow rate for gasoline testing.

As was mentioned above, fillneck cross sectional area also affects required fillneck height and had to be standardized. Because most stock fillnecks have an outer diameter of approximately two inches, this was chosen as the base fillneck diameter and tygon or metal tubing of this diameter was used.

Also mentioned above, fuel nozzle orientation can also affect required fill height, but the optimal orientation is different for each fillneck configuration. Also, nozzle orientation is one of the key human factors in vehicle refueling, and may vary significantly from operator to operator and vehicle to vehicle. For these reasons, fuel nozzle orientation was not standardized to minimize fill height. Instead, for each fillneck configuration the nozzle was oriented in the manner that would normally occur in-use if the nozzle were to rest vertically in the fillneck perpendicular to the surface.

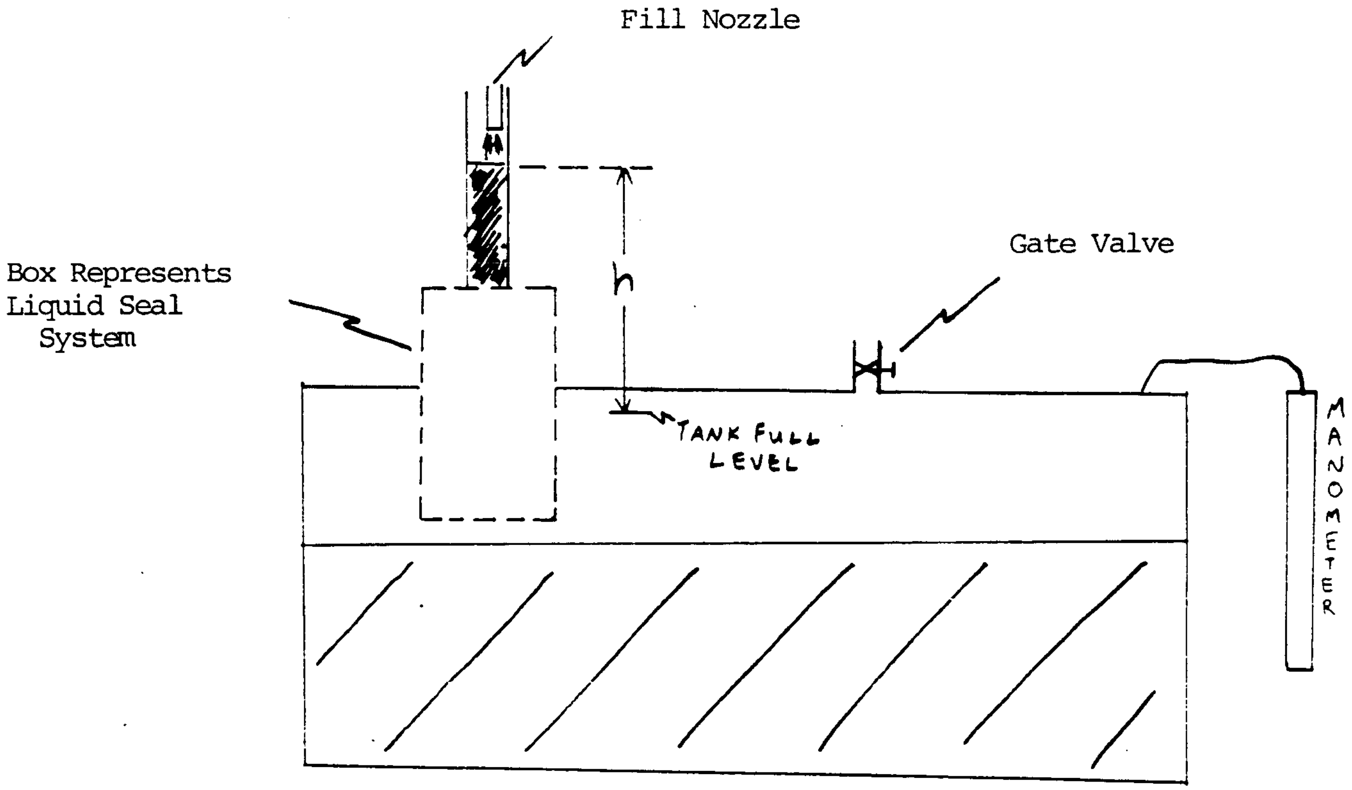
The standard test conditions described above were then incorporated into the standard test procedure developed for the gasoline testing. The standard setup for testing the liquid seal designs is shown in Figure 3. The gate valve mounted on top of the tank was used to regulate the size of the orifice through which any vapor leaving the tank must pass. The backpressure induced in the fuel tank was controlled for any fuel inflow rate by changing the position of the gate valve.

Prior to the start of each test, the manometer was zeroed, the fuel tank was leveled, and the gate valve opened to about one fourth of wide open. The fuel cart was turned on and fuel dispensed at the highest available rate. The gate valve was then closed until backpressure was stabilized at the desired value (initially, 5 inches H_2O). The height of the fluid/bubble column in the fillneck was then measured when backpressure stabilized. This value was recorded as the required fill height. The tank was drained and the operation repeated.

Figure 3

Standard Experimental Setup

h = required fillneck height



At this point, fuel RVP and dispensed and tank temperature were not important. Neither the RVP of the fuel or the fuel temperatures mentioned above were controlled.

The testing of each system generally adhered to the test procedure outlined above, although some details were specific to the individual systems being tested. The most significant difference between individual tests was the measurement of fill height. Fill height can be generally defined as follows:

> The value of the vertical component of a vector from a point on the plane of full tank fuel level to the point where the tip of the dispensing nozzle rests in the fillneck (the vertical distance from the tank full level to the nozzle tip).

The peculiarities of the measurement of fill height for each individual system will be discussed in the sections of this report which deal with the specific designs. It should also be noted here that fill height, as used in this report, <u>does not</u> include the distance from the inserted nozzle tip to the gas cap location. This distance (2-3 inches) would have to be included in any fillneck design.

B. <u>In-Tube Liquid Trap</u>

1. <u>Introduction</u>

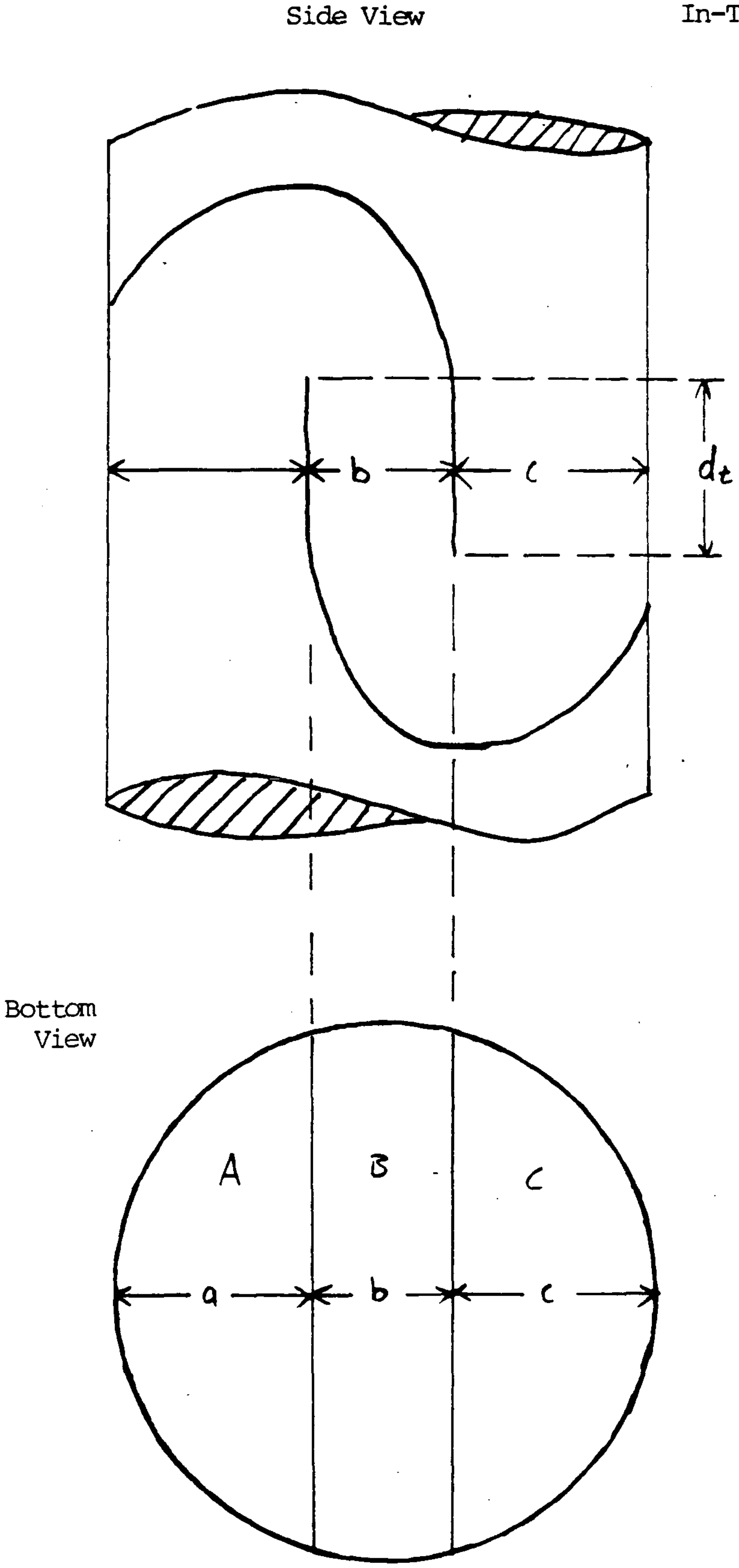
The first liquid seal approach tested was the "in-tube" liquid trap. The in-tube trap was chosen for study because the preliminary water testing showed that the system could provide a positive seal and could be installed by modifying only the fillneck, leaving the tank essentially unchanged. If this were possible, and the fillneck height requirements permitted, the design could be adapted to fit a number of vehicles. This section looks at the in-tube trap and its performance under the standard test conditions.

An in-tube trap in the fillneck operates by creating a liquid barrier between the gasoline vapor in the tank and the atmosphere. Its operation is similar to that of the home sink drain pipe, but the 'U' shaped trap is built into the fillpipe rather than bending the fillpipe into a 'U' shape.

A diagram of the in-tube liquid trap and illustrations of the parameters describing its construction are shown in Figure 4. The trap was designed to divide the tube into three channels of equal cross-sectional area. Liquid is trapped in the upward opening 'U', and if tank backpressure increases

Figure 4

In-Tube Trap



Dimensions

Plexiglass

a = c = 0.73"
b = 0.54"
D = 2.0"

Metal

a = c = 1.1"
b = 0.8"
D = 3.0"

d_t = Trap Depth

A = B = C

during refueling, a liquid column will rise above that 'U' until the pressure is offset. "Trap security" describes the susceptibility of the trap system to allowing vapor to pass through it during the refueling event. Trap security can be increased by increasing the depth of the liquid seal, but increasing this depth might also increase the required fillneck height. Normally, with an in-tube liquid trap, the depth would just need to be adequate to accommodate refueling on sloped terrain. So, to refuel on a 30° incline, a trap depth of one-half inch would be sufficient (for the large trap shown in Figure 4).

