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Fuel Filler Pipe Assembly Design Practice to Meet Low Evaporative Emission Requirements

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1. Scope—This SAE Recommended Practice covers design and evaluation of the entire gasoline filler pipe assembly used on cars and light trucks with respect to compliance with CARB (California Air Resources Board) LEV II (meeting or exceeding EPA Tier 2 and EU Stage-5 evaporative emissions requirements). It is limited to an assembly which is joined to the fuel tank using either a hose, Quick Connect Coupling, or a grommet type sealing device.

The Design Practice covers the filler cap, filler pipe, filler pipe assembly to tank hose, and filler pipe assembly to tank grommet or spud. It includes recommendations for design of components and assemblies intended to perform successfully in evaporative emission SHED (Sealed Housing for Evaporative Determination) tests, based on best practices known at the time of release.

2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

2.1.1 SAE REFERENCES—Available from SAE, 400 Commonweatlh Drive, Warrendale, PA 15096-0001.

SAE J30—Fuel and Oil Hoses—(Table 7 Dimensions and Tolerances for SAE 30R6, 7, and 8)
SAE J1231—Formed Tube Ends for Hose Connections and Hose Fittings
SAE J1508—Hose Clamp Specifications
SAE J1697—Recommended Practices for Design and Evaluation of Passenger and Light Truck Coolant Hose Clamped Joints
SAE J1645—Fuel System—Electrostatic Charge
SAE J1737—Test Procedure to Determine the Hydrocarbon Losses from Fuel Tubes, Hoses, Fittings, and Fuel Line Assemblies by Recirculation
SAE J2027—Standard for Protective Covers for Gasoline Fuel Line Tubing
SAE J2236—Standard Method for Determining Continuous Upper Temperature Resistance of Elastomers
SAE J2044—Quick Connector Specification for Liquid Fuel and Vapor/Emissions Systems
SAE J2260—Nonmetallic Fuel System Tubing with One or More Layers
SAE Technical Paper Series 2001-01-0730 Estimating Real Time Diurnal (RTD) Permeation from Constant Temperature Measurements

2.1.2 UL PUBLICATION—Available from Underwriters Laboratories, 333 Pfingsten Road, Northbrook, IL 60062-2096.

UL 746A—Polymeric Materials—Short Term Property Evaluations

2.1.3 CALIFORNIA PUBLICATIONS—Available from California Air Resources Board, 1001 "I" Street, P.O. Box 2815, Sacramento, CA 95812, helpline@arb.ca.gov.

California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Trucks (6-1-99 proposal)
California Evaporative Emissions Standards and Test Procedures for 2001 and Subsequent Model Motor Vehicles (6-1-99 Proposal)

2.1.4 FEDERAL PUBLICATIONS—Available from the Superintendent of Documents, U. S. Government Printing Office, Mail Stop: SSOP, Washington, DC 20402-9320.

Federal Register Vol 58/ No 55 page 16045 § 86.146-96 (Fuel Dispensing Spitback Procedure)

3. ***Abstract*—**Design of clamped hose and elastomeric grommet sealed filler pipe joints is not an exact science; therefore, precise formulas and methods cannot accurately predict performance. However, theoretical and philosophical constructs based on empirical data and industry experience can be used to develop standard practices for evaluating automotive filler neck joining techniques compatible with LEV II evaporative emission demands.

Beyond the basic functionality of easily allowing the customer to transfer fuel from fuel dispensing nozzles to the fuel tank of the vehicle, four major design considerations of the filler neck assembly are:

a. Fuel System Integrity/Crashworthiness
b. Evaporative emission performance for 15 years / 241 350 km (150 000 miles)
c. Prevent or minimize the buildup of electrostatic charges
d. Ease of assembly, with force levels within accepted ergonomic limits.

Although this document primarily addresses compliance with evaporative emission regulations, the proposed ranking of these considerations is in the order listed previously.

Fuel System Integrity/Crashworthiness is the most important concern and is so stated in the environmental regulations governing evaporative emissions.

Evaporative emission performance is the main topic for this document. Because the CARB LEV-II regulations for passenger cars have the strictest target (for high volume markets), we will focus on that specific subject here. To satisfy that CARB regulation the filler pipe assembly must not add more than its allotted portion of the total hydrocarbon evaporative emission limit when exposed to the prescribed hot soak, diurnal, running loss and ORVR (On Board Refueling Vapor Recovery) SHED tests.

As with crashworthiness, electrostatic discharge dissipation should not be under-rated based on its ranking. It was given this ranking based on the intent of this emission control oriented design guideline.

Ease of Assembly, is an important design consideration due to increasing emphasis being given to ergonomics. If the other requirements have been met there will be some minimum assembly force value that can be achieved.

4. ***Sealability of the Filler Cap*—**The filler cap not only provides a seal to the filler neck, but also acts as an air induction device to allow outside air to enter the fuel system in the event that the fuel system pressure is below specification. The cap often also has the ability to act as a pressure relief in the event of an over pressurization of the system.

