GENERATION PROBLEM OF STATIC ELECTRICITY DURING OIL FILTRATION

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Almost all hydraulic systems use filters in the main stream of oil at a suction side or at a delivery side or at a return side in order to protect hydraulic and lubricating system from harmful contamination. There is a current tendency that very fine bypass filters are used in addition to the line filters for the sophisticated hydraulic systems with proportional valves and servo valves which are sensitive to oil contamination. But one still can have hydraulic problems due to contaminants. Then we have to think the reason why such fine pore filters cannot solve the hydraulic problems due to contamination in hydraulic oils. One important fact that oil and fibers for fine filter elements are both dielectric has been overlooked. There is a high possibility that static electricity will be generated when oil passes through fine filter elements.

The author has invented a test device to demonstrate spark discharge of static electricity generated by friction of the oil and filter housing. This investigation confirms that static electricity can be generated during filtration and that it causes spark discharges in the filter element and in an oil tank. The spark discharges of static electricity crack oil molecules.

This paper has three new findings; the first is that the potentials of electric charge on oil is higher when a machine or a filter is grounded than when insulated, the second that the electric charge of oil will be not lost from the flat surface of the oil tank and be accumulated in oil even if the oil tank is made of conductive materials and grounded, the third that cracked oil molecules will be adsorbed on the metal surface and polymerized there.

Key words

Filters, Lubricants, Static Electricity.

INTRODUCTION

It is well known that the majority of hydraulic problems are attributable to contaminants in hydraulic oils. Many good studies have been done about hydraulic problems due to particulate contaminants [1)-5)]. Modern machinery requires highly accurate control and servo and proportional valves have become popular for use in hydraulic systems, since they are excellent for accurate control. Therefore mechanical filters have been widely recommended to protect hydraulic and lubricating systems [6)]. As they are very sensitive to oil contaminants, fine pore filters are used for sophisticated hydraulic systems. However there are still lots of unsolved problems caused by contaminants. Then it is natural to have a question why such fine pore filters cannot solve the hydraulic problems due to contamination in hydraulic oils. The author has investigated hydraulic problems which may have been caused by oil oxidation products [7)-10)] and has found that oil oxidation products play an important role on hydraulic problems in addition to particulate contaminants. Then the next question was how oil would oxidize. Many hydraulic systems are operated at a very mild oil temperature about 40–45 degree C and hydraulic oils have oxidation inhibitors. However even such oils oxidize in use. The author has observed spark discharges of static electricity during filtration and thought that spark discharge of static electricity may cause oil oxidation.

Lauer and Antal measured streaming electric current through poly-tetrafluoro-ethylene filter membranes in the range from 2 to 30 micron. They demonstrated that smaller the pore sizes produced the larger streaming currents. Also the larger the flow velocity, the larger the streaming current [11)]. These studies do not discuss the problems of hydraulic and lubricating oils when they are circulating in machines. There is no doubt that the oil and the filter element have friction when oil passes through a filter element. As the oil and the fiber are dielectric, there is a high possibility that static electricity will be generated and accumulated on the filter element and in the oil. In the case of static electricity, the current is small but the potential is high. Accumulated static electricity will be discharged with sparks between the electrified filter material and any conductive material close to it in the filter element. The author has collected used filters. He cut and examined several used pleated type filter elements and found evidence of spark discharges of static electricity between the dielectric filter material and the sharp edges of the punched holes of the center core of a filter element. As the temperature of the discharged sparks is very high[12)], there is a possibility that static electricity generated, when oil passes through fine pore mechanical filters, can crack oil molecules and produce new contaminants. There is also a possibility that spark discharges of static electricity will be caused between the electrified oil and the sharp end of the pipe submerged in oil in an oil tank. On the basis of this assumption, spark discharges were confirmed and recorded on a video tape while a lubricating system of an electric power plant was flushed with an absolute 3 micron filter.

This paper demonstrates that a mechanical filter can generates static electricity by friction when oil passes through a filter element and that the accumulated static electricity is discharged with sparks in a filter and in an oil tank.

TEST APPARATUS

Common Test Apparatus

The general view of the test apparatus is shown in Figure 1.

