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400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE RECOMMENDED PRACTICE

Submitted for recognition as an American National Standard Ansi
J1645 REV APRIL 156, 2002 Issued 1994-02
Revised Proposed Draft Superseding J1645 Jul98

(R) FUEL SYSTEM—ELECTROSTATIC CHARGE

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***1. Scope*—**The purpose of this SAE Recommended Practice is to explain electrostatic charge phenomena that may occur in automotive fuel systems and recommend methods to minimize their occurrence and/or mitigate their adverse effects. . This document applies to the group of components that comprise the fuel system and those portions of the vehicle adjacent to the fuel system. Furthermore this document will deal with electrostatic phenomena that arise from the following circumstances of vehicle operation:

a. Flowing fuel in the fuel delivery system
b. Flowing fuel being dispensed to the vehicle while it is being fueled
c. Electrostatic charge differentials that exist between the vehicle and its operator as the operator initially attempts to refuel the vehicle.

. . . .
. The vehicle OEM using the fuel system should be consulted for information on specific requirements. This document is intended to providing guidelines on how to proceed.

2. References

2.1 Applicable Publications —

2.1.1 SAE PUBLICATIONS — Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAEJ2260 — Non-metallic, Low-permeation, Fuel System Tubing With One or More Layers Specifications for Liquid Fuel Systems

2.1.2 ASTM PUBLICATIONS — Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D257-90 — Standard Test Method for DC Resistance or Conductivity of Insulating Materials (March 14, 1990)

ASTM D4496-87 — Standard Test Method for DC Resistance or Conductivity of Moderately Conductive Materials (October 30, 1987)

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

Federal Test Method 4046.1—Antistatic Properties of Materials

2.1.4 MILITARY SPECIFICATION—Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robins Avenue, Philadelphia, PA 19111-5094.

Military Specification MIL-B-81705B—Barrier Materials, Flexible, Electrostatic, Free, Heat Sealable

2.1.5 NFPA PUBLICATION—Available from the National Fire Protection Association, 1Battery March Park, Quincy, Massachusetts, 02269.

NFPA Code 56A—Paragraph 466: Standard for the Use of Inhalation Anesthetics, Antistatic Accessories & Testing

NFPA77—Recommended Practice on Static Electricity 1993 Edition

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document; they mainly provide background information.

2.2.1 SAE PUBLICATIONS – Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAEJ1645 FEB94 — Fuel System—Electrostatic Charge Informational Report

SAE J2044 — Quick Connector Specification for Liquid Fuel and Vapor/Emission Systems

SAE J2045 — Tube/Hose Assemblies

2.2.2 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D150—Test Methods for A-C Loss Characteristics & Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials

ASTM D 991—Rubber Property—Volume Resistivity of Electrically Conductive & Antistatic Products

ASTM D 2679—Electrostatic Charge

ASTM D 3509—Electrostatic Field Strength Due to Surface Charges

ASTM D 4470—Standard Test Method for Static Electrification

ASTM D4865-88—Standard Guide for Generation & Dissipation of Static Electricity in Petroleum Fuel Systems (November 17, 1988)

2.2.3 API PUBLICATION — Available from American Petroleum Institute, 1220 L Street Northwest, Washington D.C. 20005

API 2003 — Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents

2.2.4 DIN PUBLICATION — DIN Deutsches, Institut fur Normung, Burggrafeng Strasse 6, Postfach 1107, D-1000 Berlin 30 Germany.

DIN 53-486/VDE 030 Part 8/4.75 (April, 1975) VDE Specifications for Electrical Tests on Insulating Materials: Evaluation of Electrostatic Behavior

2.2.5 OTHER PUBLICATIONS—DETAILED BACKGROUND

Journal of Research Article (Oct-Dec, 1965)—"Electric Currents & Potentials Arising from the Flow of Charged Liquid Hydrocarbons Through Short Pipes:

ISO 3915-1981 (E)—"Plastics—Measurement Of Resistivity of Conductive Plastics"

IEEE Transactions on Electrical Insulation Volume 23, No. 1 (ISSN 0018-9367) (February, 1988)—"Electrical Insulation & Breakdown in Vacuum"

IEEE Transactions on Electrical Insulation Volume 23, No. 1 (ISSN 0018-9367) (February, 1988)—"Flow Electrification in Electrical Power Apparatus"

Naval Research Laboratory Report 8021—"Pro Static Agents in Jet Fuels" (August 16, 1976)

Coordinating Research Council—Electrostatic Discharge in the Fuel Systems of Gasoline Powered Vehicles in North America (Paper by Ron Tharby, Nov, 1990)

ESSO Research & Engineering Company - Charging Tendency Test (April 9, 1959)

Naval Research Laboratory Report 8484 - "Generation of Electrostatic Charge in Fuel Handling Systems: A Literature Survey" (September 24, 1981)

January, 1988 issue of Plant/Operations Progress magazine—Collection of articles on aspects of electrostatic charge concerns arising in handling chemicals

Research studies Press, Inc. John Wiley & Sons—"Electrostatic Hazards in the Petroleum Industry" by W.M. Bustin & W.G. Dukek

1992 Issue of Automotive Technology International magazine—"Flow Electrification in Automotive Fuel Systems" by J.C. Dean of Hercules

3. Definitions

3.1 Absolute Charge Sensor—

3.2 Absolute Humidity— 3).

An increase in the amount of electrostatic charge present on a fuel system component resulting from a rate of charge dissipation that is slower than the rate at which charge is delivered.

An instrument for measuring current in an electric circuit.

