

Selecting the Optimum Viscosity Grade of Hydraulic Fluid

The proper viscosity grade of hydraulic fluid will allow equipment to start smoothly at low temperatures and also deliver adequate oil flow rates needed for efficient operation at high temperatures, thus boosting performance and reducing cost. Here is an overview.

By Steven N. Herzog, Christian D. Neveu, and Douglas Placek, RohMax

Hydraulic systems are widely used in the manufacturing, construction, forestry, mining, and transportation industries. Over the years, systems for the transmission and distribution of power have become increasingly sophisticated, their applications more numerous, and their operating conditions more demanding.

Selection of an appropriate hydraulic fluid has become a critical task for the operator. It is important to consider the maximum operating pressure, the minimum and maximum operating temperatures, and the viscosity recommendations provided by the pump manufacturer.

Viscosity is one of the most important criteria in the selection of a hydraulic fluid. At low temperature, excessive viscosity may result in poor mechanical efficiency, difficulty in starting, and wear. As oil temperature increases, viscosity decreases, resulting in lower volumetric efficiency, overheating, and wear. Pump and motor manufacturers often provide in their documentation hydraulic fluid recommendations covering:

- The maximum start-up viscosity under load
- The range of optimum operating viscosity

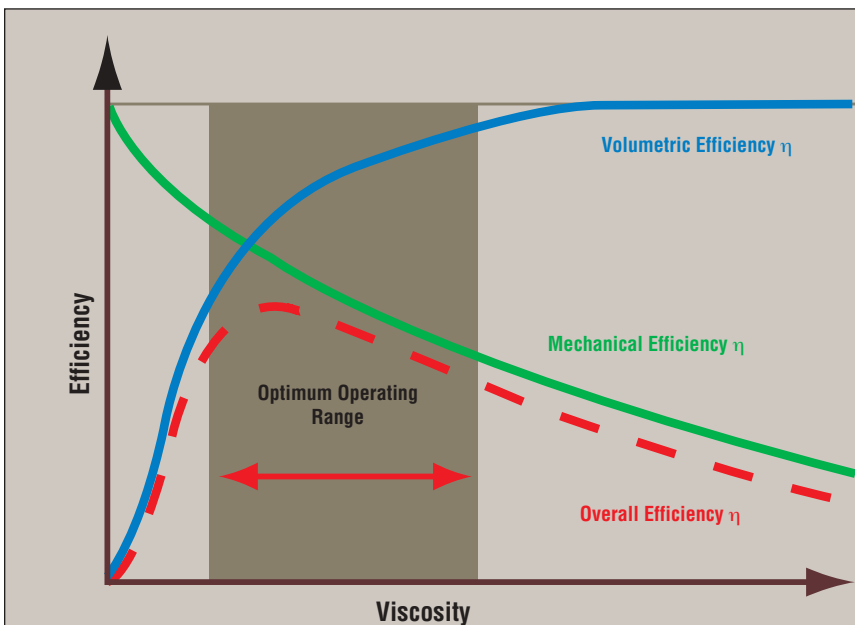


Fig. 1: Relationship of viscosity to pump efficiency

- The maximum and minimum operating viscosity

Selection of the optimum fluid viscosity grade will provide the most efficient pump performance at standard operating temperatures, which will minimize lost time and energy/fuel costs for the operator.

Pump efficiency

The performance of hydraulic pumps and motors is a critical factor in overall hydraulic system reliability. There are two elements of hydraulic efficiency: volumetric efficiency and hydro-mechanical efficiency. Hydro-mechanical efficiency relates to the frictional

