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HYDRAULIC SYSTEMS:
SELECTING THE CORRECT LUBRICANT

Choosing the right viscosity can go a long way toward achieving hydraulic system operating efficiency, reliability and long-term performance.

In TLT we've introduced articles focusing on lubricant selections most likely to provide long-term operability and reliability to the equipment owner. This month these concerns are secondary to the question of machine efficiency.

This may seem to run against the point of previous Best Practice articles, but in fact it doesn't. Given that approximately a fifth of a hydraulic motor's energy is lost to heat, and that this loss is directly affected by how the fluid properties impact mechanical and volumetric efficiency, the question of energy efficiency becomes the leading point of interest.

Even if the mechanical components run perpetually, if the overall efficiency of the pump is 65%, then 35% of the energy used to drive the pump is lost. The cost of energy losses to poor efficiency can easily outweigh the cost associated with poor long-term component reliability. With that said, component conditions do impact overall system efficiency.

This article focuses primarily on selecting fluids that produce the best overall efficiency. In future articles, we'll address the issues of system condition and contamination control. This month we'll address:

- Explanation of system efficiency
- System fluid requirements for optimum efficiency
- Hydraulic fluid performance criteria:
  - Viscosity
  - Viscosity index
  - Cold flow limits
  - Fluid additive classification (R&O, AW)
- Selection of a "best fit" fluid option based on the known performance criteria.

KEY CONCEPTS:

- Overall efficiency is a product of mechanical efficiency and volumetric efficiency, both of which are influenced by fluid viscosity.
- There are several lubricant properties that a reliability engineer should understand and properly apply when considering hydraulic oil selection.
- A seven-step process can help you select the AW type product that meets the optimum viscosity operating state and that also meets the cold-start absolute limit.

HYDRAULIC SYSTEM EFFICIENCY

Hydraulic pump efficiency is a central critical concern for hydraulic system performance. If the operating conditions, including the fluid viscosity, do not allow the pump to operate at optimum efficiency, then the driving motor must perform additional work to overcome system losses. Systems with fixed-capacity electric motors can operate sluggishly with poor control and poor response. If the motor is a combustion engine, then the engine must burn more fuel to overcome system losses in order to maintain output. Particularly, in the case of engine-driven hydraulic systems (outdoor construction and mining machines), the operating cost premium can be severe.

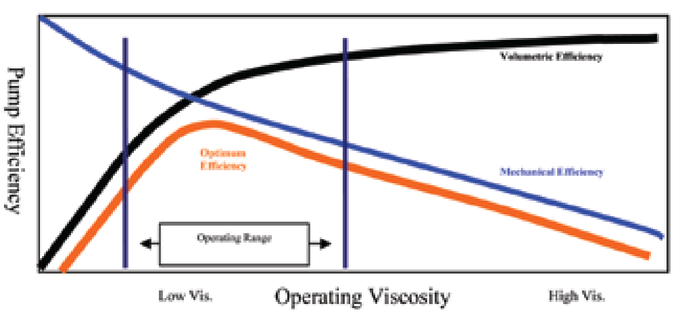
The viscosity limits for system pumps are nearly always a central point of focus for new system installations.

Overall efficiency is a product of mechanical efficiency and volumetric efficiency. Mechanical efficiency is a function of the frictional losses and the energy necessary to overcome these losses. Frictional losses result from rubbing metal surfaces and fluid friction (resistance to flow). In a normal operating state, where the system has oil continuously flowing through the pipes, most frictional resistance is from fluid friction. Volumetric efficiency is a function of the flow losses occurring within the system. Both mechanical and volumetric efficiency are influenced by fluid viscosity.

Mechanical efficiency improves as the oil thins (viscosity decreases). Volumetric efficiency is just the opposite. It improves as the oil viscosity increases. It stands to reason that there has to be a trade-off between mechanical and volumetric efficiency since separately these are best served by apparently contradictory conditions.

