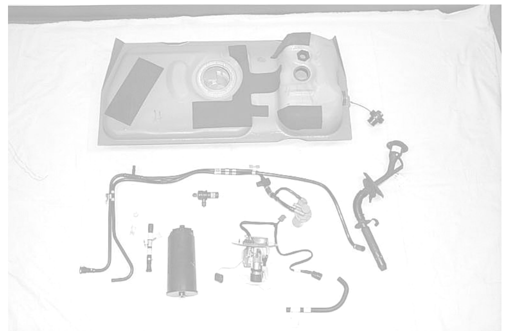

Automotive Fuel System Anti-siphoning and Leak Prevention Technology Review

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Preface

This report constitutes the final deliverable for the review of anti-siphoning and leak prevention technologies. The work was conducted at the request of Dr. Ken Digges of the Motor Vehicle Fire Research Institute.

The opinions expressed herein are those of Biokinetics and Associates Ltd. and do not necessarily reflect those of Dr. Ken Digges or the Motor Vehicle Fire Research Institute.

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1. Introduction

Previous research conducted for the Motor Vehicle Fire Research Institute (MVFRI) investigated the usage of spill prevention technologies/component designs employed by automotive fuel tank systems [Ref. 1, 2]. Typically, these technologies prevented fuel leakage when a tank system was inverted or rotated from its upright position. Under these circumstances several spring loaded valve designs were found to be effective amongst the twenty 2003 model year vehicle tank systems that were inspected in detail. However, another possible cause for fuel leakage which was not explicitly ascertained during the tests is siphoning. Siphoning, which is the removal of fuel by suction, may occur even if a tank remains in an upright orientation, but would require the severed end of a fuel carrying hose or pipe to drop below the fuel level in the fuel tank. The technologies that were identified to prevent leakage from the tank when overturned may not necessarily be effective against siphoning.

The initial evaluation of the 2003 model year tank systems consisted of a visual inspection to identify technologies that may have prevented fuel spillage following a collision in which the fuel lines emanating from the tank were severed. Leakage specifically related to fluid flow due to gravity resulting from an overturned tank was investigated. The tests comprised filling the tank systems to capacity with water and rotating the systems collinear with the longitudinal axis of the vehicle. At eight discreet angles during the rotation, the fuel systems' hoses were disconnected one at a time and leakage was observed. The results of the leak tests are documented in Table 1. Of the tanks tested, four did not leak in any orientation. The components of those four tanks and the design strategies employed were inspected and documented in detail.

Table 1: Leak test results for 2003 vehicles.

Vehicle	Tank Orientation							
	0^o	60^o	90^o	120^o	180^o	210^o	270^o	300^o
Acura 3.2 TL / Honda Accord	n	y	y	y	y	y	y	n
Audi A8	y	y	y	y	y	y	y	y
BMW 325i	n	n	n	n	y	y	y	y
Chevrolet Corvette	y	y	y	y	y	y	y	y
Chrysler Cirrus (Stratus)	n	n	n	n	n	n	n	n
Dodge Neon	n	n	n	n	n	n	n	n
Ford Mustang	n	n	n	n	n	n	n	n
GMC Sierra	n	y	y	y	y	y	y	y
Honda Odyssey	n	y	y	y	y	y	y	n
Jeep Cherokee	y	n	n	y	y	y	y	y
KIA Spectra	n	n	n	n	n	n	n	n
Mazda MPV	y	y	y	y	y	y	y	y
Mercury Grand Marquis	n	y	y	n	n	n	n	y
Plymouth Grand Voyager	n	y	y	y	y	y	y	y
Toyota Camry	y	y	y	y	y	y	y	y
Toyota Corolla	y	y	y	y	y	y	y	y
Toyota Prius	n	y	y	y	y	y	y	y
VW Jetta	n	y	y	y	y	y	y	y
Mercedes S430	y	y	y	y	y	y	y	y
Saturn SL	n	n	n	n	y	y	y	y

The 20 fuels tank systems that were initially inspected for leakage prevention technologies were further inspected, under the current work, for anti-siphoning devices and the results are reported on herein. An additional three 2006 model year tank systems were also inspected and the results are presented.

This report focuses primarily on technologies and component designs that were found to be effective for spill prevention and/or preventing siphoning. Little emphasis will be placed on ineffective designs.

2. Tank Evaluations

The lines from each of the 20 vehicle sending units as described in Table 1, which include the fuel delivery, fuel return and the vent lines, were evaluated for any technologies that might prevent siphoning with the results presented in Section 2.3. The inspection comprised a simple siphon test that applied a vacuum to the fuel lines. The details of the siphon test are described in Section 2.2.

A detailed inspection and disassembly of the four tank systems that did not leak in any orientation was also conducted to ascertain the design features that were effective at preventing leakage. The components of these four tanks were also tested for anti-siphon capabilities and the results are presented in Section 2.4.

The results of the additional inspection and testing of three 2006 model year tank components are presented in Section 3.

2.1 Leakage vs. Siphoning

Leakage and siphoning are two mechanisms by which fuel can be expelled from a tank. Fuel leakage will occur if the hydrostatic pressure[1] of the fuel at a valve or other tank component exceeds the resistive force of said tank component. For example, if a normally closed spring valve existed in Case #1 of Figure 1 and the spring force was sufficient to overcome the hydrostatic pressure then no leakage would occur; if however, the hydrostatic pressure exceeded the spring force then fuel would escape from the valve. Leakage could also occur if a hose or pipe is ruptured below the fuel level surface.

Fuel siphoning[2] will occur given the following conditions. The line must be primed (contain fuel), it must pass through a point that is above the surface of the fuel in the tank and the exit point must lie below the fuel surface (designated by the dimension "h" in Case #2 of Figure 1 and referred to as the "head"). A vacuum created by the flow of fuel from the discharge point draws liquid from the tank. Fuel flow will continue until the fuel level in the tank reaches the level

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[1] Fluid at rest creates a pressure that is a function of the density of the fluid, earth's gravitational constant and the depth of the point of interest from the fluid surface. This pressure is known as hydrostatic pressure. The mathematical expression for hydrostatic pressure is $P=\rho g z$ where, ρ= the density of the fluid, g=gravitational constant and z=depth from the fluid surface.

[2] Definition of Siphon: A tube through which a liquid is lifted over an elevation by a differential in pressure and is then emptied at a lower level. The siphon must discharge at a level lower than that of the liquid surface.

of the discharge point or if, in an otherwise sealed tank, the vacuum created in the ullage matches that of the siphon.

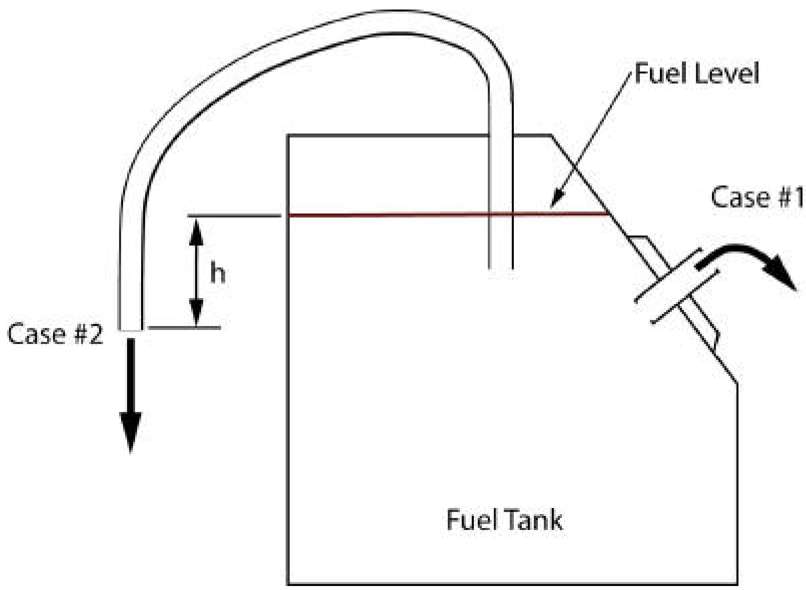

Figure 1: Leakage and Siphoning Diagram.

2.2 Siphoning Evaluation Procedure

The tank components' resistance to siphoning were evaluated with a simple device comprising a vacuum pump (see description and specifications of pump in Appendix A), vacuum gauge and hose. The evaluation procedure consisted of placing the end of the vacuum hose against the port on a tank component and applying a vacuum. The magnitude of the vacuum created was recorded. Only a perfect vacuum would ensure siphoning would not occur[3].

In these tests, air, not fuel was drawn through the components. However, if the air is replaced by a fluid, the fluid's surface tension and viscosity may prevent siphoning at less than the full vacuum being measured. Additionally, although not indicated by the siphoning test, the placement of a valve within a tank may prevent siphoning from occurring. If for example a normally open valve is located at the top of the tank, above the surface of the fuel, siphoning would not occur in the upright orientation despite the fact that a full vacuum could not be generated.

An additional test was conducted to establish a relationship between the flow rate of a liquid and the measured vacuum pressures. This additional test was

[3] -29.929 in-Hg is considered a perfect vacuum

performed to establish the amount of flow for a given amount of vacuum. The test apparatus consisted of a flexible tube with a ball valve installed mid length. With the valve set to different closure levels the vacuum pressure created by tube was measured. For each valve setting the tube and valve assembly was primed and one end was placed in a tank of water[4]. The other end of the tube was placed in a graduated cylinder at a fixed distance below the surface level of the water in the tank. The volume of flow that occurred in one minute was measured. Measured flow in relation to the measured pressure is plotted in Figure 2.

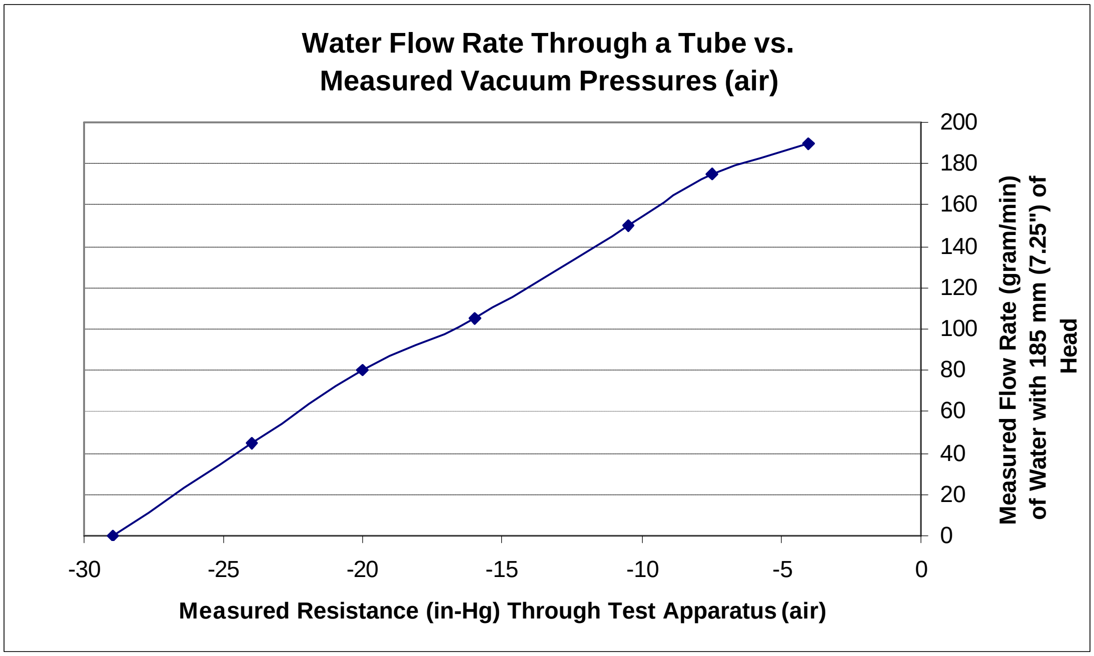

Figure 2: Graph of Volumetric Flow Rate vs. Vacuum Generated .

To put the leakage rates presented in Figure 2 into perspective, the Federal Motor Vehicle Safety Standard 301 (FMVSS 301) requires that a tank system cannot exceed a leakage rate of 28 grams/minute. This rate equates to a vacuum pressure of approximately -26 inches of mercury (in-Hg) in the flow tests conducted. Note that these tests measured the flow through a hollow tube using a ball valve to vary the flow restriction.

With the introduction of a mechanical resistance (check valve, regulator or pump assembly), additional vacuum would be required to overcome the resistance and initiate flow. Therefore, a less than perfect vacuum measured in a test can result in the prevention of siphoning. For example, if a vacuum of -5 in-Hg is required to overcome a mechanical resistance, a head of 2.29 m (7.5 ft) would be required to initiate flow.

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[4] For safety and environmental reasons water was used instead of gasoline.

2.3 Evaluation of Sending Units for Prevention of Siphoning

Each of the 20 sending units, from the previously purchased tanks, were inspected for technologies that would prevent fuel siphoning. Further, each hose coming from the sending unit (fuel delivery, fuel return or fuel vapour return) was subjected to a vacuum test to evaluate the effectiveness of the sending unit at preventing siphoning. The results of the vacuum tests are shown in Table 2. To reiterate, all the sending units in the following section are from 2003 model year vehicles and assume the tank to be in an upright orientation.

Table 2: Results of vacuum tests on 2003 model year sending units.

Vehicle Make/Model (Tank Material)	**Results: Anti-siphon ability of sending unit**	Summary of vacuum results from hoses coming from sending unit (in-Hg)		
		Fuel Delivery Line	Fuel Return Line	Fuel Vapour Return Line
Acura 3.2 TL(Steel) / Honda Accord (Plastic)	No fuel vapour return line Partial vacuum (-10 in-Hg) generated by the fuel delivery line by the pump No vacuum generated by the fuel return line - line exits at mid tank	-10	0	N / A
Audi A8 (Plastic)	No fuel vapour return line Partial vacuum (-21 in-Hg) generated by the fuel delivery line by the pump Full vacuum generated by the fuel return line by a flapper style check valve - has anti-siphon ability - line exits at bottom of tank	-21	-29 (Full)	N / A
BMW 325i (Plastic)	Two fuel units: 1) pumping unit + fuel level indicator, 2) fuel return unit + fuel level indicator No fuel vapour return line Partial vacuum (-15 in-Hg) generated by the fuel delivery line by the pump Full vacuum generated by the fuel return line by a flapper style check valve - has anti-siphon ability - line exits at bottom of tank	-15	-29 (Full)	N / A
Chevrolet Corvette (Plastic)	Full vacuum generated on fuel return line by a normally closed, spring loaded check valve - line exits at mid tank - has anti-siphon ability No vacuum is generated by the fuel vapour return line - exits at mid tank Partial vacuum (-15 in-Hg) is generated by the fuel delivery line by the pump	-15	-29 (Full)	0
Chrysler Cirrus (Plastic)	No fuel vapour return line Partial (-8 in-Hg) vacuum generated by the fuel delivery line by the pump Partial vacuum (-20 in-Hg) generated by the fuel return line by a normally closed spring loaded valve - probably has anti-siphon ability - line exits at mid tank	-8	-20	N / A
Dodge Neon (Plastic)	Returnless system Partial (-10 in-Hg) vacuum generated by the fuel delivery line by pump	-10	N / A	N / A
Ford Mustang (Steel)	Returnless system Full vacuum generated by the fuel delivery line by a normally closed ball-spring loaded check valve - has anti-siphon ability	-29 (Full)	N / A	N / A
GMC Sierra (Plastic)	Partial (-13 in-Hg) vacuum generated on fuel delivery line by the pump No vacuum generated by the fuel vapour return line, exits at top of tank, equipped with a roll over valve No vacuum generated by the fuel return line - exits at bottom of tank	-13	0	0
Honda Odyssey (Plastic)	No fuel vapour return line No vacuum by the fuel return line- exits at bottom of tank Partial vacuum (-10 in-Hg) generated by the fuel delivery line by the pump	-10	0	N / A
Jeep Cherokee (Plastic)	Returnless system Partial vacuum (-15 in-Hg) generated by the fuel delivery line by the pump	-15	N / A	N / A
KIA Spectra (steel)	No fuel vapour return line Partial (-12 in-Hg) vacuum generated by the fuel delivery line by the pump Full vacuum generated by the fuel return line by a normally closed, spring loaded check valve - line exits at bottom of tank - has anti-siphon ability	-12	-29 (Full)	N / A
Mazda MPV (Steel)	Returnless system Partial vacuum (-15 in-Hg) generated by the fuel delivery line by the pump	-15	N / A	N / A
Mercury Grand Marquis (Steel)	No fuel vapour return line Partial (-5 in-Hg) vacuum generated by the fuel delivery line by the pump Full vacuum generated by the fuel return line by a plunger style check valve - line exits at bottom of tank - has anti-siphon ability	-5	-29 (Full)	N / A
Plymouth Grand Voyager (Plastic)	No fuel vapour return line Partial (-10 in-Hg) vacuum generated by the fuel delivery line by the pump Full vacuum generated by the fuel return line by a normally closed, spring loaded check valve at top of the sending unit -line exits at mid tank - has anti-siphon ability	-10	-29 (Full)	N / A
Toyota Camry (Steel) Toyota Corolla (Steel)	Returnless system Partial vacuum (-15 in-Hg) generated by the fuel delivery line by the pump	-15	N / A	N / A
Toyota Prius (Steel)	Returnless system Partial vacuum (-15 in-Hg) generated by the fuel delivery line by the pump	-15	N / A	N / A
VW Jetta (Plastic)	No fuel vapour return line Full vacuum generated by the fuel return line - plunger style check valve - exits at bottom of tank - has anti-siphon ability Partial vacuum (-10 in-Hg) generated by the fuel delivery line by the pump	-10	-29 (Full)	N / A
Saturn SL (Plastic)	Partial vacuum (-15 in-Hg) generated by the fuel delivery line by the pump No vacuum is generated by the fuel vapour return line - exits at top through a roll over check valve No vacuum is generated by the fuel return line - exits at top of sending unit through a roll over valve	-15	0	0
Chevrolet Cavalier (Plastic)	No vacuum generated by the fuel vapour return line - exits at top, equipped with a roll over valve Partial vacuum (-10 in-Hg) generated by the fuel delivery line by the pump Full vacuum generated by the fuel return line by a flapper style check valve at the top of the sending unit - has anti-siphon ability - line exits at bottom of tank	-10	-29 (Full)	0

N / A - Not Applicable

* Sending unit was not available for evaluation

Based on the test results presented in Table 2, systems or components that demonstrated a definite ability to prevent siphoning by generating full vacuum in the test were inspected and their construction documented.

The fuel delivery line of each of the sending units is fed by a fuel pump located inside the tank. These pumps vary in design and provide a wide range of resistances to fuel flow when the pump is de-energized, which is exemplified by the vacuum pressures that ranged from -5 in-Hg to a full vacuum (-29 in-Hg), as shown in Table 2. To determine whether the measured vacuum of the fuel delivery line is a result of a mechanical resistance or from a fluid dynamic resistance the measured vacuum pressures were cross referenced to the previous study which evaluated the leak resistance of a fuel system in multiple tank orientations [Ref. 1, 2]. If the delivery line leaked in any of the orientations tested then it can be assumed that a mechanical resistance did not exist and therefore the line would have a propensity to permit siphoning. However, if leakage did not occur, then some form of mechanical resistance must exist in the line. Therefore, if a vacuum is measured on a line but no leakage was observed during the leak tests, siphoning would not occur unless a sufficient head (differential pressure) is present to generate the required vacuum. However, if the system did leak then the measured vacuum would represent a hydrodynamic flow restriction not a mechanical restriction and siphoning would be possible.