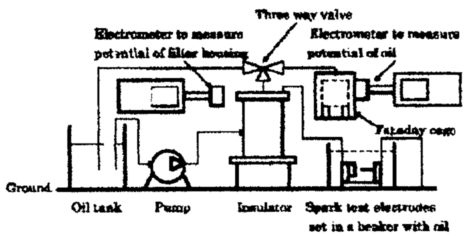

Fig. 1 Schematic diagram of electrification test apparatus

The apparatus consists of an oil tank, a pump with an electric motor and a test filter. The oil tank, the pump and the test oil cleaner are connected by hoses made of insulating material (vinyl) with 6mm inside diameter. As it is impossible to measure the potentials of the static electricity on a grounded filter, the filter housing was insulated by installing on a poly-tetrafluoro-ethylene plate. The oil tank and the pump are grounded to release electric charge from the test oil.

Measurement of Potentials

In order to shut off the noise from the atmosphere, we used a combined unit of Faraday cage with 27.0 pF capacitance and a commercially available electrometer as shown in Figure 2.

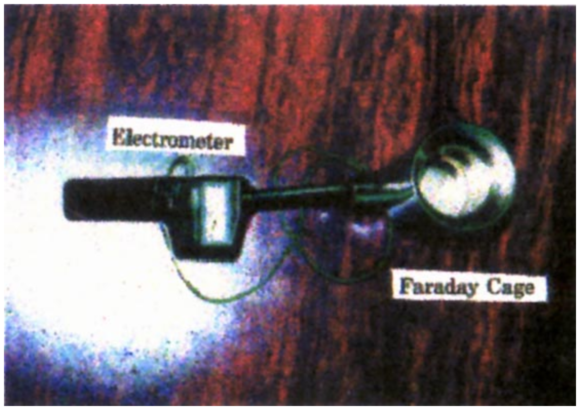

Figure 2 – Faraday Cage & Electrometer

In order to maintain a constant oil flow velocity with which oil passes through the test filter element, a three way valve was fixed at the outlet of the test filter housing for oil sampling. As the potential of the static electricity was very high, a long and thick plastic tube was used to cover the valve handle for safety.

The electrometer is detachable. The potentials of the electrified filter housing were measured by the detached electrometer at a distance of 50 mm from the filter housing.

The room temperature was 25 ± 1℃ and the temperature of the oil passing through the filter was 35 ± 2℃, when the potentials of the oil and the filter housing were measured.

Test Oil

Naphthenic base transformer oil with 7.1 cSt at 40℃ was used for the filtering test. Turbine quality, ISO 32 grade R & O lubricating oil was used for the spark discharge test in a beaker. The higher the oil viscosity, the higher the oil friction. In order to perform tests at room temperature without heating the oil, naphthenic base transformer oil was selected for filtering tests.

Test Filters

The following two filters were tested; a nominal 2 micron polypropylene depth type filter and an absolute 3 micron pleated type filter.

The polypropylene filter elements with two different conditions were prepared for the test; one was dried in a thermostatic oven at 80℃ for 24 hours and the other exposed to the humid atmosphere for 2 weeks.

EXPERIMENTAL TO KNOW THE EFFECT OF OIL FLOW ON POTENTIAL

Tests

In order to determine the effects of oil flow on potential, a filter housing designed for the test of polypropylene depth filter with 0.15L in volume was used. The vinyl hose was fixed to the stainless steel pipe at an end of a three way valve on the outlet of the filter housing. The inside diameter of the pipe was 5 mm and the length was 25 mm. The vinyl hose was 6 mm in inside diameter and 350 mm in length from the stainless steel pipe to the Faraday cage. The volume of the Faraday cage was 0.5L. In view of relaxation time of static electricity and in view that the oil turbulence with high flow velocity might cause spillover of oil out of Faraday cage, the potentials of oil was measured by taking 0.1 L and 0.2 L oil samples in the Faraday cage.

The potentials of 0.2 L oil were measured without any filter element in the filter housing in the rage of the flow velocity from 0.75 to 5.0 L/min. Potentials of 0.1 L and 0.2 L oil passing through a grounded dry polypropylene filter were measured in Faraday cage.

Results and Discussion

The electrometer measures the potential of oil sample in accordance with the following equation [13].

$$V = Q/C \quad \cdots\cdots \quad (1)$$

where Q: Electric charge (Coulomb)

C: Capacitance (27.0 pF)

V: Potential (Volt)

When the tested oil is electrified, the potential of the oil can be measured by voltage.