3.5 Breakdown Voltage—

3.6 Bonding

3.7 Capacitance—

(C) is defined as the total electric charge (on the body) (q) divided by its electric potential (V) (C=q/V).

3.8 Charge—

3.9 Charge Density—

3.10 Conductance— **W**

3.11 Conduction—

3.12 Conductivity—

σ

3.13 Corona Discharge—

3.14 Coulomb—

3.15 Current—

3.16 Dielectric—

3.17 Dielectric Breakdown—

3.18 Discharge—

3.19 Dissipation—

3.20 Electrometer—

3.21 Electrostatic Charge—

3.22 Electrostatic Force—

3.23 Electrostatic Potential—

3.24 Erosion, electrical—

3.25 Faraday Cup or Cage—

3.26 Field Strength Meter—

3.27 Field Strength—

3.28 Grounding—

3.29 Insulative—

3.30 Insufficiently Conductive – Materials
ouch liquid fuel are considered "insuficiently conductive" if their surface resistance volume resistivity is great than 10^8 · cm

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_– The unit of electrical resistance (Ω); when 1 amp (A) of current flows through a 1 Ω resistance, 1 volt (V) of potential difference is produced.

_– **ε_0)—** ε_0

ε_0

ε_0 $^{-12}$ farad/meter.

_– The partial pressure of water vapor in the atmosphere as a percentage of the saturation water vapor pressure (at the same temperature).

_– _e R)— _e 0).

_– **Relaxation—**
τ :

$$\tau = R*C$$

$$\tau = (\varepsilon_R \cdot \varepsilon_0)/\sigma$$

ε_R
ε_0
σ

3.365 Relaxation Time—
_e _e

3.376 Resistance—

Ω

Ω of resistance, R·I² watts of power is dissipated.

_– Material with a surface resistivity or a volume resistivity that lies between those of materials termed conductors or insulators (e.g., volume resistivity between 10^{6} ^{4} and 10^{8} (Ohm×cm). In the context of this document, the semi-conductive definition also applies to the term "sufficiently dissipative".

NOTE TO SUBCOMMITTEE: (Although the statement above about the ranges of resistivities is correct it is not a definition for semiconductivity. What should the definition be? semiconductivity!). What should the definition be?

3.398 Shear Rate—

3.4039 Siemens— Ω

3.401 Streaming Current—

3.4.2. Sufficiently Conductive – Materials

6 .

3.4.3 Sufficiently dissipative – Materials

3.441 Surface Resistance— Ω

If the voltage is applied to the area given by t* d and flows along the direction of f then the total resistance is:

R = *f / t*d

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When f = d then the sample is a square and the absolute size of f and d does not matter. The resistance of the square sample is independent of the size. So the resistance in terms of Ohm per square is simply:

$$R = \quad / t$$

The resistance measured in this case is the resistance of a conductive sheet of thickness t and the specific resistivity

NOTE—Sometimes the terms surface resistance and surface resistivity are interchangeable terms (for this document, we will use the term surface resistance).

3.452 ½ Time Constant – See Relaxation (3.34).

3.4.63.Voltage—

3.474 Voltmeter—

3.485 Volume Resistivity—

.

4. Recommended Practices for Minimizing Electrostatic Charges and Their Effects —

4.1 Material Requirements –

6

least 72 hrs at room temperature and 50% relative humidity after the plaque's manufacture (refer to 5.2.1.3).It is recommended that materials that have direct contact with flowing liquid fuel or are required to be "conductive" or semi-conductive in fuel system applications have a volume resistivity of 10^8 • cm or less as determined by test procedure 5.2.1. The procedure is applied to the material without any fuel exposure and on a standard plaque that has been equilibrated at least 72 hours at room temperature and 50% relative humidity after the plaque's manufacture (see also 5.2.1.3 and appendix, section A1.2.2.3).

Criteria for individual components depend on numerous factors. The end user should be contacted for specific requirements that must be met for the component in question. All criteria, however, will be such that the system requirements of section 4.3 will be met. In addition, components that are part of the liquid fuel system are recommended to have the following characteristics:

- Materials used in that portion of the component that touches the flowing fuel shall meet the recommendations of section 4.1.
- The conductive materials used in the component shall have a means to be bonded to the vehicle ground either as part of the overall liquid fuel system or by an independent manner (such as a ground strap or conductive mounting clip, for example).

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- When the components are assembled in the fuel system, all requirements in section 4.3 must be met. NOTE: This requirement applies to all components, even those that may be identified as an exception noted above.

There are some possible exceptions to these first two points that are noted in the Design Guidelines that are listed in the Appendix, section A.3.

~~**NOTE: What test to use? Do we need this or is 4.3 sufficient to also cover components.**~~

4.3 Fuel System Design Requirements (as it is installed on a vehicle)

4.3.1 For all channels within the fuel system which are specifically designed to conduct fuel from one component to another, the electrical resistivity~~ance~~ measured between points A and B and between points A and C must not exceed ~~100 M~~$1X10^8$Ω when measured ~~using 500V excitation~~by procedure 5.2.3. ~~.~~ Definitions of point A, B & C are as follows:

A. Any point on any surface that is in contact with flowing fuel.
B. The highest capacitance metallic component in the vehicle.
C. Any metallic component that could come within 25mm of any fuel system component.