Of the 13 sending units with a fuel return line, the vacuum measured on the line ranged from zero to a full vacuum (-29 in-Hg). The fuel return line on eight sending units generated full vacuum, whereas zero vacuum was measured in four cases. One sending unit generated a partial vacuum of -20 in-Hg on the fuel return line. Of the five sending unit fuel return lines that did not generate full vacuum, four exited at the middle or the bottom of the tank and could allow siphoning. The fifth vehicle's fuel return line which exited at the top of the sending unit would resist siphoning.

Only four of the inspected vehicles had a fuel vapour return line, none of which generated a vacuum. In three of the four sending units the vapour return line exited at the top of the tank and therefore would not permit siphoning of fuel if the tank remained in an upright orientation. The Chevrolet Corvette's fuel vapour return line, however, exited at the mid tank level and therefore would permit siphoning.

As mentioned above, if a fuel line is equipped with a mechanical flow resistive mechanism then siphoning can only occur if that resistance is overcome. In light of the siphon vacuum test results and the inspection of the sending unit components, Table 3 summarizes whether the lines coming from the sending unit have the ability to prevent siphoning even though a full vacuum could not be generated in the tests.

Table 3: Ability of sending unit lines to prevent siphoning for 2003 model year vehicles.

Vehicle Make/Model	Protects Against Siphoning		
	Fuel Delivery Line	Fuel Return Line	Fuel Vapour Return Line
Acura 3.2 TL / Honda Accord	N	N	N / A
Audi A8	Y	Y	N / A
BMW 325i	Y	Y	N / A
Chevrolet Corvette	N	Y	N
Chrysler Cirrus	Y	Y	N / A
Dodge Neon	Y	N / A	N / A
Ford Mustang	Y	N / A	N / A
GMC Sierra	N	N	Y
Honda Odyssey	N	N	N / A
Jeep Cherokee	Y	N / A	N / A
KIA Spectra	Y	Y	N / A
Mazda MPV	N	N / A	N / A
Mercury Grand Marquis	Y	Y	N / A
Plymouth Grand Voyager	Y	Y	N / A
Toyota Camry	N	N / A	N / A
Toyota Corolla Toyota Prius	N	N / A	N / A
VW Jetta	Y	Y	N / A
Saturn SL	Y	Y	Y
Chevrolet Cavalier	*	*	*

N / A - Not Applicable

* - No leak tests performed

2.3.1 Acura 3.2 TL / Honda Accord (2003)

No technology was evident that would prevent siphoning.

2.3.2 Audi A8 (2003)

The Audi A8 utilized an axial flapper valve on the fuel return port on the sending unit. As the fuel returns to the tank, it displaces the orange rubber disc (see Figure 3). If fuel is forced to flow in the opposite direction, the rubber disc is pushed against the perforated surface, creating a seal and preventing reverse flow. This style of valve demonstrates anti-siphon characteristics.

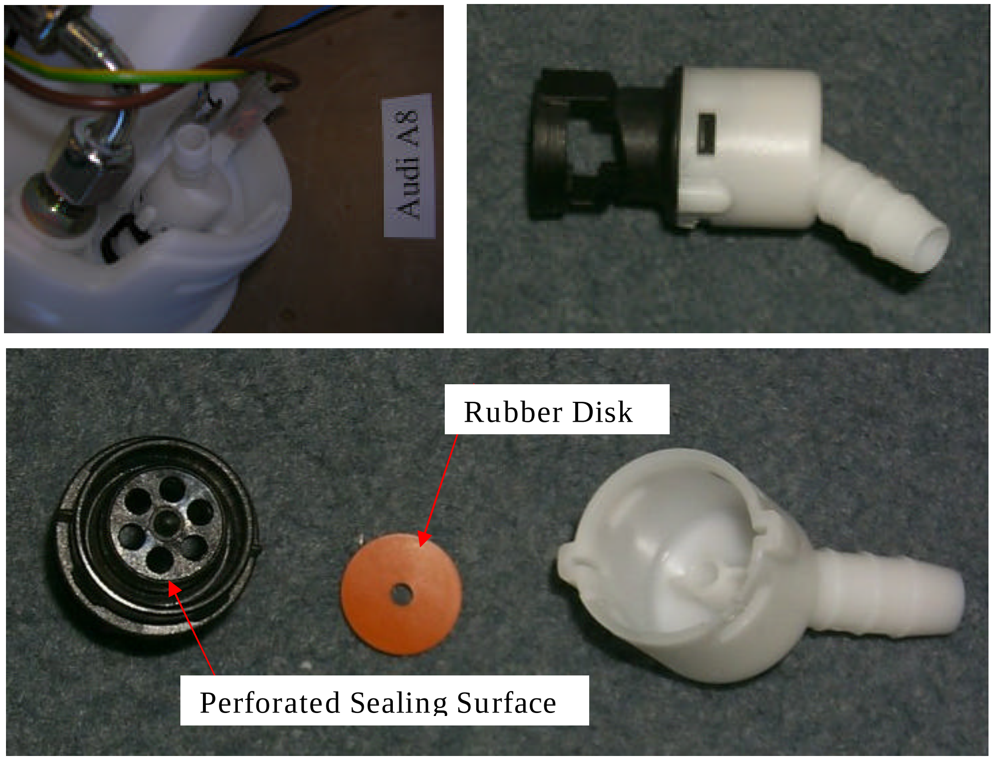


Figure 3: Audi A8 - fuel return line valve.

The fuel delivery line from the A8 also generated approximately -21 in-Hg vacuum with its internal gear pump, shown in Figure 4. A schematic of the gear pump mechanism is shown in Figure 5. This design of the internal gear pump is intrinsically safe, that is, fuel can only move through the pump when the pump is rotating.

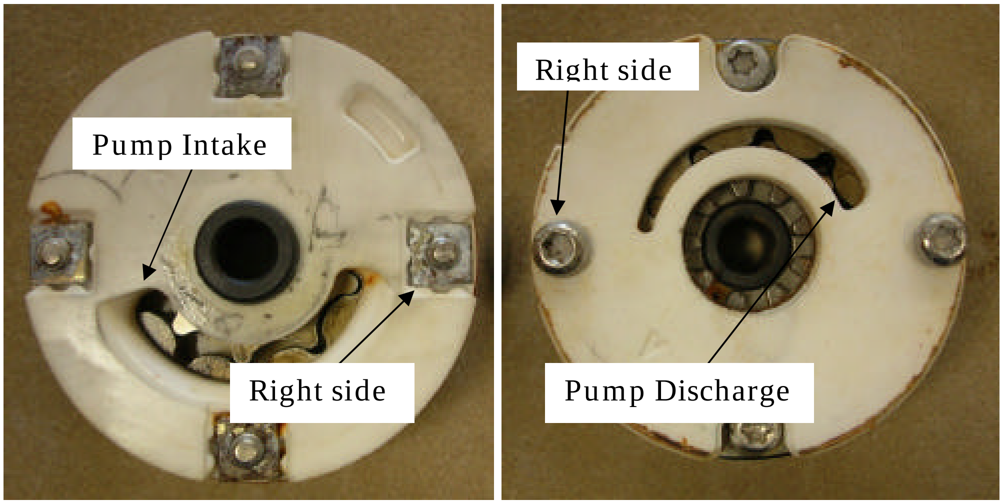


Figure 4: Internal gear fuel pump for the Audi A8.

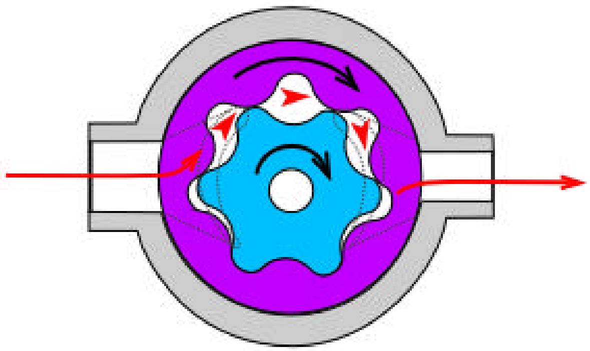


Figure 5: Internal Gear Pump Schematic.

2.3.3 BMW 325i (2003)

The BMW 325i uses a similar fuel return line valve design as the Audi A8. This valve is shown in Figure 6. This style of valve demonstrates anti-siphon characteristics.

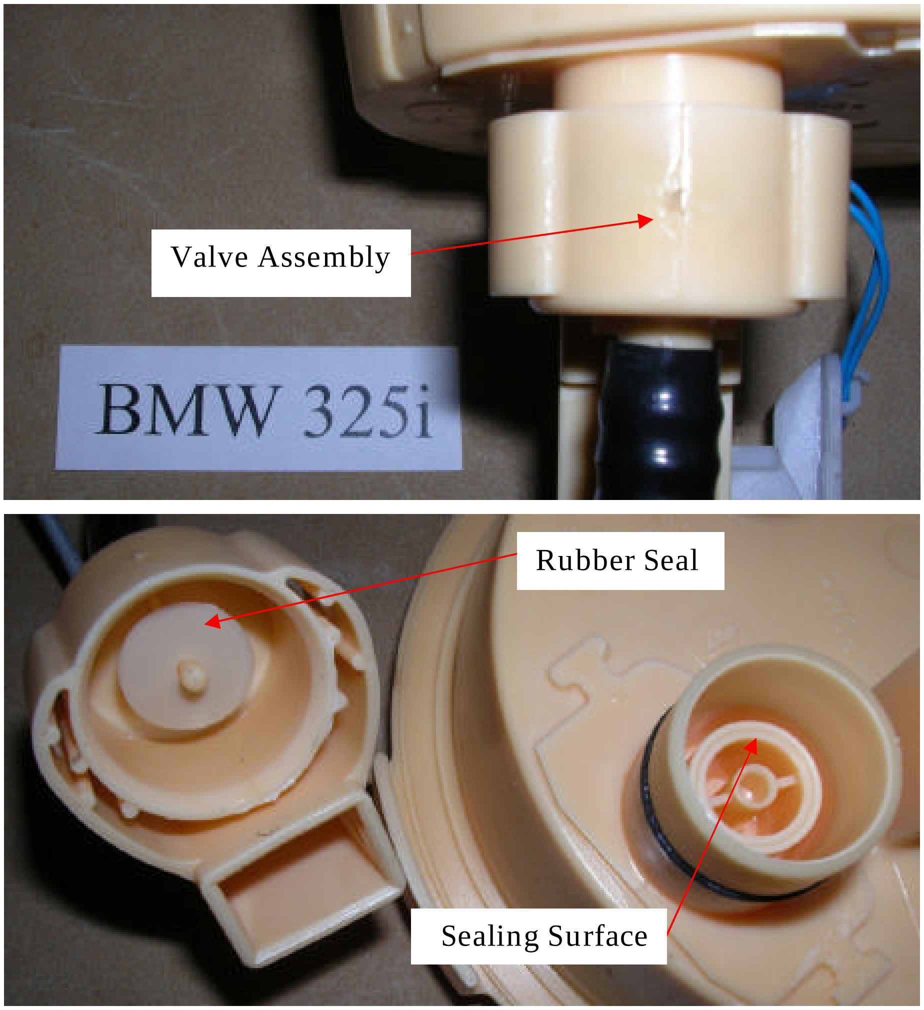


Figure 6: BMW 325i - fuel return line valve.

2.3.4 Chevrolet Corvette (2003)

The Chevrolet Corvette utilizes a normally closed, spring loaded check valve at the end of the fuel return line located in the sending unit. Given that the valve is spring loaded, fuel can only flow in one direction: into the tank. Figure 7 shows the valve and its location in the sending unit. This style of valve also demonstrates anti-siphon characteristics.

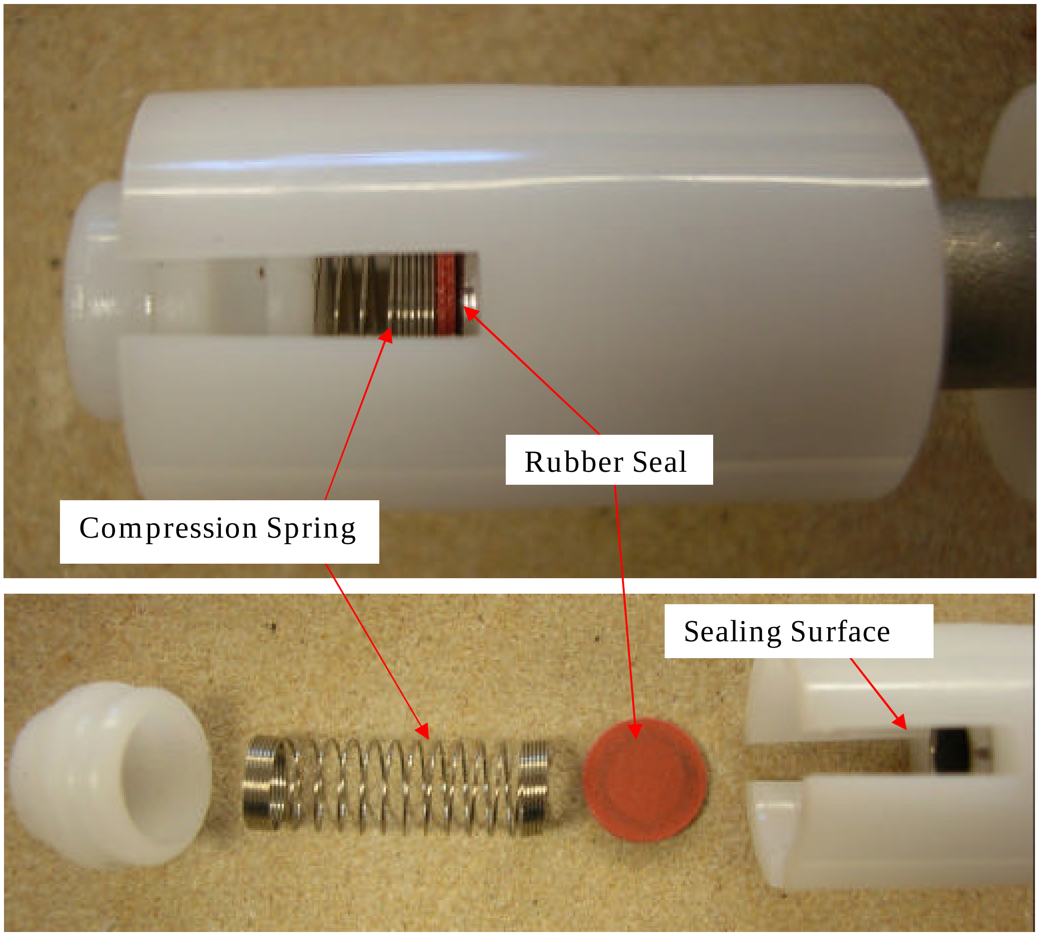


Figure 7: Chevrolet Corvette normally closed fuel return valve.

2.3.5 Chrysler Cirrus, Dodge Neon and Ford Mustang (2003)

These tanks did not leak in any orientation during the leak test and their components, including any anti-siphon devices are described in further detail in Section 2.4.

2.3.6 GMC Sierra, Honda Odyssey and Jeep Cherokee (2003)

No technology was evident in these vehicles that would prevent siphoning.

2.3.7 Kia Spectra (2003)

This tank did not leak in any orientation during the leak test. Its components, including the anti-siphon device are described in further detail in Section 2.4.

2.3.8 Mazda MPV (2003)

No technology was evident that would prevent siphoning.

2.3.9 Mercury Grand Marquis (2003)

The Mercury Grand Marquis is fitted with a small flow valve at the end of the fuel return line located at the bottom of the fuel tank The valve is shown in Figure 8. The rubber seal is small and light weight and therefore responsive to fluid movement. Fuel returning to the tank displaces the rubber seal and drains into the tank. Should reverse flow in the return line occur, the rubber washer seals against the opening, thereby preventing fluid from escaping. It should be noted that this seal requires a differential in pressure for the seal to function. This valve design would be effective at preventing siphoning.

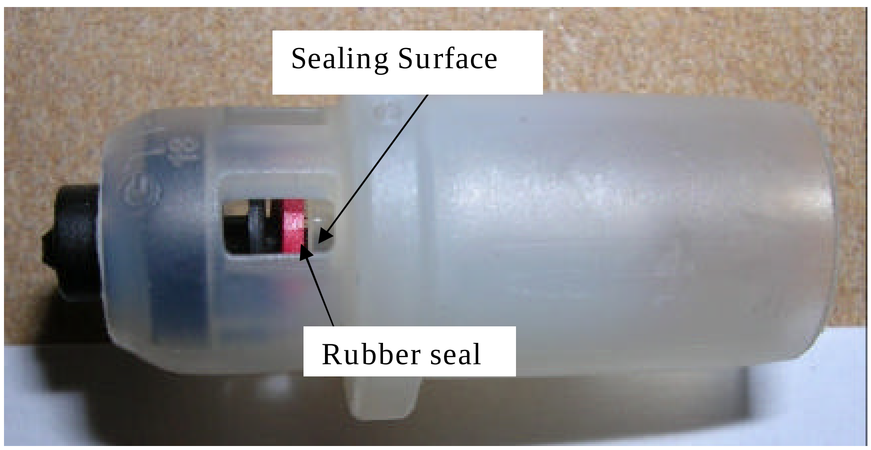


Figure 8: Mercury Grand Marquis - fuel return line valve.

2.3.10 Plymouth Grand Voyager (2003)

The Plymouth Grand Voyager has a normally closed spring loaded valve in the fuel return line, which is located close to the top of the sending unit as shown in Figure 9. A disassembly of the valve[5] is shown in Figure 10. Fuel returning to the tank via the fuel return line enters the valve through orifice A, pushes on the diaphragm, compressing the spring and flows between the sealing surfaces and exits towards the tank through orifice B. A good seal at the sealing surface is obtained due to the large spring force acting on the diaphragm.

[5] This valve is also used in other vehicle makes and models as a flow regulator.

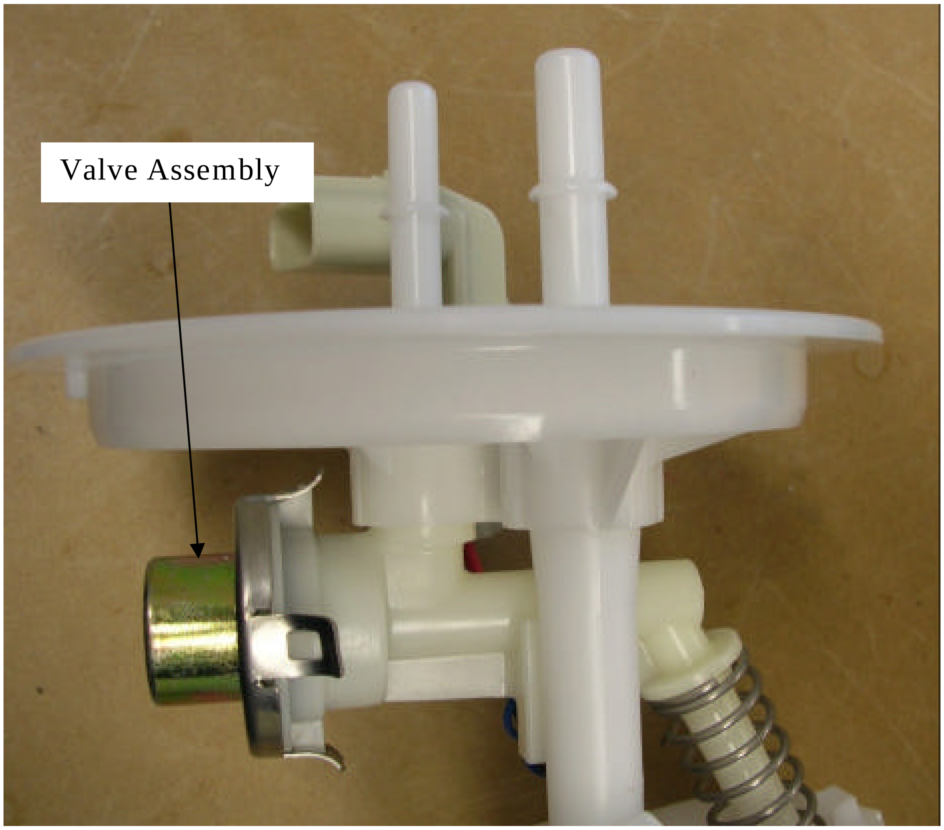


Figure 9: Plymouth Grand Voyager – sending unit.