Two traps were built for testing. The smaller trap was set in a two inch diameter plexiglass tube. This trap was built so that flow through the trap could be visually monitored during the preliminary water testing. A larger 3 inch diameter trap was built entirely of metal so that gasoline could be used as the primary test fluid.

2. Test Procedures

Figure 5 is a schematic of the experimental setup used to test the in-tube liquid traps. It is important to note the location of the trap in relation to the tank full level. If spatial efficiency were optimized in a production configuration, the trap would actually be at the roof of fuel tank inside the vapor space and, the upward opening 'U' would open at the tank full level. However, for the sake of convenience, these traps were built on top of the tank, and hence required fill height was measured from the top of the upward opening 'U' to the nozzle tip.

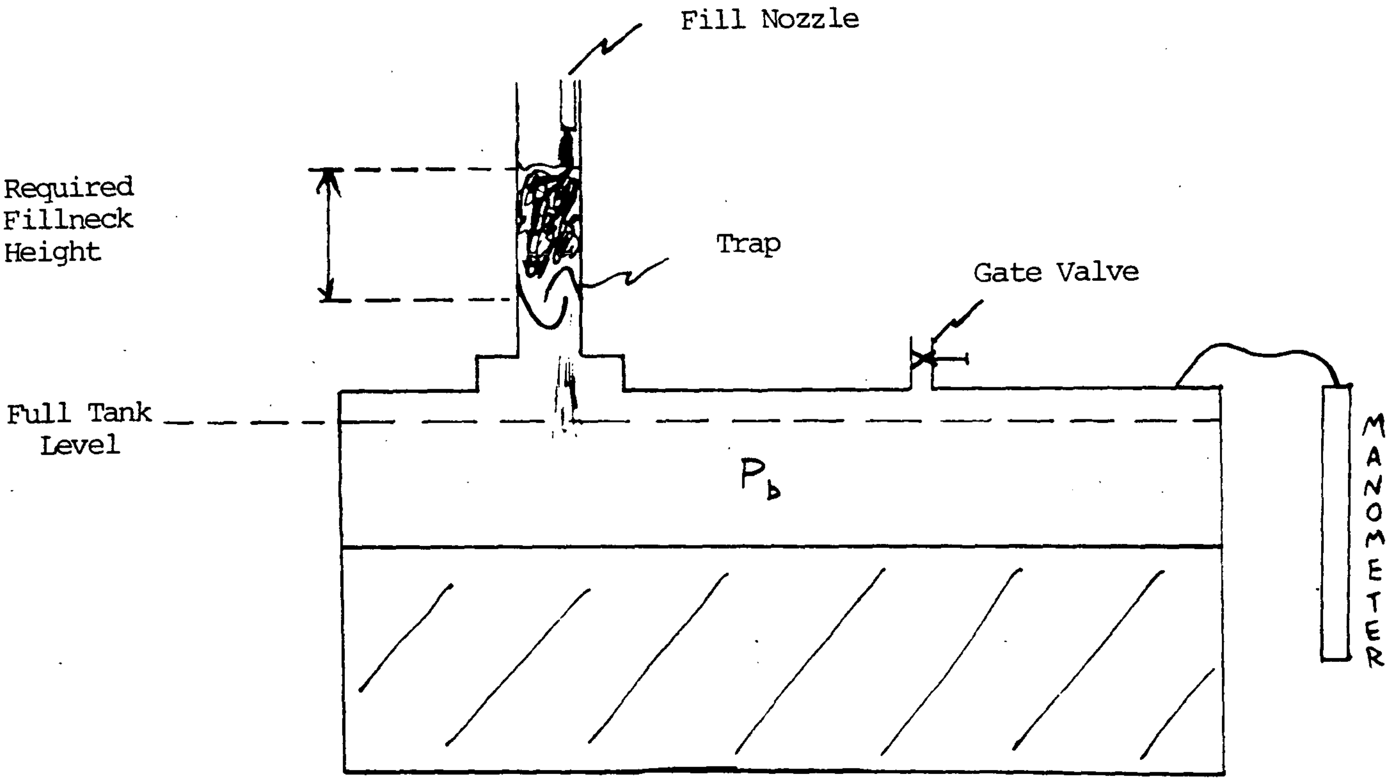
3. Results/Discussion

As was mentioned previously, some of the developmental testing discussed earlier in this report was done on an in-tube liquid trap. The dimensions of that trap are those listed under "Plexiglass" in Figure 4. The developmental testing showed that a trap built inside a 2 inch diameter tube would not be large enough to support a backpressure of 5 inches H_2O. The channels through which liquid was supposed to flow (approximately 1 square inch) simply were not large enough to allow liquid to pass through quickly.

In order to accommodate gasoline and higher flow rates and to reduce required fillneck height, a larger in-tube trap was set in a 3 inch diameter tube. The dimensions of the trap are shown in Figure 4 under "Metal". Using the standard test

Figure 5

Experimental Setup For In-Tube Trap



procedure, the tank was filled with a required fill height of only 11 inches. This is a very good result, considering that in the static situation a neck height of 7 inches would be needed to support a 5 inch H_2O backpressure (5 inches/0.72 = 6.94 inches). The implications of this result are discussed later in the report.

4. Conclusions

A fill height of approximately 11 inches for the in-tube liquid trap is quite acceptable for many vehicle applications. However, the in-tube liquid trap approach has some drawbacks. First, the in-tube trap could be relatively complex to construct on a production basis. Also, since the trap required a 3 inch diameter fillneck to perform adequately under the standard test conditions, current fillpipe designs might have to be modified to accommodate its use.* A 3 inch diameter expansion in some fillnecks may create vehicle packaging problems. However no fuel tank changes would be necessary and the in-tube liquid trap has all the advantages of liquid seal systems that were described above. Packaging problems could be eliminated if the in-tube trap were built into the inside top of the fuel tank. The advantages and disadvantages of the in-tube trap are discussed further following the examination of the other liquid seal approaches.

C. "J" Tube Liquid Seal

1. Introduction

The second liquid seal approach to refueling vapor containment examined was the 'J' tube liquid seal. The 'J' tube was chosen for study because it was a logical extension from the in-tube trap approach and would take only minor changes in fuel tank and fillneck to install and has all the advantages of liquid seals. This section looks at the fill height necessary for the 'J' tube system when evaluated under the standard test conditions.

The 'J' tube system is shown in Figure 6. The 'J' tube is simply a modified 'U' tube (like that shown in Figure 2). The difference is that in the 'J' system the fuel tank itself replaces the downstream, vertical portion of the drainpipe.

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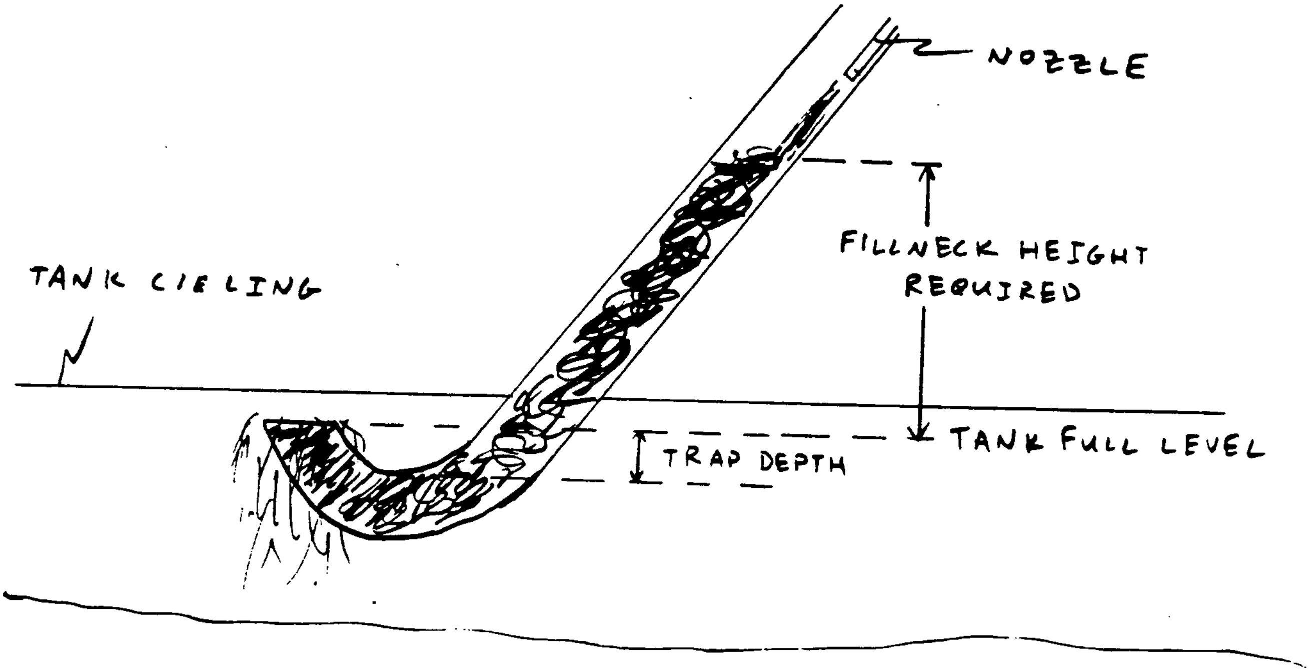
* The ultimate size of the trap and fillpipe diameter needed depend in part on the system backpressure. System backpressure less than the 5-inch H_2O used here are achievable, and would reduce the diameter of the in-tube trap.

Figure 6 - 'J' Tube



The dimensions of the 'J' system along with illustrations of some of the descriptive terms used in the discussion are given in Figure 6. It should be noted that the liquid trap is located inside the fuel tank, and the top of the trap is located on or near the full tank plane. This promotes spatial efficiency and makes maximum use of available fillneck height.

2. Test Procedure

Because the 'J'-tube trap is located inside of the fuel tank and fill height is measured from full tank level to the nozzle insertion point, the standard test method was followed exactly in this case.

3. Results/Discussion

The 'J' tube test results are listed below:

Fuel dispensing rate = 7.5 gal/min.

Backpressure (inches H_2O)	Required Fill Height (inches)
5.0	16.0
4.0	13.5
3.0	11.0

The 16 inches of fill height required to fill the tank at five inches H_2O backpressure was more than expected based on extrapolation of the results of the developmental water tests discussed earlier. Although bubbling, due to the mixing of water with air in the fillneck, was observed during developmental tests, the violence of the bubbling during gasoline testing was not fully expected. The extensive bubbling in the fillneck was the cause of the large required fill heights. It was clear from this testing that if bubbling could be controlled, required fillneck heights could be reduced. This could be managed by reducing the backpressure or controlling the proliferation of bubbles in the fillneck during refueling.

4. Conclusion

The 'J' tube, a simple modification of the 'U' tube, was tested using the standard test method. Excessive turbulence and bubbling in the fillneck made a fill height of 16 inches necessary for refueling under the standard test conditions. The control of the bubble problem, and some methods of fillneck height reduction are discussed in section E.