System designers plan for and build for an optimum viscosity range and encourage system users to operate as much as possible within the range. As volumetric efficiency increases, mechanical efficiency decreases. Therefore, it is necessary to find a middle ground between the benefits of the two, as shown in Figure 1.

Figure 1 | **Optimum Efficiency Curve**



If a system's operating temperature could be maintained at exactly the same level throughout the operation cycles of the system, then the system could operate at peak efficiency.[1] Unfortunately, anything that influences operating temperature of the oil in the sump influences the systems' overall efficiency. Change in temperature and, consequently, viscosity is a double-edged sword. Operating temperature is influenced by many routine operating factors, including:

- Changing ambient temperature (cold and high atmospheric temperatures)
- Changing process temperatures
- Change in load-state
- Change in the amount of air and water vapor contained within the oil.
- Change in mechanical condition of the components serving the system.

OEM VISCOSITY RECOMMENDATIONS

Hydraulic system component suppliers have provided ample information about the limits for safe operation of system components. Component builders place emphasis on the viscosity and system performance limits imposed by the pump itself. Valves, cylinders, motors, actuators and other components also might influence overall system function and should not be ignored. The viscosity limits for system pumps are nearly always a central point of focus for new system installations. Limits vary for pump type (gear, vane, axial piston, radial piston) and operating speed. Figure 2 represents pump type, viscosity ranges, viscosity maximums and target efficiency values for a variety of common pump models. Figure 3 represents a summary of the viscosity parameters for four common component types.

Figure 2 | **Typical Viscosity Requirements for Various Hydraulic System OEMs**

Pump OEM			Viscosity, cSt.		
Name	Pump Type	Pump Model	Optimum	Max. Startup	Range
Bosch	Radial Piston		21 - 54	162	10 - 65
Bosch	Axial Piston		32 - 65	647	14 - 450
Denison	Piston		24 - 31		13 +
Denison	Vane		30	860	10 - 107
Eaton	HD Piston		10 - 39	2158	6+
Eaton	Med. Duty Piston		10 - 39	432	6+
Eaton-Vickers	Mobile Piston		16 - 40	860	10 - 200
Eaton-Char-lynn	Motors	J, R, S, Disc Valve Motors	20 - 43	2158	13+
Eaton-Char-lynn	Motors	A and H Series	20 - 43	2158	13+
Kawasaki	Radial Piston		50	2000*	25 - 150
Kawasaki	Axial Piston	K3V/G		2000	10 - 200
Mannesmann Rexroth	Radial Piston	R4	25 - 160	-	10 - 200
Mannesmann Rexroth	Pumps	V3, V4, V5, V7	25 - 160	800	25+
Mannesmann Rexroth	Pumps/Motors	G2, G3, G4	25 - 160	1000	10 - 300
Parker Hannifin	Axial Piston		12 - 100	850	-
Parker Hannifin	Var. Vol. Piston		17 - 180	1000	-
Parker Hannifin	Vane Pumps	Series T1	10 - 400	1000	10+
Sauer-Sunstrand, USA	All		13	1600	6.4+
Sauer-Sunstrand, GmBH	Motors	Series 10, 20	12 - 60	1000	7+
Sauer-Sunstrand, GmBH	Gear Pumps		12 - 60	1000	10+

* - No Load

Figure 3 | **Summarized Range for Pump Types Only Based on Typical Values for Each Type**

			Range, Viscosities in cSt		
	Pump Type	Pump Model	Optimum	Max. Startup	Range
	Radial Piston		21 - 160	2000 *	10 - 200
	Axial Piston		12 - 100	2000	14 - 450
	Vane		10 - 400	1000	10 +
	Gear		12 - 160	1000	10 +
	Motors		12 - 160	2158	7 +

* - No Load

As shown in Figure 3, observing the viscometric requirements for a variety of types of applications, one can observe that the optimum viscosities, the maximum startup and the possible working ranges are more similar than dissimilar.

