

SURFACE VEHICLE INFORMATION REPORT

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FUEL SYSTEM ELECTROSTATIC CHARGE

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- 1. Scope**—The purpose of this SAE Information Report is to provide a summary of the electrostatic charge phenomenon (as it relates to an automotive fuel system) and how that phenomenon could be handled if it develops. The "fuel system" that is the subject of this document is the group of components used during the operation of the vehicle (tank, filler neck, pump, filter, lines, connectors, etc.). Electrostatic charge that may arise during refueling is also included.

It is very important to note that this is a collection of ideas and generalities that are summarized from literature and presentations, inferred from some laboratory experimentation, and interpreted by the Electrostatics Subcommittee of the SAE Fuel Lines and Fittings Standards Committee. Some of the discussions are simplified. If more technical information is needed by users of this document, experts should be consulted or literature should be examined directly.

Any questions that arise concerning a specific fuel system should be handled by direct testing or other experimentation involving the system or individual components. This document may be useful for providing guidelines on how to proceed.

2. References

- 2.1 Applicable Documents**—The following publications form a part of this specification to the extent specified herein.

- 2.1.1 ASTM PUBLICATIONS—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM D 150—Test Methods for A-C Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials

ASTM D 991—Rubber Property - Volume Resistivity of Electrically Conductive and 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

- 2.2 Related Publications**—The following publications are provided for information purposes only and are not a required part of this document.

- 2.2.1 ASTM PUBLICATIONS—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM D 257-90—Standard Test Methods for D-C Resistance of Conductance of Insulating Materials (March 14, 1990)

ASTM D 4865-88—Standard Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems (November 17, 1988)

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2.2.2 OTHER PUBLICATIONS

Journal of Research Article (October-December, 1965) — "Electric Currents and Potentials Arising from the Flow of Charged Liquid Hydrocarbons Through Short Pipes"

DIN Specification (April, 1975) — "VDE Specifications for Electrical Tests on Insulating Materials; Evaluation of the Electrostatic Behavior"

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 and 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)

Co-ordinating Research Council — Electrostatic Discharge in the Fuel Systems of Gasoline Powered Vehicles in North America (Paper by Ron Tharby, November, 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)

National Fire Protection Association — Recommended Practice on Static Electricity (1988 Edition)

American Petroleum Institute, Recommended Practice 2003 — "Protection Against Ignitions Arising out of Static, Lightning and Stray Currents" (March, 1982)

January, 1988 issue of Plant/Operations Progress magazine — It's a collection of articles on all aspects of electrostatic charge concerns that can arise in handling of chemicals

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

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

2.3 Definitions

ABSOLUTE CHARGE SENSOR — A device for sampling a continuous flow process and calculating the volumetric charge density in the flow medium (e.g., gasoline).

ABSOLUTE HUMIDITY — The mass of water vapor per unit volume of air (grains/ft³).

ACCUMULATION — The process of electrically charging a body.

AMMETER — An instrument for measuring current in an electric circuit.

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CAPACITANCE—Capacitance is that property of a system of conductors and dielectrics which permits the storage of electrically separated charges when potential differences exist between the conductors. The capacitance of a body (c) is defined as the total electric charge (on the body) (q) divided by its electric potential (V) ($C=q/V$).

CHARGE—Quantity of unbalanced electricity on (or in) a body; i.e., an excess or deficiency of electrons, giving the body negative or positive electrification, respectively.

CHARGE DENSITY—The net electric charge per unit volume

CONDUCTANCE—Reciprocal of resistance. The unit of measure is the Siemens ($1/\Omega$).

CONDUCTION—Transmission of energy by a medium that does not involve movement of the medium itself. An example of this is the flow of electrons or ions in a material.

CONDUCTIVITY—Reciprocal of resistivity.

CURRENT—The rate of flow of electrical charge in a substance. Unit of measure is the ampere (A).

DIELECTRIC—A material (solid, liquid, or gas) that can withstand a steady electric field; an insulator. A perfect dielectric has zero conductivity.