~~**NOTE: The point made by item "C" above has been questions as being very difficult to comply with. Is this what we want to say? If not, how should it be reworded?**~~

~~Flow Rate Questions~~

~~At this moment the requirements of sections 4.3.1 apply to any systems/component containing flowing fuel (under all conditions of that flow). Note that sloshing fuel inside a tank does not apply. Questions have been raised about this. Please consider them and respond.~~

- ~~Some flows inside the fuel tank may not contribute to charging (such as the overflow over the edge of the fuel tank reservoir that can occur sometimes)~~
- ~~Turbulent flow is necessary to form significant charge separation. Turbulent flow always occurs inside the filter as the fuel moves through the filter media.~~

- ~~Sustained high flow rates that cause turbulence are necessary to develop significant accumulated charge. "On demand fuel systems, which might only flow fuel at a high rate during WOT operation, might be excused from this requirement.~~
- ~~Is there a minimum flow rate necessary before this requirement becomes "in effect".~~

4.3.2 The electrical resistance between a typical marketplace filler nozzle inserted into the filler pipe and a ~~metallic plate placed under the nearest tire~~vehicle ground shall not exceed 1~~5~~00 MΩ when measured ~~using 500V excitation~~by procedure 5.2.3.

~~4.3.3 Means should be provided to dissipate any electrostatic charge that the user may have accumulated prior to them initially gaining access to the fuel filler pipe.~~

4.3.~~3~~4 All of the ~~above~~ requirements of sections 4.3.1 and 4.3.2 must be met throughout vehicle life under all conditions of vehicle usage, aggressive fuel usage and filler nozzle usage representative of the marketplaces in which the vehicle is intended for sale, noting that chemical attack by fuels can degrade the conductivity of semi-conductive materials.

~~6.General~~*5.0 Testing Procedures*

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[cm]

- ACCEPTANCE CRITERIA – In accordance with ASTM D 4470 for purpose of charge generation, materials having a volume resistivity of up to 10^8 cm will be termed conductors.

ADDITIONAL NOTE TO THE SUBCOMMITTEE: Does anybody have an idea for an equivalent ISO test procedure.that would be preferred. Acceptance Criteria would be volume resistivity of 10^8 ·cm

NOTE: ~~It's been recommended to remove this test. It is not accurate in the ranges of conductivity/resistance that we need to look at. It is a test, which is designed for materials that are much more insulative than conductive.~~

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Ω

Ω

8 •

NOTE: **What test to use in 5.2.1.3?**

NOTE TO SUBCOMMITTEE:

In our lengthy discussion, there seemed to be agreement that the same basic test should be used for all items that fall in this category. The contacts would be critical to define in each case; the group felt they should be as close to the configuration of the actual connectors used for that component/subsystem in each case. The key consideration is to measure the resistance along the flow path of the component or along the various elementsw of subsystem being tested. The diagram of the equipment needed and some procedure notes are seen on the the handwritten sketch on page 13. We talked about possible test procedures for a good portion of the meeting. Eventually, we settled on the diagram on the following page as a reasonable possibility. It's most a resistance measurement device, but (probably) can be used for determining some charge dissipation information as well. This basic approach seemed to be applicable to many different types of components and small subsystems. The connections used would be a key aspect. The group felt those connections should be as close to "real world" connections as practical. An important aspect of this proposed procedure is the "voltage drive". We identify it in the sketch as 1000 volts.that is what we felt the maximum should be. If the component being te3sted meets the acceptance criteria with a lower voltage drive (simpler and less expensive) than that should be fully acceptable.

ADDITIONAL NOTE:

Next page (13) shows the sketch of the system we had at the meeting. It relates very closely to the circuit diagram that Bob Halsall recommended for section 5.3 (see page 17).

I like how those two relate to each other.what do you think?

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RESISTANCE MEASUREMENT PROCEDURE
(PART OF SECTION 5.2.2 of SAE J1645)

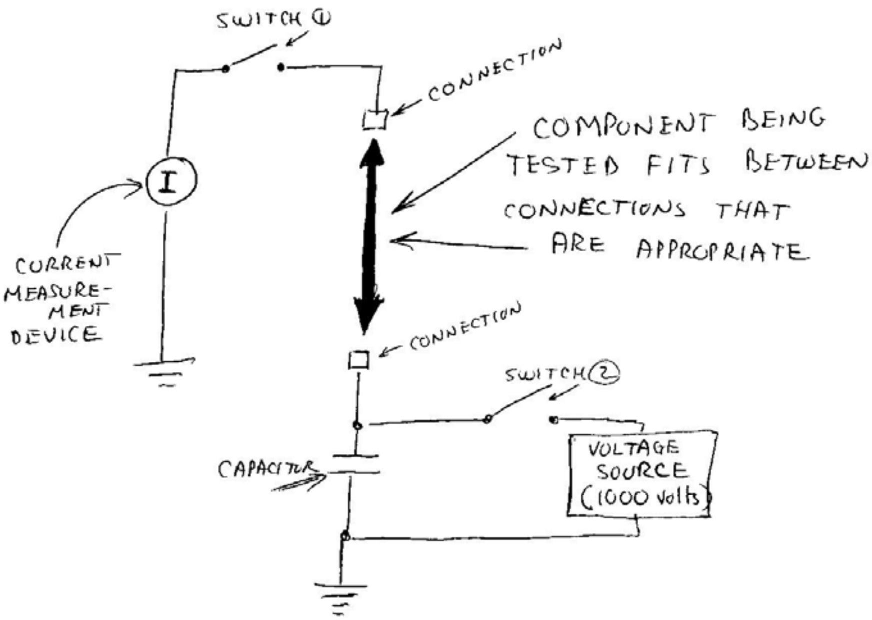

DIAGRAM OF BASIC EQUIPMENT NEEDED FOR RESISTANCE MEASUREMENT DEVICE THAT COULD BE USED TO DETERMINE TIME NEEDED TO DISSIPATE CHARGE (OF KNOWN VALUE) THROUGH A COMPONENT

Our expectation (apparently) is that this will take the place of all previous resistance type test procedures we've had before (such as SAE J2260, section 7.9).