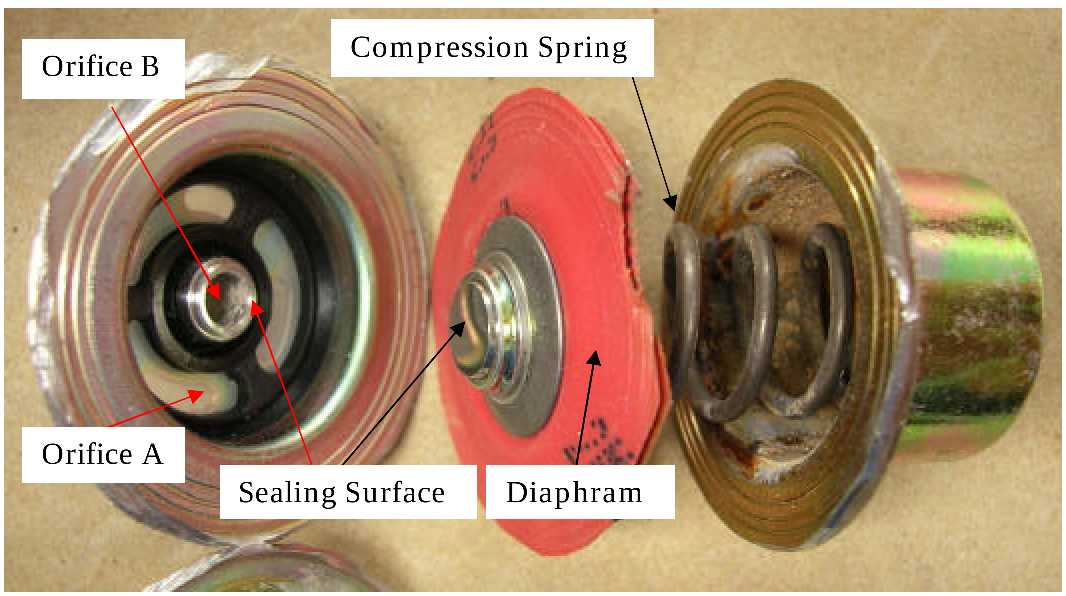


Figure 10: Plymouth Grand Voyager - fuel return line valve - disassembled.

2.3.11 Toyota Camry, Corolla and Prius (2003)

No technology was evident that would prevent siphoning.

2.3.12 VW Jetta (2003)

The VW Jetta utilizes a normally closed, rubber disk valve on the fuel return line. This valve is located underneath the sending unit's top plate. The rubber disk is cone shaped and constantly applies a light pressure to the sealing surface. Fuel returning to the tank displaces the rubber disk allowing flow into the tank. Any fuel flowing in the reverse direction is prevented by the normally closed seal. This style of valve serves to prevent leakage due to siphoning.

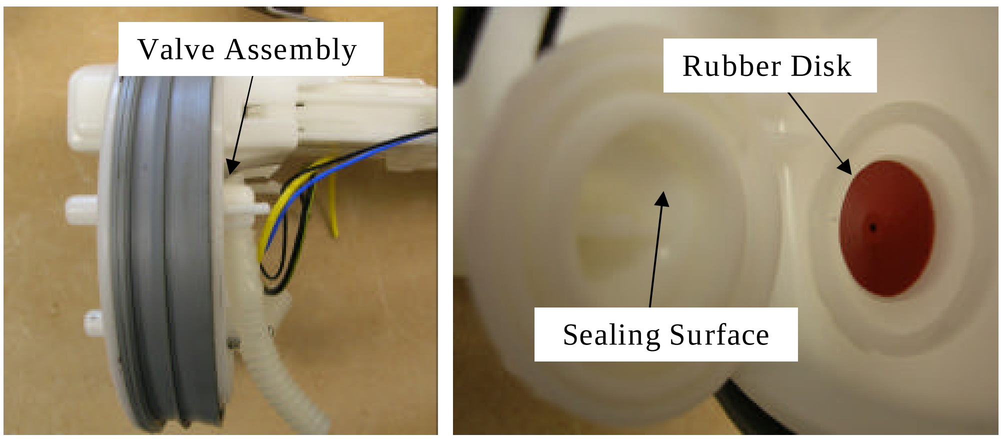


Figure 11: VW Jetta – fuel return line valve.

2.3.13 Saturn SL (2003)

No technology was evident that would prevent siphoning.

2.3.14 Chevrolet Cavalier (2003)

The Chevrolet Cavalier was not included in any previous tank system evaluations but its review is included here to demonstrate a unique valve design. The tank's sending unit incorporates a unique fuel line return valve that prevents siphoning. Figure 12 shows the location and geometry of the normally closed valve. The valve geometry permits fuel to flow into the tank by spreading the four cusps which comprise the valve. Reverse flow travelling out of the tank creates an increase in fuel pressure acting on the exterior of the four cusps which closes and seals the cusps against one another, thus preventing any fuel from leaving the tank.

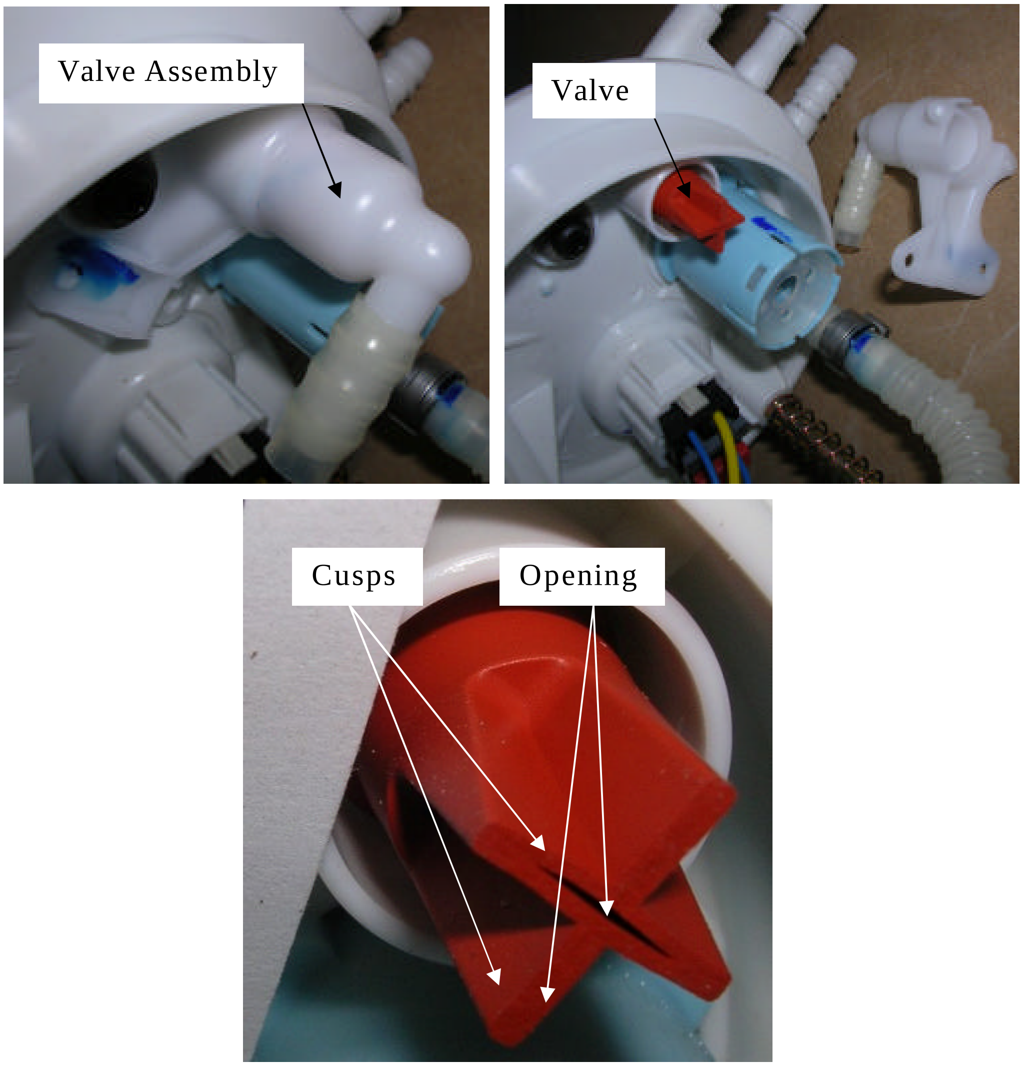


Figure 12: Chevrolet Cavalier - fuel return line valve.

2.3.15 Valve on the fuel supply line

Many of the fuel pump assemblies reviewed incorporate a small one way valve which is hypothesized to prevent fuel above the fuel pump assembly from draining back into the tank. These one way valves, as shown in Figure 13 are made up of a small plunger or spherical ball which is supported by a light pressure spring. The pressure generated by the pump compresses this spring and fuel passes through/around the valve; however, when the pump shuts down, the valve remains closed blocking any fuel from draining back into the tank. The pressure generated by the springs will contribute to the prevention of a siphoning action, however, because the springs forces are so weak, the contribution will be minimal.

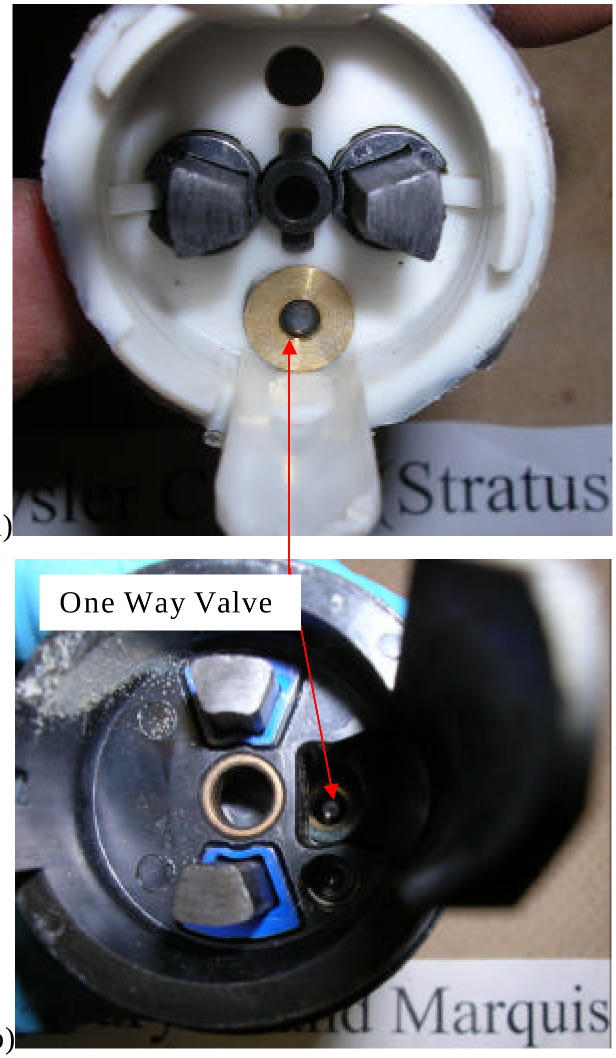


Figure 13: One way valve on fuel pump for
a) Chrysler Cirrus and b) Mercury Grand Marquis

2.3.16 Fuel Return Line Location Within the Tank

A fuel return line that terminates at the top of a tank would not be prone to siphoning if the tank remains in an upright orientation; however, a fuel return line that terminates near the bottom of the tank would be prone to siphoning if a line is severed given there is no anti-siphoning technology (valve) in place. In this orientation the end of the return line would reside in the ullage and consequently would not be able to draw fuel from the tank. If the tank is rotated sufficiently, such that the end of the fuel return line becomes immersed in fuel, siphoning or gravity fed leakage would be possible depending on the relative routing of the fuel return line outside the tanks. In this circumstance, an appropriate valve installed on the end of the return line would prevent leakage regardless of the leakage mechanism.

2.4 Detailed Review of the Four Leak Tested Tanks With No Fuel Loss Recorded

In the initial leak tests that were conducted [Ref. 1, 2] four tanks systems were found not to leak, regardless of the tank orientation, when the connections emanating from the tank were disconnected one at a time. The vehicles from which the tank systems were obtained were:

- Chrysler Cirrus
- Dodge Neon
- Ford Mustang
- Kia Spectra

A detailed description of the components from these tanks is presented in the following sections. Included is an assessment of anti-siphon technologies that may be incorporated into the designs. The results of the vacuum anti-siphon tests for these four vehicles are included in Table 2.

2.4.1 Chrysler Cirrus (2003)

Figure 14 shows the Chrysler Cirrus tank system in its entirety. The Cirrus tank has four openings which include: the filler tube, sending unit and two fuel vapour ports.

Figure 14: Chrysler Cirrus tank system.

The filler hose is fastened to a spout that is integral to the tank, see Figure 15. On the inside of the tank spout is a normally closed, spring plunger check valve as shown in Figure 16. A disassembled view of the valve assembly shown in Figure 17. The plunger of the normally closed valve is displaced as fuel enters the tank from the filler tube. When filling stops, the valve closes thus preventing reverse flow or leakage of fuel and / or vapour into the filler tube.

Figure 15: Chrysler Cirrus fuel filler spout.

Figure 16: Chrysler Cirrus filler tube valve.

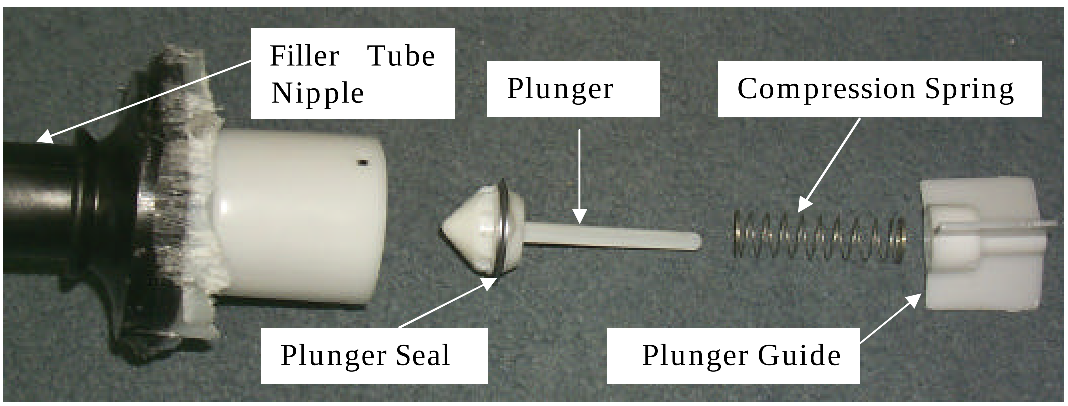


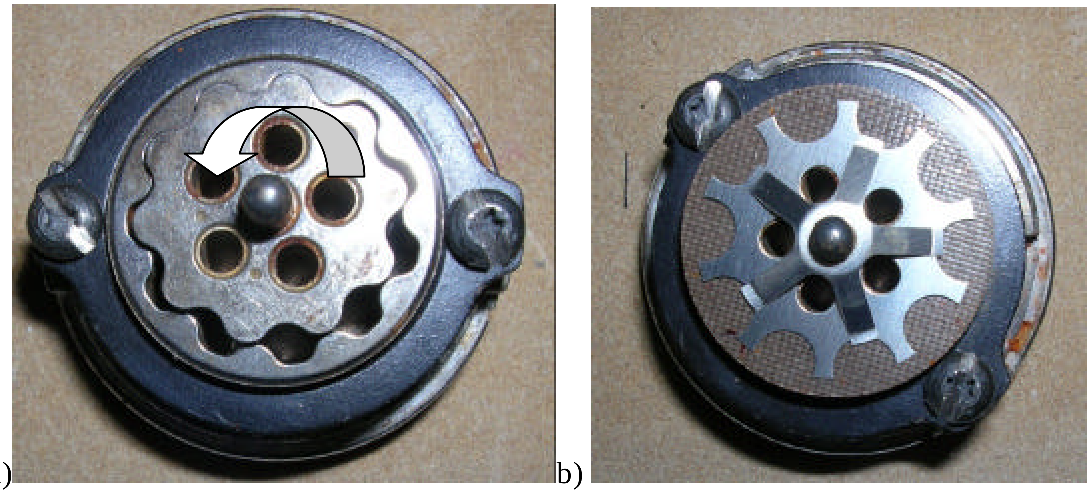
Figure 17: Chrysler Cirrus filler tube valve - disassembled.

Two fuel lines exit the top of the sending unit, shown in Figure 18. They include the fuel delivery and fuel return lines. As shown previously in Table 2, a partial vacuum (-8 in-Hg) was generated on the fuel delivery line. The only source of resistance to fuel flow in the fuel delivery line is the fuel pump which is shown in a disassembled state in Figure 19.

Figure 18: Chrysler Cirrus sending unit.

Figure 19: Chrysler Cirrus fuel pump - disassembled.

A detailed picture of the internal gear pump is shown in Figure 20. Fuel flows into the void between the internal and external gear teeth through an orifice at the bottom of the pump, see Figure 20 a). As the opening begins to close, the fuel is forced between the rigid bottom face of the gear pump and a flexible disc on the top, see Figure 20 b). The fuel circumvents the flexible disk and flows up through the armature of the motor and out of the sending unit fuel delivery line. The flexible disc which is in a normally closed state, covers the opening of the gear pump and is believed to contribute mostly to the -8 in-Hg vacuum measured.



a) b)

Figure 20: Chrysler Cirrus fuel pump (a) internal gear and (b) disk valve.

The fuel return line is equipped with a normally closed valve, similar to that shown previously in Figure 9 and Figure 10 (see Figure 21).

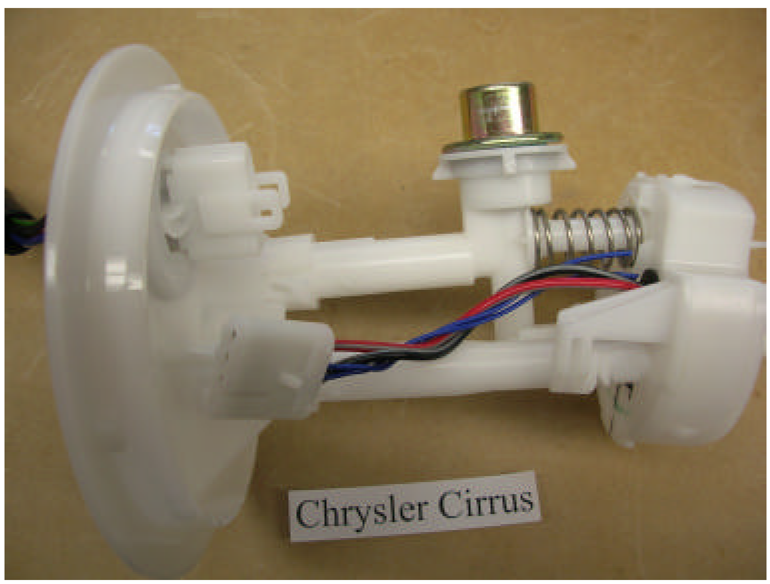


Figure 21: Chrysler Cirrus fuel return line valve on the sending unit.

