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Electrostatic Filtration

How Saturn Quadrupled Its Hydraulic Oil Life

by Mickey Jackson

My vantage point: It has been my privilege to serve as a consultant to Saturn Corporation on its use of hydraulic fluids in injection-molding machines since 1989. In an effort to solve a lacquer and varnish build-up problem, we began evaluation work in 1994 with several manufacturers of electrostatic oil cleaners; one of the manufacturers being Kleentek, a subsidiary of United Air Specialists (www.uasinc.com).

Our position has always been one of sharing information. We do not have the knowledge or skills to prove or disprove the information we have read in technical papers, but we can relate to what we have seen in our equipment and the results that we have been able to achieve. It is our hope that by sharing information, corporations with the needed resources and research capabilities can expand on the information we have developed and take it to another level. If the technical conclusions we have arrived at are confirmed to be true, then there is unlimited potential for solving production problems related to hydraulic failures and thousands of dollars to be saved from lost production.

Saturn's Injection-Molding Experience

At Saturn, electrostatically removing insoluble sediment 24-by-7 has improved hydraulic performance and extended oil life from 6,000 to a range of 22,000 to 25,000 hours between changes.

The car manufacturer uses 39 large plastic injection-molding machines to produce large exterior panels, fenders, doors, hoods, and a variety of interior automobile components. Combined, the molding machines have a total hydraulic oil reservoir capacity of approximately 40,162 gallons. Originally, 24 UBE injection-molding machines had one micron absolute mechanical filters, and 13 UBE machines had three micron absolute filters. Saturn later purchased two HPM injection-molding machines that were set up on three micron absolute filters. At that time, we used an oil analysis program that measured particulates that were reported with an ISO cleanliness code (particle count) to determine fluid cleanliness. We maintained a 14/12 or lower on the five and 15 micron ISO cleanliness code.

After approximately 6,000 hours on the oil, we experienced varnish, lacquer build-up, sticking valves, filter plugging, and increased filter change frequency. We found that the traditional industry oil analysis tests did not reflect fluid serviceability.

To understand why we were getting lacquer and varnish build-up at 6,000 hours, we sent hydraulic oil samples from many of our machines to the Mobil Oil Technical Services Laboratory in Princeton, N.J. The findings indicated that the hydraulic oils in the injection-molding machines were in an unsatisfactory condition and that insoluble oxidation and nitration compounds were causing the lacquer deposits. The test samples repeatedly reported ratings of "7" and "8" on the Ultra Centrifuge Rating (see "Hydraulic Fluid Serviceability Tests" below).

At the same time, we also sent oil samples from the same machines, taken on the same day, to the industrial used oil analysis laboratory used by the company. This report indicated that the oil was clean and in a satisfactory condition, a complete contradiction to the oil analysis sent to the Mobil Technical Services Laboratory that determined the oil unsatisfactory due to the "8" Ultra Centrifuge Rating.

Based on our experience with these two tests, we concluded the following:

- ICP tests run on metals reflect the total metals, which include both solubles and insolubles.
- Hydraulic fluids with high insoluble sediment contaminants are not serviceable, will cause system-related problems, and are harmful to the system.
- Hydraulic fluids with low insolubles are serviceable and do not cause oil-related problems in the system.
- Insoluble sediment contaminants are the source of most oil-related problems in modern hydraulic systems.
- The problems we were experiencing were primarily caused by the chemical breakdown of the hydraulic fluid and additive degradation, not from intrusion of particulates.

We also learned that new, unused oil has a neutral charge. As the oil is worked under time, temperature, and pressure, insoluble sediment is caused by a chemical breakdown of the additive package causing small numbers of the oil molecules to become oxidized. These oxidized oil molecules are polar and begin to bond together causing the oil molecule to become longer and gain molecular weight. Because they are polar, they will eventually bond to the system's metal surfaces. When the coating of the polymerized oil molecules is thick enough, the brown varnish stain appears.

Based on this understanding and our awareness that electrostatic oil cleaners are capable of removing insoluble contaminants and improving hydraulic system performance, we felt it important to conduct an exhaustive benchmark study.

Electrostatic Benchmark Study

A detailed benchmark study, using several manufacturers of electrostatic oil cleaners was conducted from Jan. 11, 1994 to Nov. 23, 1994. Based on the results of this study, we chose to implement a system of electrostatic oil cleaners. We found that by using this system, insoluble polar contaminants could be removed from the hydraulic systems as they were generated. Specifically, we learned that electrostatic oil cleaners are very effective in removing insoluble contaminants, and that if insoluble contaminants are kept at low levels, varnish and tars will not form on the metal surfaces in the system.

Specific conclusions from the study are as follows:

- Insoluble sediment is detrimental to hydraulic fluid serviceability.
 - Oil molecules are nonpolar and will not adhere to metal surfaces.
 - Additive packages in new oil are soluble. New oil has a neutral charge.
 - As oil is worked under time, temperature, and pressure, insoluble sediment is produced by a chemical breakdown of the oil molecule and degradation of the additive package, causing small numbers of the oil molecules to become oxidized. The oxidized oil molecules are polar and begin to bond together causing the oil molecule to become longer and gain molecular weight. Eventually they will bond to the systems metal surfaces. When the coating of the polymerized oil molecules is thick enough, the brown varnish stain appears.
- Polymerized oil oxidation products with molecular weights greater than 500

are insoluble in oil.