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NOTE TO SUBCOMMITTEE:

Question on Metal Parts:

Acceptance criteria for semi-conductive parts (volume resistivity of 10^8 • cm) is what we have focused on. Metal parts should be treated differently. In previous draft, we've referred to metal parts needing to have a "resistance to ground of only 100 with a voltage drive of only 10 volts. What do you think? Also, (and very important), how do we phrase statements about metal parts that may be ungrounded and also contributin virtually nothing to charging condition. Before you answer, also read 4.3.1C again.

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~~between electrodes in the direction of expected fuel flow. The volume resistivity Q_v calculated from the volume resistance R_v and the geometric dimensions of the specimen makes it possible to compare results obtained on different materials.~~

~~5.2.2.2.3 DESCRIPTION OF TERMS~~

~~Volume Resistance, R_v in Ω—The volume resistance between two electrodes that are in contact with a specimen, is the ratio of direct voltage applied to the electrodes to that portion of the current between them that is distributed through the volume of the specimen.~~

~~Volume Resistivity, Q_v in Ω•cm—The volume resistivity of a material is the ratio of the potential gradient parallel to the current in the material to the current density.~~

~~5.2.2.2.4 ARRANGEMENT—See Figure A1.~~

FIGURE 7.1—ARRANGEMENT

5.2.2.2.5 TEST SPECIMENS—The test specimen may have any practical form, e.g., flex bar. This includes also specimens like connectors, fuel filter bodies or similar parts.

5.2.2.2.6 PROCEDURE—Before measuring the volume resistance, the front surfaces of the specimen have to be silver painted. Between these contact areas the volume resistance has to be measured. Read the resistance level after 60 s of measuring.

5.2.2.2.7 CALCULATION—The volume resistivity Q v has to be calculated from the measured volume resistance R_v

$$= R_v \times A/d \qquad \text{(Eq. 71)}$$

where:

R_v Measured volume resistance in Ω
A Silver painted (smallest) area in cm squared (perpendicular to the current flow)
d Length of specimen in cm

Sample calculation for a flex bar (12.7 cm x 1.27 cm x 0.32 cm)
A = 1.27 cm x 0.32 cm = 0.4064 cm 2
d = 12.7 cm

$$= R_v (0.4064/12.7) \quad [\Omega \text{ cm}] \qquad \text{(Eq. 7.2)}$$

5.2.2.2.8 ACCEPTANCE CRITERIA—In accordance with ASTM D 4470 for purpose of charge generation, materials having a volume resistivity of up to 10^8 Ω cm will be termed conductors.

5.2.3 Systems Tests

5.2.3.1 Continuity of the System – Electrical resistivityance is an important measurement for many aspects of a fuel system: materials, components, subsystems, and even the full vehicle. Just as critical is the resistivityance across the joints and interfaces that must be maintained as those parts are connected to form subsystems and full assemblies. This is known as continuity and must be maintained throughout the use of the system. Note that an exception can apply to this; refer to section A3.2.1.

5.2.3.2 Confirming the Ground Path to Vehicle Ground —This is a measurement from a particular point of interest on a vehicle to the ground plane. This is essentially a measurement of the path that charges can follow to "correct an imbalance" that may exist at the point of measurement. It is a measurement of resistivityance; to determine if an adequate ground path exists; experience has shown that a resistivityance level of 5×10^8 Ohm is adequate (refer to for more details on this area).

COMMENT: Is this level correct?

5.2.3.2.1 It is important to realize that this ground path measurement examines several factors simultaneously:

a. Resistance of materials and those parts of components that touch the fuel

b. Continuity resistance across the interfaces and connections that exist in an operating fuel system or refueling system
c. Cumulative resistance of numerous components/materials connected in series.

Because of these factors, this ground path measurement is an important aspect of the testing that could be done.

NOTE TO SUBCOMMITTEE: Need to define the two points between which the measurement is made.

5.2.3.3 It is very important to define ground in the case of a vehicle. It usually is considered to be the body, engine block or chassis; normally, there is a large enough source of charges to correct any imbalance that may develop. Care must be taken to determine if these major vehicle components are a "sufficient ground." They may also need to be electrically connected to each other to provide an adequate ground plane. However, there could be times when those major vehicle components must also have a "path" to ground. This implies that the tires should have low enough resistance level to allow an exchange of charges between the chassis and the actual ground the vehicle sits upon. If the tires have an overall resistance level of $5x10^{8}$ Ohm or less, they can function as the adequate ground path that is sometimes needed.

We are dealing with two separate phenomena:

- The charging due to moving fuel in a fuel system
- Charging of a vehicle as it moves across the road or "earth ground"

NOTE: Do we need to indicate this?

NOTE TO SUBCOMMITTEE: Some basic resistance measurement will be applied in all cases of 5.2.3.refer to procedure that is part of 5.2.2.