There are two vapour ports on the tank, both of which are located at the top of the tank. The valve connected to the first port is shown in Figure 22. The disassembled valve is shown in Figure 23 and Figure 24. A buoyant plunger[6] seal, supported by a light force compression spring translates in the vertical

[6] A buoyant plunger is shaped somewhat like an inverted drinking cup. In a vertical oriented vehicle, as fuel rises when filling the tank, air is trapped in the plunger seal resulting in a buoyancy effect. If the vehicle overturns, fuel fills the plunger resulting in a zero buoyancy effect; the hydrostatic pressure of the fuel above assists in generating a good seal.

direction. When the fuel level is full, the buoyant[7] plunger with the assistance of the compression spring pushes up against the sealing surface, preventing fuel loss through the vapour line due to siphoning.

The plunger assembly, shown in Figure 24, is equipped with a secondary pin valve. It is unclear why the plunger assembly is comprised of two parts and why the pin valve exists.

Figure 22: Chrysler Cirrus fuel vapour port valve.

[7] Many of the tank components used by various manufacturers utilize a normally open spring plunger which is buoyant. This style of valve is used in emissions ports and sending units.

The basic system can be seen in Figure 23. As the fuel level rises in the tank, the buoyant plunger supported by the spring floats on top of the fuel surface until it seals against the port. In this configuration, the port being sealed off, liquid fuel and fuel vapours may enter the tank but no liquid fuel can escape from the tank by either hydrostatic pressure or siphoning action (Some of the designs it is hypothesized are such that fuel vapours can slip by the seal when sealed but liquid fuel is prevented from escaping the tank). As the fuel level begins to drop through usage of the vehicle, the plunger drops as well, losing its seal, allowing liquid fuel to enter and fuel vapours to enter and exit as required by the fuel vapour recovery system. Once the seal has been broken by the plunger, the fuel level is at a point where it cannot be siphoned out because the intake for the port is no longer sitting in fuel. Should the vehicle overturn in an accident, gravity along with the spring pressure will push the plunger against the port creating a seal and therefore preventing fuel from escaping the tank.

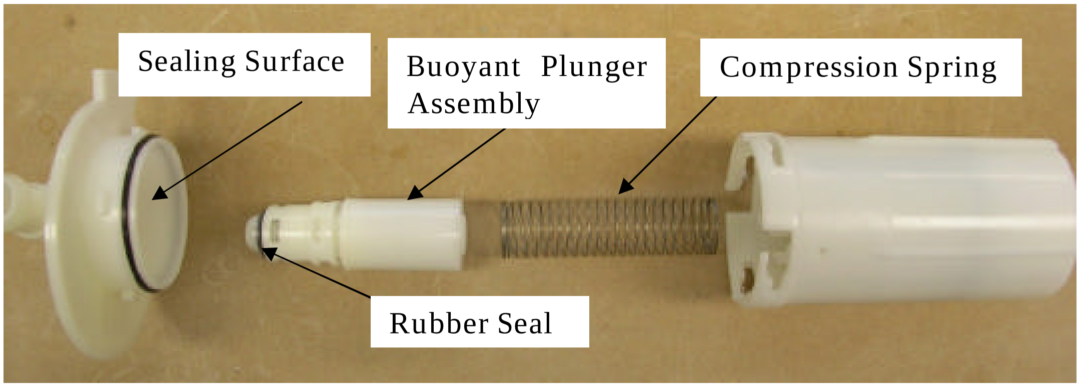


Figure 23: Chrysler Cirrus fuel vapour port – disassembled.

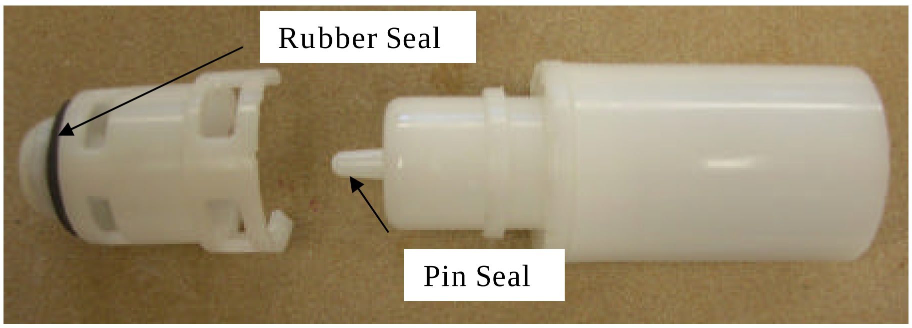


Figure 24: Chrysler Cirrus fuel vapour port – plunger assembly detail.

The second fuel vapour port is shown in Figure 25 and Figure 26. It too is equipped with a buoyant plunger and compression spring. With a full tank, the plunger is sealed, preventing fuel or vapour from escaping.

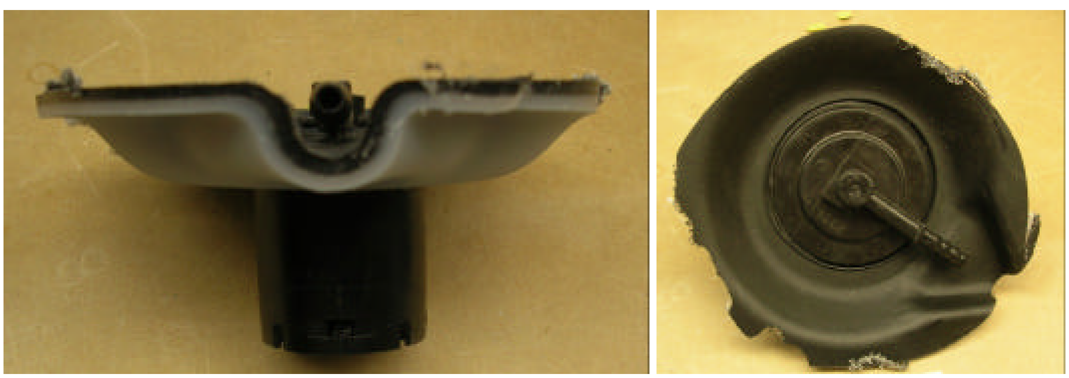


Figure 25: Second Chrysler Cirrus fuel vapour port

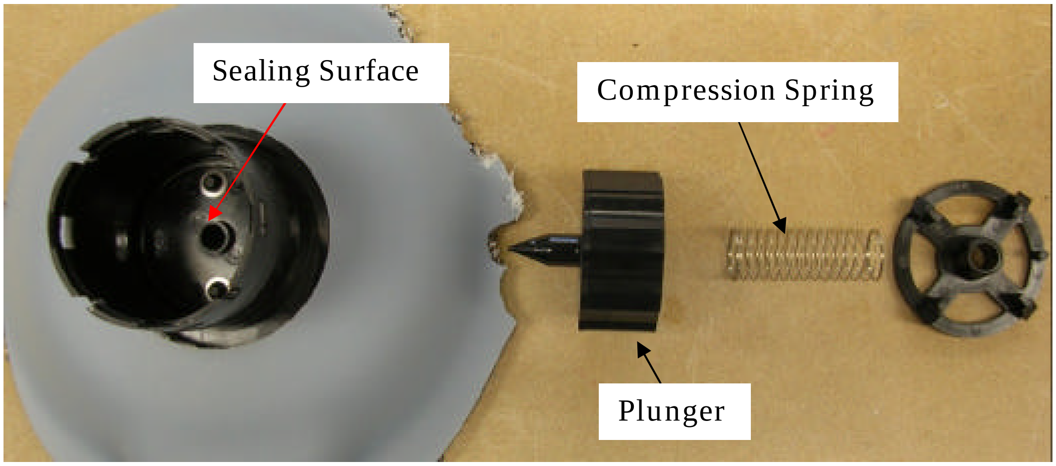


Figure 26: Second Chrysler Cirrus fuel vapour port – disassembled.

2.4.2 Dodge Neon (2003)

The complete Dodge Neon tank system is shown in Figure 27. The Neon has five openings to the tank: filler tube, sending unit and three fuel vapour ports, two of which are identical.

Figure 27: Dodge Neon tank system.

The filler hose is fastened to a spout that is integral to the tank. On the inside of the spout is a normally closed, plunger valve, see Figure 28. A disassembled view of the valve is shown in Figure 29. The normally closed valve is displaced as fuel enters the tank from the filler tube, once the fuel has stopped flowing into the tank, the valve closes thus preventing fuel and/or vapour from leaving the tank.

Figure 28: Dodge Neon filler tube spout and valve.

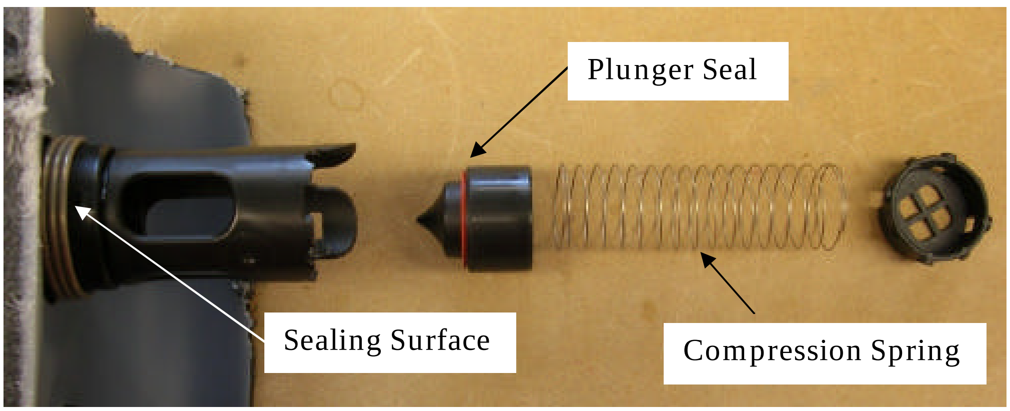


Figure 29: Dodge Neon filler neck valve - disassembled.

The sending unit, shown in Figure 30 is a returnless fuel system and therefore has only the fuel delivery line connected to it. As documented in Table 2, only a partial vacuum (-10 in-Hg) was generated on the fuel delivery line. The fuel pump provided the resistance to fuel flow in the line. The fuel pump is shown in Figure 31[8]. A detailed picture of the internal gear pump is shown in Figure 32.

[8] The rust seen in Figure 31 and Figure 32 are a consequence of the previously conducted leak tests.

The Neon's fuel pump functioned identically to that of the Cirrus and consequently a similar pressure is generated by the two systems in the vacuum test.

Figure 30: Dodge Neon sending unit.

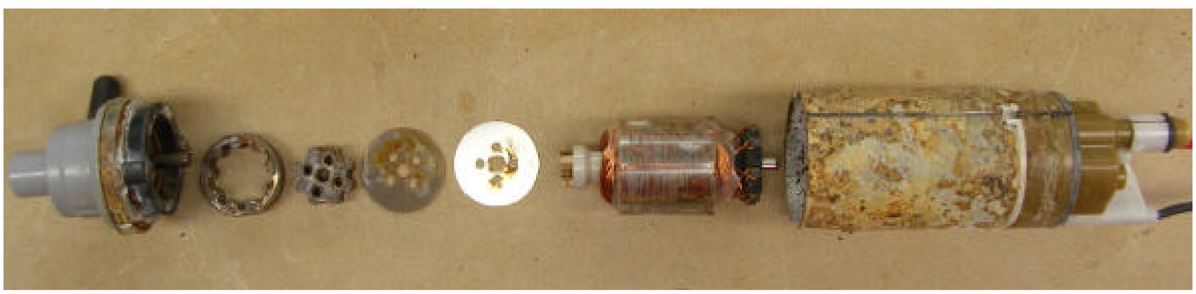


Figure 31: Dodge Neon fuel pump - disassembled.

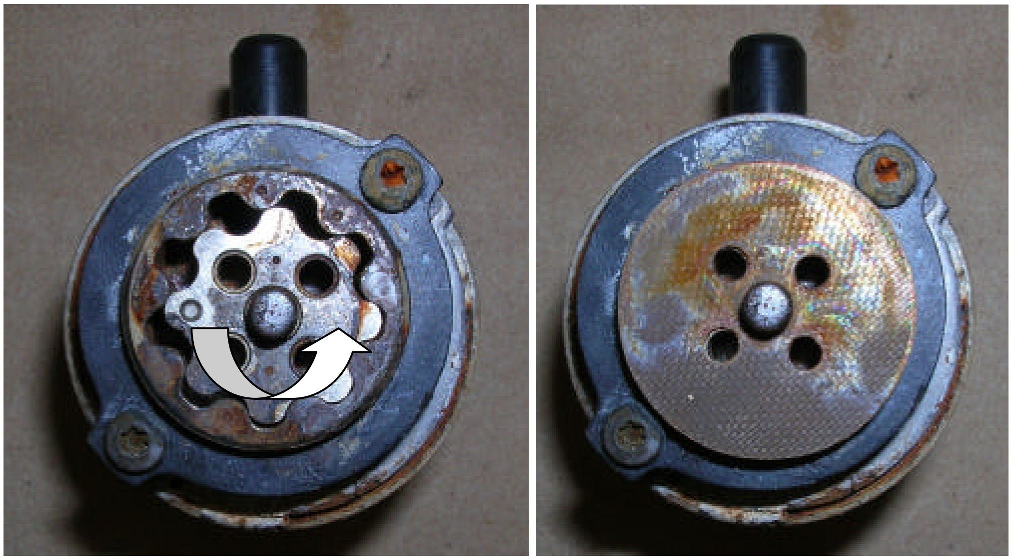


Figure 32: Dodge Neon fuel pump internal gear and disk valve.

The fist fuel vapour port valve, located on the top of the tank is shown in Figure 33 and Figure 34. This valve is similar to that of the Chrysler Cirrus and is comprised of a compression spring, a buoyant plunger assembly and a sealing surface. Similarly to the Cirrus, the plunger assembly is buoyant and therefore, in a full tank, the plunger seals itself against the sealing surface. The plunger assembly, shown in Figure 35, is equipped with a secondary spring loaded plunger. It is unclear why there is such complexity but it is hypothesized that with a full tank, the primary seal would prevent liquid fuel from leaving the valve while the secondary seal would permit the passage of fuel vapours in and out of the tank but does not permit the passage of liquid fuel. Because the fuel vapour line exits at the top of the tank, siphoning can not be initiated with the vehicle in the upright position.

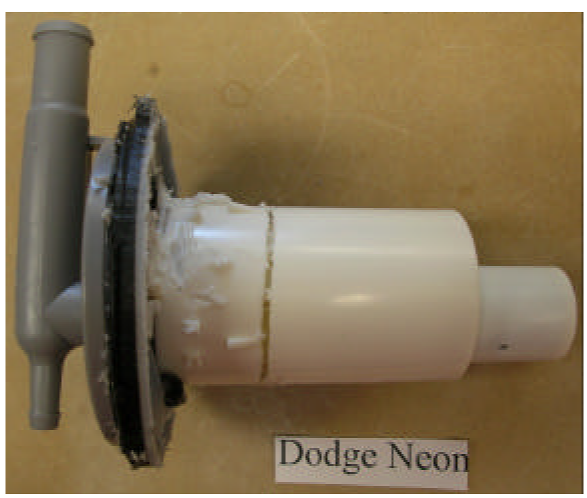


Figure 33: Dodge Neon vapour port valve.

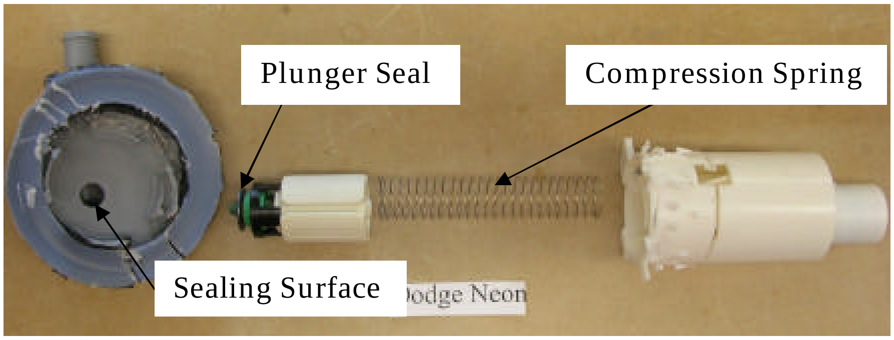


Figure 34: Dodge Neon fuel vapour valve - disassembled.

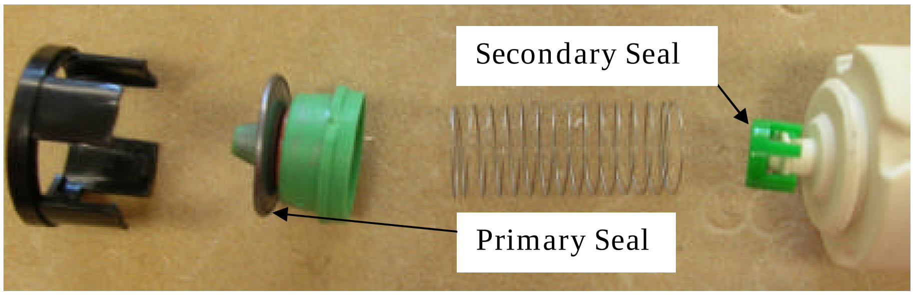


Figure 35: Dodge Neon secondary vapour valve - disassembled.

The second vapour valve, of which there are two installed in the tank is identical to that used in the Chrysler Cirrus and is shown in Figure 36 and Figure 37, they are both located at the top of the tank. The valve is equipped with a buoyant plunger and a compression spring. With a full tank, the plunger is sealed, preventing fuel or vapour from escaping. Because the fuel vapour line exits at the top of the tank, siphoning can not be initiated with the vehicle in the upright position.

Figure 36: Dodge Neon second fuel vapour valve.

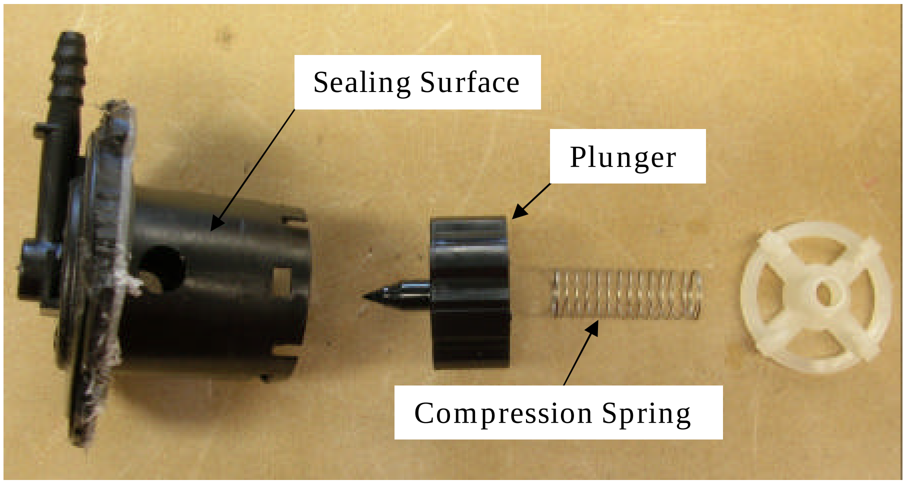


Figure 37: Dodge Neon second fuel vapour valve - disassembled.