In order to ensure that LEV II evaporative emissions demands are met, attention must be paid to the three seals located in the cap, as well as the surface finish of the sealing area of the filler neck. Figure 1 shows the three seals and their corresponding sealing surfaces. These seals and their sealing surfaces must be smooth and free of defects just as the filler pipe hose sealing surfaces must. Care must be taken that filler pipes fabricated from welded tubing do not allow weld seam defects in the Cap-to-pipe sealing area.

Emission prove-out testing of the fuel filler cap through those areas shown in Figure 1 is accomplished in three stages. First the cap is tested to the defined customer specification with air to verify valve functionality. Second the cap is Helium leak tested using an appropriate hard vacuum or accumulation test method to verify seal integrity. Finally the cap/neck assembly is Micro SHED tested.

The test setup includes a fuel reservoir with drain/fill port capability of venting fuel vapor outside of Micro SHED during testing, and a representative or actual production fill pipe. The components of the system must be constructed with the fuel filler cap being at the highest point on the fuel reservoir in the Micro SHED.

The recommended test fuels for preconditioning and testing are CARB Certified Fuel or CE10 (ASTM Fuel C with 10% Ethanol) and the preconditioning is done at a constant temperature of 40 °C in a vapor environment for 21 days or until stabilization occurs. It is recommended to use a one hour constant temperature Micro SHED test at various time intervals to prove stabilization has been achieved. Once stabilization has been proven, evaporative emissions are measured during a CARB 24-hour diurnal Micro SHED test and data taken for report out.

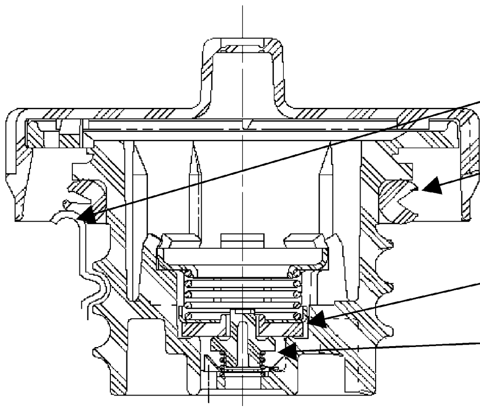

FIGURE 1—FUEL FILLER CAP

5. ***Construction of the Filler Pipe***—The inner-diameter of the fuel fill pipe must be designed in such a way as to provide a liquid seal at 4 to 10 gallon per minute rate during the vehicle fueling process, while optimizing vapor management. The liquid seal prevents fuel vapors from escaping the fill neck assembly and being discharged to the atmosphere during refueling. Vapor entrainment during fueling must also be a consideration. Ingestion of excessive amounts of atmospheric air can reduce the effectiveness of the ORVR system.

The filler pipe may be made of metallic or polymeric material. It may be a one-piece tube or an assembly as shown in Figure 2. Permeation (see Section 8) through the tube wall would not be an emission concern when a metallic filler pipe is employed, but must be considered when using a polymeric design. Leakage is a concern at each joint of the assembly (see Figure 2) as well as at the filler pipe to hose and hose to tank spud joints.

Refueling emissions standards did not change for LEV II, and have been successfully met with various “liquid seal” and “mechanical seal” designs. This technology is well established, and thus will not be included as part of this document.

Evaporative emissions from a capped fuel filler pipe can come from leaks between different components, and permeation through the materials used. There are a number of construction options for fuel fillers, but to achieve the best evaporative emission performance, it is preferable to minimize the number of leak paths and use the lowest permeation materials that still support the other functional requirements.

The following sections provide evaporative emissions considerations for various fuel filler pipe construction options that may be specified for use on LEV II applications. Assembly FMEAs (Failure Mode and Effect Analysis) and design validation plans should address these points. Helium leak detection (using pressures representative of what the component sees in-use) is a convenient method of quickly identifying any leak paths. Mini- or Micro-SHED testing is the most effective way to measure the effect of both permeation and leak paths, but accurate data requires proper conditioning with fuel, which can take hundreds of hours for low permeation materials. For materials with known permeation rates at in-use conditions, an approximation of the component’s performance can be calculated using the exposed surface area and the length of the permeation path.