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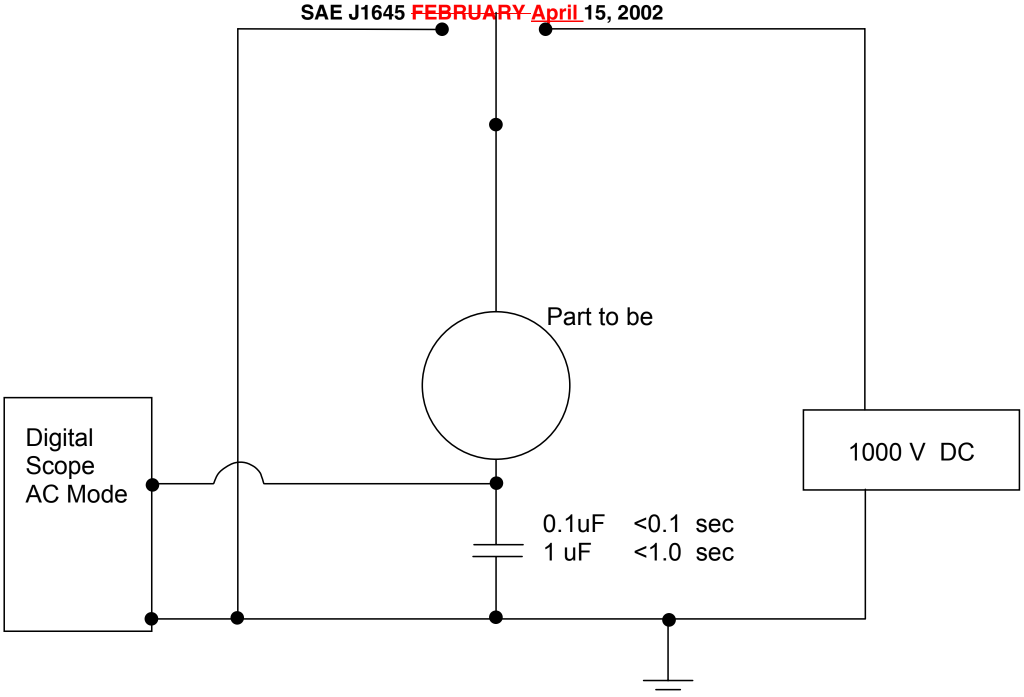
5.3 Measuring Ability to Handle a Charge

NOTE TO SUBCOMMITTEE: Bob Halsall submitted a circuit diagram for a test procedure to be used in this section (he called it a "time-constant based conductivity test". It has many similarities to the sketch we cam up with for section 5.2.2. What do you think:



Conductive ver. 02

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~~One common misconception is the attempt to measure~~

~~NOTE: Please comment on the 2 proposed tests that follow this page. Are there any other tests of a similar nature that should be inserted here?~~

NOTE TO SUBCOMMITTEE: Virtually all charge dissipation tests discussed were thought to be different variations of resistance measurement tests. The impression was that such tests may not be needed; the resistance measurement when essentially a 1000 volt drive is involved seems to be considered sufficient for all measurements made. Halsall's recommendation may fit well because it's based on the "1000 volt resistance test" of 5.2.2.

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APPENDIX

A1. Background Information

A1.2.1.1 Charge Separation—

A1.2.1.2 Charge Transport—

A1.2.1.3 Charge Accumulation—

A1.2.1.4 Charge Dissipation—

A1.2.2.1

A1.2.2.2

3

^{6} Siemens are defined as sufficiently conductive. They are also considered "sufficiently conductive" if they exhibit surface resistance of 1x10^{6} Ohm/square or lower.

^{6} as our required level, are the following two definitions necessary?

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A1.3 Mechanisms of Charge Reduction—

NOTE: This is usually an external effect. It is not a direct dissipation route for charged fuel, except for inside the fuel tank.

f. Spark discharge (dielectric breakdown of a material, usually air). Note: Should this be quantified **(energy level = _______ Joules) to differentiate from e above.**

NOTE TO SUBCOMMITTEE: Spark discharge is something we should try to avoid in a fuel system. Because of this, should all the text of sections A1.4 and A1.5 be deleted. Is the information necessary? Also.look at A1.4.2. If we keep that, is it correct?

A1.4 Spark Discharge — This mechanism of charge recombination is of primary concern for a fuel system:

a. It can result in the development of microscopic holes developing in the fuel system components
b. It can ignite combustible air/fuel mixtures.

A1.4.1 WHEN IT OCCURS — Spark discharge occurs when the electric field generated by an electrostatic charge exceeds the dielectric or breakdown strength of the material in the space where the charge is located. Spark discharges of an energy greater than 0.2 MJ can only occur from metallic or highly conductive materials because the stored charge is capable of moving rapidly across the surface to the discharge location. Discharges generally occur through a dielectric:

i. Directly to ground or to another object having a sufficiently different potential
ii. From one part of a component to another if there is sufficient potential difference between the two parts

A1.4.2 ENERGY LEVEL OF DISCHARGE — Spark discharges of sufficient energy can result in the ignition of fuel vapors if the proper fuel/air ratio exists at the discharge path. Such ratios may exist near the exterior of a vehicle:

a. Around the filler neck during refueling
b. Near atmospheric vent outlets for the vapor management system
c. Near redundant overpressure relief valves

Under certain circumstances combustible air fuel ratios may exist in the vapor space inside the fuel system. These circumstances include:

a. Diesel fuel above 60°C
b. Winter gasoline below –25°C
c. E85 (85% ethanol blended with gasoline) below 15°C

Ignition of combustible air fuel mixtures can occur if a discharge is of sufficient energy. The energy of a discharge (E) to ground (Q) is described by the equation:

E = (C x V^2)/2 (V to the second power)
E = (Q^2)/C*2 (Q to the second power)

Where:
C is the capacitance of the discharging body
V is the difference in electrical potential between the discharging body and ground.

For most common automotive fuels the minimum ignition energy for a combustible mixture of air and saturated hydrocarbon vapor is 0.25 mJ.

