

Technical White Paper

Electrostatic Charge Generation - In Hydraulic and Lubrication Systems

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Electrostatic charge generation occurs in fluid systems as a result of friction between the fluid and system components. The magnitude of charge depends on many interrelated factors, including the environment. Charges can occur during filtration of hydraulic and lubricating fluids as well as diesel and gasoline fuels. This effect manifests itself in several ways, the most obvious being an audible noise (clicking sound) as discharge of electrostatic charge accumulation causes sparking internally within the system. Less apparent effects involve migration of the electrical charge downstream of the filter when the charge dissipates by discharging itself to a grounded surface.

This article discusses the mechanisms of electrostatic charge generation, and the factors that influence both the generation and dissipation of the charge.

Electrostatic Charge Generation in Liquid Systems

Electrostatic charge is generated in a number of ways whenever there is friction between two bodies moving relative to one another. Charge generation occurs in liquid systems on the molecular level at the interface of any two unlike materials, so a static charge will be generated in any moving fluid, with positive or negative charges moving from the fluid onto the bounding surface. The causes of electrostatic charging include the following examples:

- Friction caused by fluid flowing in pipes
- High fluid velocities
- Fluids flowing in ungrounded pipes and hoses
- Passage of fluids through filter elements or other microporous structures

- Generated by turbulence in the liquids and by pumping elements, especially centrifugal pumps
- Fluid discharging on to the free surface of the reservoir
- When free air is present in the liquid, for example, in bearing and paper machine return lines
- Imparted into the liquid when component surfaces sliding is relative to one another

Fluid acquires a charge when it flows through a pipe or microporous structure, and when this charge is carried downstream, it's called a streaming current (Figure 1).

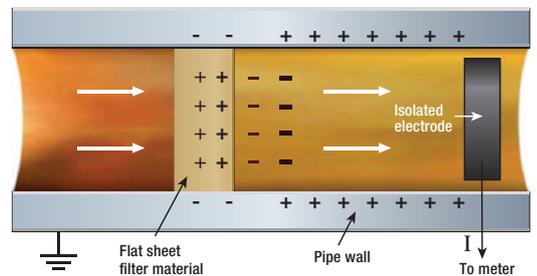


Figure 1.
Streaming Current

In pipeline flow, the streaming current will be discharged back to the pipe walls, reservoir or component surfaces, and the discharge rate is controlled by the characteristics of the fluid and its additives. This charge relaxation is described by the equations below:

$$Q_t = Q_0 e^{\left(\frac{-t}{\tau}\right)} \dots (1)$$

$$\tau = \frac{\epsilon \epsilon_0}{K} \times 10^{12} \dots (2)$$

where:

Q_t = charge at time t

Q_0 = initial charge

t = charge relaxation time constant (representing 37 percent charge decay)

E = dielectric constant of liquid (approximately 2 for oils)

E_0 = absolute dielectric constant of a vacuum
(8.854×10^{-12} F/m)

K = fluid rest conductivity (pS/m)

If the component walls are conductive, then a charge will be induced on the walls, which is of opposite polarity to the fluid. If the exterior surface is grounded, the net charge will be zero. If not, the charge will accumulate to eventually discharge. This will generate an electrostatic discharge where the charge discharges to a surface at lower voltage. In doing so, it can generate a high-energy spark. If the discharge occurs in air, the results can be both spectacular and potentially harmful (Figure 2).

Electrostatic discharge usually manifests itself as a clicking sound as charge repeatedly increases and discharges to surfaces of lower voltage (usually earth or ground) through sparking. The clicking frequency depends on the charging rate. Clearly, if the discharge occurs in a flammable atmosphere the effect can be serious, but these instances are rare. A discharge within the system is usually short-lived and extinguished by the hydraulic fluid. This can result in etching of the discharged surface, perhaps removing microscopic particles and leaving carbon deposits on the surface. There is also evidence that localized discharge can result from lubricated surfaces, especially in geared and bearing systems with a high air content. This can contribute to pitting of surfaces.

Charging in Hydrocarbon Filtration

Many investigators have studied electrostatic charge generation during filtration of liquid hydrocarbons. The charge generated may be either positive or negative, depending on the fixed charge of the filter material and the fluid used. Due to the relatively low conductivity of hydrocarbon liquids, these charges are carried downstream and accumulate without immediate discharge. The amount of charge generated by the flow of a hydrocarbon liquid and filtration is related to several fluid and filter properties. Charge generation typically strengthens with increasing flow, reducing fluid conductivity, with certain additive packages and with increasing viscosity. Charge accumulation increases with lower fluid conductivity, lower temperatures and higher viscosities. In the filter housing, the charge of the filter will be opposite in sign to that of the fluid, and the charges induced on the system will be opposite accordingly. The charge on the fluid will be transmitted downstream, and if enough charge is accumulated, the fluid can discharge to a conductive part of the filtration system that is potentially lower in magnitude, therefore damaging that part of the system. The extent of damage depends on the material involved.