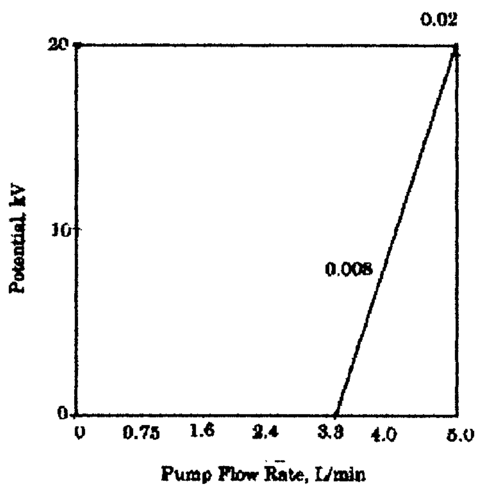

Figure 3 – Electrification of 0.2 L oil when oil Passes through a pipe and hose

The potentials of 0.2 L oil passing through an empty filter housing are shown in Figure 3. The results suggest that electrification of oil due to friction with the pipe and vinyl hose is negligible as long as the flow velocity does not exceed 4L/min.

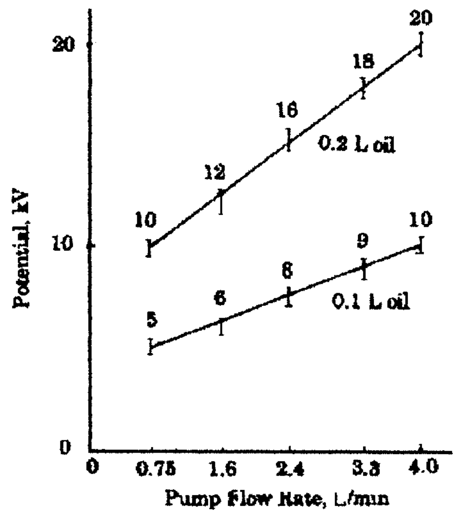

Figure 4 – Potential of 0.1 L and 0.2 L oil in Faraday cage when a dry filter was grounded

The potentials of 0.1 L and 0.2 L oil are shown in Figure 4. The potentials of 0.2 L oil were twice as same as those of 0.1 L oil. This suggests that the potential of the oil is in proportion to the quantity of oil in Faraday cage. Therefore the potentials of 0.2 L oil are taken in this paper. Besides establishment of same oil quantity, this result may suggest a possibility that the potential of oil in machines having a large volume of oil will be high, even if relaxation time of static electricity is discounted.

EXPERIMENTAL TO KNOW THE EFFECT OF GROUND AND INSULATION OF FILTER ON POTENTIAL

Tests

The potentials of oil were measured with dry polypropylene depth filter, when the filter housing was grounded and insulated by placing on a poly-tetrafluoro-ethylene plate. The potentials of the insulated filter housing were also measured.

RESULTS AND DISCUSSION

The potentials of oil of grounded and insulated filters are shown in Figure 5 and the potentials of the insulated filter housing are shown in Figure 6. The test results suggest that the oil was charged positive and the filter negative.

The potentials of oil passing through a

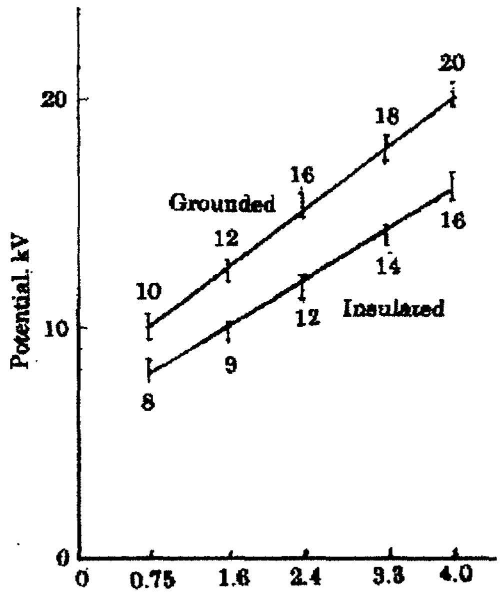

Figure 5 – Electrification of 0.2 L oil with dry filter when filter housing was grounded and insulated