It is important to note that the 'J' tube trap appeared to be doing its job of controlling emissions. A rough measurement of the hydrocarbon concentration at the fillneck mouth was taken with a lower explosive limit (LEL) meter. The meter showed no difference between the readings taken at the fillneck mouth and readings taken around the test chamber.

D. Submerged Fill

1. Introduction

The third and final liquid seal system investigated was the submerged fill. In a submerged fill system, the fillneck opens into the fuel tank below the liquid surface. By filling the tank from below the surface, a liquid seal is naturally formed between in-tank vapor and atmospheric air.

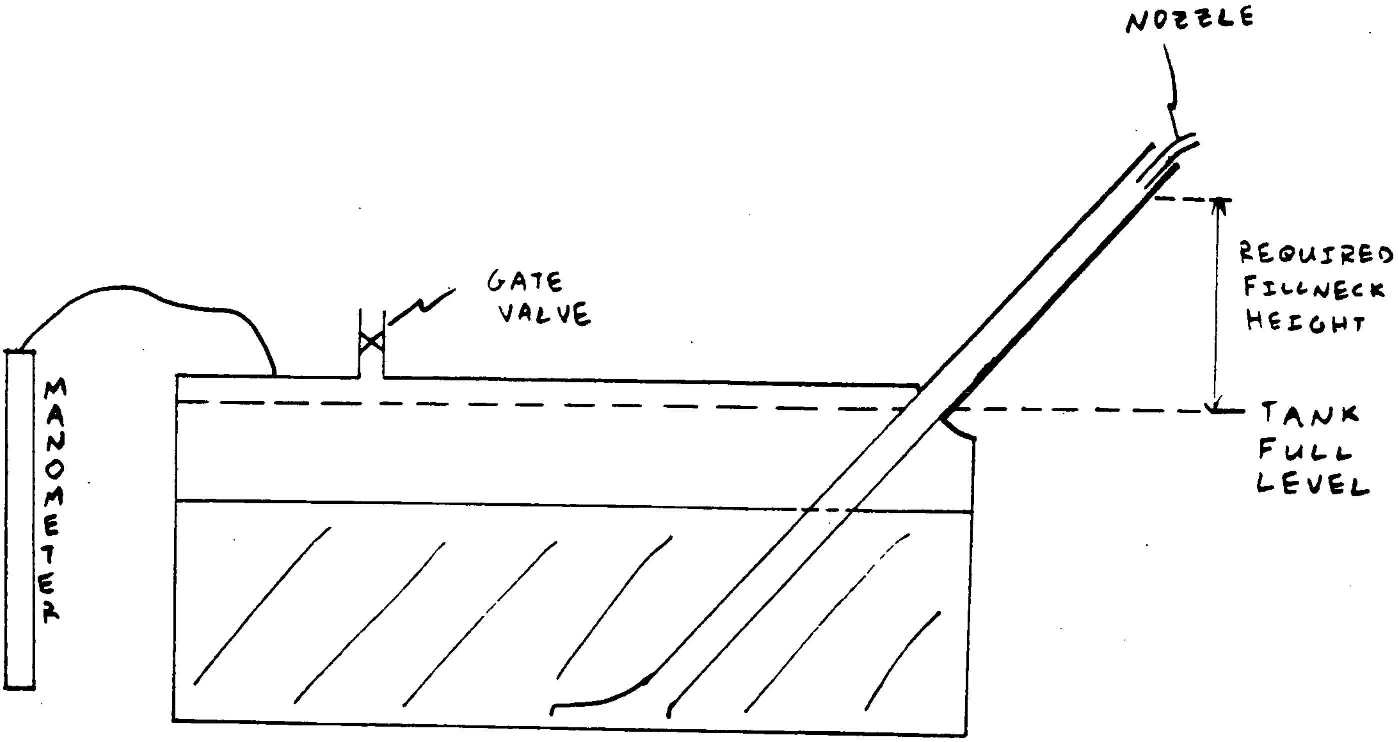
A drawing of a submerged fill system is shown in Figure 7. The significant features of the submerged fill system are listed below:

- The security of the liquid trap is good and it improves as the tank fills.
- A pressure relief valve would have to be incorporated into any submerged fill system. If the lines from fuel tank to carbon canister became blocked, tank pressurization during refueling could become a problem. If the backpressure in the tank rose between refuelings, when the gas cap was removed from the fillneck, the overpressure could cause gasoline to spit out of the neck. The pressure relief valve is needed to eliminate this problem.
- The fillneck height is not critical during the early stages of refueling. Only in the last 10 percent of the fill is the full fill height used, as the back pressure caused by the fuel level in the tank increases.

2. Test Procedure

In a submerged fill system, the location of the top of the liquid trap rises as the tank fills. One major change was made in the standard test procedure to accommodate this unique feature of the submerged fill. Since the top of the liquid trap rises during refueling, the entire fillneck height is only needed during the final stage of refueling; when the top of the trap approaches the full tank liquid level. Therefore required

Figure 7 - Submerged Fill



fill height must be measured just prior to the end of the refueling event. For these tests, fill height was measured when about 18 gallons of fuel had been dispensed (into a nominal 18 gallon tank).

3. Results/Discussion

The results of the testing of the submerged fill system are presented below:

Flow rate: 7.5 gal/min

Backpressure (Inches H_2O)	Required Fill Height (inches)
5.0	16
4.5	13

These results are similar to the results for the 'J' tube, and the bubble problem was evident once again.

There has been some previous work done to evaluate the effectiveness of the submerged fill seal in controlling refueling vapors. Preliminary lab work done by EPA in 1979 found the submerged fill to be an effective method of refueling vapor control.[4] Crude sampling done with an LEL meter supports this finding. Samples taken during refueling from near the mouth of the fillneck showed no higher hydrocarbon concentrations than did background samples.

4. Conclusions

The submerged fill approach was evaluated using the standard test procedure, and required fill height was measured just prior to completion of the refueling. At a backpressure of 5 inches H_2O a fill height of about 16 inches was needed to accommodate the large liquid/bubble column in the fillneck caused by excessive turbulence and air entrainment during refueling.

There are fuel tank fillneck configurations currently in use that could not be easily adapted to accommodate fillneck heights of 16 inches. Since bubbling in the fillneck is the reason for the larger fill heights, a reduction in the bubbling should lead to a lower required fill height. The next section of the report addresses the bubbling problem and possible control techniques.

E. Techniques For Reducing Required Fill Height

1. Introduction

All the liquid seal systems built with 2 inch diameter tubing needed extended fillnecks to accommodate the large gasoline/bubble column that rose above the liquid/air interface in the fillneck during refueling. This section of the report examines bubbling and air entrainment during refueling and evaluates some possible methods of fill height reduction. Bubbling is caused by: 1) the violent mixing of the gasoline leaving the dispensing nozzle with that already in the fillneck, and 2) air entrained in the fluid flow by the venturi system in the dispensing nozzle.

There are three basic means of controlling bubbling in the fillneck through modification of the fillneck. The first is to reduce the violence of the mixing of dispensed fuel with that already in the fillneck. Another is to physically obstruct or direct the backup of bubbles in the neck. The third is to create a system to dissipate the kinetic energy of the dispensed fuel.

Also, part of the bubble problem could be eliminated by reducing the amount of air being entrained in the fuel during refueling. This air entrainment is caused by two phenomena. First, the automatic shutoff venturi system in standard fuel dispensing equipment adds air to the fuel being dispensed. Second, air is entrained in the fuel as a by-product of the turbulence in the fillneck. The second of these two phenomena can be affected by fillneck modifications while the first could only be changed by modifying the nozzle. This section looks at the problems of air entrainment and bubbling, and examines some fillneck modifications designed to control bubbling and reduce fill heights.

2. Air Entrainment

The entrainment of air in the fluid flow affects fill height in two ways. First, as fuel is dispensed and mixes with fuel in the fillneck, air is drawn into the mixture and bubbles are formed increasing required fill height. Second, if air makes its way into the fuel tank with the fuel, the amount of vapor forced out of the tank during refueling and the tank backpressure (for a given flow rate) are increased. The bubbling problem is discussed in the next section of the report. This section looks at the entrained air that makes its way into the fuel tank.

A test was performed on the 'J' tube system to determine if air was entering the tank along with gasoline. The tank was filled with 20 gallons of gasoline and the vapors displaced by the gasoline were collected and the volume of those vapors measured by pulling the vapors through a dry gas meter.* Both the dispensed and tank fuel were at the prevailing temperature, so vapor expansion or shrinkage should have been near zero. The results of the tests are shown below:

Trial No.	Gasoline Dispensed (gallons)	Vapor Collected (gallons)
1	20	22.2
2	20	22.4
3	20	22.8

No attempts were made to identify the sources of the entrained air, but it was fairly evident that it was caused by air bubbles being trapped in the fuel entering the tank. This in turn was caused by the turbulent mixing in the fillneck. Although this testing was conducted on the J-tube system, it is also likely to occur to similar degrees in both the submerged fill and in-tube trap.

The phenomenon of entrained air entering the fuel tank is significant. When the carbon canister and tubing are designed for a given liquid seal configuration, the amount of air entrained must be determined and figured in the design. Systems that allow more air to enter the fuel tank will need to transport more vapor at a given fuel inflow rate. This may also increase the hydrocarbon load to be captured by the canister, since the entrained air may enhance evaporation of the dispensed fuel. Some of the entrainment may be avoided through the control of the mixing of gasoline and air in the fillneck. This is examined next.

3. Bubbling and Turbulence

The most obvious source of bubbling in the fillneck is the violent mixing of the gasoline being dispensed with the gasoline already in the fillneck. To examine bubble formation, a tygon fillneck was mounted on the 'J' tube system, and the pattern of bubble flow in the neck was observed. Although the pattern of flow depends on the orientation of the fuel

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* It was possible to put 20 gallons of liquid in a tank having a nominal capacity of 18 gallons because the tank was modified with a liquid seal and vent, but did not have a fill limiter. Thus the vapor space of the tank also contained fuel, which would not normally be the case.

dispensing nozzle in the fillneck and on the configuration and cross-sectional shape and area of the fillneck, a typical bubble pattern is shown in Figure 8. The pattern shown was generated in a two inch diameter tube with a round cross-section. The sketch is helpful in that it highlights the point of bubble generation and shows the route that the bubbles take in climbing toward the automatic shutoff port on the nozzle. Since gasoline bubbles in the fillneck could contribute to premature nozzle shut-offs, several different techniques to reduce bubble generation were examined. These included approaches to eliminating bubbles before they reached the fuel nozzle and approaches to reducing bubble formation by decreasing the amount of turbulent mixing in the fillneck. While the approaches examined here were by no means comprehensive, (i.e., many other options exist) one approach identified was quite successful.

This approach involved replacing a section of the standard 2 inch diameter tubing with a section of 4 inch diameter tubing. The resulting 'reservoir' added volume to the fillneck and served as a settling chamber in which the bubbles formed and burst without rising in the fillneck. The use of such a reservoir, the dimensions of which were chosen rather arbitrarily, had a significant impact on required fillneck height.