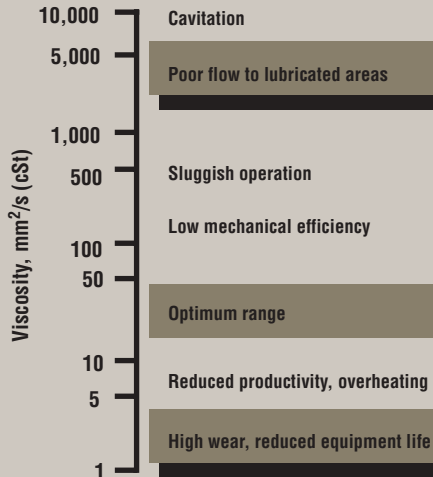


Fig. 2: Fluid viscosity vs performance

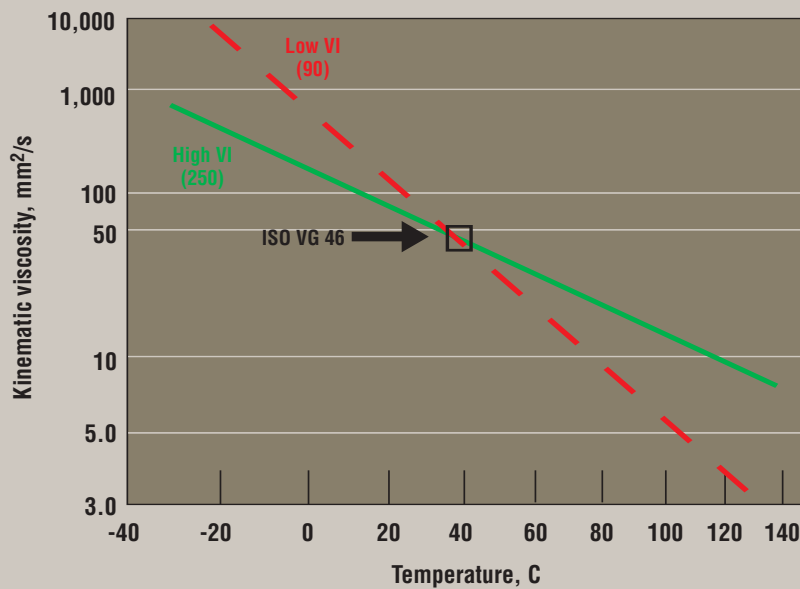


Fig. 3: Viscosity-temperature relationship for low and high VI oils

losses within a hydraulic component and the amount of energy required to generate fluid flow. Volumetric efficiency relates to the flow losses within a hydraulic component and the degree to which internal leakage occurs. Both of these properties are highly dependent on viscosity.

Hydro-mechanical efficiency drops as fluid viscosity increases due to higher resistance to flow. Conversely, volumetric efficiency increases as fluid viscosity increases because of the reduction of internal leakage. The overall efficiency of a hydraulic pump is

the product of mechanical and volumetric efficiencies:

$$\text{Overall efficiency} = \text{Hydromechanical efficiency} \times \text{Volumetric efficiency}$$

Both factors must be considered together. As can be seen in Fig. 1, there is a range of hydraulic fluid viscosity that optimizes overall efficiency.

Cavitation, wear, and system overheating

At low temperatures, high viscosity has a negative effect on the mechanical

efficiency of the hydraulic system and results in reduced system performance, lubricant starvation, and cavitation. Viscosity influences cavitation because high viscosity fluids can create excessive pressure drop at the pump inlet. Cavitation causes metal fatigue and spalling that reduces pump life and generates abrasive metal particles in the fluid. Consequently, pump manufacturers specify a maximum fluid viscosity limit at start-up to ensure that cavitation is avoided. Improperly designed or undersized inlets and strainers aggravate the problems associated with high viscosity.

Excessive viscosity under low temperature conditions also can lead to pump starvation that may result in pump failure. Loss of the lubricating film creates high contact temperatures, excessive wear, and ultimately results in pump seizure.

One of the essential functions of a hydraulic fluid is to provide a lubricating film that reduces wear between moving pump parts. The effectiveness of this film depends upon a balance between viscosity, sliding speeds, and loads within a hydraulic pump. As temperature increases and the fluid film becomes too thin, the lubricant film ruptures and metal-to-metal contact takes place. This results in wear within the pump and additional fluid heating.