DIELECTRIC BREAKDOWN—The passage of a large current through a normally nonconducting material in the presence of an intense electric field.

DIELECTRIC STRENGTH—The electric stress (volts/cm (or mm)) required to breakdown a dielectric.

DISCHARGE—The reduction of an imbalanced charge at a given point (usually to zero), by a sudden flow of current through a medium (usually to ground).

DISSIPATION—The process of reducing the amount of electrical charge on a body; also, the loss of electric energy as heat.

ELECTROMETER—An electrostatic instrument for measuring a potential difference or an electric charge.

ELECTROSTATIC CHARGE—Electric charge on the surface of a body. Causes a surrounding electrostatic field.

ELECTROSTATIC FORCE—The force that electrically charged bodies exert upon one another.

ELECTROSTATIC POTENTIAL—The electrostatic potential at any point is the potential difference between that point and an agreed-upon reference point, usually the point at infinity.

FARADAY CAGE—An apparatus for measuring electric charge. Consists of two conducting enclosures; an inner and an outer, insulated from each other. The grounded outer enclosure shields the inner from external fields; the object to be measured is placed within the inner enclosure.

FIELD STRENGTH METER—An instrument used for measuring the magnitude of an electric field.

FIELD STRENGTH—A vector quantity that represents the magnitude and direction of the force imposed on a stationary unit charge when placed in an electric field. Units: volts per meter, V/m.

GROUNDING—The intentional electrical connection of a component to earth, or to some other large conducting body; in this case, the vehicle body/frame.

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INSULATIVE—The characteristic of a material that describes its ability to resist electric current flows when a voltage is applied across the material.

INSULATOR—A dielectric material which does not conduct current.

OHM—The unit of electrical resistance (Ω); when 1 A of current flows through a 1 Ω resistance, 1 V of potential difference is produced.

RELATIVE HUMIDITY—The partial pressure of water vapor in the atmosphere as a percentage of the saturation water vapor pressure (at the same temperature).

RELAXATION—The exponential return of a system to electrical charge equilibrium. Characterized by a relaxation time constant.

RESISTANCE—The material property which causes dissipation of energy when an electric current flows through a substance (unit of measure is the ohm (Ω)). When 1 A of current flows through 1 Ω of resistance, 1 W of power is dissipated.

SEMICONDUCTIVE—Describes a material that exhibits "partial" conductivity (volume resistivity between 10^6 and 10^2 Ωm).

SHEAR RATE—The rate of deformation (of a fluid) tangent to an applied stress.

SIEMENS—The unit of electrical conductance; reciprocal of ohm (S).

STREAMING CURRENT—The flow of an electrically charged fluid constitutes an electrical current. Unit of measure is ampere (A).

SURFACE RESISTIVITY—The resistance between opposite sides of a unit square on the surface of a material.

VOLTAGE—The value of an electromotive force (or electric potential difference) expressed in volts (V).

VOLTMETER—An instrument for measuring electric potential differences.

VOLUME RESISTIVITY—The resistance measured across opposite faces of a 1 m cube of material. The units of measure are ohm-meters (Ωm).

3. Background Information

3.1 How Fuel System Components Contribute to the Electrostatic Charge Phenomenon

3.1.1 The development of an electrostatic charge in a fuel system can arise from the flow of fuel against and through the components that comprise a fuel system. Due to subtle electrical, fluid, and thermal forces, charges can become separated in the liquid and at the surfaces the liquid touches. Local velocity conditions can further separate those charges so that an electrically unbalanced condition develops. Each component of a fuel system is involved in this situation in one or more of the following four ways:

3.1.1.1 *Charge Separator*—Characteristics of the component and the dynamics of the interaction with the fuel cause separation of charges at or near interface surfaces. They can become separated "significantly," mainly by the action of the flowing fuel.

3.1.1.2 *Charge Transport*—Separated charge is moved from one part of the system to another primarily by the flowing fuel.

