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SELECTING THE OPTIMUM HYDRAULIC OIL TO MEET THE VISCOSITY REQUIREMENTS OF MAJOR PUMP MANUFACTURERS

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Abstract

Viscosity is one of the most important selection criteria for a hydraulic fluid. If the viscosity falls outside of a specified range, the pump will not operate properly. Therefore, in order to help users to select an appropriate lubricant, pump OEM's provide minimum and a maximum fluid viscosity guidelines for peak operating and start-up temperature conditions.

Using pump OEM viscosity guideline data published by the NFPA, we have developed a simple technique which enables an equipment operator to specify a single fluid capable of satisfying several groups of pumps over a given Temperature Operating Window (TOW). An optimum hydraulic fluid can be identified according to its ISO grade and viscosity index.

Considering the minimum and maximum operating viscosities for 44 different sets of pumps, NFPA recommended practice T2.13.13-2002 enables an equipment operator to determine which oil to select for a single pump when operating over a given range of temperature. However, for a large fleet utilizing a variety of pumps, using this practice to select an adequate lubricant is a complicated process.

We determined the percentage of pump sets that can operate between a given start-up and maximum operating temperature as a function of the oil grade and viscosity index (VI). This approach also highlights the benefits associated with the use of high VI hydraulic oils.

1. INTRODUCTION

Lubricant viscosity has a major effect on the performance of a hydraulic pump. It should not be too high in order to enable the equipment to operate efficiently at low temperature. On the other hand, it should not be too low in order to a) avoid excessive internal leakage and b) protect the equipment against wear. To help end-users select the proper hydraulic fluid, major pump manufacturers indicate the Minimum Operating Viscosity (MinOpV) and the Maximum Start-up Viscosity (MaxSuV) in their product data sheets.

To assist the user in selecting an optimum hydraulic fluid, the National Fluid Power Association (NFPA) developed a recommended practice T2.13.13-2002 [1,2] that takes into account the viscosity guidelines from major pump builders. Using the Minimum Start-up Temperature (MinSuT) and the Maximum Operating Temperature (MaxOpT) to which the fluid will be subjected, the practice enables the equipment user to determine the oil grade that is required to provide adequate operation over the range of temperature considered. The Temperature Operating Window, TOW, corresponds to the range MinSuT to MaxOpT.

In the latest edition of its practice, the NFPA listed the MaxSuV and MinOpV for a total of 44 sets of pumps that they obtained from major OEMs. This list is summarized in Appendix 1 and presented in Figure 1. It can be seen that the MaxSuV and MinopV cover a wide range as shown in Table 1.

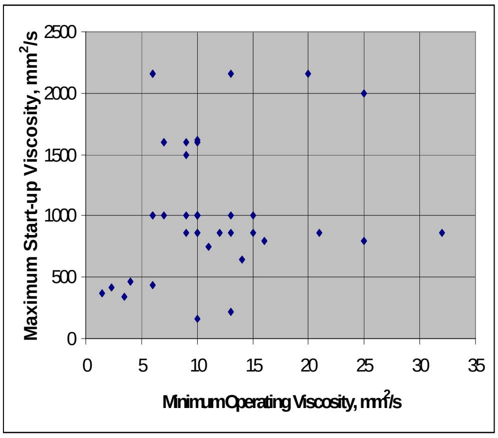

Figure 1: *Minimum Operating Viscosity (MinOpV) vs. Maximum Start-up Viscosity (MaxSuV) for 44 pumps according to NFPA T2.13.13.2002 guidelines*

Table 1: Summary of MaxSuV and MinopV statistics.

Viscosity	Minimum	Maximum	Average
MaxSuV, mm^2/s	162	2158	1069
MinOpV, mm^2/s	1.5	32	11.1

While extremely useful, this information does not provide much help in defining which pump sets are the most demanding in terms of hydraulic fluid viscometrics or TOW. In the field, a lubrication engineer needs to be able to determine which viscosity grade of fluid he should select in order to meet the demands of all pumps in operation in the service equipment fleet or manufacturing plant.