While it is intuitive that wear is undesirable, what is less obvious is that it predominantly occurs in locations within a pump that are critical in terms of volumetric efficiency. Loss of volumetric efficiency causes the pump to work harder to produce the required flow to hydraulic actuators. At the same time, high temperatures compromise volumetric efficiency as the result of low viscosity fluid bypassing critical pump clearances. Thus, inadequate viscosity due to high temperatures creates a destructive cycle of rising temperatures, accelerated wear, and increased internal leakage.

Fig. 2 provides general performance guidelines related to viscosity.

Multigrade fluids offer improvement

Multigrade hydraulic fluids are often recommended for equipment where the operating temperatures can vary widely. Multigrade fluids enable efficient equipment operation over a wider temperature range than straight-graded oils. This results from their improved viscosity-temperature relationship that is measured by the viscosity index (VI) of the fluid. Multigrade hydraulic oils are also recommended to eliminate seasonal oil changes, because a properly formulated multigrade performs adequately in both winter and summer temperatures.

Multigrade hydraulic fluids are good for cold weather start-up because, at low temperatures, their viscosity is lower than monograde oil having the same ISO viscosity grade at 40 C. This allows the hydraulic fluid to flow faster, avoiding pump cavitation and starvation. The result is smoother operation, and improved productivity.

Infrequently considered, but just as important, is the multigrade oil's effec-

Multigrade fluids enable efficient equipment operation over a wider temperature range than straight-graded oils.

tiveness in maintaining pumping efficiency at high temperatures. As temperature in a hydraulic system rises, pumping efficiency drops because the increased temperature reduces fluid viscosity, leading to increased internal leakage. The viscosity of a multigrade fluid decreases less than that of monograde fluid with increasing temperature, thus retaining an acceptable pumping efficiency at a higher temperature.

The relationship of viscosity to temperature, and the viscometric advantages of high VI multigrade hydraulic fluids, are shown in Fig. 3.

Fluid selection techniques

A viscosity grade selection system aimed at supporting equipment users has been published by the National Fluid Power Association (NFPA), based on the recommendations of leading hydraulic pump manufacturers. Optimum viscosity grades are selected based on the concept of Temperature Operating Window (TOW), which corresponds to the range of temperature where the oil viscosity provides acceptable performance in the pump (typically 13 to 860 mm²/s).

Details on the use of the ALTOW system are given in NFPA Standard Practice T2.13.13-2002, "Fluid Viscosity Selection Criteria for Hydraulic Motors and Pumps," available through the association's website at www.nfpa.com.

Performance advantage of high viscosity index oils

The most commonly used and widely available viscosity grades are ISO 32, 46, and 68. The following sections will compare the performance of monograde (low viscosity index) and multi-

TABLE 1. VISCOMETRIC PROPERTIES OF TEST OILS

Property	ISO Grade					
	VG 32		VG 46		VG 68	
VI	100	200	100	200	100	200
KV at 100 C, mm ² /s	5.36	7.16	6.72	9.53	8.73	13.06
KV at 40 C, mm ² /s	32.0	32.0	46.0	46.0	68.0	68.0
Temperature for 860 mm ² /s, C	-7	-19	-2	-14	4	-8
KV at 100 C after 40 min Sonic, mm ² /s, ASTM D 5621	-	6.26	-	8.16	-	10.98
KV at 80 C after 40 min Sonic, mm ² /s, ASTM D 5621	-	9.07	-	12.19	-	16.84
KV at 40 C after 40 min Sonic, mm ² /s, ASTM D 5621	-	28.0	-	39.39	-	57.29
VI after 40 min Sonic, ASTM D 5621	-	184	-	187	-	188
NFPA T2/13.13.2002 Grade	L32-32	L22-46	L46-46	L32-68	L68-68	L32-100

grade (high viscosity index) versions of these three fluids. It is important to recognize that shear stable fluids must be used in high pressure hydraulic systems in order to achieve desirable performance. Fluids with low shear stability are commercially available, and are typically intended for use in low pressure systems or for other applications such as automatic transmissions.

The multigrade fluids selected for comparison here are intended for high pressure hydraulic system service and have good shear stability. A description of these fluids can be found in Table 1. It is recommended that the fluid supplier be consulted for guidance on the shear stability of its products.

