Avoiding the Pitfalls of Viscosity-starved Machines



Industry rides on a film of oil. The oil's viscosity bears the load and defines the extent of clearance achieved between working surfaces. Sometimes that clearance is thick and bountiful, and other times it is deflated or extinct. Without viscosity, most machines would rapidly self-destruct with mechanical friction and wear.

There is also a well-known penalty and reliability risk from too much viscosity. Like most things, the selection of a lubricant's viscosity must be optimized to enable needed protection and disable the danger from excessive viscosity. For instance, too much viscosity can cause churning losses and excessive heat generation from molecular friction. It can also impede lubricant movement and flow to lubricant-hungry surfaces.

One of the most famous disadvantages of too much viscosity is high energy consumption. In recent years, we've seen automaker-specified viscosity being lowered in crankcase service from 5W40 to 5W30, and now in some cases to 5W20. These changes are all for the sake of energy conservation. Of course, the primary driver for energy conservation is not to save money on fuel or electricity but rather to reduce the consumption of fossil fuels, which emit harmful gases (carbon dioxide, nitric oxides, hydrocarbons, etc.) into the atmosphere as a byproduct of combustion.

While any effort to decrease energy consumption and protect the environment is a noble cause, you should be wise to how excessive viscosity trimming can backfire. Under ideal conditions, lowering viscosity in an engine may result in no harm. However, in worst-case scenarios, dangerously collapsed oil films can accelerate wear and lead to premature failure. Such scenarios in a car engine may occur due to low coolant levels, heavy loads (pulling a trailer), hot ambient temperatures, low oil levels, driving on dirt roads (high particle ingestion), short-trip driving patterns, water contamination and fuel dilution. Excessive wear in the combustion chamber region (rings, cylinder wall, valves and cams/followers) caused by aggressively low viscosity and worst-case scenarios will result in the loss of combustion efficiency, higher fuel consumption and harmful gases being released out the tailpipe.

Too low viscosity can also lead to excessive volatilization and oil consumption in engines, both of which have a negative environmental impact. Low viscosity equates to small molecules that are more prone to vaporization at high temperatures along the piston ring belt, cylinder wall and exhaust valves.

Viscosity Starvation in Worst-case Scenarios

Lubrication engineers consider numerous factors when matching viscosity selection to the needs of the machine. Speed is an important factor, as is load. Both define the viscosity needed to produce hydrodynamic and elastohydrodynamic oil films. These oil films build a clearance between working surfaces to mitigate friction and wear from mechanical contact.

Some machines operate at varying speeds. Without speed, oil films are not producible. This is why it's often said that each time you start your car or truck, you are causing mechanical wear equivalent to 500 miles of driving. Starts, stops, coast-downs, slow speeds and reverse-direction part movements are all oil film/viscosity starvation events.

Temperature is another critical factor. Usually extreme temperatures are considered first and then normal operating temperatures. At the lowest temperature extreme, the oil must be fluid enough to enable movement and flow. At the highest temperature extreme, the viscosity must not be so low that surfaces are allowed to rub and collide, resulting

in excavated working surfaces and failure. Viscosity index also plays a crucial role when temperatures are known to fluctuate widely.

Typically, charts and formulas are used when selecting a lubricant's viscosity. Risk should also be a consideration. What is the likelihood of a viscosity excursion during normal or extreme conditions? What are the consequences? Safety, cost of repair, downtime, energy consumption and environmental factors should all be taken into account.

It is easy to select viscosity for normal and generally constant-load conditions. However, extreme loading puts extreme demands on a lubricant's viscosity. This can come as a result of momentary shock or surge loading, mechanical unbalance and misalignment. Knowing when these conditions occur is essential. In many cases, the solution is not viscosity but rather film-strength additives.

We all know that viscosity produces the working clearance between surfaces in relative motion with respect to speed and load. This clearance defines the machine's sensitivity to three-body abrasion from particle contamination. The particles in the size range of this clearance create the greatest amount of abrasion. For instance, if the working clearance is 10 microns, then the particles around 10 microns cause the most abrasion and pitting. The population of small particles in a lubricant is always much greater compared to large particles. The lower the viscosity, the thinner the working clearance and the more harm done by particle contamination.

Other Causes of Viscosity Starvation

As mentioned previously, the conditions that often starve a machine of viscosity can be momentary or temporary. High ambient heat or a defective cooler can drive down viscosity. Sometimes the temperature issue is localized or specific to a transient operating condition. For example, a machine may develop a hot spot for various reasons that can cause viscosity to plunge in that same vicinity. When extreme, these hot spots can also crack the oil's molecules, leading to permanent and severe loss of viscosity.

Viscosity can drop by oil contamination and distress. Fuel dilution in engines and chemical contamination (solvents, refrigerants, natural gas, etc.) can all result in a sudden drop in viscosity. Water contamination can thin many oils that have a high solvency for water. In the case of natural and synthetic esters, water may disassemble the ester molecule to sharply reduce viscosity by a chemical reaction called hydrolysis.

Some lubricants have additive systems that include viscosity index improvers (VII). VII molecules are extremely large, and when the oil is hot, they unfurl, making them extremely susceptible to rupture by mechanical shearing in the machine's frictional zones (cam/follower contacts, swashplate/slipper contacts, pumps and rolling-element bearings). These ruptures reduce the oil's viscosity over time. Engine oils and most hydraulic fluids are at risk for VII viscosity shear thinning.