The reservoir idea was tested as an addition to the J-tube setup discussed in Section C. The reservoir is diagrammed in Figure 9. The procedure used to gauge required fillneck height was the same as that used for the J-tube without the reservoir. The results of testing this system are shown below:

Fuel inflow rate = 7.5 gal/min

Backpressure (inches H_2O)	Required Fillneck Height (inches)
5	11
4	9.5
3	6.5

Similar results were obtained when the in-tube trap and submerged fill systems were tested with reservoir type fillnecks. The in-tube trap set in 3 inch diameter tubing has a "built in" reservoir - the tubing is larger than the stock system already. This seal system needed a fill height of only 11 inches. The submerged fill system, with the reservoir used for the 'J' tube attached, achieved similar results (11 inches required fill height). The results of this test show that a properly designed reservoir system can greatly reduce required fillneck height.

Figure 8

Bubble Flow
Pattern

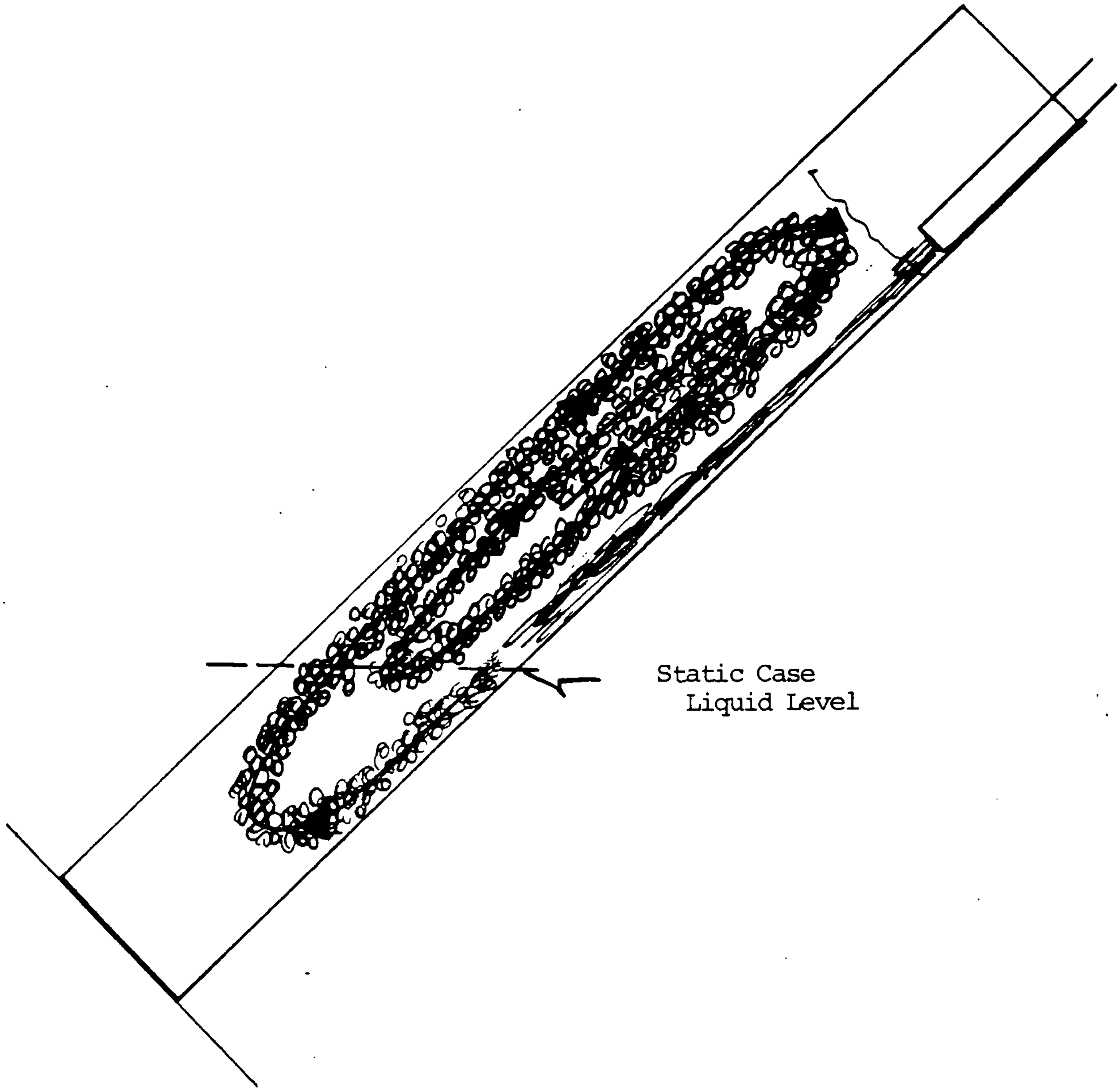
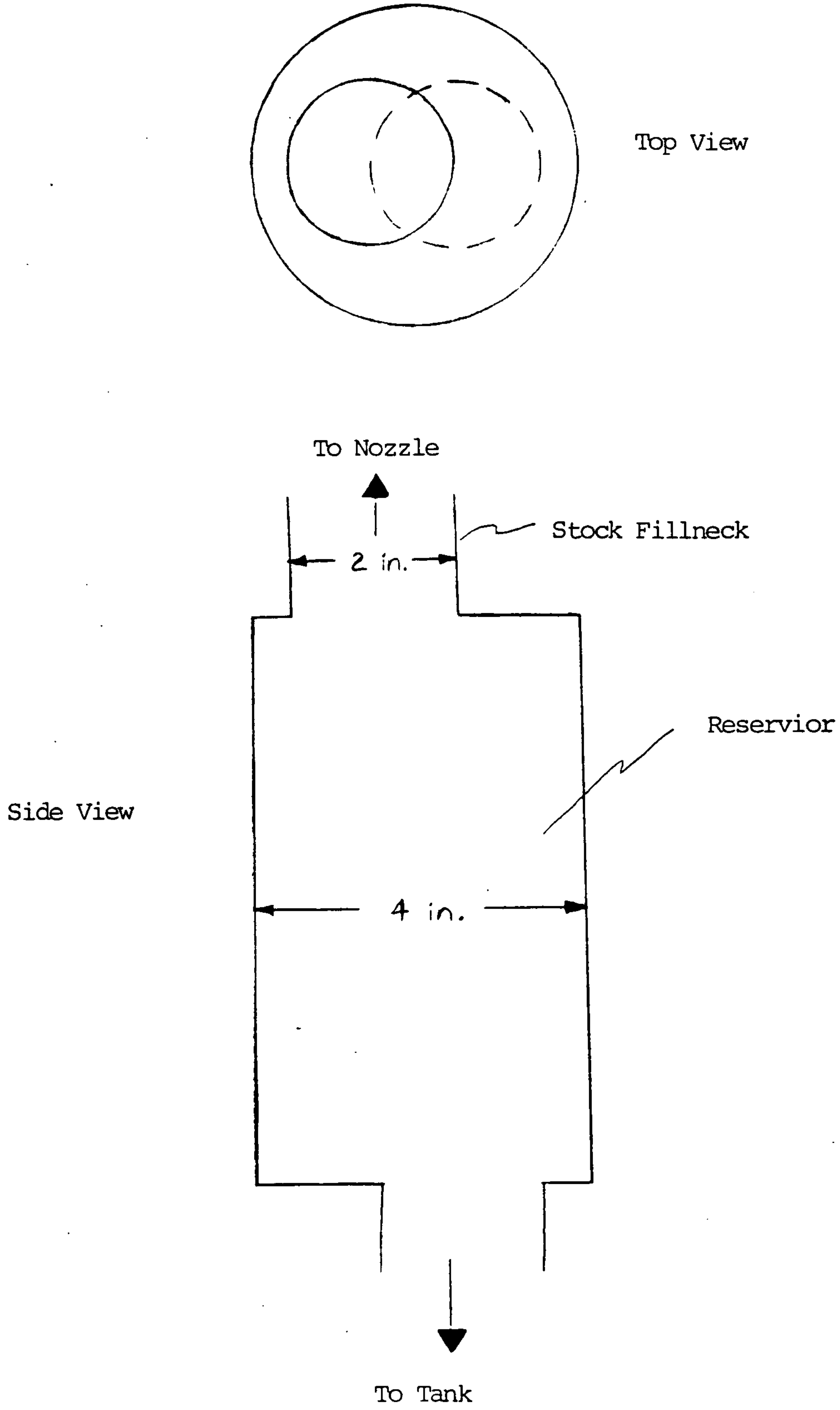


Figure 9

Resevoir



Another approach to bubble control involves the use of a simple baffle to control flow in the fillneck as is now used in some vehicle designs. More specifically the inflow of fuel and the backflow of bubbles can be separated with the use of a baffling system. The simple baffling system shown in Figure 10 directs and smooths the inflow of fuel and also directs and restrains the backflow of bubbles. The baffle restricts inflow to one portion of the fillneck and encourages much of the bubble backflow to rise in the other. The vents near the top of the baffle allow circulating air and vapor to pass through the baffle, but any remaining bubbles are popped by the edges of the vents before they can reach the nozzle venturi tube.

Tests were conducted to determine the fillneck height requirement for the submerged fill tank with a baffled fillneck. The procedure described in Section D.3. for the submerged fill without baffling was followed. At a fuel inflow rate of 7.5 gal/min and tank backpressure of 5 inches H_2O, required fillneck height was reduced to 11.5 inches, a decrease of 5.5 inches.

The baffle approach was not evaluated with the in-tube trap or J-tube, but could be used if the baffle extended for enough into the liquid to separate the liquid/bubble flow.

4. Discussion

The reservoir and baffle approaches discussed above were successful in reducing fillneck height requirements by about 30 percent. Of the portion of the fillneck height that can be attributed to the dynamic affects of refueling, the reduction is approximately 55 percent. This reduction is quite significant given the limited time and resources committed to this effort, and suggests further improvement is possible.