LUBRICANT PROPERTIES

The reliability engineer should be aware of a handful of lubricant properties and understand how to properly apply them when considering a new hydraulic oil selection. These include:

Viscosity. A fluid's internal resistance to flow. Viscosity is the single most important characteristic for selecting a lubricant for any application and clearly for hydraulic applications. There are several recognized viscosity measurement methods, but the most widely used designation is the kinematic unit designation for centistoke (cSt) and centipoise (cPs). The centistoke units represent resistance to flow from the effect of gravity alone, and the centipoise units represent resistance to flow when the fluid is placed under a dynamic force.

All viscosity designations reflect the time required for the oil to complete its movement through the test stand. For a given test method, the heavier the oil the longer it takes to complete the test process. A product with a viscosity value of 100 cSt, a medium oil grade, requires longer to complete the standardized test than a product with a viscosity value of 10 cSt.

Figure 4 shows the 18 viscosity grade range values, ac-

Figure 4 | **ISO Standard 3448 for Kinematic Viscosity Grades**

ISO VG	Kinematic Viscosities, 40°C		
	Midpoint	Min.	Max.
2	2.2	1.98	2.42
3	3.2	2.88	3.52
4	4.6	4.14	5.06
7	6.8	6.12	7.48
10	10.0	9.00	11.0
15	15.0	13.5	16.5
22	22.0	19.8	24.2
32	32.0	28.8	35.2
46	46.0	41.4	50.6
68	68.0	61.2	74.8
100	100.0	90	110
150	150.0	135	165
220	220.0	198	242
320	320.0	288	352
460	460.0	414	506
680	680.0	612	748
1000	1000.0	900	1100
1500	1500.0	1350	1650

cording to Standard 3448 of the International Standards Organization (ISO). This standard has strengths and weaknesses that will be addressed in a future article.

Centipoise viscosity units more accurately represent operating characteristics for hydraulic systems. Some lubricant suppliers provide both centipoise and centistokes values on the product data sheets, and some do not. To estimate the centipoise values for a given lubricant, multiply the centistokes value at the 40 C test temperature (100 cSt for instance) by the lubricant's specific gravity (0.85 for instance). Following the rule, one could see that a 100 cSt oil with a specific gravity of 0.85 (100 x 0.85) = 85 cPs. The charts used later will only use centistokes increments, but the results could be multiplied out to arrive at the dynamic viscosity value.

Viscosity Index (VI). A lubricant's VI number is calculated based on how much the oil thickness changes with a given amount of change in temperature. We intuitively recognize that lubricants (including hydraulic oils) get thicker when the oil's temperature declines and get thinner when the temperature increases.

The VI value of an oil is a snapshot indication of whether the fluid will enable the system to function effectively across a wide temperature rage. The higher the value, the more desirable the fluid will be for efficient system performance and safe startup at cold temperatures.

Mineral oil-based lubricants have VI values that range between 95 (API Group I - solvent refined basestocks) and 130 (API Group III - hydrocracked and severely hydrotreated basestocks), with a few high-performance mineral oil products achieving much better results. Synthetic basestock VI values range from below 95 (some esters and glycols) to well above 200.

High VI products are desirable in that these products allow for selection of an initially thinner oil with the assurance that there is an additional margin of surface protection for components operating under temperature extremes.

Pour Point. The pour point limit of the hydraulic fluid is the lowest temperature at which the oil will flow after it has been cooled under controlled conditions. The pour point limit value for a base oil may be a function of the formation of wax crystals with dropping temperatures or may be a function of the thickening of the viscosity to the extent that it simply does not flow. Oils that contain waxy constituents not removed during refining and finishing can have their pour point values improved (the pour point temperature is dropped) with the addition of additives designed to interfere with wax crystal formation caused by dropping temperatures. Wax-free oils do not benefit from this type of additive.

Pour point values drop in relation to the basestock's viscosity rating. Low viscosity oils such as is typically selected for hydraulic system operation categorically have lower pour point limits than high viscosity products.

The importance of very low pour point values increases with the risk of cold startup. For machines that are expected to start under severely cold conditions, the cold flow property of the lubricant becomes a limiting factor for operation.