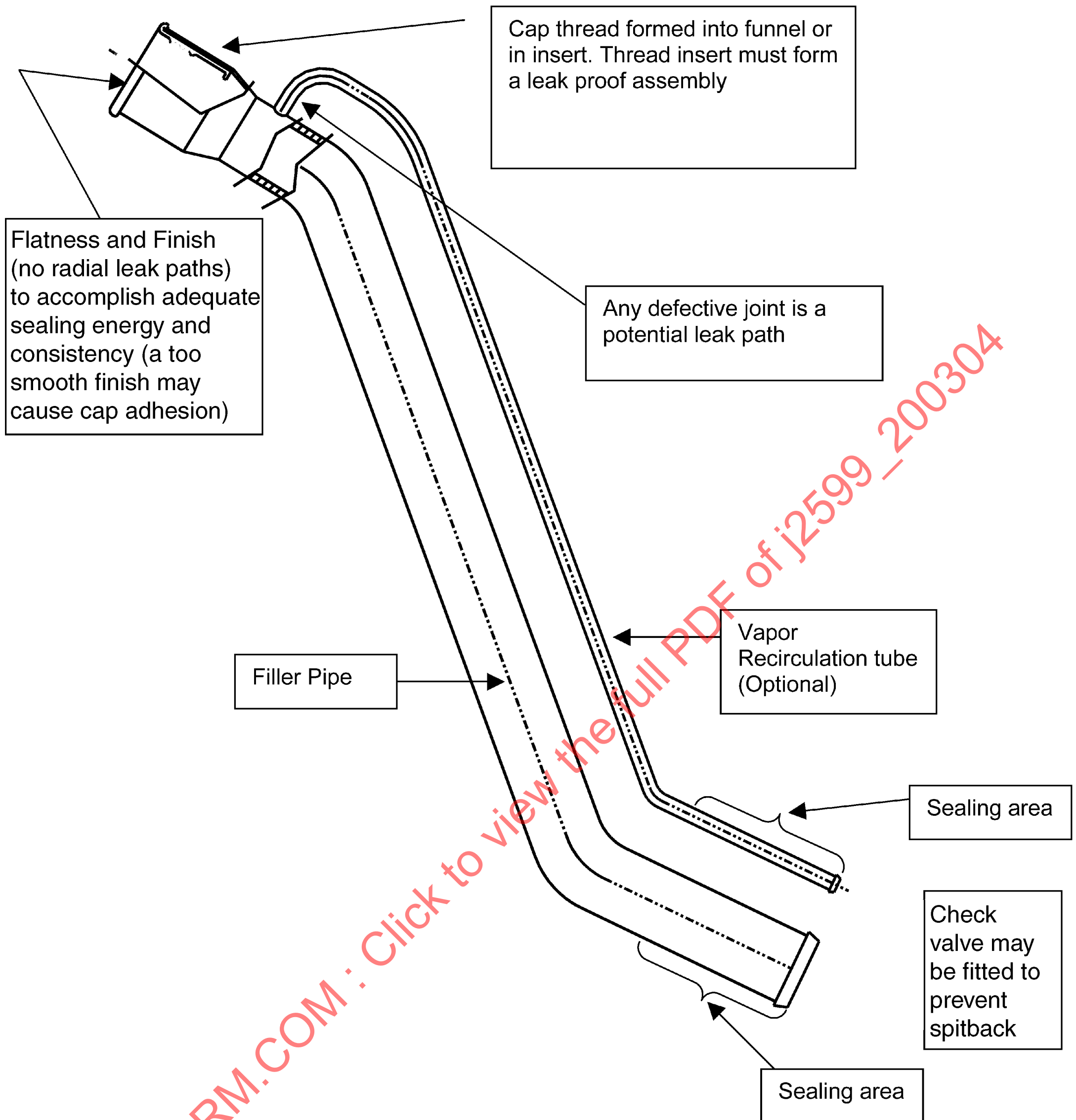

FIGURE 2—FILLER NECK

5.1 **Metal fuel fillers** (coated steel, stainless steel or aluminum) are typically zero-permeation, but may exhibit leak paths from rough surface finish (i.e., weld seam, tooling marks, coating flaws), corrosion or poor joints. Forming the full length of the main tube from a single metal tube is preferred. Coatings at the cap sealing surface must be robust against the chipping or scratching by pump nozzles during refueling that may create leak and corrosion concerns.

5.2 **Plastic fuel fillers** (Multilayer blow-molded, or extruded/injection molded combinations) have some measurable permeation rate, so minimizing the fuel-exposed area is strongly recommended. Although corrosion is typically not an issue, they carry over the requirements for smooth surface finish at sealing areas, and leak-free joints.

NOTE— Please see caution concerning sealing surface smoothness in Figures 1 and 2.

5.3 **Fuel cap retainers** may be integral with the tube forming the fuel filler, or a separate component. Forming the means of cap retention (the "thread") and the cap sealing surface in the expanded end of the tube is ideal because it minimizes the leak and permeation paths. Separate retainers may be welded, crimped or snap-fit into place. The weld of a welded retainer (plastic or metal) that seals to the cap is a potential leak path. Assemblies using crimped or snap-fit retainers require an elastomeric seal, which is itself a permeation and potential leak path. Further, if the retainer itself is of a material permeable to hydrocarbons, its contribution must also be considered in the performance of the fuel filler assembly.