grounded filter were higher than those of the insulated one. This is a new and an important finding. The results can be understood by considering that a kind of electric condenser is formed in the filter housing. Basically both positive and negative electricity are equally generated. When the filter housing is grounded, the negative charge goes to the ground and the condenser becomes empty. When the condenser is empty, negative charge can be unlimitedly supplied to the condenser and the positive charge to the oil. When the filter housing is insulated, the negative charge supplied to the condenser will be accumulated. If the condenser becomes full, it will not accept additional supply of the negative charge. However a part of the accumulated negative charge will be lost into the atmosphere through the sharp edges of the bolt threads or by relaxation. Then the condenser can accept supply of the negative charge equivalent to the lost one. The negative charge, which was separated by friction but not accepted by the condenser, will be offset with the positive charge in the oil. It is the reason why the potentials of the positive charge on the oil with the grounded filter housing were higher than those with the insulated one as shown in Figure 5.

All machines are grounded. Therefore we cannot feel any electricity even when we touch any machines. However the test results suggest a possibility that the oil in the grounded machines is electrified and that the potential of the oil may be high in the oil tank of the grounded machines.

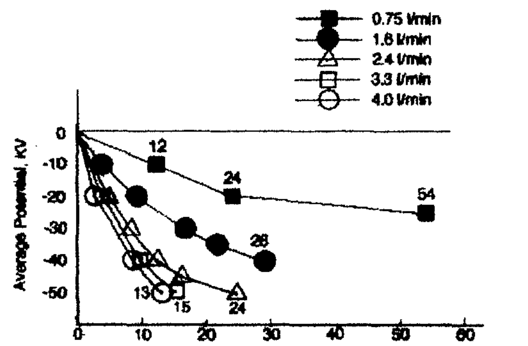

Figure 6 – Electrification of filter housing: saturated potentials and time to reach the potential with dry filter

The Figure 6 indicates that the higher the pump flow rate, the shorter the time to reach the saturated potential. While the potentials of the filter housing were measured, discharging noises were heard periodically. This suggests that the electric charges higher than –50kV are discharged into the atmosphere. The test results indicates a possibility in a working machine that the accumulated electric charge on the dielectric filter element will be discharged with sparks at the nearest sharp points of the metal in a filter installed on a grounded machine. This matter will be discussed later.

EXPERIMENTAL TO KNOW THE EFFECT OF HUMIDITY ON POTENTIAL

Tests

In order to examine the effect of humidity on potential, a polypropylene depth filter was exposed to the humid atmosphere for two weeks. The potentials of oil and the filter housing were measured when the humid filter was grounded and insulated.

RESULTS AND DISCUSSION

The measured potentials of the oil are shown in Figure 7. The saturated potentials of the insulated filter housing and the average time to reach the saturated potentials are shown in Figure 8.

The potentials of oil tested with humid filter element were substantially lower than those with

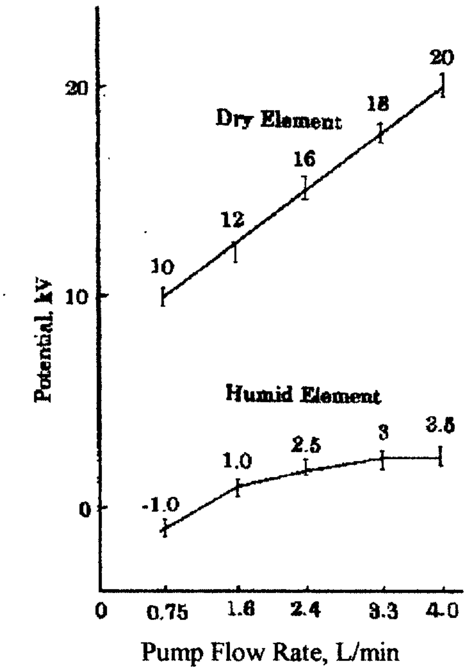

Figure 7 - Electrification of oil when oil passes through dry filter element and humid one.

dry one. The polarity of the electric charge in the oil with the humid filter element was negative at the oil flow velocity of 0.75 L/min but it turned to positive at the velocity of 1.6 L/min and larger. From this test, one cannot tell why the potential of the oil was negative at the velocity of 0.75 L/min and it turned to positive at the velocity of 1.6 L/min and higher. Further study will be worthwhile in this matter.