2. ESTIMATION OF TEMPERATURE OPERATING WINDOW WIDTH

In order to assess the severity of the viscometric requirements of a pump, we need to translate them into a Temperature Operating Window (TOW). For this purpose, we determined the MinSuT and MaxOpT for the 44 sets of pumps listed in the NFPA practice using ISO VG 32, 46 and 68 monograde fluids. Each specific pump/fluid combination will have a unique TOW. The three monograde oils are assumed to have a VI of 100 and a viscosity at 40 °C equal to the mid-point of the ISO 32, 46 and 68 grades. We first determined the viscosity at 100 °C of these three fluids and then used the MCC equation [3] to determine at which temperature they reached each of the MaxSuV and MinopV values listed in Appendix 1. The results of this exercise are presented in Figure 2

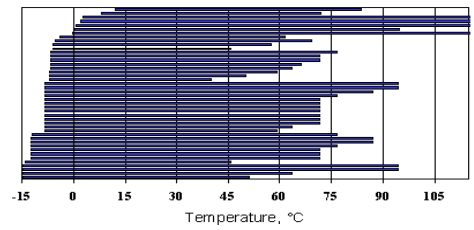

Figure 2: *TOW for the 44 sets of pumps with an ISO 32, VI=100 oil*

2.1 Relationship between MinSuT and MaxSuV

Each fluid considered has a known temperature/viscosity relationship [3], and so we have calculated MinSuT as a function of the MaxSuV. This data is presented in Figure 3.

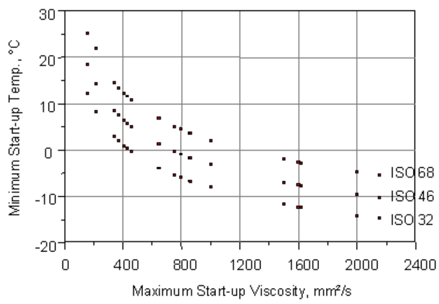

Figure 3: *Dependence of MinSuT on MaxSuV.*

As expected, MinSuT decreases when MaxSuV increases. Therefore, higher MaxSuV limits indicate that the pump is less demanding at low temperature.

2.2 Relationship between the MaxOpT and MinOpV

In Figure 4 we have plotted the MaxOpT as a function of the MinOpV for each of the three oils considered. As expected, the MaxOpT decreases when the MinOpV increases. Therefore, higher MinOpV limits indicate that the pump is more demanding at high temperature.

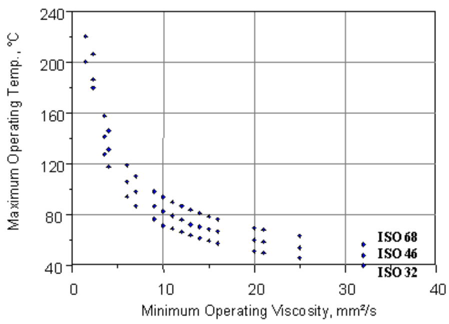

Figure 4: *Relationship between MaxOpT and MinOpV.*

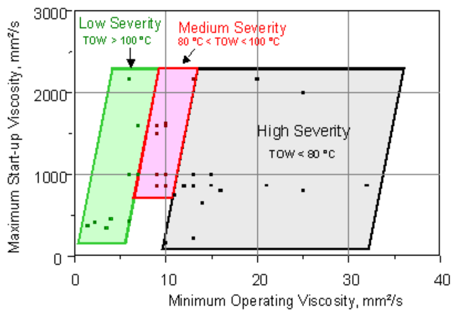

Figure 5: *Influence of MaxSuV and MinOpV on the width of the TOW*

2.3 Relative influence of MaxSuV and MinOpV on the width of the TOW

We can now consider the relative influence of MaxSuV and MinOpV on the width of the pump TOW. We have determined the average TOW with the 3 reference oils considered for the 44 sets of pumps. The pumps were then segmented in three severity tiers as shown in Table 2:

Table 2: Pump severity as a function of the width of the TOW

Pump Severity	Average TOW for the 3 oils
Low	TOW >100 °C
Medium	80 °C < TOW < 100 °C
High	TOW < 80 °C

We have identified these three groups in Figure 5. It can be seen that the MinOpV has the strongest influence on the severity of the pump, i.e. on the width of the TOW. A low severity pump does not place significant viscometric demands on the hydraulic fluid, it can operate effectively at higher temperatures because it can tolerate a low MinOpV. Low severity pumps provide acceptable performance when the viscosity drops below 10 mm²/s. A pump with high severity places much higher viscometric demands on the hydraulic fluid, requiring a higher MinOpV. High severity pumps require that the oil viscosity remains above 10 mm²/s for acceptable performance.

2.4 Percentage of pump sets that can operate at a given temperature

Using the MinSuT and the MaxOpT values for each pump set, it is possible to compute the percentage of pumps that can operate as a function of the oil temperature and the ISO grade selected. This is shown in Figure 6.

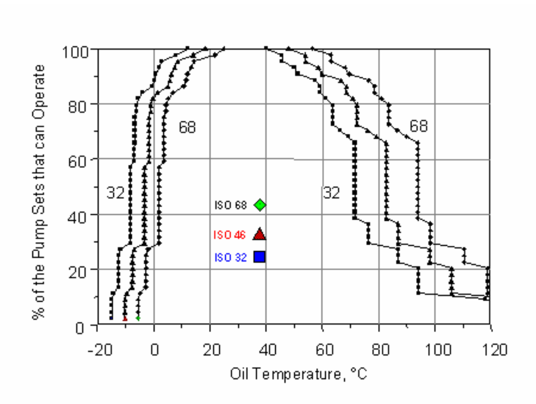

Figure 6: *Percentage of pump sets that can operate at a given temperature as a function of ISO grade.*

For example, the ISO 32 (VI=100) enables about 90% of the of pump sets to operate at 0 °C. This percentage falls to less than 30% for the ISO 68 (VI=100) oil. Alternatively, the ISO 68 enables about 85% of the of pump sets to operate at 80 °C while this percentage falls to about 30% for the ISO 32 oil.

2.5 Percentage of pump sets that can

operate between two temperatures with a given oil

In order to determine the percentage of the pump sets that can operate over a range of temperature with a selected oil, we have to consider the MinSuT and MaxOpT limits of each pump/fluid combination over the specified temperature range.

Figure 7 provides a summary of the percentage of the pump sets that can operate between given start-up and peak operating temperatures with an ISO 32 fluid, VI = 100. Based on the data from Figure 6, the surface representing the percentage of pump sets that can operate between two temperatures is highly irregular.

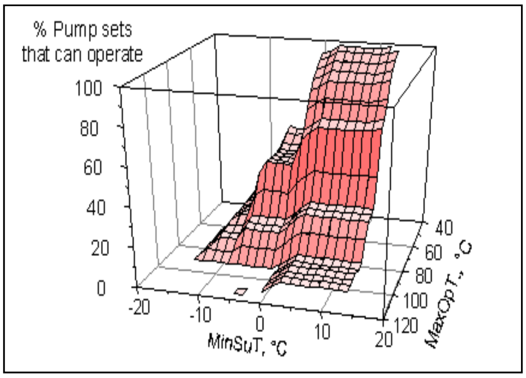

Figure 7: *Percentage of the pump sets that can operate between two temperatures - - ISO 32 oil, VI = 100.*

Finally, we can also represent the percentage of pump sets that can operate between two temperatures by increments of 5 °C. This provides a simpler, more readable view of the situation. We offer this alternative approach in Figure 8, considering the same ISO 32 fluid with a VI of 100. With this oil, less than 20 % of the pump sets can operate between -10 °C and 40 °C. This percentage decreases if we maintain a MinSuT of 10 °C and increase the MaxOpT. All the pumps can operate with an ISO 32 monograde oil if MinSuT and MaxOpT stay between 15 and 40 °C.