COMMENT: Table of known reported values to go here

Additionally, spark discharges from fuel system components may interfere with the functioning of vehicle electronic systems such as the radio or various electronic controllers.
NOTE—Refer also to Page 77.6 of NFPA 77 listed in 4.1.3).

A1.4.3 REDUCTIONS IN DIELECTRIC STRENGTH — Spark discharge becomes more likely if the dielectric strength of the material is reduced such as by the following mechanisms:

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a. Extended periods of exposure to electric fields or high but subcritical levels of electrostatic charge,
b. Environmental factors (such as lower temperatures and lower relative humidity),
c. Aging: Degradation of the dielectric strength due to chemical (fuel) exposure, thermal exposure, thermal cycling, mechanical fatigue, etc.).

A1.5 Corona Discharge — This type of charge dissipation is less rapid than a spark discharge and it usually has few destructive results. It still proceeds on the basis of breaking down the dielectric properties of a local insulator.

A1.5.1 PINHOLE FROM INSIDE — Localized dielectric breakdown and corona discharge can occur through polymeric materials. The energy released in the discharge can melt, degrade, or burn the material in the discharge path and gradually over a long period of time can produce a pinhole through the wall of an insulator. Residue from burned polymeric material has a high carbon content and the path produced by such discharges is sometimes referred to as a carbon track. Once dielectric breakdown occurs, the insulating properties of materials are weakened and subsequent breakdowns will generally occur at a lower electrical field strength. Any subsequent discharge or current flow will tend to occur along the more conductive path of the carbon track (enlarging the hole). In fuel systems where the charge is generated in flowing fuel, the hole in the non-conductive component grows from the inside out.

A1.5.2 PINHOLE FROM OUTSIDE — Discharge can also occur in the air between surface of a non-conductive component to some other nearby conductive object that is at a different electric potential. This can cause the surface to decompose. This kind of discharge will occur between components having potential differences such that the electric field intensity in the air space between the components exceeds the dielectric breakdown strength of air (≈30,000 volts/cm). Many successive discharges from the outside to the same location of the non-conductive component can lead to erosion of the surface material, and eventually a pinhole could result, from the outside in.

A1.6 Charge Dissipation — This process of slow charge reduction is preferred for fuel system design because it can occur with no destructive effects. ~~When executed properly, dissipative fuel systems:~~

~~a.Prevent the formation or accumulation of significant electrostatic charges~~

~~b.~~a. ~~Permit significant charges on vehicle operators as they approach the vehicle to initiate refueling to be dissipated without creating an incendive spark.~~

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A1.7 Charge Formation — As stated earlier, electrostatic charges can be generated within the fuel system by the flow of fuel itself and electrostatic charges can be generated external to the fuel system by the many actions of the vehicle and its operators. Fuel system design strategies that aim at preventing the occurrence of electrostatic charges will not work because the mechanisms for control of the processes involved are beyond the control of automotive designers.

A1. 7.1 FUEL — Fuel has the largest single effect on the formation of electrostatic charges because its conductivity varies from less than 10^{-12} to over 10^{-9} Siemens per meter and it contains a widely varying range of additives and impurities. There are many sources and refining techniques for automotive fuels and an extremely wide array of compositions encountered. Very small amounts (parts per billion) of impurities, additives and even moisture can have a large effect on charging influences of some fuels. No controls on automotive fuel for purposes of reducing its propensity for generating electrostatic charges are considered practical.

A1.7.1.1 The following fuel characteristics and circumstances can significantly influence the ability of an electrostatic charge to develop:

a. Temperature of the fuel (electrostatic charging tendency increases as temperature decreases),
b. Composition, including the presence or absence of alcohol,

NOTE—Alcohols are pro-static agents (i.e., materials which increase fuel chargeability more rapidly than conductivity). This effect of pro-static agents is most pronounced at low concentrations. As the concentration increases a point is reached where the conductivity effect takes over and the fuel ceases to develop electrostatic charge

c. Conductivity. Electrostatic charging is greatest in the range of 15 to 400 pico Siemens per meter. At higher conductivity levels the rate of charge generation is overtaken by the rate of charge dissipation. Relaxation time is a characteristic of materials, including fuel, that indicates how quickly charges

recombine after they have separated. Highly conductive fuels have very low relaxation times (charges recombine very quickly).
d. Viscosity (electrostatic charging tendency increases as viscosity increases),
e. Additives which are pro-static,
f. Impurities and contaminants can act as pro-static agents (these tend to be charge carriers),
g. Moisture content, especially if the level is high enough to form a second phase. Emulsions can form in 2-phase flow. The surfaces on very small droplets in emulsions tend to be places where charges could form.

A1.7.1.2 Anti-static additives are available to improve a fuel's ability to allow separated charges to recombine by raising the conductivity of the fuel. Use of these anti-static additives have proven unreliable as a "solution" for preventing electrostatic charge concerns in automotive fuel systems because:
a. There are so many fuel producers and fuel outlets that it would be virtually impossible to guarantee the addition of a specific ingredient in every case
b. These additives tend to plate out on surfaces of pipes, tanks and tubing so their effect changes over time.
c. Moisture content of the fuel can affect the performance of the additives.
d. Trace quantities of anti-static agents are pro-static and can actually cause fuel to develop more charge separation.
Highly conductive fuel may adversely effect electrical components in the fuel system, such as fuel level sensors or fuel pumps.

A1.7.2 ENVIRONMENT—The environmental factors that have the most significant effects on the electrostatic situation of a vehicle's fuel system are temperature and humidity.