If the filter is made of nonconductive material, it will acquire a charge when the fluid charges. The charge will not be able to dissipate or relax into the filtration system due to the high resistivity of the material. The filter will act as a capacitor and charge until the voltage is great enough to overcome the gap and discharge to a lower potential. If the filter is charged with a high enough voltage, it can discharge to the metal parts of the filter assembly housing, causing surface damage to the housing, burn marks and other damage to the filter element. A clicking or rattling sound in the filter housing caused by sparking indicates this cycle of charging and discharging.

In many cases, the filtration system, including the piping, reservoir and filter housing is grounded to alleviate the dangers of static charge buildup. Using a grounded system prevents the sparking of the system to nearby conductors; however, grounding the system will not prevent the charging of the filter material or fluid, nor will it accelerate the process of discharge.

Various attempts have been made to alleviate the potential of static charge accumulation in filtration systems, namely:

- Use an antistatic additive. Such additives will increase the fluid conductivity, thereby accelerating the rate of charge relaxation. Antistatic additives have been successfully used for a long time in fuel systems but have not been approved by oil manufacturers for use in hydraulic and lube systems. Additives on the market are intended for fuel systems.
- Reduce the charge exiting the filter by adding a conductive mesh downstream of the filter material which discharges some of the filter material's charge. However, not all of the fluid's charge is discharged because the mesh opening cannot be too small or it will restrict the flow.
- Reduce the flow density in the filter material by increasing the filter size. This will reduce the charge generated, as it is a function of flow density, and is perhaps the easiest of these options. However, it is not practical in all cases.
- Increase the time for the charge to decay. This will necessitate an increase in the time between successive charge generators by additional piping or increase the overall system time constant using an extra reservoir. This is an effective but costly solution.

Influence of Fluid Conductivity

As in the discussion regarding charge decay, it is noted that the decay time depends mostly on the conductivity of the fluid. Industrial lube oils are usually highly refined oils with a low concentration of additives, and as a result, generally have low conductivities. Hydraulic oils, on the other hand, traditionally have a high conductivity due to the use of metallic-based additives like zinc dialkyldithiophosphate (ZDDP), so that charge carried by the oil is generally dissipated as it passes around the system. The accumulated charge generally remains at a level where discharge is not experienced.

Environmental concerns have stimulated developments in both oils and filters. The concern about oil leakage has resulted in the increased use of synthetic oils and those having nonmetallic antiwear additives, usually based upon sulfur-phosphorous chemistry. These oils can have low conductivities, with some lower than insulating oils used in transformers and switch gears as seen in Table 1. The lower conductivity means that the charge generated may not be dissipated sufficiently, increasing the accumulated charge level and hence the likelihood of discharge.

Oil Type	K (pS/m)	Oil Type	K (pS/m)
Lube Oils		Hydraulic Oils	
Steam turbine	13	Aircraft (MIL-PRF-5606)	29
Gas turbine PAO	1,200	Industrial phosphate ester	>2,000
Gas turbine diester	1,500	Aircraft phosphate ester	>2,000
SAE 10W 40	>2,000	Industrial (Z-P based)	250
Transmission	>2,000	Synthetic	9
Paper machine (Z-P based)	350	Aircraft PAO	70
Paper machine (S-P based)	10		
Others		Others	
Cooling (silicate ester)	1,500	Insulating	12

Table 1. Examples of Conductivity of Oils at 23°C.

As a comparison, for aviation fuels, ASTM D4865 provides recommended limits on conductivity to prevent any chance of spark ignition. As an example, some military specifications require a fuel conductivity of 100 to 700 pS/m.

Filter elements are being made so that they are more easily disposed of by crushing and incineration and without the need for metal streaming, as the supporting core/shroud is contained within the housing and not the element. This has meant an increased use of polymers in filters and can result in a higher accumulated charge. The combination of lower conductivity and higher accumulated charge has resulted in an increase in static discharge, namely a clicking noise as the charge discharges to the metal surfaces downstream of the filtration medium and burn marks on the plastic end caps and downstream polymeric drainage mesh.

It was the increased static discharge activity that prompted Pall Corporation to investigate the subject and conduct research on filter materials that would result in a lower charge.

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