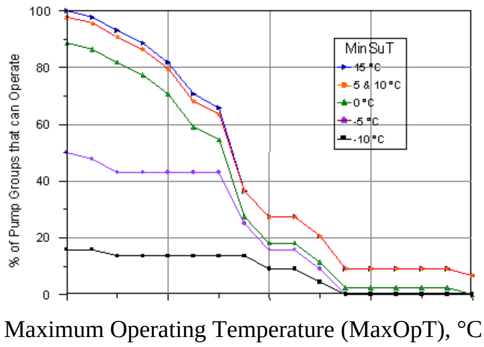

Figure 8: *Percentage of pump sets that can operate between two temperatures with an ISO 32 fluid, VI = 100.*

3. DETERMINATION OF PUMP TOW WITH HIGH VI OILS

Viscosity index quantifies the rate at which the viscosity of a fluid decreases as the temperature increases. The higher the VI, the less the oil viscosity decreases with temperature. Therefore, two oils having the same viscosity at 40 °C but different VI's, will reach a given viscosity at different temperatures. We review in Figure 9 how a fluid with higher VI will provide a pump with a larger TOW.

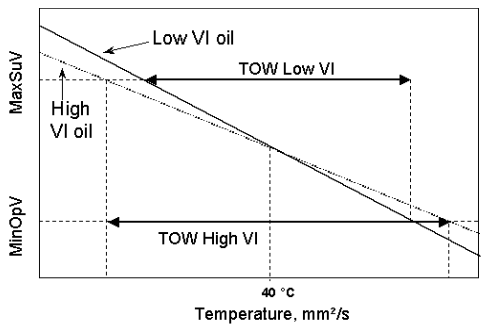

Figure 9: *Increase of the TOW resulting from an increase of VI*

3.1 Increase in TOW resulting from an increase in VI

We determined the MinSuT and MaxOpT for the 44 sets of pumps listed in the NFPA practice for three oils having a VI of 150 and a viscosity at 40 °C equal to the mid-point of the ISO 32, 46 and 68 grades. We first determined the viscosity at 100 °C of these three fluids and then used the MCC equation [3] to determine the temperature at which they reach the

MaxSuV and MinopV limits listed in Appendix 1. We have summarized the results in Table 3.

Table 3: Average TOW as a function of the ISO grade and VI

ISO Grade	Average TOW all pumps,°C		Average TOW for pumps with a MinOpV>3.5 mm²/s, °C	
	VI=100	VI=150	VI=100	VI=150
32	86.5	96.8	79.6	90.9
46	92.5	106.0	85.0	98.2
68	99.1	114.3	91.0	106.8

We also computed the increase in average TOW resulting from an increase of VI from 100 to 150 for the three ISO grades considered. The results are detailed in Table 4. The higher the ISO grade, the higher the increase of the width of the average TOW.

Table 4: Increase in the width of the average TOW as a function of the ISO grade (VI increase from 100 to 150)

ISO Grade	Increase in average TOW all pumps,°C	Increase in Average TOW pumps with a MinOpV>3.5 mm²/s; °C
32	10.3	11.3
46	13.5	13.2
68	15.2	15.8

3.2 Percentage of pump sets that can operate at a given temperature with high VI oil

Considering the MinSuT and the MaxOpT values for each pump set, it is possible to compute the percentage of pumps that can operate as a function of the oil temperature and VI of the fluid. This comparison is shown in Figure 10 for two ISO 32 fluids with VI = 100 and VI = 150.

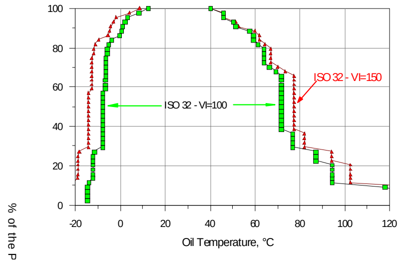

Figure 10: *Percentage of pump sets that can operate with an ISO 32 at a given temperature as a function of VI*

If low temperature start-up characteristics are compared at -10 °C, a high VI fluid can satisfy over 80% of the pumps, whereas the monograde fluid can only satisfy less than 30%. If high temperature operation characteristics are compared at 75 °C, the high VI fluid can meet the viscosity requirements of nearly 70% of the pumps, while the low VI monograde fluid meets less than 40%.