5.4 **Recirculation tubes** may be incorporated as a part of some LEV II fuel fillers to minimize the amount of fuel vapor the ORVR system must contain, or as a means of including the fuel filler and cap during OBD (On Board Diagnostics) II leak tests. If not an integral part of the primary fuel filler tube, the joint of the recirculation tube to the primary fuel filler tube must be considered a potential leak path. At the opposite end, there are many alternatives for connecting the recirculation tube to the rest of the vapor system. Typical connections may include a male end form for a quick connector (reference SAE J2044), or a male end form for a tube or hose (reference Section 6 of this document). If a tube or hose is incorporated as part of the fuel filler assembly, its permeation rate and fuel-exposed area must be considered in the performance of the fuel filler assembly.

6. ***Sealability of the Filler Pipe Hose—***At their root, all elastomerically sealed joints are compression seals. In the case of hose connections the compression is achieved through dimensional interference between the hose and the pipe, and the force added by a hose clamp.

6.1 **Interference—**Interference of the inside diameter of the hose (Hose ID Figure 3) to the sealing surface (Tube Diameter Figure 3) of the fitting is one of the most important criteria in designing a sealing system. There is a direct relationship between hose to fitting interference, including that of the barb, and push-on force. The relationship between interference and push-on will also change with hose material, reinforcement type, and construction. Worst-case tolerance stack-ups should always have at least a line-to-line fit between the inner hose diameter and the tube diameter of the interface. Installation effort requirements should never compromise this hose to fitting fit. Clearance fits of any magnitude can lead to leaks. The greater the hose to fitting interference (provided the joint can be assembled, and the elastic limits of the bulk hose are not exceeded), the better the probability of a sealed joint. Interference is calculated as shown in Equation 1:

$$((\text{Tube OD} - \text{Hose ID}) / \text{Hose ID}) \times 100 \qquad \text{(Eq. 1)}$$

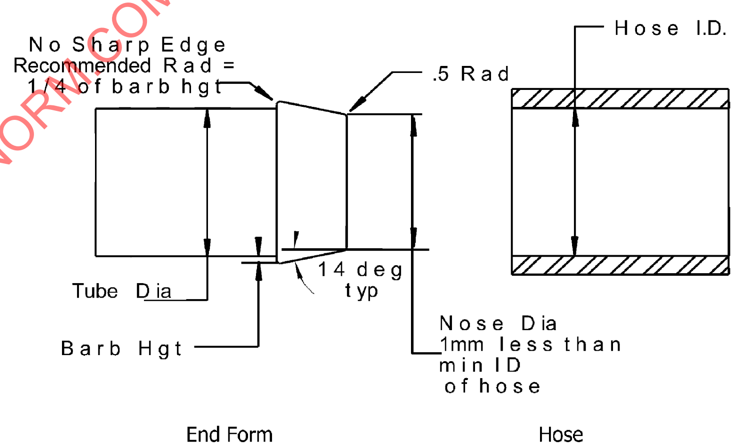

FIGURE 3—FITTING DESIGN AND HOSE FIT

TABLE 1—RECOMMENDED INTERFERENCE, HOSE TO FITTING

Nominal Hose ID Mm	Nominal Barb Hgt. mm [1]	Nominal Tube OD mm	Nominal Hose Radial Elongation %	Hose to Fitting Interference %
14	0.8	14.4	14%	2.9%
16	0.8	16.4	13%	2.5%
19	0.9	19.5	11%	2.6%
25	1.4	25.6	14%	2.4%
32	1.4	32.8	11%	2.5%
38	1.6	39.0	11%	2.6%

1. Barb heights are based on SAE J1231 and are recommended practice. Pull off loads will dictate required final barb height.

6.2 Fitting Surface Shape and Finish—The finish and shape of the mating surfaces of the fitting and the hose is a critical characteristic in the sealing design. The more consistent the sealing surface, the better the chance the joint has to seal (see fitting roundness 6.3).

6.2.1 SURFACE FINISH—The recommended surface finish for best sealing performance is as follows:

a. Has an RMS (root mean square) value equal to or less than 30 microns
b. The roughness lay must always be perpendicular to the axis of the fitting
c. No longitudinal flaws that exceed the roughness limit are permitted on the barb of the fitting
d. Any flaws on the shank of the fitting that form a continuous leak path must be considered detrimental to sealing.
e. Circumferential roughness or flaw usually do not contribute to leaks and may be allowed (see Figure 4).

