

TECHNICAL BULLETIN

IMPACTS OF FILTRATION ON NEW LUBRICANT PERFORMANCE

Background

It is well established that ensuring lubricant cleanliness, and avoiding lubricant contamination, is essential to maximizing equipment life. Abrasive particles in lubricants reduce the useful life of equipment components and, in the worst cases, can lead to sudden equipment failure resulting in unplanned downtime and possible safety issues.

As the prevalence of proactive and predicative maintenance strategies rise, more and more equipment operators are taking steps to ensure the cleanliness of their lubricants. Setting a cleanliness standard for new lubricants and testing is the first step. Many find their new lubricants cannot meet the tight cleanliness needs for equipment with high pressures and tight machine tolerances. Thus, lubricant filtration has grown in popularity. The most common method employed to ensure cleanliness targets are achieved for both new and in-service lubricants is on-site filtration. Identifying filtration parameters that enable all equipment to meet cleanliness specifications, without excessive process time and without damaging the lubricant can be a challenging task. This technical paper will describe two watch points when tackling filtration: Foaming and Demulsibility.

Before we get into the nuts and bolts, a little background about finished lubricant formulations will help set the table. Finished lubricants contain a variety of additives over a large range of sizes. Additives exist both dissolved and dispersed in the oil. Typically, additives that are fully solubilized in the oil will range in size from less than 1 μ m up into the 5-10 μ m size range. Those that exist as dispersions of solids or semi-solids are also primarily in the 1 μ m – 10 μ m range. However, dispersed additives are present at sizes over 14 μ m in significant numbers and can even exceed 20 μ m [1, 2, 3, 4]. This is further complicated by temperature. Solubility of the base oil increases with



temperature, temporarily dissolving some of the non-solubilized additives. However, increased temperature also causes some of the large, dissolved, molecules to further increase in size [5]. As the lubricant cools, the temporarily dissolved additive precipitates out of the oil and back into a dispersion.

These lubricant formulation behaviors are unique to the specific lubricant. In which the presence of moisture or other contaminants may create further difficulties for safe and effective filtration. When acidic and basic additives interact with contaminants, a neutralization reaction can occur forming a salt and water. The byproducts of the neutralization reaction can then agglomerate and become susceptible to removal by filtration. However, acidic and basic components are not the only area of concern. Some additives, borated EPs for example, can react with water to form agglomerates and/or gels that may then settle out of the fluid or be removed by filtration.

Additionally, it's not only the physical dimensions of the additives that can result in removal by filtration. Surfactants are additives that are active at a liquid-liquid, liquid-gas, or liquid-solid boundary.

Dispersants, foam inhibitors, demulsifiers, and corrosion inhibitors are all surfactants. Some surfactants, such as dispersants, are molecules with one polar and one non-polar end. In the case of dispersants, the polar end of the molecules bonds with contaminants. Once the contaminate is surrounded by dispersant molecules it can remain in solution until it is transported to the filter and removed. Foam inhibitors on the other hand do not have a non-polar end to keep them in solution with the bulk fluid and actually have a greater affinity for filter media than the bulk lubricant. As a result of their affinity for the filter elements, foam inhibitors can be removed by "sticking" to filter elements even when the filter mesh is much larger than the foam inhibitor droplets.

Foam Tendency and Stability

A crucial watch point when filtering lubricants is foam performance in terms of tendency and stability. ASTM D892 provides a means of evaluating the foaming characteristics of lubricating oils [6]. Air is passed through a diffusing stone into a sample of oil for five minutes at controlled temperature. After five minutes have elapsed, the volume of foam is recorded in milliliters as the oil's foaming tendency. The oil is then allowed to rest for ten minutes. At the conclusion of ten minutes the remaining volume of foam is recorded as the foam stability. A sequence of three measurements is prescribed by ASTM D892. The first trial, Sequence I, is carried out at 24 \pm 0.5 °C. A second sample, Sequence II, is tested at 93.5 \pm 0.5 °C. For the third test, Sequence III, the second sample is re-tested at 24 \pm 0.5 °C.

Filtration impacts on foam inhibitor has been studied extensively. As far back as 1987, T.V. Friesen investigated reports that tractor hydraulic fluid which met ASTM foam performance specifications at production, but then failed foam tests after 50 hours of operation. The study revealed a relationship between filtration and foam performance. It was found that tractor hydraulic fluid circulated through a 25 μ m paper filter for up to 93 hours successfully met foam specifications. However, the addition of a 7 μ m synthetic filter resulted in a sharp increase in foaming and failure to meet specifications after only 24 hours of filtration [7].

Subsequent tests with a selection of filters found that the loss in foam performance was accentuated by decreasing filter pore size and synthetic filter media. Finally, it was determined that the increase in foaming was not fluid specific; three widely used fluids were tested under identical conditions. All of the fluids showed dramatic increases in foaming tendency and foam stability, and analysis of the filters indicated that the increase in foam tendency and stability was likely the result of foam inhibitor removal [7].