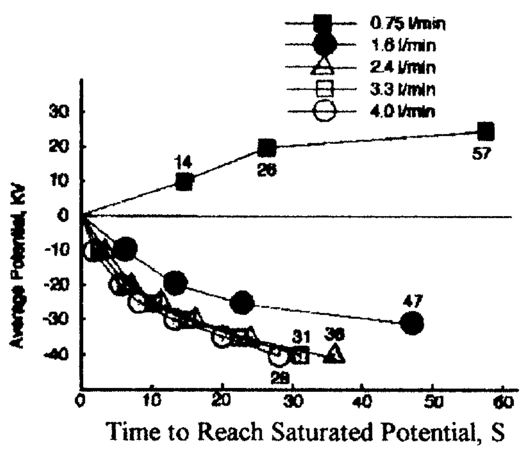

Figure 8 – Electrification of filter housing saturated potentials and time to reach the saturated potentials with Humid filter.

The potentials of oil were almost proportionally increased with the flow velocity from 0.75 to 2.4 L/min but they were almost saturated with the flow velocity larger than 2.4 L/min. This suggests that the separated charge will be affected by and offset against the opposite charge in the humid filter element. This also may suggest that a conductive filter element will electrify oil less.

The saturated potentials of the filter housing with a humid filter show in Figure 8 were a little bit lower than those with dry filter in Figure 6. The time to reach the saturated potentials with humid filter was longer than with a dry one. Such difference may come from the absorbed moisture which has free ion. A part of the electric charge of oil may be offset with such ions or other carriers in the moisture on the humid filter element. These data suggest that a humid filter reduces both the potentials of oil and the filter housing. However the potentials of the filter housing is still high at the flow rate larger than 1.6 L/min.

The saturated potential and the time to reach the potentials of ±10kV, ±20kV and ±25kV at the velocity of 0.75 L/min in Figures 6 and 8 show an interesting similarity with the opposite polarity. However one cannot find the meaning yet.

EXPERIMENTAL OF SPARK DISCHARGE Tests

To demonstrate spark discharges of the static electricity which was accumulated on a filter element, a pair of electrodes fixed with 1mm gap on a poly-tetrafluoro-ethylene frame was prepared. One electrode with a flat surface was connected to the filter housing by a high voltage electric cable and the other needle electrode was grounded as shown in Figure 9. The electrodes assembly was put in the 0.15 L oil in a beaker.

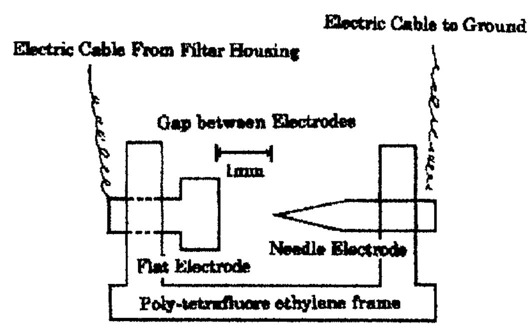

Figure 9 – Schematic construction of spark test Electrodes device

RESULTS AND DISCUSSION

Repeated spark discharges of the static electricity were noticed between the electrodes in the oil in a beaker almost every second at the flow velocity of 4.0 L/min. The interval of spark discharges was shorter at the higher flow velocity. Gas babbles and traces of carbon came out at the electrodes at every spark. This suggests that oil molecules are cracked by spark discharges of static electricity. The color of the spark discharge was white. This is a corona discharge. It is said that the temperature of corona discharge is very high and sometimes reaches 30,000 degree C and that the corona phenomena is used for Chemical Vapor Deposition[12]. Therefore the spark discharges in the oil will damage the oil.

EXPERIMENTAL OF PLEATED FILTER

Tests

The pleated filter was installed on the steel frame and mounted on a poly-tetrafluoro-ethylene pedestal as shown in Figure 10. As the filter had no pump, an external pump was used for the test. According to the makers catalogue of the pleated filter, the flow velocity of the oil with the viscosity of 32 cSt is about 60 L/min when the pressure drop of the filter assembly is about 98 kPa (1kgf/cm^2). However the tests were performed with the flow velocity in the range 2.6 to 7.4 L/min, as the higher flow rate caused spillover of oil out of the Faraday cage and oil spillover contaminated the sensor of the electrometer.