2.4.3 Ford Mustang (2003)

All the components of the Ford Mustang tank system are shown in Figure 38. The Mustang has four openings to the tank: filler tube, sending unit and two fuel vapour ports.

Figure 38: Ford Mustang tank system.

A rigid filler tube is connected to the tank through a rubber seal and fastened to the tank to prevent pull out, see Figure 39. Attached to the end of the filler hose is a normally closed plunger valve similar to that used by the Neon, see Figure 40.

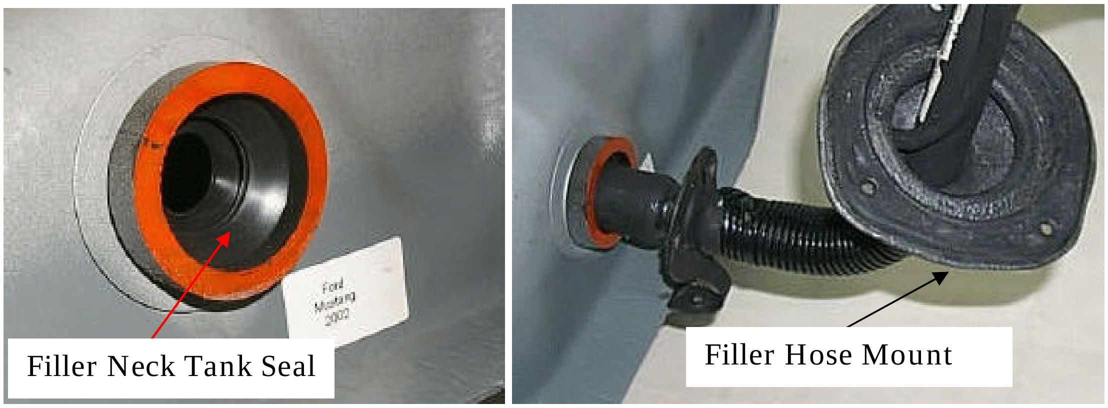


Figure 39: Ford Mustang filler hose connection to tank.

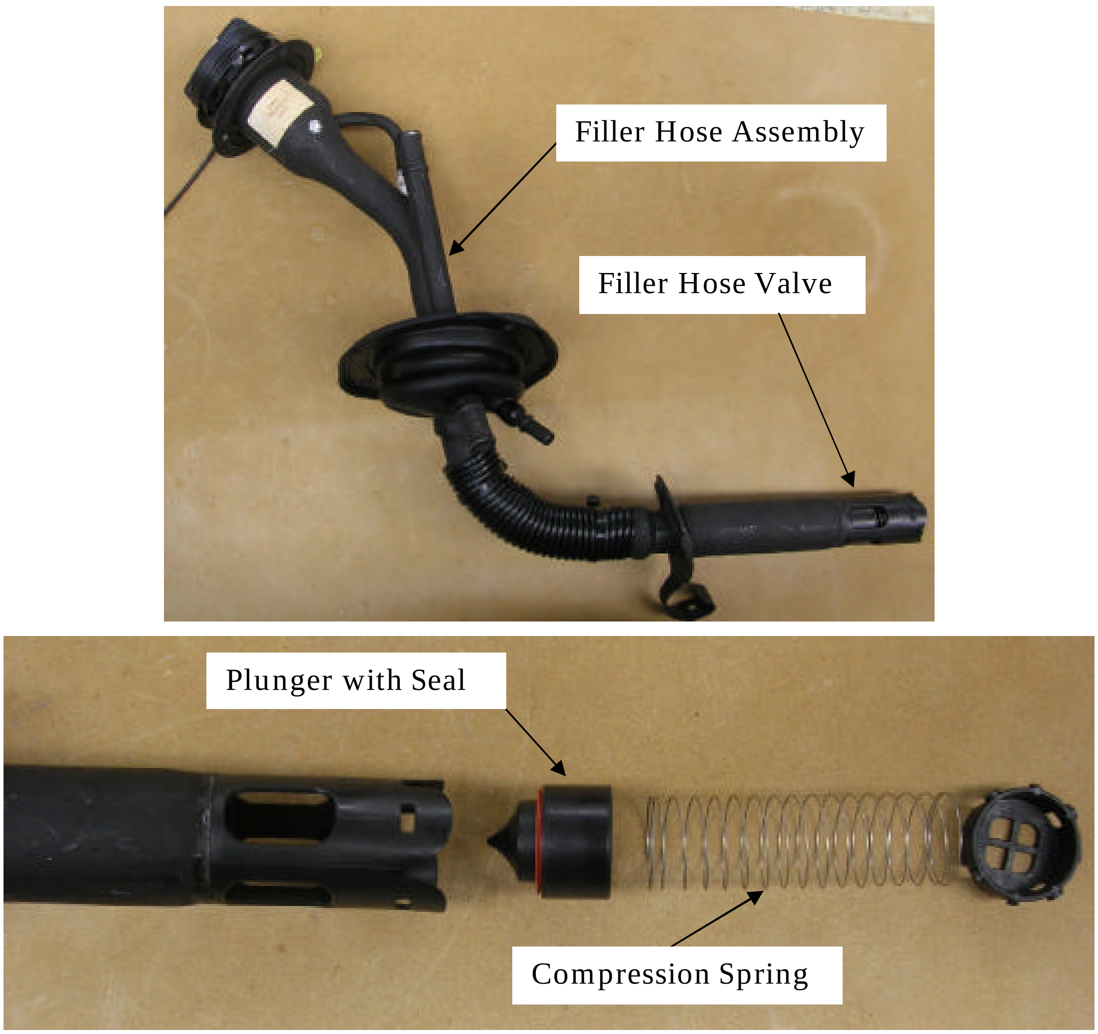


Figure 40: Ford Mustang filler hose and valve - disassembled.

The sending unit, shown in Figure 41 is a returnless system and therefore it only has a fuel delivery line. The Mustang's sending unit is unique in that it contains two fuel pumps that are mounted in parallel. As documented in Table 2, a full vacuum was generated on the fuel delivery line for this vehicle. The resistance to fuel flow in the fuel delivery line stems from a valve assembly located just down stream of both fuel pumps, see Figure 42. The valve comprises two spring loaded plungers which seal against a brass fitting. The first plunger prevents fuel from draining back into the tank once the pumps have shut off keeping the line primed. This valve also provides the full vacuum generated on the fuel delivery line during the vacuum test to assess siphoning. The second plunger appears to function as an overflow valve such that, if the fuel pressure in the line exceeds that required by the engine, fuel is diverted back into the tank. This valve assembly would prevent siphoning.

Figure 41: Ford Mustang sending unit.

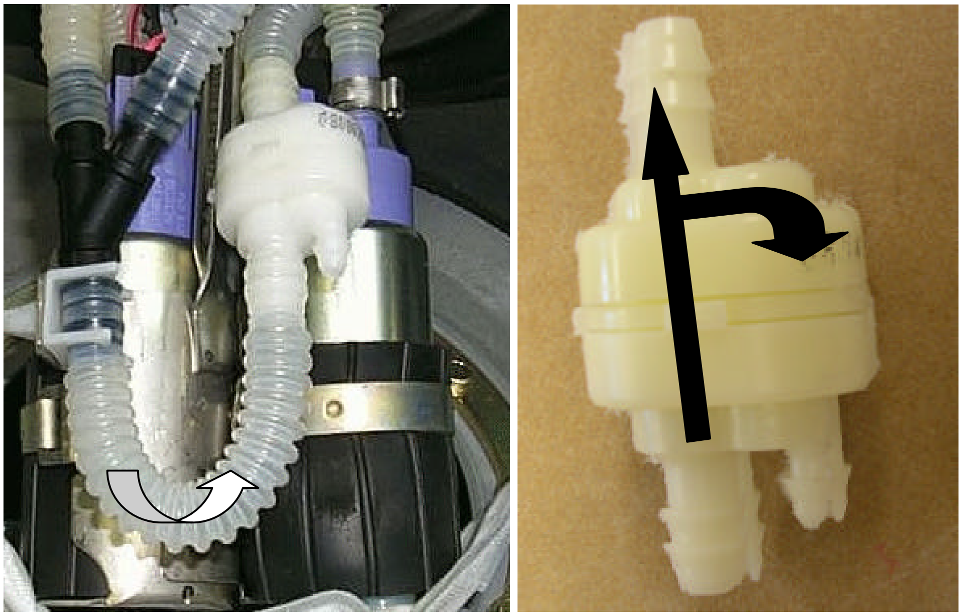


Figure 42: Ford Mustang fuel delivery line valve.

There are two vapour ports on the Mustang tank, both of which are located at the top of the tank. The valve installed at the first port is shown in Figure 43. This valve comprises a compression spring, a buoyant plunger assembly and a sealing surface, see Figure 44. Like the Chrysler Cirrus and the Dodge Neon, the plunger assembly is buoyant. The plunger assembly, shown in Figure 45, is equipped with a secondary spring loaded valve similar to that of the Dodge Neon.

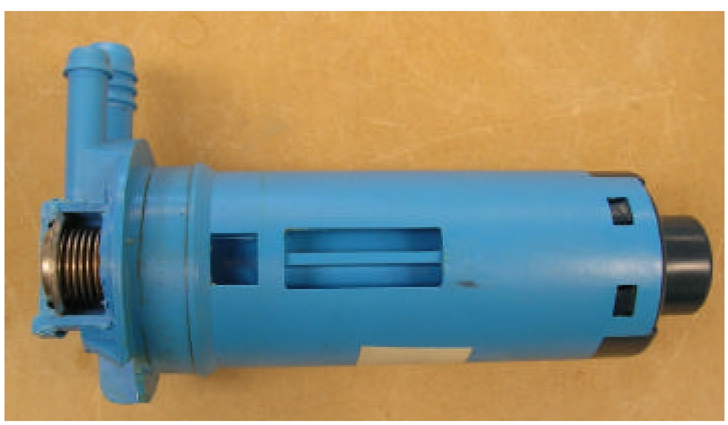


Figure 43: Ford Mustang fuel vapour valve.

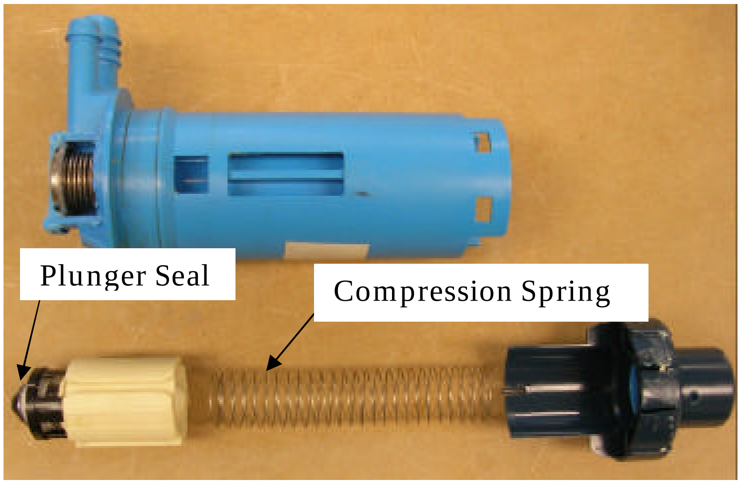


Figure 44: Ford Mustang fuel vapour valve - disassembled.

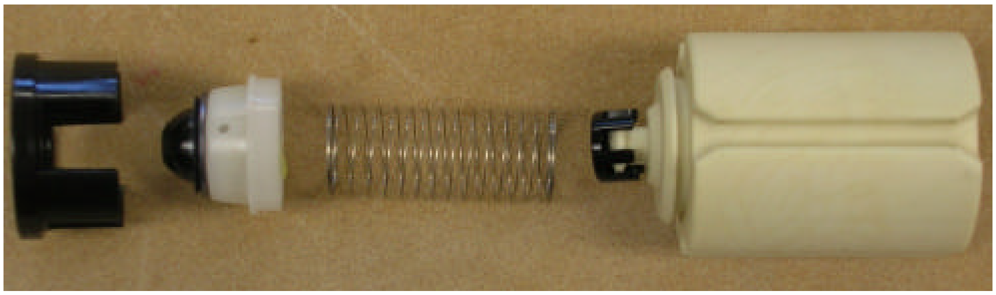


Figure 45: Ford Mustang fuel vapour port plunger - disassembled.

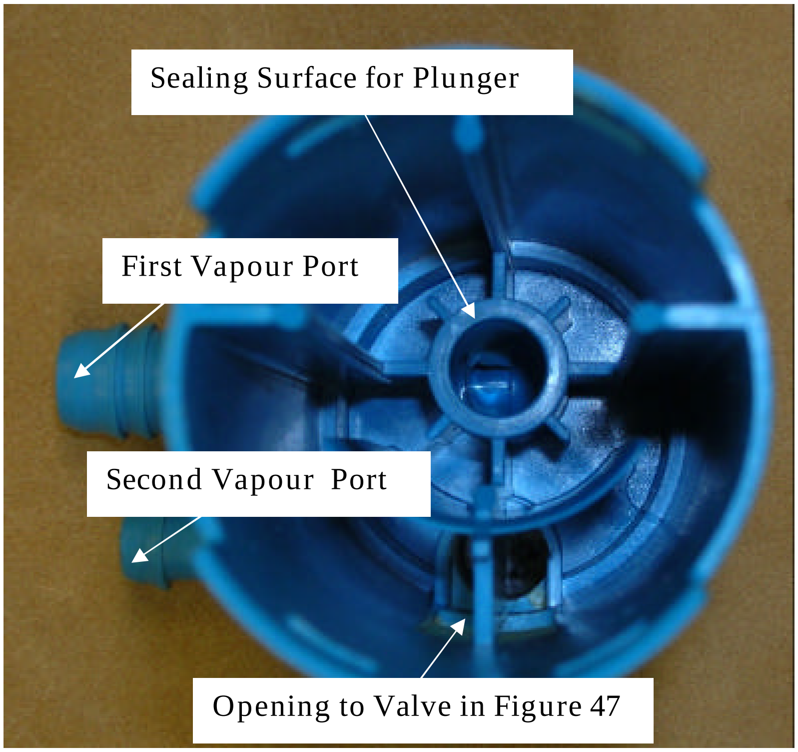


Figure 46: Ford Mustang fuel vapour valve - inside view.

The first fuel vapour valve assembly incorporates a secondary port, with a normally closed spring valve (Figure 46), which connects to a second vapour valve (Figure 47) installed at a different location. This valve prevents fuel or vapour from entering the tank. It is believed that its function is to vent vapour in the ullage as the tank is being filled. The spring force acting on the seal is sufficiently strong to prevent fuel leakage if the vehicle is overturned. Because the fuel vapour line exits at the top of the tank, siphoning can not be initiated with the vehicle in the upright position.

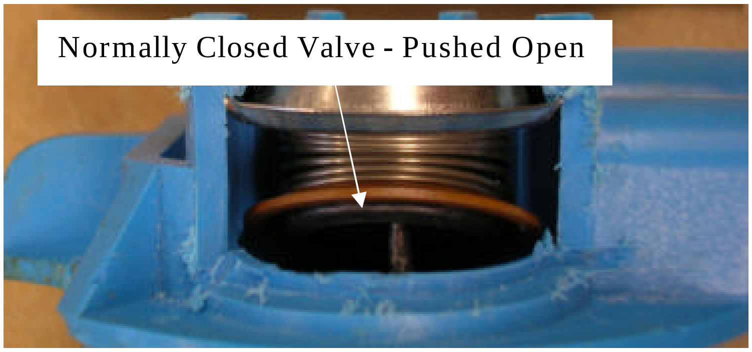


Figure 47: Ford Mustang fuel vapour valve – one way valve detail.

The second vapour port is shown in Figure 48. As with the first vapour valve, the plunger is also buoyant with the assistance of the compression spring, see Figure 49.

When the tank is in an upright orientation, a ball and recess arrangement on the second vapour valve only permits vapour to exit the tank, see Figure 48. If the vehicle overturns, the ball valve would loose its seal and the plunger assembly would create a seal to prevent fuel leakage.

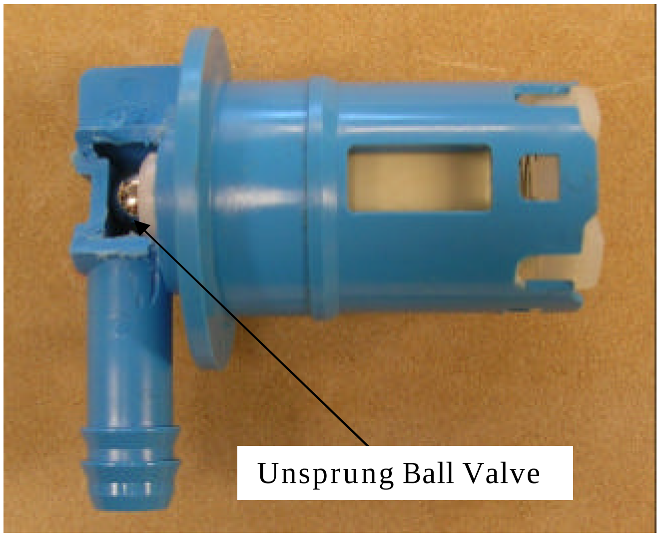


Figure 48: Ford Mustang second vapour valve.

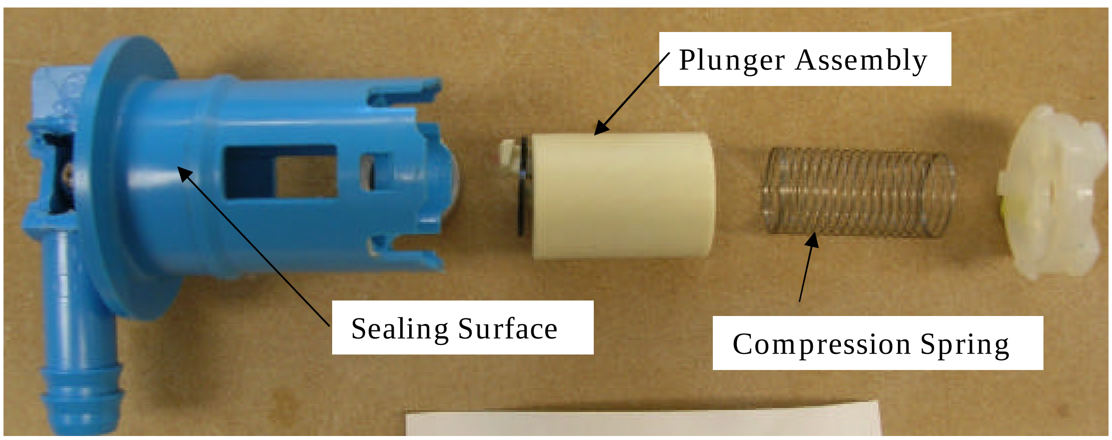


Figure 49: Ford Mustang second fuel vapour valve - disassembled.

2.4.4 Kia Spectra (2003)

The components for the Kia Spectra tank system are shown in Figure 50. The Spectra has four openings to the tank that include the filler tube, sending unit and two fuel vapour ports.

Figure 50: Kia Spectra tank system.

The filler hose is fastened to a spout that is welded to the tank, see Figure 51. On the inside of the tank, the filler spout is terminated with a normally closed, spring loaded flapper valve, as seen in Figure 52. The valve uses a rubber disk to enhance the seal when closed. The normally closed flapper valve is displaced as fuel enters the tank and closes to prevent reverse flow of fuel and/or vapour once filling is stopped.

Figure 51: Kia Spectra filler tube spout.