Efforts to over-treat the fluid in hopes that enough silicone would remain in the fluid, post filtering, to meet foaming specifications

proved unsuccessful. Two fluids, one with 10 ppm silicone and the other with 3000 ppm silicone, were filtered with a 7 μ m synthetic filter for 24 hours. Both fluids initially met foaming specifications. However, after filtration neither fluid did. Friesen's 1987 study concluded that in-use fluids should not be expected to meet new fluid foam specifications and that specifications should anticipate the lost performance.

The issue of filtering out anti-foam first came to light with the use of silicone foam inhibitors in lubricant formulations. Since then, other foam inhibitor chemistries have become more common in the marketplace (polyacrylates, for example) and may be more stable in finished lubricants as they are more finely dispersed in the oil. However, they still remain vulnerable to removal by filtration.

Three more examples of the impacts of filtration on the foam performance of finished lubricants are presented below:

First, an ISO 460 synthetic machine oil with a silicone foam inhibitor and an ASTM D892 [6] foam tendency requirement of 50 mL or less was filtered through an 8 μ m ß1000 micro-glass filter at 135°F for 25 filter passes, where a filter pass describes the amount of flow required for the total volume of oil in the equipment to pass through the filter one time (*Figure 1*).



The new fluid as received (fresh) meets the foam specification with 0 mL of foam tendency. A sample taken from the equipment at start-up (unfiltered) continues to meet foam requirements. Within 5 filter passes, Seq II and Seq III foam are more than 5 times the 50 mL limit and by the time the fluid has passed through the filter 25 times, there is nearly 500 mL of foam tendency. The test was repeated with a 12 μ m ß1000 micro-glass filter at 135° F (*Figure 2*). Recall that foam inhibitor can be removed from finished lubricants even when it is small enough to "pass through" the filter mesh, and note that the larger filter slowed, but did not prevent the loss of foaming performance. By the time the fluid reaches 25 filter passes, the 12 and 8 μ m D892 foam tendencies results are equally unacceptable.



The next example is where excessive foaming was observed in the sight glass on a gear box at large petrochemical plant. The plant operator drained, cleaned, and refilled the gearbox with fresh synthetic ISO 220 gear oil that employed multiple foam inhibitor technologies. However, after several months of foam free operation the issue returned. Initial causal investigations focused on identifying and eliminating potential causes of lubricant foaming including contamination, over or under-fill, etc. The unit was taken out of service, cleaned, and refilled three times over the course of two years. Each time the issue returned (*Figure 3*). Figure 3: ASTM D892 Foam Tendency for an in-service ISO 220 synthetic gear oil with multiple foam inhibitor chemistries that was filtered through an onboard 10 μ m absolute filter.



During the last causal investigation, it was noted that the oil seemed especially clean for an in-service gear box with an ISO 4406 [8] cleanliness of 15/13/10.

The plant operator was employing continuous kidney loop filtration with a 10 µm absolute filter. Additional analysis confirmed that the loss in foam performance was likely the result of foam inhibitor removal. Rather than increase filter size, the operator worked with their lubricant supplier to identify an alternative lubricant. They selected a synthetic ISO 220 gear oil with a different base oil – foam inhibitor combination. The replacement product has now been in service, without issue, for more than a year.

While the first two examples illustrate how quickly a product can be damaged by filters when filtration parameters and formulation are not carefully matched, the next two illustrate instances where formulation knowledge is leveraged to reduce the risk of over filtration.

As it has been established that reducing filter pore size increases foam inhibitor removal, tight filtration is sometimes employed to reduce the time required to stress a finished product. The next two filtration examples employ <4 µm ß1000 (2.5 µm nominal)

filters to reduce the time required to "break" the fluid. It is, again, important to recall that foam inhibitor can be removed by filters with pore sizes that are larger than the foam inhibitor droplets.

Figure 4 details the progressive loss of foam performance for a modern high-performance ISO 150 synthetic gear oil with a polyacrylate foam inhibitor (Gear Oil A). During the filtration, steps were taken to limit contamination however the filtration occurred at operating temperature. All other filtration conditions (filter media, flow rate, etc.) were standardized and carefully controlled. Even after 100 passes of 2.5 µm filtration, the gear oil continues to meet foam requirements (<50 mL tendency). A second gear oil (Gear Oil B, *Figure 5*), an ISO 150 synthetic gear oil with a silicone-based foam inhibitor, provides even better resistance, showing no loss of foam performance after 100 filtration passes with a 2.5 µm nominal filter. Steps were again taken to control contamination and standardized filtration parameters were employed, including filtration at a preselected and carefully controlled temperature during filtration.

Figure 4: ASTM D892 Foam Tendency for ISO 150 Gear Oil A, a synthetic gear oil with polyacrylate foam inhibitor filtered through a <4 μ m ß1000 (2.5 μ m nominal) micro-glass filter at operating temperature for 100 filter passes.