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3.1.1.3 Charge Accumulator—Separated charges accumulate in areas of flow transition, causing a charge imbalance. This imbalance continues to grow until the rate of dissipation equals the rate of accumulation or some limiting mechanism (such as electrical discharge) causes the level of charges to become balanced or at least reduced.

3.1.1.4 Charge Dissipation—Dissipation is the action of unbalanced charge being reduced through conduction to ground or by recombining with some other charge of the opposite sign.

3.1.2 How the primary components of the fuel system contribute to the electrostatic charge phenomenon (as described previously) is shown in Table 1.

TABLE 1—IMPACT OF PRIMARY FUEL SYSTEM COMPONENTS ON ELECTROSTATIC CHARGE

Type of Involvement in the Electrostatic Charge Phenomenon	Fuel Pump	Fuel Lines	Fuel Filter	Fuel Tank	Filler Neck
Charge Separation	Yes (Medium)	Yes (Small)	Yes (Very Large)	Yes (Small)	Yes (Small)
Charge Transport	Yes (Medium)	Yes (Large)	Yes (Medium)	—	Yes (Medium)
Charge Accumulation	—	Yes (Medium)	Yes (Large)	Yes (Medium)	Yes (Small)
Charge Decay or Dissipation	—	Yes (Small)	Yes (Large)	Yes (Large)	Yes (Small)

3.2 Mechanisms of Charge Reduction—If a charge builds up in a fuel system, there are six separate mechanisms by which that charge can be reduced:

- Bulk conduction through components (to a ground source)
- Dissipation through the fuel (to a ground source)
- Surface dissipation along a component or along the interface with the liquid (to a ground source)
- Ionization of air (corona effect and/or brush discharge)

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

- Recombining of charges in the liquid
- Spark discharge (dielectric breakdown of a material)

3.3 Spark Discharge—Of these mechanisms of charge reduction, the one that is of primary concern for a fuel system is the spark discharge. It can result in a hole developing in the fuel system or, under some circumstances, even ignite the air/fuel mixture. The following are pertinent comments concerning this:

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3.3.1 Spark discharge occurs when the electric field generated by a certain charge level exceeds the dielectric or breakdown strength of the area where it is located. Discharges generally occur in the following ways:

- a. Directly to ground (through air)
- b. From one part of a component to another (through air)
- c. Through walls of a component (by dielectric breakdown)

3.3.2 Electrical or electrostatic stress which occurs over an extended period of time may measurably lower the breakdown strength of the material used in a fuel system component.

3.3.3 If a dielectric breakdown spark discharge occurs, the energy released in the discharge can melt, degrade, or burn the material in the discharge path and can produce a pinhole. This path can also be marked by a carbon track. Once dielectric breakdown occurs, the insulative properties of material 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 this case the hole grows from the inside out.

3.3.4 Sparking can also occur in the air from the surface of the material or component to some other nearby object. This can cause the surface to decompose. Many successive sparks from the outside lead to erosion of the material; eventually a pinhole could result. If a hole develops in this manner, it grows from the outside in.

4. The Factors That Cause It

4.1 General Comments

4.1.1 Development of electrostatic charge can occur in every fuel system; no design configuration can be made that will completely eliminate the occurrence of charge separation. It's important to note that this does not mean that the charges will build up to a level where a spark discharge could occur.

4.1.2 There are four situations for a fuel system where electrostatic charge build-up will not be a concern:

- a. If fuel is sufficiently conductive (> 1000 pico Siemens/m).
- b. If fuel has zero velocity.
- c. If the system is constructed solely of highly conductive materials with unbroken electrical continuity and adequate connection to ground. (However, selection of such materials or components is not always possible because of other requirements that a fuel system must meet, such as necessary flexibility of some components, corrosion resistance, internal chemical resistance, cost, etc.)
- d. Surface area of fuel is extremely low.

4.1.3 If an electrostatic charge situation develops, it is a systems phenomenon. No single design factor is the whole cause, so no single design factor can be the whole solution.

4.1.4 Electrostatic charge can develop to levels of concern when charges are accumulated faster than they are dissipated.