F. Discussion/Conclusions

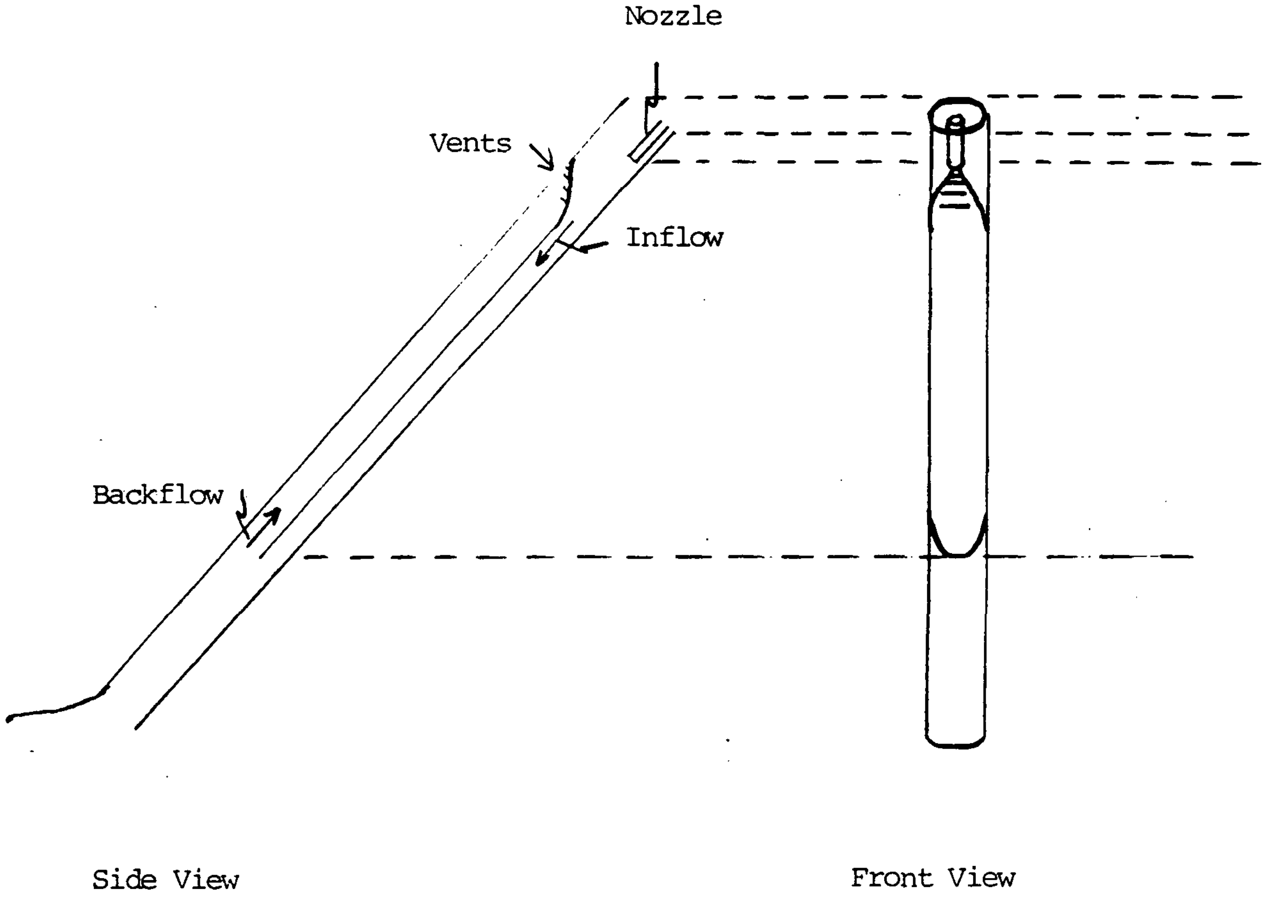
1. Summary

One of the key components of an onboard refueling vapor recovery system is a fillneck seal to prevent the escape of vapors during refueling. While mechanical seal approaches have been demonstrated successfully, there are concerns about the safety, durability, and integrity of the mechanical seal approach. As an alternative to a mechanical seal, EPA has evaluated the practicality of implementing a liquid seal approach.

The practicality aspect of the liquid seal approach involves three factors: fill height requirements, safety, and system efficiency. System efficiency is discussed in the next

Figure 10

Baffled Fillneck



portion of this report. Fill height requirements are important because of concerns regarding premature nozzle shut-off. In order to evaluate the potential suitability of various liquid seals with respect to fill height requirements, systems were tested under standard test conditions: a fuel dispensing rate of 7.5 gal/min and a tank backpressure of 5 inches H_2O. The vertical fillneck height required for normal refueling on each at the three liquid seal approaches was measured and recorded for each system.

Due to the excessive amount of bubbling generated during refueling, fillneck heights of at least 16 inches were needed to refuel the tank for the J-tube and submerged fill approaches. Because of fillneck height limitations imposed by some current vehicle models, efforts were made to reduce the fill height requirements of the liquid seal systems. This involved fillneck modifications aimed at controlling air entrainment and bubbling in the fillneck. Through the use of reservoirs and baffles, fill heights were reduced to 11 inches. The reduction of 5 inches is significant, considering that seven inches of fillneck height would be necessary to support a backpressure of 5 inches H_2O under static conditions. The effect of dynamics was reduced to 4 inches. The results of the fill height evaluations are summarized in Table 2.

The safety of liquid seal approaches must also be considered. Most notably, liquid seal systems cannot pressurize during refueling such as could occur for mechanical seal systems. Any increase in pressure during refueling would cause fuel to rise in the fillneck and automatic shutoff to occur. The one safety problem that must be addressed for the liquid seal system is the possible spitback of fuel when the gas cap is removed prior to refueling.

Spit back could occur if the lines to the carbon canister became blocked and pressure built in the tank prior to refueling. When the gas cap was removed, some of the fuel forming the liquid seal could be forced out of the fillneck as pressure equalized. Spit back can be avoided by either 1) removing the liquid seal after refueling or 2) including a pressure relief system to vent tank pressure before spit back can occur. The in-tube trap and 'J' tube use the first alternative. By drilling a small hole at the bottom of the upward opening 'U' in these designs, the liquid trap can operate during refueling, and then drain soon after the event has been completed.

Table 2

Bench Test Fill Height Requirement

System	Static	Base System	Modified System
In-Tube Trap	7"	-	11" (3" pipe diam.)
J-Tube	7"	16"	11" (reservoir)
Submerged Fill	7"	16"	11" (baffle)

5" H_2O backpressure, 7.5 gpm dispensing rate, 2" fillpipe diameter.

The submerged fill system, on the other hand, must include a more complex pressure relief system. There are a number of ways to incorporate the pressure relief system into the submerged fill. One of the simpler pressure relief systems is shown in Figure 11. The small tube enters the tank above the full tank liquid level, so it is never submerged. As refueling takes place, the 'U' portion of the small tube is filled with fluid. When the gas cap is removed prior to refueling, the pressure is vented through the small tube before spitback can occur. The amount of pressure needed to vent the system can be changed by changing the depth of the 'U' portion of the small tube. Although the spit back problem can be easily solved for any of the systems, the alteration of the submerged fill is clearly more complex than that required for the in-tube trap or 'J' tube liquid seals.

2. Conclusions

There are two main questions to be addressed in concluding the first portion of this report. First, is the liquid seal approach to fillneck vapor containment a practical alternative to the mechanical seal as part of an onboard refueling vapor recovery system? Second, which systems tested in the study are the most promising for further development?

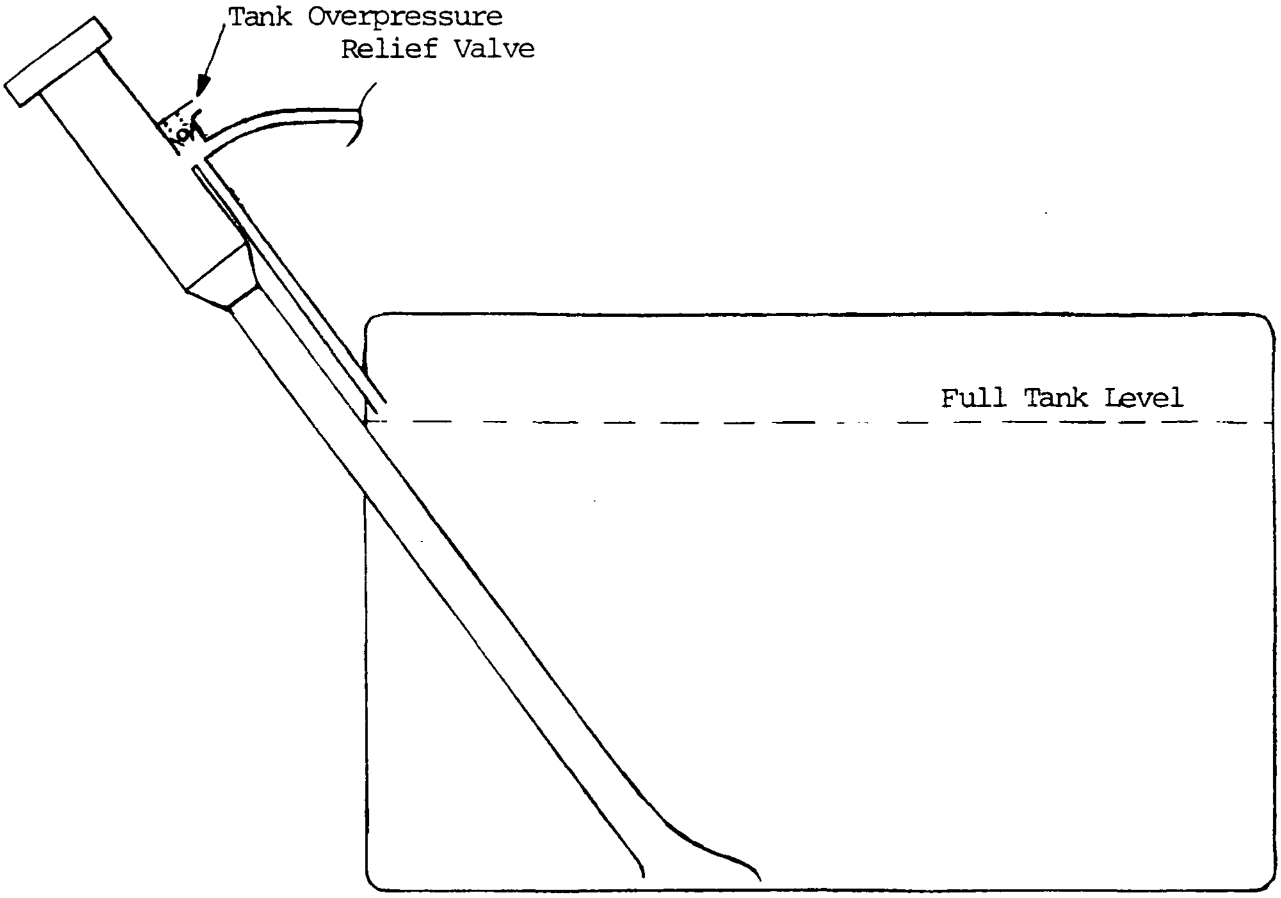
The answer to the first of these questions is generally yes. The liquid seal could be adapted to fit most light-duty vehicles and trucks as currently produced, but there are some vehicles that do not provide adequate fill height to employ the liquid seal. There are two major classes of fillneck configurations, the side fill and the rear fill. The side fill configurations will be discussed first.

The liquid seal design is adaptable to most side fill vehicles. In fact, most vehicles could probably be equipped with an unmodified fillneck (no baffle or reservoir). For other vehicle models, the length of the fillneck is sufficient to permit the use of a liquid seal with a modified, bubble reducing fillneck. Further, it appears that changes could be made in most side fill vehicles to increase the fillneck height if needed, by changing the location of the gas cap on the vehicle body.