Performance advantage at low temperature

We have calculated the additional energy, or hydromechanical losses (in kW), required to operate a mobile vane pump having a displacement of 10.8 ml/rev. at 800 rpm and 100 bars, conditions typical of those prevailing at start-up. These data are shown in Fig. 4.

The multigrade fluids selected for comparison here are intended for high pressure hydraulic system service. . .

If we take the example of ISO VG 46 fluids at 0 C, the data in Fig. 4 indicate that the monograde fluid requires 125 percent more energy (18 kW vs 8 kW) than the multigrade to overcome the viscous drag in the pump.

The theoretical power input for the pump in this example is only 1.4 kW, assuming no hydromechanical energy losses take place (energy required to turn the rotor with no viscous drag). The additional energy required to overcome the higher viscosity of the 100 VI fluids increases significantly at temperatures below 40 C, and dramatically at tem-

peratures below 0 C. The volumetric efficiency of this pump will be discussed in the following section (see performance data for Cartridge A in Tables 2-5).

Performance advantage at high temperature

We have computed the actual flow rate and the total power requirement for vane pumps based on a given body, using four cartridges of different sizes. Internal cartridge sets (rotors and vanes) are sized to deliver a specific flow rate by controlling the discharge volume per revolution. Calculations were made at a pressure of 200 bars, a speed of 2000 rpm, and at two temperatures, 80 C and 100 C.

Flow rate advantage and time savings

Knowing the actual flow rate Q_a , we can determine the time needed to fill a given linear motor of volume V using the equation

$$Time = V/Q_a$$

A linear motor is typically a hydraulic cylinder that fills with fluid, displacing a rod that delivers motion under load.

We can estimate the time advantage for the high VI oil to deliver the same volume of fluid as a lower VI oil by calculating the ratio of the time required for two oils having the same ISO VG grade but different VI using the equation:

$$Time_{(VI=100)} / Time_{(VI=200)} = Q_{a(VI=200)} / Q_{a(VI=100)}$$

In this work, we always used the viscosity of the high VI oils after the Sonic 40 minute shear test to compute the actual flow rate (see Table 1). This represents a good estimate of the used oil viscosity in a 2000 psi vane or piston pump system.

It can be seen that the benefit offered by the high VI oils decreases when increasing the cartridge size and increasing the ISO grade. This results from the fact that the larger the cartridge, the lower the internal leakage relative to the pump flow rate.

Field studies showed that peak oper-

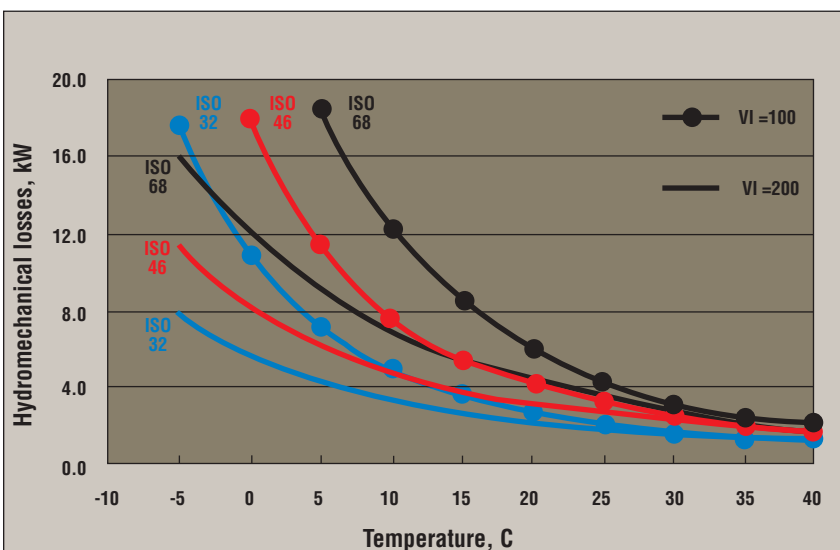


Fig. 4: Hydromechanical losses as a function of temperature, ISO grade, and VI

TABLE 2. ADDITIONAL TIME REQUIRED FOR A 100 VI FLUID TO DELIVER THE SAME VOLUME AS A 200 VI FLUID AT 80 C, 200 BARS, AND 2000 RPM