4.1.5 Electrostatic charge is a very focused phenomenon:

- a. If any significant charge levels develop in a fuel system, they are most probable to occur on the feed side. Charges reaching "levels of concern" in the return side, fuel tank, or filler neck are very rare. (Each system design is unique, however, and should be assessed individually.)

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- b. Significant charges do not occur in the vapor, emissions, or vacuum systems of gasoline vehicles because flows are negligible.

4.1.6 The returnless or demand fuel systems that are being developed will probably develop less electrostatic charge because the flow rate is low most of the time. However, these designs have not been evaluated fully.

4.2 Uncontrollable Factors

4.2.1 FUEL

4.2.1.1 The following fuel characteristics usually have the greatest effect on the electrostatic charge situation in a fuel system:

- a. Temperature of the fuel
- b. Chemistry¹
- c. Conductivity¹
- d. Viscosity¹
- e. Ingredients and additives¹
- f. Impurities and contaminants¹ (these tend to be charge carriers)
- g. Moisture content, two phase flow

4.2.1.2 Fuel is a factor that is difficult to control. Very small amounts of impurities, additives, and even moisture can have a large effect on charging influences of a fuel. These amounts can be in the levels of "parts-per-billion."

4.2.1.3 The use of antistatic additives in the fuel could also improve the fuel's ability to allow the charges to recombine. Use of these antistatic additives probably could not be relied upon as a "solution" for resolving electrostatic charge concerns in automotive fuel systems. The primary reason is that 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. Also, such additives can plate out on surfaces so their effect changes over time. Moisture content of the fuel can also affect the performance of the additives. Finally, trace quantities of an antistatic agent can actually cause fuel to develop more charge separation.

4.2.1.4 The fuel that results in an electrostatic charge problem for one specific situation will not necessarily cause the same problems in another specific situation. (This means there is no known "worst case" fuel for every possible condition or fuel system design. However, a fuel that is chargeable with a given filter and has low conductivity is a good starting point for test development.)

4.2.1.5 A very important characteristic of a fuel (that determines its effect on electrostatic charge build-up) is relaxation time. (That is a measure of how quickly charges recombine after they have separated.) Highly conductive fuels have very low relaxation times (charges recombine very quickly).

¹ These characteristics are interrelated.

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4.2.2 ENVIRONMENT—Both humidity and temperature must be controlled or monitored when measuring the electrostatic condition of a fuel system. When considering the environmental factors that can affect charge separation, absolute humidity is the most important. A lower absolute humidity environment (such as typically experienced at lower temperatures) is more likely to cause dielectric breakdowns by allowing a higher charge accumulation before breakdown. Humidity of the environment primarily affects the exterior of the fuel system. Fuel and material conductivity decrease as temperature goes down and fuel viscosity goes up which all contribute to higher charge probability at low temperatures.

4.3 Factors That Are Design Dependent

4.3.1 FUEL FILTER

4.3.1.1 The fuel filter is the component that tends to have the greatest effect on electrostatic charge. The principal aspect is charge separation that arises during the filtration process due primarily to the small pore size and the very large surface of the filter media in contact with the fuel. The filter body can also act as a charge accumulator (if the body is constructed of a nonconductive material or is not grounded).

4.3.1.2 Key aspects are:

- a. Filter media material and efficiency requirements (most important aspects of this are the size of the pores or holes in the filter element and the surface area of the element)
- b. Flow restrictions
- c. How well the filter case is grounded
- d. Conductivity level of the materials used in each filter component

4.3.1.3 If the filter casing is made of a material that is sufficiently conductive and it is well-grounded, charge accumulation can be negligible. The charge separation of the filtering process will still be a significant factor.

4.3.2 FUEL PUMP

4.3.2.1 The fuel pump is the component in the fuel system whose overall effect on the electrostatic charge situation is second to the filter. It is also the source of the fluid energy which drives the charge separation process.