A1.7.2.1 High humidity can create a conductive path which permits charge recombination on fuel system surfaces, thus preventing charge accumulation and discharge. A low absolute humidity environment such as experienced at temperatures below freezing, is more likely to permit dielectric breakdowns by allowing a higher degree of charge accumulation. While environmental humidity primarily affects the exterior of the fuel system, it can also affect the moisture content of the fuel. A change in moisture content can cause fuel to change its conductivity.

A1.7.2.2 As temperature goes down, fuel conductivity decreases, fuel chemistry can change, and fuel viscosity goes up, all of which contribute to higher charge probability.

A1.7.3 Factors External to the Vehicle

A1.7.3.1 Fuel Dispensing Equipment — Local regulations and codes usually require that fuel dispensing equipment be conductive (or sufficiently conductive) and provide a connection from the dispenser nozzle to earth ground (per NFPA 77). If the electrical connection to earth is interrupted or if a nonconductive component is used in the fuel dispensing fluid circuit, electrostatically charged fuel could be delivered to a vehicle during refueling. Also, the use of pump mechanisms that greatly agitate fuel or cause air bubbles to form in the fuel can generate high charge levels.

A1.7.3.2 People-Induced Charges — The actions of vehicle operators can cause them to develop a charge (e.g., sliding across a vehicle's seat). In addition, artificial materials used in some modern shoe bottoms tend to keep charges on a person rather than allowing them to pass onto ground readily. Given this charged state, a discharge is possible to whatever part of the vehicle or fuel dispensing equipment that person touches. No fuel system or fuel dispenser equipment design practice can adequately deal with this circumstance. However the following might prove useful:
a. Vehicle and fuel dispenser operators might be advised to either remain in contact with the dispenser throughout the refueling operation or to ground themselves to the vehicle at a point away from combustible air/fuel vapor mixtures before contacting the fuel dispenser nozzle.
b. Vehicle designs which include a filler door which covers the fuel filler inlet can provide a charge dissipation point if the filler door is not completely opened by a remote release mechanism.
c. Fuel system designs should prevent the build up of pressure inside the fuel tank. A pressurized fuel system can release a quantity of fuel vapor when the gas cap is unsealed. This could pose a concern if the vapor release is coincident with an electrostatic discharge from the vehicle operator.

A1.7.3.3 Filling Fuel Tanks that are not Part of the Vehicle — Occasionally, vehicles are used to transport personal fuel containers (i.e., "jerry cans"), power equipment, small motor vehicles or other devices that have fuel tanks that are completely separate from the transporting vehicle. When those containers or tanks are filled with fuel, they may be sitting inside the vehicle or on the bed of a pick-up truck. In many cases the surface on which these devices rest can be nonconductive (e.g., plastic bedliners in a pickup truck, carpeting inside a vehicle, protective plastic mats inside the trunk of a vehicle, etc.). Under some conditions (see 5.1), refueling these ungrounded fuel tanks can generate and build up enough charge that arc discharge can occur to the fuel dispenser nozzle or some other nearby ground path. Incidents have been documented where such an arc has ignited the fuel vapors present.

There is no adequate design practice for the vehicle or fuel dispensing equipment to address this situation. To help prevent this situation, warnings should be provided to vehicle operators to:

a. Remove the container, small vehicle or power equipment from the vehicle and place it on the ground for refueling.
b. Hold the dispenser nozzle in contact with the fuel inlet of the container, small vehicle or power equipment during refueling.

jerry cans mean previous points are meaningless. Does section apply only to metal cans?

A2.1 General Comments/Cautions

NOTE: **These same conditions can cause vehicles in use to experience electrostatic charge issues when none were observed on new parts or vehicles in a laboratory setting.**

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A3.0 Design Guides

NOTE: Little input has been received on this section.please make suggestions/improvements, etc.

A3.1.1 Fuel Velocity and Turbulence

A.3.1.1.1 Turbulent Flow –

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d.

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A3.1.1.2 Low Flow Rates –

$\times$ v $\times$ p

Number μ

(no dimensions)

Where:

d = diameter (cm)

v = fluid velocity (cm/sec)

p = fluid density (g/cm^3)

μ = fluid viscosity (Poise)

Note: Based on AAM survey data for 23 cities in 1006, gasoline viscosity at 60 deg. F average 0.0043 Poise, with a maximum of 0.0051 Poise.

Reynolds number values of 500 or less can be considered low enough so that electrostatic charging is not an issue. By comparison, turbulent flow has Reynolds number values of greater than 3000.

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A3.1.2 Arrangement of Components—The configuration of the elements of a fuel system can be important, particularly within the fuel delivery system

A3.1.2.1 Minimize sharp points or sheared edges such as, burrs, slivers, screws, etc. on exterior surfaces of the fuel system or on the vehicle in close proximity to the fuel system. Such features can provide a focused discharge path.