Additive Classification (AW, R&O). AW stands for antiwear and R&O stands for rust and oxidation inhibited. These acronyms describe properties of commonly found additive packages. The AW type of product is designed to help protect load supporting surfaces when the surfaces begin to rub against one another. R&O products lack the specific type of agents designed to protect rubbing metal surfaces but tend to compensate for this weakness by providing longer service life cycles with less production of oxidation byproducts and compounds. For low pressure and low temperature systems, R&O oils may be a wholly suitable product type option.

Engine, transmission and hydraulic oils use antiwear additives. Although hydraulic fluids are specifically designed with this wear resistance characteristic in mind, these oils also must be designed to shed air and water and fight oxidation. The balance of additives in the hydraulic fluids enables these performance capabilities. Engine and transmission oils certainly provide a degree of wear resistance needed by hydraulic circuits, but some of the additives that are necessary to serve engine life are counterproductive in hydraulic circuits, particularly the detergents and dispersants and VI modifiers.

Some OEMs of heavy construction and mining machines specify the use of either engine or transmission oil in the hydraulic circuits as a means of simplifying maintenance and minimizing costs associated with carrying additional products. Although this specification does accomplish that objective, the move toward engine oils may also limit life cycles of hydraulic system mechanical components due to the effects of increased water and air content that remain trapped in the oil.

If the option is present, it would be better to operate hydraulic systems with specifically designed and appropriately selected (viscosity) AW type hydraulic fluids. You then should monitor the fluid's health for its long-term tendency to shed water and air and for its long-term oxidation stability.

PROCESS FOR SELECTING THE BEST VISCOSITY OPTION

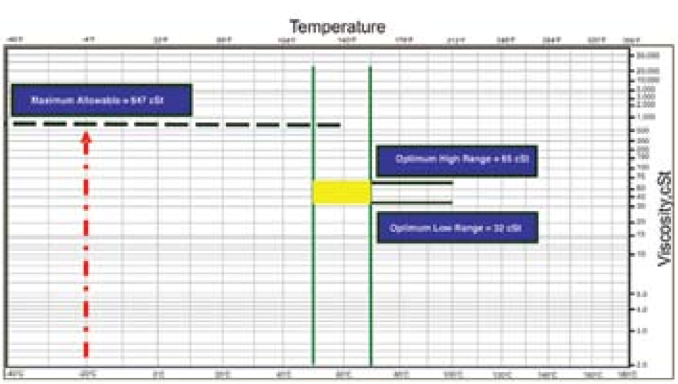
Selecting the viscosity that is best for the overall operating temperature range is relatively simple. The objective is to find the AW type product that meets the optimum viscosity operating state and that also meets the cold-start absolute limit. To accomplish this, one first must determine what these viscosity characteristics are and then plot the performance characteristics of the acceptable and available options on a viscosity reference chart to determine which ones are the best fit, as shown in the following steps:

Step 1. Determine the OEM operating viscosity parameters. This example will use information that was provided in Figure 2. This is a typical condition only.

Name	Pump Type	Pump Model	Optimum	Max. Startup	Range
Bosch	Axial Piston		32 - 65	647	14 - 450

Step 2. Determine the projected operating temperature range and the cold temperature startup low-limit. If the system is not yet operating, the expected operating temperature range will have to come from the design documentation. For our hypothetical system, let's assume that the normal operating temperature range will be between 50 C and 70 C and the coldest possible point at which the system would have to start is -20 C.

