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HOW TO DETERMINE THE CAUSE AND SOURCE OF HYDRAULIC OIL VARNISHING

Darko Lovrec
University of Maribor, Faculty of Mechanical Engineering
SI-2000 Maribor
Slovenia

Vito Tič
University of Maribor, Faculty of Mechanical Engineering
SI-2000 Maribor
Slovenia

ABSTRACT
While performing ordinary oil condition monitoring on industrial systems, we can often notice that hydraulic oil has changed its color. The source of the problem can be very difficult to locate and is often consequence of complex chemical processes in hydraulic oil. Finding the root cause of oil varnishing in hydraulic machine design and its operating conditions can be very demanding.
The paper preliminarily presents the most common causes that usually lead to oil darkening. Accordingly, a forensic search method for determining the root cause of oil varnishing is presented and applied on an example of a large hydraulic press system, controlled by a complex valve control system mounted on the control block.

Keywords: hydraulic oil**,** thermal oxidation, causes of oil darkening, RCA, OCM

1. INTRODUCTION

According to the experience of users of hydraulic devices, if we use the conventional mineral oil of the HLP quality class with the correct design of the entire hydraulic system, from the reservoir to the actuator, we can expect oil change intervals from 20,000 to 40,000 operating hours. Of course, under normal operating conditions. In the case of inadequate or incorrectly designed hydraulic system, extreme working conditions, unsuitable fluids used for a given application, ... however, the oil useful lifetime can be considerably shorter. In such cases, there is a lot of users' dissatisfaction with the unplanned early cost, which often leads to "shaking" the anger at the oil supplier, explaining "your oil is bad". The actual cause of this problem could not be in the oil itself, but in the modified operating conditions of the device, the occurrence of a fault in the device, or in the design error that was already committed by the device manufacturer. [1]

Users of hydraulic devices or maintenance workers of these systems are often concerned when they notice a rapid change in oil colour (the darkening of hydraulic oil) in open industrial hydraulic systems. This is often accompanied by the steady increase of oil acidity, the formation of sediments in lacquer products and the characteristic odor of burning - Figure 1.

Figure 1. Rapid darkening of the oil in a short service period

This is why users very often say that so called "Burning of oil” is appearing, which results in the formation of sludge and varnish. However, this phenomenon can occur due to very different causes, from which most likely are briefly present below.

2. COMMON CAUSES OF OIL DARKENING

The causes of oil varnishing can be different: ones are closely related to the type of hydraulic oil, liquids and its additives, and others derive from the operation of the hydraulic system and the design of the device. These causes are the most common and relate to the thermal oxidation process. This occurs due to the increased temperature, and the result is, apart from the changed oil colour, also the formation of sludge that slowly settles and accumulates at the bottom of the reservoir, and the formation of lacquer products that adhere to the parts of hydraulic structures and stain them in yellow or gold-brown shades – Figure 2. Varnish produced by lubrication degradation causes increased wear, filter plugging, restricted flow, poor heater / cooler performance and valve sticking in a variety of industrial applications.

Figure 2. Varnish formation on the valve control slider (left) [2] and inside of the tank (right) [3]

There are several reasons for (including the only locally) elevated temperature in the hydraulic system and they are more or less known to the user:

- Friction in the fluid itself, and especially between the fluid and the metal surface in the hydraulic system, as well as possible rubbing of one surface next to another, can generate temperatures between 180 °C and 450 °C and is always present.
- Adiabatic compression, like a diesel effect, can generate temperatures between 600 °C and 900 °C.
- The occurrence of electrical/static discharge is less known. Without the presence of sparking, this phenomenon can lead to local temperatures between 5000 °C and 10,000 °C, and in the event of a spark occurrence, in an extremely short time of a few

nanoseconds, the local temperatures can cause local temperatures even between 10,000 and 20,000 °C [4] [5].

- A fairly common cause of oil "burning" is the incorrect use of liquid heaters installed in the hydraulic reservoir in order to reduce the viscosity of the liquid before starting the pump in the event of lower temperatures. If the heater is located in the tank area where there is no liquid flow (i.e. dead zone), the oil surrounding the surface of the heating body locally burns.
- The most common cause of thermal oxidation is the diesel effect, the cause of which is the presence of air and air bubbles in a hydraulic system and hydraulic oil. We will continue to pay attention to this in the future.