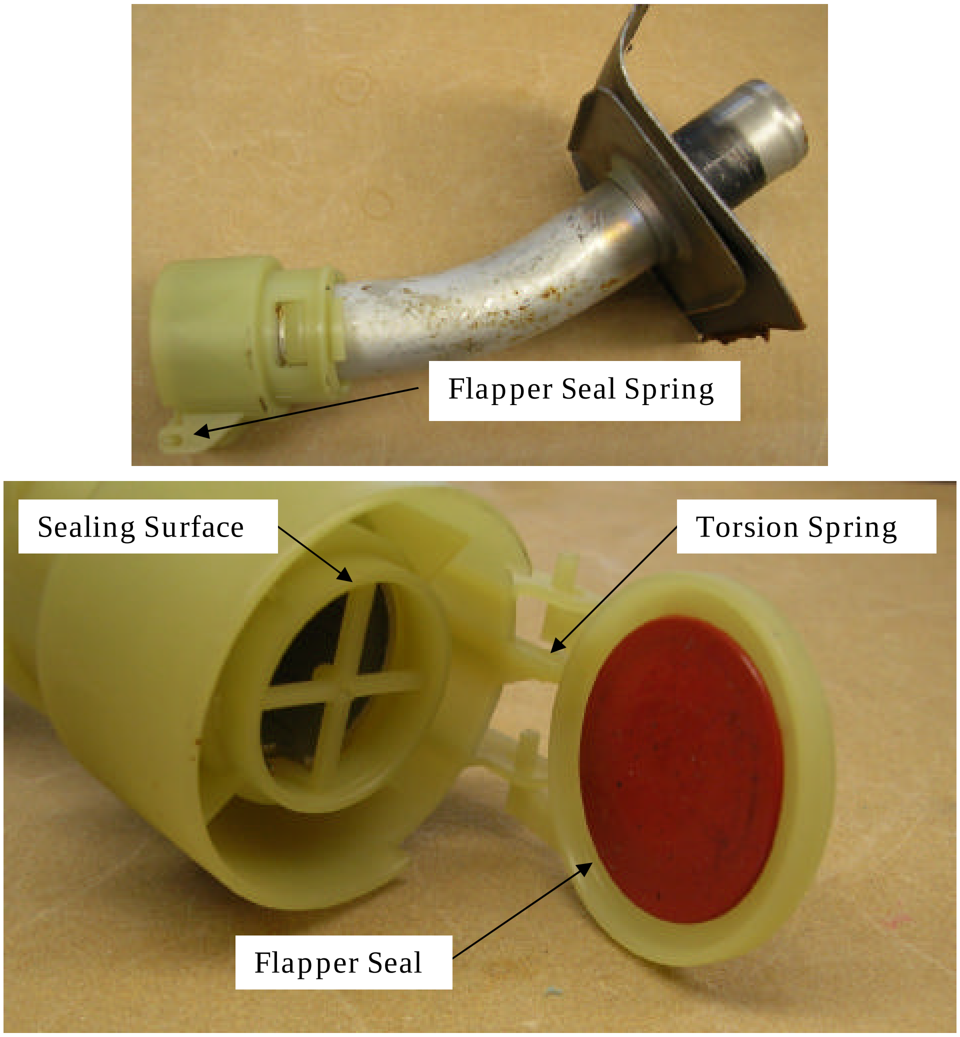


Figure 52: Kia Spectra filler tube valve.

There are two connections on the Kia Spectra sending as shown in Figure 53. The connections include the fuel delivery and fuel return lines. As documented in Table 2, a partial vacuum (-12 in-Hg) was generated on the fuel delivery line during the vacuum test to assess siphoning. The source of the flow resistance in the fuel delivery line stems from the fuel pump which is shown disassembled in Figure 54. The pumping mechanism employs a finned disc that pushes the fuel around a groove in the pump housing. The fuel is then diverted up through the motor armature and out of the sending unit.

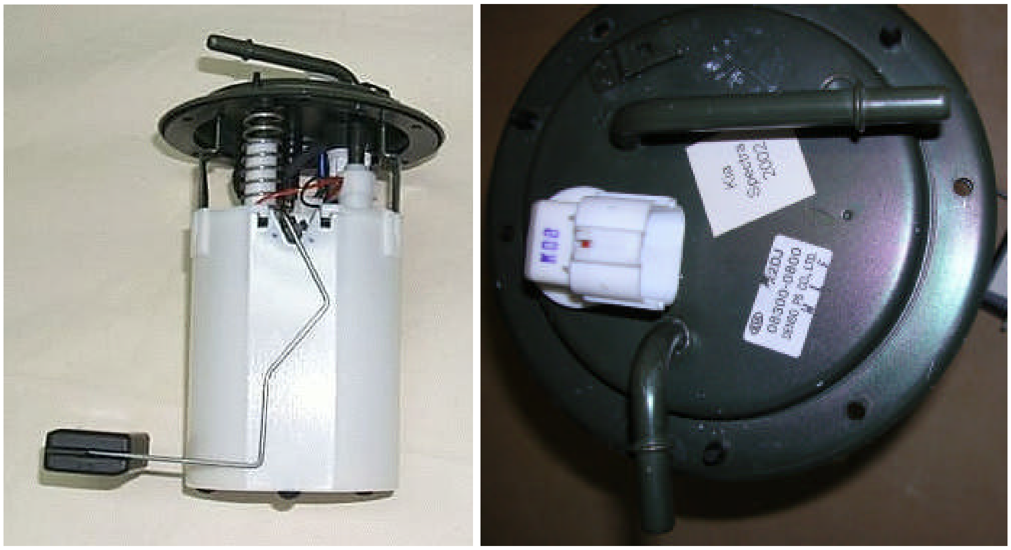


Figure 53: Kia Spectra sending unit.

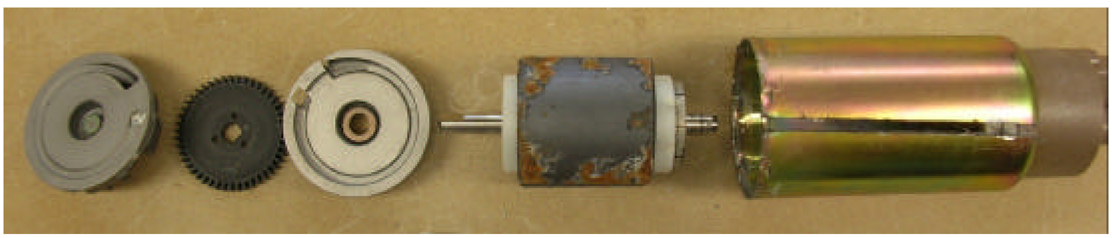


Figure 54: Kia Spectra fuel pump - disassembled.

The fuel return line is fitted with a normally closed valve located at the very bottom of the sending unit, as shown in Figure 55.   This valve is identical to the valve used in the Grand Voyager's and the Chrysler Cirrus' sending units. The valve mechanism was shown previously in Figure 10.

Figure 55: Kia Spectra fuel return valve.

There are two vapour ports on the Kia tank, both are located on the top of the tank. The first is shown in Figure 56. The vapour port is comprised of a sealed float that is attached to a sprung flapper valve. The components of this valve are shown in Figure 57 through Figure 59.

Figure 56: Kia Spectra fuel vapour valve.

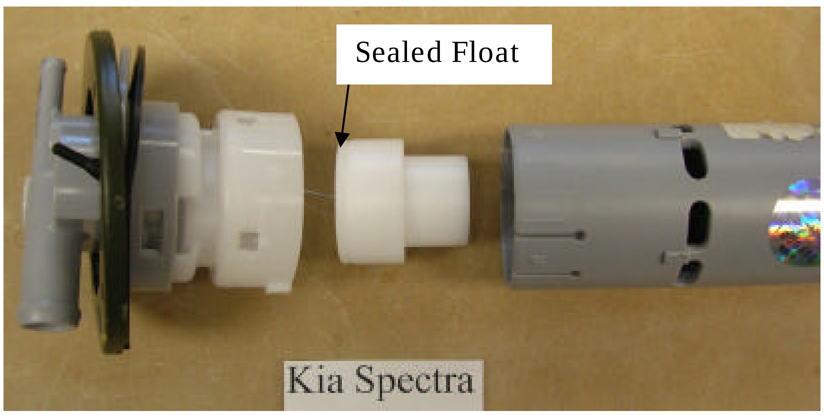


Figure 57: Kia Spectra fuel vapour port – disassembled.

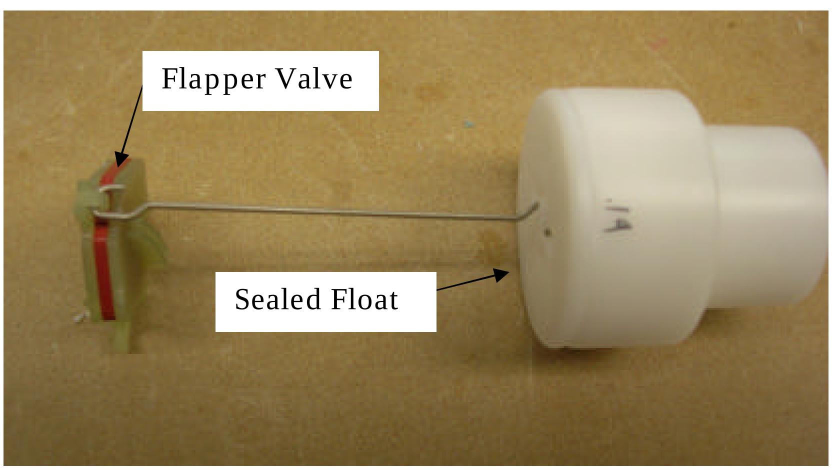


Figure 58: Kia Spectra fuel vapour port - flapper valve - float detail.

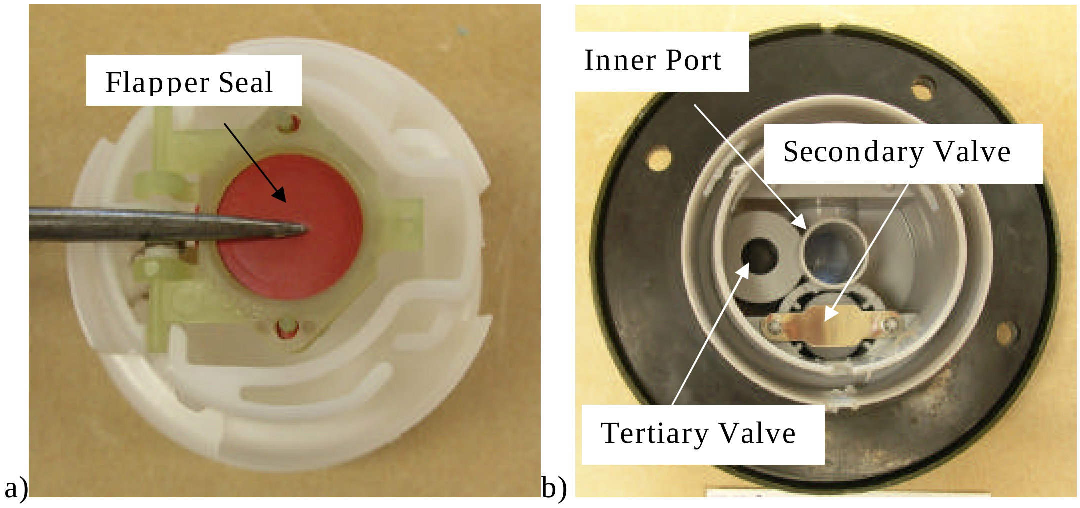


Figure 59: Kia Spectra fuel vapour port - flapper valve detail.

When the tank is full, the float assists the flapper valve in closing and creating a seal against the inner port opening as shown in Figure 59. In this position, neither fuel nor vapour can escape. As the fuel level decreases, the float drops and pulls the flapper down, permitting vapour to pass unrestricted. The float and flapper valve assembly also acts as a roll over valve. The mass of the float, the flapper torsional spring and hydrostatic pressure all combined generate a seal[9] and prevents fuel from escaping. Since the vapour line exits the tank at the top, siphoning can not be initiated with the vehicle in the upright position.

There are two additional valves in this vapour port which are shown in Figure 59 b). The secondary valve is a normally closed spring plunger valve, shown disassembled in Figure 60. The secondary valve prevents either fuel or vapour from leaving the tank but will allow both to enter. It should be noted that Nipple #1 (connected to the flapper valve) and Nipple #2 (connected to the secondary valve) seen in Figure 62 are connected together at the top of the vapour port. It is unclear why there are two valves on the same vapour line but it is hypothesized that when the flapper valve is closed and sealed, the secondary valve will still permit fuel or vapour to enter the tank. The third valve connected to the remaining nipple is a normally closed spring plunger valve, see Figure 61. This valve permits vapour to leave the tank given a large enough pressure to overcome the spring pressures of the valve.

[9] The mass of the float, the torsional spring and the hydrostatic pressure all combined overcome the buoyancy force that is generated by the sealed float.

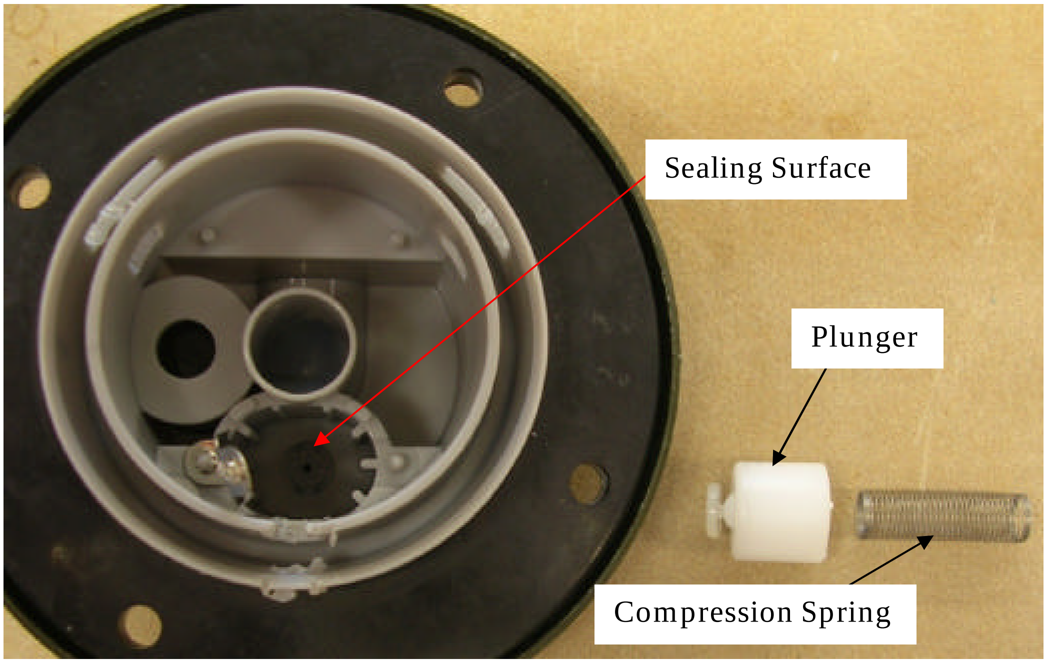


Figure 60: Kia Spectra fuel vapour port - secondary plunger disassembled.

Figure 61: Kia Spectra fuel vapour port - one way valve.

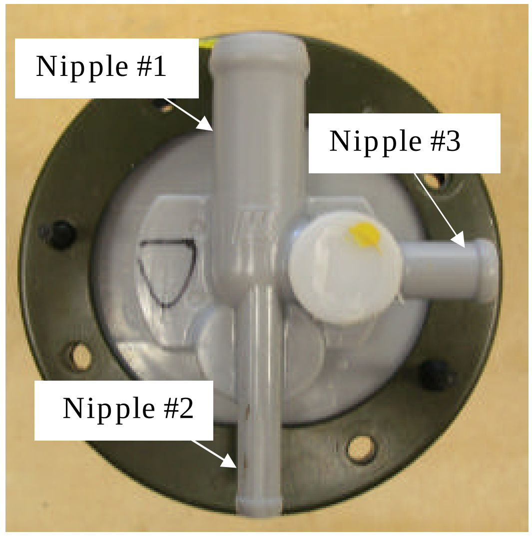


Figure 62: Kia Spectra fuel vapour port - top view

The second fuel vapour port is shown in Figure 63. It is equipped with a plunger and compression spring, seen in the disassembled view in Figure 64. As with the first fuel vapour port, the plunger is buoyant with the assistance of the compression spring. Because the fuel vapour line exits at the top of the tank siphoning can not be initiated with the vehicle in the upright position.

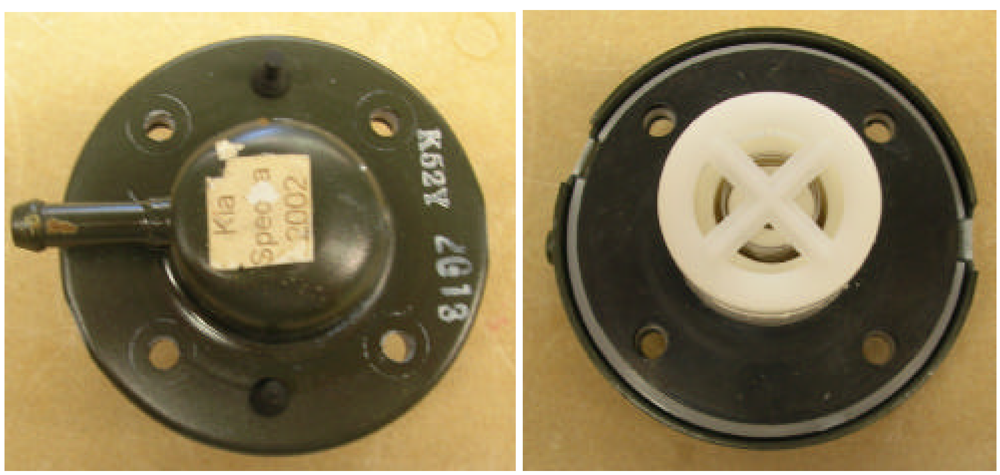


Figure 63: Kia Spectra second fuel vapour port.

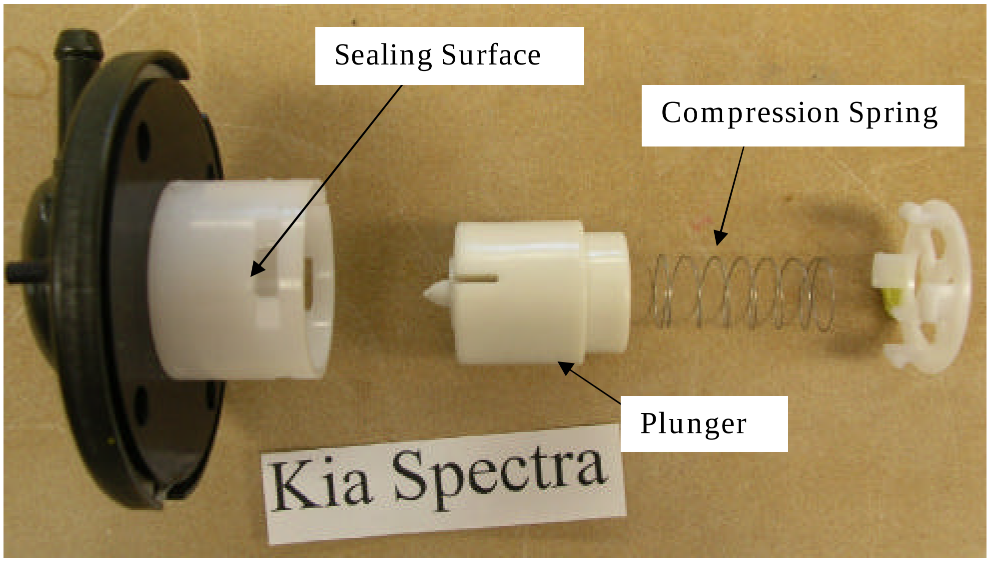


Figure 64: Kia Spectra second fuel vapour port - disassembled.