4.3.2.2 Key aspects are:

- a. Shear rate (primarily)
- b. Pump design
- c. How well pump is grounded

4.3.3 TURBULENCE—Generally, increased fluid turbulence can result in increased levels of charge separation.

4.3.4 VELOCITY—The higher the velocity of the fuel, generally, the greater will be the rate of charge developed for a given fuel.

4.3.5 FUEL LINES AND CONNECTORS

4.3.5.1 Fuels lines and connectors also contribute to charge; the effect is usually less than that of the pump.

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4.3.5.2 Key aspects are:

- a. Level of conductivity of the tubing and the connector body materials
- b. Surface contaminants
- c. Number, location, and degree of bends
- d. Internal diameter and its resultant effect on velocity
- e. Number and location of restrictions and orifices
- f. Internal smoothness
- g. How well it's grounded (both the attachment to ground through fasteners and continuity through connectors to ground)

4.3.5.3 General Comments

- a. More turbulence in flow of the fluid through the lines or connectors will tend to develop a higher level of charges.
- b. If a multilayer tubing has a conductive layer, it **must** be the innermost layer (and it must be grounded).

4.3.6 FUEL TANK—A small amount of charge separation may develop through sloshing of the fuel in the tank. Charges can accumulate in the tank if they are transported in from other areas of the fuel system or are introduced through the filler neck during the fill process. Due to the long residence time of the fuel in the tank, however, charges that do separate or accumulate usually will combine or dissipate well before they develop to any significant level.

4.3.7 FUEL FILLER NECK

4.3.7.1 Since filler necks tend to have a tubular shape, most of the comments that relate to lines and connectors (4.3.5) also pertain to this part of the fuel system.

4.3.7.2 If refueling occurs at a high rate of flow or causes a significant amount of turbulence, then charge separation would be much more significant. Besides refueling rate, turbulence can also be caused by differing geometrics of the neck itself.

4.3.7.3 Another area to consider is the possible usage of a refueling nozzle that has an accumulated charge or is ungrounded. This situation does not cause charge separation, accumulation, etc., within the fuel system but can be an electrostatic condition that must be anticipated in the design of the filler neck.

4.3.8 GROUNDING—Providing a dissipation path for all components is critical. Charges need a clear path to ground if they are to adequately dissipate. A highly conductive component can behave like one plate of a capacitor if grounding is inadequate. Any capacitor-like element can accumulate charges and can contribute significantly to a possible discharge situation.

4.3.9 CONFIGURATION—Arrangement of components can be important. Generally, excessive charge build-up is most likely to occur on the feed side of a fuel system. This is because most components that are the primary charge separators and accumulators are located there. Also, if a charge accumulator is placed **immediately** after a charge separator, the resulting electrostatic charge situation will usually tend to be worse.

5. Testing and Measurements

5.1 General Comments

5.1.1 Small, seemingly inconsequential variations in test method (e.g., surface conditions, fuel, environment, etc.), can cause wide differences in results. All experimental conditions must be controlled very carefully.

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5.1.2 Fuel tends to be one of the largest sources of variability (chemistry, ingredients, impurities, etc.). Fuel that is used for the testing should be carefully selected. Subsequent fuels used should be compared to that original test fuel for a given fuel system.

5.1.3 No tests yet exist that can predict a specific fuel system will always be free of excessive electrostatic charge build-up under all possible conditions.

5.1.4 While several tests exist that can evaluate the electrostatic charge development for a specific fuel system, they have not demonstrated a correlation with all possible normal vehicle operating conditions.

5.2 Measuring Current and Charges

5.2.1 It is relatively simple to measure an electrostatic parameter, but very difficult to correctly interpret what the value of the parameter implies about the electrostatic condition of the system.

5.2.2 The method used to measure electrostatic charge and the associated voltage affects the values obtained.

5.2.3 In order to accurately compare one charge level or amount of current at a specific location to another then all test conditions and surrounding environmental aspects must be identical.

NOTE—Very subtle differences in conditions can have a significant difference in results obtained.

5.2.4 ASTM D 4470 outlines the usual methods for measuring charge. The two devices most commonly used are an electrometer and a field strength meter (or field meter).