3. AIR AND THE HYDRAULIC FLUID

The air is present in the hydraulic system because of various reasons and can appear in various forms. It can be visible to the eyes, as it appears in the form of foam or in the form of air bubbles, but it can also be "invisible" because it is dissolved in the oil. The latter can be observed in elementary form, such as bubbles, when the operating state (pressure conditions) changes, which is also closely related to the design of the individual blocks of hydraulic system.

Thus, we must differentiate between the appearance of foam on the surface of the oil in the reservoir, which is actually not dangerous, and the appearance of air bubbles in the oil itself, which usually leads to all other consequences – Figure 3. In the presence of air in the device, the compressibility of the media increases, and effects the entire hydraulic system (eg, the precision of actuator motion, the phenomenon of fluctuations, the need to change the settings of the controller parameters ...). However, the air does not only effect the operation of the hydraulic device, but also has influence on the oil condition.

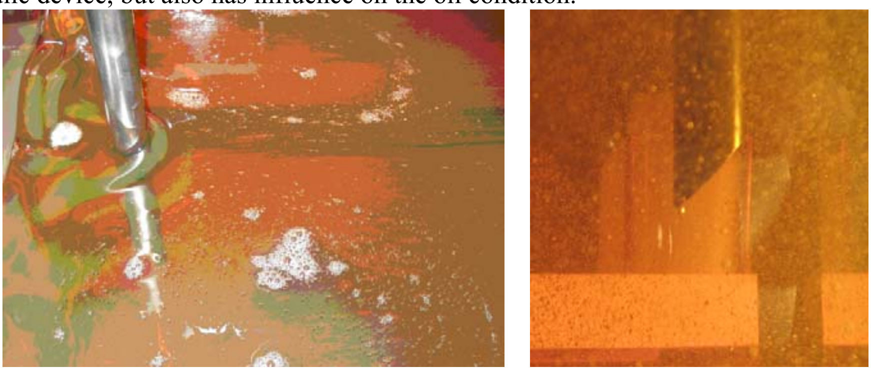

Figure 3. Foam on the surface of the oil (left) and air bubbles inside the oil(right)

Figure 3 shows foam on the surface of the oil in the reservoir (left) and air bubbles in the oil (right). From experience, it is known that the phenomenon of oil foaming can be caused by:

- heterogeneous or non-uniform composition of mixture of mineral oils. It is known that strongly heterogeneous mixtures are more prone to foaming than fluids with a more uniform composition,
- excessive surface tension of the liquid. In order to make it difficult to penetrate the surface of the liquid and to quickly disappear, the surface tension must not be too high,

- selected unsuitable viscosity of oil for a particular hydraulic device. Oils of lower viscosity are less prone to foaming,
- extracted air at vacuum (e.g. in suction line),
- inadequate operation of the hydraulic system.

In the case of a properly designed and fault-tolerant hydraulic system, foaming of hydraulic oil is barely possible. If foaming occurs with fresh, clean mineral oil, the root cause of foam formation should be searched for on the hydraulic system itself. The causes may vary, for example:

- too small hydraulic tank or a small tank fill opening that causes the vortexing of the oil and thus the absorption of air,
- the pump sucks air through a leaky location on the pump or suction line,
- the return line is not run under the surface of the liquid. Thus, the returning liquid falls into the reservoir and air enters the oil and leads to the formation of foam and air bubbles; which is later sucked by the pump.
- poor deaeration of newly filled devices. Thus, air can remain in the pipeline, which is then under pressure transferred into the oil and leads to oil foaming.

The possibilities and causes for air bubbles to appear in the hydraulic system are therefore many and of diverse nature. In principle, the most common causes of the appearance of air bubbles can be divided into two major groups. The air, in the form of air bubbles, can enter into the hydraulic system from the environment through the leaky spots on the pipelines, or it may occur as a result of abnormal events in the reservoir itself, the most common of which is due to the wrong design of the inside of the reservoir [6].