A3.1.2.2 Aspects pertaining to the fuel delivery system are:

a. A component that can accumulate charges should not be placed immediately following a charge separator
b. Place semi-conductive or conductive and bonded components immediately downstream of charge separators to provide for ~~charge dissipation~~a path to the vehicle ground.
c. After filtering, fuel should be allowed to reside in a component that is bonded and sufficiently conductive for enough time to allow for charge dissipation to occur

A3.1.3 Materials—

A3.1.4 Relaxation Time—

A3.1.5 Corrosion Protection—

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Sometimes it may be better to use a nonconductive part if it may be electrically isolated. What else should we add here? Should metal parts be allowed an exemption (read also section 4.3.1.C again)

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A3.2.2.4 Effect on Refueling Operation —

Large radius bend (> normal minimum)

1.5. Minimize the number and size of flow restrictions (e.g., fittings and connectors)
1.6. Place flow restrictions as far away from charge generators as possible
1.7. Internal surfaces should be smooth, if possible
1.8. If possible, avoid usage of 90 degree fittings, or angled fittings in the fuel distribution system, including connectors to fuel filters, fuel regulators, and engine fuel rails, as well as, the fuel tank module and inlets/outlets

2. Conductivity
   2.1. The portions of the tubing and connector that contact the liquid fuel should be ~~sufficiently~~ conductive (section 4.1, 5.2.1, and A1.2.2.3).
   2.2. Eliminate surface contaminants and roughness present on components
   2.3. All components are well bonded to a major ground plane of the vehicle
   2.4. Electrical continuity exists between components and between liquid fuel and ground
3. Some types of connectors may not provide a good bond between fuel line components. Simply making the connector case from a conductive material may not be sufficient. The O-rings and spacers inside could electrically isolate the components that are being connected. Testing of complete tube assemblies for electrical continuity is recommended.
4. For multi-layer tube constructions the innermost layer must be conductive and bonded to other conductive elements of the fuel system. If the outer layer is conductive (such as steel braid or a conductive elastomer covering), there may be no measured external voltage or field even though a large field might exist at the inner

layer (because the outer layer acts as a shield). Such an outer layer should also be bonded to the vehicle or the rest of the fuel system.

A3.2.4 Fuel Filter

A3.2.4.1 General Comments—During operation of the fuel delivery system, the fuel filter is the component that is the single greatest factor in the electrostatic charge situation.

a. Filter body can act as a charge accumulator as the fuel enters the unit.
b. If the filter housing is made of a sufficiently conductive material and is bonded to the vehicle, charge accumulation on the filter housing can be negligible.
c. The filter media causes charge separation as fuel flows through because it has a large surface area and numerous pores that are small in size. Note that this separation occurs independent of the material from which the filter housing is made and whether that housing is grounded.
d. The amount of charges generated during the filtering process will be approximately the same no matter what material is used for the filter housing.

A3.2.4.2 Design Factors

a. Filter media material and efficiency requirements have an effect. The most important aspects of this are the size of the pores in the filter element and the surface area of the element. If pore size can be increased and/or surface area can be decreased, electrostatic charging will be decreased.
b. Increasing surface area of media will tend to reduce localized charge separation.
c. Flow restrictions cause shear in the fluid, which causes charge separation.
d. Filter case should be bonded to the vehicle to reduce accumulation of charges.
e. The materials used in filter case should have sufficient level of conductivity so it can reduce the accumulation of charges (refer to section 4.1, 5.2.1, and A1.2.2.3 ~~xxxx~~).

A3.2.5 Fuel Rail

The fuel rail is the part of the fuel delivery system mounted on the engine that distributes fuel to and holds the fuel injectors. During fuel delivery system operation, the normally rail plays a minor role in electrostatic charge processes.

A3.2.5.2 Design Factors

a. As fuel enters, the velocity slows because inside dimensions are greater than the inside diameter of the fuel lines leading to the rail.
b. There is some turbulence in the flow pattern, so there could be some minor charge separation.
c. There should be an electrical bond between the rail and the engine. Special attention must be paid to metal fuel rails attached to non-metallic intake manifolds.
d. Residence time of the fuel is much longer than for an equivalent length of fuel line. This gives more time for any imbalance of charges to be reduced through recombining of unlike charges.

Because of these factors, the charge of the fuel leaving the rail is usually less than the charge in the fuel as it enters the rail. The design steps that would further help the situation with the fuel rail are essentially the same as those for the fuel lines and connections (see A3.2.3).

A3.2.6 Pressure Regulator

A3.2.6.1 This component is typically located at or near the fuel outlet end of the fuel rail in fuel recirculation systems. For mechanical returnless fuel delivery systems, the regulator can be located at either the outlet of the fuel filter or the fuel pump. In either design, the role that the unit plays in the electrostatic charge process during operation of the fuel delivery system is essentially the same. There can be some charge separation and transport; to a lesser degree, there can be some charge accumulation.

A3.2.6.2 Design Factors:

a. The degree of flow restrictions influences electrostatic charging
b. The pressure regulator body should be grounded
c. Conductive ~~or sufficiently conductive~~ materials should be used (refer to section 4.1, 5.2.1, and A1.2.2.3)

d. Location in the fuel system (if it is positioned immediately after the filter, there will be many more charges entering the unit than if it was located just after the fuel rail)

A3.2.7 Fuel Tank — The fuel tank plays an equal role in the electrostatic charge situation for both the fuel delivery and the refueling process. If electrostatic charges are present inside the tank in either situation, they occur because the fuel entering the tank had a charge on it. The tank does not transport the charges further, nor does it cause any further charge separation.
NOTE — Strong sloshing of fuel in a tank could result in some charge separation, but is considered negligible.

There are two actions that can take place to reduce the charges that may be accumulating in the tank:
a. Charges will recombine as the fuel sits in the tank,
b. Charges can dissipate through bonded connections to points the outside of the tank.

A3.2.7.1 Design Factors:
a. The tank system should provide an electrically conductive path between the contained fuel and the vehicle by using bonded, conductive components (pump, gauge, sending unit, etc.).
b. the body of the fuel tank does not need to be made of a sufficiently conductive material as long as the criteria of "a" are met.

A3.2.8 Fuel Filler Pipe Assembly

A3.2.8.1

A3.2.8.2