Rear fill configurations are much less receptive to the liquid seal approach than are side fills. The fillneck height of some rear fill vehicles is as little as 5 inches. A fill height of 5 inches could accommodate a backpressure of only 3.15 inches H_2O under static conditions. The limited testing conducted by EPA suggests that with a carefully designed

Figure 11

Submerged Fill with Pressure Relief



reservoir, a fillneck height could probably be reduced to approximately 6.0 inches (3.0 inch H_2O backpressure and a 7.5 gal/min fill rate). If a manufacturer were convinced of the superiority of the rear fill configuration, and wanted to use a liquid seal system, changes in fuel tank and gas cap locations would have to be made. However, these changes might be relatively involved. Another approach would be to create a horizontal reservoir by extending the fillpipe horizontally across the top of the fuel tank, (either outside or inside). The fuel would then enter the tank at the opposite end. Another option open to manufacturers of rear fill vehicles would be the use of a mechanical seal. The accompanying safety concerns would have to be addressed. Nevertheless, it is important to note that most current rear fill vehicle models are being phased out and no new models of this design have been introduced recently. In the post 1990 time frame few, if any, new models with rear fill tanks are expected in the new car/light truck fleet.

The second question to be addressed is which system examined is promising for further development. There are four characteristics that are important in comparing these liquid seals. The first is the spatial efficiency of the system as measured by required fill height. The test results suggest that all of the systems can be modified to get nearly equal results. Each system evaluated needed a fillneck height of approximately 11 inches to support a backpressure of 5 inches H_2O at a fuel dispensing rate of 7.5 gal/min. The submerged fill system does have an advantage in this area, however, since the full fill height is needed only as the tank approaches the full level.

Refueling safety is the second major characteristic for comparison of the liquid seal systems. Both the in-tube trap and 'J' tube need only one minor modification to avoid any spitback problem. However, the submerged fill system needs a pressure relief system like that described earlier. The submerged fill system is at a disadvantage in this respect.

The third characteristic of comparison for these systems is the complexity of the liquid seal itself. The in-tube trap is the most complex of the three. The submerged fill and 'J' tube designs would be much less difficult to build and are probably more practical for this reason.

The final basis of comparison is the security of the liquid seal defined in terms of the probability of vapor escaping to the atmosphere during refueling. The biggest concern about trap security arises when a vehicle sits on sloped terrain during refueling. The in-tube trap and 'J' tube traps can be designed to ensure security up to any reasonable angle chosen. The submerged fill system works differently than these systems, however. For the submerged fill to function properly, the fuel must enter the tank below the liquid surface, but when the tank is nearly empty, the mouth of the fillneck will be only slightly below the liquid level. If the vehicle were on an incline, the fillneck may not be submerged at all or may be only partially submerged, and some vapor could escape during the early stages of refueling.

It is clear from the discussion that each system has both strong and weak points, but most of the problems with any of the systems can be resolved with a moderate amount of effort. The relative complexity of the in-tube trap suggests that this design may be the most costly to produce, but if installed in the inside top of the tank it could be implemented with no other fillpipe modifications. The other two systems are also clearly worth further investigation if the liquid seal concept is being developed. Based on the safety advantage, the J-tube is somewhat preferable to the submerged fill, and EPA has selected that approach for inclusion in the prototype liquid seal onboard system developed for bench testing. The J-tube was also selected because of EPA's previous experience with the submerged fill which showed very high efficiencies in a bench test.[4]

The next portion of this report covers EPA's program to evaluate the efficiency of a J-tube liquid seal. The discussions cover the remainder of the components needed for a bench evaluation of the system and the efficiency testing conducted by EPA.

III. Bench Testing of a Liquid Seal Onboard System

A. Description of the Prototype System

1. Introduction

Once the evaluation of the three liquid seal concepts was complete, EPA desired to evaluate the efficiency of a liquid seal in a simple prototype onboard refueling control system. As will be described below, the prototype system constructed for this evaluation was relatively crude, and incorporated only the essential components. No attempts were made to add components or incorporate modifications to reduce the refueling emission rate or optimize system efficiency. This section of the report briefly examines the three components added downstream of the fuel tank to complete the prototype system.

To complete the prototype system three additional components were needed. These include a fill limiter, a properly sized vapor line, and an activated carbon canister. Each of these components is discussed below, in the context of the flow rate and backpressure design characteristics mentioned above and the overall efficiency of the prototype system.

2. Fill Limiter

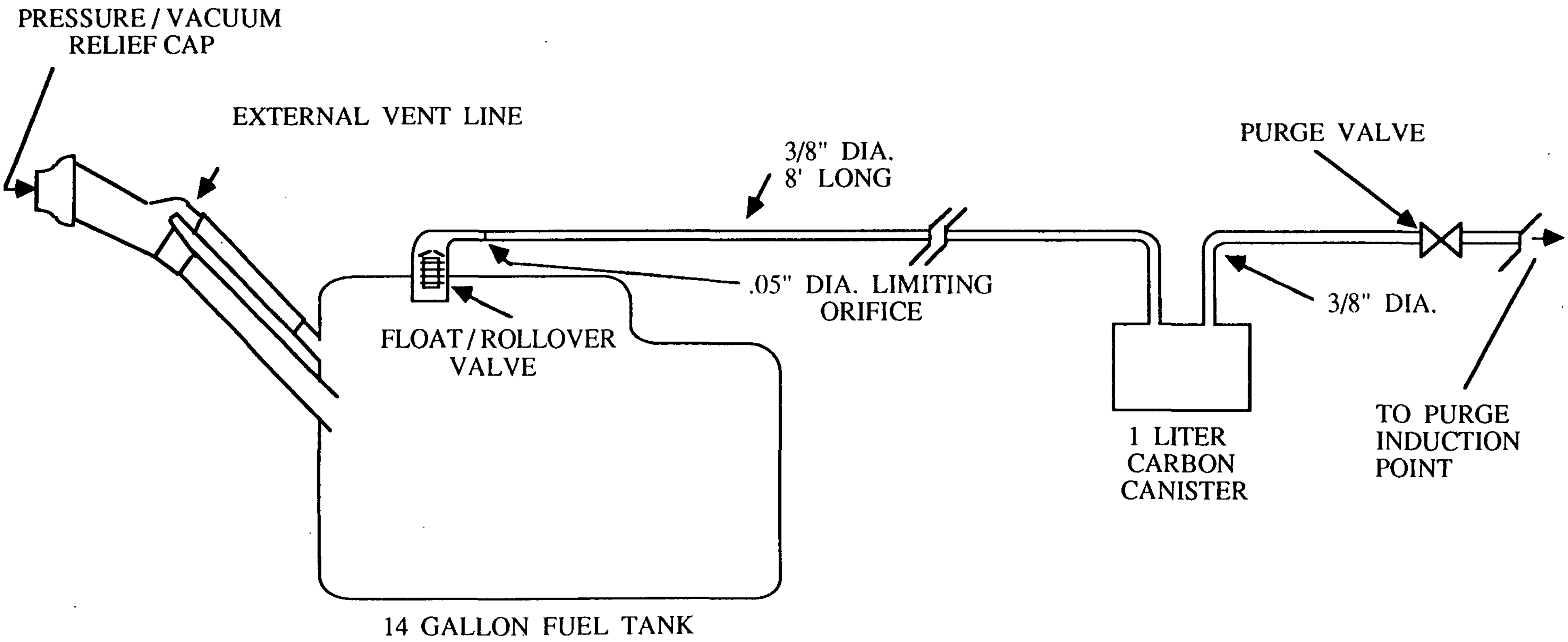
While it does not directly affect system backpressure or efficiency, a fill limiter is needed in onboard system designs where the vapor vent outlet is located in the fuel tank vapor drive. On present fuel tanks, the automatic shut-off feature of the fuel nozzle is activated when tank back pressure increases at the end of the refueling event and causes the fuel in the tank to back up into the fillneck and cover the nozzle spout with liquid. However, with a properly designed onboard system fuel tank backpressures are minimal since vapor is vented during refueling. The small amount of system backpressure which does exist is not adequate to back the fuel up into the fillneck and allow operation of the automatic shut-off feature of the fuel nozzle. Therefore, a fill limiter is needed to close the vapor vent when the tank is full and thus increase the backpressure. Without a fill limiter it is quite possible that the tank could be filled well beyond its nominal capacity. For onboard equipped vehicles using side fill tanks with external vent lines (as in Figure 12), the onboard system has little effect on the refueling process. The refueling event terminates the way it does on present vehicles, and thus a fill limiter is not needed.

The EPA prototype onboard system used a rear fill fuel tank without an external vent line, so a simple float valve was needed as a fill limiter. The float was constructed of the same material used for the tank's fuel level indicator. It was suspended from the roof of the tank on a simple wire in such a way that it would float on the fuel as the tank approached full, and would nest into the vapor vent when the tank was full. This would stop the venting of vapor which would immediately increase system backpressure and thus would quickly lead to activation of the nozzle automatic shut-off.

Before discussing the vapor line, two points about the fill limiter and its operation should be noted. First, EPA's simple prototype did not include a liquid/vapor separator, rollover valve or a vent closure valve. These were not necessary for a simple bench set-up intended only for evaluation of refueling emissions control. Second, EPA did not experience significant problems with fuel spillage due to operation of the fill limiter, as has been suggested by

Figure 12

Typical Current Evaporative System



some.[5] This perhaps was due to the fact that the system evaluated by EPA included a reservoir in the fillneck.

3. Vapor Line

The purpose of the vapor line is to convey gasoline vapor from the fuel tank to the carbon canister. It must be sized and constructed of material such that it does not unnecessarily increase the system backpressure (which affects the fill height requirement), and must be impermeable to gasoline vapors. To meet these requirements, three characteristics of the vapor line and its use must be considered and evaluated concurrently. These include the vapor line diameter, the vapor line configuration or layout, and the vapor line material. The affect of these three characteristics on system backpressure and permeability of vapors is discussed below.

As gasoline vapors flow through the lines, both major and minor pressure losses occur which inhibit vapor flow and directly affect system backpressure. The vapor line diameter makes a major contribution to the pressure losses, since it represents a major contraction in the flow. The other major pressure losses are caused by functional resistance to the vapor flow. This is a function of the vapor line diameter, length of vapor line used, and to some degree the vapor line material.

Minor pressure losses are mainly caused by the vapor line layout or configuration. This includes any bends, elbows, expansions or contractions in the line, as well as any other deviations from the straight flow in a vapor line of a constant cross sectional area.

As was discussed earlier in relation to fillneck seals, the control system was designed so that the vapor line and canister result in a fuel tank backpressure of no more than 5 inches of H_2O. A series of tests was designed to empirically determine what size vapor line would be appropriate for a typical light duty vehicle application. These tests were performed on complete control systems (J-tube equipped fuel tank, vapor line, carbon canister) subjected to actual refuelings. The test conditions were constant except for the cross-sectional area of the tubing which was varied from test to test. Although only one tubing material was tested, the tests (summarized in Table 3) showed that vapor line with an inner diameter of at least 1/2 inch would have to be used to keep back pressure below 5 inches H_2O for the entire system. To be safe, vapor line of 5/8 inch inner diameter was used for

Table 3

Vapor Line Pressure Drop Contributions

Tube ID, Inch	Tube Configuration	P, Inches H_2O Bench Test
3/8	15 ft., 6 bends	5
1/2	15 ft., 6 bends	2.2
5/8	15 ft., 6 bends	1.2
1/2	8 ft., 4 bends	1.5
5/8	12 ft., 4 bends	.9

control system testing, although 1/2 inch vapor would clearly be reasonable for many vehicle applications.*

The tubing material is also very important to the functioning of the control system. The most important characteristic of appropriate tubing materials is impermeability to gasoline and gasoline vapors. If a vapor line which was permeable to gasoline vapors was used as part of the control system, hydrocarbons could escape from the tubing, defeating the purpose of the control system. There are a number of tubing materials which would be appropriate for this application. Flexibility, density and cost characteristics are all factors to be weighed in deciding between hard rubber, softer, more flexible rubber and steel materials. A double walled, flexible rubber fuel line was used in EPA'a prototype onboard control system since 5/8 inch impermeable vapor line was not commercially available.