Air bubbles can also be generated as a result of dissolved air in the liquid itself, from which it is excreted as elemental air (air bubble) when the pressure and / or current conditions in the hydraulic system are altered, e.g. in the pipeline, valves, valve blocks ... The latter cause is usually hidden from the naked eye and it is always very difficult to find. In certain cases it is very useful to know the tendency of elevated thermal oxidation and its pattern of occurrence.

4. IMPLEMENTING OF ON-LINE CONDITION MONITORING

When looking for a possible cause of thermal overloading and burning of oil, a modern way of constant monitoring of all changes of the most important physico-chemical parameters, which are closely connected with the appearance of thermal overload, can be used.

As an example of such an approach, an example of large hydraulic press can be presented, which operates most often in four shifts, and on which the persistent oil burning in a relatively short time interval – already 3000 to 5000 operating hours is occurring. In order to thoroughly investigate this phenomenon, an on-line system for continuous monitoring of important parameters was installed on the hydraulic system of the mentioned press, such as temperature, relative humidity, dielectric constants and electrical conductivity,… as an indication of oil condition and oil acidification. To monitor these parameters, the multifunctional sensor was installed in a bypass line and the graphical interface for monitoring changes was designed. We can monitor these on the site itself and from a remote location. The integrated on-line multifunction sensor and graphical interface with the most important changes in the parameters observed are shown in Figure 4.

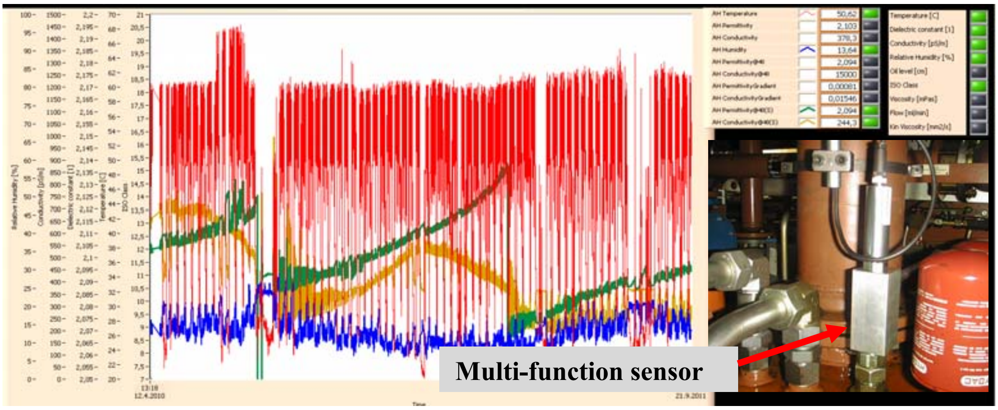

Figure 4. Integrated on-line multifunction sensor and graphical interface with the most important changes in the parameters

The temperature monitoring process is clearly seen from the picture, which proves that the thermal overloading is not happening in the hydraulic reservoir. Other parameters (moisture, cleanliness ...) are within normal limits. Nevertheless, the dielectric constant and the electrical conductivity of oil have always been increasing in a more or less similar profile after the oil fill was replaced. The cause of the oil burning was therefore somewhere else.

5. DETERMINING OTHER POSSIBLE CAUSES

As already mentioned, the causes of air intrusion into the system can be several: from leaky spots on pipelines to an inadequately designed reservoir ... to errors in the wrong design of hydraulic components.

Besides the wrong dimensions of the pipeline and its laying (damping places, knees ...) too high fluid velocity in the tube leads to problems associated with air excretion. Although the mineral oil can take a relatively large amount of air (at 300 bar approx. 3000 vol %) at operating pressures, the pumping may cause the extraction of the air from the oil in the pressure zone of the pipeline. In this case, it is a matter of so-called pseudo-cavitation (compare with the concept of cavitation in which the pressure drop in the system is below the vapor pressure level [7], [8]).

The energy of a flowing liquid consists of, in accordance with the law of energy conservation or the simplified Bernoulli equation, two main proportions of pressure: from a static pressure and a dynamic pressure. In this case, if one of these pressures changes, the other has to change. If the velocity (continuity equation) changes according to the physical effect due to constriction, the pressure conditions will also change – Figure 5 (the Ventouri effect).

When the difference in cross sections is large a high local increase in the fluid velocity occurs in the narrowest place and, consequently, the pressure falls below the pressure of air extraction from oil – that is pressure limit below where pseudo-cavitation occurs.

