

Hydraulic Fluid Viscosity Selection for Improved Fuel Economy

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ABSTRACT

Multiple field trials and nearly a decade of laboratory studies have demonstrated that shear stable multigrade hydraulic fluids improve fuel economy. These studies have determined that fuel efficiency is dependent upon temperature, fluid viscosity and shear stability. This paper presents a viscosity classification system proposed by the National Fluid Power Association (NFPA) Fluids Technical Committee. This system is analogous to the SAE J300 viscosity classification system for engine oils. The letter "L" is used in place of "W" as the designation for the low temperature grade. Under this new classification system, NFPA 32L-68 fluids will provide the low temperature viscosity properties of an ISO VG 32 hydraulic fluid and the high temperature viscosity properties of an ISO VG 68. In addition, fluids that meet the requirements of the proposed NFPA Energy Efficient classification system increase fuel economy and productivity while reducing CO₂ emissions. A summary of field trial results and explanation of the proposed NFPA Energy Efficient viscosity classification system are provided.

INTRODUCTION

An "Energy Policy Conservation Act," was enacted by Congress in 1975 in response to the 1973-74 oil embargo. This law led to the establishment of Corporate Average Fuel Economy (CAFE) standards with the intent of doubling new car fuel economy. CAFE standards are administered by the National Highway Traffic Safety Administration (NHTSA). The penalty for a company failing to meet CAFE standards is \$5.50 per tenth of a mile per gallon for each tenth under the target value

times the total volume of vehicles manufactured by that company in a model year. (1) In order to maximize CAFE performance, automotive manufacturers have implemented a variety of fuel saving measures, including the development of fuel efficient engine oils.

Fuel efficient engine oils are certified in the SAE Sequence VIB test per ASTM D 6837. Fuel Efficiency Index (FEI) requirements are based upon SAE J300 viscosity grades. For instance, SAE 0W-20 and 5W-20 viscosity grades have a 2.3% minimum FEI, which is the highest rating. (2) Straight grade engine oils have not been approved for use in passenger cars for decades. There are several reasons for this, not the least of which is they are unable to meet fuel economy requirements.

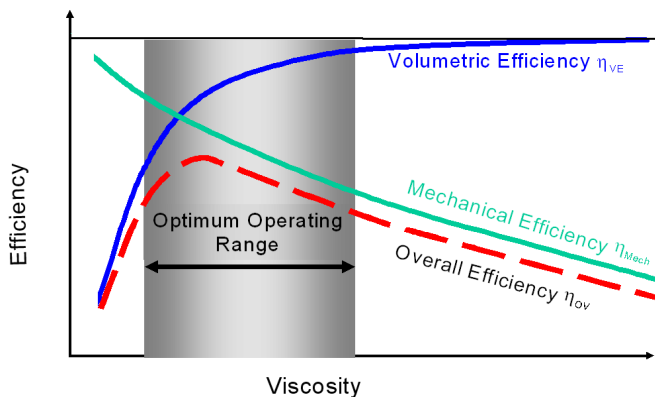
Straight grade hydraulic fluids are used in many fluid power applications. In industrial applications where machines are operating in a temperature controlled environment this is a practical option. In commercial vehicle and mobile fluid power applications, operating temperatures and energy efficiency considerations should lead to the use of multigrade hydraulic fluids. In order to facilitate transition of fluid power equipment to energy efficient hydraulic fluids, a system analogous to SAE J300 is proposed. In this viscosity classification system the letter "L" is used in place of "W" as the designation for the low temperature grade. For instance, a NFPA 32L-68 hydraulic fluid provides the low temperature viscosity properties of an ISO 32 hydraulic fluid and the high temperature viscosity properties of an ISO 68. The "L" designation is used instead of the "W" designation in order to avoid possible confusion with engine oils.

A critical difference between hydraulic and engine oils applications is *oil pressure*. The oil pressure in an engine lubrication system is typically 40 to 60 psi. Fluid power systems routinely operate at pressures two orders of magnitude higher. This high pressure condition creates shear stresses that could possibly destroy the polymers used in multigrade engine oils. Consequently shear stable polymers must be used in NFPA Energy Efficient hydraulic fluids. This paper presents a proposed viscosity classification system developed by the NFPA Fluids Technical Committee that defines the standard requirement for Energy Efficient hydraulic fluids.