NOTE— All previous comments concerning surface finish apply to both coated and uncoated fittings

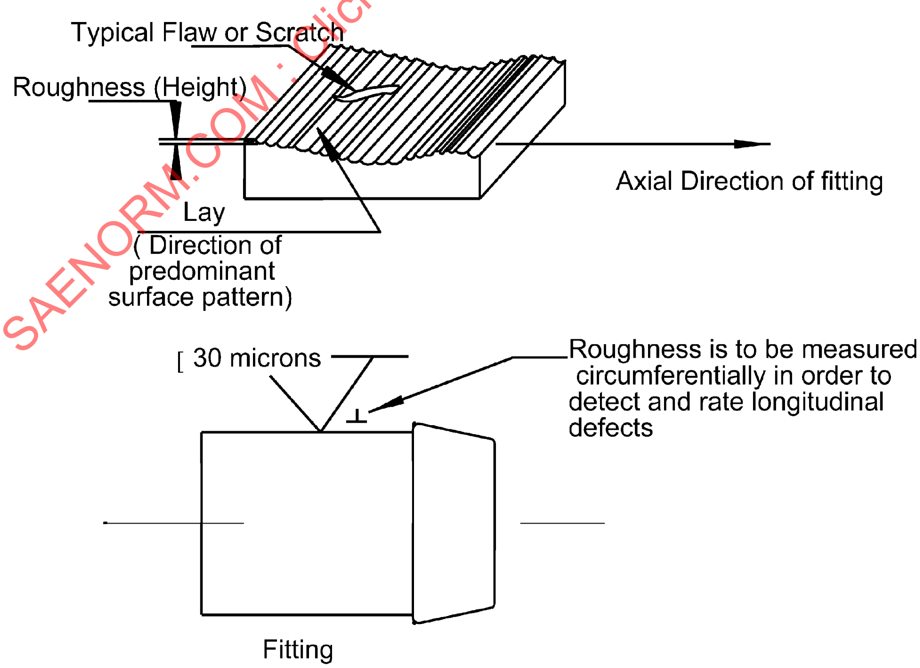

FIGURE 4—FITTING SURFACE FINISH

6.3 **Fitting Roundness—**Parting lines and weld seams can be direct leak paths. Larger parting lines have a higher probability of causing a joint leak than joints with smaller, faintly visible parting lines. Depressions or crevices below the contact surface may also cause leaks. Mismatch of dies or molds may also cause a leak path either directly, or as a result of scoring the ID of the hose during assembly. For this document, parting lines, flash and mismatch are considered flaws and must be smaller than the surface roughness specifications. Furthermore, these flaws, if present, must not form a continuous leak path (see Figure 5).

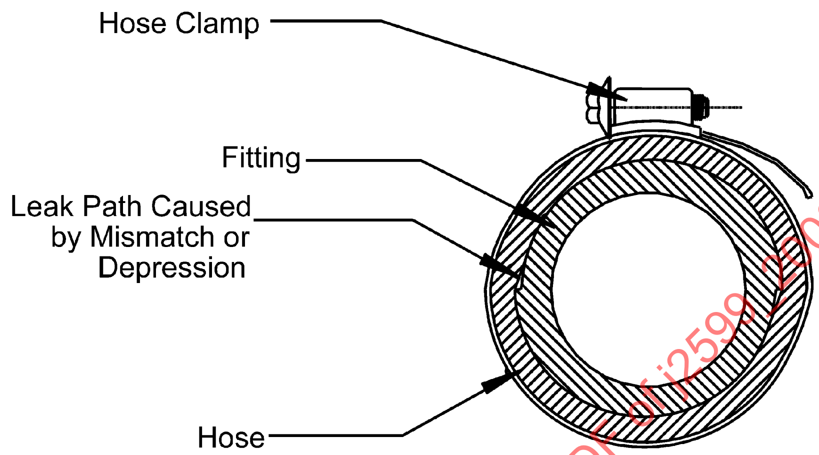

FIGURE 5—MISMATCH

6.4 **Sealing Length—**Longer sealing lengths provide a more robust design and assembly process. If the sealing length is not long enough, there is a greater potential that the clamp will be mis-positioned. In production settings, where accurate placement of the clamp cannot be guaranteed (assuming loose assembly), there is a greater possibility that the clamp will be placed either on the bead of the fitting or the hose stop. If the clamp is not perpendicular to the pipe axis, a leak may develop (see Figure 6).