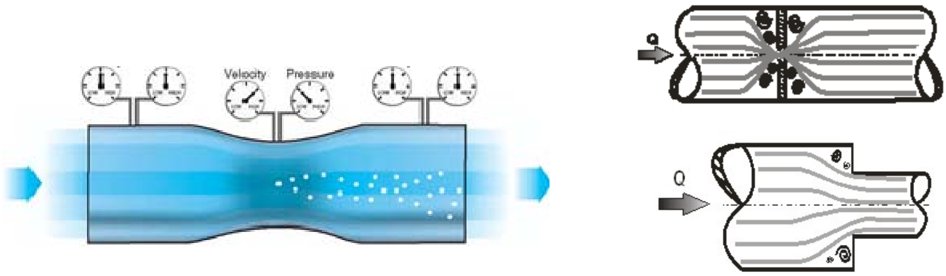

Figure 5. Pressure and speed conditions in tube with restriction causes air excretion

This phenomenon is present everywhere where, due to high flow velocities, the liquid can no longer follow the shape of the changed geometry. This occurs in all major changes in the pipe sections (reducers), knees, reducing knees, tubular arches with a low radius, S-shapes, and also inside the valve blocks – Figure 6.

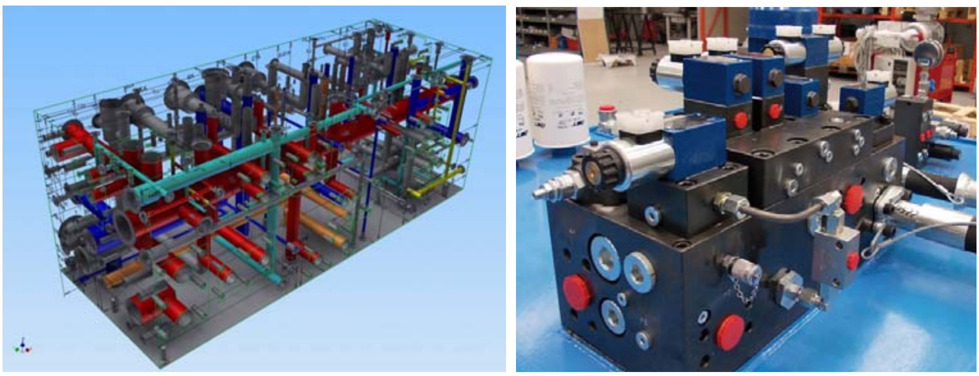

Figure 6. Principled view of the interior and exterior of the valve block

This problem is particularly acute in the interior of the valve blocks, as it is very difficult to find this narrowed site. Usually, this is a hidden error, which is only known to the constructor of the block, and it is very difficult to eliminate it. It can only be eliminated with the new design of internal links in the block itself.

6. CONCLUSION

When a thermal decomposition is the cause of the problem – the darkening of the oil, it is essential to perform the RCA analysis (Root Cause Anylysis) to determine the actual source of the problem of this burning of oil. The oil user often avoids solving the root cause of the problem and rather blames the oil producer and its oil of poor quality. Resolving the problem is therefore on the other side. If you find that the heat source is associated with an error in the design of the system, you may choose to use the separation technology of the side products from the hydraulic fluid. Unfortunately, this is only a temporary solution and it will require a new system or at least a renewal of the system to permanently resolve the problem.

If the main cause of thermal decomposition is the presence of air or air bubbles formed while the liquid flows from the tank to higher pressure zones, such as valves and pumps, there are products for removing air bubbles. Different anti-foaming agents can be very effective, which, if necessary, are added to the liquid. However, these solutions are usually only temporary, as their long-term effectiveness is questionable. We may need to add these additives several times or they will no longer be effective after a certain time. Therefore, it is much more correct to solve the problem of the presence of air in the system focusing only on the construction of the hydraulic system and its components, such as reservoir, pipelines, valves ... By properly designing and designing these we will not only temporarily solve the problem, but rather permanently reduce the possibility of its formation. Or, as we have shown in this case, the actual cause of the problem was determined by using modern on-line oil condition monitoring methods and performing the RCA analysis.

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