- Insoluble sediment will vary with temperature.
- Insoluble sediment will not be picked up on a particle count. There is no correlation between insoluble sediment and particle count. There are three types of contaminants regardless of particle size — positive, negative, and neutral.
- Insoluble sediment cannot be removed with mechanical filters.
- Mechanical filters create a pressure differential caused by friction. Static electricity is generated by friction and accumulated static electricity is discharged with a spark discharge, which results in degradation of the oil.
- There is a strong correlation between the Mobil Ultra Centrifuge (UC) rating and the Kleentek Colorimetric tests to measure insoluble sediment.

Based on these conclusions, we determined that using electrostatic oil cleaners makes it possible to remove and lower insoluble contaminants in the fluid. We observed fluids in machines with high Ultra Centrifuge ratings lowered to a rating of "1" and fluids with a high Kleentek Colormetric test rating and a dark colored patch being reduced to a low rating and a very white patch. From these observations, we determined that electrostatic oil cleaners would remove insoluble contaminants from the hydraulic fluid. Thus, we consider hydraulic fluids that test low for insoluble sediment (i.e., have a low Ultra Centrifuge Rating and/or a low Colormetric test rating) to be clean.

Using these conclusions, Saturn decided to purchase 42 Kleentek electrostatic oil cleaners. An electrostatic oil cleaner was installed on each of Saturn's 39 injection-molding machines, leaving three as spares. From the benchmark study, we found that industry-standard oil analysis tests use ISO particle counts to determine fluid cleanliness, and that the industry does not understand the effects that insoluble sediment contaminants have on hydraulic systems (i.e., A particle count will not pick up insolubles). Based on our belief that insoluble sediment is the main issue, we have been able to extend the service life of the hydraulic oil in Saturn's injection-molding machine systems with electrostatic oil cleaners from 6,000 hours to a range of 22,000 to 25,000 hours between oil changes. The electrostatic oil cleaners operate as a kidney loop on each machine. They run 24 hours a day and continue to clean the oil in the hydraulic system even when the injection-molding machines are not in operation.

Ongoing Experience

As part of our ongoing experience with Kleentek electrostatic oil cleaners since 1995, we have found hydraulic oil formulation differences. Some hydraulic oils have more stable additive packages than others. The ExxonMobil DTE series oils we use (DTE 25 and DTE Excel 46), have a very stable additive package. Both oils are difficult to clean with electrostatic oil cleaners, but since the Kleentek system design is 100 percent electrostatic (not electrostatic in support of a mechanical filter system), it recognizes and gathers all three types of insoluble particle contaminants — positive, negative, and neutral. Some systems only recognize positive and negatively charged particles. Going forward, we believe manufacturers would be wise to develop oils that better support electrostatic oil cleaners.

Throughout, we have continued to work with ExxonMobil to develop used oil analysis tests to determine hydraulic fluid serviceability of the oil used in Saturn's injection-molding machines. We sample each machine monthly using the ExxonMobil ServoGard analysis (which will be replaced in the near future by the Signum Precision Hydraulic Analysis). Samples are sent to the ExxonMobil Customer Service

Laboratory in Kansas City, Kan. The battery of tests we use to determine hydraulic fluid serviceability in Saturn's injection-molding machines includes:

- Viscosity
- Wear Metals in PPM
- Particle Count
- Total Acid Number
- Ultra Centrifuge Rating
- Oxidation
- Nitration
- Karl Fischer Water

During the testing process we placed particular emphasis on the Ultra Centrifuge Rating, Oxidation tests, Nitration tests, and the Karl Fischer Water test. However, it is important to note that any one of these tests can generate unwanted results that produce unsatisfactory fluid condition (see "Hydraulic Fluid Serviceability Tests" below).

Conclusive Findings

Determining hydraulic fluid serviceability can be a problem. — Used oil analysis laboratories do not run the battery of tests that accurately measure fluid condition, nor do they address insoluble sediment, which we have found to be the basic cause of most hydraulic-related problems. The industry continues to use particle counts to determine fluid cleanliness. But we found no correlation between insoluble sediment and particle count. Rather, we found that a low particle count can still result in high insoluble sediment. It is the insoluble sediment that causes tar and varnish build up. To effectively manage large hydraulic systems, it is important to maintain insolubles at a low level.

Reduced filter micron size does not prevent the accumulation of varnish and tars. — Varnish and tars continue to form on the metal surfaces of the system regardless of micron size. Smaller micron size filters only serve to create friction, pressure differential, accumulation of static electricity, and eventually spark discharge.

Hydraulic fluid additive packages do not currently eliminate varnish and tars. — These oils are designed for use with mechanical filters. Oils need to be designed with additive packages that will allow electrostatic oil cleaners to be highly efficient and operate at optimum levels in removing degraded insoluble contaminant sediment.