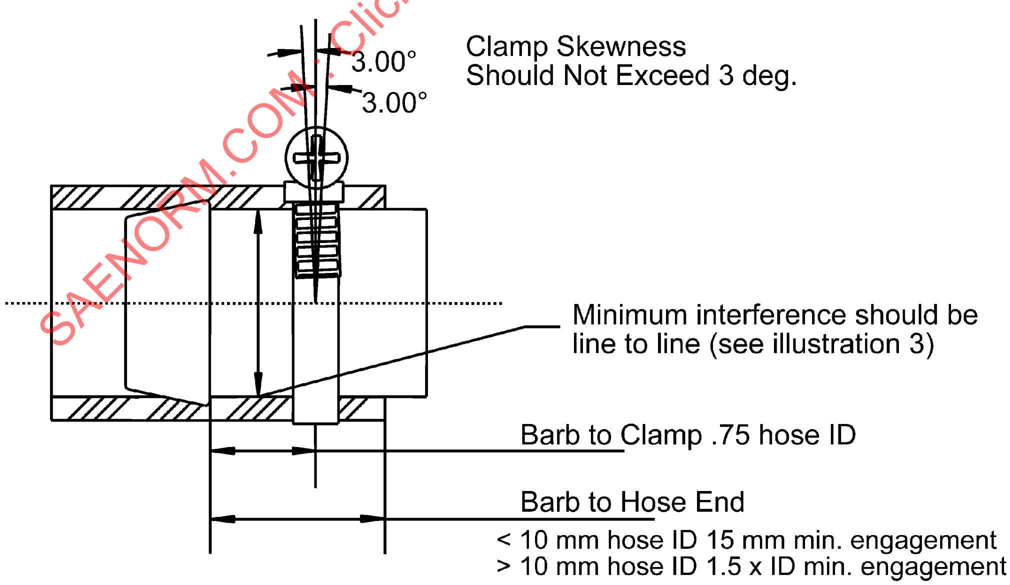

FIGURE 6—ASSEMBLY RECOMMENDATIONS

6.5 Clamping Requirements—As a reference for clamping components see specification SAE J1508 type "SLFEO". Worm gear drive clamps should be installed using the following speeds:

MAX 350 RPM for sizes up to DIA 70-90 mm
MAX 200 RPM for sizes DIA 90-100 and above

Clamps for use in fuel filler pipe assemblies should be manufactured using a grade of stainless steel that will insure that the hose clamp functions after exposure to a metallic corrosion test as suggested in Section 13. Filler pipe hoses seal to filler pipe and gasoline tank spuds because of the compression of the rubber hose caused by the hoop stress of the expanded hose and the clamp force. It is therefore imperative that the rubber hose exhibit long lasting stored energy and that the worm gear clamp be torqued correctly at assembly. Installation torque requirements for all SAE J1508 clamps that require torquing a screw or nut for installation are shown in that specification.

6.6 Crimped Hose/Tube Connections—Crimped hose/tube connections may be used as an alternative to clamped hose/tube connections on a fuel filler assembly. The sealing and retention mechanism is similar to that described in Section 6 of this document, but a cylindrical metal sleeve, the ferrule, is used in place of the clamp. When the components are positioned in the design intent position, the ferrule is radially crimped, reducing its diameter, and causing a compressive force on the hose/tube within the ferrule. Because the elasticity of the crimped ferrule is minimal, this method is best used on hose/tube materials that exhibit minimal compression set, such as thermoplastic tubing. Similarly, crimped joints are not intended to be serviceable, so any fuel filler assembly required to be separated from the fuel tank or other components (considered serviceable) should include a quick connector (reference SAE J2044 and SAE J2599) or similar device. Stainless steel is the recommended material for crimp ferrules, for durability. The end form for a crimped connection will resemble that of a clamped assembly, with the sealing diameter slightly larger than the maximum ID of the hose/tube. However, the bead height may be reduced if a thin wall tube is being used. The crimp dies should be relieved at the bead end of the crimp to form a flare in the ferrule, so that under tensile load, as the hose/tube and ferrule slide towards the bead, the hose/tube will not be pinched by the edge of the ferrule. As an option, a low permeation elastomeric seal can be used between the end form and the hose/tube in the crimp area. This seal is recommended for high modulus tube materials such as fluoropolymer tubing, or if the end form surface finish cannot be maintained sufficiently to prevent leaks.

6.7 Fuel Filler Pipe Quick Connect Couplings—For quick connect couplings on the recirculation tubes of fuel filler pipe assemblies, reference the "low pressure" portions of SAE J2044 for design and performance guidelines.

For quick connect couplings included as part of the primary tubes of fuel filler pipe assemblies (i.e., 1 inch or larger in size), reference the "low pressure" portions of SAE J2044 for design and performance guidelines, with the following considerations:

6.7.1 (SAE J2044.1) Due to the unique application, fuel filler pipe quick connect couplings may use non-standard end form configurations. However, surface finish specifications (SAE J2044.3) shall apply to the mating end form seal area.

6.7.2 (SAE J2044.5.3) Pull apart effort shall meet the minimum specified for high pressure-quick-connect couplings, unless this is exceeded by application-specific customer requirements.

6.7.3 (SAE J2044.5.6) Compliance with the electrical resistance requirements for connectors involving flowing liquid fuel is mandatory.

6.7.4 (SAE J2044.6.5) Life cycle testing per SAE J2044 can be omitted if the life cycle testing specified in SAE J2599 is performed with the fuel filler quick connect coupling included as part of the assembly. If this is not the case, perform SAE J2044.6.5 as written, but use tubing or hose that has been pre-formed into the test configuration.

6.7.5 (SAE J2044.6.6) Not applicable to fuel filler pipe quick connect couplings. Flow restriction performance will be included as part of the vehicle fuel fill test requirements.