4. SELECTING A HYDRAULIC FLUID THAT CAN MEET THE VISCOSITY REQUIREMENTS OF SEVERAL PUMP SETS

When we evaluated the effect of MaxSuV and MinOpV on MinSuT and MaxOpT respectively, we found that the more demanding pumps where those with the lowest MaxSuV and highest MinOpV. Therefore, when several pumps are considered, it is easy to determine the range of viscosity that will satisfy all of them. This is exemplified in Table 5. If the following 3 sets of pumps were in use in a manufacturing plant or mobile equipment fleet, it would be advantageous to select a single oil with a TOW that is capable of meeting the operating viscosity range of 1500 mm²/s to 13 mm²/s

Table 5: Determination of the range of viscosity required to satisfy a given set of pumps.

Manufacturer	Equipment	Minimum mm^2/s	Maximum mm^2/s
Eaton – Char-Lynn	J,R, and S Series Motors	13	2158
Poclain	Series T1	9	1500
Denison Hydraulics	Piston Pumps	10	1618
All 3 manufacturers	**All 3 sets of pumps**	**13**	**1500**

If we determine that these pumps have to operate between known MinSuT and MaxOpT values, the oil that can provide adequate performance over that range of temperature will have a viscosity of 1500 mm²/s at MinSuT and 13 mm²/s at MaxOpT. Knowing the viscosity of the oil at the two specified operating temperatures will allow us to also calculate its viscosity at 40 and 100 °C using the MCC equation [3] and determine its viscosity index. We have determined the ISO Viscosity Grade and VI of the oils required to operate the three sets of pumps discussed above between two different temperatures [4]. The results are shown in Table 6.

Table 6: ISO Viscosity Grade and VI required for 3 pump sets to operate over a given Temperature range

MaxOpT, °C	MinSuT, °C	ISO Grade	Viscosity Index
60	0	32	100
60	-10	32	100
70	0	46	100
70	-10	46	125
80	0	68	100
80	-10	46	165
90	0	68	140
90	-10	68	160
100	0	100	125
100	-10	100	200

In all these calculations attention should be paid to the fact that the viscosity and VI of the fluid must be representative of oil after break-in. Hydraulic fluids formulated with polymeric viscosity index improvers will show some degree of viscosity loss when exposed to the shearing conditions of the application [5]. Premium fluids formulated with shear stable viscosity index improvers will not show significant viscosity loss, and will provide the TOW necessary for optimum performance. Sonic shear test (ASTM D 5621) [6] and the KRL 20 hour test test (CEC-L-45-T-93) [7] are often used to assess the shear stability of hydraulic fluids and provide viscosity and VI after shear that correspond closely to those seen by the pump in medium and high severity applications respectively.

5. CONCLUSIONS

Using the information collected by NFPA on 44 sets of hydraulic pumps and motors, we have determined the MaxOpT and MinSuT corresponding to the MinOpV and MaxSuV respectively for three fluid viscosity grades (ISO VG 32, 46, 68) and two levels of Viscosity Index (VI=100 and VI = 150). Using these data we can calculate the TOW for any pump/fluid combination.

We determined the percentage of the pump sets that can operate at a given low or high temperature as a function of the ISO grade and VI. High VI fluids can meet the viscosity requirements of a significantly larger number of pump sets at any given range of MinSuT and MaxOpT.

Hydraulic fluids with high VI expand the TOW for all pumps by 10 to 15 °C, and can enable an operator to select a single fluid that can meet the OEM viscosity requirements for multiple pumps in a manufacturing plant or mobile equipment fleet. An example is provided that demonstrates how a single oil can be selected to meet the viscosity requirements of several pump OEM’s over a given temperature operating range. The selection of a fluid with high VI can reduce fluid maintenance complexity and inventory costs.