4. Carbon Canister

Activated carbon for capture and storage of gasoline vapors has been used successfully in automotive applications for more than ten years. To apply this technology to control of refueling emissions in EPA's bench evaluation, the canister must not increase system backpressure more than is necessary, and it must be sized and loaded with enough activated carbon to efficiently capture essentially all refueling emissions. These two factors are closely linked since canister size and design both impact backpressure.

Rather than designing an optimum canister, it was EPA's goal to construct or obtain a canister which was adequately sized to capture all refueling emissions from an 18 gallon fuel tank and yet would not increase total system backpressure to more than 5 inches H_2O.

First, to assist in meeting the backpressure requirement, EPA held discussions with several manufacturers of activated carbon. Based on these discussions, EPA selected Westvaco extruded wood base activated carbon for use in the canister. Information presented by the vendor indicated that the extruded activated carbon might have a higher working butane working capacity and better pressure drop characteristics than the more conventional activated carbons now used in evaporative emission applications. However, it appears that any of the activated carbon types sold by the different companies would also work successfully in capturing refueling vapors, but these would

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* This discussion briefly addresses how vapor line diameter affects backpressure. Any system design would have to consider vapor line length, configuration, canister effects, etc., in addition to vapor line diameter.

have different performance characteristics and would require a different amount of activated carbon.

In sizing the canister, the next step would be to estimate the total amount of activated carbon needed, based on gasoline vs. butane working capacity, apparent density, carbon aging and other factors. As is shown on Table 4, EPA estimates that a carbon bed of 1050 grams would be required to capture all refueling emissions from an 18 gallon tank. At an apparent density of 30 gm/100 ml, a canister of about 3500 milliliters would be needed.

Alternatively, however, EPA turned to work previously conducted by Mobil Research and Development in their 1978 onboard demonstration program. In that program Mobil used a 4350 ml canister to control refueling and evaporative emissions from a carburetted 1978 Pontiac Sunbird which had an 18.5 gallon fuel tank.[1] An inquiry to Mobil revealed that the canister shell which is shown in Figure 13 was still on hand and available for loan, so this canister shell was used by EPA in the prototype system. This canister was loaded with approximately 1400 grams of activated carbon, somewhat more than needed based on Table 4.

5. Conclusion

We have now described all portions of the prototype onboard system used to evaluate the efficiency of the J-tube liquid seal. The prototype onboard system included the following components:

- J-tube liquid fillneck seal with reservoir
- 18 gallon fuel tank
- fill limiter
- 5/8 inch vapor line
- 4350 ml activated carbon canister

The results of EPA's evaluation testing on this system are described in the next portion of this report.

B. Evaluation of System Efficiency

1. Introduction

Once the prototype onboard system had been constructed in a bench configuration, a series of refueling emissions tests were conducted to evaluate the efficiency of the system and to

Table 4

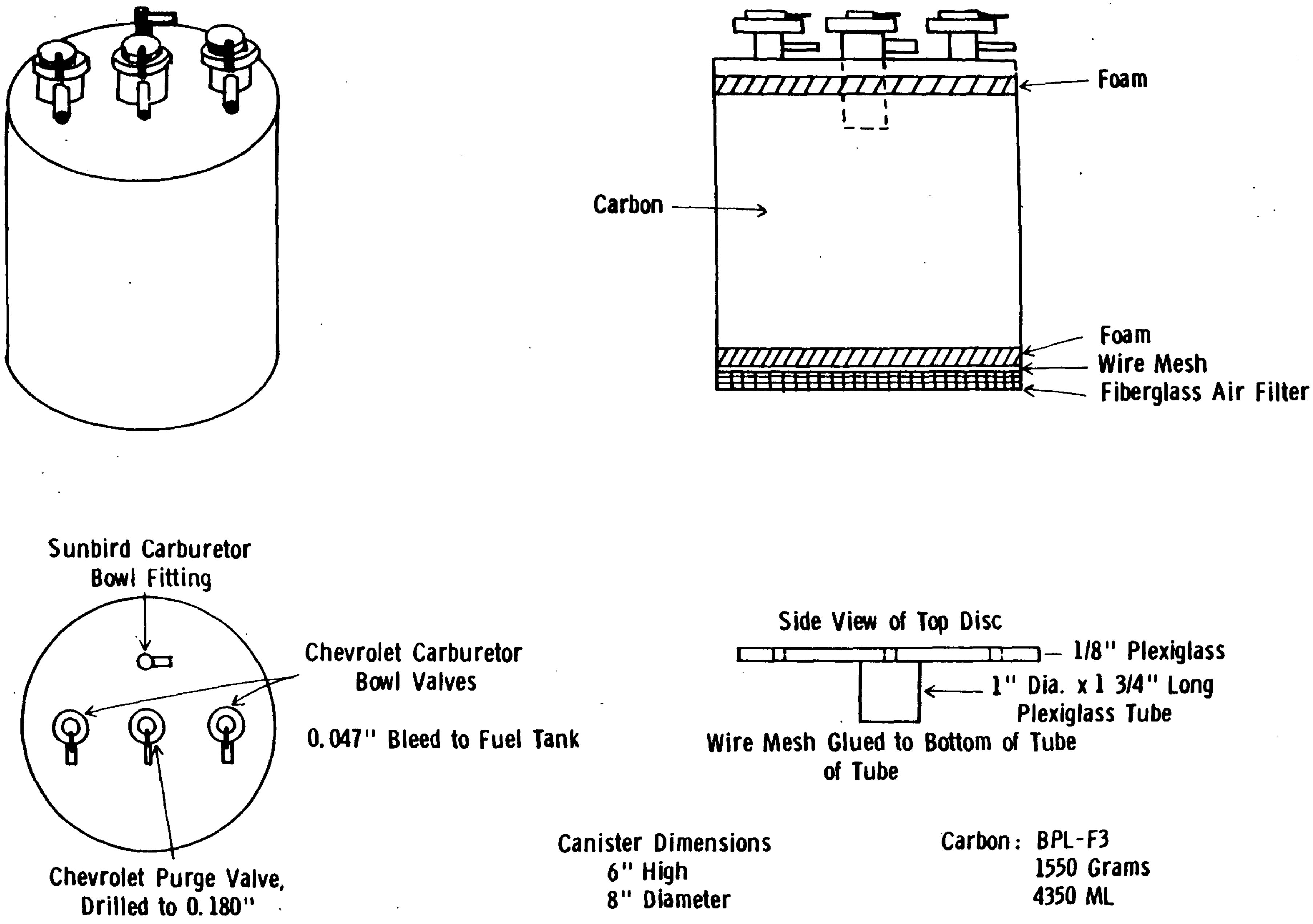
Total Required Carbon Bed

Refueling Emissions (at 8 g/gal for 18 gallons)	144 g
Activated Carbon Needed:	700 g
50 Percent Carbon Aging Allowance and Safety Factor	350 g
Total	1050 g

Based on a gasoline working capacity of 6.3 gm gasoline vapor/100 ml carbon, and an apparent density of 30 gm carbon/100 ml carbon.

FIGURE 13

REFUELING SYSTEM CARBON CANISTER



Canister Dimensions
6" High
8" Diameter

Carbon: BPL-F3
1550 Grams
4350 ML

draw some conclusions as to whether liquid seal systems could have as high an efficiency as mechanical seals. This portion of the report describes how these tests were done, the results of the testing, and draws some conclusions about the efficiency of liquid seal systems.

2. Description of Test Procedure

The refueling tests were conducted in a standard evaporative emissions SHED which had been modified to allow the entry of a fuel hose fitting into the side wall. Fuel was dispensed from a standard fuel delivery cart.

The general test procedure followed is outlined in Table 5, and is discussed below. The refueling control system bench system was placed in the SHED and filled to 10 percent of nominal tank capacity. The fuel tank was then heated to the desired temperature inside the open SHED with the fuel cap on.* The purge fan was operating in the SHED during this time. The dispensed fuel had been heated to its desired temperature previously.

At the end of the heating, the heating blankets were unplugged, the fuel nozzle was inserted into the fillneck, the mixing fans were restarted, and the SHED was sealed. A background reading was taken in the sealed SHED before refueling began. The refueling was then performed by turning on the fuel cart from the outside the SHED. The refueling was terminated when automatic shut off occurred. A final FID reading was then taken in the SHED, and the SHED floor and fillneck area were checked for fuel spills. The refueling emissions to the SHED were evaluated as the difference between the initial and final FID readings, with appropriate adjustments for the small portion of the SHED volume occupied by the bench apparatus.

Following the termination of the testing, the carbon canister was weighed and then purged with a total of 300 cfm of ambient air to remove refueling vapors from the canister. Based on reduction in canister weights, this amount of air was more than sufficient. Following completion of the purge, the canister was weighed again.

Finally, before describing the results of the testing, it is important to discuss the temperature and RVP characteristics

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* As will be discussed later, a couple of tests were conducted with the fuel cap loose during the heat build to estimate the effects of heat build emissions.

Table 5

Test Sequence

1. Drain and refuel tank to 10 percent of nominal capacity.
2. Connect heat blankets and thermocouples, fuel cap on.
3. Heat tank to desired temperature and stabilize.
4. Insert fuel nozzle, set latch at high level.
5. Close SHED and start mixing fans.
6. Take initial sample reading (using FID).
7. Remove cap, refuel tank to automatic shut-off.
8. Check for spills and nozzle shut-off.
9. Take final sample reading (using FID).
10. Disconnect heat blankets and thermocouples.

of the test fuels used. The dispensed and fuel tank temperatures were set at 92°F ± 2°F to be consistent with previous testing conducted by EPA and to be representative of the temperature proposed by EPA in its recommended practice for testing of refueling emissions levels.[6,7] Fuels of 11.8 and 9.0 psi RVP were used in the program. However most tests were conducted using the 11.8 RVP fuel since it would be expected to create higher refueling emissions and thus would be a more stringent evaluation of system efficiency.

3. Refueling Emission Test Results

The results of the refueling emission tests are summarized in Table 6; more detailed information on each test is provided in Appendix A. The emission results shown include 7 tests at 11.8 RVP and 3 tests at 9.0 RVP.