6.7.6 (SAE J2044.6.7) For fuel filler pipe quick connect couplings; the minimum requirement for elevated temperature burst shall be 69 kPa (10 psig).

7. ***Sealability of the Filler Pipe to Tank Grommet—***At their root, all elastomerically sealed joints are compression seals. In the case of grommet joints, compression is achieved through a combination of dimensional interference between the grommet, the aperture it is in and the pipe as well as some swelling of the grommet cause by absorption of fuel.

7.1 Grommets should be designed as follows:

7.1.1 OD of grommet sealing surface should be line to line with the maximum aperture ID before the pipe is inserted.

7.1.2 Grommet maximum ID should be smaller than the minimum pipe OD such that when the grommet ID is expanded by fitting the pipe into it there is sufficient stretch (10 to 12%) while allowing ease of assembly (see Figure 7).

7.1.3 When the pipe is inserted into the grommet in its aperture there should be a target of 16 to 20% with a minimum of 10 to 15% compression of the rubber (see Figure 7).

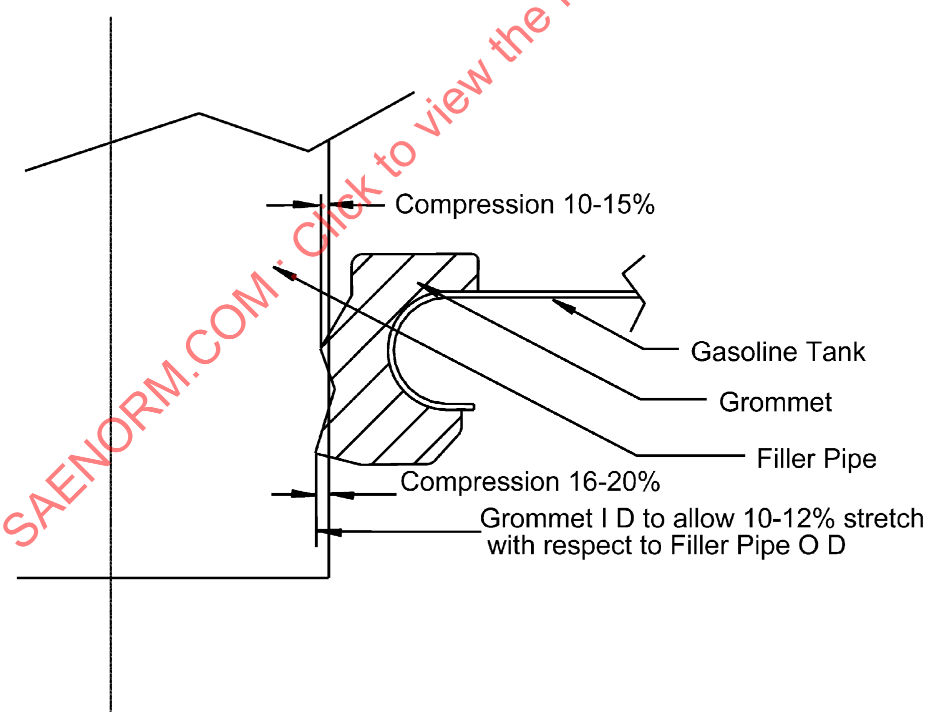

FIGURE 7—GASOLINE TANK TO FILLER PIPE GROMMET

7.1.4 Grommet rubber material should be selected such that volume swell in fuel is less than 30%.

7.1.5 Grommet material failure strength measured after soaking in CARB Certified fuel must be about 2X the maximum stress caused by pipe interference and volume swell.

7.1.6 Fuel Filler pipe end form finish requirements for grommets are the same as those for hose end forms.

7.1.7 A tether or clip is typically used to prevent the fuel filler pipe from pulling out of the grommet during vehicle crash conditions.