5.2.4.1 *Electrometer*—The electrometer can be used as a sensitive ammeter to measure current. An example of an application would be to insert the electrometer between a steel fuel filter body and the vehicle ground. The electrometer would then measure the difference between the current flowing into and out of the fuel filter (that is flowing to/from ground).

NOTE—A charge accumulation inside the filter would affect this result.

An electrometer can also be used to measure charge by operating it in the voltmeter mode. Measurements are taken in conjunction with a Faraday Cup or cage. By using the relationship $Q=CV$, knowing the capacitance (C), and measuring the voltage (V), the charge (Q) can be calculated. This is covered in detail in ASTM D 4470.

5.2.4.2 *Field Meter*—Field meter must be calibrated for the geometry of the component charge situation which is being measured. Field meters are designed for use over a flat plate. It can be used, like the electrometer, in a specific system location for component comparison to a benchmark or the resulting effect of various charge separators or accumulators on the benchmark.

A field meter indicates only an imbalance of charge. A high level of charge separation can be present and the field meter could indicate zero.

To measure a field, the head of the field meter must be located in it; being in the field affects the value measured by the meter.

5.2.5 An absolute charge sensor (developed by Massachusetts Institute of Technology) is one of the laboratory instruments to measure charge density. This can be used for comparisons at various locations around a fuel system or at a specific location when comparing two fuel systems.

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5.3 Types of Tests**5.3.1 FOR MATERIALS**

5.3.1.1 When concerns about electrostatic charges arise, the first reaction, many times, is to choose materials that have high conductivity characteristics (low resistivity levels). It may not always be possible to utilize such materials, so details of testing the resistivity or conductivity levels could be important.

5.3.1.2 Surface and volume resistivity are easily measured and frequently are used to infer the electrostatic behavior of a material. Surface resistivity is typically measured in Ω per opposite sides of a square on the surface; volume resistivity is typically measured in Ω meters or Ω centimeters. Resistivity values are the reciprocal of conductivity values. Conductivity is measured in Siemens/meter. (1 Siemens meter is equivalent $1/[\Omega \text{ meters}]$ or $10^{-2}/[\Omega \text{ centimeters}]$.) Resistivity levels are useful for inferring electrostatic behavior of a material when the material is somewhat conductive ($10^8 \Omega\text{cm}$ or less) or highly insulative ($10^{11} \Omega\text{cm}$ or higher).

5.3.1.3 The range of volume resistivity levels between $10^8 \Omega\text{cm}$ and $10^{11} \Omega\text{cm}$ represent a transition in the electrostatic performance of a material (even though at these levels, a material would normally be considered electrically nonconductive). The transition refers to the difference between "always behaving electrostatically like a conductor" and "always behaving like an insulator." For materials that exhibit that transitional behavior, more information is needed than can be implied from the resistivity level alone. Other tests can provide important information about the electrostatic performance of such materials (when resistivity levels fall in this transitional phase).

For example:

- a. Rate of charge dissipation for a given charge level (half life measurement can be useful for transition materials, since it is generally independent of charge level).
- b. Ability to accept a charge can also be determined by measuring level of charge at steady-state and time to achieve that level. This would be for a given amount of electrical current flowing into or onto the material.

5.3.1.4 For all measurements of electrostatic material characteristics, many factors must be carefully and consistently controlled:

- a. Geometry of specimens being tested
- b. Humidity
- c. Temperature
- d. Surface condition and contamination
- e. Frequency and method of grounding
- g. Many details of how charges or resistances are measured

5.3.2 FOR FUELS

5.3.2.1 Volume resistivity and/or level of conductivity.

5.3.2.2 Rate of charge dissipation.

5.3.2.3 Level of build-up of charge (charging tendency).

5.3.2.4 Comparing one candidate fuel to another for a given set of conditions.

5.3.2.5 Measuring characteristics versus time at normal and low temperatures.

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5.3.3 FOR COMPONENTS

5.3.3.1 Surface or volume resistivity.

5.3.3.2 Level of build-up of charge.

5.3.3.3 Rate of charge dissipation.

5.3.3.4 Comparing one candidate to another for a given set of conditions.

5.3.3.5 Testing to failure (does discharge occur for a given set of conditions?).

5.3.4 FOR SYSTEMS

5.3.4.1 Test until an electrostatically induced leak occurs during recirculation (destructive).

5.3.4.2 Comparing voltage or field levels for a given set of conditions.

5.3.4.3 Time to dissipate a given charge level.

5.3.4.4 When a recirculation technique is used for testing a system, many times a liquid such as hydraulic fluid is used. This is because it has a greater tendency to result in charge separation.