6. BIBLIOGRAPHY

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[7] Minutes of the CETOP G6 ad hoc Group "Viscosity Classification" Chaired by R. Schweder on March 22, 1997 at VDMA Haus, Frankfurt, Germany.

APPENDIX 1- NFPA Summary of Equipment Builders Viscosity Guidelines

Manufacturer	Equipment	MinOpV mm^2/s (cSt)	MaxSuV mm^2/s (cSt)
Dynex/Rivett axial piston pumps	PF4200 Series	1.5	372
Dynex/Rivett axial piston pumps	PF2006/8, PF/PV4000, and PF/PV6000 Series	2.3	413
Dynex/Rivett axial piston pumps	PF 1000, PF2000 and PF3000 Series	3.5	342
Sauer-Danfoss, USA	PVG Valves	4	460
Eaton	Medium Duty Piston Pumps and Motors – Non-charged Systems	6	432
Sauer-Danfoss, USA	Closed Circuit Axial Piston Pumps and Motors	6	1000
Sauer-Danfoss, USA	LSHT Motors	6	1000
Eaton	Heavy Duty Piston Pumps and Motors, Medium Duty Piston Pumps and Motors Charged Systems, Light Duty Pumps	6	2158
Eaton	Gear Pumps, Motor, and Cylinders	6	2158
Sauer-Danfoss, GmbH	Series 10 and 20, RMF (Hydrostatic Motor)	7	1000
Sauer-Danfoss, USA	Open Circuit Axial Piston Pumps	7	1600
Sauer-Danfoss, GmbH	Series 40, 42, 51 and 90, CW S-8 Hydrostatic Motor	7	1600
Eaton - Vickers	Mobile Vane Pumps	9	860
Sauer-Danfoss, GmbH	Series 45	9	1000
Poclain Hydraulics	H and S Series Motors	9	1500
Sauer-Danfoss, GmbH	Series 60, LPM (Hydrostatic Motor)	9	1600
Rexroth Corporation	Radial Piston (SECO)	10	162
Denison Hydraulics	Vane Pumps	10	860
Eaton - Vickers	Mobile Piston Pumps	10	860
Kawasaki P-969-0190	K3V/G Axial Piston Pumps	10	1000
Linde	All	10	1000
Parker Hannifin	Series T1	10	1000
Rexroth Corporation	G2, G3, G4 Pumps and Motors, G8, G9, G10 Pumps	10	1000
Sauer-Danfoss, USA	Steering and Valves	10	1000
Sauer-Danfoss, USA	Bent Axis Motors	10	1000
Sauer-Danfoss, GmbH	Gear Pumps plus Motors	10	1000
Commercial Intertech	Roller and Sleeve Bearing Gear Pumps	10	1600
Sauer-Danfoss, USA	Gear Pumps and Motors	10	1600
Denison Hydraulics	Piston Pumps	10	1618
Haldex Barnes	W Series Gear Pumps	11	750
Sauer-Danfoss, GmbH	Series 15 Open Circuit	12	860
Eaton - Vickers	Industrial Piston Pumps	13	220
Eaton - Vickers	Industrial Vane Pumps	13	860
Parker Hannifin	VCR2 Series	13	1000
Eaton - Char-Lynn	J, R, and S Series Motors, and Disc Valve Motors	13	2158
Rexroth Corporation	Axial and RKP Piston	14	647
Rexroth Corporation	FA, RA,; K	15	864
Rotary Power	'SMA' Radial Piston Motor	15	1000
Rexroth Corporation	V2 Pumps	16	800
Eaton - Char-Lynn	A Series and H Series Motors	20	2158
Rexroth Corporation	Q, Q-6, SV-10, 15, 20, 25, VPV 16, 25, 32	21	864
Rexroth Corporation	V3 , V4, V5, V7 Pumps	25	800
Kawasaki P-969-0026	Staffa Radial Piston Motors	25	2000
Rexroth Corporation	SV-40, 80 and 100 VPV 45, 63, 80, 100, 130,164	32	864