Figure 5: ASTM D892 Foam Tendency for ISO 150 Gear Oil B, a synthetic gear oil with silicone-based foam inhibitor filtered through a <4 µm ß1000 (2.5 µm nominal) micro-glass filter under controlled conditions for 100 filter passes.



Although both gear oils completed filtration testing without loss of foam performance, the risk was not completely eliminated. Foam tendency of the polyacrylate containing sample, Gear Oil A, is increasing with filter passes and reaches 40 mL at 100 passes (*Figure 4*). It is reasonable to expect that if filtration had continued the fluid would have failed to meet the specification of 50 mL maximum foam tendency.

Gear Oil B, with the silicone-based foam inhibitor showed no foam tendency for the duration of the test. However, additional investigation showed that filtration was gradually removing the silicone-based foam inhibitor. *Figure 6* illustrates the change in foam inhibitor content of the gear oil by monitoring silicon content as filtration progresses. The fresh fluid contains just over 26 ppm of silicon. At 100 filter passes the silicon content of the gear oil has been reduced to 19.6 ppm, a nearly 25% loss. Thus, when performing continuous filtration it's important to monitor the lubricant routinely for foaming performance.

Figure 6: Silicon content by ICP for ISO 150 Gear Oil B, a synthetic gear oil with silicone-based foam inhibitor filtered through a $<4 \mu m \&1000 (2.5 \mu m nominal) micro-glass filter under carefully controlled conditions for 100 filter passes.$



Water Separability

Filtration can also impact a lubricant's ability to shed water. Although there is little literature on loss of demulsibility from filtration, a 2013 article in Tribology and Lubrication Technology notes that an un-named lubricant supplier found that demulsifier was removed from a finished lubricant by a 1 μ m filter [2], and while 1 μ m filtration is not common, testing shows that a loss of demulsibility can result from much larger filters.

One such example is shown in *Figure 7*. This industrial lubricant was filtered for 25 passes through a 12 µm filter. Steps were taken to protect against contamination and filtration parameters were standardized. Several samples were drawn and evaluated for water separability. The new fluid, as received, met the product's ASTM D1401 [9] water separability specification of <3 mL of emulsion within 60 minutes. A sample taken from the equipment at start-up (unfiltered) continued to meet demulsibility requirements, but as filtration progresses, the time to reach 3 mL or less emulsion gradually increases until it exceeds 60 minutes at 20 filter passes. Past this point, the emulsion remaining at the

Figure 7: ASTM D1401 water separability results for an industrial lubricant filtered for 25 passes through a 12 μ m filter.



test's conclusion (60 minutes) depicts an increase from 0 mL for the unfiltered and 5 pass samples to 6 mL and 14 mL of emulsion at 20 and 25 passes respectively. Thus, after 20 passes the lubricant no longer passed ASTM D1401.

Figure 8 and Figure 9 present the ASTM D1401 water separability results for ISO 150 Gear Oil A and ISO 150 Gear Oil B respectively. Recall that both were filtered for 100 passes through a <4 µm ß1000 (2.5 µm nominal) filter and that the filtrations were conducted in a manner that limited contamination and standardized filtration parameters, except that Gear Oil A, in Figure 8, was filtered at ambient temperature, while Gear Oil B in Figure 9, was filtered at a pre-selected and carefully controlled temperature. Gear Oil A initially meets water separability requirements, with both the fresh sample and unfiltered equipment sample reaching <3 mL emulsion within 60 minutes, but filtration drastically impacts the lubricant's performance. After only 10 filtration passes, Gear Oil A fails to shed water, retaining nearly all of the added water as in emulsion. Gear Oil B on the other hand successfully completes the filtration, shedding all of the water, with 0 mL of emulsion @ only 10 minutes even after 100 filter passes.







Conclusion

In conclusion, it's tempting to select a low-micron high-efficiency filter and perform the filtration under ambient conditions, for example, using a portable kidney loop on a bulk or day tank. The tight, high efficiency filter allows operators to reach, or exceed, cleanliness targets. However, this approach neglects to consider the potential impact of the filtration process on lubricant additives and post-filtration performance.

Overall, the benefits of clean oil have been thoroughly documented, and maximizing equipment reliability demands the use of oils that meet equipment cleanliness requirements. However, care must be taken to avoid damaging the lubricant while it is being cleaned. Filters can remove additives by mechanical blockage (when the additive is larger than the filter) or by adherence to the filter element, which can remove particles smaller than the filter's rating. Contamination (water, particulate, other lubricants) can cause additives that are typically dissolved in the oil or dispersed smaller than the filter pores to agglomerate, form salts and/or gels that can then be removed by filtration. In order to mitigate the risk of additive removal, you must understand the chemistry of the lubricant being filtered along with filter selection (media, size, etc.), operating conditions, and process temperature. Thus, filtration parameters, such as temperature, filter media and flow rate, should be standardized and tested thoroughly to ensure no harm is done to the lubricant. Since the results of filtration are highly application and product specific, it is important to develop an effective process and ensure that it is carefully repeated. A lack of process consistency can easily lead to unexpected results and damage the lubricant.

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