8. Emission Testing of the Filler Pipe Hose to Filler Pipe Assembly

8.1 Hydrocarbon emission from a filler pipe assembly is defined as the sum of all hydrocarbons (see Figure 8):

8.1.1 Traveling through the wall of the hose (permeation)

8.1.2 Traveling out the wall area of the hose (wicking), and

8.1.3 Traveling through an opening between hose and fitting surface (leakage).

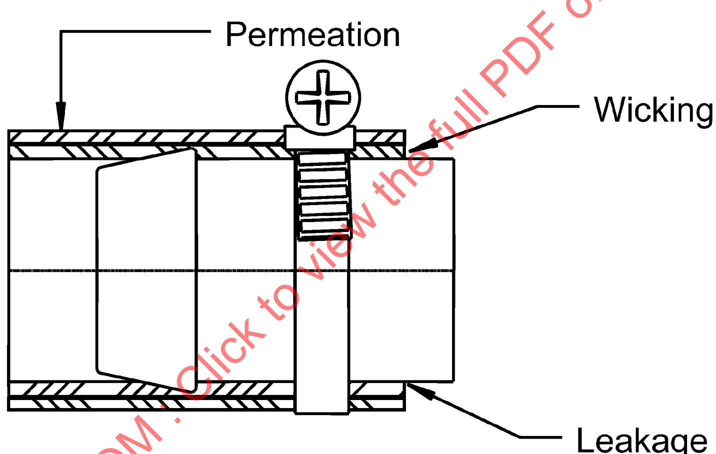

FIGURE 8—EMISSION SOURCES FROM A FILLER NECK HOSE JOINT

8.2 Emission Testing of Filler Pipe—Emission testing of filler pipe hose to tank assemblies is accomplished in three stages. First, the materials of construction for the hose or seal as well as the hose or seal itself are permeation tested using a permeation of elastomeric hose or tube by weight loss technique such as a Cup Weight loss method, the Canister Weight Loss Method or a Plug and Fill Weight Loss Method. Alternatively the SAE J1737 recirculation technique may be employed. Second, the filler neck assembly is Helium or Hydrocarbon leak tested. And lastly, the assembly is Mini or Micro SHED tested using an appropriate test protocol.

The recommended test fuel for preconditioning and testing is CARB Certified Fuel and the test temperature for all testing is held constant. It is recommended that the product be tested:

a. Always at 40 °C and 60 °C
b. If material 20 °C $\leq T_g \leq$ 60 °C
   Test at 30 °C, 40 °C, 50 °C, and 60 °C
c. If measuring multilayer component
   Test at 40 °C, 50 °C, 60 °C

The advantages of using a constant temperature test plan are that it is more sensitive and accurate at low emission levels, inconsistencies can be more easily discovered (10% change in permeation per °C) and there are fewer variables in the test. Diurnal performance can then be calculated using the Arrhenius equation. This method is described in SAE Technical Paper Series 2001-01-0730 Estimating Real Time Diurnal (RTD) Permeation from Constant Temperature Measurements.

The contribution of the filler pipe assembly to the total evaporative emission deficiency of the vehicle varies with vehicle design. For example, LEV II requirements state a total diurnal hydrocarbon emission of 0.5 grams for passenger cars. If a 33.3% safety factor is used, this leaves 0.333 grams for the maximum emission. Deducting non-fuel system sources results in a 166 mg for the fuel system. The filler neck has a small portion of this 166 mg allowance.

In order to design a LEV II compliant filler neck assembly one must determine the contribution of permeation, wicking, and leakage to the total emission of the assembly. These three emission sources can be determined by a combination of permeation, helium, and Mini or Micro SHED testing. All three emission contributors should be determined using assemblies made with components from the same production runs. The testing should be designed so as not to disturb any joints or connections. Two suggested test methods follow:

In both methods the hose assemblies are filled with fuel and plugged as shown in Figure 9.

In method 1, the assemblies (Figure 9a- short hose and 9b- long hose) are immediately Mini or Micro SHED tested to determine leakage (no ageing); then they are removed from the Mini or Micro SHED and aged 21 days. They are then returned to the SHED and total emission is determined (permeation, leakage and wicking). Subtracting the leakage from the total emission will reveal permeation and wicking for both length hoses. Then subtracting the two permeation-wicking numbers will yield the increased permeation for the longer hose. Using effective permeation areas 1 and 2, permeation as a function of hose area can then be determined for each hose. Subtracting permeation and leakage from the total emission number will then yield a wicking emission.

Method 2 again determines leakage by immediately testing the filled hose assembly (does not require testing a long and short assembly) in the Mini or Micro SHED. The assembly is then aged 21 days and returned to the Mini or Micro SHED to determine total emission. It is then removed and the entire end surface is sealed with epoxy (Figure 9c) and it is returned to the Mini or Micro SHED to determine permeation only. This will yield a leakage emission, a total emission, and a permeation emission. By subtraction, a wicking emission can be determined.

9. ***Electrostatic Discharge***—Filler pipe assemblies designed to meet requirements of this document must demonstrate the ability to dissipate a static charge. When refueling occurs, fuel flow can cause a significant amount of turbulence, which can lead to charge separation. Turbulence can be influenced by refueling flow rate as well as differing geometries of the neck itself. For additional information about fuel system electrostatics please refer to SAE J1645.

The filler pipe assembly must exhibit acceptable conductivity, and when installed in a vehicle, the filler pipe assembly and its attachments must have a continuous path to the common ground of the vehicle. Static electrical conductivity should be verified using SAE J2260, paragraph 7.9. Under no circumstances should any portion of fuel filler pipe assemblies exposed to liquid flow contain isolated metallic components.

10. ***Fuel Fill Performance***—The Filler pipe assembly shall conform to the requirements stated in Federal Register Vol 58/ No 55 page 16045 § 86.146-96 (Fuel Dispensing Spitback Procedure).