FLUID POWER EFFICIENCY

Several studies have established that hydraulic pump efficiency is dependent on the hydraulic fluid viscosity after shear. (3,4,5) There are two elements of pump efficiency; volumetric efficiency and mechanical efficiency. Mechanical efficiency relates to the frictional losses within a hydraulic component and the energy required to generate rotary motion in a pump or motor. Volumetric efficiency relates to the flow losses within a hydraulic component and the degree to which internal leakage occurs. Both of these properties are to a large degree viscosity dependent. As can be seen in **figure 1**, volumetric efficiency increases with viscosity while mechanical efficiency decreases with viscosity. (6) The optimal overall efficiency of a pump corresponds to the maximum product of volumetric and mechanical efficiency.

Figure 1 - Model Hydraulic Pump Efficiency Curves

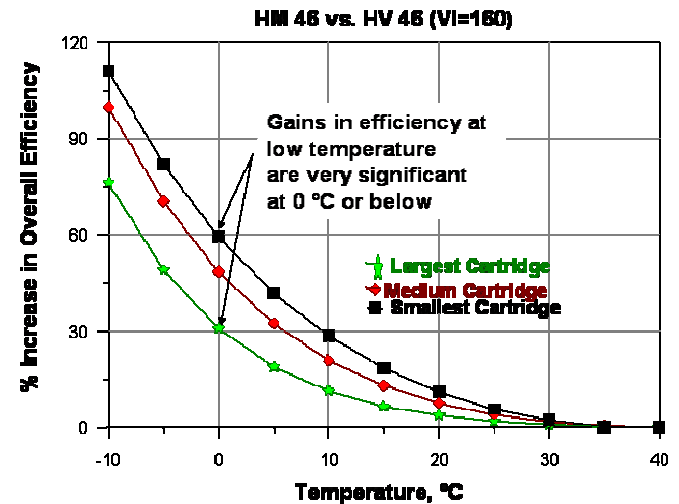


Since mobile hydraulic systems generally operate in the steep portion of the volumetric efficiency curve, increasing the viscosity of the hydraulic fluid at high temperatures improves volumetric efficiency and reduces energy consumption. During cold temperature start up where the viscosity of the hydraulic fluid is potentially very high, a low viscosity hydraulic fluid would improve mechanical efficiency which would lead to better overall efficiency. Both of these goals can be achieved through the use of a shear stable high VI hydraulic fluid.

LOW TEMPERATURE EFFICIENCY IMPROVEMENTS

Figure 2, shows the low temperature efficiency improvements that may be realized in a vane pump by increasing the VI of an ISO 46 hydraulic fluid from 100 to 160. Depending upon the pump displacement, at 0°C (32°F), hydromechanical energy losses due to viscous drag are 30 to 60% higher for a 100 VI fluid than a 160 VI shear stable fluid.

Figure 2 – Increase in Overall Efficiency in Vane Pump with Higher VI Hydraulic Fluid



HIGH TEMPERATURE EFFICIENCY IMPROVEMENTS

Fluid testing in a variety of pumps has been used to develop models for predicting volumetric efficiency as a function of viscosity. (7) These equations are of the general form shown in **equation 1**:

$$\text{Equation 1} \quad Q_a = Q_n - k(P/\eta)$$

where

Q_a = Actual flow rate
 Q_n = Nominal flow rate
 k = Geometric constant for the pump
 P = Discharge pressure
 η = Kinematic viscosity after shear

In this equation, the term $k(P/\eta)$ represents the internal leakage in the pump. Leakage decreases as the fluid viscosity increases resulting in greater actual flow rates and improved volumetric efficiency.

Field trials have been conducted in a medium size excavator, mini excavator, and skid steer loader. In each of these field studies, OEM recommended oils were used to establish baseline efficiency and productivity levels. (8, 9, 10) In the medium excavator trial, the OEM fluid was an SAE 10W hydraulic fluid (104 VI). In the mini excavator and skid steer trials, the OEM recommended oil was an "all season" ISO 46