Cartridge size	Nominal flow rate ml/rev.	Time Difference, %		
		ISO 32	ISO 46	ISO 68
A	22	20.8%	15.5%	11.1%
B	34	9.2%	7.6%	6.0%
C	46	6.0%	5.2%	4.2%
D	70	3.6%	3.2%	2.6%

Performance gains are based on used oil viscosity, after shear

TABLE 3: ADDITIONAL TIME REQUIRED FOR A 100 VI FLUID TO DELIVER SAME VOLUME AS A 200 VI FLUID AT 100 C, 200 BARS, AND 2000 RPM

Cartridge size	Nominal flow rate ml/rev	Time Difference, %		
		ISO 32	ISO 46	ISO 68
A	22	x	x	30.4%
B	34	22.5%	17.9%	13.8%
C	46	13.2%	11.3%	9.2%
D	70	7.2%	6.4%	5.4%

Performance gains are based on used oil viscosity, after shear. x Data not reported because the volumetric efficiency for the 100 VI oils ISO 32 and 46 was lower than 50 percent.

TABLE 4: ENERGY SAVINGS WITH HIGH VI OILS AT 80 C TO DELIVER SAME VOLUME (200 BARS, 2000 RPM)

Cartridge size	Nominal flow rate ml/rev.	Energy Savings, %		
		ISO 32	ISO 46	ISO 68
A	22	20.0%	14.6%	9.0%
B	34	8.3%	6.8%	4.7%
C	46	5.7%	4.6%	3.2%
D	70	3.3%	2.7%	2.0%

* Performance gains are based on used oil viscosity, after shear

TABLE 5: ENERGY SAVINGS WITH HIGH VI OILS AT 100 C TO DELIVER SAME VOLUME

Cartridge size	Nominal flow rate ml/rev.	Energy Savings, %		
		ISO 32	ISO 46	ISO 68
A	22	x	x	27.9%
B	34	22.0%	17.4%	12.9%
C	46	12.8%	11.0%	8.5%
D	70	6.9%	6.2%	5.0%

Performance gains are based on used oil viscosity, after shear. x Data not reported because the volumetric efficiency for the 100 VI oils ISO 32 and 46 was lower than 50 percent.

ating temperatures in mobile hydraulic equipment were often in excess of 100 C. Therefore, we also calculated the flow rates in this series of pumps at this higher temperature. The data in Table 3 indicate that the high VI fluids at 100 C deliver between 5 and 30 percent greater flow rate, allowing a cylinder to fill more quickly.

Comparing the data at 80 C to the data at 100 C, one can see that high VI fluids show an even greater advantage as fluid temperatures increase above 80 C.

Efficiency advantage and cost savings

Knowing the total power required to deliver the hydraulic power and to overcome the hydromechanical losses, we can determine the energy needed to fill the linear motor of volume V using the equation:

$$Energy = Total Power \times Time$$

We have calculated the power needed to drive the pump at 80 C and 100 C, using fluids with different VI. This allowed us to determine the difference in energy required to deliver the same volume of fluid under a given pressure and pump speed, using the equation:

$$\frac{Energy_{(VI=100)}}{Energy_{(VI=200)}} = \frac{(Power_{(VI=100)} \times Q_a_{(VI=200)})}{(Power_{(VI=200)} \times Q_a_{(VI=100)})}$$

The data in Table 4 indicate that the high VI multigrade fluid at 80 C, 200 bars, and 2000 rpm may save between 2 and 20 percent in energy consumption over the 100 VI fluid.

Similar to the approach taken in the “Flow Rate Advantage” section, we also calculated energy consumption at 100 C, to identify the potential energy savings at a temperature closer to a typical peak operating temperature. The data in Table 5 indicate that the high VI fluid at 100 C, 200 bars, and 2000 rpm may save between 5 and 28 percent in energy consumption.

As fluid temperature increases, the

energy savings attributed to the high VI fluids is amplified.

