

polymer to the viscosity of the polymeric-oil blend is greater at higher temperatures.

When system fluids contain VI improvers and are subjected to high rates of shear (mechanical agitation, turbulence, cavitation, orifice flow, etc.), the fluids often suffer a loss in viscosity and VI because of polymer “shear down” (rupture and scission of the polymeric chains). This characteristic viscosity loss is described by the term “shear stability.” Technologists can usually obtain an acceptable shear stability by choosing the proper type of polymer and the proper length of the polymer chain. Permanent viscosity loss can also be the result of the chemical attack on the polymer, or to the polymer’s thermal instability.

Fluid viscosity changes with respect to the quantity of air bubbles present in the fluid. The empirical relationship is expressed as follows:

$$\mu_b = \mu_0(1 + 0.015B) \quad (2-5)$$

where μ_b = viscosity of bubbly oil
 μ_0 = viscosity of non-bubbly oil
 B = air content of fluid in percent, (%) volume

For example, if B is 5%, Eq. (2-5) gives $\mu_b = 1.075\mu_0$. In other words, the viscosity increases 7.5%.

Viscosity Selection

In selecting a fluid that will satisfy the requirements of a particular hydraulic system, two categorical aspects must be considered (see Table 2-3):

- **Performance effects**—those affecting the kinetic activity of the fluid or the energy losses of the system
- **System tribological effects**—those affecting friction, heat, wear and the lubrication of the system

The *performance effects* become obvious by examining the pressure-flow relationship described by the Hagen-Poiseuille’s equation.

$$Q = (K)(\Delta P) \left(\frac{1}{\mu} \right) \quad (2-6)$$

where Q = flow through fluid passage or clearance
 ΔP = pressure differential across the flow passage of clearance
 μ = fluid viscosity
 K = a design factor,
 e.g., $= \frac{\pi D^4}{128L}$ for a circular tube of diameter D and length L

Table 2-3. Viscosity Selection Aspects.

Performance Effects		
Factor	Relationship	Graphics
Pressure Loss Reduced flow High power consumption Heat from high internal friction Cavitation Pump starvation Damping action Sluggish performance Poor response	High viscosity effects $\Delta P = \left(\frac{Q}{K} \right) \mu$	
High leakage High slippage in pumps/motors Rod creep Loss of position hold in cylinders Capillary flow across clearances Loss of fixed orifice control Leakage at fittings	Low viscosity effects $Q = (K\Delta P) \frac{1}{\mu}$	
Tribological Effects		
Factor	Relationship	Graphics
Non-wetted surfaces Wearing surfaces not wetted by oil Critical clearance spaces not penetrated	High viscosity effects $Q \propto \frac{1}{\mu} \ll$	
Excessive loading and film squeeze Loss of lubrication film Inadequate film thickness (h) to separate adjacent asperities	Low viscosity effects $f \propto \frac{1}{h} \propto \frac{1}{\mu} \gg$	

Equation (2-6) indicates that flow Q is inversely proportional to viscosity μ , while conversely, pressure differential ΔP is directly proportional to μ . Therefore, a high viscosity fluid provides a high flow resistance that results in a greater pressure loss, a lower net positive suction pressure available (NPSHA) to pump, poor response, etc. On the other hand, if the viscosity is low, a high fluid leakage occurs.

The *tribological effects* are basically governed by the lubrication mode and the surface conditions of the moving objects as shown in Fig. 2-9. Most hydraulic components are designed to operate under hydrodynamic conditions. The coefficient of friction and the film thickness under a specific operating condition can be mathematically expressed using Petroff's formula:

$$f = 2\pi^2 \frac{\mu N}{P} \frac{r}{c} \quad (2-7)$$

where f = friction coefficient
 μ = absolute viscosity of fluid
 N = shaft rotation speed

P = load per unit of projected bearing area
 r = journal radius
 c = radial clearance

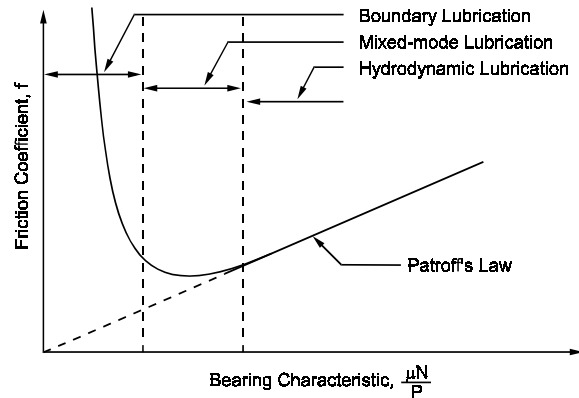


Figure 2-9. Stribeck Curve.