Hydraulic oil contains 8 percent to 9 percent air. — Minute air bubbles in the fluid under high pressure are adiabatically compressed, causing localized temperatures in excess of 2000 F, thus producing nitration. If the air bubbles in oil could be reduced, or eliminated, it would significantly reduce oil degradation.

In humid areas, hydraulic fluid brings atmospheric moisture into the system. — Free and dissolved water have negative effects on oil chemistry. For electrostatic oil cleaners to be effective in removing insoluble contaminants, the calcium additive package and water levels need to be low. We experimented with sealing off the reservoir with bladders and pulling humid air from the reservoir and pushing it with a blower through desiccant and circulating the dry air back into the reservoir air that is above the fluid level. We also tried vacuum dehydrators. Neither system was effective in bringing moisture levels in the high calcium and zinc additive

package oil to our target level of less than 100 PPM.

Zinc-free and lower-calcium oils have lower total acid numbers and lower water levels. — The Mobil DTE Excel 46 hydraulic oil used in the 15 VIS injection-molding machines is a zinc-free oil with a low calcium additive package. Here, the used oil analysis tests reflect much lower water levels and total acid numbers than with the Mobil DTE 25 hydraulic oil used in the injection-molding machines. The additive packages in both oils are very stable and, when used with mechanical filters, are much more resistant to varnish build-up than hydraulic fluids with less stable additive packages.

Electrostatic oil cleaners can remove insoluble contaminants as they are generated. — If the mechanical filters are removed so that the pressure differential, friction, static electricity, accumulation of static electricity, and spark discharge from the mechanical filters are eliminated, and if water can be controlled at levels less than 100 PPM in the system, electrostatic oil cleaners can be used to remove insoluble contaminants from the system as they are generated.

About the Author

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Hydraulic Fluid Serviceability Tests

Ultra Centrifuge Rating A small oil sample is run for 30 minutes at 17,500 RPM in a Sorval SS-3 Auto Superspeed Centrifuge. By subjecting the oil to forces of up to 34,800 Gs, the laboratory is able to extract oil degraded insoluble contaminant sediment that will not be picked up on a particle count and cannot be removed from the hydraulic fluid with mechanical filters. Based on field tests and laboratory simulation, ExxonMobil established an eight-step rating scale, against which samples are matched. An Ultra Centrifuge Rating of "5" or "6" indicates the start of the oxidation chain reaction and varnish formation. A "7" or "8" rating indicates a strong tendency to deposit varnish. Oil with this rating should be changed immediately. Used oil with a "0," "1," "2," "3" or "4" rating is in satisfactory condition. At Saturn, we normally change the oil when the Ultra Centrifuge Rating is "3" and we are unable to reduce the rating to a "2" by adding make-up oil.

Oxidation & Nitration Ratings These are tested using the Fourier Transform Infrared Analysis. Infrared energy is absorbed by certain molecules at specific wavelengths. The amount of energy absorbed is related to the concentration of the molecules in the sample. The used oil sample is compared to a reference of new oil and differences between the two are calculated and reported. On the ExxonMobil oil analysis report, used oil with a "0," "1," or "2" is rated in satisfactory condition. A rating of "3," "4," or "5" is borderline, and a "6" rating is unsatisfactory. At Saturn, the oil is normally changed when the Oxidation or Nitration Rating is "3," and we are unable to reduce the rating to a "2" by adding make-up oil.

Karl Fischer Water Test Water is undesirable in a hydraulic system because it

causes the oil and oil additive package to rapidly degrade. The infusion of water into hydraulic oil results in free water and dissolved water being emulsified in the oil. Dissolved water can only be removed from the oil by vacuum distillation. A high water content will indicate some type of improper mechanical condition. Water in Saturn's injection molding machines comes from three sources:

- The atmosphere through the breather during humid weather
- Cooling system heat exchanger
- Cooling system mold chill water loop

Water restricts electrostatic oil cleaners from operating at optimum levels. When water levels exceed the 500-PPM range, they will "short out." ExxonMobil rates used oil with water up to 0.040 in the oil in satisfactory condition. Used oil with water in the oil between 0.041 and 0.100 is rated borderline, and used oil with greater than 0.100 water in it is rated unsatisfactory. To convert the water reported on the ExxonMobil oil analysis report to PPM, move the decimal four places to the right. For example, 0.041 water equates to 410-PPM water.

Electrostatic Oil Cleaners

Kleentek DOC is a side-loop, liquid cleaning process that draws oil from a main reservoir and circulates it at a very low velocity. It continually removes contaminants from hydraulic fluids and lubricating oils.

The Kleentek system uses the principles of electrostatics to collect fluid contaminants. Its unique design with gradient force permits it to take advantage of the natural charge that each contaminant contains. Contaminants that have a positive charge are drawn toward a negative electrode within the system while those with an inherent negative charge are drawn toward a positive plate. As the fluid flows freely through the system, the cleaner removes contaminants, submicron particles, dust, dirt, and products of oil oxidation, such as tars and varnishes. These contaminants are trapped on a cellulose collector for easy disposal.