3. Inspection of New Sending Units/Tanks

The sending units and tanks from three, 2006 model year vehicles were purchased to evaluate anti-siphoning technologies that may have been implemented since the inspections of the 2003 model year vehicles. Vehicles from Ford, GM and Chrysler that have recently been released were selected were:

- Ford Fusion
- Chevrolet HHR
- Jeep Grand Cherokee

The components for these fuel systems were purchased, inspected and tested as per the vacuum test previously described to evaluate the anti-siphoning potential of the originally inspected and tested tanks systems. The results of the anti-siphon testing on the sending units from these three vehicles is presented in Table 4 below.

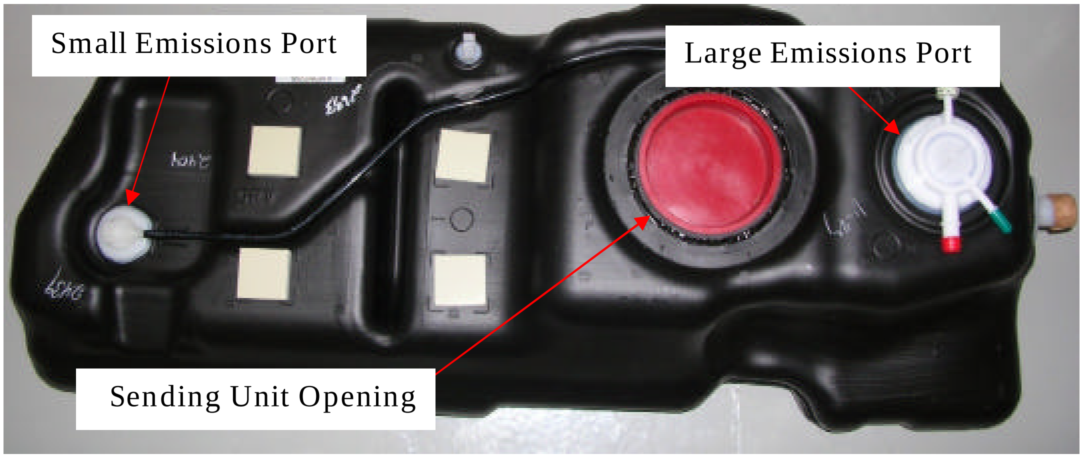
Table 4: Results of vacuum tests on three 2006 model year sending units.

Vehicle Make/Model	**Results: Anti-siphon ability of sending unit**	Summary of vacuum results from hoses coming from sending unit (in-Hg)		
		Fuel Delivery Line	Fuel Return Line	Fuel Vapour Return Line
Jeep Grand Cherokee	Returnless system Partial vacuum (-10 in-Hg) generated by the fuel delivery line by the pump	-10	N/A	N/A
Ford Fusion	Returnless system Partial vacuum (-10 in-Hg) generated by the fuel delivery line by the pump	-10	N/A	N/A
Chevrolet HHR	No fuel vapour return line No vacuum generated by the fuel return line- exits at top of tank Partial vacuum (-7 in-Hg) generated by the fuel delivery line by the pump	-7	0	N/A

None of the lines connected to the sending units of the three 2006 model year vehicles generated a full vacuum.

3.1 Jeep Grand Cherokee (2006)

The Jeep Grand Cherokee's plastic tank has four openings which include: the filler tube, sending unit and two fuel vapour ports as shown in Figure 65.



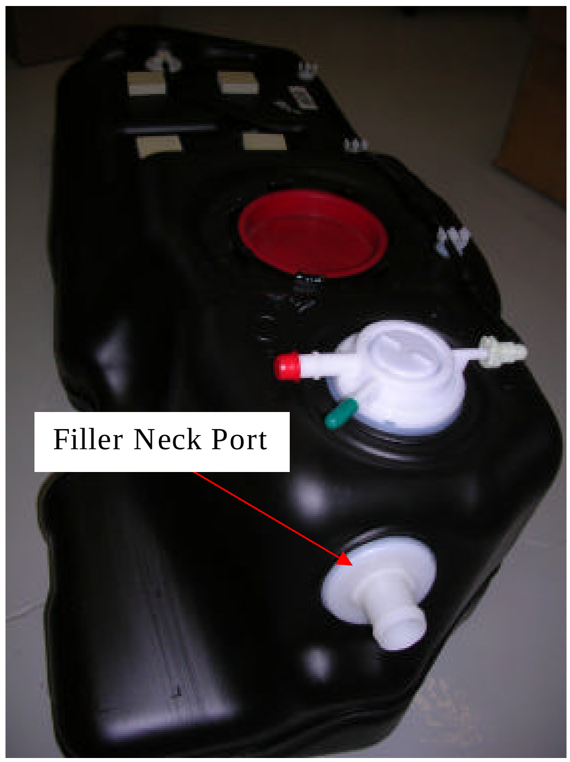


Figure 65: Jeep Grand Cherokee Fuel Tank.

The sending unit, shown in Figure 66 is a returnless system and therefore it only has a fuel delivery line. With the vacuum pump applied to the fuel supply nipple, -10 in-Hg of vacuum was generated.

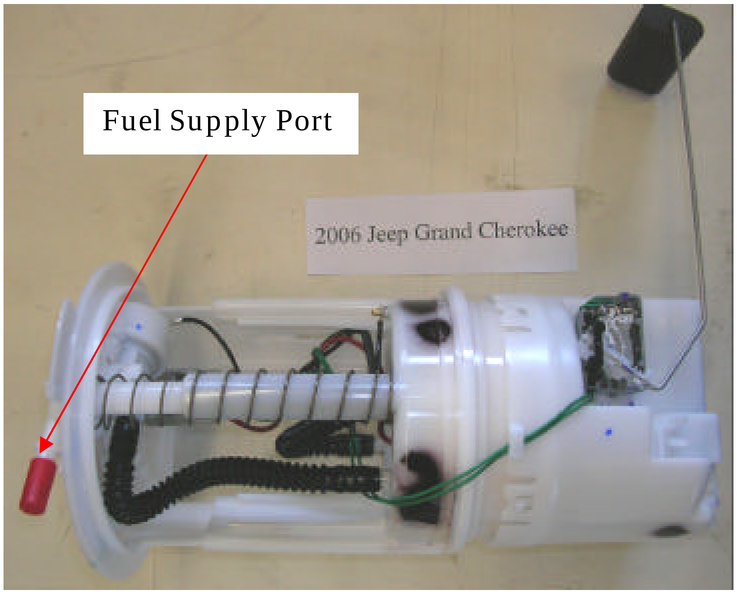


Figure 66: Jeep Grand Cherokee Sending Unit.

The filler neck is fitted with a check valve on the inside of the tank. The valve is shown in a disassembled state in Figure 67. The valve comprises a normally closed spring plunger design. The pressure of the fuel entering the tank displaces the valve allowing fuel to enter the tank. The seal is such that no fuel and/or vapour could leak from the tank under any circumstances, including siphoning.

Figure 67: Jeep Grand Cherokee Filler Port and Check Valve.

The larger of the two vapour ports on the top of the tank was removed and is shown in Figure 68. This port has three nipples; one connects to the small emissions port the other two are presumed to connect with the fuel vapour recovery system.

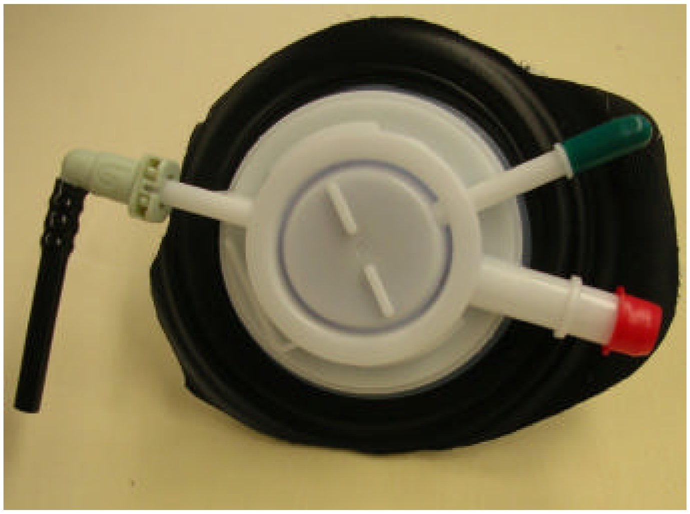


Figure 68: Jeep Grand Cherokee-Large Emissions Port.

An exploded view of the larger vapour port is shown in Figure 69. The port comprises two, normally open, buoyant spring plungers. When the vacuum pump was applied, a full vacuum was generated by all three nipples providing the other two ports were plugged. The plungers of the two normally open valves were sufficiently sensitive such that they sealed from the volumetric flow of the vacuum pump. The two plungers also generated a seal when the tank was full, thereby not allowing fuel to leave the port by means of a siphoning action.

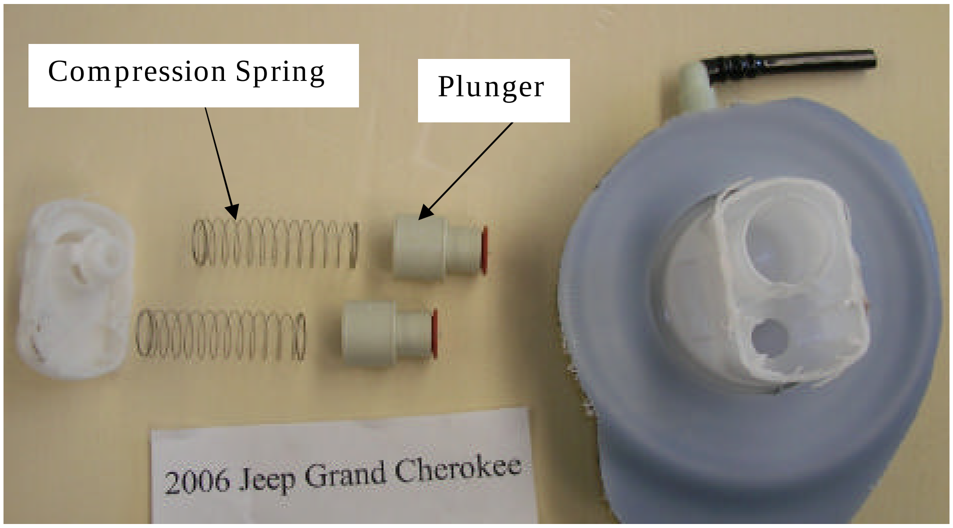


Figure 69: Jeep Grand Cherokee: Large Emission Port - Exploded State.

The smaller emissions port, shown in Figure 70 is located on the top of the tank and utilizes a normally open, buoyant spring plunger valve assembly. The spring plunger fully closes when the tank is full and a full vacuum can be generated. With the plunger valve open, a -13 in-Hg vacuum was measured.

This smaller vapour port is also equipped with a metal disk that permits fuel vapours to escape but restricts the passage of vapours back into the tank.

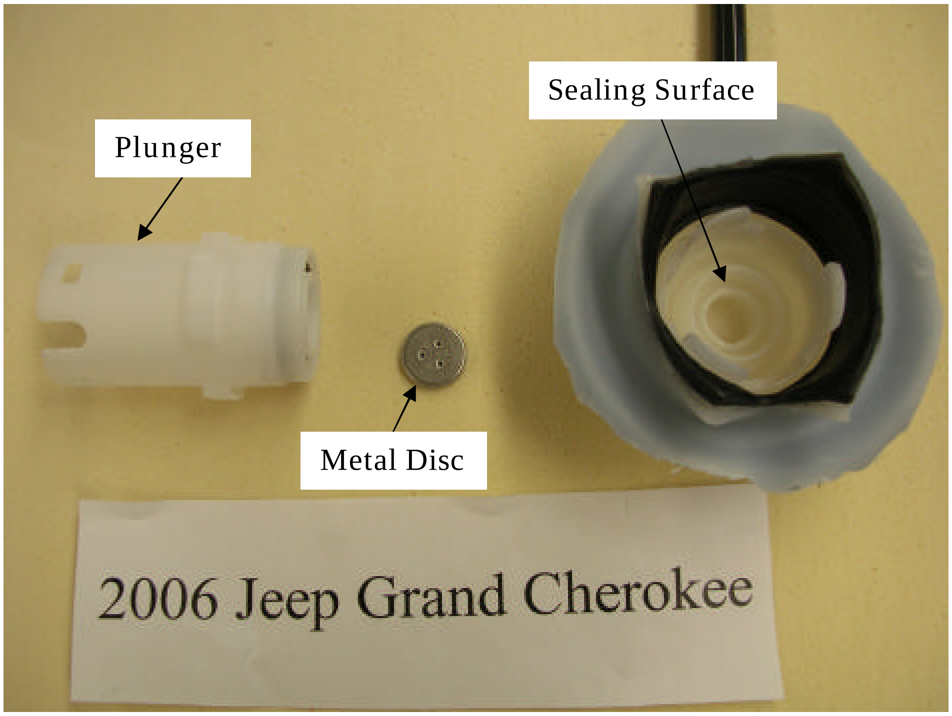


Figure 70: Jeep Grand Cherokee: Small Emission Port.

3.2 Ford Fusion (2006)

The Ford Fusion's steel tank has three openings which include: the filler tube, sending unit and one fuel vapour port as shown in Figure 71.

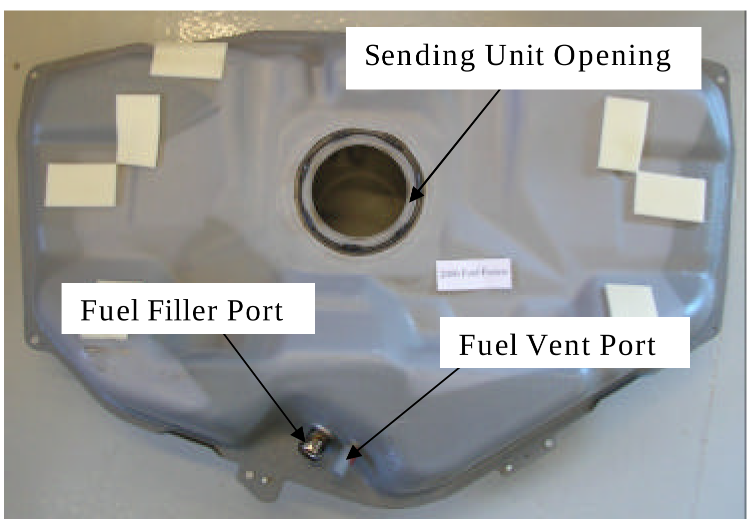


Figure 71: Ford Fusion Fuel Tank.

The Ford Fusion uses a returnless fuel delivery system and therefore only a single line is connected to the sending unit as shown in Figure 72. With the vacuum pump applied to the fuel supply nipple, -11 in-Hg of vacuum was generated.

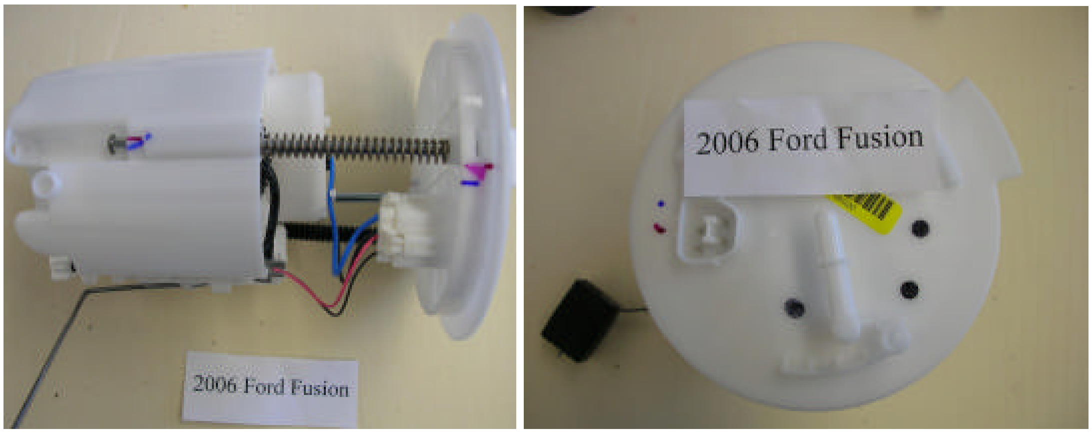


Figure 72: Ford Fusion Sending Unit.

Figure 73 shows the filler and vent port cut out from the tank. A normally closed spring plunger valve is connected to the filler spout on the inside of the tank. An exploded view of the spring plunger valve is shown in Figure 74.

Figure 73: Ford Fusion Filler and Vent Ports.

Figure 74: Ford Fusion Filler Port and Valve.

As shown in Figure 75, there is a 2 mm (0.080”) diameter hole in the plunger which would permit fuel to be siphoned or to leak in a rollover situation. There is no clear explanation for the use of the hole in the fuel filler plunger. It should be noted that the fuel filler port would be submersed in fuel when the tank is full of fuel. Therefore if the fuel filler tube were to be severed, leakage would occur because of the 2 mm (0.080”) hole.

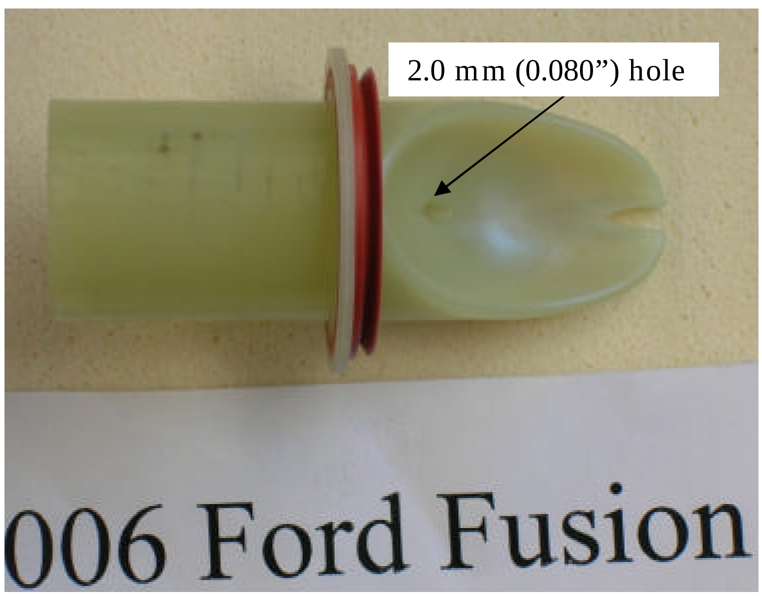


Figure 75: Ford Fusion Filler Port Plunger.

The fuel vent tube, shown in Figure 73 is connected to two check valves mounted on the inside top surface of the fuel tank. Neither of the valve assemblies generates a vacuum and therefore does not exhibit any anti-siphoning abilities. The two check valves mounted to the inside of the tank are shown in Figure 76.

Figure 76: Ford Fusion Internal Tank Check Valves.

3.3 Chevrolet HHR (2006)

The Chevrolet HHR's plastic tank has five openings which include: the filler tube, sending unit and three fuel vapour ports as shown in Figure 77.