5.3.4.5 Usually done on-vehicle (engine running, but vehicle static); environment controlled to conditions known to favor charge generation.

5.3.5 AUTO INDUSTRY PROCEDURES

5.3.5.1 General Motors has developed a destructive bench test to evaluate lines, filters, and connectors for fuel leaks induced by electrostatic discharge. Components are evaluated by measuring the time to leak fluid at a puncture under a specific set of conditions. General Motors has established a "minimum time to leak" acceptance criteria.

5.3.5.2 Ford has developed a charge measurement procedure. Comparisons are made between two components that are inserted in a given recirculation system. Voltage level of the first component is compared to the voltage level of second component when they are interchanged. Ford has established a minimum percent of breakdown voltage acceptance criteria.

6. *Mitigation Techniques*

6.1 General Comments

6.1.1 Electrostatic discharge is a systems phenomenon. No single design factor is the whole cause; therefore, no single design step can be the whole solution.

NOTE—Using a highly conductive fuel or near zero velocity for the fuel would tend to eliminate electrostatic charge build-up. Since neither of these is usually practical, other techniques must be followed.

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6.1.2 The direct approach when confronted with a concern over electrostatic charge is to increase conductivity of the components and to provide a good path to the ground plane. It is important to note that increasing conductivity (or lowering resistivity) may not always be possible. There are many other factors that must be considered. Increasing conductivity may cause other "properties" to change to an unacceptable level. Examples of other factors that have to be considered are:

- a. Degree of flexibility
- b. Resistance to impact
- c. Long-term chemical resistance
- d. Cost

6.1.3 Even though many factors are involved, some have a far greater effect on reducing electrostatic charge than others.

6.1.4 Generally, system design steps must be taken to reduce the rate of charge separation, accumulation, and to increase the rate of charge dissipation. To minimize concern for electrostatic charge, the rate of dissipation must be greater than the rate of accumulation.

6.1.5 Increasing conductivity of a particular component and decreasing its tendency to develop a charge are two very different steps that can be taken.

6.2 Steps That Relate to the Overall System

6.2.1 Complete grounding of all conductive components is essential. This is especially true when the part utilizes metal or other conductive materials. Particular attention must be paid to the interface between a component and the ground path. That interface must be such that there is good continuity to the ground. Attachment to a conductive element that is in turn attached to ground **does not** mean it is adequately grounded. The characteristics of the interface are very important. Care must be taken to insure there is a good electrical path **across** the interface. (An example of this situation would be painted metal parts.)

6.2.2 Arrangement of components can be helpful.

- a. A component that can accumulate charges should not be placed immediately following a charge separator.
- b. It is desirable to place semiconductive or conductive and well-grounded components immediately downstream of charge separators to improve system dissipation.

6.2.3 For all components in the fuel system, efforts should be taken to eliminate any sharp points that may exist on any exterior surface.

6.3 Steps That Relate to the Fuel

6.3.1 Decreasing velocity of fuel flow can help.

6.3.2 Reducing turbulence of the fuel flow can help.

6.3.3 Increase the time that fuel resides in the grounded conductive portion of the system (slower rate of throughput gives more chances for separated charges to recombine).

6.3.4 Increasing conductivity of fuel can help (to a level of conductivity greater than 1000 pico Siemens/meter).

NOTE—If the fuel is highly nonconductive to start (<50 pico Siemens/meter), then increasing conductivity would initially tend to result in more charge separation.