The efficiency of the control system can be evaluated by comparing the refueling losses to the SHED to the total refueling emissions based on the sum of refueling losses to the SHED and canister weight gain. Under this approach the efficiency can be calculated as shown below:

$$\text{EFF} = 1 - \frac{\text{losses to SHED}}{\text{canister wt. gain + losses to SHED}} \quad \text{x } 100\%$$

Using this approach, the average efficiency is 98 percent for the 11.8 psi fuel and 96.6 percent for the 9.0 psi fuel. Values ranged from 95.8 to 99.4 percent with an average of about 97 percent. However, these results clearly indicate that theoretical efficiencies of 98 percent or more are available for liquid seal systems. This compares to efficiencies of 96-99 percent for a mechanical seal system.[1,8]

As was noted previously, two tests were conducted with the fuel cap loose during the heat build to assess how much heat build emissions were affecting the total canister vapor load. Referring to Table 6, tests 1-5 were conducted with the fuel cap on and fully sealed during the heat build, while tests 6 and 7 were conducted with the cap only loosely in place. A comparison of the tests shows that the canister weight gain and the apparent refueling emission rate were greater when the cap was on and sealed. To some degree the canister was accepting vapor from the tank during the heat build similar to what now occurs in a diurnal evaporative emissions test. However, as can be seen from Table 6, this has little effect on the system efficiency evaluation for the program. All values fall within the 96-99 percent efficiency range.

Table 6

Liquid Seal Control System Efficiencies

RVP	Test	Conditions T_T	T_D	Gal	Loss to SHED(g)	Canister Wt Gain(g)	Percent Efficiency
11.8 psi	1	91.0	92.0	12.5	2.3	153.3	99.4
	2	90.8	90.3	15.5	3.6	168.1	97.9
	3	92.0	90.5	15.0	6.1	164.1	96.4
	4	91.0	91.7	15.1	4.9	129.3	96.3
	5	91.9	91.9	14.0	2.5	123.9	98.0
	6	92.0	92.0	15.5	2.0	170.5	98.8
	7	91.0	92.5	12.5	1.5	163.0	99.1
						Avg. EFF	98.0
9.0 psi	08	92.0	93.0	18.5	6.0	135.5	95.8
	09	93.0	92.2	15.0	3.6	121.1	97.1
	10	92.0	92.5	15.0	4.0	120.8	96.8
						Avg. EFF	96.6

The turbulent mixing in the fillpipe discussed previously and the subsequent entrainment of bubbles in the liquid entering the tank suggests that the liquid seal may be generating additional refueling emissions relative to the uncontrolled fuel tank. Uncontrolled refueling emissions were not evaluated on the bench system, but a similar fuel tank was evaluated on the 1983 Oldsmobile Cutlass evaluated in a previous EPA test program.[7] The results of that testing indicate that uncontrolled refueling emissions for this vehicle can be predicted using the equation

Losses (g/gal) = $-5.584 - 0.114[\Delta T(°F)] + 0.0857\ [T_D(°F)] + 0.520\ [RVP(psi)]$, where $\Delta T = T_T - T_D$.

Substituting the temperature and RVP conditions of Table 6 into this equation ($T_D = 92°F$, $\Delta T = 0F°$, $RVP = 11.8$ psi) yields an emission rate of 8.4 g/gal.

For comparison, two tests were conducted on the prototype onboard system without the canister in place. The refueling emission rate averaged 9.9 g/gal for the two tests (Tests 85-1363, 1364 in Appendix A).

The comparison of the actually occurring and predicted emissions discussed above, leads to the conclusion that in this case the liquid seal increased the emission rate. However, using this data it is not possible to precisely quantify the effect; the use of an average could be misleading due to the relatively small number of tests and the range in values seen. Ideally, comparisons should be made between identical tanks with and without a liquid seal with as many other variables as possible controlled.

A close review of the detailed results in Appendix A reveals that 14-15.5 gallons was dispensed in most tests, but over 18 gallons was dispensed in one test. This later test was the first conducted in the series and led to the conclusion that the fill limiter installed in the tank did not work properly and an overfill occurred. However, when the fill limiter was modified and reinstalled it dropped too low into the tank and about a gallon of nominal tank capacity was lost. This accounts for the difference in the dispensed gallons among the tests, and explains why the amount of fuel dispensed in most tests was somewhat less than 90 percent of nominal tank capacity.

4. Source of Emissions

In addition to assessing the control efficiency of the system, tests were also conducted to locate the source of refueling emissions from the control system. The first step in this process involved checking the fuel tank and vapor line for leaks. This was done by removing the canister from the system, plugging the vapor line (at the canister end) and pressurizing the tank. A liquid was then applied to the tank and vapor line so that leaks could be seen. The system was free from leaks so the only possible sources of emissions were the fillneck and the canister (if breakthrough were occurring). In order to isolate the emissions from the fillneck, the canister was left off of the system and was replaced with a plastic vapor bag. Refueling operations were performed with the vapor bag in place and the refueling loss was measured. In this way, only the emissions from the fillneck were measured. The results from this set of tests are shown in Table 7.

The refueling losses from the control system with the vapor bag are very similar to those emitted from the control system with the canister in place. The projected efficiencies shown in Table 7 were developed by dividing the refueling losses by the predicted emission level found using the equation cited previously.

Since the refueling loss and efficiency numbers of Table 7 are very similar to those in Table 6, it appears that most of the refueling loss comes from the fillneck.

IV. Conclusions

The purpose of the development and test programs conducted was to evaluate the practicality and feasibility of liquid fillneck seals as an alternative to the more widely demonstrated mechanical seals. The EPA program covered a laboratory evaluation of three different liquid seal concepts and bench testing of a simple prototype onboard system using a liquid seal.

The evaluation of the liquid seal concept led to several conclusions.

- The available fill height on most side fill passenger cars and light trucks is sufficient to permit the use of liquid seals without premature nozzle shut-off.

- For some side fill vehicles, reductions in fill height would need to be achieved through internal fillpipe modifications to control the bubbles caused by the strong turbulent mixing in the fillpipe.

- Rear fill vehicles would require more substantial fillpipe, tank, or other modifications to use liquid seals and thus may be better suited to mechanical seals.

Table 7

Sources of Refueling Emissions on a Controlled System*

Test	T_T	Conditions T_D	Gal.	Loss to SHED(g)	Predicted Emissions(g)	Percent Efficiency
11	91.0	92.5	13.3	2.4	115.0	97.9
12	91.0	92.5	13.5	2.8	116.8	97.6

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* Vapor bag used to replace canister; RVP = 11.8.

- Liquid seal systems (especially the J-tube and in-tube trap) appear to have safety advantages over the mechanical seal and submerged fill.
- The strong turbulent mixing in the fillpipe entrains air into the fuel entering the tank, and increases the volume of vapor which is displaced from the tank as it is refilled.

Several key conclusions can also be drawn from the bench testing of a prototype onboard system using a liquid seal.

- The efficiency of the liquid seal systems is comparable to that achieved by mechanical seals. The mechanical seal systems evaluated by API showed efficiencies of 96 to 99 percent. The liquid seal systems evaluated in this project showed efficiencies in that range.
- With improvements in the control system, consistently high control efficiencies (98 percent and greater) are easily within reach for liquid seal systems.
- For a liquid seal system with an adequately sized carbon canister, most refueling losses appear to arise from the fillneck.
- The air entrainment caused by the turbulent mixing in the fillneck appears to increase the total refueling emissions load to the carbon canister. Data generated in this test program is insufficient to precisely quantify this effect.

The primary purpose of this program was to demonstrate the feasibility of liquid fillneck seal concepts. The bench prototype developed here was clearly a first generation system; no attempts were made to optimize the design to reduce the effects of entrainment or to maximize control efficiencies. Improvements in both areas are possible, as demonstrated in later work conducted by API.[8] This work shows that onboard systems using liquid fillneck seals can consistently control refueling emissions with efficiencies of 98 to 99 percent.

The development and test programs conducted by EPA demonstrate that liquid seal systems are indeed practical alternatives to mechanical seal systems. Analysis suggests that liquid seals are superior to mechanical seals in the areas of durability, tampering, and safety, and have equal efficiencies for controlling refueling emissions. However, the work conducted by EPA indicates that liquid seals may be more attractive for side fill than rear fill vehicles, and the air entrainment caused by turbulent mixing in the fillpipe may actually increase refueling emissions and create the need for a larger canister than that required for mechanical seals. Thus some trade-offs may exist between mechanical and liquid fillneck seals.

Either liquid or mechanical fillneck seals could be used as part of an onboard system. Each approach has its strengths and weaknesses, but both have been demonstrated to have high efficiencies on prototype systems. Whether a liquid or mechanical seal system is preferable would have to be evaluated separately for each vehicle model.

References

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4. "Status of In-House Refueling Loss Measurements," Memorandum from Martin Reinemann to Robert Maxwell, U.S. EPA, SDSB, March 6, 1979.

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APPENDIX A

Detailed Test Results

Fuel Tank Bench Tests

FUEL-COMMERCIAL UNLEADED, SUMMER, 92°F DISPENSED*

		Temperatures °F										
Test No.	Date	Initial	Final	Final Vap	Max T	Dispensed	Dispensed Gallons	Refueling Loss, gms.	Canister Wt Gain	Dispensing Time Min,Sec	Heat Time Hr,Min	Spillage/Comments
85-0694	10-31-84	66.8	91.0	89.0	3.0	92.0	12.5	2.3	153.3	1'46"	57"	None
85-0120	11-05-84	68.2	91.0	88.8	3.0	92.5	13.3	2.4	NA	2'04"	52"	None, vapor bag
85-0121	11-06-84	68.3	90.8	89.0	3.0	90.3	15.5	3.6	168.1	2'11"	56"	None, manual shutoff
85-0123	11-07-84	69.5	91.0	89.0	3.5	91.0	13.5	2.8	NA	1'57"	45"	None, vapor bag
85-0698	11-08-84	67.55	92.0	90.0	3.0	92.0	15.5	2.0	170.5	2'19"	51"	None, can in box multi-fueling
85-0699	11-09-84	67.0	91.0	89.5	3.0	92.5	12.5	1.5	163.0	1'49"	55"	None, multi fueling
85-1358	12-19-84	61.0	92.0	88.5	3.5	90.5	15.0	6.1	164.1	2'16"	58"	None, Benzene 13A
85-1362	01-04-85	67.7	91.0	89.5	3.0	91.7	15.1	4.9	129.3	2'08"	40"	Controlled
85-1368	01-11-85	60.5	91.9	91.0	5.3	91.9	14.0	2.5	123.9	2'50"	45"	None, canister only during refueling
84-5633	08-23-84	69.0	92.0	90.2	2.0	93.0	18.5	6.0	135.5	3'41"	46"	None
84-5634	08-24-84	67.0	93.0	89.0	2.0	92.2	15.0	3.6	121.1	2'56"	48"	None, manual shutoff
84-5635	08-24-84	67.9	92.0	90.3	2.0	92.5	15.0	4.0	120.8	2'55"	48"	None, manual shutoff
85-1363	01-04-85	70.7	92.0	89.0	4.0	89.8	14.3	134.8	NA	2'00"	56"	Controlled w/o canister
85-1364	01-03-85	67.7	92.5	90.8	3.0	90.0	14.5	151.5	NA	2'09"	42"	Controlled w/o canister

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* All tests were at 11.8 RVP except 84-5633, 5634, and 5635.