Figure 5 | **Hydraulic System Viscosity and Temperature References**



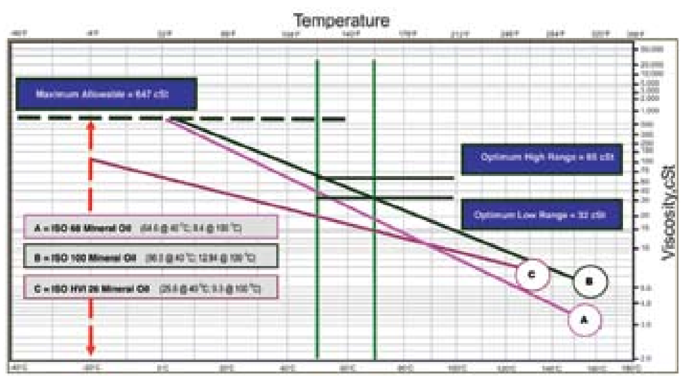
Step 3. Plot the optimum high, low and maximum viscosity for cold-start conditions on a temperature-viscosity chart (available from all oil company customer service departments). This step is shown in Figure 5. Determine the optimum working range on the viscosity reference chart. This is noted in yellow in the example. This represents the area that the best lubricant selection will occupy.

Step 4. Identify the hydraulic oil options that are available for use, then locate and review the product data specifications, as shown in Figure 6. The viscosity details are nearly always shown for the viscosities at 40 C and 100 C. Locate these values and plot them on the chart. (The temperature range is at the bottom, and the oil viscosity is at the side of the chart).

For our example:

Option A: ISO 68 Mineral Oil Viscosity = 64.6 cSt @ 40 C, and 8.4 cSt @ 100 C.
Option B: ISO 100 Mineral Oil Viscosity = 98.5 cSt @ 40 C, and 12.8 cSt @ 100 C.
Option C: ISO 26 HVI Mineral Oil Viscosity = 25.8 cSt @ 40 C, and 9.3 cSt @ 100 C.

Figure 6 | **Hydraulic Oil Performance Criteria vs. System Requirements**



Step 5. Determine if the plotted lines cross through the optimum target window. These products will, based on the provided inputs, allow the system to operate within its target viscosity range for optimum system efficiency.

Step 6. Evaluate the cold-start limit capabilities of the products that meet the system viscosity requirements for optimum viscosity. This is done by plotting the viscosity slope for each product through the maximum allowable viscosity line (top line on the chart). If the viscosity line crosses the limit line at a temperature that is higher than the expected cold-start conditions (the red line at -20 C in our example), then the product fails to meet this criteria.

Step 7. The choice exists to change the cold-start lower limit by inserting heaters in the system or by selecting a product that meets this criterion and fits into the ideal operating window for the system conditions. The VI value of the oil comes into question at this point. We stated earlier that products with higher VI values change viscosity more slowly when the temperature changes. VHVI (Very High Viscosity Index) and XHVI (Extremely High Viscosity Index) mineral oils and a variety of synthetic products are available with VI values approaching 200. These products carry a price premium but, depending on the application, may have a lower actual use cost than a lower price but less suitable conventional oil.

www.mehf.com is a useful Web site for helping system owners determine the best fit viscosity parameters. The site provides a mechanism to input system operating characteristics, motor types, fuel costs, etc., to determine the potential for improvement in operating cost that may exist through the use of VHVI type products. This site will be particularly helpful for those with engine-driven hydraulic systems as they look for ways to curb cost associated with the rising price of diesel fuel.

SUMMARY

Hydraulic systems fluid specifications have a distinct efficiency component to consider. Machine and component reliability is no less critical than for other systems. Regardless of component reliability, if the volumetric and mechanical efficiencies of the system are not balanced, then the system will consume and waste a significant amount of energy while performing its normal system functions.

Several fluid properties are central to product selection, including the kinematic viscosity, the VI, the pour point limits and the types of additives. Engine oil and transmission fluids are sometimes specified for hydraulic systems on construction and mining machines, but these products do carry a penalty associated with the types of additives in use and the impact those additives have on contaminant (water and air) release.

Properly formulated AW hydraulic oils that meet the optimum efficiency requirements and cold flow limits will serve system health and efficiency requirements most effectively. TLT

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REFERENCE

1. Michael, P.W., Herzog, S.N., and Marougy, T.E. (2002), *Fluid Viscosity Selection Criteria for Hydraulic Pumps and Motors*, NFPA Recommended Practice – T2.13.13, **www.nfpa.com.**