Relative operational cost comparisons

The relative energy saving data presented above can be used to generate cost saving estimates for specific applications. Consider the case of a single mobile vane pump running at typical mobile construction equipment operating conditions of 200 bar, 2000 rpm, and 80 C. Depending on the particular pump size, the potential diesel fuel savings are on the order of 200 to 300 gallons per year. Cost saving calculations can be made using the following formulas:

$$\begin{aligned} \text{Total fuel consumption (liters)} = & \\ \text{Pump power requirement (kW)} \times & \\ \text{Hours of pump operation (hours)} \times & \\ \text{Diesel fuel consumption rate} & \\ (0.22 \text{ kg/kWh}) \times \text{Density of diesel fuel} & \\ (1.19 \text{ liters/kg}) & \end{aligned}$$

The high VI oils contributed to significantly lower hydromechanical losses at temperatures lower than 40 C.

$$\text{Fuel savings (liters)} = \text{Total fuel consumption} \times \text{Relative energy savings (\% from Tables 4 and 5)}$$

$$\text{Cost savings} = \text{Fuel savings} \times \text{Local cost of diesel fuel}$$

Fuel and cost savings calculations for an ISO 46 hydraulic fluid in a single pump and a medium size construction equipment fleet are presented in Tables 6 and 7.

TABLE 6: FUEL AND COST SAVINGS FOR SINGLE MOBILE VANE PUMP AT 200 BAR, 2000 RPM, 80 C

Pump	A	B	C	D
kW	15.5	24.0	31.9	48.1
Gallons of diesel fuel used	2,141	3,316	4,407	6,645
Gallons of diesel fuel saved	313	224	201	182
Annual \$ saved	\$469	\$336	\$301	\$272

Assumptions: 8 hours/day, 250 days/year, diesel fuel in U.S. @ \$1.50/gallon
Performance gains are based on used oil viscosity, after shear. x Data not reported because the volumetric efficiency for the 100 VI oils ISO 32 and 46 was lower than 50 percent.

TABLE 7: FUEL AND COST SAVINGS FOR CONSTRUCTION EQUIPMENT FLEET, 100 UNITS (200 MOBILE VANE PUMPS AT 200 BAR, 2000 RPM, 80 C)

Pump	A	B	C	D
kW	15.5	24.0	31.9	48.1
Gallons of diesel saved	37,557	26,888	24,108	21,797
Annual \$ saved	\$56,335	\$40,332	\$36,162	\$32,695

Assumptions: 8 hours/day, 150 days/year, diesel fuel in U.S. @ \$1.50/gallon

Conclusions

The comparison of the performance at low and high temperature of six hydraulic fluids with three different ISO grades (VG 32, 46, and 68) and two different Viscosity Indices (100 and 200) showed that:

The high VI oils contributed to significantly lower hydromechanical losses at temperatures lower than 40 C. The gain in hydromechanical efficiency can exceed 50 percent at start-up temperature, resulting in lower energy consumption, shorter warm-up times, and reduced wear.

At temperatures of 80 C and 100 C, calculations made for a series of vane pumps showed that the high VI oils deliver a higher flow rate and a better overall efficiency. This translates into higher equipment productivity, as well as significantly lower operating costs for the equipment user due to lower fuel consumption. Energy and fuel savings in a range up to 20 percent can be expected under standard operating conditions when high VI multigrade oils are used. Higher productivity gains and savings can be achieved at peak operating temperatures.

The cost savings associated with the use of multigrade hydraulic fluids in a single vane pump are approximately \$345 per year per pump. This advantage could be expected to result in approximately \$41,000 savings annually for a medium sized equipment fleet.

Steven N. Herzog and Douglas Placek are associated with RohMax USA, 723 Electronic Dr., Horsham, PA 19044; telephone (215) 706-5800. Herzog can be reached at steven.herzog@degussa.com; Internet www.rohmax.com. Christian D. Neveu is associated with RohMax France, Paris, France.

For a complimentary copy of this article and more information circle 101 or visit www.LFPfreeinfo.com