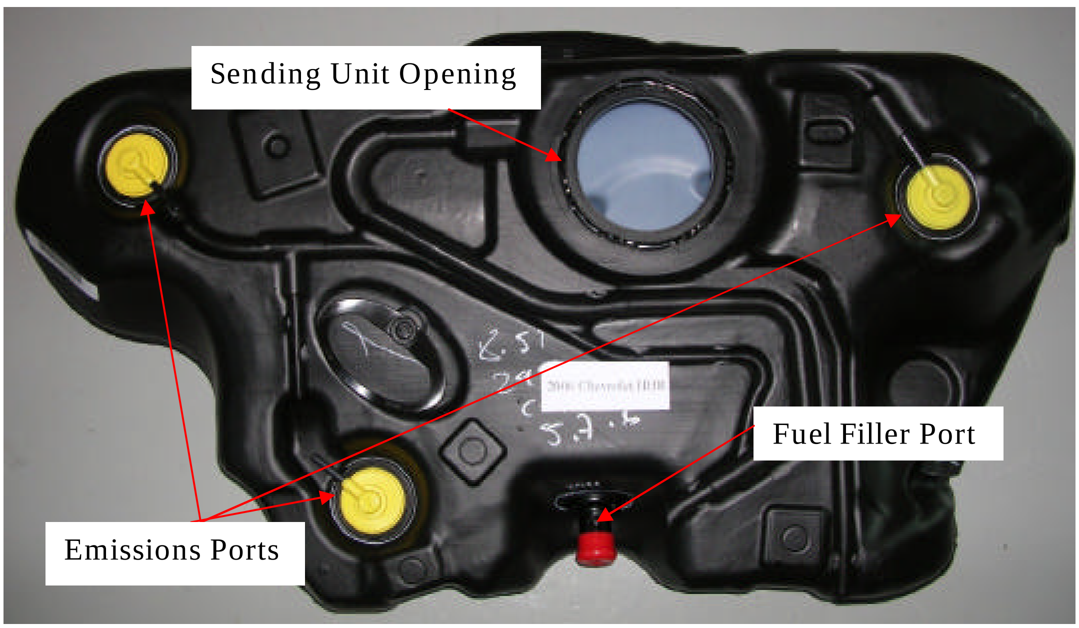


Figure 77: Chevrolet HHR Fuel Tank.

The sending unit, shown in Figure 78 has both a fuel delivery and fuel return line connection. The vacuum siphon test generated -7 in-Hg of vacuum when applied to the fuel supply nipple. The fuel return line offered no flow resistance in the siphon test.

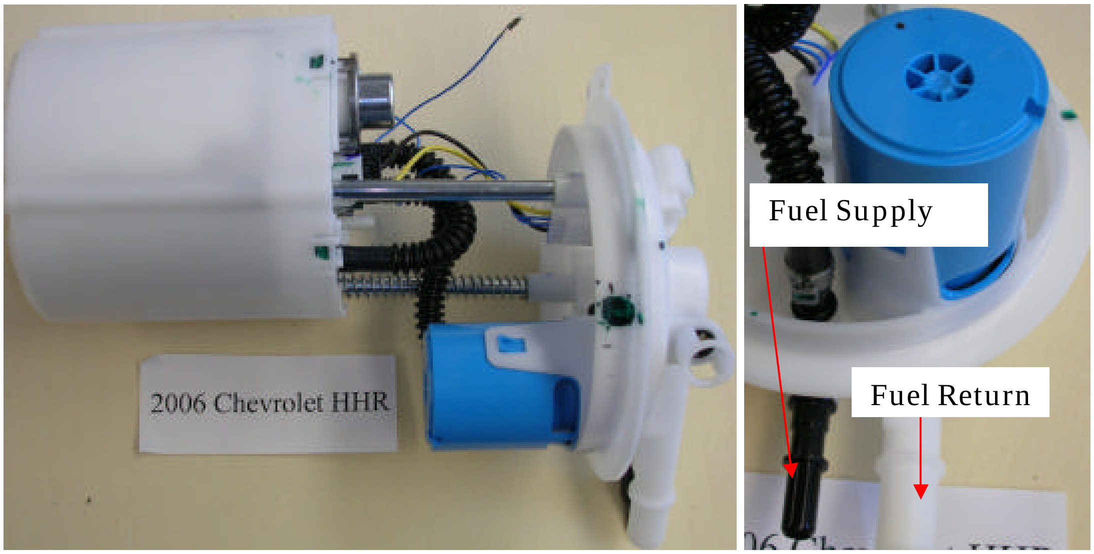


Figure 78: Chevrolet HHR Sending Unit.

A valve assembly on the inside the mounting plate of the sending unit is connected to the fuel return line. The components of the normally open, spring plunger valve assembly is shown in Figure 79. When the fuel level in the tank is full, the buoyant plunger will create a seal and prevent fuel loss through the fuel return line, thus siphoning can not occur in the upright position.

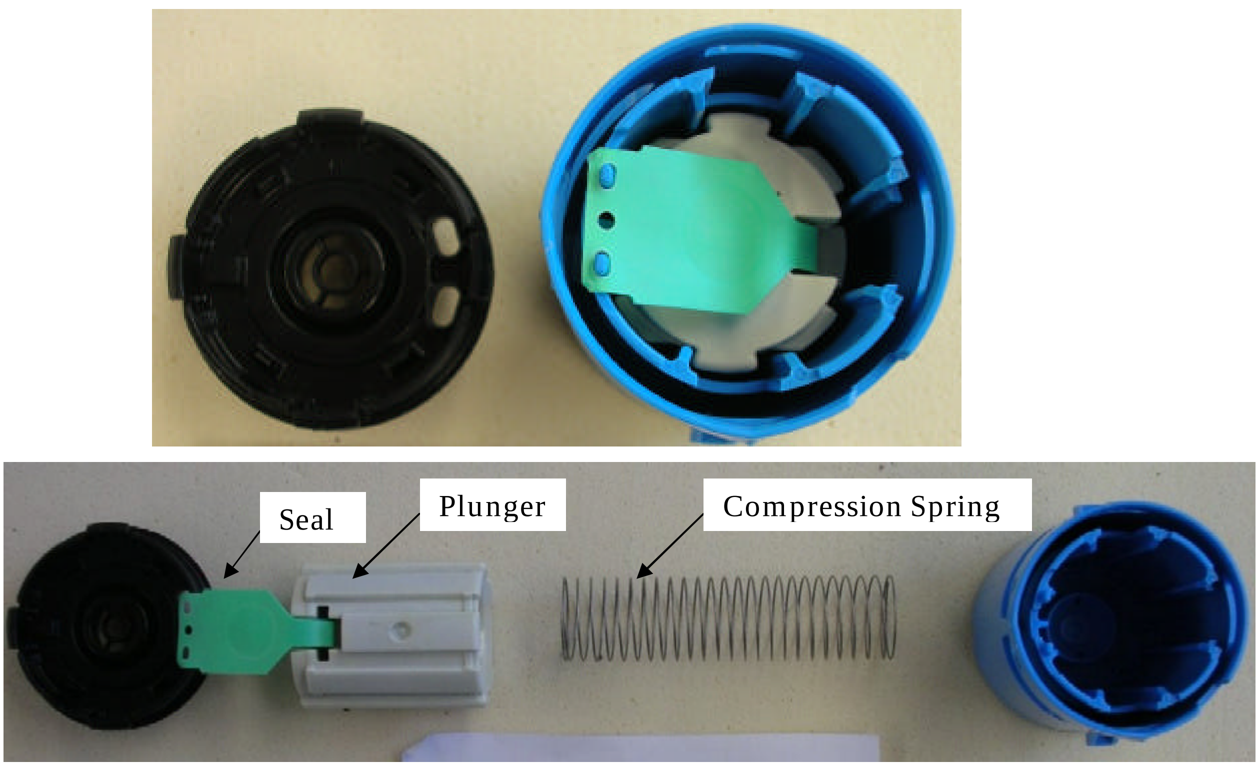


Figure 79: Chevrolet HHR Fuel Return Valve.

An exploded view of the filler neck, cut from the tank, is shown in Figure 80 and Figure 81. A normally closed spring plunger valve is connected to the filler neck on the inside of the tank. The pressure of the fuel entering the tank displaces the valve allowing fuel to enter the tank. The seal is such that no fuel and/or vapour could leak from the tank under any circumstances, including siphoning.

Figure 80: Chevrolet HHR Filler Port.

The Chevrolet HHR is fitted with three identical vapour ports as shown in Figure 77; all of which are located on the top of the tank. An exploded view of the port is shown in Figure 81. A vacuum of -13 in-Hg was measured when the vacuum siphon test was applied with the valve remaining open. With a full tank the valve's buoyant plunger would be forced upward, creating a seal and preventing the possibility of fuel loss due to siphoning.

Figure 81: Chevrolet HHR Emissions Port.

4. Summary and Conclusions

Short of catastrophic tank damage occurring in a collision, fuel can be expelled from a fuel tank by leakage resulting from a tank puncture or from a severed fuel line. Depending on the fuel line routing, siphoning is another possible mechanism by which fuel can be expelled from a severed line. Previously conducted research comprising vehicle and tank inspections has been conducted to investigate the use of leak preventative technologies or components. Additional research has been conducted to assess the propensity of these tanks and tank components to also prevent siphoning. In total, 20 tank systems from 2003 model year and three tank systems from 2006 model year vehicles have been inspected.

The previously conducted leak tests on 20 tank systems identified four tanks that did not leak, regardless of the tank orientation, when the connections emanating from the tank were disconnected one at a time and the tank rotated through eight discreet angles. In all four tank systems, each connection to the tank was routed through a valve that was effective at retaining fuel. The filler tube, in three instances, employed a normally closed spring plunger arrangement whereas a flapper valve with a rubber seal was seen in the fourth. The vent ports of each system incorporated a normally open valve that closed when the tank was rotated from its upright orientation. Spring assistance acting to close the valve increased the sensitivity of these valves to inversion.

The tank components' resistances to siphoning were evaluated by measuring the vacuum generated when connected to a vacuum pump. Of the tank systems inspected only one was found to generate a full vacuum on the fuel delivery line. Eight of the fifteen sending units that included a fuel return line generated a full vacuum on that line, whereas, none of the four sending units with a vapour return line generated a full vacuum on the vapour return line.

In principle, those sending unit lines that did not generate a full vacuum in the tests are susceptible to siphoning, with the flow rate varying depending on the resistance that is present in the lines. However, if a mechanical resistance exists that requires a minimum vacuum to be generated before flow can commence, less than perfect vacuum measurements on a line may be sufficient to demonstrate that the line could not be siphoned. Additionally, the placement of an exit point or valve within a tank may prevent siphoning regardless of the ability to generate a vacuum in the test conducted. Exit points or valves located at the top of a tank would prevent siphoning in an upright orientation.

The qualities of a tank system that have been found, through leak testing and siphon testing, to be effective at preventing fuel loss either from leakage or siphoning are listed below and depicted in Figure 82.

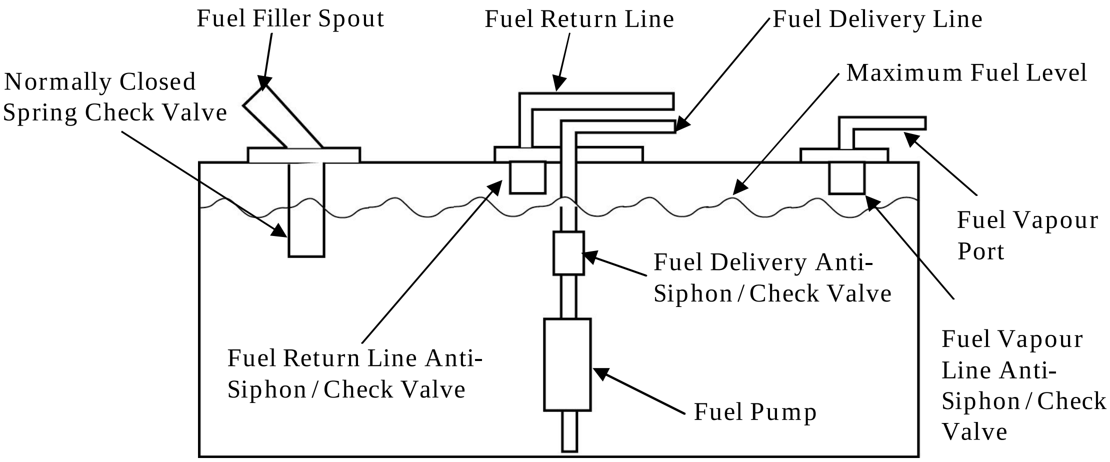


Figure 82: Ideal Gas Tank Component Locations and Features.

1. Effective, normally closed check valve located on the filler tube.
2. Rollover valves on all vapour ports.
3. Vapour port exit points inside the tank located at the top of the tank.
4. A returnless sending unit with a spring loaded check valve in the fuel delivery line.
5. Check valve or anti-siphon valve located inside the tank, at the top for the fuel return line and fuel vapour return line (if present).

5. References

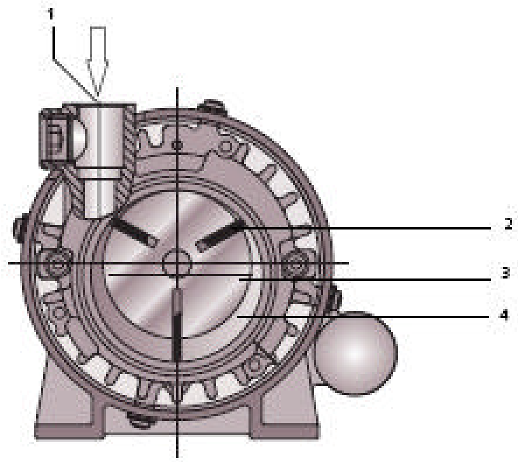
Ref. 1 Fournier, E., Kot, J., "Comparisons of Internal Tank Components – 20 Fuel Systems", Biokinetics and Associates Ltd. report to the Motor Vehicle Fire Research Institute, report no. R04-06c, July 26, 2004.

Ref. 2 Fournier, E., Kot, J., Sullivan, D., "Assessment of Fuel System Safety Technology Use in 2003 Model Year Vehicles", Society of Automotive Engineers (SAE) World Congress Paper 2005-01-1423, Detroit MI, April 2005.

Appendix A: Vacuum Pump Specifications

The model number for the pump that was used for the described testing is R5 PB 0003A.

Funktionsprinzip
Principle of operation
Principe de fonctionnement



1 Sauganschluss
2 Schieber
3 Rotor
4 Verdichtungsraum

1 Inlet connection
2 Vane
3 Rotor
4 Compression chamber

1 Raccordement
2 Palettes
3 Rotor
4 Compression d'aspiration

Funktionsprinzip und Arbeitsweise

Diese Vakuumpumpenpumpen arbeiten nach dem Drehschieberprinzip.
Ein exzentrisch gelagerter Rotor (3) dreht sich im Zylinder. Durch die Zentrifugalkraft der Drehbewegung werden die Schieber (2), die in Schlitzen im Rotor gleiten, an die Zylinderwand gedrückt. Die Schieber teilen den sichelförmigen Raum zwischen Zylinder und Rotor in Kammern ein. Bei Verbindung der Kammern mit dem Saugkanal wird das Gas angesaugt, bei weiterer Drehung verdichtet und anschließend in den Ölnebelabscheider ausgestoßen.
Durch den Differenzdruck wird ständig Öl in die Verdichtungsräume eingespritzt. Dieses Öl wird zusammen mit dem Medium in den Ölnebelabscheider ausgestoßen und dort durch die Schwerkraft und das Luftentöl-
element von der Abluft getrennt.
Das Öl sammelt sich unten im Abscheider und wird wieder in den Verdichtungsraum eingespritzt. (Umlaufschmierung).

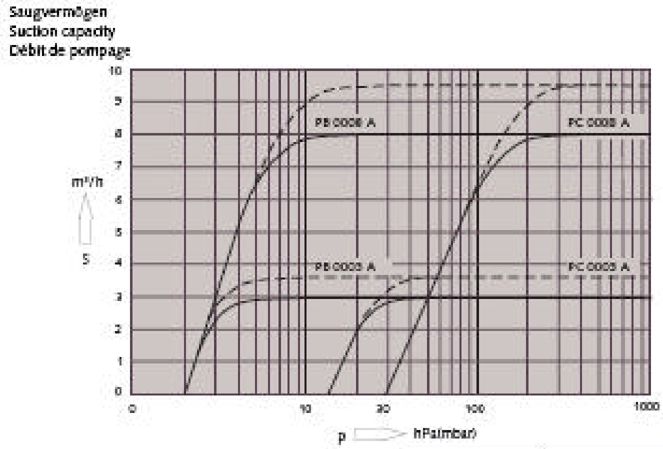
Principle of operation

These vacuum pumps work according to the rotary vane principle.
An eccentrically installed rotor (3) rotates in the cylinder. The centrifugal force of the rotation pushes the vanes (2), which glide in slots in the rotor, towards the wall of the cylinder.
The vanes separate the sickle-shaped space between rotor and cylinder into chambers. When the chambers are connected with the inlet channel, gas is sucked in, compressed by the next rotation and pushed into the oil separator.
The differential pressure constantly causes oil to be passed into the compression chambers.
The oil and the process gas are then discharged into the oil mist separator and there separated from the exhaust air by gravity and the exhaust filter.
The oil collects on the bottom of the oil separator and is then passed into the compression chamber again (recirculation).

Principe de fonctionnement

Ces pompes à vide fonctionnent selon le principe des pompes à palettes rotatives.
Un rotor excentré (3) tourne dans un cylindre. La force centrifuge pousse les palettes (2), qui coulissent librement dans leur logement, contre la paroi du cylindre.
Les palettes divisent l'espace libre en forme de croissant en plusieurs chambres. Lorsqu'une chambre est en face de la bride d'aspiration, le gaz est aspiré, puis comprimé par la rotation suivante et ensuite rejeté dans le séparateur de brouillard d'huile.
Le mélange gaz et huile est rejeté dans le séparateur de brouillard d'huile où il est séparé par gravité et par le filtre d'échappement. L'huile s'accumule dans le bas du réservoir d'huile. Ensuite elle est injectée dans la chambre de compression (principe de recirculation).

Technische Daten
Technical data
Spécifications techniques



—— 50 Hz
- - - - 60 Hz

Die Kennlinien gelten für Luft von 20°C. Toleranz: ± 10%
The displacement curves are valid for air at 20°C. Tolerance: ± 10%
Les courbes sont données pour de l'air à 20°C. Tolérance: ± 10%

Technische Daten Technical data Spécifications techniques		R 5 PB 0003 A	R 5 PC 0003 A	R 5 PB 0008 A	R 5 PC 0008 A
Nennsaugvermögen Nominal displacement Débit nominal	50 Hz m³/h 60 Hz m³/h	3 3,6	3 3,6	8 9,6	8 9,6
Enddruck Ultimate pressure Pression finale	hPa(mbar)	2	15	2	30
Motornennleistung Nominal motor rating Puissance nominale du moteur	50Hz kW 60 Hz kW	0,1 0,1	0,1 0,1	0,35 0,45	0,35 0,45
Motornenndrehzahl Nominal motor speed Vitesse de rotation nominale	50 Hz min⁻¹ 60 Hz min⁻¹	3000 3600	3000 3600	3000 3600	3000 3600
Schalldruckpegel (DIN 45635) Noise level (DIN 45635) Niveau sonore (DIN 45635)	db(A)	59	59	61	61
Ölfüllung Oil filling Quantité d'huile	l	0,06	0,06	0,25	0,25
Gewicht ca. Weight approx. Poids approx.	kg	5,1	5,1	10,3	10,3