The potentials of the filter housing and the test stand were measured during the test at the five points of A to E.

RESULTS AND DISCUSSION

The test results are shown in Fig. 11. The measured potentials of oil were negative , although the polarity of electric charge of the oil passing through polypropylene filter element was positive as shown in Figure 5. As the polarity of the electric charge on the ebonite which is rubbed with a piece of silk cloth is different from that which is rubbed with a piece of a cat's skin, the polarity of electric charge is variable with the material which has friction with the oil. The pleated filters were made of three layers of synthetic unwoven fibers. The details of the materials were unknown. Therefore it is difficult to presume the cause of the opposite polarity.

The shapes of the measuring positions on the filter test stand and the measuring direction and the results of the measurement were shown in Figures 12 and 13. The potentials of the flat point

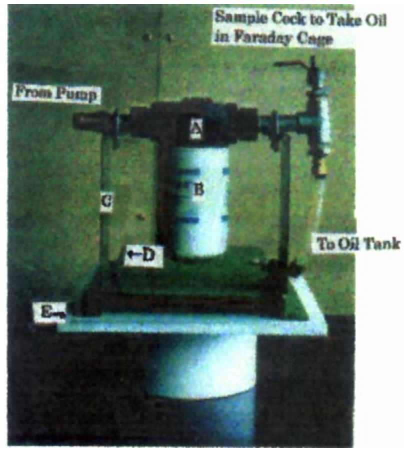

Figure 10 – Pleated filter on an insulating pedestal: A,B, C, D, and E are measuring point of potential

were quite different from those of the sharp point although the measuring condition was same. Such difference reflected the electric flux density which depended on the radius of curvature at the measuring points of the test stand and the filter housing. The more sharp, the higher the potential was.

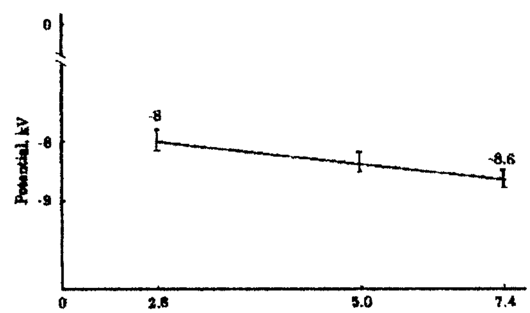

Figure 11 – Electrification of oil passing through pleated filter

This suggests that there is a possibility that spark discharges of static electricity accumulated in oil happen at the sharp edge of the pipe end submerged in oil in an oil tank. One of the friends of the author noticed and confirmed, by recording on a video movie, the spark discharges in an oil tank during a flushing operation of the lubrication system at an electric power plant. Many people have thought that electric charge, even if oil is electrified, of oil will disappear immediately in an oil tank, as it is made of steel and grounded. The measured potentials shown in Figure 13 and spark

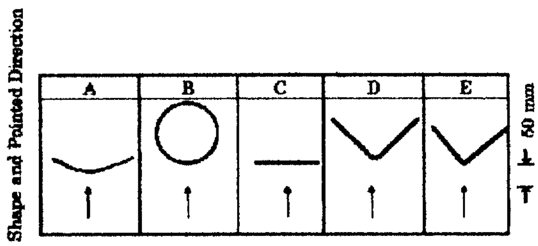

Figure 12 – The shape of the point A, B, C, D, and E at which the electrometer pointed

discharges of static electricity in oil tank suggest a new and important finding that the electric charge will not be easily lost from the flat surface of steel plate and that electric charge will be accumulated in oil in an oil tank.

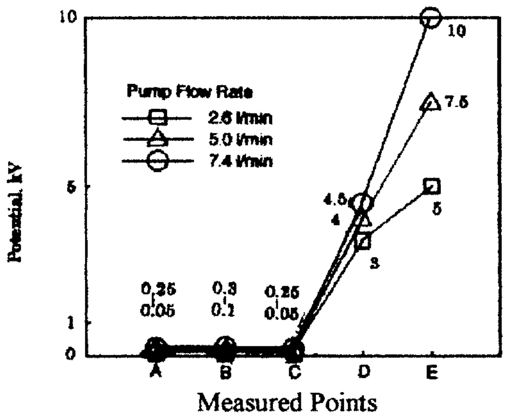

Figure 13 – Measured potentials at 5 points of A to E on the test stand and the pleated filter housing.