Many times, Eq. (2-7) is expressed in terms of the Sommerfeld number

$$f \frac{r}{c} = 2\pi^2 S \quad (2-8)$$

and the Sommerfeld number, S , is defined by the following relationship:

$$S = \left(\frac{r}{c} \right)^2 \frac{\mu N}{P} \quad (2-9)$$

However, from the Stribeck curve shown in Fig. 2-9, Eq. (2-7) will only be valid when the dimensionless bearing characteristic parameter $\mu N/P$ is greater than a certain value; otherwise, hydrodynamic lubrication is lost. In addition, the film thickness normally must be larger than at least four times the surface roughness of the mating parts to avoid a metal-to-metal contact. A low viscosity fluid will not provide an adequate film thickness to support the load at normal operating speed. Conversely, a high viscosity fluid will generate a high friction force. In practice, design engineers are devoted to finding an optimum film thickness that is large enough to provide hydrodynamic lubrication, but not so large as to create excessive leakage nor so small as to create undesirable asperity contact friction. In other words, they must balance the conditions in Eq. (2-6) with those in Eq. (2-7) to optimize their design.

In general, hydraulic fluid must be within the viscosity limits established by the pump manufacturer in order to obtain the mechanical and volumetric efficiencies as well as the pump service life purported by the manufacturer. Below a viscosity of about 5 centistokes, it is difficult to adequately seal pressurized fluid. With petroleum based fluids, efficient lubrication is only

realized when a viscosity of at least 5 centistokes exists. Hence, 5 centistokes represent a nominal minimum viscosity limit for a practical oil hydraulic system. For guidance purposes the viscosities recommended by the manufacturers of vane, gear and piston pumps are presented in Fig. 2-10 along with the viscosity at which various operating conditions in hydraulic systems tend to occur.

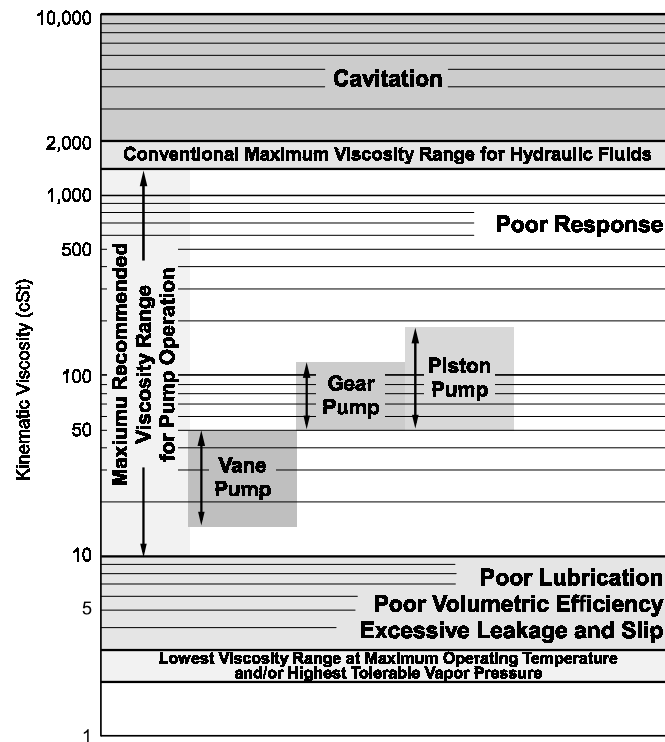


Figure 2-10. Viscosity Selection Chart.

2.6 Bulk Modulus

Next to viscosity, bulk modulus is the most important physical property that a hydraulic fluid can possess. Bulk modulus is a measure of a fluid's resistance to compression. Since bulk modulus reflects the spring-like characteristics of a fluid, a design which does not take this important property into consideration together with its system volume and pump characteristics, can produce serious undesirable harmonic vibrations. In fact, such undesirable noise generating velocity characteristics that are associated with bulk modulus, can produce significant material cavitation damage and deterioration in both pump and valve elements. Bulk modulus is the physical property which establishes—

- The static rigidity of the system
- The amount of gain or amplification that a system can achieve