RISK-HEDGING STRATEGIES FOR MACHINE VISCOSITY STARVATION

RISK FACTOR	STRATEGY
High temperature from low coolant, high ambient conditions, low oil levels, machine hot spots	Monitor temperature frequently and correct the root cause. Use high VI oil.
High loads and/or slow speeds	Select viscosity to match machine loads and speeds.
Periodic shock loads, frequent stops/starts	Use a lubricant with film-strength additives to protect against two-body abrasion, adhesion and galling. Examples are anti-wear (AW), EP and friction modifiers.
Mechanical unbalance or misalignment	Monitor for these conditions and remediate accordingly. Use additives to mitigate such as AW, EP and friction modifiers.
Fuel dilution or chemical contamination	Use oil analysis to detect and prescribe a remedy.
Hydrolysis of esters from water contamination	Proactively control water contamination. Use oil analysis to detect and prescribe a suitable remedy
VII shear thinning	Use oils resistant to excessive VII shear thinning.
Dirt ingression risk	Employ contaminant exclusion strategies. Use more effective contaminant removal methods (e.g., filters). Monitor particle levels regularly. Consider increasing oil viscosity.

Consequences of Inadequate Viscosity

Machines starved of viscosity suffer from a range of problems that translate to operational costs and impaired reliability. In certain situations, viscosity deprivation can lead to sudden catastrophic death of machine components such as bearings and gears. In other cases, the effects are milder and may only slightly shorten the life of the machine. The following consequences can occur when viscosity is lower than ideal:

Mechanical Wear

In many circumstances, viscosity is the most important lubricant property that prevents or mitigates wear. When viscosity falls below a critical threshold, mechanical wear is accelerated. This includes abrasive wear (two-body and three-body), adhesive wear (scuffing and galling), surface fatigue (micropitting, etc.), and delamination wear.

Thermal Circle of Despair

Low viscosity causes wear and friction, which generate heat. Heat lowers oil viscosity, leading to more friction and wear as well as more heat. This is the thermal circle of despair. The accelerated wear shortens machine life, and the heat shortens the lubricant life.

Short Lubricant Life

When frictional surfaces are deprived of viscosity, the lubricant's additives are affected in three ways. The first is from heat (as mentioned above). This heat accelerates the depletion of additives such as antioxidants. This results in base oil oxidation. The second is the rupture of VII additives, which leads to more loss of viscosity. The third is the mechanical friction from low viscosity that causes anti-wear and extreme-pressure (EP) additives to sacrificially deplete more rapidly.

Leakage

Low viscosity will increase the rate of leakage. This includes both out-leakage and internal leakage. Out-leakage causes a loss of lubricant, while internal leakage affects machine function (speed and control in the case of hydraulic systems) and energy consumption.

Engine Oil Consumption and Environmental Effects

Low crankcase oil viscosity increases the rate of oil consumption in diesel and gasoline engines, which is an operational cost. The oil that is released to the exhaust path produces hydrocarbon emissions, which endangers human health and leaves a carbon footprint.

Recognizing Viscosity-starved Machines

Don't assume the lubricant in your machine has the right viscosity simply because it is the one specified in the machine's service manual. Challenge conventional recommendations for viscosity. Some machines are operating at conditions far afield from that intended by the machine designer. Machine applications vary sharply due to duty cycle, work environment, temperature, close-proximity contaminants and operating conditions. Many machines run at speeds and loads far below the maximum rated by the manufacturer. Other machines are just the opposite, operating in excess of catalog speeds and loads. All of this has a sharp effect on the machine's viscosity needs.

One way to stay alert to inadequate viscosity (or excessive viscosity) is to "listen" to the machine. This can be done using the following techniques:

Oil Analysis — Test for viscosity/viscosity index, contamination (fuel, water, dirt, etc.), oxidation stability, thermal stability, wear metals, etc. Look for both root causes (of thin oil) and the effects of viscositystarved machines.

Sound — Bearings, pumps and gears emit sharply different sounds when they are starved of lubricant or viscosity.

Heat Monitoring — Use infrared heat guns and cameras to detect hot spots and unusually high oil and component temperatures. Machines with resistance temperature detectors (RTDs) and temperature gauges can report important temperature excursions on the oil, coolant and bearing metal (thrust, journal, etc.).

Oil Level Change — Contaminants such as fuel, process chemicals and even water can sharply change oil viscosity when they enter the oil. This can often be viewed as a sudden rise in the oil level at gauges and sight glasses.

Stressed Frictional Surfaces — Cylinder walls, journal bearings, gear teeth and cams are examples of machine surfaces that can frequently be inspected periodically for abnormal wear from oil or viscosity starvation.

Out-leakage — A sudden lowering of oil viscosity can sometimes increase leakage across multiple points.

Lubricant Starvation vs. Viscosity Starvation

The dangers of lubricant starvation have been discussed extensively in *Machinery Lubrication*. This condition describes machines and critical surfaces that receive an inadequate supply of oil or grease. Viscosity starvation is different. The amount of lubricant may be adequate, but the load-bearing ability of the lubricant is impaired by thin oil. Keep both forms of starvation in focus with your condition monitoring program.