FIELD INVESTIGATION

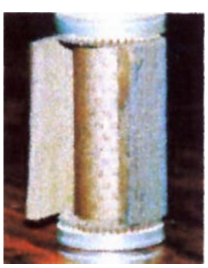

Figure 14 – A cut view of a pleated filter: black dots show spark discharges

Several pleated filter elements which were used in factories were cut and examined to find some evidence of spark discharges of static electricity in the filter element. Figure 14 shows the center core of a pleated filter element.

It had many black dots. Figure 15 is an enlarged picture of one of the dots. It shows carbonized punched holes of the center core of the filter element. The photograph suggests that the electric charge was accumulated on the insulating fibers and discharged at the sharp edges of the punched holes where the electric flux density was high. This can be explained by the test results shown in Figure 13.

Figure 16 shows a cut view of a filter element. The internal surface of the center core is coated with polymerized and greasy oil oxidation

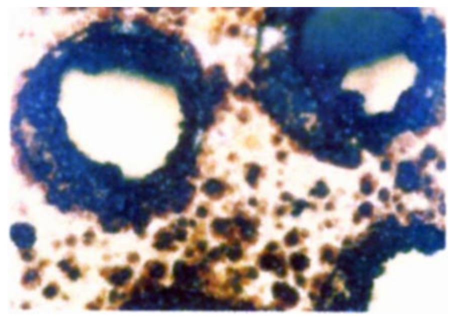

Figure 15 – Evidence of spark discharges at the sharp corner of punched holes of a pleated filter center core.

products. The filter was connected to a steel pipe which was grounded. The oil flowed from the outside of the filter element to the inside of it with a high flow rate. Static electricity was generated by friction of oil with the fiber of the filter element. Static electricity was accumulated on the fiber and discharged with sparks to the center core of the filter element at the sharp edges of punched holes.

Figure 16 – The outside of a filter (left) and the inside of the filter (right): Oil oxidation products which was produced by spark discharges coat the inside of the center core of the filter.

The spark discharges cracked the oil molecules and produced free radicals. Figure 16 indicates that the free radicals having free hands are very fast to be adsorbed on the metal surface and polymerize there, although the oil flows with high velocity at the punched holes. This was also a new finding.

THE CURRENT DESIGN OF OIL CIRCUIT

Many machines incorporate filters in the main stream of oil at a suction side or at a delivery side or at the return side. Some machines use by-pass filters. The velocity of the oil flow is high in general in the main stream of oil. The higher the flow velocity, the higher the potentials of the oil and the filter element. Almost all of machines are grounded. It suggests that the potential of oil is high. In view that the larger the oil volume, the higher the potential of oil from Figure 4 and Equation (1), there are some possibility that the potential of oil in an oil tank will become high and that spark discharges may damage the oil.

Many excellent hydraulic components and control systems have been developed by the efforts of hydraulic specialists and researchers. Their efforts may be jeopardized by spark discharges of static electricity which will be generated by friction of oil with filter elements. From the point of protection of oil and machines and in view of the facts which were investigated in this paper, the current design of using mechanical filters in the main oil stream may have to be reconsidered.

CONCLUSION

1 Oils are electrified by friction when they pass through filter elements and the potentials of oils increase in proportion to the oil flow velocity.
2 The potentials of oil are higher with the dry filter element than with the humid one.
3 The potentials of the oil are higher when the filter housing is grounded than it is insulated.
4 The filter elements are electrified with the opposite polarity of the oils and the electric charge on the filter elements can be accumulated to high level and discharged with spark.
5 Static electricity accumulated on the fibers of fine pleated filter elements will be discharged with sparks between the fiber and the sharp edge of the punched holes of the center core of the grounded filter.
6 From the point of the protection of oil and machines, mechanical filter have a possibility of damaging the oil and the use of mechanical filters on the main oil stream may have to be reconsidered.

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